ATTACHMENT 19

NUREG/CR-6613, "Code Manual for MACCS2: User's Guide," Vol. 1
(May 1998)

NUREG/CR-6613
SAND97-0594
Vol. 1

Code Manual for MACCS2: Volume 1, User's Guide

Manuscript Completed: March 1997
Date Published: May 1998

Prepared by
D. Chanin
Technadyne Engineering
Albuquerque, NM 87112

M.L. Young
Sandia National Laboratories
Albuquerque, NM 87185

J. Randall, NRC Project Manager
K. Jamali, DOE Project Manager

Prepared for

Division of Systems Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555
NRC JC W6231

Office of Technical and Environmental Support
Defense Programs
U.S. Department of Energy
Washington, DC 20585
US DOE Contract DE-AC04-94AL85000

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

This report describes the use of the MACCS2 code. The document is primarily a user's guide, though some model description information is included. MACCS2 represents a major enhancement of its predecessor MACCS, the MELCOR Accident Consequence Code System. MACCS, distributed by government code centers since 1990, was developed to evaluate the impacts of severe accidents at nuclear power plants on the surrounding public. The principal phenomena considered are atmospheric transport and deposition under time-variant meteorology, short- and long-term mitigative actions and exposure pathways, deterministic and stochastic health effects, and economic costs. No other U.S. code that is publicly available at present offers all these capabilities. MACCS2 was developed as a general-purpose tool applicable to diverse reactor and nonreactor facilities licensed by the Nuclear Regulatory Commission or operated by the Department of Energy or the Department of Defense. The MACCS2 package includes three primary enhancements: (1) a more flexible emergency-response model, (2) an expanded library of radionuclides, and (3) a semidynamic food-chain model. Other improvements are in the areas of phenomenological modeling and new output options. Initial installation of the code, written in FORTRAN 77, requires a 486 or higher IBM-compatible PC with 8 MB of RAM.

THIS PAGE INTENTIONALLY LEFT BLANK

Contents

List of Figures

List of Tables

Preface

This report describes the MACCS2 code; it is composed of two volumes. Volume 1 is based on the MACCS *User's Guide*, NUREG/CR-4691, Vol. 1 (Chanin *et al.* 1990). It is intended to allow experienced users of MACCS or other consequence codes to prepare input files and interpret code results.

The MACCS2 documentation does not duplicate information already contained in the MACCS *Model Description*, NUREG/CR-4691, Vol. 2 (Jow *et al.* 1990). It is thus essential that the MACCS *Model Description* be available to the reader.

The companion to this report, Volume 2, (Chanin and Young, 1997-draft) describes the MACCS2 preprocessor codes COMIDA2, FGRDCF, and IDCF2. COMIDA2 is a food pathway model that calculates food-chain doses per unit of deposited activity from multiple radionuclides. FGRDCF and IDCF2 generate dose conversion factors (DCFs) that can be used by MACCS2.

DOSFAC2, an additional DCF preprocessor provided in the MACCS2 package, is described in a separate draft document, the DOSFAC2 *User's Guide* (Young, Chanin, and Banjac 1997-draft). Sample files generated by these preprocessors for use by MACCS2 are provided as part of the distribution package. Operation of the MACCS2 sample problems requires that those files be installed on the host system, but all features of MACCS2 can be exercised without the need to actually run the preprocessor programs. The preprocessors are provided for those users who wish to generate DCF or food pathway data based on assumptions other than those used to generate the data in the DCF and COMIDA2 files provided with the MACCS2 sample problems.

The distribution package includes both FORTRAN source code and PC executables. To the greatest possible extent, MACCS2 and its preprocessors comply with American National Standards Institute standard FORTRAN, making only limited use of FORTRAN 90 extensions to the FORTRAN 77 language standard.

Installation of the complete software package requires a 486 PC or higher processor, 8 MB of RAM, and approximately 30 MB of hard disk space. The executables provided were developed in a DOS environment. Additional software, such as proprietary memory managers for DOS, are not required, but some of these may facilitate the use of the code. Guidance is provided in regard to DOS memory managers and the installation of the package on other computer systems.

THIS PAGE INTENTIONALLY LEFT BLANK

Acknowledgments

The authors would like to acknowledge all of the individuals who have contributed to the development and refinement of the MACCS code. They include J.J. Gregory, H.-N. Jow, L.A. Miller, L.T. Ritchie, and J. L. Sprung of Sandia National Laboratories; J. D. Johnson and J. A. Rollstin of GRAM, Inc.; and J. Foster of Technadyne Engineering Consultants, Inc.

We would like to thank Kamiar Jamali of the U.S. Department of Energy and Christiana Lui and John Randall of the U.S. Nuclear Regulatory Commission for supporting the MACCS2 development effort.

A number of people made important contributions to this work: Dr. Eric Haskin and Ken Summa of the University of New Mexico carried out a productive independent verification of the code, and Mike Abbott and Art Rood of EG&G Idaho, Inc. developed COMIDA and supported the development of COMIDA2. We benefited greatly from the comments and feedback given by Jennifer Powell and Lih-Jenn Shyr of Sandia, the members of the MACCS2 Beta Test Group, and the International MACCS User's Group. We would particularly like to thank Jackie East of the Savannah River Site and Keith Eckerman of Oak Ridge National Laboratory for their comments and suggestions.

J. J. Jones and N. DeHerrera of Sandia provided invaluable administrative assistance during this project, and Ruth Haas of Tech Reps provided dedicated and thorough editorial review throughout the writing of this document.

THIS PAGE INTENTIONALLY LEFT BLANK

Conversion Factors and Abbreviations for Units of Measure

1 meter (m) = one million microns = 3.281 feet (ft)
1 square kilometer (km^2) = 100 hectares (ha) = 247.1 acres = 0.3861 square miles
1 cubic meter (m^3) = 35.31 cubic feet (ft^3)
1 kilogram (kg) = 2.204 pounds (lb)
1 curie (Ci) = 3.7×10^{10} becquerels (Bq)
1 disintegration per minute (dpm) = 1/60 becquerel
1 gray (Gy) = 100 rad = 1 joule/kilogram
1 sievert (Sv) = 100 rem

Standard Prefixes for Powers of Ten

Prefix	Abbreviation	Power of Ten
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	µ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}

THIS PAGE INTENTIONALLY LEFT BLANK

1.0 Introduction

1.1 Historical Background

The *Reactor Safety Study* (NRC 1975) presented the first comprehensive probabilistic risk assessment (PRA) of hypothetical nuclear power plant accidents. (This report is also commonly referred to as WASH-1400.) As part of that study, the CRAC code was developed to calculate the health and economic consequences of accidental releases of radioactive material to the atmosphere.

Prior to the *Reactor Safety Study*, the major focus of safety analyses for nuclear facilities was on evaluating the adequacy of facility siting and design in order to ensure that the public was adequately protected against potential accidents. These "authorization basis" analyses, as called for by 10 CFR 100 (Reactor Site Criteria), focus on the maximal off-site doses that could be faced by the population in the event of design basis accidents (DBAs).

DBAs are typically chosen to represent the design limits of the facility, for example, a large-break loss-of-coolant accident (LOCA) in a commercial power reactor. The analysis of these accidents is documented in the facility's safety analysis report (SAR). Operation of commercial power plants requires the approval of SARs by the Nuclear Regulatory Commission (NRC). The analytical methods used to demonstrate compliance with the applicable requirements are very simple, and incorporate a high degree of conservatism.

Also, because these analyses are performed prior to the operation of the facility, information on equipment failure rates, accident precursors, etc., is not utilized. Operating experiences are an extremely valuable source of information on the risks posed by a facility as it is configured and operated from day to day, but this information is usually not considered in authorization basis studies.

As a result of this and other factors, there developed an interest in more realistic analysis methods so that an accurate picture could be obtained of the risks posed by the operation of these facilities. According to Kaplan and Garrick (1981), the estimation of accident risks requires consideration of both frequencies of accident occurrence *as well as* the resultant consequences of those accidents. For completeness, the entire spectrum of accidents, ranging from minor to severe, would need to be considered, and this was a major goal of the *Reactor Safety Study*.

Since its 1975 inception, probabilistic consequence modeling of postulated commercial reactor accidents has received widespread attention and application throughout the world, and a number of consequence models have been developed, both in the United States and abroad. CRAC2, released to the public by Sandia National Laboratories (SNL) in 1982, incorporated major improvements over CRAC in the areas of weather sequence sampling and emergency-response modeling (Ritchie, Johnson, and Blond 1983; Ritchie *et al.* 1984).

However, in using CRAC2 for diverse applications such as the *Sandia Siting Study* (Aldrich *et al.* 1982), it became apparent that the code did not offer sufficient flexibility for the performance of sensitivity studies and the evaluation of alternative parameter values for its models. In fact, because the purpose of CRAC was to perform the *Reactor Safety Study* calculations, with no other applications foreseen, many parameter values were fixed in CRAC and its successor CRAC2.

In order to perform parametric studies or site-specific analyses, it was necessary to repeatedly modify the FORTRAN source code of CRAC2 and maintain multiple versions of the software, a complication that resulted in extra costs and difficulties in quality assurance. In addition, CRAC2 was not portable across computer systems because the FORTRAN standard used at the time, FORTRAN 66 (American National Standards Institute 1966), encouraged a proliferation of language extensions with little or no consistency among the various compilers.

MACCS was developed to remedy these shortcomings. The goal of the MACCS development effort was to produce a portable code with a modular architecture and flexible database. These features were intended to facilitate the performance of site-specific calculations, evaluation of sensitivities and uncertainties, and the future incorporation of new phenomenological models. All MACCS coding was required to conform to American National Standards Institute (ANSI) standard FORTRAN 77 (American National Standards Institute 1978), a language designed to foster portability. Almost all of the MACCS model parameter values are defined by the user in order to facilitate the performance of uncertainty and sensitivity analyses.

The principal phenomena considered in MACCS are atmospheric transport, short-term and long-term mitigative actions and exposure pathways, deterministic and stochastic health effects, and economic costs. Among the U.S. consequence codes that are publicly available, MACCS is unique in its capability for modeling short-term and long-term mitigative actions, and their associated economic costs, in conjunction with modeling both deterministic and stochastic health effects.

The first version of MACCS released to the public, version 1.4, was distributed by Sandia National Laboratories beginning in 1987. Along with a draft user's guide and model description, it was distributed to over 40 recipients. MACCS 1.4 was used for the calculations of the *Reactor Risk Reference Document* (NRC 1987), a public first draft of the study now commonly referred to as NUREG-1150. (Subsequent references to this document will use NUREG-1150.)

MACCS 1.4 was also used to study the relative importance of individual radionuclides (Alpert *et al.* 1987) and the sensitivity and uncertainty of model predictions to variations in input parameters (Helton *et al.* 1989). This version was also used evaluate the potential economic costs of commercial reactor accidents (for example, see Alonso and Gallego 1987; Alonso, Gallego, and Martin 1990; and Lonergan, Goble, and Cororaton 1990).

MACCS 1.4 had a major deficiency that impeded its convenient use, namely, it was composed of not a *single* FORTRAN code, but of five separate codes that had to be exercised in sequence, with the calculated results propagated from one code to the next through binary files on the host computer system. This was a cumbersome arrangement, but, despite this limitation, the code was

used successfully outside of SNL for the K reactor probabilistic risk assessment (PRA) (O'Kula and Mendoza 1989) with a methodology based on that of the first-draft NUREG-1150. MACCS 1.4 was also used for Savannah River Site (SRS) K reactor analyses intended to fulfill both authorization basis purposes (Westinghouse Savannah River Company 1990) and those of a PRA (Amos *et al.* 1991). The use of MACCS to support a risk-based authorization basis for the K reactor was the first DOE application of this type.[1]

MACCS 1.5 remedied the cumbersome architecture by merging the five programs into one. During the course of that effort, an independent inspection of the code was conducted (Dobbe *et al.* 1990). Additional NRC-sponsored efforts in support of the code were those by Tveten (1990a,b; 1995).

In 1990, version 1.5.11 was made available to the public by the National Energy Software Center (NESC) of Argonne, IL and the Radiation Shielding Information Center (RSIC) of Oak Ridge, TN. A three-volume set of published manuals (Chanin *et al.* 1990; Jow *et al.* 1990; Rollstin *et al.* 1990) was issued as the code's documentation.

The Department of Energy (DOE) has had a long-standing interest in the evolution of MACCS. In order to assess the impact of the code upgrade from versions 1.4 to 1.5 on the calculated results, the DOE sponsored an investigation into the impact of the code changes (O'Kula and East 1990), and then requested an additional effort to define the DOE needs for enhancement of the code (O'Kula 1991).

MACCS 1.5.11 was distributed on 9-track magnetic tape, with the target machine being a Digital Equipment Corporation (DEC) VAX computer running the VMS operating system. Soon thereafter, the 386 processor came into use on IBM-PC compatibles and a FORTRAN 77 compiler for the PC platform became available. Because of the convenience offered by desktop computers, the code was converted to run on the PC (Jones, Dobbe, and Knudson 1991), but this version was not widely distributed, and the originators were not tasked with providing user support.

SNL was then tasked by the NRC to adapt the code to the PC platform, and to implement a revised cancer risk model based on BEIR V (National Academy of Sciences 1990). During the course of the effort, internal changes to the coding were made to make it as portable as possible, given the limitations of ANSI FORTRAN 77. Also, a number of coding errors were corrected and a few additional minor enhancements were made to the code's models. The resultant code, MACCS 1.5.11.1, was readily installable on five different types of computer systems, with a diskette-based distribution package that included an executable for 386 or higher PC-compatibles (Chanin *et al.* 1993).[2]

---

[1] A similar approach, using MACCS and beta-test MACCS2, would later be adopted for risk-based authorization basis analyses by the Rocky Flats Plant.

[2] In the remainder of this report, for brevity, the simple term MACCS will often be used to refer to verson 1.5.11.1 of that code, the immediate predecessor of MACCS2. However, when the discussion pertains to only a specific version, the version number will always be specified.

MACCS has come into wide use within the United States and abroad (Neymotin 1994) for the evaluation of commercial power plant safety, with over 170 copies distributed by the Energy Science and Technology Center (ESTSC) of Oak Ridge, TN. However, despite the code's intended use for nuclear power plants, a sizable fraction of the code's users have always been engaged in studies assessing the safety of DOE facilities, and the code has occasionally been used to assess Department of Defense (DoD) nuclear facilities as well.

When the successive versions of MACCS have been applied to DOE facilities, in almost every instance there has been a problem with the limited set of radionuclides selected for commercial reactor applications. In order to remedy this shortcoming, and implement a number of other changes that enhance the code's usefulness for all types of reactor and nonreactor facilities, the MACCS2 development effort was initiated at SNL in 1991. The purpose of this effort was to develop a generally applicable analysis tool for use in assessing potential accidents at a broad range of reactor and nonreactor nuclear facilities. MACCS2 development efforts have been sponsored by the DOE Office of Defense Programs and the NRC, with additional DOE-related work supported by Los Alamos National Laboratory (LANL) (Chanin 1992).

The MACCS2 enhancements were developed through cooperation and joint efforts with the technical staff at Brookhaven National Laboratory (BNL), Idaho National Engineering Laboratory (INEL), Los Alamos National Laboratory, Oak Ridge National Laboratory (ORNL), Rocky Flats Plant (RFP), Savannah River Site, and Hanford Reservation. Furthermore, it has benefited from ongoing NRC research, as well as NRC joint efforts with the European Commission (EC) in uncertainty analyses (Harper *et al*. 1995).

Over the course of the MACCS2 development process, a few coding errors "inherited" from MACCS have been corrected, as is discussed in Section 3. These are primarily (1) the incomplete implementation in all versions of MACCS of the coding for generation of the intermediate-phase results and (2) correction of the MACCS 1.5.11.1 implementation of the dose and dose rate reduction factor (DDREF) used to estimate cancer risks.

MACCS2 has been in limited-distribution beta test by a small set of DOE users since April 1993. Feedback from this core group of long-term MACCS/MACCS2 users has been of great value in the code development process, identifying errors and making suggestions on additional enhancements, which have been implemented from 1993 up to the present.

In addition to the *ad hoc* verification efforts of the beta-test group, the University of New Mexico (UNM) has completed a formal independent verification study of the code package which has included detailed hand calculations. The results of that effort are to be published in a formal report.

1.2 Application of MACCS and the MACCS2 Package

MACCS/MACCS2 allows the user to define values for a wide range of model parameters. In addition, MACCS2 allows the user to select among alternative modeling approaches with regard to emergency evacuation and radionuclide transfer through the food chain. This flexibility makes

the code useful for diverse purposes. An overview of previous MACCS and MACCS2 applications is given in the following sections to illustrate possible uses of the code.

1.2.1 PRA Applications

PRAs are generally used to assess the relative risks posed by various types of operations and facilities, to understand the relative importance of the risk contributors, and to obtain insights on potential safety improvements. There is usually no pass-fail criterion that must be met to allow operations to continue. A major goal of PRAs is to gain insights that can be used to either minimize the chances (probability) of accidents or to minimize the impacts (consequences) of accidents that might occur.

For PRA applications, the radiological consequences are presented in the form of a complementary cumulative distribution function (CCDF). The CCDF produced by the code is based on the random sampling of a year of weather data. All other input parameters, however, are treated as point estimates. CCDFs are presented separately for each accident scenario modeled by MACCS2, and there is no provision for their summation by the code into a single overall CCDF representing a spectrum of potential accidents.

The foremost application of MACCS has been its use for the NUREG-1150 PRA-calculations (NRC 1987; 1991), assessing the risks posed by the operation of five commercial power reactors. The MACCS methodology developed by SNL for this study was subsequently applied, with some variations, to the following:

1. the previously discussed SRS K reactor PRA,
2. the Hanford N reactor (Camp *et al.* 1990),
3. the LaSalle commercial power plant (Payne 1992; Brown *et al.* 1993), and
4. the Grand Gulf commercial power plant (Brown *et al.* 1995).

1.2.2 Research Studies

The majority of the analysts using MACCS and beta-test versions of MACCS2 have been engaged in what can best be described as research studies. These studies have covered such topics as cost-benefit analyses of alternative interdiction criteria, the impact of proposed regulatory changes, and uncertainty/sensitivity studies of code output.

Helton *et al.* (1995a,b,c,d) investigated the sensitivity of MACCS consequence calculations to variations in values for imprecisely known input variables. MACCS early exposure, chronic exposure, and food pathway results were investigated. Input variables that had the greatest impact on code results were identified. The results of this effort were later applied to a joint NRC and European Commission effort to assess the uncertainty in the calculations of MACCS and the EC nuclear accident consequence assessment code, COSYMA (Commission of the European Communities 1991). This joint NRC/EC uncertainty study (Harper *et al*. 1995) elicited from phenomenological experts uncertainty distributions for the MACCS and COSYMA input parameters identified as having the greatest impact on the uncertainty in code output. Sandia,

under NRC sponsorship, will use the elicited uncertainty distributions in a future study to assess the overall uncertainty of MACCS2 consequence calculations.

MACCS was also included in an international collaborative effort to compare predictions obtained from seven consequence codes: ARANO (Finland), CONDOR (UK), COSYMA (EC), LENA (Sweden), MACCS (United States), MECA2 (Spain), and OSCAAR (Japan). (Nuclear Energy Agency of the Organization for Economic Cooperation and Development 1994). The study concluded that the spread in consequence analysis results obtained from the seven consequence codes was small compared with the overall uncertainty in consequence code predictions. The mean results obtained with the different codes typically varied by a factor of 2 although the spread in mean results was greater for a few of the tabulated consequence measures.

MACCS has also been used in a number of studies relating to commercial reactor regulatory issues. Several representative applications are as follows:

1. evaluation of proposed change in NRC guidance relating to population density in the emergency planning zone (EPZ) of commercial power reactors (Young 1994);

2. definition of a large release (Hanson, Davis and Mubayi 1994), per the NRC safety goal (NRC 1986, 1991); and

3. evaluation of the economic consequences of hypothetical severe accidents at commercial power plants (Mubayi, Sailor, and Anandalingam 1995).

1.2.3 NEPA Studies

When MACCS is used for National Environmental Policy Act (NEPA) studies such as environmental impact statements (EISs), the results of the calculations are typically used to compare the accident risks posed by various alternatives (see 40 *CFR* 1500–1508, Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act; DOE 1992a, 1993, 1996e).

In contrast to EISs, for the smaller-scope NEPA analyses usually performed for environmental assessments (EAs), results from a MACCS analysis can be used to determine if a proposed action would result in significant impacts to the environment as defined in the pertinent regulations. For both EISs and EAs, however, NEPA imposes no fixed criterion by which to decide whether a given action is acceptable or unacceptable, allowing discretionary judgments to be made by the agency proposing to undertake the action.

MACCS has been widely used for DOE NEPA studies since the use of version 1.5.11 for the new production reactor (NPR) EIS (DOE 1991a). A number of large-scope EISs utilizing MACCS have recently been issued by the DOE:

1. tritium supply and recycling (DOE 1995b),
2. foreign research reactor fuel (DOE 1996a),
3. stockpile stewardship and management (DOE 1996b),
4 Pantex plant site-wide EIS (SWEIS) (DOE 1996c), and

5. storage and disposition of fissile materials (DOE 1996d).

In addition, the beta-test MACCS2 was utilized for a large-scope EA pertaining to the Y-12 plant at Oak Ridge National Laboratory (DOE 1994a; Fisher and Lenox 1995). Further, MACCS is currently being utilized for the forthcoming LANL draft SWEIS and the forthcoming final version of the EIS on disposition of surplus highly enriched uranium (DOE 1995c). Finally, both MACCS and the beta-test MACCS2 have been utilized for the forthcoming Rocky Flats Environmental Technology Site (RFETS) draft SWEIS.

1.2.4 Authorization Basis Studies

In contrast to NEPA studies, in the authorization basis analyses performed for SARs, the analyst is interested in conservatively calculated, bounding dose estimates for well-defined DBA and beyond-DBA accident scenarios. The results of this analysis are used to determine if the safety basis of the facility is adequate for operation (DOE 1989, 1992b).

When MACCS2 is used for authorization basis studies, it is very important to carefully review the code's phenomenological models and input parameter values to ensure that they conform to applicable guidance and are appropriate for the accident scenario being modeled. The identification of deficiencies in these areas could bring into question the safety basis of a facility. If errors are later found in authorization basis calculations, an unreviewed safety question (USQ) could be raised (DOE 1991b), and continued operation of the facility would then require a demonstration that the facility's safety basis was adequate.

MACCS and MACCS2 have received limited use for DOE authorization basis studies. Two of the known applications are as follows:

1. MACCS 1.5.11.1 was used for the Rocky Flats Building 707 SAR (Stone and Webster 1991).

2. MACCS 1.5.11.1 was used for the Nevada Test Site (NTS) Device Assembly Facility (DAF) SAR (Raytheon Systems Services 1995).

Also notable is the use of beta-test versions of MACCS2 for detailed analyses focused on Rocky Flats (Peterson 1993a,b; 1994a,b; 1995). These analyses were performed for NEPA (such as EAs) as well as authorization basis studies. In addition, beta-test MACCS2 was used for studies relating to the SRS Defense Waste Processing Facility (DWPF) SAR (East 1996).

THIS PAGE INTENTIONALLY LEFT BLANK

2.0 Basic Code Features Preserved in MACCS2

This section presents an overview of the MACCS features that have been preserved unchanged in MACCS2. The present version of the code will be referred to as MACCS2, although the features discussed in this chapter apply to both MACCS and MACCS2.

2.1 Overview of Code Structure

The structure of MACCS2 is based on that of CRAC2 (Ritchie *et al.* 1984), as descended from the *Reactor Safety Study* (NRC 1975). Additional information on the technical background of reactor-based assessment codes can be found in the *PRA Procedures Guide* (American Nuclear Society and Institute of Electrical and Electronic Engineers 1983).

MACCS2 is used to estimate the radiological doses, health effects, and economic consequences that could result from postulated accidental releases of radioactive materials to the atmosphere. The specification of the release characteristics, designated a "source term," can consist of up to four Gaussian plumes (Systems Applications 1982), with these often referred to simply as "plumes."

The radioactive materials released are modeled as being dispersed in the atmosphere while being transported by the prevailing wind. During transport, whether or not there is precipitation, particulate material can be modeled as being deposited on the ground. If contamination levels exceed a user-specified criterion, mitigative actions can be triggered to limit radiation exposures. If mitigative actions are triggered, the economic costs of these actions are calculated and can be reported.

There are two aspects of the code's structure that are basic to understanding its calculations: (1) the calculations are divided into modules and phases and (2) the region surrounding the facility is divided into a polar-coordinate grid. These concepts are described in the following subsections.

2.1.1 Division of Calculations into Modules and Phases

MACCS2 is divided into three primary modules: ATMOS, EARLY, and CHRONC. The input data they require are described in Sections 5, 6, and 7, respectively.[3]

There is also another fundamental division in the code's calculations. This division is based on the sequence of societal responses that would follow the occurrence of an accident. These phases are defined by the Environmental Protection Agency (EPA) (1992) in its *Protective Action*

[3] As stated in Section 1.4, the original design of MACCS incorporated five separate FORTRAN programs executed in sequence. These were named ATMOS, EARLY, CHRONC, MERGER, and SUMMER. Functions of the former MERGER and SUMMER are now performed by the OUTPUT module. Results generated by ATMOS, EARLY, and CHRONC are written to binary files, which are then processed by OUTPUT in order to generate CCDFs.

Guides, and referred to as the emergency, intermediate, and long-term phases. Because these concepts are basic to an understanding of the code, the relationships among the code's three modules and the three phases of exposure are summarized below.

2.1.1.1 The ATMOS Module: Atmospheric Transport and Deposition

ATMOS performs all of the calculations pertaining to atmospheric transport, dispersion, and deposition, as well as the radioactive decay that occurs prior to release and while the material is in the atmosphere. The results of the calculations are stored for use by EARLY and CHRONC. The downwind transport of up to four plumes can be modeled. A number of parameters are stored. In addition to the air and ground concentrations, ATMOS stores information on wind direction, arrival and departure times, and plume dimensions.

2.1.1.2 The EARLY Module: Emergency-Phase Calculations

EARLY performs all of the calculations pertaining to the emergency phase. The emergency phase begins, at each successive downwind distance point, when the first plume of the release arrives. The duration of the emergency phase is specified by the user, and it can range between 1 and 7 days. The exposure pathways considered during this period are cloudshine, groundshine, and resuspension inhalation. Mitigative actions that can be specified for the emergency phase include evacuation, sheltering, and dose-dependent relocation.

2.1.1.3 The CHRONC Module: Intermediate- and Long-Term-Phase Calculations

CHRONC performs all of the calculations pertaining to both the intermediate and long-term phases, as is summarized below. The mitigative action models that can be utilized for these periods are not fully described in the MACCS *Model Description*. For that reason, and because MACCS2 incorporates some changes to the corresponding models of MACCS, an expanded description of the CHRONC mitigative action models is presented in Section 7.1. This description supersedes the MACCS *Model Description*.

2.1.1.4 Intermediate Phase

The intermediate phase begins, at each successive downwind distance point, upon the conclusion of the emergency phase. The duration of the intermediate phase is specified by the user, and it can range between 0 and 1 year. The exposure pathways considered during this period are groundshine and resuspension inhalation. Potential doses from food and water ingestion during this period are not considered.

These models are implemented on the assumption that the radioactive plume has passed and the only exposure source is from ground-deposited material. It is for this reason that MACCS2 requires that the total duration of a radioactive release be limited to no more than 4 days. The only mitigative action that can be specified for the intermediate phase is dose-dependent relocation. If a user-specified dose criterion is exceeded, resident individuals are assumed to be relocated for the duration of the intermediate phase.

2.1.1.5 Long-Term Phase

The long-term phase begins, at each successive downwind distance point, upon the conclusion of the intermediate phase. The exposure pathways considered during this period are groundshine, resuspension inhalation, and food and water ingestion.

The exposure pathways considered are those resulting from ground-deposited material. A number of protective measures can be modeled in the long-term phase in order to reduce doses to user-specified levels: decontamination, temporary interdiction, and condemnation. These mitigative actions are modeled separately for two land uses: residential and agricultural.

2.1.2 Distinction Between Acute and Lifetime Doses

Two types of doses are calculated by the code. They are referred to as "acute" and "lifetime doses" in this report. A brief introduction to the meaning of these terms is given below.

2.1.2.1 Acute Doses

Acute doses are calculated for the sole purpose of estimating the "deterministic" health effects that can result from high doses delivered at high dose rates. Such conditions may occur in the immediate vicinity of a nuclear power plant following hypothetical severe accidents where containment failure has been assumed to occur. Some examples of the health effects that are based on acute doses are as follows: early fatality, prodromal vomiting, and hypothyroidism. With only a few exceptions, typically focused on risks to on-site workers at DOE facilities, the need for calculation of acute doses has usually been limited to commercial power plant analyses.

For most DOE applications, where off-site doses fall well below the thresholds for inducing deterministic health effects, there is no need to calculate these doses, and the MACCS2 calculations can thereby be simplified to run at greater speed, benefiting also from a larger database of radionuclides that can be considered.

2.1.2.2 Lifetime Doses

Lifetime doses are the conventional measure of detriment used for radiological protection. These are the 50-year dose commitments to either specific tissues (e.g., red marrow and lungs), or a weighted sum of tissue doses defined by the International Commission on Radiological Protection (ICRP) (1991) and referred to as "effective dose." Lifetime doses may be used to calculate the stochastic health effect risk resulting from exposure to radiation. MACCS2 uses the calculated lifetime dose in cancer risk calculations.

2.1.3 Polar-Coordinate Grid

All of the calculations of MACCS2 are stored on the basis of a polar-coordinate spatial grid with a treatment that differs somewhat between (1) calculations of the emergency phase and (2) intermediate and long-term phases, as described later. The region potentially affected by a release is represented with an (r, θ) grid system centered on the location of the release. The

radius, *r*, represents downwind distance. The angle, θ, is the angular offset from north, going clockwise.

The user specifies the number of radial divisions as well as their endpoint distances. Up to 35 of these divisions may be defined, extending out to a maximum distance of 9999 km. The angular divisions used to define the spatial grid are fixed in the code (they are not user defined) and correspond to the 16 points of the compass, each being 22.5 degrees wide. The 16 points of the compass are used in the United States to express wind direction. The compass sectors are referred to as the "coarse grid." Figure 2-1 provides an example of a MACCS2 spatial grid and the numbering system associated with the 16 compass directions.

Since the emergency-phase calculations utilize dose-response models for early fatalities and early injuries that can be highly nonlinear (again, as specified by the user), these calculations are performed on a finer grid basis than the calculations of the intermediate and long-term phases. For this reason, the calculations of the emergency phase are performed with the 16 compass sectors divided into 3, 5, or 7 (as specified by the user) equal angular subdivisions. The subdivided compass sectors are referred to as the "fine grid."

The compass sectors are not subdivided into fine subdivisions for the intermediate and long-term phases because these calculations do not include estimation of the often highly nonlinear early fatality and early injury health effects, being limited to cancer and genetic effects. In contrast to the emergency phase, the calculations for these phases are performed using doses averaged over the full 22.5-degree compass sectors of the coarse grid.

2.2 Sequence of Calculations

MACCS2 calculations are performed in three phases: (1) input processing and validation, (2) phenomenological modeling, and (3) output processing. These are described in Sections 2.2.1 through 2.2.3.

2.2.1 Input Processing and Validation

The calculations begin with the processing of the primary user-supplied input. These input data are provided in three text files, named for the modules they supply: the ATMOS input file, EARLY input file, and CHRONC input file. Following the terminology used in the MACCS *User's Guide*, these three files are referred to generically as user input files. The variables defined in these files are described in Sections 5 through 7. The manner in which this input is processed is described in remainder of this section.

Error checking of the ATMOS, EARLY, and CHRONC input files is performed by the code so that errors are located and diagnosed before the phenomenological modeling phase is initiated. If any errors are detected, the program will sometimes validate as much of the subsequent input as possible to facilitate the debugging process. However, in many instances, the detection of an input error will cause an immediate termination of the program's execution. In all cases, when an error is detected in the code's input, the execution of the program will be terminated before the modeling calculations are performed.

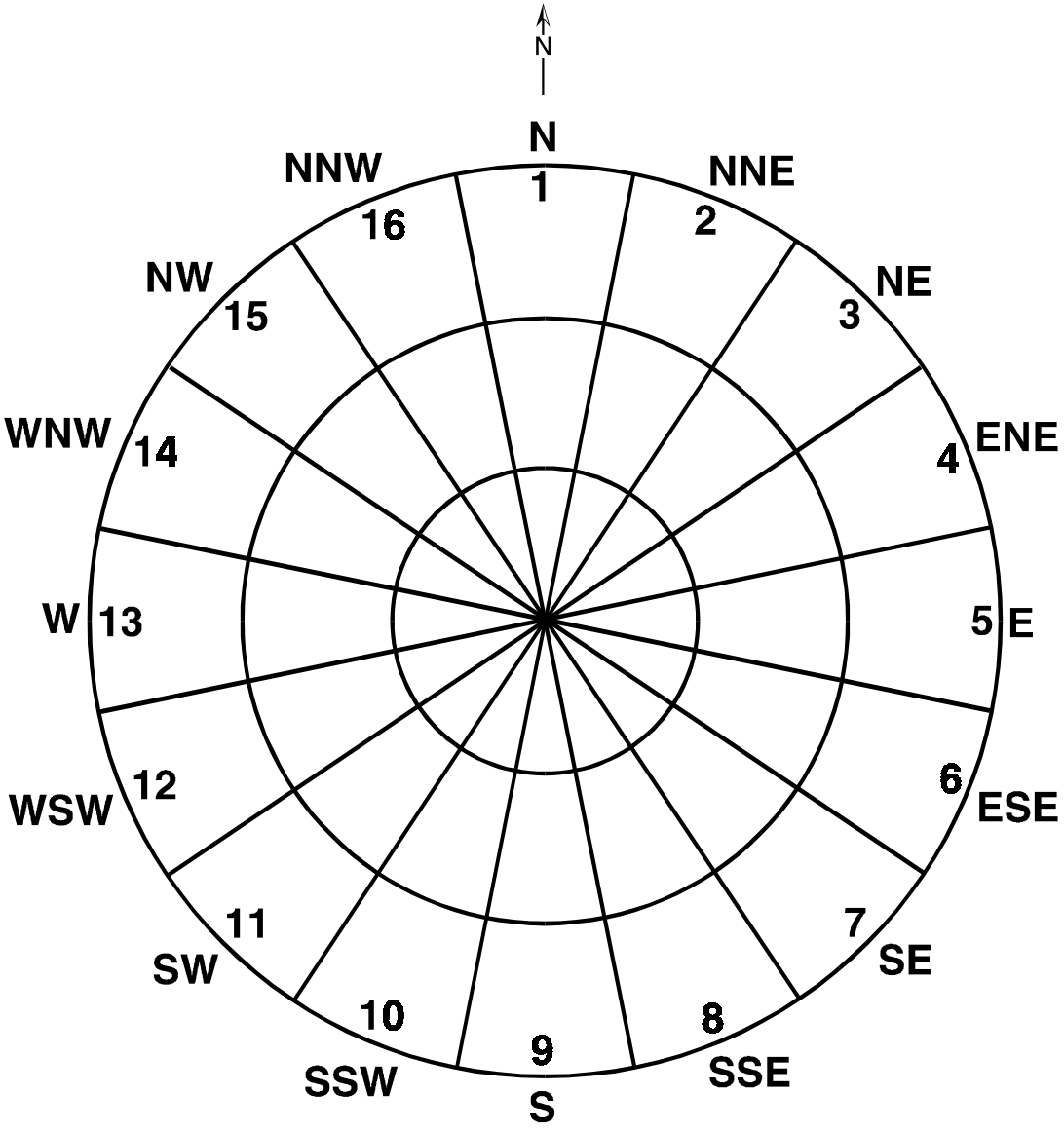


Figure 2-1. A MACCS2 polar-coordinate grid with 3 radial divisions. The numbers on the grid refer to the 16 compass directions.

2.2.1.1 Data Types Processed by the Code

Data required by MACCS2 can be of four different types: logical, character, integer, or real. Logical values are represented as either .TRUE. or .FALSE. as defined in the American National Standards Institute (1978) FORTRAN 77 standard. Character values can be any ASCII string delimited by apostrophes ('). If the string has no embedded blanks, the apostrophes are optional provided that the string is not interpreted to be a data item of another type. Integer values can be preceded with an optional plus or minus sign but they cannot have a decimal point. Real values can be written either as an optionally signed number with a decimal point or else in exponential notation as defined in the ANSI standard.

The code first evaluates an item to determine if it is of type logical. If the item is not a logical data type, it is evaluated to determine if it is of type integer. If the item is neither a logical nor integer type, the item is evaluated to determine if it is a real variable. Items that are neither logical, integer, or real are considered to be of type character.

2.2.1.2 Free-Format Input Processor

The ATMOS, EARLY, and CHRONC input files are processed sequentially by the INPRE free-format input processor, which was developed specifically for MACCS. The INPRE processor allows comments to be freely interspersed with the data. The input file can thus be made essentially self-documenting. The INPRE free-field input processor reads each line of the text-based input file as a data record. Each line of the file is allowed a length of up to 100 characters.

The individual data records consist of the content of the text line up to a carriage return or the 100th column. Each line of the file is either a comment record or a data record. Comment records, denoted by an asterisk (*) in column 1, are not processed by the INPRE processor. Data records are required to begin in column 1 with an 11-character record identifier consisting of 8 or 9 alpha-numeric identification characters that are usually followed by 2 or 3 numeric characters that are used for sequencing. An example of a record identifier is RIATNAM1001. The end of the input data file must be delimited by a period (.) in column 1.

The input processor begins by sorting all the data records in the file according to the collating sequence of their record identifiers. If more than one data record has the same record identifier, the last data record encountered is used and all earlier data records with the same identifier are ignored. Data records may appear in any order. The ordering is important only for records sharing the same identifier.

The variables for which values are provided in the user input files consist of either a single value (scalar) or a set of values (array) that are all of the same type. The record identifier used for scalar values is always of the same form. The first two characters are a mnemonic for the data group to which the identifier belongs. For example, the mnemonic for the Run Identification data is RI. The next six characters of the record identifier are the name of the FORTRAN variable within the program that is used to store the value. The record identifier is always 001. Only the first item found on the data record for a scalar quantity will be processed. Anything to

the right of the data item will be ignored by the input processor. This allows the use of descriptive comments alongside the data item, as is illustrated by the sample problems.

Arrays are found in the user input files in two different forms. The first method is similar to the approach used for scalars. A starting record identifier is constructed the same way as above: a two-letter mnemonic, followed by the six-letter variable name, followed by 001. More than one value can appear on the data record separated by blanks or a comma. Multiple blanks may be inserted between values; multiple commas between values are not allowed. You may place as many values on the card as will fit into the 100 columns. Successive cards with ascending sequence numbers are processed until all the required data items have been supplied. The record identifiers of the succeeding cards differ from the starting record identifier only in their last three digits.

The second method used for arrays is more structured. Several arrays of the same length whose values are related appear as columns across the page. The arrays can be of different type but they all share the same record identifier. The name of a program variable is not used to construct the record identifier since more than one variable receives its value from this data record. Instead of array values being read from left to right in rows, they are read from top to bottom in columns.

2.2.1.3 Error Checking of Input Data

The code checks for three different types of errors in the user input files:

1. mismatch between data type of the variable and data type of the input data,
2. data value outside the numerical limits required for the variable, and
3. specification of a data value inconsistent with another specified value.

The input processor will not convert data from one type to another. For example, if an integer value is to be supplied, as specified in later sections of this report, then an integer value must be supplied by the user. If a decimal point appears in what should be an integer value, an error flag will be set, and execution will be terminated upon completion of the input processing phase. Likewise, the absence of a decimal point in what should be a real value will be interpreted as an input error and cause the error flag to be set.

The code determines the validity of the numeric input parameters (both integer and real) by checking whether they fall within a specified range. The allowable range of each datum is listed in this report. Limits are also specified for lengths of character strings and these limits are also listed in this report. If a value is encountered that falls outside the required range, the error flag will be set and a diagnostic message issued to the output file. This message will list the minimum and maximum allowable values (or string lengths) for the item in order to facilitate the debugging process.

In addition to checking to see if a particular datum is of the proper type and within the allowable range, many user-supplied variables are further checked to determine if they are consistent with other data specifications. In all instances where these additional tests are performed, the applicable requirements are described in Sections 5 through 7 in close proximity to the

description of the variable and the specification of its allowable range. If these constraints are violated, a diagnostic error message will be generated and further execution terminated.

2.2.1.4 Specification of Multiple Accident Scenarios

The code allows the consideration of multiple source terms and multiple emergency-response strategies in a single run of the code. Multiple source terms for ATMOS and multiple emergency-response strategies for EARLY can be specified by the addition of change records positioned at the end of the ATMOS and EARLY input files. Change records specify new values for previously defined source-term or emergency-response scenario variables. When these are encountered, the code's calculations are rerun based on the new values for variables defined in the set of change records and new output is generated for each specified source term and emergency-response scenario.

Sets of change records are input after a complete set of ATMOS or EARLY input values have been specified [the end of the base case is indicated by the period (.) in column 1]. The end of each set of change records is also specified by a period in column 1. ATMOS allows up to 59 sets of source term change records and EARLY allows up to two sets of emergency-response change records. A text field identifying the scenario must be defined for each source term and emergency-response scenario.

The change records can only be used to replace previously defined data items in the base-case input. The change-record processor simply replaces a previously defined data record with a new data record having the same record identifier. If a set of change records contains data records with identifiers that have not been defined in the base-case input, it is possible that the code will terminate execution abnormally or that spurious results will be generated. Also, if the user tries to redefine previously defined input variables that are not part of the source term or emergency-response data blocks, those revised data records will not be processed by the program. The source term data block variables are discussed in Section 5.11, and the emergency-response data block variables are discussed in Section 6.6.

2.2.2 Phenomenological Modeling

The second phase of the code execution is the phenomenological modeling phase. The sequence in which the phenomena are evaluated closely follows the temporal order of events that would occur in the real world in the event of a facility accident. The phenomenological models incorporated in the code are of a simple character, and mathematics beyond undergraduate-level calculus is not utilized. The incorporated models utilize empirical data, often have analytical solutions, and are computationally straightforward.

An overview of the sequence of the phenomenological modeling performed in each of the three code modules (ATMOS, EARLY, and CHRONC) is provided in Tables 2-1 through 2-3. For each of the major modeling areas, these tables indicate where the details of the modeling approach can be found.

Table 2-1. Phenomenological Models of ATMOS

Phenomenology	Location of Model Description
Source Term Specification	MACCS *Model Description*, Section 2.2
Weather Data	MACCS *Model Description*, Section 2.3
Risk-Dominant Plume	MACCS *Model Description*, Section 2.4
Initial Plume Dimensions	Section 5.10 describes a change to MACCS *Model Description*, Section 2.5
Representative Weather Point	MACCS *Model Description*, Section 2.6
Downwind Transport	MACCS *Model Description*, Section 2.7
Plume Rise	MACCS *Model Description*, Section 2.8
Dispersion—Gaussian Plume Model	MACCS *Model Description*, Section 2.9
Overview of Plume Depletion	MACCS *Model Description*, Section 2.10
Depletion by Radioactive Decay	Section 3.2.1 describes a change to MACCS *Model Description*, Section 2.10.1
Depletion by Dry Deposition	MACCS *Model Description*, Section 2.10.2
Depletion by Wet Deposition	MACCS *Model Description*, Section 2.10.3
Centerline Air and Ground Concentrations	MACCS *Model Description*, Section 2.11

Of the three phenomenological modules in MACCS2, ATMOS is the only one that must always be exercised. The execution of the other modules (EARLY and CHRONC) may be inactivated by the specification of a control variable in the previous module's user input file. For example, if the last module to be exercised is EARLY, a control variable in the EARLY input file can be used to trigger the skipping of CHRONC. Similarly, if both EARLY and CHRONC are to be skipped, this can be achieved by setting a control variable in the ATMOS input file. If any module is inactivated in this way, there is no need to prepare its corresponding user input file.

2.2.3 Output Processing

The generation of results is controlled by user specifications in the ATMOS, EARLY, and CHRONC input files. There is no provision for specifying each accident's expected rate of occurrence (accident frequency). All consequence measures calculated by MACCS2 are conditional on the occurrence of a particular accident.

All of the results generated by MACCS2 are calculated in a manner that takes full account of any mitigative actions triggered by user input. These are all produced in CCDF form, even in cases when the code is utilizing only a single weather trial. A one-line summary of the CCDF for each of the requested results is written to the output file. For any subset of the results, the user can, in addition, instruct the code to print the entire CCDF table to the output file.

Table 2-2. Phenomenological Models of EARLY

Phenomenology	Location of Model Description
Overview of Exposure Pathways	MACCS *Model Description*, Section 3.1
Off-Centerline Correction Factor	MACCS *Model Description*, Section 3.1.1
Cloudshine	MACCS *Model Description*, Section 3.2.2
Groundshine	MACCS *Model Description*, Section 3.1.3
Direct Inhalation	MACCS *Model Description*, Section 3.1.4
Resuspension Inhalation	MACCS *Model Description*, Section 3.1.5
Emergency-Phase Relocation Costs	MACCS *Model Description*, Section 4.1
Evacuation	Section 6.6 describes revisions to MACCS *Model Description*, Section 5.1.1
Sheltering	Section 6.6 describes revisions to MACCS *Model Description*, Section 5.1.2
Dose-Dependent Relocation	MACCS *Model Description*, Section 5.1.3
Acute Health Effects—Early Fatality and Early Injury Models	MACCS *Model Description*, Section 6.1
Cancer Health Effect Models	Chanin *et al.* (1993) describes a revision to MACCS *Model Description*, Section 6.2

Table 2-3. Phenomenological Models of CHRONC

Phenomenology	Location of Model Description
Overview of Exposure Pathways	MACCS *Model Description*, Section 3.2
Off-Centerline Correction Factor	MACCS *Model Description*, Section 3.2.1
Groundshine	MACCS *Model Description*, Section 3.2.2
Resuspension Inhalation	MACCS *Model Description*, Section 3.2.3
COMIDA2 Model for Food Ingestion	Section 7.10 of this volume, and Chapter 3 of Volume 2 of this report
MACCS Model for Food Ingestion	Section 7.11 of this volume, and MACCS *Model Description*, Section 3.2.4
Water Ingestion	MACCS *Model Description*, Section 3.2.5
Mitigative Action Models	MACCS *Model Description*, Section 4.2
Economic Costs from Intermediate Phase	MACCS *Model Description*, Section 5.2
Economic Costs from Long-Term Phase	Section 7.1 describes revisions to the MACCS *Model Description*, Section 5.3

When more than one source term is specified, the results for each are presented on the output listing in the order of their appearance in the ATMOS input file. The OUTPUT module will print a description of *all* the results for each source term, as encountered in turn, before going on to the next source.

The various types of results that can be requested are referred to as Results 0–13 and A–B. None of these outputs is generated by default. For each result requested, the user can define the region of interest (defined by its inner and outer boundaries), the health effect or organ of interest (as appropriate), as well as other parameters (as pertinent). The results available from each module are listed in Table 2-4.

When any of these results are requested, several numerical measures (or metrics) are written to the output file, representing a one-line summary of the CCDF. In addition to these one-line summaries, the code can also report the entire CCDF for a user-specified subset of the requested results. The appearance of the one-line summary is illustrated in Figures 2-2 through 2-4, while the appearance of the CCDF table is illustrated in Figure 2-5. Additional information on the interpretation of these outputs is given in the remainder of this section, and further details may be found in Section 6.10.

2.2.3.1 Presentation of Multiple Source Terms and Multiple Cohorts

When multiple source terms are defined, the treatment is quite straightforward, with the results from each presented successively in the output file in the order in which they were defined in the ATMOS input file. In that file, the user is required to provide a unique text identifier for each source term, and that identifier is echoed to the output file so that results from multiple source terms can be readily distinguished.

The treatment of multiple emergency-response scenarios differs somewhat from the treatment of multiple source terms, and is somewhat more complex. Three important points are crucial. First, the allowance for multiple emergency-response scenarios extends only to the EARLY module, and there is no capability offered for the variation of assumptions used by the CHRONC module.

Second, the code treats the results from each emergency-response scenario as a separate cohort for which results are reported separately in the output file. If CHRONC is exercised, then its results are also reported as a separate cohort, following the EARLY results.

Third, if the user has requested the generation of results for multiple cohorts (either by specifying multiple emergency-response scenarios, or by exercising the CHRONC module), the very first set of results presented is labeled the "overall results," and represents the combined results from the various cohorts that have been defined.

The most straightforward approach to describing this aspect of the code's output is to utilize output taken from one of the sample problems as an example. Sample problem A, based on the input data used for the NUREG-1150 calculations, will be used for that purpose.

Table 2-4. Results Available from ATMOS, EARLY, and CHRONC

Result Name	Notes
Type 0: Atmospheric Results at Specified Downwind Distances	Requested in ATMOS input file; see Section 5.18. Results only available for the first source term of a multiple-source-term run. They are provided as a block of eight results. User specifies the radial distance index and the plume(s) of interest.
Type 1: Cases of Specified Health Effect	Requested in EARLY input file; see Section 6.11. If CHRONC is exercised, it automatically generates corresponding outputs for cancer health effects.
Type 2: Early Fatality Radius	Requested in EARLY input file; see Section 6.12. Only generated by EARLY.
Type 3: Population Exceeding Dose Threshold	Requested in EARLY input file; see Section 6.13. Only generated by EARLY.
Type 4: Average Individual Risk of Health Effects	Requested in EARLY input file; see Section 6.14. If CHRONC is exercised, it automatically generates corresponding outputs for cancer health effects.
Type 5: Total Collective Dose from Material Deposited Within Region	Requested in EARLY input file; see Section 6.15. If CHRONC is exercised, it automatically generates corresponding outputs for total collective dose from all pathways combined, including ingestion.
Type 6: Centerline Dose versus Distance	Requested in EARLY input file; see Section 6.16. Result only available when the straight-line plume option (IPLUME=1) is being utilized.
Type 7: Centerline Risk versus Distance	Requested in EARLY input file; see Section 6.17. Result only available when the straight-line plume option (IPLUME=1) is being utilized.
Type 8: Population-Weighted Safety Goal Risk	Requested in EARLY input file; see Section 6.18. If CHRONC is exercised, it automatically generates corresponding Type 8 outputs for groundshine and resuspension. Ingestion is not included in the Type 8 results.
Type A: Maximum Observed Dose at a Specified Distance Ring (r) (Direction-Independent Dose)	Requested in EARLY input file; see Section 6.19. If CHRONC is exercised, it automatically generates corresponding outputs for groundshine and resuspension. Ingestion is not included in the Type A results.
Type B: Maximum Observed Dose at a Specified (r,θ) Location (Direction-Dependent Dose)	Requested in EARLY input file; see Section 6.20. If CHRONC is exercised, it automatically generates corresponding outputs for groundshine and resuspension. Ingestion is not included in the Type B results.
Type 9: Breakdown of CHRONC Population Dose by Pathway	Requested in CHRONC input file; see Section 7.14. The reported doses are the result of contamination deposited within the stated region; for the ingestion paths and decontamination workers, doses may be incurred by individuals residing elsewhere.

Table 2-4. Results Available from ATMOS, EARLY, and CHRONC (continued)

Result Name	Notes
Type 10: Economic Costs of Mitigative Actions	Requested in CHRONC input file; see Section 7.15. The reported costs are the result of contamination deposited within the stated region.
Type 11: Maximum Distance for the Various Mitigative Actions	Requested in CHRONC input file; see Section 7.16. For each weather simulation, the code reports the furthest distance at which each of these actions is modeled as taking place.
Type 12: Impacted Area/Population Results	Requested in CHRONC input file; see Section 7.17. For mitigative actions affecting population, the number of affected individuals within the stated region is reported. For agricultural actions, the affected farmland area (hectares) is reported.
Type 13: Maximum Individual Dose from COMIDA2 Food-Chain Model	Requested in CHRONC input file; see Section 7.18. Unavailable when the MACCS food-chain model is utilized. Calculated using the same individual food consumption rates used for triggering mitigative actions for farming.

2.2.3.2 Interpretation of the One-Line Summaries

While NRC emergency planning requirements call for a high level of preparedness in the 10-mile emergency planning zone, it is possible that some population subgroups might remain behind, requiring steps by local authorities to locate them and provide any necessary assistance in leaving contaminated areas. In the 1987 public draft of NUREG-1150, it was assumed that 95% of the EPZ populace would evacuate upon receiving notification to do so, and that 5% of the EPZ populace would remain behind, with the remaining populace of contaminated areas subject to relocation after either 12 or 24 hr of exposure, depending on the doses incurred.

Sample problem A is based on the assumption that for the population within 10 miles of the plant there would be two emergency-response scenarios: evacuation at a specified time after the initiation of the accident and dose-dependent relocation. It thus incorporates two cohorts for the EARLY calculations. The CHRONC calculations represent a third and additional cohort. Sample problem A reports a large number of results; however, for simplicity, only the 50-mile cancer fatality results will be shown in the illustrative figures.

Figure 2-2 summarizes the cohorts included in the overall results. The two emergency-response scenarios (cohorts 1 and 2) are combined utilizing "fraction-of-the-people" weighting fractions of

Figure 2-2. Overall results.

```
  DATE AND TIME OF RUN = MACCS2 06/25/96   22:17:09   version 1.12, last modified 6/25/96: final test
  "ATMOS"  DESCRIPTION = IN1A.INP, Sample Problem A--Using Table-Lookup Sigmas, ATMOS input
  "EARLY"  DESCRIPTION = IN2A.INP, Sample Problem A of NUREG/CR-4691, Vol. 1, EARLY input
  "CHRONC" DESCRIPTION = IN3A_O.INP, Sample Problem A, "Old" NUREG-1150 Food Model

SOURCE TERM  1 OF  2:
    SECOND DRAFT 1150, WORST CASE SOURCE TERM FOR EARLY FATALITIES

OVERALL RESULTS OBTAINED BY COMBINING 2 EMERGENCY RESPONSE COHORTS FROM "EARLY" WITH THE WEIGHTING FRACTIONS BELOW APPLIED TO THEM:

                                                                                  FRACTION OF THE PEOPLE
                                                                                                 ------
    COHORT 1 = EVACUATION WITHIN 10 MILES, RELOCATION MODELS APPLY ELSEWHERE                      0.950

    COHORT 2 = NO EVACUATION, RELOCATION MODELS APPLY EVERYWHERE                                  0.050

AND THEN MERGING THE 2 RESULTS ABOVE WITH THE SINGLE SET OF RESULTS FROM "CHRONC" DESCRIBED BELOW:

    COHORT 3 = IN3A_O.INP, Sample Problem A, "Old" NUREG-1150 Food Model

RESULTS WHICH ARE PRODUCED ONLY BY "EARLY" OR ONLY BY "CHRONC" ARE PRESENTED IN LATER SECTIONS.

06/25/96   22:17:09    PAGE   1          PROB                          QUANTILES                                PEAK      PEAK  PEAK
                                       NONZERO   MEAN      50TH      90TH      95TH      99TH     99.5TH     CONS      PROB  TRIAL
HEALTH EFFECTS CASES
...
 CAN FAT/TOTAL               0-80.5 km  1.0000  1.72E+03  9.62E+02  4.07E+03  5.93E+03  9.57E+03  1.11E+04  2.06E+04  2.85E-04  123
```

Figure 2-3. EARLY results for cohort 1: evacuation.

```
  DATE AND TIME OF RUN = MACCS2 06/25/96   22:17:09   version 1.12, last modified 6/25/96: final test
  "ATMOS"  DESCRIPTION = IN1A.INP, Sample Problem A--Using Table-Lookup Sigmas, ATMOS input
  "EARLY"  DESCRIPTION = IN2A.INP, Sample Problem A of NUREG/CR-4691, Vol. 1, EARLY input

SOURCE TERM  1 OF  2:
    SECOND DRAFT 1150, WORST CASE SOURCE TERM FOR EARLY FATALITIES

RESULTS FOR A SINGLE EMERGENCY RESPONSE COHORT WITHOUT ANY WEIGHTING FRACTIONS BEING APPLIED

    COHORT 1 = EVACUATION WITHIN 10 MILES, RELOCATION MODELS APPLY ELSEWHERE

06/25/96   22:17:09    PAGE   3          PROB                          QUANTILES                              PEAK      PEAK  PEAK
                                        NONZERO   MEAN      50TH      90TH      95TH      99TH     99.5TH     CONS      PROB  TRIAL
HEALTH EFFECTS CASES
...
 CAN FAT/TOTAL              0-80.5 km  1.0000  9.26E+02  4.27E+02  2.28E+03  3.13E+03  7.11E+03  8.79E+03  1.90E+04  2.85E-04  123
```

Figure 2-4. EARLY results for cohort 2: no evacuation.

```
  DATE AND TIME OF RUN = MACCS2 06/25/96   22:17:09   version 1.12, last modified 6/25/96: final test
  "ATMOS"  DESCRIPTION = IN1A.INP, Sample Problem A--Using Table-Lookup Sigmas, ATMOS input
  "EARLY"  DESCRIPTION = IN2A.INP, Sample Problem A of NUREG/CR-4691, Vol. 1, EARLY input

SOURCE TERM  1 OF  2:
    SECOND DRAFT 1150, WORST CASE SOURCE TERM FOR EARLY FATALITIES

RESULTS FOR A SINGLE EMERGENCY RESPONSE COHORT WITHOUT ANY WEIGHTING FRACTIONS BEING APPLIED

    COHORT 2 = NO EVACUATION, RELOCATION MODELS APPLY EVERYWHERE

06/25/96   22:17:09    PAGE   5          PROB                          QUANTILES                              PEAK      PEAK  PEAK
                                        NONZERO   MEAN      50TH      90TH      95TH      99TH     99.5TH     CONS      PROB  TRIAL
HEALTH EFFECTS CASES
...
 CAN FAT/TOTAL              0-80.5 km  1.0000  1.03E+03  5.93E+02  2.40E+03  3.36E+03  5.42E+03  5.94E+03  9.00E+03  1.11E-03   51
```

Figure 2-5. CHRONC results for cohort 3.

```
  DATE AND TIME OF RUN = MACCS2 05/20/96   09:57:55   v. 1.11f, 4/16/96: new option BOUNDARY/CENTERPOINT
  "ATMOS"  DESCRIPTION = IN1A.INP, Sample Problem A--Using Table-Lookup Sigmas, ATMOS input
  "EARLY"  DESCRIPTION = IN2A.INP, Sample Problem A of NUREG/CR-4691, Vol. 1, EARLY input
  "CHRONC" DESCRIPTION = IN3A_O.INP, Sample Problem A, "Old" NUREG-1150 Food Model

SOURCE TERM  1 OF  2:
    SECOND DRAFT 1150, WORST CASE SOURCE TERM FOR EARLY FATALITIES

RESULTS FROM THE "CHRONC" MODULE ALONE

    COHORT 3 = IN3A_O.INP, Sample Problem A, "Old" NUREG-1150 Food Model

05/20/96   09:57:55    PAGE   7          PROB                          QUANTILES                                PEAK      PEAK  PEAK
                                        NONZERO   MEAN      50TH      90TH      95TH      99TH     99.5TH     CONS      PROB  TRIAL
HEALTH EFFECTS CASES
...
 CAN FAT/TOTAL               0-80.5 km  1.0000  7.87E+02  4.16E+02  1.95E+03  2.70E+03  3.89E+03  4.43E+03  6.77E+03  2.15E-04  102
```

0.95 and 0.05. Fraction-of-the-people weighting means that the respective *consequence* values from the two scenarios are weighted by the corresponding weighting fraction.[4] In contrast, "fraction-of-the-people" weighting would indicate that the associated *probabilities* are to be scaled by the specified weighting fractions.

In the example of Figure 2-2, for each weather trial, and each wind direction, the overall result is calculated by summing two values: (1) 95% of the consequence value calculated for the evacuation cohort (cohort 1), and (2) 5% of the consequence value calculated for the relocation cohort (cohort 2).

The values of Figure 2-2 are discussed from left to right. The probability of a nonzero consequence was 1.0, indicating that there were no weather conditions that resulted in a consequence estimate of 0. The mean (expected value) was 1.72E+03, the 50th quantile (median) was 9.62E+02, the 90th quantile was 4.07E+03, the 95th quantile was 5.93E+03, the 99th quantile was 9.57E+03, and the 99.5th quantile was 1.11E+04. The observed peak value out of all weather conditions modeled was 2.06E+04, with an associated probability of 2.85E–04, resulting from weather trial number 123.

A simple hand calculation can be performed to illustrate the relationship between the overall results and the results from the three cohorts given in Figures 2-3 through 2-5. This involves the mean consequence results from the respective cohorts. Of all the metrics presented, the mean is the only one that is additive. For cohort 1, the mean cancer fatalities are shown as 9.26E+02; for cohort 2 the mean cancer fatalities are shown as 1.03E+03; and for cohort 3 the mean cancer fatalities are shown as 7.87E+02. We have the following:

$$1.72E+03 = (0.95 \bullet 9.26E+02) + (0.05 \bullet 1.03E+03) + 7.87E+02.$$

2.2.3.3 Interpretation of the CCDF Tables

The CCDF output for the three sample problem A cohorts and the overall results are presented in Figure 2-6. The CCDF for any of the MACCS2 results is represented as two arrays of floating point values, with the two arrays of the same length. These two arrays represent a series of (consequence, probability) doublets that indicate the spectrum of outcomes from low-consequence/high-probability to high-consequence/low-probability. For additional discussion on representations of risk, see Kaplan and Garrick (1981).

The first array of the CCDF, listed in the second column of the output file, and denoted PROB>=X in the output file, represents the estimated probability of equaling or exceeding a specific consequence value, X. The second array of the CCDF represents the associated consequence values X.

[4] The other alternatives are (1) fraction-of-the-time and (2) separate population distributions (SUMPOP), described in Sections 6.1.2, 6.6.7, and 6.10, and Section A.3 of Appendix A.

Figure 2-6. CCDF tables for overall results and cohorts 1 to 3.

```
MACCS2 06/25/96   22:17:09   version 1.12, last modified 6/25/96: final test     PAGE  10

SOURCE TERM  1 OF  2:
    SECOND DRAFT 1150, WORST CASE SOURCE TERM FOR EARLY FATALITIES

RESULT NAME = HEALTH EFFECTS CASES
               CAN FAT/TOTAL               0-80.5 km

   PEOPLE FRACTION =       0.9500                0.0500
```

OVERALL		EMER. RESP. # 1		EMER. RESP. # 2		CHRONC RESULTS	
X	PROB>=X	X	PROB>=X	X	PROB>=X	X	PROB>=X
1.00E-04	1.00E+00	1.00E-04	1.00E+00	1.00E-04	1.00E+00	1.00E-04	1.00E+00
2.00E-04	1.00E+00	2.00E-04	1.00E+00	2.00E-04	1.00E+00	2.00E-04	1.00E+00
3.00E-04	1.00E+00	3.00E-04	1.00E+00	3.00E-04	1.00E+00	3.00E-04	1.00E+00
5.00E-04	1.00E+00	5.00E-04	1.00E+00	5.00E-04	1.00E+00	5.00E-04	1.00E+00
7.00E-04	1.00E+00	7.00E-04	1.00E+00	7.00E-04	1.00E+00	7.00E-04	1.00E+00
1.00E-03	1.00E+00	1.00E-03	1.00E+00	1.00E-03	1.00E+00	1.00E-03	1.00E+00
2.00E-03	1.00E+00	2.00E-03	1.00E+00	2.00E-03	1.00E+00	2.00E-03	1.00E+00
3.00E-03	1.00E+00	3.00E-03	1.00E+00	3.00E-03	1.00E+00	3.00E-03	1.00E+00
5.00E-03	1.00E+00	5.00E-03	1.00E+00	5.00E-03	1.00E+00	5.00E-03	1.00E+00
7.00E-03	1.00E+00	7.00E-03	1.00E+00	7.00E-03	1.00E+00	7.00E-03	1.00E+00
1.00E-02	1.00E+00	1.00E-02	1.00E+00	1.00E-02	1.00E+00	1.00E-02	1.00E+00
2.00E-02	1.00E+00	2.00E-02	1.00E+00	2.00E-02	1.00E+00	2.00E-02	1.00E+00
3.00E-02	1.00E+00	3.00E-02	1.00E+00	3.00E-02	1.00E+00	3.00E-02	1.00E+00
5.00E-02	1.00E+00	5.00E-02	1.00E+00	5.00E-02	1.00E+00	5.00E-02	1.00E+00
7.00E-02	1.00E+00	7.00E-02	1.00E+00	7.00E-02	1.00E+00	7.00E-02	1.00E+00
1.00E-01	1.00E+00	1.00E-01	1.00E+00	1.00E-01	1.00E+00	1.00E-01	1.00E+00
2.00E-01	1.00E+00	2.00E-01	1.00E+00	2.00E-01	1.00E+00	2.00E-01	1.00E+00
3.00E-01	1.00E+00	3.00E-01	1.00E+00	3.00E-01	1.00E+00	3.00E-01	1.00E+00
5.00E-01	1.00E+00	5.00E-01	1.00E+00	5.00E-01	1.00E+00	5.00E-01	1.00E+00
7.00E-01	1.00E+00	7.00E-01	1.00E+00	7.00E-01	1.00E+00	7.00E-01	1.00E+00
1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
2.00E+00	1.00E+00	2.00E+00	1.00E+00	2.00E+00	1.00E+00	2.00E+00	1.00E+00
3.00E+00	1.00E+00	3.00E+00	1.00E+00	3.00E+00	1.00E+00	3.00E+00	1.00E+00
5.00E+00	1.00E+00	5.00E+00	1.00E+00	5.00E+00	1.00E+00	5.00E+00	1.00E+00
7.00E+00	1.00E+00	7.00E+00	1.00E+00	7.00E+00	1.00E+00	7.00E+00	1.00E+00
1.00E+01	1.00E+00	1.00E+01	1.00E+00	1.00E+01	1.00E+00	1.00E+01	1.00E+00
2.00E+01	1.00E+00	2.00E+01	9.99E-01	2.00E+01	1.00E+00	2.00E+01	1.00E+00
3.00E+01	1.00E+00	3.00E+01	9.99E-01	3.00E+01	1.00E+00	3.00E+01	1.00E+00
5.00E+01	1.00E+00	5.00E+01	9.90E-01	5.00E+01	1.00E+00	5.00E+01	1.00E+00
7.00E+01	1.00E+00	7.00E+01	9.71E-01	7.00E+01	9.98E-01	7.00E+01	9.99E-01
1.00E+02	9.99E-01	1.00E+02	9.43E-01	1.00E+02	9.91E-01	1.00E+02	9.98E-01
2.00E+02	9.96E-01	2.00E+02	7.98E-01	2.00E+02	8.87E-01	2.00E+02	8.41E-01
3.00E+02	9.53E-01	3.00E+02	6.54E-01	3.00E+02	7.57E-01	3.00E+02	6.51E-01
5.00E+02	7.91E-01	5.00E+02	4.44E-01	5.00E+02	5.79E-01	5.00E+02	4.30E-01
7.00E+02	6.38E-01	7.00E+02	3.28E-01	7.00E+02	4.34E-01	7.00E+02	3.24E-01
1.00E+03	4.85E-01	1.00E+03	2.42E-01	1.00E+03	3.03E-01	1.00E+03	2.38E-01
2.00E+03	2.40E-01	2.00E+03	1.34E-01	2.00E+03	1.40E-01	2.00E+03	9.68E-02
3.00E+03	1.55E-01	3.00E+03	5.48E-02	3.00E+03	6.61E-02	3.00E+03	3.98E-02
5.00E+03	7.47E-02	5.00E+03	1.73E-02	5.00E+03	1.86E-02	5.00E+03	2.64E-03
7.00E+03	3.40E-02	7.00E+03	1.05E-02	7.00E+03	1.43E-03	6.77E+03	2.15E-04
1.00E+04	8.40E-03	1.00E+04	3.27E-03	9.00E+03	1.11E-03	N.D.	N.D.
2.00E+04	2.85E-04	1.90E+04	2.85E-04	N.D.	N.D.	N.D.	N.D.
2.06E+04	2.85E-04	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

Figure 2-2 shows that for the overall results, as previously discussed, the observed peak value from all weather conditions modeled was 2.06E+04, with an associated probability of 2.85E–04. An overall consequence value of 1.00E+03 in Figure 2-6 is shown as being exceeded 4.85E–1 of the time (48.5%), and this value is just slightly higher than the median value of 9.62E+02 reported in the one-line summary, as expected.

Continuing on to the CCDF table (Figure 2-6) for cohort 1 (the evacuation case of EARLY), we see that a consequence magnitude of 7.00E+03 is estimated to be equaled or exceeded only 1.05% of the time, which is very close, as expected, to the 99th quantile value of 7.11E+03 shown in the one-line summary for this cohort (Figure 2-3).

2.2.3.4 Interpretation of One-Line Summaries for Single Weather Trial Runs

A CCDF is generated internally irrespective of whether weather sampling is utilized. If weather sampling is not utilized, depending on the user-specified option for input variable IPLUME (see Section 6.2.2), the code will generate a CCDF consisting of either 1 consequence/probability pair or 16 such pairs for the single weather sequence evaluated.

If IPLUME is assigned a value of 1, all of the plume segments travel in the same direction and the modeling results (risk values) for each plume segment are rotated around the 16 compass sectors to obtain a set of results based on the probability of the wind blowing in each direction and the population distribution defined for that compass sector.

For IPLUME = 2, each plume segment travels in the direction that the wind is blowing at the time of release and, as with IPLUME = 1, the modeling results are rotated around the compass sectors to obtain a set of results based on the probability of the wind blowing in each direction and the population distribution defined for that compass sector.

For IPLUME = 3, modeling results are *not* rotated around the compass sectors so that only one set of results is generated for each weather trial. Regardless of the defined wind rose or the population distribution, only mean consequence values will be listed for IPLUME=3 runs when weather sampling is not utilized.

2.2.3.5 Use of Interpolation

In conclusion, one more concept must be mentioned. This relates to the code's use of an interpolation algorithm to estimate the quantiles shown in the one-line summaries. The underlying data used to generate the quantiles shown in the one-line summaries are those shown in the CCDF tables, and interpolation is used to estimate the fixed quantiles of the one-line summaries.

The interpolation technique used to estimate the quantiles is log-linear (logarithmic on probability, linear on consequence). The calculation method unavoidably introduces some interpolation error in the quantile estimates, particularly for the higher quantile (*e.g.*, the 99.5th quantile results). For this reason, it may sometimes be found that a small change in input assumptions (such as variation of the initial random seed of the weather sampling algorithm) can

yield differences of 10% or more in the higher quantile dose estimates. This behavior is inherent in the algorithm implemented in the code.

3.0 Code Enhancements Implemented in MACCS2

The principal changes implemented in MACCS2 include the addition of code preprocessors (Section 3.1), enhancements to ATMOS (Section 3.2), enhancements to EARLY (Section 3.3), enhancements to CHRONC (Section 3.4), and additional minor enhancements and code corrections (Section 3.5). Appendix B describes the sequence of operations needed to convert MACCS user input files for use with MACCS2.

3.1 MACCS2 Preprocessors

The only preprocessor for MACCS developed prior to MACCS2 was the DOSFAC code. DOSFAC generated a file of dose conversion factors (DCF) required for MACCS dose calculations. DOSFAC was not publicly distributed because it was not designed to process user-defined parameter values through a user input file. All parameter values used in the DOSFAC calculations were fixed in the code.

The MACCS2 package includes a number of preprocessors that can be used to generate data files utilized in MACCS2 calculations. The MACCS2 package includes an enhanced version of DOSFAC, DOSFAC2, which processes user-defined parameter values provided in a user input file. Two additional DCF preprocessors and a new ingestion pathway model preprocessor are included in the code package. These preprocessors allow the code user to expand the list of radionuclides beyond the set provided in DOSFAC2 and used in the code's sample problems.

The MACCS2 distribution package includes data files generated by the new preprocessors and used in the code's sample problems. The user must run the preprocessors only if an analysis requires input data that differ from those included in the sample problem files of the distribution package.

An overview of the MACCS2 preprocessors is provided in the remainder of this section. Volume 2 of this report serves as a user's guide for the preprocessors distributed as part of the MACCS2 package.

3.1.1 Dose Conversion Factor Preprocessors

Dose conversion factors express the relationship between (1) environmental concentrations (or intakes) and (2) resultant human doses or dose rates. They are developed for specific exposure pathways, organs, and radionuclides. For example, the DCF for the skin dose from exposure to cesium-137 ground contamination is 2.75E–16 Sv/Bq-s-m^{-2} (Eckerman and Ryman 1993). MACCS2 requires DCFs for the inhalation, ingestion, cloudshine, and groundshine exposure pathways for each organ for which doses are to be calculated, and for each radionuclide that is to be included in the scenario.

DCFs are provided to MACCS and MACCS2 through a data file read by the code. The DOSFAC code was developed to produce a MACCS input file of DCFs for the 60 radionuclides considered important for nuclear power plant analyses. Although MACCS was dimensioned to

allow the simultaneous consideration of 150 radionuclides, calculations were limited by the availability of DCFs.[5]

As a practical matter, unless code users generated DCFs themselves, or obtained them from published sources, MACCS was limited to processing only the 60 radionuclides included in the DOSFAC-generated DCF file. Another factor that discouraged expansion of the MACCS radionuclide set by users was the code's limitation of decay chains to two members, with the branch fraction from parent to daughter fixed at 100%. This limitation, for example, introduced a major difficulty for criticality source terms, where longer chains are needed.

3.1.1.1 Three DCF Preprocessors

The MACCS2 package contains three DCF preprocessors that can be used to generate MACCS2 DCF data files: FGRDCF, IDCF2, and DOSFAC2. Each of these preprocessors accesses different DCF databases and accepts user-defined input data.

3.1.1.2 DOSFAC2

DOSFAC2 allows the user to specify input parameters defining relative biological effectiveness, acute dose reduction factors, clearance class, and particle size. DOSFAC2 obtains DCFs for cloudshine and groundshine from a DOE (1988) database, referred to later by its report number, DOE/EH-0070. DCFs for exposure resulting from the inhalation or ingestion of radionuclides are generated from a 1987 DCF database provided by Keith Eckerman of Oak Ridge National Laboratory. The primary disadvantage of DOSFAC2 is that it is limited to generating DCFs for the original library of 60 radionuclides identified as important for commercial nuclear power plant analyses. This limitation is not a limitation of the code *per se*, but is due to the unavailability of inhalation dose commitments by time period for radionuclides other than the 60 considered important for commercial reactor accidents. The dose commitments by time period are used to generate acute inhalation DCFs.

3.1.1.3 FGRDCF

FGRDCF provides the user with access to the DCFs issued by the EPA in *Federal Guidance Report* (FGR) 11 (Eckerman, Wolbarst, and Richardson 1989) and FGR 12 (Eckerman and Ryman 1993). The FGRDCF preprocessor accesses inhalation and ingestion DCFs for over 600 radionuclides, and cloudshine and groundshine DCFs for 825 radionuclides (Radiation Shielding Information Center 1994). The DCFs provided by FGRDCF are sufficient for MACCS2 lifetime dose calculations. FGRDCF does not provide the DCFs required for MACCS2 acute dose calculations. However, for many applications, the analyst may be interested only in the calculation of the effective dose equivalent, for which an FGRDCF-generated file can be sufficient.

---

[5] The format of the DCF file utilized by MACCS2 is the same as that used by MACCS. This allows MACCS2 to be exercised using the DCF file that was distributed with MACCS. MACCS2 sample problem A (see Appendix C) makes use of the DOSDATA.INP file that was distributed with MACCS 1.5.11.1.

3.1.1.4 IDCF2

IDCF2 provides the capability of generating inhalation DCFs required for acute dose calculations that are not available from DOSFAC2 or FGRDCF. IDCF2 accesses immersion and groundshine DCFs for approximately 800 radionuclides from DOE/EH-0070. Inhalation and ingestion DCFs for approximately 500 radionuclides are calculated by the IDCF code developed by the Idaho National Engineering Laboratory for assessment of hypothetical accidents at fusion power reactors (Fetter 1988, 1991). IDCF calculates inhalation DCFs based on ICRP 30 models; however, its results sometimes differ from ICRP 30-based inhalation DCFs generated using other calculation methods (Rood and Abbott 1991).

3.1.1.5 Choice of DCF Preprocessor

For DOE applications, FGRDCF is the preferred source of DCFs because it accesses the DCF database issued by the EPA. The FGRDCF DCFs, however, because they only include 50-year dose commitments from inhalation, cannot be used to calculate acute health effect risks such as early fatality and prodromal vomiting. The calculation of those health effects requires a preprocessor that can generate dose commitments for incremental time periods as short as the days and weeks following inhalation intake.

The situation is different for NRC applications assessing the safety of commercial power plants. For those, there is often a need to model acute health effects resulting in early fatalities and early injuries. DOSFAC2 is recommended as a DCF source for reactor accident analyses because it allows the calculation of acute health effects. In addition, IDCF2 provides a source of DCFs required to calculate acute health effects that are not available from FGRDCF or DOSFAC2. It is possible that IDCF2 could be used to augment the set of 60 radionuclides considered by DOSFAC2, or to evaluate the need for such augmentation.

Additional details on FGRDCF and IDCF2 and the data files they generate are provided in Sections 4 and 5 of Volume 2 of this report. The DOSFAC2 preprocessor is described in the DOSFAC2 *User's Guide* (Young, Chanin, and Banjac 1997-draft).

3.1.2 New Ingestion Pathway Preprocessor—COMIDA2

MACCS incorporates a food ingestion pathway model for deposition to growing crops and root uptake that requires the user to supply unitless transfer coefficients for each radionuclide and crop type considered by the code. These transfer factors represent the fraction of material deposited on farmland that is eventually incorporated into edible portions of foodstuffs. The sample problems distributed with MACCS include input data for only six radionuclides: ^{89}Sr, ^{90}Sr, ^{131}I, ^{133}I, ^{134}Cs, and ^{137}Cs. (These terms are written as Sr-89, Sr-90, I-131, I-133, Cs-134, and Cs-137 in the code.) The derivation of the corresponding input data required by the MACCS ingestion model is a very labor-intensive task, and is described in Sprung *et al.* (1990).

A major drawback of this model is that it stands somewhat alone among food-chain modeling approaches, deviating substantially from the predecessor models of the *Reactor Safety Study*. The MACCS food model is based on the original work of Ostmeyer (1986). This approach, making use of unitless transfer factors, is known to have been used for only two transportation-focused

accident assessment codes: RADTRAN (Neuhauser and Kanipe 1996) and RISKIND (Yuan *et al.* 1996). As a result of this limited use, there is sparse literature to support the derivation of the requisite input parameters; all instances of such have been one of a kind, focused on transportation applications, as described in the three citations.

In contrast, the input parameters required by the new MACCS2 ingestion pathway model preprocessor, COMIDA2, are readily available in the literature. COMIDA2 is based on INEL's COMIDA code (Abbott and Rood 1993, 1994). COMIDA is a dynamic food-chain model that estimates yearly harvest concentrations for five human crop types and integrated concentrations for four animal products for the unit deposition of radionuclides that occur on any user-specified day of the year. COMIDA was developed to support accident analysis of fusion-power test facilities, and COMIDA's modeling capabilities are similar to those of the PATHWAY code (Whicker and Kirchner 1987; Whicker *et al.* 1990).

COMIDA2 generates a database of dose-to-source ratios in the units of dose to an organ per initial unit of deposition of a single deposited radionuclide, considering any daughter buildup after deposition. The COMIDA2-generated database provides dose-to-source ratios for up to nine accident times spaced throughout the year. This allows consideration of seasonality effects, which can have a marked influence on the food ingestion pathway. COMIDA2 is described in Section 3 of Volume 2 of this report.

3.2 Enhancements to ATMOS

ATMOS incorporates a number of enhancements that provide the user with greater flexibility than MACCS. These enhancements relate primarily to the following: radioactive decay, specification of initial plume dimensions, specification of dispersion parameters, and output capabilities. Overviews of these enhancements are provided in the following subsections. All of the input parameters utilized by ATMOS are described in Section 5.

3.2.1 Expansion of Radioactive Decay Chain Calculations

MACCS models only simple parent-daughter decay (that is, two-member chains). MACCS2 incorporates decay-chain data for 825 radionuclides and models decay for decay chains with up to six generations. Decay in MACCS2 is calculated analytically using an iterative representation of the differential equations for first-order kinetics as described by Skrable *et al.* (1974) and Birchall (1986). The algorithm is the same as that used in the RSAC-5 code (Wenzel 1994).

3.2.2 Increased Flexibility in Defining Initial Plume Dimensions

The initial plume dimensions were calculated in MACCS based on the assumption that building wake effects determined the initial plume dimensions. The initial plume dimensions were calculated in the code based on the user input values for building height and width. σ_y was initialized to the building width divided by 4.3, and σ_z was initialized to the building height divided by 2.15. MACCS2, in contrast, does not include a model to convert building height and width into initial plume dimensions. Instead, users now must consider building wake effects outside of the code, and specify the initial plume dimensions for σ_y and σ_z. These values are

specified separately for each plume of a multiple-plume release. Further, while previous beta-test versions of MACCS2 did not allow plumes to overlap each other in time, the code now allows overlapping plumes. This change to MACCS2 thus allows the modeling, for example, of the HOTSPOT code's "stem and cap" model of initial cloud sizes that was used to represent explosive releases in the EIS for the Dual Axis Radiographic Hydrodynamic Test Facility (DOE 1995a).

When the source-term looping feature is utilized for consideration of multiple source terms in a single MACCS2 run, the initial dimensions of each plume of each source term can be specified independently. In contrast, MACCS utilized a *single* specification of initial plume dimensions (based on the user-specified building height and width) to initialize *all* of the released plumes; there was no provision to reset the building dimensions for the successive source terms of a multiple source-term run. Guidance on the specification of initial σ_y and σ_z values as a function of building dimensions, and a description of the format of this new input data are provided in Section 5.10.

3.2.3 New Lookup-Table Option for Dispersion Parameter Data

ATMOS has been modified to include a new code feature allowing a lookup-table scheme to be used as an alternative to the power-law functions for the σ_y and σ_z dispersion parameters. The σ_y and σ_z parameters represent plume expansion in the vertical and horizontal directions in the Gaussian plume model implemented in the code. The power-law function and the lookup-table options are described in Sections 5.7.1 and 5.7.2. The new option allows the user to provide a table of σ_y and σ_z values versus downwind distance in the ATMOS input file.

σ_y and σ_z lookup tables for three dispersion parameterization schemes are included in the MACCS2 package. The dispersion parameterization schemes included are the Tadmor–Gur (for 0.5 to 5 km) curves as presented in Dobbins (1979), as well as the two sets of Briggs curves for open country and urban terrain as presented in Hanna, Briggs, and Hosker (1982). For additional information on the use of the lookup-table option, see Section 5.7.2.

The motivation for implementing this new feature was to allow the use of parameterizations other than the simple power law. Also, if tracer experiments are available for a site, it might be possible to process such data into the tables of horizontal and vertical standard deviations (σ_y and σ_z) required by this new feature of MACCS2.

3.2.4 CCDFs of Atmospheric Dispersion and Deposition Results

No versions of MACCS had the capability to generate complementary cumulative distribution functions of the atmospheric modeling parameters calculated by ATMOS. The only capability offered by MACCS to report the results of the atmospheric modeling was the debug print option in ATMOS that printed a page of formatted output for each plume and each weather trial. For sample problem A, with two source terms each having two plumes, and 135 weather trials, turning on this option would result in 540 pages of output written to the output file.

In MACCS2, if requested by the user, ATMOS will now generate CCDFs of ten atmospheric modeling parameters for user-specified distances and plume segments. Air and ground concentrations are reported for a user-specified radionuclide. In addition to the results produced for the single specified radionuclide, the total radioactivity on the ground from all radionuclides is also reported.

3.3 Enhancements to EARLY

The enhancements to EARLY include the implementation of a more flexible evacuation model and the capability to calculate direction-dependent doses. The more flexible evacuation model was added to enable the code to model the characteristics of an evacuation that could occur as a result of an accident at a large DOE reservation. The new approach to evacuee movement enables the code to model variable evacuation speeds and simplifies the modeling of evacuee movement with respect to the plume.

The direction-dependent dose option allows the calculation of 99.5th percentile direction-dependent dose as defined in Reg. Guide 1.145 (NRC 1983) and Snell and Jubach (1981). As called for by Reg. Guide 1.145 and DOE Order 6430.1A (DOE 1989), MACCS2 allows the user to select from the larger of (1) the 95th percentile dose calculated for direction-independent meteorology and (2) the 99.5th percentile dose at a user-specified distance and direction.

Direction-dependent doses can be of great interest at facilities where the distance to the site boundary varies significantly with direction from the release point, or where authorization basis calculations make use of the 95% direction-independent dose and the 99.5% direction-dependent dose as stipulated in DOE Order 6430.1A.

3.3.1 MACCS2 Emergency-Response Model

The MACCS evacuation model could only model a straight-line evacuation path away from a release point and a constant evacuation speed. In 1992, under the sponsorship of Los Alamos National Laboratory, the coding of MACCS 1.5.11.1 was modified to improve its flexibility (Chanin 1992). The three principal enhancements include the capabilities to model the following: (1) nonradial evacuation paths; (2) evacuation travel speeds that vary with time; and (3) up to three population distributions, with each cohort following its own distinct pattern of emergency response. Additional enhancements included the options to: (1) model sheltering prior to evacuation, (2) implement different evacuation delay times at each distance, and (3) model sheltering/evacuation triggered by plume arrival.

These new features allow the user to model the following: (1) evacuation travel on road networks, (2) traffic jams causing slowdowns in travel speed, and (3) distinct population subgroups (*e.g.*, guards and health physics teams) responding to the accident. Any evacuation scenario modeled with MACCS can also be modeled with MACCS2. Information describing the MACCS2 evacuation model is provided in Section 6.6.

3.3.2 Alternative Options for Modeling Evacuee Movement

The MACCS and MACCS2 evacuation models move evacuees in discrete increments rather than in a smooth fashion over their predefined travel path. Evacuees "jump" from point to point after the elapse of a delay time based on the travel distance and their travel speed. The successive points at which they are located are always the centerpoints of the polar-grid elements that they traverse. This simplification is inherent in the design of the code.

Since the earliest versions of MACCS, evacuees have been modeled as leaving one element (their origin) and entering their destination when a sufficient time has elapsed for them to travel the distance required for them to cross the boundary line that separates the origin element from the destination element.

MACCS2 provides the user with the option of modeling evacuee movement using:

1. the MACCS approach in which movement occurs when an individual crosses the *boundary* line between the two elements, or

2. a new approach developed specifically for MACCS2 where an individual is presumed to enter the destination element when he or she has traveled a sufficient distance to reach the *centerpoint* of the destination.

The advantages of the new CENTERPOINT option are that:

1. The evacuee movement algorithm for the CENTERPOINT option can better model scenarios where a change in evacuation speed occurs. The BOUNDARY option could not adequately handle scenarios involving variable evacuation speeds.

2. The CENTERPOINT evacuee movement option is consistent with the plume dispersion model, which is based on the movement of the plume from element centerpoint to centerpoint. The CENTERPOINT option thus simplifies the modeling of evacuee movement with respect to the movement of the plume.

The use of the BOUNDARY option is restricted to cases where the evacuation speed is defined to be constant. If the user attempts to perform a calculation with a time-variant evacuation speed in conjunction with the BOUNDARY option, an input error will be diagnosed, and further execution inhibited. The results of the MACCS sample problems A–C may thus be replicated using the MACCS2 BOUNDARY option because those cases utilize an evacuation speed that is constant over time.

The CENTERPOINT option may be implemented for cases where evacuation speed is constant, as well as where it is time-variant. Although the CENTERPOINT approach has certain conceptual advantages over the BOUNDARY approach, it was deemed imprudent to simply substitute the new approach for the old. A major reason for preserving the prior model was the desirability of being able to replicate MACCS analyses with MACCS2. If the BOUNDARY approach had been deleted from MACCS2, the replication of MACCS results from sample problems A–C with MACCS2 would not be possible.

3.3.3 Direction-Dependent Doses

Both MACCS and MACCS2 provide the user with the option of calculating plume-centerline dose and risk values (Type 6 and 7 results). The plume-centerline dose is calculated independently of wind direction and represents the maximum dose or risk to an individual directly under the plume. Because the plume-centerline dose and risk calculations are calculated independently of wind direction, they are not appropriate for analyses for which nonradial evacuation is being modeled. In order to remedy this deficiency, MACCS2 has a new output option, the Type B result, which provides a maximum direction-dependent dose for a user-specified direction and downwind distance.

The Type B result of MACCS2 may be used to obtain site boundary doses for direction-dependent meteorology. The results are for direct exposure only; *i.e.*, doses resulting from groundshine, cloudshine, inhalation, and skin deposition exposures. The generation of the Type B results is controlled by user input in the EARLY input file and these results are reported separately for each of up to three emergency-response scenarios. If CHRONC is exercised, it will automatically generate the corresponding Type B results in the same manner as is done for the Type 1, 4, 5, and 8 results.

3.4 Enhancements to CHRONC

The enhancements to the CHRONC module include modifications to the user input required to specify the duration of the intermediate and long-term phases and the capability to process data from the COMIDA2 food pathway model.

3.4.1 Specification of the Intermediate and Long-Term Phase Exposure Periods

In MACCS the user defined the end of the intermediate phase by specifying the CHRONC input variable TMIPND. TMIPND was defined as the number of seconds following plume arrival at which the intermediate phase ended. The long-term phase period was defined as beginning at TMIPND, and extended into time for one million years.

In MACCS2, the duration of the intermediate and long-term phases is specified by the user and is not dependent on the definition of other input parameters; *i.e.*, the user simply defines a duration for the intermediate phase and for the long-term phase—MACCS2 variables DUR_INTPHAS and EXPTIM respectively. The maximum exposure period the user can define for the long-term phase is 317 years.

3.4.2 Enhanced Food Pathway Modeling Capabilities

MACCS2 allows the user to choose either the COMIDA2 or MACCS food ingestion model. Some of the advantages of COMIDA2 over the MACCS food model are as follows:

1. uptake into the edible portion of plants is modeled as a function of plant growth, and thus seasonality effects are considered;

2. parameter values required by the code are widely available in the literature, facilitating further augmentation of the list; and

3. radioactive decay chains with lengths of up to four generations can be modeled, with branch ratios fixed at 100% (MACCS is limited to one- or two-member chains).

Section 7.10 describes the implementation of the MACCS2 input parameters required for operation of the COMIDA2 food model. Additional details on COMIDA2 are provided in Section 3 of Volume 2 of this report.

3.5 Minor Enhancements and Corrections to MACCS

MACCS2 corrects three coding errors present in MACCS 1.5.11.1, as described in Sections 3.5.1 through 3.5.3. Section 3.5.4 describes an improvement in the code's reporting of economic cost measures. Section 3.5.5 discusses changes to the way the code calculates groundshine doses after passage of a plume. Section 3.4.6 reviews an additional error-checking capability. Finally, Section 3.5.7 reviews two minor changes relating to MACCS input and output. Minor modifications that improve the code's ability to detect and diagnose errors in the user input files are not described because their correction should have no impact on any prior calculations.

3.5.1 DDREFA Implementation Error

A coding error was made in the MACCS 1.5.11.1 implementation of the dose-dependent reduction factor (input variable DDREFA) that is used to modify the cancer risk factor in order to distinguish between low and high dose exposures incurred during the emergency phase (Abrahamson *et al.* 1991; Chanin *et al.* 1993). The error affected only the application of the dose-dependent reduction factor in the EARLY module. The reduction factor *was* correctly applied in the CHRONC dose calculations.

The test that was newly implemented in the MACCS 1.5.11.1 EARLY module to adjust cancer risk estimates between low-dose and high-dose regimes incorrectly based the dose test on the dose calculated to occur at the rightmost (or outermost) fine-grid element of the compass sector. This dose test should be based on the doses calculated for *each* fine-grid element.

Because the doses in the outermost fine-grid elements are almost always lower than those in the more central fine-grid elements, MACCS was incorrectly using DDREFA for much more of the population than was warranted. As a result, if DDREFA is greater than 1, the cancer predictions generated by the EARLY module of MACCS will be underestimated. If, however, DDREFA is 1, the coding error has no effect.

The magnitude of the error will depend on the magnitude of the doses calculated by EARLY. If all the calculated doses fall below a specified threshold (input variable DDTHRE, Section 6.9), the error will have no effect. As an example of the potential impact of the error, Table 3-1

Table 3-1. MACCS2 vs. MACCS Sample Problem A Results for Total Weighted-Sum Overall Results—EARLY plus CHRONC

	MACCS2			MACCS 1.5.11.1		
	Mean	50th	95th	Mean	50th	95th
0-1609 km Total Cancer Fatalities	1.35E+4	7.90E+3	4.29E+4	1.24E+4	6.93E+3	4.04E+4
0-16 km Safety Goal Cancer Risk	4.53E–3	1.11E–3	1.92E–2	2.96E–3	7.31E–4	1.36E–2
0-1609 km Population Dose (Sv-effective)	2.92E+5	1.63E+5	1.01E+6	2.94E+5	1.67E+5	9.90E+5

presents the overall results of the weighted sum (EARLY plus CHRONC) estimates of three important consequence measures for source term 1 of sample problem A.

The two results shown represent the combined results from EARLY and CHRONC and are for identical input assumptions and an identical DCF file. Minor differences (of about 1%) in the dose algorithms implemented by MACCS and MACCS2 are apparent in the results listed for total population dose. The total cancers and cancer risk values calculated by MACCS, however, are somewhat less than the total cancers and cancer risk values calculated by MACCS2 as a result of this coding error.

Because the DDREFA error has no effect on CHRONC results, and only affects the results generated by EARLY, an additional comparison is presented in Table 3-2. This comparison shows the impact of the DDREFA error on results generated by EARLY for the same source term as before, but with consequence values reported for the nonevacuating cohort of EARLY. This set of results from sample problem A yields the highest individual doses as calculated by EARLY, and is thus most sensitive to the coding change. For this most-affected cohort, exposures are subject to mitigation using the 0.5 and 0.25 Sv relocation criteria.

The results of Table 3-2 show a small decrease (1–2%) in the 0–1609 km population dose that is due to the revised (and more accurate) algorithm for groundshine after passage of a cloud. The 0–16 km safety goal cancer risk results show a bigger change (48–89%) than is seen for the 0–1609 total cancer fatalities (29–39%) because doses are higher within the close-in region, and the impact of the DDREFA error is largest when doses are high.

3.5.2 Type 3 Result (Number of People Exceeding Dose Threshold)

When the user requests the code to generate the Type 3 results, information can be obtained on the number of people whose emergency phase doses exceed various user-specified dose thresholds. These results can be useful, for example, as an adjunct to the code's reporting of the number of cases of health effects (the Type 1 results).

Table 3-2. MACCS2 vs. MACCS Sample Problem A Results from EARLY Alone—Nonevacuating Cohort of EARLY

	MACCS2			MACCS 1.5.11.1		
	Mean	50th	95th	Mean	50th	95th
0-1609 km Total Cancer Fatalities	1.58E+3	1.16E+3	3.74E+3	1.14E+3	8.97E+2	2.69E+3
0-16 km Safety Goal Cancer Risk	5.59E–3	2.07E–3	2.10E–2	3.14E–3	1.39E–3	1.11E–2
0-1609 km Population Dose (Sv-effective)	3.12E+4	2.41E+4	7.48E+4	3.18E+4	2.44E+4	7.60E+4

MACCS 1.5.11.1 incorporated a coding error affecting situations where the user requested the generation of ten of the Type 3 results (the maximum number allowed). Also, when that code echoed the user-specified dose criterion to the output file, small values were erroneously reported as zero. These two problems, and the resultant fixes incorporated into MACCS2, are summarized below.

3.5.2.1 Incorrect Calculations when Ten Results Are Generated

MACCS and MACCS2 both allow the user to request the generation of ten of the Type 3 results (number of people exceeding a dose threshold, see Section 6.13). Due to a coding error, MACCS 1.5.11.1 generates erroneous results or fails to execute if NUM3 is assigned a value of 10. The code, however, operates properly if NUM3 is limited to values between 0 and 9. The impact of the error can vary across different computer systems because the storage area corrupted by the error can occur in different locations. In some cases, ten results have been generated without error because the corrupted storage location was not utilized in the calculations.

If prior analyses using MACCS have utilized EARLY input files with NUM3 values of 10, the results of those calculations may be in error. In order to determine if results are erroneous, it is recommended that the number of Type 3 results be reduced to nine, and the calculations be rerun with MACCS. If there is no change in the code outputs, the code error has had no effect on the results. The subject coding error has been corrected in MACCS2.

3.5.2.2 Inability to Report Small Values of the Dose Threshold

In addition to the correction described above, a minor enhancement has been made to the functionality of the Type 3 result. If the user of MACCS specifies dose thresholds less than 0.0005 Sv (50 mrem), the output file summary of results will identify all of the corresponding dose thresholds as being 0.000 Sv, because of that code's use of a fixed-format edit descriptor.

In order to avoid this problem, MACCS2 utilizes an edit descriptor that automatically switches between fixed and exponential formats to write the dose threshold to the output file, allowing the meaningful reporting of dose thresholds specified to have extremely small values.

3.5.3 Incomplete Implementation of the Intermediate Phase

The predecessor codes to MACCS (CRAC and CRAC2) incorporated the capability to model only two postaccident periods: the emergency phase and the long-term phase. When MACCS was first developed, these phases were augmented to include a third, the intermediate phase, which could, at the option of the user, be defined to occur in-between the emergency phase and the long-term phase. The intermediate phase was anticipated to be useful because the *Protective Action Guides* (EPA 1992) refer to an intermediate period during which detailed assessments could be made of contamination levels, and the planning for long-term interdiction efforts would be accomplished.

The intermediate-phase model, however, was not implemented in NUREG-1150 and was never fully implemented in MACCS. None of the formal verification activities performed for MACCS investigated this feature of the code. MACCS2 fully implements the intermediate-phase calculations and models mitigative actions based on the intermediate-phase results.

3.5.3.1 Intermediate-Phase Health Effects and Collective Doses

MACCS correctly provided intermediate-phase Type 6 and 7 results (centerline dose and risk) but intermediate-phase Type 1 and 5 results (cases of health effects and collective dose) were always reported as 0. It was found that the implementation of the intermediate phase did not correctly store the intermediate-phase doses for later use. This error was corrected in MACCS2.

3.5.3.2 Lack of Interaction in MACCS Between Intermediate-Phase Relocation and Farm Interdiction

The MACCS mitigative action model for the long-term phase is based on the assumption that agricultural production can *only* take place in locations suitable for habitation. The reverse condition is not applied: that is, habitation *can* take place in locations exceeding the criteria for agricultural production.

The problem with the MACCS mitigative action model as it pertains to the intermediate phase is that the doses were not utilized in any way in the code's determination of whether land was habitable, and therefore whether agricultural production would occur if the criteria for agriculture were satisfied. It was only the habitability tests for the long-term phase that governed whether this land was suitable for farming activities.

In MACCS2, the user can specify the existence of both an intermediate and a long-term phase, and the code allows the duration of each to be specified as 1 year. If this is done, the code will model a 1-year intermediate phase followed by a 1-year long-term phase. In making its decision as to whether land is suitable for agriculture in the first year after deposition, MACCS and beta-test versions of MACCS2 prior to 1996 have utilized the results of the habitability test from the long-term phase.

In the example at hand, this means that the decision on the first year's farming will depend on whether the land is suitable for habitation in the second year, and this is clearly of doubtful validity. At least for this example, where the intermediate phase includes within its range *all* of

the first year of potential farming, it would be more logical to utilize the habitability test of the intermediate phase (rather than the long-term phase) in deciding whether the agricultural land was habitable.

MACCS2 has been modified to ensure that intermediate-phase mitigative actions are based upon intermediate-phase results. Section 7 describes the revised mitigative action models of the intermediate and long-term phases, and how the mitigative action models triggered by habitability criteria interact with the mitigative action models for agricultural production. Section 7 also describes the code's assessment of the corresponding economic costs and the user-supplied input parameters that control the operation of those models.

3.5.4 Summation of Early and Intermediate-Phase Costs

All versions of MACCS report the Type 10 result, evacuation and relocation costs. This code output is calculated as the sum of (1) per-diem expenses for evacuees and (2) the per-diem costs for individuals relocated for the duration of the CHRONC intermediate phase. MACCS thus was summing the aggregate economic costs from two phases of the calculations (emergency phase and intermediate phase), and there was no provision to allow reporting the two cost components separately.

In MACCS2, what was previously reported as evacuation and relocation cost is now reported as two separate results: emergency-phase costs and intermediate-phase costs. This code enhancement requires no action on the part of the user since the Type 10 results are automatically produced as a set, reporting the total costs as well as the breakdown of costs by category.

3.5.5 Dose Calculations for Groundshine Following Plume Passage

MACCS2 implements a more accurate approach for the calculation of doses from groundshine following plume passage than was implemented in MACCS. MACCS calculates these doses in the emergency phase by interpolating and extrapolating groundshine doses based on 8-hr and 1-week groundshine DCFs using a logarithmic interpolation scheme. The resultant errors can be quite sizable for short-lived radionuclides with half-lives of a few hours or less.

MACCS2 does not utilize 8-hr and 1-week groundshine DCFs. It performs an exact numerical integration of the EARLY dose for groundshine following plume passage for ten time periods of successively increasing duration spanning EARLY's maximum exposure period of 1 week. MACCS2 linearly interpolates between the ten tabulated values to obtain the appropriate DCF for the exposure period. The resultant tables of DCF data for the initial deposit of a single radionuclide are generated in a way that takes account of all radioactive progeny that the user

included in the list of radionuclides being considered (as well as any implicit daughters defined in the DCF file).[6]

Linear interpolation is less accurate, everything else being equal, than logarithmic interpolation because the dose typically decreases exponentially. Nevertheless, because ten periods of increasing duration are defined, the MACCS2 method for calculating doses from groundshine following plume passage in EARLY is much more accurate than the MACCS approach, particularly when short-lived radionuclides are important contributors to groundshine dose.

3.5.6 Nonprintable Characters in Site Data File and FORTRAN Source Code

When code users have used text editors to edit the population counts in the Site Data file, there have been several occurrences where the code diagnoses an input conversion error and aborts execution. It has proved very difficult for users to identify and remedy the problem. A possible explanation for these problems is the inadvertent inclusion of nonprintable ASCII characters or control codes in the file.

In order to facilitate user debugging of Site Data files, MACCS2 tests for and diagnoses the location of any embedded nonprintable characters in the Site Data file. If any unusual ASCII characters are encountered during the echoing of the Site Data file to the output file, a diagnostic message is issued to the console and further processing is inhibited.

In such events, the output file will contain a series of messages that identify the location of the unusual ASCII characters on the line in which they appear. For further help in remedying the problem, or preventing its occurrence, the decimal ASCII codes causing the problem are also printed. In the context of MACCS2, unusual ASCII characters are defined as those with control codes less than 32 or greater than 126. None of the Site Data files currently used in the sample problems contain unusual ASCII characters.

In conjunction with the implementation of this change to MACCS2, there was a related modification to the MACCS2 FORTRAN source code. ANSI FORTRAN 77 does not specify how a compiler is to treat nonprintable characters embedded in the FORTRAN source code, allowing a processor-dependent treatment of special ASCII codes such as TAB. The source code for MACCS was distributed in a form that included the TAB. All nonprintable characters have been deleted from the MACCS2 FORTRAN source code in order to maximize the portability of the code.

3.5.7 Minor Changes to Input and Output

The column of results previously used to report the 99.9th quantile was changed in MACCS2 so that it now shows the 99.5th quantile. This change was made to allow examination of the χ/Q

[6] An implicit daughter is defined here as a short-lived daughter product assumed to be in secular equilibrium with its parent. A well-known example is the $^{137}Cs \rightarrow {}^{137m}Ba$ decay chain. For economy, the decay from parent to daughter is not explicitly modeled; rather the ^{137}Cs DCF represents the parent as well as the daughter.

and maximally exposed individual doses according to the methodology described in NRC Reg. Guide 1.145 (NRC 1983).

The variable DLBCST defined in the CHRONC input file specifies the cost of labor (dollars/person-year) for personnel involved in decontamination. In MACCS, the user was allowed to specify a value of 0 for this parameter. However, DLBCST is used in the denominator of an expression and thus the specification of a zero value leads to a floating-point exception due to a divide-by-zero. The minimum allowable value for this parameter in MACCS2 has been changed to 1.0 (that is, one dollar per person-year).

THIS PAGE INTENTIONALLY LEFT BLANK

4.0 Installing and Running MACCS2

4.1 Introduction

Installation instructions and system requirements for the MACCS2 package are provided in the READMAC2.TXT file listed in Appendix B of this document and distributed with the MACCS2 package ZIP files. This file provides additional information not included in this section. It is recommended that the user review this file before exercising MACCS2.

Fourteen sample problems are included in the MACCS2 package. These may be exercised to ensure that the code has been correctly installed. The sample problems also provide example applications of various features of the code and are briefly described in this section.

4.2 Hardware Requirements

MACCS2 requires an IBM-compatible/486 or Pentium PC with 8 MB of RAM and approximately 30 MB of free disk space for installation of the entire software package. The use of MACCS2 on non-PC platforms will require a recompilation of the source code. The READMAC2.TXT file included in the code package provides information for users who need to exercise MACCS2 on a non-PC platform.

When MACCS2 is installed on other computers, the numeric output values by and large should be identical or very close to identical. The only significant deviation might lie in the probabilities of nonzero and peak value consequences since the precision of arithmetic and the handling of underflow can vary on different computer systems.

4.3 Running MACCS2

A MACCS2 run is generated by calling the RUNMAX2.BAT file. Six filenames may be specified along with the RUNMAX2.BAT filename. MACCS2 sample problem A, for example, is executed as follows:

RUNMAX2 IN1A IN2A IN3A METSUR SURSIT LISTA

Unless specified as null parameter (indicated by the use of " "), each of the first five filenames specified must be a valid pathname to a previously created file to which the user has read access. The input sequence of the six filenames and a brief description of the files is as follows:

1. ATMOS User Input File: IN1A
   This parameter is always required and a null parameter is not allowed.

2. EARLY User Input File: IN2A
   This parameter can be omitted if the user is exercising only the ATMOS module (ENDAT1 set to .TRUE. on the ATMOS input); in that case, the parameter is given as double quotation marks ("").

3. CHRONC User Input File: IN3A
   This parameter can be omitted if the user is skipping the CHRONC module (if ENDAT1 was set to .TRUE. on the ATMOS input or ENDAT2 was set to .TRUE. on the EARLY input); in that case, the parameter is given as double quotation marks ("").

4. Meteorological Data File: METSUR
   Name of a weather data file with a year of hourly recordings. This file is described in Appendix A.1 of this volume. The format and processing of the file are unchanged from MACCS. The parameter may be omitted if a single weather sequence is defined on the ATMOS user input file (METCOD = 3 or 4); in that case, the parameter is given as double quotation marks ("").

5. Site Data File: SURSIT
   Name of a Site Data file for the surrounding region. This file is described in Section A.3 of Appendix A of this volume. MACCS2 will successfully process Site Data files generated for use with MACCS. Previously generated MACCS site files are thus forward-compatible with MACCS2. The parameter may be omitted if a uniform population density is defined on the EARLY user input file (POPFLG = .TRUE.); in that case, the parameter is given as double quotation marks ("").

6. List Output File: LISTA
   Name of the file on which to write the list output of the run. An existing file with this filename and the .OUT extension will be overwritten. If this argument is omitted, the results will be written to the system default filename for FORTRAN unit 6; a filename must be specified here, and it must be a valid pathname to a file that the user can write upon. Six arguments must be supplied. No default filenames are provided. If any of the input files are not required for the analysis, a null argument is specified as double quotation marks ("). The minimum filenames that must be specified are the ATMOS input and list output filenames. With the files provided, sample problem C is executed as follows:

```
RUNMAX2 IN1C IN2C IN3C "" "" TEMPC
```

The EARLY and CHRONC modules require a dose conversion factor file. The DCF filename is specified in the EARLY input file (see EARLY DCF_FILE input parameter described in Section 6.2.2). The format for the DCF file is presented in Section A.2 of Appendix A.

The MACCS2 ZIP files include a .BAT file, RUNEM.BAT, that executes all of the sample problems. This .BAT file is executed by simply typing RUNEM on the DOS command line when in the MACCS2 subdirectory.

4.4 MACCS2 Sample Problems

The MACCS2 ZIP files contain both the input and output files associated with the 14 sample problems. The input files may be identified by the .INP extension and the output files may be identified by the .OUT extension. The ATMOS input data, EARLY input data, CHRONC input data, Meteorology Data, Site Data, and output filenames used in a MACCS2 run are listed in the first few lines of the output file. The output file echoes the contents of the ATMOS, EARLY, CHRONC, and Site Data input files.

All of the sample problems exercise the new Type 0 and Type A results. Sample problem F exercises the new Type B results.

4.4.1 Sample Problems A–C

Sample problems A–C of MACCS2 represent a close-to-exact translation of sample problems A–C distributed with MACCS 1.5.11.1. The three sample problems distributed with versions of MACCS prior to MACCS2 are analyses of commercial nuclear reactor accident scenarios. These sample problems, denoted with either an A, B, or C suffix to the input filename, are focused on a severe accident at the Surry commercial reactor, as evaluated in NUREG-1150.

Two versions of sample problem A are provided. Sample problem A_O implements the MACCS food pathway model. Sample problem A_N implements the new COMIDA2 food pathway model. In addition, the ATMOS input files for both MACCS2 versions of sample problem A use the new lookup-table option for assigning values to the σ_y and σ_z dispersion parameters.

Sample problem A illustrates how MACCS can automatically loop on source terms and emergency-response assumptions in a single run of the code. The weather category bin sampling method is used in this problem to estimate the distribution of consequences based on the uncertainty in predicting weather conditions at the time of the accident. Automatic looping is illustrated as follows: the ATMOS user input file for sample problem A causes results to be calculated for two hypothetical source terms, and the EARLY user input file specifies two different emergency-resonse scenarios (95% evacuation and 5% nonevacuation). An additional sheltering case is presented for illustration. There is no provision in MACCS or MACCS2 for looping on the CHRONC module and only a single set of assumptions is used to determine the modeling in the long-term chronic exposure phase of the calculations.

Sample problem B illustrates how MACCS2 can be used to examine one of the weather sequences that was selected in the weather sampling used for sample problem A. This type of examination is usually done when some type of unusual result is noticed on the output listing and the user wishes to determine if the calculations are being performed properly. The output listing of sample problem A shows that the peak value of economic cost from the first source term was 271 billion dollars and it was obtained from the calculation of weather trial 2. By going back to the first part of the listing, we can see that this trial began at day = 157 and hour = 10 on the Surry weather data file.

For sample problem B, the ATMOS user input file of sample problem A has been modified to run only the first source term and to calculate results for only the single weather sequence that led to the peak economic cost as described earlier. We have turned on the diagnostic print options in all three of the user input files by changing the values of the following input parameters from 0 to 1: IDEBUG in ATMOS, IPRINT in EARLY, and KSWTCH in CHRONC. A large amount of print output results.

In sample problem C, the code is set up to run the source term of sample problem B with constant meteorology; D-stability, 5 m/s wind speed, no rain. A uniform population distribution of 50 people/km^2 is used for the calculations and therefore there is no need for a Site Data file. Since wind direction is not defined for constant meteorology, the value of IPLUME is changed from 2 to 1. In this run, the diagnostic print statements of sample problem B have been turned off and only the standard presentation of results from the OUTPUT module appears on the output listing.

4.4.2 Sample Problem D

Sample problem D is focused on an accident considered in the F-Canyon plutonium solutions EIS (DOE 1994b). The F-Canyon facility at the Savannah River Site was previously used to reprocess spent fuel and target assemblies from DOE production reactors. As a result of the reconfiguration of the weapons complex, reprocessing activities at SRS were temporarily suspended but solutions containing plutonium remained present in the F-Canyon. The accidental release of plutonium at this facility could present a health risk to on-site workers and the public.

The EIS for the F-Canyon includes analyses of both on-site worker and public doses that could result from a total collapse of the facility. The EIS assumed that a seismically induced total collapse of F-Canyon could result in a release of 92.1 Ci of material to the atmosphere. The analysis completed for the EIS estimated that this source term would yield an uninvolved worker dose of 21.8 rem (at 640 m) and an off-site dose of 0.447 rem (at the 8-km site boundary).

Six versions of sample problem D are provided that implement six different dispersion parameterization schemes. The D set of sample problems illustrates the impact of varying user input values for the dispersion parameter.

Two sample problems utilize the Briggs curves (Hanna, Briggs, and Hosker 1982). LISD_BRO.OUT was generated using the lookup-table option with the Briggs open country curves, and LISD_BRU.OUT was generated using the lookup-table option with the Briggs urban curves.

Two sample problems utilize the Tadmor and Gur (1969) curves, as corrected by Dobbins (1979). LISD_TG1.OUT was generated using the lookup-table option to implement the Tadmor–Gur power-law function for the 0.5- to 5-km distance range, and LISD_TG2.OUT was generated using the lookup-table option to implement the Tadmor–Gur power-law function for the 5- to 50-km range.

Finally, two sample problems utilize different parameterizations of the "Julich" system, developed for Kernforschungszentrum Karlsruhe in Germany. LISD_JU1.OUT was generated using the power-law function to implement the Julich system for a release at a height of 50 m (Vogt 1977), and LISD_JU2.OUT was generated using an alternative power-law parameterization implementing the Julich system for the same 50-m release height (Panitz 1989).

4.4.3 Sample Problem E

Sample problem E illustrates a comparison of the two food-chain models—the "old" MACCS food-chain model and the "new" COMIDA2-based food-chain model. This case illustrates the source-term looping feature by defining eight unit-release source terms for single radionuclides. The weather conditions are held constant at D-stability, with a 5 m/s wind speed.

4.4.4 Sample Problem F

Sample problem F illustrates a comparison of the weather-category sampling algorithm (METCOD=2, see Section 5.13) with the stratified random sampling algorithm (METCOD=5; see Section 5.13), which has been set up to sample every hour of the year. This comparison illustrates an approach that can be used to evaluate the adequacy of the weather-category sampling algorithm for a site-specific calculation.

4.5 Migration from MACCS to MACCS2

This section provides instructions for converting MACCS ATMOS, EARLY, and CHRONC files into MACCS2 input files. The format and input requirements for MACCS Site, DCF, and Meteorology files are identical to MACCS2 and thus no modifications to these files are required. This section includes tables that list the new MACCS2 input variables that must be added to the MACCS ATMOS, EARLY, and CHRONC input files. A glossary of MACCS2 ATMOS, EARLY, and CHRONC input file variables and the location of the variable descriptions is provided in Appendix D.

MACCS2 radionuclide names are specified using uppercase letters for the first letter in the radionuclide symbol and lowercase for the second letter. The second letter in all radionuclide names must be changed from uppercase to lowercase in the MACCS input files. The "M" metastable designation must also be changed to lowercase. It is necessary, for example, to change TC-99M to Tc-99m. All organ names specified in the EARLY and CHRONC input files must be prefixed by an 'A-' or an 'L-' (see Sections 6.2.1 and 6.4).

MACCS input parameters that are not required by MACCS2 are not processed. With the exception of the PARENT data provided in the MACCS ATMOS input file, including obsolete MACCS parameters will not result in an error in MACCS2 calculations.

4.5.1 MACCS ATMOS File

Table 4-1 lists the new MACCS2 ATMOS input parameters that must be added to the MACCS ATMOS input file. The primary difference between the MACCS and MACCS2 ATMOS files is

Table 4-1. Input Parameters that Must Be Added to MACCS ATMOS Input Files to Convert Them to MACCS2 Input Files

MACCS2 FORTRAN Variable Name (ATMOS File Record Identifier)	ATMOS Input File Data Block[a]	Location of Description in MACCS2 *User's Guide*	Function of Input Parameter Value
NUMSTB (ISNUMSTB)	Radionuclide	5.4	Defines the number of pseudo-stable nuclides
NAMSTB (ISNAMSTB)	Radionuclide	5.4	Identifies pseudostable radionuclides
SIGYINIT (SIGYINIT)	Release	5.10	Defines initial size of σ_y
SIGZINIT (SIGZINIT)	Release	5.10	Defines initial size of σ_z
APLFRC (RDAPLFRC)	Release	5.11	Specifies how release fractions are applied to ingrowth decay products
NUM0 (TYPE0NUMBER)	Release	5.18	Specifies number of Type 0 outputs requested

[a] This column provides the name of the data block that contains the new parameters in the MACCS2 sample problems.

the format and input requirements for the definition of the radionuclide inventory. MACCS2 automatically calculates six generations of radioactive decay and ingrowth for each radionuclide specified in the inventory unless pseudostable radionuclides are specified by the user.

Parent-daughter relationships and radiological decay rates are no longer specified in the ATMOS file. The PARENT column in the Radionuclide Group Data section (ISOTPGRP record identifier) must be deleted. The data contained in the HAFLIF column of the ISOTPGRP records will not be processed by the code. The WEBUILDW record indentifier is also not processed by MACCS2. A value of WEBUILDH must be defined for each plume released.

4.5.2 MACCS EARLY File

Table 4-2 lists the new MACCS2 EARLY input parameters that must be added to the MACCS EARLY input file. Table 4-3 lists the MACCS EARLY file input parameters that are not processed by MACCS2.

Table 4-2. Input Parameters that Must Be Added to MACCS EARLY Input Files to Convert Them to MACCS2 Input Files

MACCS2 FORTRAN Variable Name (EARLY File Record Identifier)	EARLY Input File Data Block[a]	Location of Description in MACCS2 *User's Guide*	Data Provided by Input Parameter Value
DCF_FILE (DCF_FILE)	Miscellaneous	6.2.1	DCF filename and location
ORGNAM (MIORGDEF)	Miscellaneous	6.4	Defined organs
ORGFLG (MIORGDEF)	Miscellaneous	6.4	Flag indicating whether an organ is to be used in the calculations
TRAVELPOINT (TRAVELPOINT)	Evacuation Zone	6.6.8	Evacuee movement option
EVATYP (EZEVATYP)	Evacuation Zone	6.6.8	Type of evacuation
DURBEG (EZDURBEG)	Evacuation Zone	6.6.8	Duration of beginning of evacation phase
DURMID (EZDURMID)	Evacuation Zone	6.6.8	Duration of middle of evacuation phase
REFPNT (EZREFPNT)	Evacuation Zone	6.6.8	Reference time point for beginning of evacuation and sheltering
NUMEVA (EZNUMEVA)	Evacuation Zone	6.6.8	Outer boundary of evacuation/sheltering region
DLTSHL (EZDLTSHL)	Evacuation Zone	6.6.8	Delay to take shelter for each interval
DLTEVA (EZDLTEVA)	Evacuation Zone	6.6.8	Delay to evacuation for each ring
NUMA (TYPEANUMBER)	Result A Options	6.19	Number of Type A results
NUMB (TYPEBNUMBER)	Result B Options	6.20	Number of Type B results

[a] This column provides the name of the data block that contains the new parameters in the MACCS2 sample problems.

Table 4-3. MACCS EARLY File Input Parameters that Are Not Processed by MACCS2

MACCS EARLY File Record Identifier	MACCS EARLY Input File Data Block
ODNUMORG	Organ Definition
ODORGNAM	Organ Definition
EZINIEVA	Evacuation Zone
EZLASEVA	Evacuation Zone
EZEDELAY	Evacuation Zone
SRTTOSH1	Shelter and Relocation Zone
SRSHELT1	Shelter and Relocation Zone
SRLASHE2	Shelter and Relocation Zone
SRTTOSH2	Shelter and Relocation Zone
SRSHELT2	Shelter and Relocation Zone
TYPE3OUT (Dose Flag)	Dose flag switch indicates whether the dose is an acute or lifetime dose

The ESPEED parameter must be defined for the three phases of evacuation modeled in MACCS2. The MACCS2 ORGFLG input parameter (see Section 6.4) must be set to .TRUE. for all organs used in the analysis.

4.5.2 MACCS CHRONC File

Table 4-4 lists the new MACCS2 CHRONC input parameters that must be added to the MACCS CHRONC input file. TMIPND is the only MACCS CHRONC input parameter that is not processed by MACCS2 when the MACCS food model is implemented.

Table 4-4. Input Parameters that Must Be Added to MACCS CHRONC Input Files to Convert Them to MACCS2 Input Files

MACCS2 FORTRAN Variable Name (CHRONC File Record Identifier)	CHRONC Input File Data Block[a]	Location of Description MACCS2 *User's Guide*	Function of Input Parameter Value
FDPATH (CHFDPATH)	Miscellaneous	7.10.2	Specifies whether the MACCS or COMIDA2 food pathway model is to be applied
DUR_INTPHAS (DUR_INTPHAS)	Long-term Protective Action	7.4	Duration of intermediate phase
EXPTIM (CHEXPTIM)	Long-term Protective Action	7.4	Maximum exposure time for CHRONC calculations

[a] This column provides the name of the data block that contains the new parameters in the MACCS2 sample problems.

THIS PAGE INTENTIONALLY LEFT BLANK

5.0 ATMOS Input File

5.1 Introduction to ATMOS

ATMOS calculates the dispersion and deposition of material released to the atmosphere as a function of downwind distance. It utilizes a Gaussian plume model with Pasquill-Gifford dispersion parameters (Turner 1970). The phenomena that ATMOS treats are (1) building wake effects, (2) buoyant plume rise, (3) plume dispersion during transport, (4) wet and dry deposition, and (5) radioactive decay and ingrowth. A detailed discussion of the atmospheric dispersion and deposition models implemented in MACCS2 is provided in Chapter 2 of the MACCS *Model Description*.

At the midpoint of each spatial interval along the transport path, air and ground concentrations for all the radionuclides are calculated as well as miscellaneous information about plume size, height, and transport timing. These data are stored in common blocks which are used later by the EARLY and CHRONC modules of MACCS2.

Transport and deposition in ATMOS are treated with a one-dimensional model. Concentration values are calculated only for the plume centerline. There is no calculation in ATMOS of off-centerline concentrations. The adjustment for off-axis location is handled in the EARLY and CHRONC modules.

MACCS incorporated a database limited to 60 radionuclides. In any single MACCS2 run, the user can define a list of up to 150 radionuclides (including all of the daughter products) which are to be considered in the analysis. All of the selected radionuclides must be present in the decay-chain database included in the MACCS2 package and in the selected DCF file used for code execution.

In order to allow the user more flexibility in selecting the radionuclides to be considered, a new feature has been added to MACCS2, namely, the definition of a list of radionuclides that are to be excluded from the calculations. These radionuclides are designated as "pseudostable" and defined in the ATMOS input file. The pseudostable radionuclides are treated by MACCS2 as if they were not radioactive. They do not contribute to doses and they produce no radioactive progeny. The definition of pseudostable radionuclides was motivated by the following.

In the very first beta-test version of MACCS2, version 1.00, the user was required to include in the calculations all progeny down to six generations. In the code's sample problems, this meant that several chains of actinides six generations long needed to be included, despite the fact that progeny beyond two or three generations are negligible contributors to dose. This resulted in a lack of economy in the calculations, since daughter products far down the chains generally do not contribute to the total dose.

The decay-chain processor considers radioactive decay over a maximum of six generations. Six generations means that the sequential list of radionuclides in a chain is limited to six members. For species that have progeny spanning more than six generations (*e.g.* ^{253}Cf), the dose due to

progeny beyond six generations is ignored. At each step of decay in the chain, branching is allowed with up to three different daughter products, using branch ratios.

The decay-chain database was obtained from the Radiation Shielding Information Center (1994). It is present in the distribution package as file INDEXR.DAT. If radionuclides are defined to be pseudostable, the specified pseudostable radionuclides are not used in the calculations and there is no need to include their progeny in the calculations. The DOS FORTRAN program, CHAIN.EXE, provides decay chains for user input radionuclides. CHAIN.EXE is included in the MACCS2 program package.

Several different options for specifying weather conditions are available to the user. These include two weather sampling options—category bin sampling and strictly random sampling—as well as three different methods of specifying a single weather trial: (1) constant weather conditions, (2) fixed start time in the weather file, and (3) user-supplied 120-hr weather sequence.

It is up to the user to specify the various parameters needed for these calculations. There are no default values. All of this information is supplied through the user input file to ATMOS and all of the input parameters are described in this chapter.

5.1.1 Format of Input Parameter Description Block

The conventions used in processing the ATMOS input file are identical to the conventions followed in processing the EARLY and CHRONC input files. Section 2.2.1.2 provides an overview of the MACCS/MACCS2 free-format input processor.

Each file line containing user input data must begin with a record identifier. Record identifiers must begin in column 1 and consist of 11 characters. Record identifiers usually begin with a two-character mnemonic for the data group to which the identifier belongs, followed by the variable name and three numeric characters that are used for sequencing. The two-character data group mnemonics are included in parentheses in the remaining headings of this section. Sample data records are provided for each input parameter.

Each ATMOS input parameter is described in a stylized block of text that presents the following information: (1) the FORTRAN variable name used in the code, (2) the type of the data item (integer, real, logical, or character), (3) an indication of whether only a single value (scalar) or multiple values (array) are required, (4) minimum and maximum allowable values (or lengths), (5) a statement describing the variable, and (6) an example of the variable's use.

5.2 Run Identification (RI) Data

In order to identify the computer run that is being performed, the user is required to supply a text field that will be printed on all of the list output produced for this run by MACCS2. All of the MACCS2 programs obtain the current date and time from the computer operating system so it is not necessary to include information of that type. In addition to this text field, a text field

describing the source term is supplied separately in the release description data block that defines the source term.

Variable Name - ATNAM1
Variable Type - Character, Scalar
Allowed Range - $1 \leq \text{length} \leq 80$
Purpose - Identifies this MACCS2 calculation. This identification information will be printed at the top of all pages of the output listing.
Example Usage:

```
*
* GENERAL DESCRIPTIVE TITLE
*
RIATNAM1001 'IN1A.INP, SURRY, SAMPLE PROBLEM A, ATMOS INPUT'
```

Note: The asterisk in column 1 denotes a comment.

5.3 Geometry (GE) Data

A polar-grid coordinate system is used by MACCS2 to represent the region surrounding the facility. The facility itself is always located at the centerpoint of the coordinate system (r = 0). The data in this section define the grid spacing between spatial elements in the radial direction. All of the consequence calculations performed by MACCS2 are stored on the basis of the radial spacing defined here.

For example, air and ground concentrations are calculated to be representative of the entire length of the spatial element (not its centerpoint). The values of σ_y and σ_z representative of the spatial interval are average values, as follows,

$$\sigma_{average} = 0.5(\sigma_{initial} + \sigma_{final}),$$

where $\sigma_{initial}$ is the plume size upon entering the spatial interval and σ_{final} is the plume size upon leaving the spatial interval. Deposition processes are similarly averaged over the length of the spatial interval, as described in the MACCS *Model Description*, pages 2-18 through 2-24.

Variable Name: NUMRAD
Variable Type: Integer, Scalar
Allowed Range: $2 \leq \text{value} \leq 35$
Purpose: Number of radial spatial intervals defined in the model. This quantity defines the polar coordinate spatial grid that will be used by all three of the program modules: ATMOS, EARLY, and CHRONC. If a Site Data file is being used, the value supplied here must match exactly the value supplied on that file as variable NSPDTS.

Example Usage:

```
*
* NUMBER OF RADIAL SPATIAL ELEMENTS
*
GENUMRAD001  26
```

Variable Name: SPAEND
Variable Type: Real, Array
Allowed Range: 0.05 ≤ value ≤ 9999. (kilometers)
Purpose: Distance in kilometers to the endpoints of the spatial intervals. If a Site Data file is being used, the values supplied here must be within 10 % of the corresponding parameter values supplied on that file for the array SPDSTS. The spacing between adjacent spatial intervals is now required to be at least 0.1 km.

Note: The Gaussian plume dispersion parameterizations commonly available (see Section 5.7) are likely to be of limited value at distances less than 0.5 km because of building wake effects. If close-in assessments are required, the user is cautioned to examine the CCDFs of the atmospheric dispersion parameters (Section 5.18) and verify the adequacy of the results.

Example Usage:

```
*
* SPATIAL ENDPOINT DISTANCES IN KILOMETERS
*
GESPAEND001     0.16       0.52       1.21       1.61       2.13
GESPAEND002     3.22       4.02       4.83       5.63       8.05
GESPAEND003     11.27      16.09      20.92      25.75      32.19
GESPAEND004     40.23      48.28      64.37      80.47      112.65
GESPAEND005     160.93     241.14     321.87     563.27     804.67
GESPAEND006     1609.34
```

Note: Elements in the array must be separated by blanks or a comma. The number of items per card is left to the user's discretion. The sequence numbers of the record identifiers must be in ascending order.

5.4 Radionuclide (IS) Data

This section defines the physical characteristics of the radionuclides that are to be modeled. They are divided into groups that share similar physical and chemical characteristics. The radioactive decay data (half-life and decay schemes) are provided to MACCS2 by the file INDEXR.DAT. Decay chain data may be obtained by exercising the CHAIN.EXE program included in the MACCS2 program package.

Variable Name: NUMISO
Variable Type: Integer, Scalar
Allowed Range: 1 ≤ value ≤ 150
Purpose: Number of radionuclides defined in the model. Several other input parameters use this value to determine the number of values that must be supplied. Each defined radionuclide must be present in the decay-chain definition file, INDEXR.DAT. Also, the dose conversion factor file specified for EARLY (see Section 6.2), must include data for each of the radionuclides defined here.
Example Usage:

```
*
* NUMBER OF NUCLIDES
*
ISNUMISO001 60
```

Variable Name: MAXGRP
Variable Type: Integer, Scalar
Allowed Range: 1 ≤ value ≤ 10
Purpose: Number of chemical element groups defined in the model. Each radionuclide will be assigned to a chemical element group, *e.g.*, noble gases. The wet and dry deposition characteristics of a radionuclide, as well as its release fraction, depend on the number of the element group (IGROUP) to which it is assigned.
Example Usage:

```
*
* NUMBER OF ELEMENT GROUPS
*
ISMAXGRP001  9
```

Variable Name: WETDEP
Variable Type: Logical, Array
Allowed Value: .TRUE. or .FALSE.
Purpose: Logical flag for each of the element groups that indicates whether they are subject to wet deposition. The user must supply MAXGRP number of values in column 1 of the data block.

Variable Name: DRYDEP
Variable Type: Logical, Array
Allowed Value: .TRUE. or .FALSE.
Purpose: Logical flag for each of the radionuclide groups that indicates whether they are subject to dry deposition. The user must supply MAXGRP number of values in column 2 of the data block.

Example Usage of WETDEP, and DRYDEP:

```
*
* WET AND DRY DEPOSITION FLAGS FOR EACH NUCLIDE GROUP
*
*               WETDEP      DRYDEP
*
ISDEPFLA001    .FALSE.     .FALSE.
ISDEPFLA002    .TRUE.      .TRUE.
ISDEPFLA003    .TRUE.      .TRUE.
ISDEPFLA004    .TRUE.      .TRUE.
ISDEPFLA005    .TRUE.      .TRUE.
ISDEPFLA006    .TRUE.      .TRUE.
ISDEPFLA007    .TRUE.      .TRUE.
ISDEPFLA008    .TRUE.      .TRUE.
ISDEPFLA009    .TRUE.      .TRUE.
```

In contrast to MACCS, MACCS2 obtains decay chains directly from a database file. As a result, the ATMOS input file no longer contains information on parent-daughter relationships or radiological decay rates. Those data are taken from the file INDEXR.DAT, supplied by the Radiation Shielding Information Center as part of the FGR-DOSE/DLC-167 data package.

When MACCS2 is executed, it attempts to open a file named INDEXR.DAT in the current directory. If the file is not present, the code will not execute. There is no provision for the user to specify an alternative directory (or filename) for this information as is possible for the dose conversion factor file. If special applications require switching between alternative versions of the decay-chain database, the user would have to modify the RUNMAX2.BAT file in order to copy the various files into a file in the local directory named INDEXR.DAT.

Since the decay-chain database INDEXR.DAT defines the parent-daughter relationships, the input variables PARENT and HAFLIF are not used in MACCS2. As a result, the ISOTPGRP data block in MACCS2 consists of two columns of data, whereas the corresponding data block in MACCS has four columns of data defining the radionuclide list and the chemical group assignment of each radionuclide.

Note that the spelling of radionuclide names in MACCS and MACCS2 input files is case-sensitive, that is, an uppercase letter is different from a lowercase letter. In the dose conversion factor database provided with prior versions of MACCS, radionuclide names were specified using all uppercase (capital) letters. In the MACCS2 databases, only the first letters of the radionuclide names are capitalized.

Each decay chain considered by MACCS2 is limited to a maximum of six generations. There is no transfer of material between the separate chains. The code's list output file lists the chains that are being used in the calculations. If an input error occurs because a daughter product is omitted, a message on the output listing will identify the missing radionuclide(s) and further execution will be inhibited. If error messages are generated by the omission of daughter products, the user should determine if the missing daughters are needed in the calculations. If they are not needed, calculational expense may be reduced by specifying the missing daughters to be pseudostable.

MACCS2 requires approximately twice as much execution time as MACCS version 1.5.11.1. The increased run time of MACCS2 is due almost entirely to the number of calculations performed in the decay-chain processor's integration of daughter ingrowth and decay. Thus, the most expedient means of reducing run time is to keep the radionuclide set limited to those species thought to be important contributors to risk.

Variable Name: NUMSTB
Variable Type: Integer, Scalar
Allowed Range: $0 \leq \text{value} \leq 150$
Purpose: Defines the number of pseudostable radionuclides.

Variable Name: NAMSTB
Variable Type: Character, Array
Allowed Length: $3 \leq \text{length} \leq 8$
Purpose: Defines the list of pseudostable radionuclides. Pseudostable radionuclides do not contribute to doses. Progeny of pseudostable radionuclides should not be included on the list of radionuclides, NUCNAM. The user must supply NUMSTB values in column 1 of the data block.
Example Usage:

```
*
* NUMBER OF PSEUDOSTABLE RADIONUCLIDES (USED TO TRUNCATE THE DECAY CHAINS)
*
ISNUMSTB001      11
*
* LIST OF PSEUDOSTABLE RADIONUCLIDES
*
*           NAMSTB
*
ISNAMSTB001 I-129       (DAUGHTER OF Te-129 AND Te-129m)
ISNAMSTB002 Xe-131m     (DAUGHTER OF I-131)
ISNAMSTB003 Xe-133m     (DAUGHTER OF I-133)
ISNAMSTB004 Xe-1351m    (DAUGHTER OF I-135)
ISNAMSTB005 Cs-135      (DAUGHTER OF Xe-135 AND Xe-135m)
ISNAMSTB006 Sm-147      (DAUGHTER OF Pm-147)
ISNAMSTB007 U-234       (DAUGHTER OF Pu-238)
ISNAMSTB008 U-235       (DAUGHTER OF Pu-239)
ISNAMSTB009 U-236       (DAUGHTER OF Pu-240)
ISNAMSTB010 U-237       (DAUGHTER OF Pu-241)
ISNAMSTB011 Np-237      (DAUGHTER OF Am-241)
```

Variable Name: NUCNAM
Variable Type: Character, Array
Allowed Range: $3 \leq \text{length} \leq 8$
Purpose: Name of the radionuclide, *e.g.*. Co-58. The user must supply NUMISO values for this variable in column 1 of the data block.

Variable Name: IGROUP
Variable Type: INTEGER, Array
Allowed Range: 1 ≤ value ≤ MAXGRP
Purpose: This is the chemical element group to which the radionuclide is assigned. The radionuclides should be grouped according to their physical/chemical properties. Both the deposition behavior and the release fraction of a radionuclide depend on the element group to which it is assigned. All members of an element group have the same deposition characteristics and release fraction. The user must supply NUMISO values for this variable in column 2 of the data block.

Example Usage:

```
*
*                 NUCNAM            IGROUP
*
ISOTPGRP001       Co-58              6
ISOTPGRP002       Co-60              6
ISOTPGRP003       Kr-85              1
ISOTPGRP004       Kr-85M             1
ISOTPGRP005       Kr-87              1
ISOTPGRP006       Kr-88              1
ISOTPGRP007       Rb-86              3
ISOTPGRP008       Sr-89              5
```

5.5 Wet Deposition (WD) Data

The washout model predicts how much material is deposited on the ground by rainfall. Washout is a function of both rain duration and rain intensity. The fraction remaining after wet deposition is:

$$\exp\left(-\text{CWASH1} \cdot \text{rain duration} \cdot \text{rain intensity}^{\text{CWASH2}}\right),$$

where rain duration is in seconds and rain intensity is in millimeters per hour (Brenk and Vogt 1981).

Variable Name: CWASH1
Variable Type: Real, Scalar
Allowed Range: 0.0 ≤ value ≤ 1.0
Purpose: The linear term of the washout function.
Example Usage:

```
*
* WASHOUT COEFFICIENT NUMBER ONE, LINEAR FACTOR
*
WDCWASH1001  9.5E-5
```

Variable Name: CWASH2
Variable Type: Real, Scalar
Allowed Range: 0.0 ≤ value ≤ 1.0
Purpose: The exponential term of the washout function.
Example Usage:

```
*
* WASHOUT COEFFICIENT NUMBER TWO, EXPONENTIAL FACTOR
*
WDCWASH2001  0.8
```

5.6 Dry Deposition (DD) Data

Dry deposition is modeled using the source depletion method. This method makes use of the simplifying assumption that deposition onto the ground does not affect the vertical distribution of the material. That is, the plume always maintains a Gaussian distribution.

The concentration of material at any single point on the ground is the product of the integrated ground-level air concentration times the deposition velocity. The material in each element group can be distributed among several particle size groups, with each element group having a different distribution of material among the particle size groups. The particle size distribution of each element group is specified in the release description data. All of the plume segments will have the same distribution of particle sizes at the time of their release, but this distribution can change with time as the plumes travel downwind.

Variable Name: NPSGRP
Variable Type: Integer, Scalar
Allowed Range: 1 ≤ value ≤ 10
Purpose: The number of particle size groups that will be used for the dry deposition model. A deposition velocity must be specified for each representative particle size group.

Example Usage:

```
*
* NUMBER OF PARTICLE SIZE GROUPS
*
DDNPSGRP001   3
```

Variable Name: VDEPOS
Variable Type: Real, Array
Allowed Range: $0.0 \leq$ value ≤ 10.0 (meters/second)
Purpose: The representative dry deposition velocities of the particle size groups. The user must supply NPSGRP values for this variable on one or more cards.

Example Usage:

```
*
DDVDEPOS001   0.001    0.01     0.02
```

5.7 Dispersion Parameter (DP) Data

The Gaussian plume model of atmospheric dispersion uses spatially dependent dispersion parameters, σ_y and σ_z. These can be supplied in two different ways: as power-law functions or in the form of precalculated tables for a lookup-table algorithm.

The power-law function approach is described in Section 5.7.1. The lookup-table approach is described in Section 5.7.2. The user's choice as to which of the two models is to be used can be controlled by the ATMOS input variable NUM_DIST (described in Section 5.7.1). If this data record is not found, or if an input value of 0 is specified, the code will perform its calculations using the power-law approach described in the next section. If, however, a data record containing this record identifier is found, the code will process a set of tables defining σ_y and σ_z as functions of distance, and use those data values for the dispersion calculations, thus bypassing the power-law functions completely.

5.7.1 Definition of Power-Law Function Parameters

The MACCS2 power-law functions for σ_y and σ_z are functions of the form:

$$\sigma_y = \text{CYSIGA} \cdot X^{\text{CYSIGB}}, \quad \text{and}$$
$$\sigma_z = \text{CZSIGA} \cdot X^{\text{CZSIGB}},$$

where σ_y, σ_z, and X (the downwind distance from the source), are all in meters. There are numerous parameterizations available in the literature. The user must ensure that the categorization scheme used to define the stability classes for the meteorology is consistent with the dispersion parameterization defined by the following variables. Input parameter values for three parameterization schemes are presented in the Example Usage section that follows.

Variable Name: CYSIGA
Variable Type: Real, Array
Allowed Range: 1.E-6 ≤ value ≤ 10.0
Purpose: The linear term of the expression for σ_y. The user must supply six values of CYSIGA, one for each of the six Pasquill–Gifford stability classes (classes A through F).

Variable Name: CYSIGB
Variable Type: Real, Array
Allowed Range: 1.E-6 ≤ value ≤ 10.0
Purpose: The exponential term of the expression for σ_y. The user must supply six values of CYSIGB, one for each of the six Pasquill–Gifford stability classes (classes A through F).

Variable Name: CZSIGA
Variable Type: Real, Array
Allowed Range: 1.E-6 ≤ value ≤ 10.0
Purpose: The linear term of the expression for σ_z. The user must supply six values of CZSIGA, one for each of the six Pasquill–Gifford stability classes (classes A through F).

Variable Name: CZSIGB
Variable Type: Real, Array
Allowed Range: 1.E-6 ≤ value ≤ 10.0
Purpose: The exponential term of the expression for σ_z. The user must supply six values of CZSIGB, one for each of the six Pasquill–Gifford stability classes (classes A through F).

Example Usage:

```
*
*   TADMOR AND GUR PARAMETERIZATION FOR DISTANCE RANGE 0.5 TO 5.0 KM
*   AS TAKEN FROM ATMOSPHERIC MOTION AND AIR POLLUTION (DOBBINS 1979).
*
* P-G CLASS:    A          B         C         D         E         F
DPCYSIGA001  0.3658       0.2751    0.2089    0.1474    0.1046    0.0722
DPCYSIGB001  0.9031       0.9031    0.9031    0.9031    0.9031    0.9031
DPCZSIGA001  2.5E-4       1.9E-3    0.2       0.3       0.4       0.2
DPCZSIGB001  2.125        1.6021    0.8543    0.6532    0.6021    0.6020

*"KARLSRUHE-JULICH" SYSTEM FOR 50-M RELEASE HEIGHT AS TAKEN FROM
* PANITZ (1989).
*
* P-G CLASS:    A        B        C        D        E        F
DPCYSIGA001  1.503    0.876    0.659    0.640    0.801    1.294
DPCYSIGB001  0.833    0.823    0.807    0.784    0.754    0.718
DPCZSIGA001  0.151    0.127    0.165    0.215    0.264    0.241
DPCZSIGB001  1.219    1.108    0.996    0.885    0.774    0.662
```

```
*"ST. LOUIS" SYSTEM FOR URBAN AREAS AS TAKEN FROM VOGT (1977).
*(NOTE: THE REFERENCE PROVIDED DATA ONLY FOR CLASSES B THROUGH E.)
*
* P-G CLASS:    A        B        C        D        E        F
DPCYSIGA001  1.7000   1.7000   1.4400   0.9100   1.0200   1.0200
DPCYSIGB001  0.7170   0.7170   0.7100   0.7290   0.6480   0.6480
DPCZSIGA001  0.0790   0.0790   0.1310   0.9100   1.9300   1.9300
DPCZSIGB001  1.2000   1.2000   1.0460   0.7020   0.4650   0.4650
```

5.7.2 σ_y and σ_z Lookup-Table Option

The lookup-table option allows the user to bypass the power-law functions for σ_y and σ_z. This code option utilizes an interpolation algorithm that avoids the numerical instabilities observed with cubic spline fits. The calculational approach utilizes the Hermite cubic approach of SUBROUTINE PCHEZ, as obtained from Kahaner, Moler, and Nash (1989). This new lookup-table algorithm can be used to implement alternative dispersion parameterizations or to utilize fits to site-specific tracer data.

Invocation of the lookup-table feature is triggered by the inclusion of a card with a record identifier of NUM_DIST on the ATMOS input file. Allowable values for NUM_DIST, if such a card is present, are either 0 (signifying that no tables are being provided), or integers between 3 and 50, inclusive.

Specifying a value of 0 is equivalent to deleting the data record and the code will then proceed to use the power-law model for calculating the σ_y and σ_z dispersion parameters, functioning exactly the same as its predecessors. Specifying values of 1 or 2 for NUM_DIST will result in the diagnosis of an input error.

When NUM_DIST is given a value between 3 and 50, MACCS2 will not process the data records with record identifiers CYSIGYA, CYSIGB, *etc.*, instead obtaining dispersion parameter data from the input file tables with record identifiers A-STB/DIS01 through F-STB/DIS50. However, irrespective of which option is utilized, the data records DPYSCALE and DPZSCALE, defining linear scaling factors for σ_y and σ_z, must be supplied.

The format of that file is intended to be self-explanatory. Figures 5-1 through 5-3 list portions of the σ_y and σ_z input tables developed to represent the Tadmor–Gur (0.5–5-km) curves as presented in Dobbins (1979) and the Briggs curves for open country and urban terrain as presented in Hanna, Briggs, and Hosker (1982).

This new feature was implemented to allow the use of parameterizations other than the simple power law (*e.g.*, the Briggs formulas). Also, if tracer experiments are available for a site, it might be possible to process such data into the tables of horizontal and vertical standard deviations (σ_y and σ_z) required by this new feature of MACCS2.

Variable Name: NUM_DIST
Variable Type: Integer, Scalar
Allowed Range: 0 or 3 ≤ value ≤ 50
Purpose: The number of distances at which the dispersion table is being defined. Values of σ_y and σ_z must be supplied for each of these distances and for each of the six stability classes (A–F). If this data record is omitted, the calculations proceed as if the card was present, but with NUM_DIST set to a value of 0.
Example Usage:

```
*
NUM_DIST001   0  (DISPERSION TABLES ARE NOT BEING SUPPLIED)
OR
NUM_DIST001  50  (DISPERSION TABLES ARE BEING SUPPLIED FOR 50
*                 DISTANCES)
```

Variable Name: DISTANCE
Variable Type: Real, Array
Allowed Range: 1.0 ≤ value ≤ 1.E+8 (meters)
Purpose: The downwind distances at which σ_y and σ_z values are being defined. This record is only processed when NUM_DIST is defined to have a value of at least 3. The user must supply NUN_DIST values of DISTANCE. The values specified must be monotonically increasing, and an error will be diagnosed if successive values are decreasing or identical. These values are organized into six different data-block tables, with each table corresponding to one of the stability classes A through F. The values of DISTANCE are specified in column 1 of the data blocks.

Variable Name: SIGMA_Y
Variable Type: Real, Array
Allowed Range: 1.0E–6 ≤ value ≤ 1.E+20 (meters)
Purpose: Defines the user-specified tables of σ_y as a function of distance. One table is provided for each of the six stability classes. The user must supply NUM_DIST values of SIGMA_Y. The values specified must be monotonically increasing, and an error will be diagnosed if successive values are decreasing or identical. These values are organized into six different data-block tables, with each table corresponding to one of the stability classes A through F. The values of SIGMA_Y are specified in column 2 of the data blocks.

Variable Name: SIGMA_Z
Variable Type: Real, Array
Allowed Range: 1.0E–6 ≤ value ≤ 1.E+20 (meters)
Purpose: Defines the user-specified tables of σ_z as a function of distance. One table is provided for each of the six stability classes. The user must supply NUM_DIST values of SIGMA_Z. The values specified must be monotonically increasing, and an error will be diagnosed if successive values are decreasing or identical. These values are organized into six different data-block tables, with each table corresponding to one of the stability classes A through F. The values of SIGMA_Z are specified in column 3 of the data blocks.

Examples of the appearance of DISTANCE, SIGMA_Y, and SIGMA_Z for F-stability are shown in Figures 5-1 through 5-3. Figure 5-1 illustrates σ_y and σ_z values as functions of distance when the Tadmor–Gur formula (for 0.5 to 5 km) is utilized; this is the formula used to generate the ATMOS input file for sample problem A (input file IN1A.INP included in the distribution package). Figure 5-2 illustrates the Briggs formula values for open country (0.1 to 10 km); this is the formula used for sample problem D, subcase BRO (input file IN1D_BRO.INP included in the distribution package). Finally, Figure 5-3 illustrates the Briggs formula values for urban areas (0.1 to 10 km); this is the formula used for sample problem D, subcase BRU (input file IN1D_BRU.INP included in the distribution package).

5.7.3 Scaling Factors for Dispersion

In order to allow for situations where the user wishes to apply across-the-board linear scaling factors to σ_y and σ_z, the input parameters YSCALE and ZSCALE are provided. These scale factors are applied under both the power-law and lookup-table options. When specified to have values other than 1, these scaling factors are used to adjust the values of σ_y and σ_z that have been defined under either of those options. The same scaling factor is applied for each of the six stability classes.

Variable Name: YSCALE
Variable Type: Real, Scalar
Allowed Range: 0.01 ≤ value ≤ 100.0 (unitless)
Purpose: A linear scaling factor that is applied to the formula to calculate σ_y. This parameter is a convenient method for adjusting all the linear factors (CYSIGA) by a constant multiplicative factor.
Example Usage:

```
*
* LINEAR SCALING FACTOR FOR SIGMA-Y FUNCTION, NORMALLY 1
*
DPYSCALE001    1.
```

Figure 5-1. F-stability dispersion table—Tadmor–Gur formula (for 0.5 to 5 km).

* F-stability	Distance (m)	SIGMA_Y (m)	SIGMA_Z (m)	
F-STB/DIS01	1.000E+00	7.2200E-02	2.0000E-01	Tadmor/Gur (0.5-5 km)
F-STB/DIS02	1.400E+00	9.7838E-02	2.4491E-01	Tadmor/Gur (0.5-5 km)
F-STB/DIS03	2.000E+00	1.3502E-01	3.0356E-01	Tadmor/Gur (0.5-5 km)
F-STB/DIS04	3.000E+00	1.9473E-01	3.8749E-01	Tadmor/Gur (0.5-5 km)
F-STB/DIS05	4.000E+00	2.5250E-01	4.6076E-01	Tadmor/Gur (0.5-5 km)
F-STB/DIS06	5.000E+00	3.0887E-01	5.2700E-01	Tadmor/Gur (0.5-5 km)
F-STB/DIS07	6.000E+00	3.6415E-01	5.8814E-01	Tadmor/Gur (0.5-5 km)
F-STB/DIS08	8.000E+00	4.7219E-01	6.9934E-01	Tadmor/Gur (0.5-5 km)
F-STB/DIS09	1.000E+01	5.7761E-01	7.9989E-01	Tadmor/Gur (0.5-5 km)
F-STB/DIS10	1.000E+02	4.6210E+00	3.1991E+00	Tadmor/Gur (0.5-5 km)
F-STB/DIS11	1.400E+02	6.2619E+00	3.9174E+00	Tadmor/Gur (0.5-5 km)
F-STB/DIS12	2.000E+02	8.6417E+00	4.8557E+00	Tadmor/Gur (0.5-5 km)
F-STB/DIS13	3.000E+02	1.2463E+01	6.1981E+00	Tadmor/Gur (0.5-5 km)
F-STB/DIS14	4.000E+02	1.6161E+01	7.3700E+00	Tadmor/Gur (0.5-5 km)
F-STB/DIS15	5.000E+02	1.9769E+01	8.4297E+00	Tadmor/Gur (0.5-5 km)
F-STB/DIS16	6.000E+02	2.3307E+01	9.4076E+00	Tadmor/Gur (0.5-5 km)
F-STB/DIS17	8.000E+02	3.0222E+01	1.1186E+01	Tadmor/Gur (0.5-5 km)
F-STB/DIS18	1.000E+03	3.6969E+01	1.2795E+01	Tadmor/Gur (0.5-5 km)
F-STB/DIS19	1.400E+03	5.0096E+01	1.5667E+01	Tadmor/Gur (0.5-5 km)
F-STB/DIS20	2.000E+03	6.9135E+01	1.9420E+01	Tadmor/Gur (0.5-5 km)
F-STB/DIS21	3.000E+03	9.9707E+01	2.4789E+01	Tadmor/Gur (0.5-5 km)
F-STB/DIS22	4.000E+03	1.2929E+02	2.9476E+01	Tadmor/Gur (0.5-5 km)
F-STB/DIS23	5.000E+03	1.5815E+02	3.3714E+01	Tadmor/Gur (0.5-5 km)
F-STB/DIS24	6.000E+03	1.8646E+02	3.7625E+01	Tadmor/Gur (0.5-5 km)
F-STB/DIS25	8.000E+03	2.4178E+02	4.4739E+01	Tadmor/Gur (0.5-5 km)
F-STB/DIS26	1.000E+04	2.9576E+02	5.1172E+01	Tadmor/Gur (0.5-5 km)
F-STB/DIS27	1.400E+04	4.0078E+02	6.2661E+01	Tadmor/Gur (0.5-5 km)
F-STB/DIS28	2.000E+04	5.5309E+02	7.7669E+01	Tadmor/Gur (0.5-5 km)
F-STB/DIS29	3.000E+04	7.9767E+02	9.9142E+01	Tadmor/Gur (0.5-5 km)
F-STB/DIS30	4.000E+04	1.0343E+03	1.1789E+02	Tadmor/Gur (0.5-5 km)
F-STB/DIS31	5.000E+04	1.2653E+03	1.3484E+02	Tadmor/Gur (0.5-5 km)
F-STB/DIS32	6.000E+04	1.4917E+03	1.5048E+02	Tadmor/Gur (0.5-5 km)
F-STB/DIS33	8.000E+04	1.9343E+03	1.7893E+02	Tadmor/Gur (0.5-5 km)
F-STB/DIS34	1.000E+05	2.3661E+03	2.0466E+02	Tadmor/Gur (0.5-5 km)
F-STB/DIS35	1.400E+05	3.2063E+03	2.5061E+02	Tadmor/Gur (0.5-5 km)
F-STB/DIS36	2.000E+05	4.4248E+03	3.1063E+02	Tadmor/Gur (0.5-5 km)
F-STB/DIS37	3.000E+05	6.3815E+03	3.9651E+02	Tadmor/Gur (0.5-5 km)
F-STB/DIS38	4.000E+05	8.2748E+03	4.7149E+02	Tadmor/Gur (0.5-5 km)
F-STB/DIS39	5.000E+05	1.0122E+04	5.3927E+02	Tadmor/Gur (0.5-5 km)
F-STB/DIS40	6.000E+05	1.1934E+04	6.0183E+02	Tadmor/Gur (0.5-5 km)
F-STB/DIS41	8.000E+05	1.5475E+04	7.1563E+02	Tadmor/Gur (0.5-5 km)
F-STB/DIS42	1.000E+06	1.8929E+04	8.1852E+02	Tadmor/Gur (0.5-5 km)
F-STB/DIS43	1.400E+06	2.5651E+04	1.0023E+03	Tadmor/Gur (0.5-5 km)
F-STB/DIS44	2.000E+06	3.5400E+04	1.2424E+03	Tadmor/Gur (0.5-5 km)
F-STB/DIS45	3.000E+06	5.1053E+04	1.5858E+03	Tadmor/Gur (0.5-5 km)
F-STB/DIS46	4.000E+06	6.6200E+04	1.8857E+03	Tadmor/Gur (0.5-5 km)
F-STB/DIS47	5.000E+06	8.0980E+04	2.1568E+03	Tadmor/Gur (0.5-5 km)
F-STB/DIS48	6.000E+06	9.5474E+04	2.4070E+03	Tadmor/Gur (0.5-5 km)
F-STB/DIS49	8.000E+06	1.2380E+05	2.8621E+03	Tadmor/Gur (0.5-5 km)
F-STB/DIS50	1.000E+07	1.5144E+05	3.2736E+03	Tadmor/Gur (0.5-5 km)

Figure 5-2. F-stability dispersion table—Briggs open country formula (0.1 to 10 km).

* F-stability	Distance (m)	SIGMA_Y (m)	SIGMA_Z (m)	
F-STB/DIS01	1.000E+00	3.9998E-02	1.5995E-02	Briggs Open Country (0.1-10 km)
F-STB/DIS02	1.400E+00	5.5996E-02	2.2391E-02	Briggs Open Country (0.1-10 km)
F-STB/DIS03	2.000E+00	7.9992E-02	3.1981E-02	Briggs Open Country (0.1-10 km)
F-STB/DIS04	3.000E+00	1.1998E-01	4.7957E-02	Briggs Open Country (0.1-10 km)
F-STB/DIS05	4.000E+00	1.5997E-01	6.3923E-02	Briggs Open Country (0.1-10 km)
F-STB/DIS06	5.000E+00	1.9995E-01	7.9880E-02	Briggs Open Country (0.1-10 km)
F-STB/DIS07	6.000E+00	2.3993E-01	9.5828E-02	Briggs Open Country (0.1-10 km)
F-STB/DIS08	8.000E+00	3.1987E-01	1.2769E-01	Briggs Open Country (0.1-10 km)
F-STB/DIS09	1.000E+01	3.9980E-01	1.5952E-01	Briggs Open Country (0.1-10 km)
F-STB/DIS10	1.000E+02	3.9801E+00	1.5534E+00	Briggs Open Country (0.1-10 km)
F-STB/DIS11	1.400E+02	5.5612E+00	2.1497E+00	Briggs Open Country (0.1-10 km)
F-STB/DIS12	2.000E+02	7.9212E+00	3.0189E+00	Briggs Open Country (0.1-10 km)
F-STB/DIS13	3.000E+02	1.1824E+01	4.4037E+00	Briggs Open Country (0.1-10 km)
F-STB/DIS14	4.000E+02	1.5689E+01	5.7143E+00	Briggs Open Country (0.1-10 km)
F-STB/DIS15	5.000E+02	1.9518E+01	6.9565E+00	Briggs Open Country (0.1-10 km)
F-STB/DIS16	6.000E+02	2.3311E+01	8.1356E+00	Briggs Open Country (0.1-10 km)
F-STB/DIS17	8.000E+02	3.0792E+01	1.0323E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS18	1.000E+03	3.8139E+01	1.2308E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS19	1.400E+03	5.2449E+01	1.5775E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS20	2.000E+03	7.3030E+01	2.0000E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS21	3.000E+03	1.0525E+02	2.5263E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS22	4.000E+03	1.3522E+02	2.9091E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS23	5.000E+03	1.6330E+02	3.2000E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS24	6.000E+03	1.8974E+02	3.4286E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS25	8.000E+03	2.3851E+02	3.7647E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS26	1.000E+04	2.8284E+02	4.0000E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS27	1.400E+04	3.6148E+02	4.3077E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS28	2.000E+04	4.6188E+02	4.5714E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS29	3.000E+04	6.0000E+02	4.8000E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS30	4.000E+04	7.1554E+02	4.9231E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS31	5.000E+04	8.1650E+02	5.0000E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS32	6.000E+04	9.0711E+02	5.0526E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS33	8.000E+04	1.0667E+03	5.1200E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS34	1.000E+05	1.2060E+03	5.1613E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS35	1.400E+05	1.4459E+03	5.2093E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS36	2.000E+05	1.7457E+03	5.2459E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS37	3.000E+05	2.1553E+03	5.2747E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS38	4.000E+05	2.4988E+03	5.2893E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS39	5.000E+05	2.8006E+03	5.2980E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS40	6.000E+05	3.0729E+03	5.3039E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS41	8.000E+05	3.5556E+03	5.3112E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS42	1.000E+06	3.9801E+03	5.3156E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS43	1.400E+06	4.7161E+03	5.3207E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS44	2.000E+06	5.6428E+03	5.3245E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS45	3.000E+06	6.9167E+03	5.3274E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS46	4.000E+06	7.9900E+03	5.3289E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS47	5.000E+06	8.9353E+03	5.3298E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS48	6.000E+06	9.7898E+03	5.3304E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS49	8.000E+06	1.1307E+04	5.3311E+01	Briggs Open Country (0.1-10 km)
F-STB/DIS50	1.000E+07	1.2643E+04	5.3316E+01	Briggs Open Country (0.1-10 km)

Figure 5-3. F-stability dispersion table—Briggs urban formula (0.1 to 10 km).

* F-stability	Distance (m)	SIGMA_Y (m)	SIGMA_Z (m)	
F-STB/DIS01	1.000E+00	1.0998E-01	7.9994E-02	Briggs Urban (0.1-10 km)
F-STB/DIS02	1.400E+00	1.5396E-01	1.1199E-01	Briggs Urban (0.1-10 km)
F-STB/DIS03	2.000E+00	2.1991E-01	1.5998E-01	Briggs Urban (0.1-10 km)
F-STB/DIS04	3.000E+00	3.2980E-01	2.3995E-01	Briggs Urban (0.1-10 km)
F-STB/DIS05	4.000E+00	4.3965E-01	3.1990E-01	Briggs Urban (0.1-10 km)
F-STB/DIS06	5.000E+00	5.4945E-01	3.9985E-01	Briggs Urban (0.1-10 km)
F-STB/DIS07	6.000E+00	6.5921E-01	4.7978E-01	Briggs Urban (0.1-10 km)
F-STB/DIS08	8.000E+00	8.7860E-01	6.3962E-01	Briggs Urban (0.1-10 km)
F-STB/DIS09	1.000E+01	1.0978E+00	7.9940E-01	Briggs Urban (0.1-10 km)
F-STB/DIS10	1.000E+02	1.0786E+01	7.9407E+00	Briggs Urban (0.1-10 km)
F-STB/DIS11	1.400E+02	1.4986E+01	1.1084E+01	Briggs Urban (0.1-10 km)
F-STB/DIS12	2.000E+02	2.1170E+01	1.5765E+01	Briggs Urban (0.1-10 km)
F-STB/DIS13	3.000E+02	3.1182E+01	2.3478E+01	Briggs Urban (0.1-10 km)
F-STB/DIS14	4.000E+02	4.0853E+01	3.1081E+01	Briggs Urban (0.1-10 km)
F-STB/DIS15	5.000E+02	5.0208E+01	3.8579E+01	Briggs Urban (0.1-10 km)
F-STB/DIS16	6.000E+02	5.9270E+01	4.5976E+01	Briggs Urban (0.1-10 km)
F-STB/DIS17	8.000E+02	7.6594E+01	6.0474E+01	Briggs Urban (0.1-10 km)
F-STB/DIS18	1.000E+03	9.2967E+01	7.4600E+01	Briggs Urban (0.1-10 km)
F-STB/DIS19	1.400E+03	1.2330E+02	1.0182E+02	Briggs Urban (0.1-10 km)
F-STB/DIS20	2.000E+03	1.6398E+02	1.4033E+02	Briggs Urban (0.1-10 km)
F-STB/DIS21	3.000E+03	2.2249E+02	1.9931E+02	Briggs Urban (0.1-10 km)
F-STB/DIS22	4.000E+03	2.7288E+02	2.5298E+02	Briggs Urban (0.1-10 km)
F-STB/DIS23	5.000E+03	3.1754E+02	3.0237E+02	Briggs Urban (0.1-10 km)
F-STB/DIS24	6.000E+03	3.5794E+02	3.4823E+02	Briggs Urban (0.1-10 km)
F-STB/DIS25	8.000E+03	4.2940E+02	4.3149E+02	Briggs Urban (0.1-10 km)
F-STB/DIS26	1.000E+04	4.9193E+02	5.0596E+02	Briggs Urban (0.1-10 km)
F-STB/DIS27	1.400E+04	5.9944E+02	6.3612E+02	Briggs Urban (0.1-10 km)
F-STB/DIS28	2.000E+04	7.3333E+02	8.0000E+02	Briggs Urban (0.1-10 km)
F-STB/DIS29	3.000E+04	9.1526E+02	1.0234E+03	Briggs Urban (0.1-10 km)
F-STB/DIS30	4.000E+04	1.0672E+03	1.2095E+03	Briggs Urban (0.1-10 km)
F-STB/DIS31	5.000E+04	1.2002E+03	1.3720E+03	Briggs Urban (0.1-10 km)
F-STB/DIS32	6.000E+04	1.3200E+03	1.5179E+03	Briggs Urban (0.1-10 km)
F-STB/DIS33	8.000E+04	1.5319E+03	1.7750E+03	Briggs Urban (0.1-10 km)
F-STB/DIS34	1.000E+05	1.7179E+03	2.0000E+03	Briggs Urban (0.1-10 km)
F-STB/DIS35	1.400E+05	2.0398E+03	2.3878E+03	Briggs Urban (0.1-10 km)
F-STB/DIS36	2.000E+05	2.4444E+03	2.8737E+03	Briggs Urban (0.1-10 km)
F-STB/DIS37	3.000E+05	3.0000E+03	3.5386E+03	Briggs Urban (0.1-10 km)
F-STB/DIS38	4.000E+05	3.4677E+03	4.0972E+03	Briggs Urban (0.1-10 km)
F-STB/DIS39	5.000E+05	3.8794E+03	4.5883E+03	Briggs Urban (0.1-10 km)
F-STB/DIS40	6.000E+05	4.2514E+03	5.0318E+03	Briggs Urban (0.1-10 km)
F-STB/DIS41	8.000E+05	4.9117E+03	5.8182E+03	Briggs Urban (0.1-10 km)
F-STB/DIS42	1.000E+06	5.4931E+03	6.5103E+03	Briggs Urban (0.1-10 km)
F-STB/DIS43	1.400E+06	6.5019E+03	7.7104E+03	Briggs Urban (0.1-10 km)
F-STB/DIS44	2.000E+06	7.7733E+03	9.2222E+03	Briggs Urban (0.1-10 km)
F-STB/DIS45	3.000E+06	9.5223E+03	1.1301E+04	Briggs Urban (0.1-10 km)
F-STB/DIS46	4.000E+06	1.0997E+04	1.3053E+04	Briggs Urban (0.1-10 km)
F-STB/DIS47	5.000E+06	1.2295E+04	1.4596E+04	Briggs Urban (0.1-10 km)
F-STB/DIS48	6.000E+06	1.3469E+04	1.5991E+04	Briggs Urban (0.1-10 km)
F-STB/DIS49	8.000E+06	1.5554E+04	1.8468E+04	Briggs Urban (0.1-10 km)
F-STB/DIS50	1.000E+07	1.7390E+04	2.0649E+04	Briggs Urban (0.1-10 km)

Variable Name: ZSCALE
Variable Type: Real, Scalar
Allowed Range: $0.01 \leq$ value $\leq$ 100.0 (unitless)
Purpose: A linear scaling factor that is applied to the formula used to calculate σ_z. It is normally used to adjust the vertical dispersion parameters to take account of surface roughness.
Example Usage:

```
*
* LINEAR SCALING FACTOR FOR SIGMA-Z FUNCTION,
* NORMALLY USED FOR SURFACE ROUGHNESS LENGTH CORRECTION.
* (Z1 / Z0) ** 0.2,   FROM CRAC2 WE HAVE  (10 CM / 3 CM) ** 0.2 =
* 1.27
*
DPZSCALE001    1.27  (VALUE INTENDED TO BE USED WITH TADMOR AND GUR
*                     PARAMETERS)
```

5.8 Plume Meander (PM) Data

In order to account for the effect of meander during transport of the plume, an expansion factor, EXPFAC, is calculated which serves to widen the plumes in the cross-wind direction. It acts as a linear factor on σ_y during the calculation of χ/Q, but it does not affect the rate of growth of σ_y. A two-part function is used. The expansion factors used for different plume segments are independent of each other. If the release duration of the plume segment is less than or equal to BRKPNT, then the following formula will be used,

$$\text{EXPFAC} = [\text{MAX (plume segment release duration, TIMBAS) / TIMBAS}]^{\text{XPFAC1}} .$$

If the plume segment duration exceeds BRKPNT, then a different factor is used for the exponent of the function,

$$\text{EXPFAC} = [\text{MAX (plume segment release duration, TIMBAS) / TIMBAS}]^{\text{XPFAC2}} .$$

In both expressions, the duration of the plume segment should be limited to 10 hr because the formula is not intended for use outside of that range. For that reason, a nonfatal warning is printed on the output listing if the user specifies a release duration exceeding 10 hr.

If the user does not wish to use the plume meander model, this can be accomplished by setting TIMBAS to the duration of the plume (PLUDUR). However, this approach to turning off the meander model can only be used if there is a single plume, or if all plumes have the same duration.

Variable Name: TIMBAS
Variable Type: Real, Scalar
Allowed Range: $60.0 \leq$ value $\leq$ 86400.0 (seconds)

Purpose: The time base associated with the parameterization of the plume meander adjustment factor (seconds).

Example Usage:

```
*
* TIME BASE FOR EXPANSION FACTOR (SECONDS)
*
PMTIMBAS001   600.    (10 MIN)
```

Variable Name: BRKPNT

Variable Type: Real, Scalar

Allowed Range: $60.0 \leq$ value $\leq$ 86400.0 (seconds)

Purpose: The time breakpoint in the formula used to calculate the plume meander expansion factor (seconds). If the release duration is less than or equal to this value, the first formula is used. If the release duration exceeds this value, the second formula is used.

Example Usage:

```
*
* BREAKPOINT FOR FORMULA CHANGE (SECONDS)
*
PMBRKPNT001   3600.
```

Variable Name: XPFAC1

Variable Type: Real, Scalar

Allowed Range: $0.01 \leq$ value $\leq$ 1.0 (unitless)

Purpose: The exponential factor used in calculating the plume meander expansion factor for releases having durations that are less than or equal to BRKPNT.

Example Usage:

```
*
* EXPONENTIAL EXPANSION FACTOR NUMBER 1
*
PMXPFAC1001   0.2
```

Variable Name: XPFAC2

Variable Type: Real, Scalar

Allowed Range: $0.01 \leq$ value $\leq$ 1.0 (unitless)

Purpose: The exponential factor used in calculating the plume meander expansion factor for releases having durations that are greater than BRKPNT.

Example Usage:

```
*
* EXPONENTIAL EXPANSION FACTOR NUMBER 2
*
PMXPFAC2001   0.25
```

5.9 Plume Rise (PR) Data

A plume rise model based on the recommendations of Briggs (1975, 1984) is incorporated into MACCS. There are three basic components of the model: (1) entrainment of buoyant plumes in a building wake, (2) plume rise under unstable and neutral conditions (classes A to D), and (3) plume rise under stable conditions (classes E to F).

These component models are described in the MACCS *Model Description*. The individual numeric coefficients utilized by these models are fixed in the code with no provision for their convenient modification by the user. While it is not possible for the user to vary the individual coefficients utilized by the three components of the plume rise model, it is possible to modify their end results by the specification of linear scaling factors that are described in this section.

Variable Name: SCLCRW
Variable Type: Real, Scalar
Allowed Range: $0.001 \leq$ value $\leq$ 1.0E6
Purpose: Linear scaling factor on the critical wind speed used in determining if buoyant plumes will be trapped in the turbulent wake of the facility building complex. Parameter values less than unity make plume rise less likely to occur because plume liftoff occurs only if the ambient wind speed at the time of release is less than the calculated critical wind speed.

MACCS2 implements the plume rise entrainment model recommended by Hall and Waters (1986), as described in the MACCS *Model Description*, page 2-6, where the critical wind speed is a function of the height of the building and the thermal power of the plume (ATMOS input variables PLHEAT and BUILDH). This model is based on wind tunnel experiments for buildings of a size associated with commercial reactors.

If there is a need to ignore the effect of building wake entrainment, for example, for a point-source release, or from a small building, this can be achieved by setting SCLCRW to its maximum allowable value. When that is done, the calculation of the height of the plume is based strictly on the Briggs plume rise formulas, irrespective of building height and the corresponding critical wind speed.

Example Usage:

```
*
* SCALING FACTOR FOR ENTRAINMENT OF BUOYANT PLUME
*
PRSCLCRW001   1.
```

Variable Name: SCLADP
Variable Type: Real, Scalar
Allowed Range: $0.01 \leq$ value $\leq$ 100.0 (unitless)

Purpose: Linear scaling factor on the plume rise formula used to determine the amount of plume rise that will occur when unstable or neutral atmospheric conditions occur (classes A through D).

Example Usage:

```
*
* SCALING FACTOR FOR THE A–D STABILITY PLUME RISE FORMULA
*
PRSCLADP001   1.
```

Variable Name: SCLEFP
Variable Type: Real, Scalar
Allowed Range: $0.01 \leq$ value $\leq$ 100.0 (unitless)
Purpose: Linear scaling factor on the plume rise formula used to determine the amount of plume rise that will occur when atmospheric conditions are stable (classes E and F).

Example Usage:

```
*
* SCALING FACTOR FOR THE E–F STABILITY PLUME RISE FORMULA
*
PRSCLEFP001   1.
```

5.10 Wake Effects (WE) Data

The initial size of the plume is determined by the width and height of the building wake. In MACCS, the initial plume dimensions were initialized to fixed fractions of the user-specified building dimensions. σ_y was initialized to the building width divided by 4.3, and σ_z was initialized to the building height divided by 2.15.

The height of the building wake is also used to determine if the plume is entrained in the turbulent region surrounding the building. Consequently, in addition to determining the initial plume size, the wake height is used to determine whether buoyant plume rise will occur (see Section 5.9).

The dispersion of a plume of material released in the wake of a large building is subject to a large degree of uncertainty. For that reason, MACCS2 should not be used for estimating doses at distances less than 0.5 km from laboratory or industrial-scale facilities. It has long been recognized that the turbulent eddies in the lee of an obstacle are very difficult to model. A good example is the data of Ramsdell (1990), who showed that, in contrast to standard Gaussian plume formulas in which concentrations are inversely proportional to wind speed, air concentrations in a building's wake can increase with increased wind speed.

The earliest formulation for building wake effects in current use is the "area source" model attributed to Fuquay by Gifford (1960). In that formulation, for a ground-level source and receptor,

$$\chi/Q = 1 / (\pi \cdot u \cdot \sigma_y \cdot \sigma_z + c \cdot A),$$

where A is the cross-sectional area of the building normal to the wind, and c is an empirical factor judged intuitively to be between 0.5 and 2.0. Later work (Gifford 1976) shows that a value of 0.5 for c is supported by empirical data and is an appropriate conservative value.

In CRAC2, the initial plume standard deviations are

$$\sigma_y = W / 3$$
$$\sigma_z = H / 2.15 ,$$

where W is building width and H is building height, while in MACCS the corresponding formulas are

$$\sigma_y = W / 4.3$$
$$\sigma_z = H / 2.15 .$$

A very similar model is recommended by Jones (1983):

$$\sigma_y = W / 3$$
$$\sigma_z = H / 3$$

with the additional guidance that the building releases should be adjusted to occur at an effective release height of $H/3$.

Variable Name: BUILDH
Variable Type: Real, Scalar
Allowed Range: $1.0 \leq$ value ≤ 1000.0 (meters)
Purpose: Defines the height of the facility building. This value is used in the evaluation of whether a buoyant plume is entrained in the turbulent wake of the building. The building height, in contrast to MACCS, is no longer utilized to define the initial value of σ_z for the plume.
Example Usage:

```
*
* BUILDING HEIGHT (METERS) THIS IS NOW USED ONLY FOR PLUME RISE
*  ENTRAINMENT.
*
WEBUILDH001   50.   SURRY
```

Variable Name: SIGYINIT
Variable Type: Real, Scalar
Allowed Range: $0.1 \leq$ value ≤ 1000.0 (meters)
Purpose: Defines the initial value of σ_y for each of the plumes released.
Example Usage:

```
*
```

```
* INITIAL VALUE FOR SIGMA-Y (METERS)
*
SIGYINIT001  9.302  (INITIAL SIGMA-Y, CALCULATED FOR 40-M WIDE
*                        BLDG.)
```

Variable Name: SIGZINIT
Variable Type: Real, Scalar
Allowed Range: $0.1 \leq$ value ≤ 1000.0 (meters)
Purpose: Defines the initial value of σ_z for each of the plumes released.
Example Usage:

```
*
* INITIAL VALUE FOR SIGMA-Z (METERS)
*
SIGZINIT001  23.26  (INITIAL SIGMA-Z, CALCULATED FOR 50-M-HIGH
*                        BLDG.)
```

5.11 Release Description (RD) Data

ATMOS can handle multiple plume segments in order to treat the release of a source term that has a composition that varies with time. The plume segments that comprise a release can be separated by a time gap, can directly follow the preceding segment, or they can overlap. Different release heights, heat contents, release durations, and initial values for σ_y and σ_z may be assigned to each plume. Only one particle size distribution may be assigned to each chemical element group.

MACCS2 incorporates the capability for calculating the consequences from up to 60 different source terms in a single run of the code. This is accomplished by appending change records to the ATMOS input file. The first source term is defined in the main body of the ATMOS input file. Up to 59 additional source terms can be defined through change record sets positioned at the end of the file.

The delimiter used to separate the change record sets is a period (.) in column 1, which also signifies the end of the file. All of the MACCS2 user input files must thus end with a period in column 1. The sample ATMOS input file listed in Appendix D.1 of the MACCS *User's Guide* is an example illustrating the use of change records for a PRA application of the code.

The purpose of the change record processing in ATMOS is solely to allow modification of the previously specified release description data. If data items from another data block appear in the change records, they will be ignored. Each set of change records must include a new value of ATNAM2, a text field describing the source term. Also, each set of change records must specify a change in at least one of the numeric input variables described in this data block.

Variable Name: ATNAM2
Variable Type: Character, Scalar
Allowed Range: $1 \leq$ length ≤ 80
Purpose: Identifies the name of the source term being studied. This name will be printed on all pages of the OUTPUT listing. A unique name must be specified for each source term.
Example Usage:

```
*
* SPECIFIC DESCRIPTIVE TEXT DESCRIBING THIS PARTICULAR SOURCE
* TERM
*
RDATNAM2001 'HYPOTHETICAL SOURCE TERM NUMBER 1'
```

Variable Name: OALARM
Variable Type: Real, Scalar
Allowed Range: $0.0 \leq$ value $\leq$ 604800.0 s (1 week)
Purpose: Defines the time at which notification is given to off-site emergency response officials to initiate protective measures for the surrounding population. This time is a function of the accident sequence. It is measured from accident initiation (scram time) and is given in units of seconds.
Example Usage:

```
*
* TIME AFTER ACCIDENT INITIATION THAT OFF-SITE ALARM IS INITIATED
*
RDOALARM001  17280.
```

Variable Name: NUMREL
Variable Type: Integer, Scalar
Allowed Range: $1 \leq$ value ≤ 4
Purpose: Defines the number of plumes that will be released.

Note: If the multiple source term feature is being used, it is not possible to provide a larger value for NUMREL in the change records than the value that was defined previously. That is, the values of NUMREL specified on change records cannot be larger than the value of NUMREL specified in the base-case data.

Example Usage:

```
*
* NUMBER OF PLUME SEGMENTS THAT ARE RELEASED
*
RDNUMREL001   2
```

Variable Name: MAXRIS
Variable Type: Integer, Scalar
Allowed Range: $1 \leq$ value $\leq$ NUMREL

Purpose: Specifies which plume segment is to be considered risk dominant. The selection of this plume is usually based on its potential for causing early fatalities. Release of the risk-dominant plume always begins at the selected meteorological start time of the weather sequence.

Example Usage:

```
*
* SELECTION OF RISK-DOMINANT PLUME SEGMENT
*
RDMAXRIS001    1
```

Variable Name: REFTIM
Variable Type: Real, Array
Allowed Range: $0.0 \leq$ value $\leq$ 1.0
Purpose: Specifies the representative time point of each plume segment (0.0=leading edge, 0.5=midpoint, 1.0=trailing edge). The characteristics of a plume are uniform along its length. This parameter allows the user to locate the contents of the plume in a so-called bucket of material situated at some point within the plume's length. The radioactive decay, dry deposition, and dispersion calculations are all performed as if the entire contents of the plume segment are located at this point. The user must supply NUMREL values of REFTIM, one for each plume segment.

The choice of this parameter will have no impact on the wet deposition calculations since those are performed as if the entire contents of the plume are uniformly distributed along its length.

Example Usage:

```
*
* REPRESENTATIVE TIME POINT FOR DISPERSION AND RADIOACTIVE DECAY
*
RDREFTIM001  0.  0.5 (CORRESPONDING TO HEAD AND MIDPOINT WEATHER)
```

Variable Name: PLHEAT
Variable Type: Real, Array
Allowed Range: $0.0 \leq$ value $\leq$ 1.E10 (watts)
Purpose: Specifies the rate of release of sensible heat in each plume segment. This quantity should be calculated as the amount of sensible heat in the plume segment divided by the duration of the plume segment. The value specified here is used to determine the amount of buoyant plume rise that will occur. The user must supply NUMREL values of PLHEAT, one for each plume segment.

Example Usage:

```
*
* HEAT CONTENT OF THE RELEASE SEGMENTS (WATTS)
* A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS
*
RDPLHEAT001   6.37E+06   3.43E+06
```

Variable Name: PLHITE
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1000.0 (meters)
Purpose: Specifies the height above ground level at which each plume segment is released. The user must supply NUMREL values of PLHITE, one for each plume segment.
Example Usage:

```
*
* HEIGHT OF THE PLUME SEGMENTS AT RELEASE (METERS)
* A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS
*
RDPLHITE001  30.    30.
```

Variable Name: PLUDUR
Variable Type: Real, Array
Allowed Range: 60.0 ≤ value ≤ 86400.0 (seconds) 1 day
Purpose: Specifies the duration in seconds of each plume segment. The user must supply NUMREL values of PLUDUR, one for each plume segment. In contrast to MACCS, where multiple plume segments were not allowed to overlap each other in time, MACCS2 allows the specification of overlapping plumes.
Example Usage:

```
*
* DURATION OF THE PLUME SEGMENTS (SECONDS)
* A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS
*
RDPLUDUR001  9000.  12588.
```

Variable Name: PDELAY
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 345600.0 (seconds) (4 days)
Purpose: Specifies the start time of each plume segment in seconds from the time of accident initiation, *e.g.*, reactor scram. The user must supply NUMREL values for PDELAY, one for each plume segment. In contrast to MACCS, where multiple plume segments were not allowed to overlap each other in time, MACCS2 allows the specification of overlapping plumes.
Example Usage:

```
*
* TIME OF RELEASE FOR EACH PLUME (SECONDS FROM SCRAM)
* A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS
*
RDPDELAY001  17280.   26280.
```

Variable Name: PSDIST
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0
Purpose: Defines the fraction of the released material allocated to each of the particle size (deposition velocity) bins. All of the plume segments must use the same distribution of material among these bins.

The user must specify one data record for each of the chemical element groups. The number of chemical element groups was defined as variable MAXGRP in Section 5.4. On each of these cards, the user must supply an allocation fraction to be associated with each of the particle size groups. The number of particle size groups was defined as the input variable NPSGRP in Section 5.6.

Example Usage:

```
*
* PARTICLE SIZE DISTRIBUTION OF EACH ELEMENT GROUP
*
*           0.001   0.01   0.02  DEPOSITION VELOCITY OF EACH GROUP (METERS/SECOND)
*
RDPSDIST001  0.1    0.8    0.1
RDPSDIST002  0.1    0.8    0.1
RDPSDIST003  0.1    0.8    0.1
RDPSDIST004  0.1    0.8    0.1
RDPSDIST005  0.1    0.8    0.1
RDPSDIST006  0.1    0.8    0.1
RDPSDIST007  0.1    0.8    0.1
RDPSDIST008  0.1    0.8    0.1
RDPSDIST009  0.1    0.8    0.1
```

Variable Name: CORINV
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.E20 (becquerels)
Purpose: Defines the inventory of each radionuclide present in the facility at the time of accident initiation. The inventory is given in units of becquerels (disintegrations/second). All of the radionuclides that have been previously defined in the list of radionuclides (NUCNAM array in Section 5.4) must be listed here. The radionuclide names and their respective inventories may appear in any order.

Example Usage:

```
*
*           NUCNAM      CORINV (BECQUERELS )
*
RDCORINV001 Co-58       3.223E+16
RDCORINV002 Co-60       2.465E+16
RDCORINV003 Kr-85       2.475E+16
RDCORINV004 Kr-85m      1.159E+18
```

Variable Name: CORSCA
Variable Type: Real, Scalar
Allowed Range: 2.7E–10 ≤ value ≤ 1.0E12
Purpose: This is a linear scaling factor that can be used to adjust the inventory of all the radionuclides defined in the model. It is preferable to obtain new sets of inventory values when studying reactors of varying power levels but this is not always possible.

When facility-specific inventories are not available, a representative inventory may be obtained by linear scaling of the inventory of a similar reactor having a different thermal power level. The scale factor used can be chosen to be the ratio of the two reactors' thermal power levels.

The parameter CORSCA may also be used to convert the facility inventory from one set of units to another during the input processing phase in order to avoid the tedium of manually converting a set of data from one set of units to another. For example, to convert from curies to becquerels, use a value of 3.7E10 for CORSCA.

Example Usage:

```
*
* SCALING FACTOR TO ADJUST THE CORE INVENTORY
*
RDCORSCA001   0.715   *   SURRY
```

Variable Name: RELFRC
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0
Purpose: Defines the release fractions for each of the plume segments. One card is supplied for each plume and it contains as many values as there are element groups. All components of an element group are released from the facility in the same fraction.

Variable Name: APLFRC
Variable Type: Character, Scalar
Allowed Value: 'PARENT' or 'PROGENY'
Purpose: Specifies how release fractions are applied to ingrowth decay products produced after accident initiation. PARENT indicates that the code is to handle the release fractions in the same way that they are fixed in previous versions of MACCS. That is, daughter ingrowth products are released in the same proportion as their parent.

The new option, PROGENY, indicates that the release fraction applied to daughter ingrowth products is defined by the release fraction for the isotope group to which the daughter is assigned (variable ISOGRP).

Example Usage:

```
*
RDAPLFRC001    PARENT   (APPLY RELEASE FRACTIONS THE SAME AS PRIOR VERSIONS)
*
*            Xe/Kr     I       Cs      Te      Sr      Ru      La      Ce      Ba
*
RDRELFRC001  7.0E-1  4.7E-1  4.7E-1  3.4E-1  3.0E-1  5.0E-3  3.0E-2  4.5E-2  2.2E-1
RDRELFRC002  2.9E-1  1.0E-2  9.0E-3  5.3E-3  2.0E-3  4.E-04  1.0E-4  9.6E-4  2.3E-3
```

5.12 Output Control (OC) Data

The user has the option of looking at tables of dispersion data for all of the trials that are performed. This information includes air and ground concentrations, σ_y and σ_z values, arrival time, and time overhead for each plume segment at each spatial interval. These data are written to the list output file.

Variable Name: ENDAT1
Variable Type: Logical, Scalar
Allowed Value: .TRUE. or .FALSE.
Purpose: Control flag that allows the user to execute only the ATMOS module. A value of .TRUE. tells the code that EARLY and CHRONC will not be run. When this is done, the user input files for EARLY and CHRONC and a site data file need not be supplied. If the user wishes to skip execution of the CHRONC module, that can be accomplished through the input variable ENDAT2 on the EARLY input file.

Example Usage:

```
*
* FLAG INDICATING THAT ONLY ATMOS IS TO BE RUN
*
OCENDAT1001  .FALSE. (SET TO .TRUE. IF YOU WANT TO SKIP EARLY AND CHRONC)
```

Variable Name: IDEBUG
Variable Type: Integer, Scalar
Allowed Range: $0 \leq$ value ≤ 8
Purpose: Specifies the quantity of debug output to be printed. *(Note: If DEBUG is assigned a value greater than 1, the ATMOS input parameter NUM0 must also be assigned a value greater than 1.)* For normal runs, IDEBUG should be set to 0 (*i.e.*, no debug output is printed). If IDEBUG is set to 1 or 2, a print of the atmospheric transport results described below will be generated for each weather trial and each plume segment. If IDEBUG is set to a value of 3 or more, the hourly meteorological data used for each weather trial will also be printed.

The debug output for atmospheric transport prints the results described below, based on conventional nomenclature for Gaussian plume models (Jow *et al*. 1990).

NUCNAM = name of the radionuclide for which results are being presented,

DISTANCE = distance to the center of the spatial interval (m),

GL AIRCON = centerline ground-level integrated air concentration from this plume segment averaged over the spatial interval's length (Bq-s/m^3),

GRNCON = centerline ground concentration after passage of this plume averaged over the spatial interval's length (Bq/m^2),

GL χ/Q = centerline ground-level χ/Q; the ratio of air concentration (χ) to source strength (Q), averaged over the interval's length (s/m^3),

WETREM = fraction of material remaining in the plume segment after wet deposition over the spatial interval's length (unitless),

DRYREM = fraction of material remaining in the plume segment after dry deposition over the spatial interval's length (unitless),

REMINV = adjusted source strength of the plume upon entering each spatial interval after adjustment for losses in the previous intervals due to radioactive decay and wet and dry deposition (Bq),

PLSIGY = horizontal dispersion parameter σ_y averaged over the spatial interval's length (m),

PLSIGZ = vertical dispersion parameter σ_z averaged over the spatial interval's length (m),

WEATHER = indices to the first and last hours of the weather sequence used for determining atmospheric conditions during transport across each spatial interval,

HTFCTR = ratio of the centerline ground-level air concentration (z=0) to the plume centerline air concentration (z=H), (unitless),

AVGHIT = average height (H) of the plume as it traversed the spatial interval (m),

TIMCEN = time after accident initiation at which the leading edge of the plume arrived at the center of the spatial interval (s),

TIMOVH = duration for which the plume was overhead at the centerpoint of the spatial interval (s).

Example Usage:

```
*
OCIDEBUG001   1       (REQUEST A TRACE OF ATMOSPHERIC DISPERSION)
```

Variable Name: NUCOUT
Variable Type: Character, Scalar
Allowed Range: $3 \leq$ length ≤ 8
Purpose: Specifies which radionuclide will appear on the dispersion listing if one is produced. The dispersion listing is only produced if IDEBUG is greater than 0. The specified radionuclide name must appear on the previously defined list of radionuclides, NUCNAM, defined in Section 5.4. This item is required only if IDEBUG is greater than 0.

Example Usage:

```
*
* NAME OF THE NUCLIDE TO BE LISTED ON THE DISPERSION LISTINGS
*
OCNUCOUT001  Cs-137
```

5.13 Meteorological Sampling (M1) Specification

There are five options available to the user for specifying the weather data that will be used by ATMOS. The code can be used to run either a single weather sequence or multiple weather sequences, as described in the following paragraphs.

If a single weather sequence is desired, there are three ways to specify the weather. The user can (1) specify data for 120 hr of weather on the ATMOS input file, (2) specify a starting day and hour in the weather data file for the weather sequence, or (3) specify constant weather conditions.

For the specified starting day and hour option, the program will obtain 120 hr of weather data from the weather file beginning at the specified date and time. A file of hourly weather data covering a period of 1 year (8760 hr) is required if the fixed start time or either of the weather sampling options are to be used. The format of this file is described in Section A.1 of Appendix A.

The two methods of weather sampling are (1) a modified version of the weather bin sampling method used by CRAC2 (Ritchie *et al.* 1984) and (2) a stratified purely random sampling approach. The weather bin sampling method sorts weather sequences into categories and assigns a probability to each category according to the initial conditions (wind speed and stability class) and the occurrence of rain (intensity and distance). Because the rain bins depend on rain intensity as well as the downwind distance at which rain occurs, the user is required to supply parameters defining the rain weather bins as part of the ATMOS input file. The definitions of the other, nonrain weather bins, that is, those defined by initial stability class and wind speed, are fixed in the code. A description of the MACCS2 weather sampling algorithm can be found in the MACCS *Model Description* (Jow *et al.* 1990).

The stratified random sampling method allows the user to sample weather from each day of the year after division of each day into one, two, three or four equal time periods. Each weather sequence selected is considered to have the same probability of occurrence, that is,

$$P = \frac{1}{\text{total selected samples}} \ .$$

Because of the flexibility that ATMOS affords in the specification of the geometric grid, it is necessary to guard against the possibility of running out of weather data. It is possible that 120 hr of weather may not suffice to carry all the plume segments out to the last spatial interval. Also, the user may wish to specify the occurrence of rain in the outermost spatial intervals in order to prevent radioactive material from escaping consideration. For these reasons, the user must specify a set of boundary weather conditions.

Variable Name: METCOD
Variable Type: Integer, Scalar
Allowed Range: $1 \leq$ value ≤ 5
Purpose: Meteorological sampling option code:
1 - fixed start time in the weather file (day,hour),
2 - weather bin sampling,
3 - 120 hr of weather supplied by the user,
4 - constant weather conditions (use boundary weather),
5 - stratified random sampling from equally spaced intervals.
Example Usage:

```
*
* METEOROLOGICAL SAMPLING OPTION CODE:
*
M1METCOD001  2
```

5.14 Boundary Weather (M2) Data

Boundary weather data are required for all possible values of METCOD. This data block specifies the weather conditions that will be used if 120 hr of recorded weather data do not transport the last plume through the limiting spatial interval for measured weather, LIMSPA. The boundary weather data are also used to predict the behavior of the plume at all spatial intervals beyond LIMSPA.

For the case of constant weather, METCOD=4, the boundary weather data in this section define the constant weather conditions that will be used. In this case, the boundary weather is used throughout the atmospheric calculations and the value of LIMSPA is ignored by the program.

Variable Name: LIMSPA
Variable Type: Integer, Scalar
Allowed Range: $0 \leq$ value $\leq$ NUMRAD
Purpose: This is the limiting spatial interval for use of recorded weather data. All spatial intervals beyond this interval will use the boundary weather conditions specified below.

Boundary weather conditions are applied to all spatial intervals if a value of 0 is specified for this parameter. If METCOD=4, the value of LIMSPA is ignored.

Example Usage:

```
*
* LAST SPATIAL INTERVAL FOR MEASURED WEATHER
*
M2LIMSPA001  25
```

Variable Name: BNDMXH
Variable Type: Real, Scalar
Allowed Range: 1.E2 ≤ value ≤ 1.E4 (meters)
Purpose: This is the mixing layer height that will be used for the boundary weather conditions.

Example Usage:

```
*
* BOUNDARY WEATHER MIXING LAYER HEIGHT
*
M2BNDMXH001  1000.  (METERS)
```

Variable Name: IBDSTB
Variable Type: Integer, Scalar
Allowed Range: 1 ≤ value ≤ 6
Purpose: This is the stability class that will be used for the boundary weather conditions. The integers 1 through 6 represent Pasquill–Gifford stability classes A through F, respectively.

Example Usage:

```
*
* BOUNDARY WEATHER STABILITY CLASS INDEX
*
M2IBDSTB001  1      (A-STABILITY)
```

Variable Name: BNDRAN
Variable Type: Real, Scalar
Allowed Range: 0.0 ≤ value ≤ 99.0 (millimeters / hour)
Purpose: This is the rain rate that will be used for the boundary weather conditions.

Example Usage:

```
*
* BOUNDARY WEATHER RAIN RATE
*
M2BNDRAN001  0.     (0 MILLIMETERS/HOUR = NO RAIN)
```

Variable Name: BNDWND
Variable Type: Real, Scalar
Allowed Range: 0.5 ≤ value ≤ 30.0 (meters / second)
Purpose - This is the wind speed that will be used for the boundary weather conditions.
Example Usage:

```
*
* BOUNDARY WEATHER WIND SPEED
*
M2BNDWND001  0.5     (METERS/SECOND)
```

5.15 Fixed Start Time (M3) Data

The data in this section must be supplied for all values of METCOD except METCOD=2 (meteorological bin sampling) and METCOD=5 (stratified random sampling). The data are needed for all of these option choices because the food pathway calculations of the CHRONC module depend on the day the accident occurs. If the user has chosen METCOD=1, the values of ISTRDY and ISTRHR specify the starting day and hour in the weather file of the single weather trial that will be performed.

Variable Name: ISTRDY
Variable Type: Integer, Scalar
Allowed Range: 1 ≤ value ≤ 365
Purpose: This is the day in the year on which the weather sequence is to begin.
Example Usage:

```
*
*  START DAY OF THE WEATHER SEQUENCE
*
M3ISTRDY001    152
```

Variable Name: ISTRHR
Variable Type: Integer, Scalar
Allowed Range: 1 ≤ value ≤ 24
Purpose: This is the hour of day on which the weather sequence is to begin.
Example Usage:

```
*
*  START HOUR OF THE WEATHER SEQUENCE
*
M3ISTRHR001    17
```

5.16 Meteorological Bin Sampling (M4) Data

The data in this section must be supplied if the user chooses METCOD=2. This sampling method requires that the meteorological data be sorted into a set of weather bins. The bins are defined to represent rain conditions in different distance intervals downwind from the accident site together with 16 bins for initial conditions (stability class and wind speed).

Definition of the rain intensities and distance intervals that define the rain bins is the responsibility of the user. The user must specify either two or three rain intensities that are used as breakpoints in the categorization of rain rate (NRINTN). A rain intensity of 0 is not allowed. For example, if the user specifies two rain intensity breakpoints of 1 mm/hr and 4 mm/hr, the following three rain intensity bins, where x is the rain intensity, will result:

1. 0 mm/hr $< x \leq$ 1 mm/hr,
2. 1 mm/hr $< x \leq$ 4 mm/hr,
3. 4 mm/hr $< x$.

The concept of rain distance intervals used in MACCS2 is similar to that used by CRAC2 but MACCS2 requires that the user specify the rain distances to be used in the weather categorization. Let us suppose that the user specifies 2, 4, 8, and 16 km as four distance intervals (*i.e.*, NRNINT=4. Then these values define the following four rain distance intervals:

1. 0 km $\leq$ distance of first rain occurrence $\leq$ 2 km,
2. 2 km $<$ distance of first rain occurrence $\leq$ 4 km,
3. 4 km $<$ distance of first rain occurrence $\leq$ 8 km,
4. 8 km $<$ distance of first rain occurrence $\leq$ 16 km.

The total number of weather bins, N, is determined by the expression N=NRNINT•(NRINTN+1)+16, where NRNINT is the number of distance intervals and NRINTN is the number of rain intensity breakpoints. Thus, the total number of defined bins can range from 28 to 40, depending on the values supplied by the user.

The 16 initial condition weather bins are fixed in the code as follows:

METBIN	STABILITY	WIND SPEED (u)
1	A/B	0 m/s $< u \leq$ 3 m/s
2	A/B	3 m/s $< u$
3	C/D	0 m/s $< u \leq$ 1 m/s
4	C/D	1 m/s $< u \leq$ 2 m/s
5	C/D	2 m/s $< u \leq$ 3 m/s
6	C/D	3 m/s $< u \leq$ 5 m/s
7	C/D	5 m/s $< u \leq$ 7 m/s
8	C/D	7 m/s $< u$
9	E	0 m/s $< u \leq$ 1 m/s
10	E	1 m/s $< u \leq$ 2 m/s
11	E	2 m/s $< u \leq$ 3 m/s
12	E	3 m/s $< u$
13	F	0 m/s $< u \leq$ 1 m/s
14	F	1 m/s $< u \leq$ 2 m/s
15	F	2 m/s $< u \leq$ 3 m/s
16	F	3 m/s $< u$

The user controls how many weather sequences are chosen from each weather bin by the choice of a value for NSMPLS, defined later in this section. This can be done in two different ways: either (1) request that the same number of weather sequences is to be chosen from each bin and specify the number of sequences, NSMPLS, to be selected (1≤ NSMPLS≤ 10); or (2) specify a nonuniform sampling from the categories (NSMPLS=0) as defined below.

Variable Name: NRNINT
Variable Type: Integer, Scalar
Allowed Range: 4 ≤ value ≤ 6
Purpose: Defines the number of rain distance intervals used in the weather categorization.
Example Usage:

```
*
* NUMBER OF RAIN DISTANCE INTERVALS FOR BINNING
*
M4NRNINT001  5
```

Variable Name: RNDSTS
Variable Type: Real, Array
Allowed Range: 0.001 ≤ value ≤ 99.9 (kilometers)
Purpose: Defines the rain distance interval endpoints to be used for the weather categorization. These distance values must lie within 10% of the spatial interval endpoint distances (variable SPAEND in Section 5.3), *i.e.*, 0.9•SPAEND(i) ≤ RNDSTS(j) ≤ 1.1•SPAEND(i), for each j and some value of i. The user must supply NRNINT unique values in ascending order.
Example Usage:

```
*
* ENDPOINTS OF THE RAIN DISTANCE INTERVALS (KILOMETERS)
*
* NOTE: MUST BE CHOSEN TO MATCH THE SPATIAL ENDPOINT DISTANCES
*       SPECIFIED FOR THE ARRAY SPAEND (10% ERROR IS ALLOWED).
*
M4RNDSTS001  3.22  5.63  11.27  20.92  32.19 KM
```

Variable Name: NRINTN
Variable Type: Integer, Scalar
Allowed Range: 2 ≤ value ≤ 3
Purpose: Defines the number of rain intensity breakpoints to be used for the weather categorization.
Example Usage:

```
*
* NUMBER OF RAIN INTENSITY BREAKPOINTS
*
M4NRINTN001   3
```

Variable Name: RNRATE
Variable Type: Integer, Array
Allowed Range: 0.001 ≤ value ≤ 100.0 (millimeters/hour)
Purpose: Defines the rain intensity breakpoints. The user must supply NRINTN different values in ascending order.
Example Usage:

```
*
* RAIN INTENSITY BREAKPOINTS FOR WEATHER BINNING (MILLIMETERS/HOUR)
*
M4RNRATE001   2.  4.  6.
```

Variable Name: NSMPLS
Variable Type: Integer, Scalar
Allowed Range: 0 ≤ value ≤ 24
Purpose: Defines the number of weather sequences to be chosen from each of the individual weather-category bins (when METCOD=2), or from each day of the year (when METCOD=5).

When METCOD=2, it is advisable to set a value of at least 4; the more samples that are taken, the more robust is the sampling. If the user supplies a value of 0 for NSMPLS, and METCOD=2, the variables NSBINS, INDXBN, and INWGHT allow the user to specify how many samples are to be chosen from each of the weather-category bins.

When METCOD=5, setting NSMPLS=24 will have the code sample every hour of the year, a capability that can provide insights into the adequacy of the operation of the weather binning algorithm. In using the METCOD=5 option, it is advisable to select values for NSMPLS that are divisors of 24 because then each interval is composed of a whole number of hours. That is, NSMPLS should be set to one of the following: 1, 2, 3, 4, 6, 8, 12, or 24. Test calculations by the code developers indicate that taking stratified random samples from each 6-hr interval of the year yields results close to those obtained from sampling all 8760 hr of the year. There may thus be diminishing returns from taking more samples, since calculation time is proportional to the number of samples.
Example Usage:

```
*
* NUMBER OF SAMPLES PER BIN
*
M4NSMPLS001  4  (A VALUE OF 4 WAS USED WITH NUREG-1150)
```

Variable Name: IRSEED
Variable Type: Integer, Scalar
Allowed Range: $0 \leq$ value $\leq$ 255
Purpose: Defines the initial seed of the random number generator. Changes to this value will cause different weather sequences to be selected.

The random number generator of MACCS2 is included in the FORTRAN source code and therefore runs made on different types of computers should select identical sets of weather sequences.

Example Usage:

```
*
* INITIAL SEED FOR RANDOM NUMBER GENERATOR
*
M4IRSEED001   79
```

Note: The cards in this section are needed only if NSMPLS=0.

Variable Name: NSBINS
Variable Type: Integer, Scalar
Allowed Range: $1 \leq$ value $\leq$ N, total number of weather bins
Purpose: Defines the number of bins from which weather sequences are to be chosen. Sampling a subset of all the weather bins allows the effects of weather type to be examined.

Example Usage:

```
*
* NUMBER OF BINS TO BE SAMPLED (WHEN NSMPLS = 0)
*
M4NSBINS001  6
```

Variable Name: INDXBN
Variable Type: Integer, Array
Allowed Range: $1 \leq$ value $\leq$ N, total number of weather bins
Purpose: Defines the list of bins from which weather sequences are to be selected. The user must supply NSBINS values in column 1 of the data block.

In order to find the index number to a rain bin, please refer to the page of the output listing with the title METEOROLOGICAL BIN SUMMARY.

Variable Name: INWGHT
Variable Type: Integer, Array
Allowed Range: $1 \leq$ value $\leq$ 8760
Purpose: Defines the number of weather sequences which the user would like to be selected from the specified weather bin. If the requested number of

sequences cannot be found, the code will select all of the sequences in the specified bin. The user must supply NSBINS values in column 2 of the data block.

Example Usage:

```
*
*                    BIN-NUMBER        SAMPLE-SIZE
*                     INDXBN            INWGHT
M4SMPLDF001              3                 8
M4SMPLDF002              4                16
M4SMPLDF003              5                12
M4SMPLDF004              6                 4
M4SMPLDF005              7                 4
M4SMPLDF006              8                 4
```

5.17 User-Supplied Weather Sequence (M5) Data

The data in this section must be supplied if the user chooses METCOD=3. There must be one data record for each hour of weather in the sequence. The five arrays in this section are supplied in a block of data as columns.

Variable Name: HRMXHT
Variable Type: Real, Array
Allowed Range: 1.E2 ≤ length ≤ 1.E4 (meters)
Purpose: These are the mixing layer heights that will be used for the single trial. They are given in units of meters. The user must supply 120 values of ISTAB in column 1 of the data block.

Note: The atmospheric dispersion model currently being used cannot accommodate a mixing layer height that varies with time during a weather sequence. The single value of mixing height that will be used in the atmospheric model is the largest value in the following set of values: the 120 values supplied here, and the boundary weather mixing layer height, BNDMXH.

Variable Name: IHRSTB
Variable Type: Integer, Array
Allowed Range: 1 ≤ value ≤ 6
Purpose: Defines the stability classes that will be used for the single trial. The integers 1 through 6 represent the Pasquill–Gifford stability classes A through F. The user must supply 120 values of ISTAB in column 2 of the data block corresponding to each of the 120 hr in the weather sequence.

Variable Name: HRRAIN
Variable Type: Real, Array

Allowed Range: 0.0 ≤ value ≤ 99.0 (millimeters/hour)
Purpose: Defines the rain rates that will be used for the single trial. They are given in units of millimeters per hour. The user must supply 120 values of RNMM in column 3 of the data block.

Variable Name: HRWNDV
Variable Type: Real, Array
Allowed Range: 0.5 ≤ value ≤ 30.0 (millimeters/second)
Purpose: Defines the wind speeds that will be used for the single trial. They are given in units of meters per second. The user must supply 120 values of WINDSP in column 4 of the data block.

Variable Name: IHRDIR
Variable Type: Integer, Array
Allowed Range: 1 ≤ value ≤ 16
Purpose: Defines the wind directions that will be used for the single trial. They are given as integers corresponding to the wind directions north through north northwest. The user must supply 120 values of IHRDIR in column 5 of the data block.

Example Usage:

```
*
* 120 HR OF WEATHER EXPLICITLY SPECIFIED BY THE USER
* (THESE DATA ARE PROCESSED ONLY IF METCOD IS SET TO 3)
*
*              HRMXHT         IHRSTB      HRRAIN      HRWNDV      IHRDIR
M5METDAT001    1000.           4.          0.          3.4          2
M5METDAT002    1000.           3.          0.          4.6          4
M5METDAT003    1000.           4.          0.          3.8          3

AND LIKEWISE FOR A TOTAL OF 120 DATA RECORDS

M5METDAT120    1000.           2.          0.          5.4          8
```

5.18 CCDFs of Atmospheric Results

In MACCS, complementary cumulative distribution functions could be produced by the EARLY and CHRONC modules. However, there was no capability for generating CCDFs of the atmospheric modeling parameters calculated by ATMOS. In MACCS2, if requested by the user, the ATMOS module will now generate CCDFs of ten atmospheric modeling parameters for user-specified distances and plume segments. When the multiple source term looping capability of ATMOS is utilized (*i.e.*, multiple source terms are defined in a single ATMOS input file), these CCDFs may be produced only for the first defined source term.

Air and ground concentrations are reported for the radionuclide specified for the variable NUCOUT. In addition to the results produced for the single specified radionuclide, the *total*

radioactivity on the ground (from all radionuclides) is reported as well. Within a single run of the code, there is no provision in MACCS2 for generating CCDFs of air and ground concentrations for multiple individual radionuclides. If such output is needed, separate MACCS2 runs would be required to produce results for each radionuclide. With NUCOUT given a value of Cs-137, for example, the ten consequence measures produced are listed in Table 5-1.

Table 5-1. Results Available from ATMOS in CCDF Form

(1)	Selected Radionuclide Centerline Air Concentration	(becquerel-seconds/cubic meter)
(2)	Selected Radionuclide Ground-Level Air Concentration	(becquerel-seconds/cubic meter)
(3)	Selected Radionuclide Centerline Ground Concentration	(becquerels/square meter)
(4)	Total Centerline Ground Concentration	(becquerels/square meter)
(5)	Ground-Level χ/Q Dispersion Factor	(seconds/cubic meter)
(6)	Selected Radionuclide Adjusted Source Strength, Q[a]	(becquerels)
(7)	Plume σ_y, Crosswind Size	(meters)
(8)	Plume σ_z, Vertical Size	(meters)
(9)	Plume Centerline Height	(meters)
(10)	Plume Arrival Time at Centerpoint	(seconds)

[a] In Gaussian plume equations, Q is commonly used to represent the amount released. When material is deposited on the ground during transport, the effective source strength for downwind distances is diminshed. This is treated in MACCS through the definition of an "effective" source strength, which is diminished by the deposition and radioactive decay that occur over each spatial interval.

The generation of these consequence measures is requested through definition of the following variables in the ATMOS input file.

Variable Name: NUM0
Variable Type: Integer, Scalar
Allowed Range: $0 \leq$ value ≤ 35
Purpose: Specifies how many results of this type are being requested. For each result requested, a block of ten consequence measures is produced in the list output file.

Note: If DEBUG is assigned a value greater than 1, NUM0 must also be assigned a value greater than 1.

Variable Name:	INDREL
Variable Type:	Integer, Scalar
Allowed Range:	$1 \leq$ value $\leq$ NUMREL
Purpose:	Specifies the index of the plume segment for which results are to be generated.

Variable Name:	INDRAD
Variable Type:	Integer, Scalar
Allowed Range:	$1 \leq$ value $\leq$ NUMRAD
Purpose:	Specifies the index of the spatial distance for which results are to be generated.

Note: In order to obtain the entire CCDF tables for the ten ATMOS results described in this section, append the character string 'CCDF' to the line requesting the result as the third item on the data record, immediately following INDRAD, as illustrated below. The CCDF tables will be printed in the output file. If requested, these tables will be printed as blocks of ten pages each, one page of output for each CCDF.

Example Usage:

```
*
*                 NUM0
TYPE0NUMBER         2
*
*                 INDREL            INDRAD
TYPE0OUT001          1                 9
TYPE0OUT002          1                10  CCDF
```

6.0 EARLY Input File

6.1 Introduction to EARLY

The EARLY module models the time period immediately following a radioactive release. This period is commonly referred to as the emergency phase. It may extend up to 1 week after the arrival of the first plume at any downwind spatial interval. The subsequent intermediate and long-term periods are treated by CHRONC.

In the EARLY module the user may specify emergency response scenarios that include evacuation, sheltering, and dose-dependent relocation. The EARLY module has the capability for combining results from up to three different emergency response scenarios. This is accomplished by appending change records to the EARLY input file. The first emergency-response scenario is defined in the main body of the EARLY input file. Up to two additional emergency-response scenarios can be defined through change record sets positioned at the end of the file. The delimiter used to separate the change record sets is a period (.) in column 1 that is also used to signify the end of a MACCS2 user input file. All of the MACCS2 user input files must thus end with a period in column 1.

The purpose of the change-record processing in EARLY is solely to allow modification of the previously specified emergency response scenario data. Any records appearing in the change record sets must have been previously defined in either the evacuation zone data or the shelter and relocation data. If data items from another data block appear in the change records, they will be ignored. Each set of change records must include a new value of EANAM2, a text field describing the emergency response scenario. Also, each set of change records must produce a change in at least one of the numeric input variables described in the evacuation zone data or in the shelter and relocation data.

Results are output for each of the user-defined emergency-response scenarios and for a weighted sum of the emergency-response scenarios. Scenarios may be combined by assigning time fractions (frequencies of occurrence) or population fractions (fraction of the population engaging in the specified behavior) to each scenario or by a simple summation of the results for each emergency-response scenario (when a unique population distribution is defined for each emergency-response scenario).

CCDFs calculated for emergency-response scenarios combined based on time fractions are a function of the probability for each meteorological trial/wind direction multiplied by the time fraction applied to the emergency-response scenario. Emergency-response scenarios combined using population fractions are a function of the consequence calculated for each meteorological trial/wind direction multiplied by the fraction of people assigned to the scenario. The approach selected (fraction of people or fraction of time) will affect the shape of the CCDF but will not affect the mean results.

For results that are calculated by both EARLY and CHRONC, such as population dose and cancer cases, the OUTPUT module automatically adds the value of the consequence calculated

by CHRONC to the value of the same consequence measure produced by EARLY in order to generate the overall combined results. If more than one EARLY emergency response scenario is being run, these results are combined according to the weighting fractions supplied by the user in the EARLY input file, and the weighted sum is then combined with the CHRONC result to produce the overall result. Whenever results are combined by the code, the listing produced by the OUTPUT module will present the overall combination of results as well as each of the components from which it is constructed.

6.1.1 Overview of Dose Calculations

The calculation of radiation doses from early exposure considers five pathways: (1) direct external exposure to radioactive material in the plume (cloudshine), (2) exposure from inhalation of radionuclides in the cloud (cloud inhalation), (3) exposure to radioactive material deposited on the ground (groundshine), (4) inhalation of resuspended material (resuspension inhalation), and (5) skin dose from material deposited on the skin.

Two kinds of doses are calculated: (1) acute doses used for calculating early fatalities and injuries and (2) lifetime dose commitment used for calculating cancers resulting from the early exposure. The accumulation of radiation doses from early exposure is strongly dependent on the assumed emergency response, that is, evacuation, sheltering, or early relocation. Cloudshine and cloud inhalation exposures are limited to the time of cloud passage. Groundshine and resuspension inhalation doses for early exposure are limited to the duration of the emergency phase.

In general, the dose equation for an early exposure pathway in MACCS2 in a given spatial element is the product of the following quantities: radionuclide concentration, dose conversion factor, duration of exposure, and shielding factor. The quantities used in the dose equations depend on the exposure pathway. For example, for the cloud inhalation exposure pathway, these quantities are the ground-level air concentration at a spatial element, inhalation dose conversion factor, duration of exposure, and inhalation shielding factor.

The dose conversion factors for all exposure pathways are provided in the same format as the DOSDATA.INP file distributed with MACCS. The duration of exposure depends on the exposure pathway and the emergency response at a spatial element and is calculated based on the user-supplied data. The shielding factor is a unitless quantity used to reduce the radiation dose as a result of shielding protection provided by a given protective action for a given exposure pathway. Shielding factors for the various exposure pathways (cloudshine, inhalation, groundshine, and skin dose) and for three different groups of people (evacuees, people doing normal activity, and people taking shelter) are specified by the user.

The MACCS2 evacuation model incorporates a delay time before public movement, followed by evacuation radially away from the facility at an effective radial constant speed. Different shielding factors and breathing rates can be used while people await evacuation (normal activity) or are being evacuated (evacuees).

The EARLY module of MACCS2 accumulates the radiation doses for the evacuating people by adding the doses they received before they started moving and the doses received during evacuation out to a distance at which they are assumed to avoid further exposure.

Evacuees receive no additional emergency phase radiation doses after they are modeled as moving out of the evacuation zone. The CHRONC module habitability criterion determines if evacuees are moved back to their element of origin during the intermediate or long-term phase. Any additional radiation doses to the evacuees are calculated in the CHRONC module.

Before the evacuating people start moving, they are assumed to be carrying out normal activities. Shielding factors (cloudshine, groundshine, inhalation, and skin) for normal activity apply to them during this period of time. After they start moving, they become evacuees and the shielding factors for evacuees apply to them during evacuation.

The MACCS2 plume transport model assigns the plume a finite length calculated by using the assumed release duration and wind speed during the release. To simplify the treatment, the length of the cloud is assumed to remain constant following the release (*i.e.*, the front and back of the plume travel at the same speed), and the concentration of radioactive material is assumed to be uniform over the length of the cloud. The radial position of evacuating persons, while stationary and while in transit, is compared with the positions of the front and back of the plume as a function of time to determine the period of exposure to airborne radionuclides.

6.1.2 Overview of New EARLY File Input Requirements Implemented in MACCS2

The MACCS input variable ESPEED is utilized by MACCS2 but three values must now be supplied instead of the single value used by MACCS. The three evacuation speeds thus defined are used for the initial, middle, and late phases of the evacuation.

The input variable WTNAME, which in MACCS determines whether fraction-of-the-people or fraction-of-the-time weighting is to be used in combining results, is now allowed to take on three possible values: PEOPLE, TIME, or SUMPOP. The new SUMPOP option indicates that results are to be combined by simple unweighted summation.

If SUMPOP is specified, the weighting fraction input variable, WTFRAC, will not be processed. Furthermore, if SUMPOP is specified, the user must define in the Site Data file a separate population distribution for each of the up to three emergency response scenarios. The option of a uniform population density (POPFLG='UNIFORM') is not allowed in these cases.

The population distribution used for CHRONC is obtained by summing the population distributions defined for EARLY. For example, if a given spatial element on the grid was defined to have 12, 20, and 30 individuals, respectively, for the three different emergency-response scenarios, the long-term calculations performed by the CHRONC module would be based on 62 individuals residing at that location.

The shielding and exposure factors for cloudshine, groundshine, and inhalation (CSFACT, SKPFAC, GSHFAC, PROTIN, and BRRATE) may now be redefined for each emergency-response scenario. MACCS utilized a single set of these factors for both EARLY and CHRONC.

The CHRONC module, if exercised, will use numeric values from the last emergency-response scenario that was defined in the EARLY input file.

It is up to the user to specify the various parameters needed for these calculations. There are no default values. In addition to specifying the characteristics of the model, the user has complete control over the output produced by EARLY and must explicitly specify which results are to be produced. All of this information is supplied through the input file for EARLY and all of the input parameters are described in this chapter.

6.2 Dose Conversion Factor Filename and Other Miscellaneous Input Data

6.2.1 Dose Conversion Factor Filename

The MACCS2 user has a great deal of flexibility in the selection of a dose conversion factor file. The MACCS2 package includes a number of sample DCF files. Section 3.1 provides an overview of the MACCS2 DCF preprocessors that can be used to generate DCF files. MACCS2 can utilize the following types of DCF files:

1. DOSFAC files (*e.g.,* the DOSDATA.INP file distributed with MACCS 1.5.11.1),
2. DOSFAC2 files,
3. IDCF2 files, and
4. FGRDCF files.

In addition, data may be combined from these files into a single DCF file. All DCF files must contain a list of organs. MACCS2 will process a list of up to 20 organs when Types 1 - 3 DCF files (DOSFAC, DOSFAC2, and IDCF2) are utilized. However, these types of DCF files must list a minimum organ set, which can appear in any order on the DCF file. The required organ set is as follows:

EDEWBODY
RED MARR
BONE SUR
BREAST
LUNGS
THYROID
LOWER LI
BLAD WAL
LIVER
THYROIDH

Organs not included in this list are not used in MACCS2 calculations when Types 1–3 DCF files are utilized. The list of organs that can be included in MACCS2 calculations is fixed in the code and is discussed in Section 6.4.

When a COMIDA2-generated input file is used in a MACCS2 run, MACCS2 must use the same DCF file used to generate the COMIDA2 input file. The first two header records of the DCF files used by MACCS2 and COMIDA2 are read and compared to ensure that the two sets of calculations used the same DCF file.

When COMIDA2 and MACCS2 are exercised using a DCF file generated by FGRDCF, those two programs utilize an abbreviated list of nine organs that is fixed in MACCS2 and cannot be modified by the user. COMIDA2 and MACCS2 detect the use of an FGRDCF file by examining the first seven characters of the DCF file's header record.

If the DCF file was generated by FGRDCF, the first of the two header records will contain the letters FGRDCF. When COMIDA2 and MACCS2 determine that an FGRDCF file is being used, as specified by the variable DCF_FILE, the list of available organs is set to the following:

L-GONADS
L-BREAST
L-LUNGS
L-RED MARR
L-BONE SUR
L-THYROID
L-REMAINDER
L-EFFECTIVE
L-SKIN(FGR)

with those names based on the nomenclature of FGR 11 and 12. The L- prefix indicates a 50-year committed dose. The A- prefix indicates an acute organ dose. The organ L-SKIN(FGR) is based on the skin dose of FGR 12, and it differs substantially from the acute skin dose used in MACCS2 to calculate acute health effects from material deposited on the skin.

Variable Name: DCF_FILE
Variable Type: Character, Scalar
Allowed Range: $1 \leq \text{length} \leq 40$
Purpose: Identifies the DCF file to be used for the MACCS2 calculations. This filename can include a directory path; the file need not be in the current directory.

If the CHRONC module is to utilize the COMIDA2 food-chain model via a COMIDA2 binary data file of food ingestion parameters, the DCF file used in the MACCS2 calculations needs to be the same file that was used by COMIDA2.

Example Usage:

```
*
DCF_FILE001   'C:\DOSFAC2\DOSDATA.INP'
```

6.2.2 Miscellaneous Data

In addition to the specification of a DCF file, the user must supply information to identify the run, define the histogram approximating the crosswind Gaussian distribution, and also supply information describing the handling of the wind rose. It is possible to specify a single wind rose that will override the wind roses that were calculated in ATMOS for each of the weather-category sampling bins. The user must also specify how to treat changes in wind direction.

Variable Name: EANAM1
Variable Type: Character, Scalar
Allowed Range: $1 \leq \text{length} \leq 80$
Purpose: Identifies a name describing the EARLY calculations. This is printed on all pages of the OUTPUT listing. A name describing the particular emergency response assumption will be requested in addition to this name.
Example Usage:

```
*
* GENERAL DESCRIPTIVE INFORMATION FOR THE "EARLY" INPUT FILE
*
MIEANAM1001 'IN2A.INP, SURRY, SAMPLE PROBLEM A, EARLY INPUT'
```

Variable Name: ENDAT2
Variable Type: Logical, Scalar
Allowed Value: .TRUE. or .FALSE.
Purpose: Control flag that allows the user to execute only the ATMOS and EARLY modules while skipping execution of the CHRONC module. If CHRONC is to be skipped, there is no need for the user to specify a CHRONC input file. A value of .TRUE. causes MACCS2 to skip the CHRONC module. A value of .FALSE. causes the CHRONC module to be executed.
Example Usage:

```
*
* FLAG TO INDICATE THIS IS THE LAST PROGRAM IN THE SERIES TO BE RUN
*
MIENDAT2001  .FALSE.    (SET THIS VALUE TO .TRUE. TO SKIP CHRONC)
```

Variable Name: IPLUME
Variable Type: Integer, Scalar
Allowed Range: $1 \leq \text{value} \leq 3$
Purpose: Dispersion model option code:

1 - Straight-line dispersion model:
All plume segments travel in the same direction. Each set of modeling results is rotated around the 16 compass directions (population sectors) to yield 16 sets of results for each weather trial.

2 - Wind-shift plume dispersion model with rotation:
Each plume segment in the release travels in the direction that the wind is blowing at the time that its representative time point (REFTIM in Section 5.11) leaves the facility. Each set of modeling results is rotated around the 16 compass directions (population sectors) to yield 16 sets of results for each weather trial.

3 - Wind-shift dispersion model without rotation:
Each plume segment in the release travels in the direction that the wind is blowing at the time that its representative time point (REFTIM in Section 5.11) leaves the facility. No rotation of the wind shift pattern is performed. Each weather trial yields one set of results.

Example Usage:

```
*
* DISPERSION MODEL OPTION CODE: 1- STRAIGHT LINE
*                               2- WIND SHIFT WITH ROTATION,
*                               3- WIND SHIFT WITHOUT ROTATION.
MIIPLUME001  2
```

Variable Name: NUMFIN
Variable Type: Integer, Scalar
Allowed Range: 3, 5, or 7
Purpose: Number of fine-grid subdivisions used by the model. A step function is used to approximate the Gaussian distribution of the plume in the crosswind direction. Each of the 22.5-degree sectors is subdivided into NUMFIN fine-grid elements, with doses and risks being uniform in each element. NUMFIN is only used in the calculations performed by EARLY; it is not utilized in any respect in the calculations performed by CHRONC.

Example Usage:

```
*
* NUMBER OF FINE-GRID SUBDIVISIONS USED BY THE MODEL
*
MINUMFIN001  7    (3, 5 OR 7 ALLOWED)
```

Variable Name: IPRINT
Variable Type: Integer, Scalar
Allowed Range: $0 \leq \text{value} \leq 10$
Purpose: Specifies the quantity of debug output that is desired. The higher the value, the more output will be printed. Debug output is written to FORTRAN unit 6. Normal runs should specify a value of 0. The choice of any other value should be made only by people familiar with the code for detailed examination of single weather sequences.

For various values of IPRINT, the code will print out intermediate results on the list output file. These are described below.

IPRINT ≥1: skin dose conversion factors, centerline doses for all organs (if IPLUME=1), Gaussian histogram and cloudshine correction factors, return code values (RETCOD).

IPRINT ≥2: final groundshine dose rate for each organ, each plume segment.

IPRINT ≥4: total acute dose for organs 2 and 3, early fatality, early injury, and cancer risk values for each spatial element.

IPRINT ≥8: acute dose to organs 2 and 3 after completion of subroutine RELZON, acute dose to organs 2 and 3 after completion of subroutine ESTAT.

Example Usage:

```
*
* LEVEL OF DEBUG OUTPUT REQUIRED, NORMAL RUNS SHOULD SPECIFY ZERO
*
MIIPRINT001  0
```

Variable Name: RISCAT
Variable Type: Logical, Scalar
Allowed Value: .TRUE. or .FALSE.
Purpose: If the option of weather-category bin sampling was chosen by the user in the ATMOS input file (METCOD=2), the display of results produced by the OUTPUT module can show the relative contribution of each of the weather-category bins to the mean consequence value.

Example Usage:

```
*
MIRISCAT001  .FALSE. (DO NOT PRINT OUT THE RISK CONTRIBUTION TABLES)
```

Variable Name: OVRRID
Variable Type: Logical, Scalar
Allowed Value: .TRUE. or .FALSE.
Purpose: Specifies whether the wind rose probabilities are to be supplied by the user. If the weather sampling option was chosen in ATMOS (METCOD=2), wind roses for each weather sampling bin have been passed down from ATMOS. Those wind roses will be used if OVRRID = .FALSE. If no wind rose is available, a uniform wind rose will be used, that is, P = 0.0625 in each direction.

Example Usage:

```
*
* FLAG INDICATING IF WIND ROSES FROM ATMOS ARE TO BE OVERRIDDEN
*
MIOVRRID001 .FALSE. (USE THE WIND ROSE CALCULATED FOR EACH BIN)
```

Variable Name: WINROS
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0
Purpose: This input parameter is only required if the OVRRID input parameter is set to .TRUE. The values input for this parameter are the probabilities of the wind blowing from the site into each of the 16 compass sectors (rotating clockwise from N to NNW).

The sum of these values must be between 0.95 and 1.05. The user must supply 16 values in rows on one or more data records.

Example Usage:

```
*
*  SITING STUDY WIND ROSE FOR THE PEACH BOTTOM SITE
*
MIWINROS001 8.521E-02   6.360E-02   4.605E-02   5.189E-02
MIWINROS002 6.869E-02   9.493E-02   1.145E-01   1.090E-01
MIWINROS003 6.019E-02   4.326E-02   3.148E-02   3.238E-02
MIWINROS004 3.383E-02   4.625E-02   5.446E-02   6.424E-02
```

6.3 Population Distribution (PD) Data

The user must supply information to define the polar-coordinate population distribution surrounding the site. This information can be supplied from the Site Data file or a uniform population distribution can be specified by the user. The format of the Site Data file is described in Section A.3 of Appendix A.

Note: Whatever values are supplied here will be used by both the EARLY and the CHRONC modules in defining the characteristics of the region surrounding the site. There is no possibility of having EARLY and CHRONC use different population distributions.

Variable Name: POPFLG
Variable Type: Character, Scalar
Allowed Range: 4 ≤ length ≤ 7
Purpose: Specifies whether the population is to be defined by the Site Data file or if it is to be uniform. The value specified must be either FILE or UNIFORM. If a value of UNIFORM is supplied, the program will not attempt to read the Site Data file.

Example Usage:

```
*
*  POPULATION DISTRIBUTION FLAG, SPECIFY 'UNIFORM' OR 'FILE'
*
PDPOPFLG001  UNIFORM
```

Variable Name: IBEGIN

Variable Type: Integer, Scalar
Allowed Range: 1 ≤ value ≤ NUMRAD
Purpose: Specifies the spatial interval at which the population begins. Inside of this region there are no people. This allows the modeling of an exclusion zone. This value is only required if POPFLG='UNIFORM'.
Example Usage:

```
*
* FIRST SPATIAL INTERVAL IS AN EXCLUSION ZONE
*
PDIBEGIN001   2
```

Variable Name: POPDEN
Variable Type: Real, Scalar
Allowed Range: 0.0 ≤ value ≤ 1.E6 (people/km^2)
Purpose: Specifies the uniform population density of the region. This value is only required if POPFLG='UNIFORM'.
Example Usage:

```
*
PDPOPDEN001   100.0   (100 PEOPLE PER SQUARE KILOMETER)
```

6.4 Organ Definition (OD) Data

The organs referenced in the MACCS2 EARLY and CHRONC input files must be assigned a .TRUE. value for the ORGFLG variable defined in this section.

MACCS2 can calculate two kinds of doses: lifetime dose and effective acute dose. Lifetime dose is utilized to determine the need for mitigative actions and for calculating the cancer induction and population dose results. It represents the 50-year dose commitment. Effective acute doses are used for calculating the acute health effects in the EARLY module. The acute health effects are early fatalities and early injuries. A full description of the meaning of effective acute dose can be found in Section 6.7.

The list of organs for which dosimetry data are available is presented below.

Organ-Name	Acute	Lifetime	
'SKIN'	YES	NO	
'LUNGS'	YES	YES	
'RED MARR'	YES	YES	(red bone marrow)
'SMALL IN'	YES	YES	(small intestine)
'LOWER LI'	YES	YES	(lower large intestine)
'STOMACH'	YES	YES	
'THYROID'	NO	YES	
'THYROIDH'	YES	YES	(pseudothyroid just for health effects)
'EDEWBODY'	NO	YES	(effective whole-body dose equivalent)
'BONE SUR'	NO	YES	(bone surface)

'BREAST'	NO	YES
'OVARIES'	NO	YES
'TESTES'	NO	YES

In MACCS2, the two types of doses are distinguished by an L- or A- prefix to the organ name. The acute doses were constructed using effective acute dose reduction factors. A description of acute dose calculations is provided in the MACCS *Model Description* and in Section 6.7.

Within the EARLY input file, organ names must be specified as they appear in the Example Usage section following the ORGNAM and ORGFLG variable descriptions. Organ names must be specified in the EARLY and CHRONC input files as they appear in this list. Since the organ list is fixed in the code, the MACCS EARLY input file variables NUMORG and ORGNAM are no longer processed.

In applications that do not require the calculation of acute health effects, the code's run time can be reduced somewhat by defining only organs that will be actually used in the analysis. However, testing of this feature revealed that the reduction of the organ list to L-EDEWBODY and omission of all health effect calculations reduced the run time of sample problem A by only 28%.

If a DCF file generated by FGRDCF is being used for the calculations, the list of available organs is set automatically to the nine organs of FGR 11 and 12. If the header record of that file begins with the characters FGRDCF, the data below, ORGNAM and ORGFLG, are not processed by MACCS2 and the list of organs is fixed to the following:

L-GONADS
L-BREAST
L-LUNGS
L-RED MARR
L-BONE SUR
L-THYROID
L-REMAINDER
L-EFFECTIVE
L-SKIN(FGR)

Variable Name:	ORGNAM
Variable Type:	Character, Array
Allowed Length:	$3 \leq \text{length} \leq 10$
Purpose:	Defines the list of organs to be included in the calculations. This list of organs *must* be specified in exactly the same order as shown in the example that follows. If the list is specified in a different order, an input error will be diagnosed and further execution inhibited. A- indicates an acute dose and L- indicates a 50-year dose commitment.

Variable Name: ORGFLG
Variable Type: Logical, Array
Allowed Values: .TRUE. or .FALSE.
Purpose: Specifies whether each organ on the list is to be used in the calculations. At present, deleting organs from the list yields only minimal decreases in the code's execution time.
Example Usage:

```
*
*                ORGNAM           ORGFLG
*
MIORGDEF001      'A-SKIN'          .TRUE.
MIORGDEF002      'A-RED MARR'      .TRUE.
MIORGDEF003      'A-LUNGS'         .TRUE.
MIORGDEF004      'A-THYROIDH'      .TRUE.
MIORGDEF005      'A-STOMACH'       .TRUE.
MIORGDEF006      'A-LOWER LI'      .FALSE.
MIORGDEF007      'L-EDEWBODY'      .TRUE.
MIORGDEF008      'L-RED MARR'      .TRUE.
MIORGDEF009      'L-BONE SUR'      .TRUE.
MIORGDEF010      'L-BREAST'        .TRUE.
MIORGDEF011      'L-LUNGS'         .TRUE.
MIORGDEF012      'L-THYROID'       .FALSE.
MIORGDEF013      'L-LOWER LI'      .TRUE.
MIORGDEF014      'L-BLAD WAL'      .TRUE.
MIORGDEF015      'L-LIVER'         .FALSE.
MIORGDEF016      'L-THYROIDH'      .TRUE.
```

Note: If the COMIDA2-based food-chain model is being utilized, the doses L-EDEWBODY and L-THYROID must be assigned values of .TRUE.

6.5 Shielding and Exposure (SE) Data

This section defines the shielding factors for exposure to cloudshine, groundshine, inhalation, and deposition to skin for three types of activities (normal activity, evacuation, and sheltering). A breathing rate is also specified for each type of activity. In addition, the resuspension parameters to be used for the emergency phase time period (EARLY), the resuspension coefficient, and resuspension half-life are also defined.

Some of the parameter values defined in this section are used in both the EARLY and the CHRONC modules; these are (1) the normal activity groundshine and (2) inhalation protection factors as well as the (3) normal activity breathing rate. The CHRONC module does not calculate the effects resulting from direct exposure to the radioactive cloud, therefore it makes no use of the cloudshine and deposition to skin shielding factors. The long-term resuspension parameters are defined on the basis of data supplied in the CHRONC input file, and the emergency-phase resuspension parameters defined here are not used in the CHRONC module.

Variable Name: CSFACT
Variable Type: Real, Array

Allowed Range: 0.0 ≤ value ≤ 1.0 (unitless)
Purpose: Cloudshine shielding factor for the three types of activity.
Example Usage:

```
*
* THREE VALUES OF EACH PROTECTION FACTOR ARE SUPPLIED,
* ONE FOR EACH TYPE OF ACTIVITY.  THE FACTORS ARE LISTED
* IN THE FOLLOWING ORDER: EVACUATION, NORMAL ACTIVITY, SHELTERING
*
* CLOUD SHIELDING FACTOR
*
SECSFACT001  1.   0.75   0.6
```

Variable Name: PROTIN
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0 (unitless)
Purpose: Inhalation protection factor for the three types of activity.
Example Usage:

```
*
* PROTECTION FACTOR FOR INHALATION
*
SEPROTIN001   1.  0.41   .33
```

Variable Name: BRRATE
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0 (cubic meters per second)
Purpose: Breathing rates for the three types of activity.
Example Usage:

```
*
* BREATHING RATE (CUBIC METERS PER SECOND)
*
SEBRRATE001  0.000266  0.000266  0.000266
```

Variable Name: SKPFAC
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0 (unitless)
Purpose: Skin protection factors for the three types of activity.
Example Usage:

```
*
* SKIN PROTECTION FACTOR
*
SESKPFAC001  1.0  0.41  0.33
```

Variable Name: GSHFAC
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0 (unitless)
Purpose: Groundshine shielding factors for the three types of activity.
Example Usage:

```
*
* GROUND SHIELDING FACTOR
*
SEGSHFAC001   0.5  0.33  0.2
```

Variable Name: RESCON
Variable Type: Real, Scalar
Allowed Range: 0.0 ≤ value ≤ 1.0 (seconds/meter)
Purpose: Initial value for emergency-phase resuspension concentration factor. The weathering half-life associated with RESCON is defined below as RESHAF. The resuspension model used is as follows:

air concentration = ground concentration • RESCON • exp (–*t* • 0.693 / RESHAF)

where air concentration is the instantaneous air concentration resulting from resuspension of material deposited by a single plume segment at *t* seconds following the departure of that plume segment (Bq/m^3); ground concentration is the final ground concentration following the passage of the plume segment (Bq/m^2); RESCON is the initial value of the resuspension coefficient (m^{-1}); *t* is the time after passage of the plume (s); and RESHAF is the resuspension coefficient half-life (s).

Example Usage:

```
*
* RESUSPENSION INHALATION MODEL CONCENTRATION COEFFICIENT (SECONDS/METER)
*
SERESCON001   1.E-6    (RESUSPENSION IS TURNED ON)
```

Variable Name: RESHAF
Variable Type: Real, Scalar
Allowed Range: 1.0 ≤ value ≤ 1.E10 (seconds)
Purpose: Emergency phase resuspension concentration coefficient weathering half-life.
Example Usage:

```
*
* RESUSPENSION CONCENTRATION COEFFICIENT HALF-LIFE (SECONDS)
*
SERESHAF001   1.E10   (CONSTANT RESUSPENSION FACTOR)
```

6.6 Evacuation Zone (EZ) Data

This section describes the input parameters that control the dose calculations in the regions where sheltering and/or evacuation are defined to occur. MACCS2 is structured to allow the analyst a great deal of flexibility in defining emergency response strategies. This is achieved within a framework that is conceptually simpler than the MACCS model. For most sites, it will probably

be unnecessary to utilize all the features of the new model. However, availability of the MACCS2 modeling features will facilitate performance of sensitivity studies, *etc.* to evaluate alternative assumptions for emergency response.

6.6.1 Emergency-Response Scenarios

MACCS2 as well as MACCS allows the user to specify up to three emergency-response scenarios. The population data associated with each of these scenarios may be defined in either of two ways: (1) with a single population data block (as with MACCS) or (2) a separate population data block for each of the emergency-response scenarios. If multiple population distributions are defined, the user is then unable to define fraction-of-the-people or fraction-of-the-time weighting factors for summation of the overall results. In that case, the various results are simply added in reporting the CCDF summary tables generated by the code.

As was the case with MACCS, evacuation and sheltering actions may be modeled in the region surrounding the release point. Outside the evacuation and sheltering region, dose-dependent relocation actions may take place in exactly the same manner as with the previous code using the so-called hot-spot and normal relocation dose criteria.

The user may no longer define a sheltering region *per se* since evacuation and sheltering actions have been merged. However, this merging of the two actions has been accomplished in a manner that allows emulation of the MACCS model's features. In the new code's modeling of the evacuation and sheltering region, the user explicitly defines the reference time to be used for initiation of the action as being either the alarm time (input variable OALARM) associated with the source term or the arrival time of the first plume reaching the downwind location. In the region beyond the evacuation and sheltering region, that is, the so-called relocation zone, the reference time point for actions remains the plume arrival time, and no change to the MACCS model has been made.

The evacuation and sheltering region is user specified to extend a given radial distance (*i.e.*, radial spatial interval). For each radial distance in this region, the user specifies a sheltering period (which may have a zero duration) that occurs prior to the initiation of the evacuation. During the sheltering phase, shielding factors appropriate for sheltered activity are used to calculate doses for the individuals in contaminated areas.

By allowing the delay times to vary for each ring of the polar grid, a staged evacuation may be modeled in which the evacuation delay time increases as a function of distance. If desired, each emergency response scenario, of the three allowed, may utilize its own set of shielding factors.

At the termination of the sheltering phase, the resident individuals start their travel out of the region. In each of the scenarios chosen, the user defines whether evacuation is to follow radial paths (as in MACCS) or follow complex paths defined as a network.

The actions defined for each evacuation scenario are wholly independent of the other evacuation scenarios defined by the user. That is, a radial evacuation may be used for the first scenario, a network evacuation could be defined for the second scenario, and the third could have neither

evacuation nor sheltering taking place, with the entire region subject only to dose-dependent relocation actions. The results from these scenarios in the overall CCDF are combined using either (1) a single population distribution modified by weighting fractions, or (2) the simple summation of results from separate population data blocks.

6.6.2 Early, Middle, and Late Phases of Evacuation

In the new model, the user divides the evacuation period into three phases: early, middle, and late. For each of the three phases, the user defines the travel speed of the evacuees during that period. For situations where only one or two speeds are defined, the duration of the first and/or second evacuation phase may be set to 0.

For both types of evacuation (*i.e.*, radial and network) the implementation of the travel speed model is identical. Three travel speeds are defined in the EARLY input file. As individuals traverse the path defined for them, their speed of travel can vary due to transitions from one phase to the next. If these transitions occur while an individual is traversing a spatial element, the code uses linear interpolation to determine the traversal time for that element.

In order to allow all individuals to leave the evacuation region, the late phase is considered to last as long as is necessary for all evacuating individuals to leave the region. Thus, the user specifies the duration of the early and middle evacuation periods but not for the late phase.

The initial evacuation period begins when the first individuals begin their travel out of the region and lasts for the user-specified duration, DURBEG. After that period has elapsed, the middle-phase evacuation period takes place for the user-specified duration DURMID. Finally, the remainder of time necessary for all individuals to complete their travel is considered the late-phase evacuation period.

6.6.3 Radial vs. Network Evacuation

MACCS2 allows the user a choice between two evacuation network models: radial and network. Figures 6-1 and 6-2 provide illustrations of these evacuations. For both radial and excavation models, sheltering has been integrated into the model, with sheltering (if defined) *always* preceding evacuation. The internal implementation of the radial and network models is largely identical, since a radial evacuation can be described as a network evacuation constrained to have all evacuation paths in the radial directions, representing a subset of the network functionality.

For this reason, and ease of description, the functionality of these models will be explained by first describing the user-specified input parameters that define the operation of the network evacuation model. This will be followed by an explanation of how MACCS2 creates an evacuation network to represent the radial evacuation case. Finally, the approach used by MACCS2 to calculate resultant doses to residents of the sheltering/evacuation region will be described.

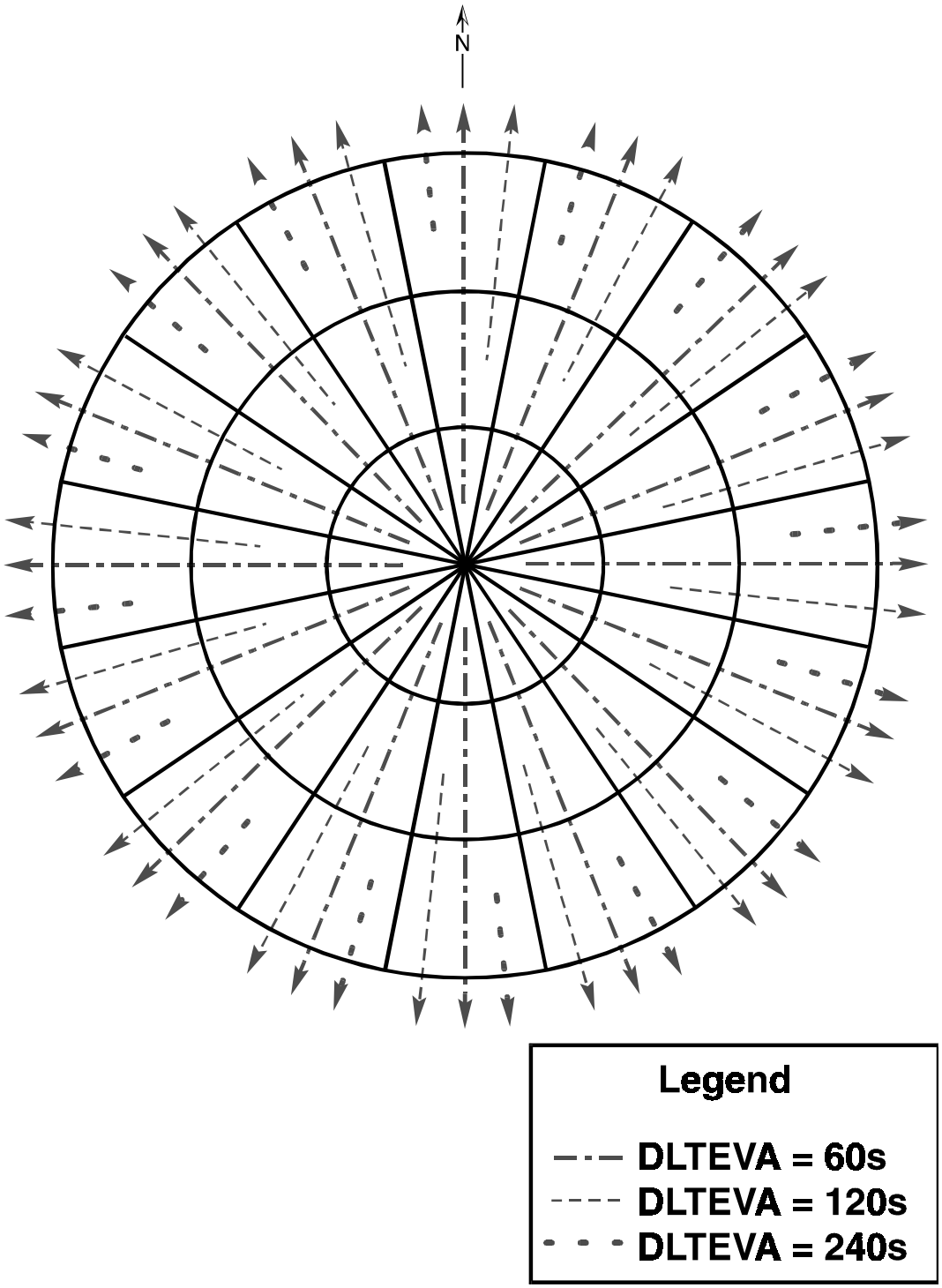


Figure 6-1. Radial evacuation paths with DLTEVA values of 60, 120, and 240 s assigned to the three spatial intervals. The DLTEVA input variable defines the duration of the sheltering period before the beginning of evacuation and is described in this section.

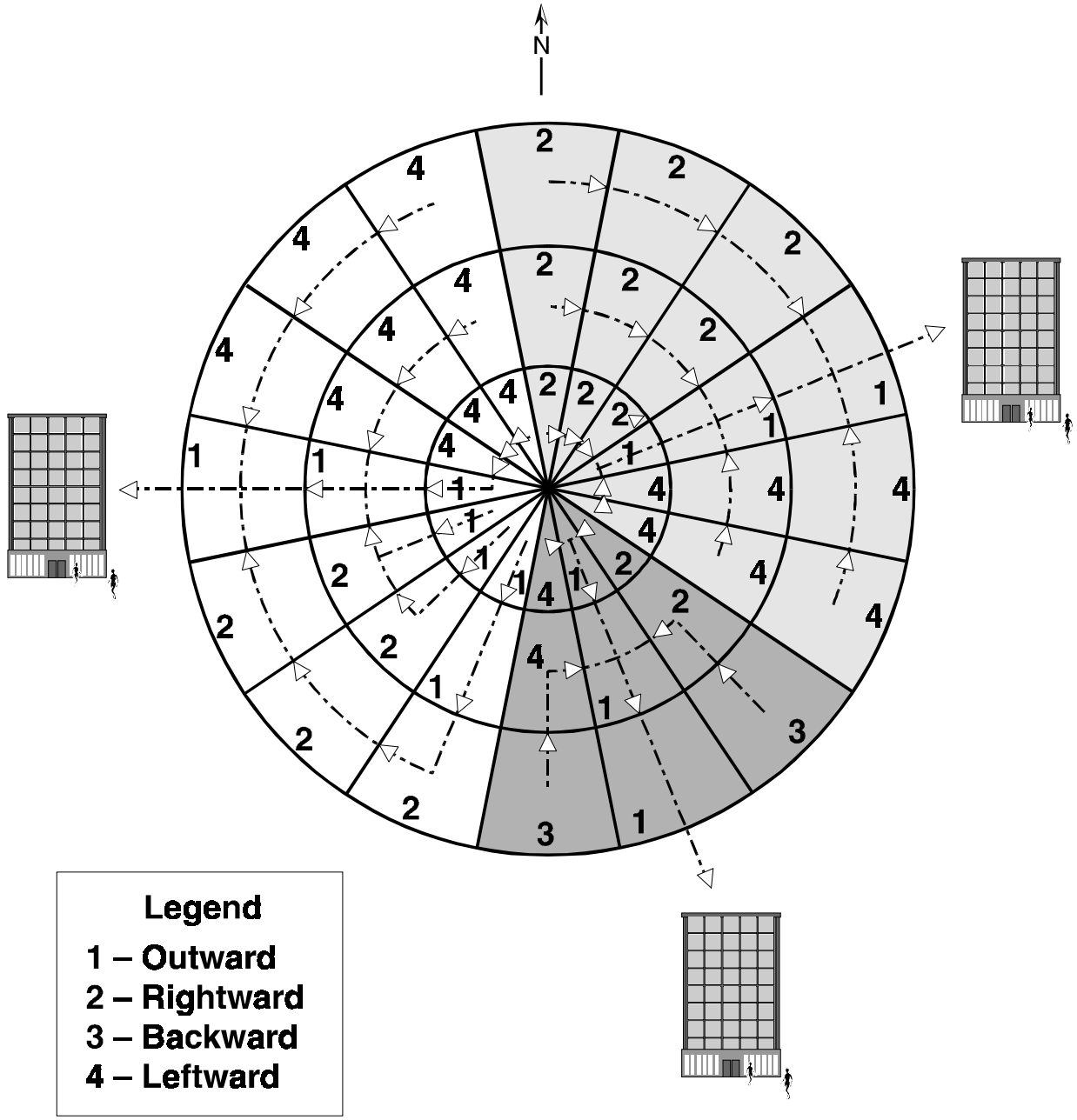


Figure 6-2. **A network evacuation grid. The numbers contained in each spatial element represent the value that would be assigned to the IDIREC input variable for the definition of evacuee movement in that spatial element. The IDIREC input variable is defined in this section and the example usage provided for this variable describes the network represented in this figure.**

6.6.4 Network Evacuation Input Data

The region in which evacuation and sheltering can occur is circular, extending from the grid centerpoint out to a user-specified distance. A number of parameters are supplied by the user to define the operation of the model when the network evacuation model is specified.

LASMOV: Defines the furthest ring in which evacuees will incur exposures. When evacuees exit this ring and proceed to the next outermost ring, no further exposures are incurred.

NUMEVA: Defines the number of concentric rings in which evacuation and/or sheltering can occur for the resident population.

REFPNT: Control flag indicating which of two time points is to be the reference time point for initiation of sheltering and evacuation. If ALARM is specified, the initiation of sheltering and evacuation actions will occur at the off-site alarm time (ATMOS input variable OALARM). If ARRIVAL is specified, the initiation of sheltering and evacuation actions will occur at the time when the first plume arrives at the centerpoint of the spatial interval, with the centerpoint of the spatial interval defined as the point midway between the inner and outer circular arcs that bound the spatial interval.

ESPEED(3): An array of three values that define evacuation travel speeds (m/s) for the three phases of evacuation: early, middle, and late.

DURBEG: Defines the duration (seconds) of the early phase of evacuation. This period begins when the sheltering period has elapsed. During this period, evacuees travel at the rate specified by ESPEED(1).

DURMID: Defines the duration (seconds) of the middle phase of evacuation. This period begins when the early-phase evacuation period has elapsed. During this period, evacuees travel at the rate specified by ESPEED(2). When this period has elapsed, evacuees travel at the rate specified by ESPEED(3).

DLTSHL(IRAD): For each distance ring in the shelter/evacuate region, this variable defines the delay to take shelter (seconds) for resident individuals. When DLTSHL is specified as 0, sheltering will occur with no delay (that is, immediately) at that distance. Prior to the initiation of sheltering, individuals may (if plume arrival has occurred) receive exposures calculated by using the shielding factors for normal activity.

DLTEVA(IRAD): For each distance ring in the shelter/evacuate region, this variable defines the duration of the sheltering period (seconds) that is to occur before evacuation begins for residents. When DLTEVA is specified as 0, evacuation will occur with no additional delay (that is, there is no shelter period at that distance).

If DLTSHL is specified to be 0 at a particular distance, sheltering begins at either of two times: off-site alarm time or plume arrival (as specified by the input variable REFPNT). If DLTSHL is specified to be 0 and REFPNT='ARRIVAL', individuals at this distance will incur no exposure

utilizing normal activity shielding factors since they are assumed to take shelter immediately upon plume arrival.

If DLTSHL is nonzero at a particular distance, sheltering begins at DLTSHL seconds after either the off-site alarm time or plume arrival. The duration of their shelter period is always DLTEVA.

At the conclusion of the sheltering period, the resident individuals begin their evacuation travel. During the sheltering period, and prior to the initiation of evacuation, individuals may (if plume arrival has occurred) receive exposures calculated by utilizing the sheltering shielding factors. At the conclusion of the sheltering period, the individuals begin their evacuation travel.

IDIREC(IRAD, JANG): A two-dimensional array defining exit directions for each element within the sheltering/evacuation region (IRAD and JANG are the indices for the spatial interval and the wind direction respectively). Allowable values are 1 through 4: 1 signifies radially outward travel, 2 signifies clockwise travel, 3 signifies radially inward travel, and 4 signifies counterclockwise travel.

6.6.5 Radial Evacuation Input Data

When radial evacuation is specified (EVATYP='RADIAL'), with only a single exception the user must supply all of the data required for specification of network evacuation. The single input parameter not required in this case is IDIREC. A network evacuation path is constructed internally by the code by setting all values for IDIREC to 1, signifying that all travel is to be in a radially outward direction.

6.6.6 Processing of Evacuation Networks

In preparation for network evacuation calculations, the code tests the network to ensure that it is valid. A valid network cannot contain any closed cycles. That is, it cannot contain a path in which evacuees would travel in an infinite loop. Radially inward travel is not allowed for the distance ring closest to the release point. Elements at the outer boundary of the region are not required to have a destination direction away from the release point though at least one boundary element must offer an outbound path.

For convenient performance of the calculations, the network is then reduced to an internally stored sequence of linear paths. This is done by testing each spatial element within the region to determine if it is a root node. A root node is a node that is not the travel destination of any other node in the network. Each network will include some number, *n*, of root nodes. Each root node is the starting point of a linear path through the network that culminates in an exit from the network. Each of the *n* linear paths is a sequence of nodes (spatial elements).

6.6.7 Dose Calculations for Evacuating Populations

In preparation for the dose calculations, the travel time in each spatial element is calculated. The travel time for each node is a simple function of travel speed and distance. The travel distance varies depending on the direction of travel within the node and its size. For radially outward or inward travel and the TRAVELPOINT = 'BOUNDARY' option, the travel distance for a node is

the difference between the radii to the spatial element's inner and outer boundaries. For the TRAVELPOINT = 'CENTERPOINT' option, the travel distance for a node is the radial distance between the centerpoints of contiguous spatial elements. When individuals initiate their travel, they are assumed to be located at the centerpoint of the spatial element and therefore their travel distance through the element is only half of the travel distance calculated for the spatial element for evacuees who begin their travel elsewhere.

For clockwise or counterclockwise travel, the travel distance is the length of the circular arc between a node and its destination node, with these nodes lying directly under the radii corresponding to the 16 compass points, and at a distance from the grid centerpoint midway between the inner and outer boundary rings surrounding the node. For example, consider a node located within a circular ring having an inner boundary of 2 km and an outer boundary of 3 km. The node is considered to be located at a distance of 2.5 km from the grid centerpoint. The distance, D , to the neighboring node in the clockwise or counterclockwise travel direction is then $D = 2 \pi r / 16$, and, with $r = 2.5$ km, $D = 0.98$ km. In this manner, travel times are calculated for each node in the network and for the travel speeds assigned to each evacuation phase.

Doses to individuals moving within the evacuation network are calculated by tracing the travel paths that begin at each of the root nodes, in turn. This is done as follows.

Each root node is the starting point of a path that terminates when individuals on that path exit the network by reaching a radial distance greater than LASMOV. The calculations for a particular root node begin with a calculation of the dose received by residents of the starting point of the path, the root node itself. These individuals will traverse all of the nodes in that path before exiting the network. Their doses are calculated by modeling their transport from element to element. If the evacuation speed changes during traversal of a node, the change in speed is fully accounted for.

When the residents of the root node (the first node on the path) exit the network, their dose calculations are complete and they receive no further exposures in EARLY. The next step in the calculations is to repeat the calculations for the residents of the second node (spatial element) on the path (the destination node of the root node), accumulating their doses until they leave the network, and so on, until the dose calculations are completed for all of the nodes on the path associated with this root node.

Upon the completion of dose calculations for all of the nodes on the first linear path, the paths for the remaining root nodes are traversed in turn. When the paths for all residents of all of the paths have been traversed, and all of the associated doses calculated, the dose calculations are complete.

6.6.8 Evacuation Data Block Input Parameters

Variable Name: EANAM2
Variable Type: Character, Scalar
Allowed Range: $1 \leq \text{length} \leq 80$

Purpose: Identifies the name of the emergency response scenario being studied. This name will be printed on all pages of the output listing. A unique name must be specified for each emergency response.

Example Usage:

```
*
EZEANAM2001 'EVACUATION WITHIN 10 MILES, RELOCATION ELSEWHERE'
```

Variable Name: WTNAME
Variable Type: Character, Scalar
Allowed Value: 'PEOPLE' or 'TIME' or 'SUMPOP'
Purpose: Defines the type of weighting to be used in generating the overall weighted sum of results. If PEOPLE or TIME are selected, the code's behavior is unchanged from the NRC version of MACCS. If the SUMPOP option is selected, the value of WTFRAC is not processed and the overall weighted sum is generated by simple summation. Also, the selection of SUMPOP indicates that the Site Data file will include a separate population distribution for each emergency response cohort.

Selection of SUMPOP requires that the population be defined via a Site Data file. An input error will thus result if the user specifies both WTNAME='SUMPOP' and POPFLG='UNIFORM' in a single run of the code.

Example Usage:

```
*
* DEFINE THE TYPE OF WEIGHTING TO BE USED
*
EZWTNAME001    'PEOPLE'
```

Variable Name: WTFRAC
Variable Type: Real, Scalar
Allowed Range: $0.0 \leq \text{value} \leq 1.0$
Purpose: Weighting fraction to be applied to the results from this emergency response scenario. This value is used by the OUTPUT module in combining results for the overall weighted sum. The weighting can be done for either fraction-of-the-people or fraction-of-the-time as determined by the input variable WTNAME.

Example Usage:

```
*
EZWTFRAC001  0.95     (95% OF THE PEOPLE WITHIN 10 MILES EVACUATE)
```

Variable Name: EVATYP
Variable Type: Character, Scalar
Allowed Value: 'RADIAL' or 'NETWORK'

Purpose: Defines whether a radial or network evacuation is to be modeled. If the radial option is chosen, the code automatically generates a network path where all individuals travel radially outward.

If the network option is chosen, the user is required to supply data for variable IDIREC. Furthermore, the selection of network evacuation is inconsistent with the straight-line plume (*i.e.*, IPLUME=1) dispersion option. When a network evacuation is specified, the user must specify a value of 2 or 3 for IPLUME. Thus, the centerline dose and risk results (Type 6 and Type 7) are unavailable when the network evacuation option is selected.

Example Usage:

```
*
EZEVATYP001    'NETWORK'
```

Variable Name: TRAVELPOINT
Variable Type: Character, Scalar
Allowed Value: 'BOUNDARY' or 'CENTERPOINT'
Purpose: Defines the option as to whether evacuees are presumed to move from a spatial element when they cross the boundary dividing the two elements ('BOUNDARY') or when they reach the centerpoint of the destination element ('CENTERPOINT').

If the 'BOUNDARY' option is chosen, the user is not allowed to specify a set of evacuation speeds (ESPEED) that vary. It is only with the 'CENTERPOINT' option that the user is allowed to specify values of ESPEED that differ.

Example Usage:

```
*
TRAVELPOINT    'BOUNDARY'
```

Variable Name: ESPEED
Variable Type: Real, Array
Allowed Range: 1.0E–6 ≤ value ≤ 1.0E+6 (meters/second)
Purpose: Defines the travel speed of evacuees during the three phases of the evacuation: initial, middle, and late.

The initial evacuation phase begins when the first individual begins to travel out of the region. The durations of the initial and middle phases of the evacuation are defined by input variables DURBEG and DURMID. As stated above, if TRAVELPOINT='BOUNDARY' all three values of ESPEED must be identical.

The late phase of the evacuation extends as long as necessary for all individuals to complete their travel. The user must supply three values for this parameter.

Example Usage:

```
*
* EVACUATION TRAVEL SPEEDS FOR THREE EVACUATION PHASES (METERS/SECOND)
*              (INITIAL)        (MIDDLE)        (LATE)
EZESPEED00       1.8              1.8             1.8
```

Variable Name: REFPNT
Variable Type: Character, Scalar
Allowed Value: 'ALARM' or 'ARRIVAL'
Purpose: Defines the reference time point for actions in the evacuation and sheltering zone. If ALARM is chosen, the reference time point for these actions is the off-site alarm time (OALARM) as defined in the ATMOS source term definition. If ARRIVAL is chosen, the reference time for evacuation and sheltering actions is the arrival of the first plume at the spatial element.

Example Usage:

```
*
* REFERENCE TIME POINT FOR EVACUATION AND SHELTERING
*
EZREFPNT001    'ARRIVAL'
```

Variable Name: DURBEG
Variable Type: Real, Scalar
Allowed Value: $0.0 \leq$ value ≤ 86400.0 (seconds)
Purpose: Defines the duration of the initial phase (beginning) of evacuation. This phase starts when the first individual in the shelter and evacuation region begins travel from the region. The speed used during this phase of the evacuation is the first value of array ESPEED.

Example Usage:

```
*
* DURATION OF THE INITIAL PHASE OF THE EVACUATION
*
EZDURBEG001     86400.0
```

Variable Name: DURMID
Variable Type: Real, Scalar
Allowed Value: $0.0 \leq$ value ≤ 86400.0 (seconds)
Purpose: Defines the duration of the middle phase of evacuation. This phase begins at the termination of the initial phase of the evacuation from the region. The evacuation speed used is the second value of ESPEED. After the middle phase has elapsed, evacuees travel at the speed defined by the third value of ESPEED.

Example Usage:

```
*
* DURATION OF THE MIDDLE PHASE OF THE EVACUATION
*
EZDURMID001     86400.0
```

Variable Name: NUMEVA
Variable Type: Integer, Scalar
Allowed Range: 1 ≤ value ≤ LASMOV
Purpose: Defines the number of radial spatial elements (*i.e.*, contiguous rings) comprising the sheltering and evacuation region. For each ring of the region, values of DLTSHL and DLTEVA must be supplied.

Note: A clarification of the difference between LASMOV and NUMEVA is necessary. LASMOV defines the outer boundary of the region that shelterees and evacuees traverse. In contrast, NUMEVA defines the region where individuals are subject to sheltering and/or evacuation. It is possible to assign the same value to both parameters; however, there is no requirement that this be the case. An example of LASMOV being larger than NUMEVA is the NUREG-1150 evacuation assumption, under which the residents of a 10-mile EPZ travel 20 miles.

Example Usage:

```
*
* NUMBER OF RINGS IN THE SHELTER AND EVACUATION REGION
*
EZNUMEVA001     12     (REGION EXTENDS TO A 10-MILE RADIUS)
```

Variable Name: DLTSHL
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 86400.0 (seconds)
Purpose: Defines the delay that elapses from the reference time point REFPNT to when individuals take shelter. The user must supply NUMEVA values for this parameter, one for each ring in the shelter/evacuate region.

Example Usage:

```
*
* DELAY TIME TO TAKE SHELTER
*
EZDLTSHL001   7200.  7200.  7200.  7200.  7200.  7200.
EZDLTSHL002   7200.  7200.  7200.  7200.  7200.  7200.
```

Variable Name: DLTEVA
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 86400.0 (seconds)
Purpose: Defines the delay that elapses from the beginning of the shelter period to when individuals begin their evacuation. The user must supply NUMEVA values for this parameter, one for each ring in the shelter/evacuate region.

Example Usage:

```
*
* DELAY TIME TO BEGIN EVACUATION
*
EZDLTEVA001   0.     0.     0.     0.     0.     0.
EZDLTEVA002   0.     0.     0.     0.     0.     0.
```

Variable Name: IDIREC
Variable Type: Integer, Array
Allowed Value: $1 \leq \text{value} \leq 4$
Purpose: Defines the destination direction of every spatial element in the evacuation and sheltering region. The destination direction is defined in terms of a coordinate system in which all individuals are facing away from the centerpoint of the polar grid. A value of 1 indicates forward travel (radially outward); 2 indicates travel to the right (clockwise travel); 3 indicates travel backward toward the centerpoint; and 4 indicates leftward (or counterclockwise) travel.

For every ring in the evacuation and sheltering region (*i.e.*, at intervals extending out to LASMOV), an input data record must be supplied. Each of those LASMOV cards contains 16 values, corresponding to the compass points N through NNW. The network path defined below is illustrated in Figure 6-2.

Example Usage:

```
*
* DEFINE THE EVACUATION NETWORK
*            N           E           S           W
EZIDIREC001  2  2  2  1  4  4  2  1  4  1  1  1  1  4  4  4  (FIRST RING)
EZIDIREC002  2  2  2  1  4  4  2  1  4  1  2  2  1  4  4  4  (SECOND RING)
EZIDIREC003  2  2  2  1  4  4  3  1  3  2  2  2  1  4  4  4  (THIRD RING)
```

Variable Name: LASMOV
Variable Type: Integer, Scalar
Allowed Range: $0 \leq \text{value} \leq (\text{NUMRAD} - 1)$
Purpose: The outermost spatial interval of the evacuation movement zone. This is the distance after which evacuees are assumed to disappear from the early health effects model and receive no further dose.

If the user specifies a value of 0, there will be no evacuation and there is no need to supply data for EVATYP, TRAVELPOINT, ESPEED, REFPNT, DURBEG, DURMID, NUMEVA, DLTSHL, DLTEVA, or IDIREC.

Example Usage:

```
*
* LAST RING IN THE MOVEMENT ZONE
*
EZLASMOV001   15     EVACUEES DISAPPEAR AFTER TRAVELING TO 20 MILES
                    (SEE EXAMPLE USAGE SECTION FOR ATMOS SPAEND VARIABLE)
```

Variable Name: ENDEMP
Variable Type: Real, Scalar
Allowed Range: 86400.0 ≤ value ≤ 604800.0 (seconds after plume arrival)
Purpose: Defines the duration of the emergency-phase period. EARLY only calculates doses that would be received during the emergency-phase time period. Doses at each spatial interval are cut off at ENDEMP seconds after the arrival of the first plume segment to reach the interval. This cutoff applies to all individuals, no matter where they are located. Any subsequent doses will be calculated by CHRONC.

ENDEMP is also the time evacuees and shelterees are kept away from their homes if there is any contamination in the coarse-grid element in which they reside.

Example Usage:

```
*
* DURATION OF THE EMERGENCY PHASE (SECONDS FROM PLUME ARRIVAL)
*
SRENDEMP001  604800.  (1 WEEK)
```

Variable Name: CRIORG
Variable Type: Character, Scalar
Allowed Range: 2 ≤ length ≤ 10
Purpose: Defines the critical organ for relocation decisions during the emergency-phase period considered by EARLY. In order to determine whether people can remain in the relocation zone, the total committed dose to the critical organ of an individual who remained in place for the entire emergency phase is calculated. The critical organ must be found on the list of organs, ORGNAM, defined in Section 6.4.

Example Usage:

```
*
* CRITICAL ORGAN FOR RELOCATION
*
SRCRIORG001 'L-EFFECTIVE'
```

Variable Name: TIMHOT
Variable Type: Real, Scalar
Allowed Range: 0.0 ≤ value ≤ ENDEMP (seconds after plume arrival)
Purpose: Defines the hot-spot relocation action time. Hot-spot relocation can only occur for individuals residing outside of the emergency-response zone. That is, doses to people awaiting evacuation or protected in shelters will not be affected by the hot-spot relocation model.

If the total lifetime dose commitment for any individual in a coarse-grid element in the relocation region exceeds DOSHOT sieverts to the critical organ, CRIORG, for someone remaining there

for the entire emergency phase (ENDEMP), people in that element are relocated at TIMHOT seconds after the arrival of the first plume at that distance.

For the purpose of evaluating the need for hot-spot and normal relocation, the total dose commitment is the dose that would be received by an individual who remained in place for the entire emergency-phase period while engaging in normal activity. The pathways used for calculating the total dose commitment are cloudshine, groundshine, direct inhalation, and resuspension inhalation. Any individuals relocated due to hot spots are removed from the problem for the duration of the emergency phase and receive no additional dose during this phase.

Example Usage:

```
*
* HOT-SPOT RELOCATION TIME (SECONDS FROM PLUME ARRIVAL)
*
SRTIMHOT001  43200.  (ONE-HALF DAY)
```

Variable Name:	TIMNRM
Variable Type:	Real, Scalar
Allowed Range:	TIMHOT ≤ value ≤ ENDEMP (seconds after plume arrival)
Purpose:	Defines the normal relocation action time. Normal relocation can only occur for individuals residing outside of the emergency-response zone. That is, doses to people awaiting evacuation or protected in shelters will not be affected by the normal relocation model.

If the total dose commitment to any individual in a coarse-grid element in the relocation region exceeds DOSNRM sieverts to the critical organ, CRIORG, for someone remaining there for the entire emergency phase (ENDEMP), people in that element are relocated at TIMNRM seconds after the arrival of the first plume at that distance. Any individuals subject to normal relocation are removed from contaminated areas for the duration of the emergency phase and receive no additional dose during this phase.

For the purpose of evaluating the need for hot-spot and normal relocation, the total dose commitment is the dose that would be received by an individual who remained in place for the entire emergency phase period while engaging in normal activity. The pathways used for calculating the total dose commitment are cloudshine, groundshine, direct inhalation, and resuspension inhalation.

Example Usage:

```
*
* NORMAL RELOCATION TIME (SECONDS FROM PLUME ARRIVAL)
*
SRTIMNRM001  86400.  (1 DAY)
```

Variable Name:	DOSHOT
Variable Type:	Real, Scalar
Allowed Range:	0.0 ≤ value ≤ 1.E10 (sieverts)

Purpose: Defines the hot-spot relocation dose threshold. If the total dose commitment to individuals outside of the evacuation and sheltering zones who remained stationary for the entire emergency phase period would exceed DOSHOT, those people are relocated (removed) at the hot-spot relocation time (TIMHOT).

Example Usage:

```
*
* HOT-SPOT RELOCATION DOSE THRESHOLD (SIEVERTS)
*
SRDOSHOT001   0.5  (50 REM)
```

Variable Name: DOSNRM
Variable Type: Real, Scalar
Allowed Range: 0.0 ≤ value ≤ DOSHOT (sieverts)
Purpose: Defines the normal relocation dose threshold. If the total dose commitment to individuals outside of the evacuation and sheltering zones who remained stationary for the entire emergency phase period exceeds DOSNRM, those people are relocated (removed) at the normal relocation time TIMNRM.

Example Usage:

```
*
* NORMAL RELOCATION DOSE THRESHOLD (SIEVERTS)
*
SRDOSNRM001  0.25   (25 REM)
```

6.7 Early Fatality (EF) Data

The individual risk of prompt fatality is modeled in MACCS2 using a two-parameter Weibull function here called a hazard function (Evans, Moeller, and Cooper 1985). The hazard function is used to sum the cumulative risk from a number of potential types of damage as follows:

$$\text{RISK} = 1 - \exp\left[-\sum_i H_i\right]$$

where $H = 0.693\left(\frac{\text{DOSE}}{\text{EFFACA}}\right)^{\text{EFFACB}} 0$

DOSE	=	effective acute dose to the target organ (described later),
EFFACA	=	the alpha (LD_{50}) parameter in the hazard function (Evans, Moeller, and Cooper, 1985, p. II-8), and
EFFACB	=	the beta or exponential parameter in the hazard function that defines the steepness of the dose-response function.

A dose threshold is incorporated into the early fatality model in the following manner. If the dose to any of the target organs is below the user-specified threshold (see EFFTHR below), then the hazard (*H*) from that organ is set to 0.

When radioactive material is inhaled and retained in the respiratory system, an individual may continue to receive a radiation dose for long periods of time after the material was inhaled. Depending on particle size and chemical form, clearance mechanisms may remove the material from the body or transport it from the respiratory system to other organs of the body. For this reason, it does not make sense to refer to radiation dose without specifying the time period of interest. The concept of lifetime dose commitment is widely used in radiation protection (Eckerman, Wolbarst, and Richardson 1989).

As applied in MACCS, lifetime dose refers to the dose received over the 50-year period following inhalation by a standard reference man who is 30 years old. This lifetime dose is used to determine the need for mitigative actions and to calculate cancers and population dose.

Implementation of the Evans, Moeller, and Cooper (1985) early health effects models requires a calculation method that takes account of dose protraction for radioactive material inhaled and retained in the respiratory system. MACCS2 applies dose reduction factors to protracted doses that contribute to early health effects. Dose reduction factors are derived from LD_{50} or D_{50} values that apply to a sequential set of time periods of fixed length. In addition, for the calculation of early fatalities and injuries in MACCS2, a new measure of dose was defined in order to reduce the computational demands of the calculations. Throughout this document it will be referred to as effective acute dose.

The effective acute dose, D_e, is that dose which if delivered entirely in 1 day, would induce the same health effects as an actual dose delivered over many days. Thus,

$$H = \ln 2 \left(\frac{D_e}{\alpha_1} \right)^{\beta} = \ln 2 \left(\sum_t \frac{D_t}{\alpha_t} \right)^{\beta},$$

where
$D_e = C \bullet F_e$
$D_t = C \bullet F_t$
C = the amount of material inhaled from the plume,
F_e = the effective acute dose conversion factor,
F_t = the dose conversion factor for the actual dose, D_t, delivered in time period t.
α_t = the LD_{50} or D_{50} for time period t.
α_1 = the LD_{50} or D_{50} for time period of 1 day.

Substitution now yields

$$F_e = \left(\sum_t \frac{\alpha_1}{\alpha_t} \right) F_t \ .$$

Effective acute dose conversion factors are supplied only for the organs used for calculating the early health effects. The acute dose commitment period from inhaled and internally deposited radionuclides is 1 year. The other organs on the dose conversion file have been given effective acute dose conversion factors of –1.0, which prevents their inadvertent use since any resulting

doses would be negative. The default dose reduction factors (*i.e.*, α_1/α_t) applied in the effective acute dose calculations are shown in Table 6-1.

Table 6-1. Effective Acute Dose Reduction Factors (unitless)

	Time Period after Exposure (Days)					
	0–1	**1–7**	**7–14**	**14–30**	**30–200**	**200-365**
	Effective Acute Dose Reduction Factors (α_1/α_t)					
RED MARR	1.0	0.5	0.5	0.25		
LUNGS	1.0	0.0625	0.0625	0.027	0.027	0.0109
THYROID	1.0	0.2	0.2	0.2		
STOMACH	1.0	0.37				
LOWER LI	1.0	0.43				
SMALL IN	1.0	0.43				

The MACCS2 DCF preprocessor, DOSFAC2, allows the user to modify the acute dose reduction factors. In the DCF preprocessor IDCF2, the acute dose reduction factors are fixed in the code and may not be modified through a user input file.

For bone marrow death (with supportive treatment), Evans, Moellen, and Cooper (1985) show LD_{50} values of 4.5 Gy for the 0- to 1-day time period, 9 Gy for the 1- to 14-day time period, and 18 Gy for the 14- to 30-day time period. Instead of calculating three different red marrow doses and applying the three different values of LD_{50} to calculate risk, we calculate a single red marrow dose using the effective acute dose conversion factor.

So, according to the above table, effective acute red marrow dose is 100% of the first day's dose, 50% of the next 13 days' dose, and 25% of the next 16 days' dose. This acute dose is then used in the risk equation with the LD_{50} for the 0- to 1-day time period to obtain the hazard to bone marrow.

The dose protraction effect described here is applied only to the internal exposure resulting from inhalation. Dose from the direct exposure pathways in EARLY (groundshine and cloudshine) are summed with no reduction factor being applied even if the exposure lasted more than 1day. The current implementation of the early health effects models does not distinguish among cloudshine, groundshine, and the 0- to 1-day inhalation dose commitment. They are considered in this model to be equally effective in causing damage.

The error introduced by attributing all the direct exposure dose to the first day is small and is in the direction of overestimating risk. In most cases, emergency plans should ensure that no individuals are permitted to remain on contaminated ground for much longer than a day if dose levels are high enough to pose a risk of early health effects.

Resuspension inhalation is another area where the importance of the pathway is overestimated somewhat. The inhalation dose from resuspended material is treated identically to the inhalation

dose from direct inhalation of the plume. That is, it is treated as though all the resuspended material was inhaled at the beginning of the exposure period.

Information in this section is used only to control the calculation of individual risk. Results to be processed by OUTPUT (*e.g.*, total cases of early fatality, average individual risk of early fatality, and centerline risk vs. distance of early fatality) are described in later sections of this volume. In order for the code to produce early fatality results, the early fatality model must be defined in this section.

Variable Name: NUMEFA
Variable Type: Integer, Scalar
Allowed Range: $0 \leq \text{value} \leq 5$
Purpose: The number of early fatality effects to be included in the total risk of early fatality. A value of zero means that the early fatality model will not be used.
Example Usage:

```
*
* NUMBER OF EARLY FATALITY EFFECTS
*
EFNUMEFA001   3
```

Note: The remaining parameters in this section are required only if NUMEFA is greater than 0.

Variable Name: ORGNAM
Variable Type: Character, Array
Allowed Range: $2 \leq \text{length} \leq 10$
Purpose: The name of the target organ for each early fatality effect. The target organ must be one of the organs listed in the organ definition data. The user must supply NUMEFA values in column 1 of the data block.

Variable Name: EFFACA
Variable Type: Real, Array
Allowed Range: $1.0 \leq \text{value} \leq 100.0$
Purpose: The alpha factor (LD_{50}) in the hazard function for the target organ. The user must supply NUMEFA values in column 2 of the data block.

Variable Name: EFFACB
Variable Type: Real, Array
Allowed Range: $1.0 \leq \text{value} \leq 100.0$
Purpose: The beta factor (shape parameter) in the hazard function for the target organ. The user must supply NUMEFA values in column 3 of the data block.

Variable Name: EFFTHR
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 100.0
Purpose: The threshold dose associated with this target organ. If the acute dose to this organ falls below threshold, it will not contribute to the risk of fatality. The user must supply NUMEFA values in column 4 of the data block.

Example Usage of EFFACA and EFFACB:

```
*
*                ORGNAM       EFFACA   EFFACB      EFFTHR
*
EFATAGRP001    'A-RED MARR'    3.8      5.0         1.5
EFATAGRP002     'A-LUNGS'     10.0      7.0         5.0
EFATAGRP003    'A-LOWER LI'   15.0     10.0         8.0
```

6.8 Early Injury (EI) Data

The individual risk of each type of early injury is modeled in MACCS2 using an approach analogous to that used for early fatality risk (Evans, Moller and Cooper 1985). The early injury risk model differs from the early fatality model in that instead of summing the damage from more than one organ, only a single organ is used. The early injury risk function is as follows:

$$\text{RISK} = 1 - e^{-H},$$

where

$$H = 0.693\left(\frac{\text{DOSE}}{\text{EIFACA}}\right)^{\text{EIFACB}} 0$$

DOSE = effective acute dose (described in Section 6.7) to the target organ,
EIFACA = the alpha (D_{50}) parameter in the hazard function (Evans, Moller and Cooper 1985, p. II-8), and
EIFACB = the beta or exponential parameter in the hazard function that defines the steepness of the dose-response function.

A dose threshold is incorporated into the early injury model in the following manner. If the dose to any of the target organs is below the user-specified threshold (see EITHRE in the following discussion), then the risk of this type of early injury is set to 0.

In addition to the values described above, the user must specify the fraction of the population that is susceptible to the injury, EISUSC. Information in this section is used only to control the calculation of individual risk. Results to be processed by OUTPUT(*e.g.,* total cases of a given injury, average individual risk of a given injury, and centerline risk vs. distance of a given injury) are described in later sections. In order for the code to produce early injury results, the injuries must be defined in this section.

Variable Name: NUMEIN
Variable Type: Integer, Scalar
Allowed Range: $0 \leq \text{value} \leq 10$
Purpose: The number of different types of early injuries that will be calculated. A value of 0 means that no early injuries will be calculated.
Example Usage:

```
*
* NUMBER OF EARLY INJURY EFFECTS
*
EINUMEIN001   7
```

Note: The remaining parameters in this section are required only if NUMEIN is greater than 0. The six arrays are arranged as rows of data in a single data block.

Variable Name: EINAME
Variable Type: Character, Array
Allowed Range: $1 \leq \text{length} \leq 16$
Purpose: The name of each type of early injury. The user may specify any name. Apostrophes are mandatory if there are any embedded blanks. The user must supply NUMEIN values in column 1 of the data block.

Variable Name: ORGNAM
Variable Type: Character, Array
Allowed Range: $2 \leq \text{length} \leq 10$
Purpose: The name of the target organ for each type of early injury. The target organ must be one of the organs listed in the organ definition data. The user must supply NUMEIN values in column 2 of the data block.

Variable Name: EISUSC
Variable Type: Real, Array
Allowed Range: $0.0 \leq \text{value} \leq 1.0$
Purpose: The fraction of the population that is susceptible to the early injury. The user must supply NUMEIN values in column 3 of the data block.

Variable Name: EITHRE
Variable Type: Real, array
Allowed Range: $0.0 \leq \text{value} \leq 1000.0$
Purpose: The threshold dose below which the risk of the injury is 0. The user must supply NUMEIN values in column 4 of the data block.

Variable Name: EIFACA
Variable Type: Real, Array
Allowed Range: 1.0 ≤ value ≤ 1000.0
Purpose: The alpha factor (D_{50}) in the hazard function for the injury. The user must supply NUMEIN values in column 5 of the data block.

Variable Name: EIFACB
Variable Type: Real, Array
Allowed Range: 1.0 ≤ length ≤ 100.0
Purpose: The beta (shape) factor in the hazard function for the injury. The user must supply NUMEIN values in column 6 of the data block.

Example Usage of EINAME, EISUSC, EITHRE, EIFACA and EFFACB:

```
*
*            EINAME            ORGNAM       EISUSC  EITHRE    EIFACA  EIFACB
*
EINJUGRP001 'PRODROMAL VOMIT'  'A-STOMACH'  1.      .5        2.        3.
EINJUGRP002 'DIARRHEA'         'A-STOMACH'  1.      1.        3.        2.5
EINJUGRP003 'PNEUMONITIS'      'A-LUNGS'    1.      5.        10.       7.
EINJUGRP004 'SKIN ERYTHEMA'    'A-SKIN'     1.      3.        6.        5.
EINJUGRP005 'TRANSEPIDERMAL'   'A-SKIN'     1.      10.       20.       5.
EINJUGRP006 'THYROIDITIS'      'A-THYROIDH' 1.      40.       240.      2.
EINJUGRP007 'HYPOTHYROIDISM'   'A-THYROIDH' 1.      2.        60.       1.3
```

6.9 Latent Cancer (LC) Induction Model

The cancer risk model included in the first public release version of MACCS was based on a linear-quadratic risk model (see MACCS *Model Description*). In response to recommendations presented in an NRC-sponsored reassessment of cancer risk models published in 1991 and referred to as LMF-132 (Abrahamson *et al.* 1991), the cancer risk model was updated in MACCS version 1.5.11.1 (Chanin *et al*. 1993) to include a piecewise linear risk function . The capability to exercise the linear-quadratic risk model was retained in MACCS 1.5.11.1 and MACCS2 although it is no longer recommended for the calculation of cancer induction risk.

6.9.1 MACCS Linear-Quadratic Dose-Response Model

The linear-quadratic risk model assumes that risk, *R*, increases linearly with increases in dose, *D*, at low doses and that risk increases quadratically with respect to dose at higher dose levels. The linear-quadratic dose-response function is of the form (International Commission on Radiological Protection 1991):

$$R(D) = D \bullet (a + \beta D).$$

The implementation of the linear-quadratic dose-response model in MACCS 1.5 was based on the recommendations of NRC-sponsored work (Evans 1990) and is described as follows. In the period modeled by EARLY, a linear-quadratic dose-response relationship is used if the dose to the target organ is less than a user-specified limit (MACCS ACTHRE input parameter).

The dose-response function used in this case was of the form:

$$R(D) = DOSE \bullet CFRISK \bullet (DOSEFA + DOSE \bullet DOSEFB) \bullet ACSUSC,$$

where

DOSE	=	50-year lifetime dose commitment to the target organ,
CFRISK	=	lifetime risk factor for cancer injury,
DOSEFA	=	the linear factor, α, of the dose dependence,
DOSEFB	=	the quadratic factor, β, of the dose dependence, and
ACSUSC	=	fraction of the population susceptible to the latent cancer.

If dose to the target organ is greater than the dose limit ACTHRE, the upper-bound linear dose-response relationship is used:

$$R(D) = \text{DOSE} \bullet \text{CFRISK} \bullet (\text{DOSEFA} + \text{ACTHRE} \bullet \text{DOSEFB}) \bullet \text{ACSUSC}$$

During the long-term phase modeled by CHRONC, it is assumed that exposure of the population will be limited to low levels by mitigative actions and therefore the quadratic term of the linear-quadratic cancer risk equation is ignored. Cancer risk is calculated using only the linear term, $R(D) = \alpha D$, of the linear-quadratic dose response function. Cancer risk from all pathways (groundshine, resuspension inhalation, and ingestion) is modeled with the linear dose-response function given below:

$$R(D) = \text{DOSE} \bullet \text{CFRISK} \bullet \text{DOSEFA} \bullet \text{ACSUSC}$$

where the meaning of DOSE and CFRISK depends on whether individual risk (groundshine and resuspension) or collective risk (ingestion and decontamination worker's doses) is being calculated.

The linear-quadratic model is not implemented in the MACCS2 sample problems. The quadratic form of the dose-response relationship is deactivated by assigning a 0 to the MACCS2 ACTHRE input parameter.

6.9.2 MACCS Piecewise Linear Dose-Response Function

In response to recommendations presented in LMF-132, the MACCS cancer risk model was updated in MACCS version 1.5.11.1 to include the capability to model a piecewise linear cancer risk function of the form:

$$R(D) = \alpha \bullet \frac{D}{\text{DDREF}} \qquad D < 0.2 \text{ Gy or } 0.1 \text{ Gy per hour}$$

$$R(D) = \alpha \bullet D \qquad D > 0.2 \text{ Gy or } 0.1 \text{ Gy per hour}$$

DDREF is defined as a "dose and dose rate reduction factor. " The LMF-132 report states that the DDREF is to be applied "when the total dose is less than 0.2 Gray, and for higher doses when the dose rate is less than 0.1 Gray per hour. " This guidance for the application of the DDREF is identical to the recommendations provided in ICRP 60. The DDREF is given a value of 2 in LMF-132 for central estimates of most cancer types. In contrast, for central estimates of breast and thyroid cancers the DDREF is assigned a value of 1 in LMF-132.

The user defines the lifetime dose commitment, MACCS2 input parameter DDTHRE, below which the DDREF is applied to cancer risk calculations for emergency-phase exposures. MACCS2 applies the DDREF to all of the dose calculations in the CHRONC module because exposures should always be less than 0.1 Gy per hour after the end of the emergency phase.

6.9.3 Input Data

In order for the code to produce cancer results, the cancers must be defined in this section. Sample problem A provides an example of the calculation of cancer risk based on doses to individual organs. An example of the implementation of ICRP 60 cancer risk factors based on the effective dose equivalent is provided in the MACCS2 series of sample problems denoted D.

Risk of latent cancer injury is calculated separately for each cancer syndrome. The risk factors for cancer injury are calculated using the same equations that are used to calculate cancer fatalities except that CIRISK is used instead of CFRISK.

Variable Name: NUMACA
Variable Type: Integer, Scalar
Allowed Range: $0 \leq$ value ≤ 10
Purpose: The number of different types of latent cancer effects that will be calculated. A value of 0 means that latent cancer effects will not be calculated.
Example Usage:

```
*
* NUMBER OF CANCER EFFECTS
*
LCNUMACA001    7
```

Note: The remaining parameters in this section are required only if NUMACA is greater than 0.

Variable Name: ACTHRE
Variable Type: Real, Scalar
Allowed Range: $0.0 \leq$ value ≤ 10.0 (sieverts)

Purpose: The lower dose limit for the linear dose-response relationship. For doses less than ACTHRE, the linear-quadratic relationship is used. This parameter should be assigned a value of 0 to deactivate the linear-quadratic risk model.

Note: The parameter ACTHRE is used only in the EARLY module. It is not used in the CHRONC module.

Example Usage:

```
*
* DOSE THRESHOLD FOR LINEAR DOSE RESPONSE (SIEVERTS)
*
LCACTHRE001  0.0
```

Variable Name: DDTHRE
Variable Type: Real, Scalar
Allowed Range: 0.0 ≤ value ≤ 1.0 (sieverts)
Purpose: The threshold dose for applying the dose-dependent reduction factor DDREFA. If the lifetime dose commitment incurred during the EARLY exposure period is less than DDTHRE, the risk of cancer from irradiation of that organ is reduced by a factor of DDREFA.

Example Usage:

```
*
* DOSE THRESHOLD FOR APPLYING THE DOSE-DEPENDENT REDUCTION FACTOR
*
LCDDTHRE001  0.2
```

Note: The next eight variables are supplied in a block of data as columns. An example of their use follows.

Variable Name: ACNAME
Variable Type: Character, Array
Allowed Range: 1 ≤ length ≤ 10
Purpose: The name of each type of latent cancer effect. The user may specify any name. Apostrophes are mandatory if there are any embedded blanks. The user must supply NUMACA values in column 1 of the data block.

Variable Name: ORGNAM
Variable Type: Character, Array
Allowed Range: 2 ≤ length ≤ 10
Purpose: The name of the target organ for each type of latent cancer effect. The target organ must be one of the organs listed in the organ definition data. The user must supply NUMACA values in column 2 of the data block.

Variable Name: ACSUSC
Variable Type: Real, Array
Allowed Range: $0.0 \leq \text{value} \leq 1.0$
Purpose: The fraction of the population that is susceptible to the latent cancer. The user must supply NUMACA values in column 3 of the data block.

Variable Name: DOSEFA
Variable Type: Real, Array
Allowed Range: $0.0 \leq \text{value} \leq 2.0$
Purpose: Defines the linear factor, α, of the dose dependence in the cancer risk model. The user must supply NUMACA values in column 4 of the data block.

Variable Name: DOSEFB
Variable Type: Real, array
Allowed Range: $0.0 \leq \text{value} \leq 2.0$
Purpose: Defines the quadratic factor, β, of the dose dependence in the cancer risk model which is used only by the EARLY module and not by the CHRONC module. Within EARLY, if the dose to the target organ is below ACTHRE, this parameter defines the quadratic term of the cancer dose-response function. The user must supply NUMACA values in column 5 of the data block. This parameter should be assigned a value of 0 to deactivate the linear-quadratic risk model.

Variable Name: CFRISK
Variable Type: Real, array
Allowed Range: $0.0 \leq \text{value} \leq 1.0$
Purpose: Lifetime risk factor for cancer death. For calculating risk to individuals, this parameter has the units risk/sievert, while for calculating collective risk from ingestion and decontamination exposures, it has the units cases/person-sievert. The user must supply NUMACA values in column 6 of the data block.

Variable Name: CIRISK
Variable Type: Real, array
Allowed Range: $0.0 \leq \text{value} \leq 1.0$
Purpose: Lifetime risk factor for cancer injury. For calculating risk to individuals, this parameter has the units risk/sievert, while for calculating collective risk from ingestion and decontamination exposures, it has the units cases/person-sievert. The user must supply NUMACA values in column 7 of the data block.

Variable Name: DDREFA
Variable Type: Real, array
Allowed Range: 1.0 ≤ value ≤ 10.0
Purpose: Dose-dependent reduction factor. If the lifetime dose commitment incurred during the EARLY exposure period is less than DDTHRE, the risk of cancer from irradiation of that organ is reduced by a factor of DDREFA. The user must supply NUMACA values in column 8 of the data block.

Example use of ACNAME, ACSUSC, DOSEFA, DOSEFB, CFRISK, CIRISK, and DDREFA based on EPA (1994) (*Estimating Radiogenic Risks*: EPA 402-R-93-076):

```
* EXAMPLE OF CANCER RISK FACTOR DEFINITION IMPLEMENTING EPA (1994: PP. 25-26)
*
LCNUMACA001   7
LCDDTHRE001   0.2
LCACTHRE001   0.0
*
*            ACNAME       ORGNAM      ACSUSC DOSEFA  DOSEFB  CFRISK  CIRISK  DDREFA
*
LCANCERS001 'Bladder     'L-BLAD WAL'   1.0   1.0     0.0   4.97E-3   9.94E–3   2.0
LCANCERS002 'Bone Sur'   'L-BONE SUR'   1.0   1.0     0.0   1.90E-4   2.71E–4   2.0
LCANCERS003 'Breast'     'L-BREAST'     1.0   1.0     0.0   4.62E-3   9.24E–3   1.0
LCANCERS004 'Colon'      'L-LOWER LI'   1.0   1.0     0.0   1.96E-2   3.56E–2   2.0
LCANCERS005 'Leukemia'   'L-RED MARR'   1.0   1.0     0.0   9.91E–3   1.00E–2   2.0
LCANCERS006 'Liver'      'L-LIVER'      1.0   1.0     0.0   3.00E-3   3.16E–3   2.0
LCANCERS007 'Lung'       'L-LUNGS'      1.0   1.0     0.0   1.43E-2   1.51E–2   2.0
LCANCERS008 'Stom./Eso.' 'L-STOMACH'    1.0   1.0     0.0   1.07E-2   1.18E–2   2.0
LCANCERS009 'Thyroid'    'L-THYROID'    1.0   1.0     0.0   6.40E-4   6.40E–3   2.0
LCANCERS010 'Remainder'  'L-EFFECTIVE'  1.0   1.0     0.0   2.92E-2   1.41E–1   2.0
```

Note: In regard to the above risk coefficients, the relative biological effectiveness (RBE) for alpha radiation for RED MARR dose is defined to be 1; for all other organs, the alpha radiation RBE is defined to be 20 (EPA 1994).

Example use of ACNAME, ACSUSC, DOSEFA, DOSEFB, CFRISK, CIRISK, and DDREFA based on ICRP 60 (International Commission on Radiological Protection 1991):

```
* EXAMPLE OF ICRP 60 CANCER RISK FACTOR DEFINITION
*
LCNUMACA001   1
LCDDTHRE001   0.2
LCACTHRE001   0.0
*
*            ACNAME    ORGNAM      ACSUSC  DOSEFA  DOSEFB  CFRISK CIRISK  DDREFA
LCANCERS001 'ICRP60' 'L-EFFECTIVE'   1.0     1.0     0.0     0.10   0.12    2.0
```

6.10 Generation of Consequence Distributions

Under the control of parameters supplied by the user on the EARLY and CHRONC input files, the EARLY and CHRONC modules can calculate a variety of different consequence measures to portray the impact of a facility accident on the surrounding region. The user has total control

over the results that will be produced. By choosing appropriate values in the user input files, the user can ensure that the code does not perform unnecessary calculations. This affords a great deal of flexibility but it also requires that the user anticipate which results will be of interest. If any are omitted, it is necessary to correct the user input and rerun the program.

In this regard, please remember that a result can only be produced if the model needed for its calculation has been previously defined in the appropriate section. If any results pertaining to health effects are requested, risk factors for that model must have been supplied in the sections entitled Early Fatality (EF), Early Injury (EI), and Latent Cancer (LC).

EARLY can produce ten different types of results. These are described in the next ten sections. Some of these types of results can also be calculated by CHRONC, but some cannot. For instance, both EARLY and CHRONC calculate cancer cases and population dose, but EARLY alone calculates early fatalities, and CHRONC alone calculates economic costs.

If the user requests EARLY to produce a result that can also be produced by CHRONC, the code will ensure that it will be produced by both EARLY and CHRONC. Whenever a result can be produced by both modules, this will be indicated in the following ten sections.

Neither EARLY nor CHRONC generate complementary cumulative distribution functions of the results that they calculate. As EARLY and CHRONC generate the requested consequence measures, those numbers are written to binary files for later processing into CCDFs.

CCDFs are generated by the OUTPUT module of MACCS2. It reads the binary files of consequence measures and automatically combines the results in a predetermined way. The user has no direct control over the OUTPUT module other than through the EARLY and CHRONC data blocks that control the generation of consequence measures.

The CCDF is an estimate of the distribution of consequence magnitudes. The variability of consequence values in MACCS2 CCDFs is due solely to the uncertainty of the weather conditions existing at the time of the accident.

If a consequence measure was calculated by both EARLY and CHRONC, the output module will present those results and their CCDFs separately for EARLY and CHRONC. Also, the output module will sum the results of EARLY and CHRONC and provide the CCDFs of their sums. The contribution of up to three sets of results generated by EARLY can be combined according to the weighting fractions described in Sections 6.1 and 6.6. The weighted sum of all consequence measures, calculated by summation of results from separate runs of EARLY, is presented at the beginning of each section of the listing produced by OUTPUT. Following the overall weighted sum, the results from each of its components are presented.

The following material describes the format of the listing produced by the OUTPUT module.

At the top of each page is printed the date and time of the run and a page number. The numbering of pages begins with the first page produced by the OUTPUT module. The leftmost 38 columns of the page provide the name of the consequence measure. These names are split into two parts: the general and the specific. For example, we have

"HEALTH EFFECTS CASES"

as the general name and

"ERL FAT/TOTAL 0–1609 KM"

as the specific part of the name. The consequence measure being presented on this line is the number of early fatality cases expected to occur in the circular region which begins at the release point and extends outward to a distance of 1609 km.

Going across the page from left to right, there are ten columns of numeric data which provide a summary of the CCDF generated by the OUTPUT module. These are described as follows:

PROB NON-ZERO	Conditional probability of having a nonzero consequence estimate, conditional on the occurrence of the release under consideration.
MEAN	The average (expected) consequence over all weather trials. This is calculated by taking the sum of all the products [(consequence value) × (associated probability of that value)] for each weather trial.
50TH QUANTILE	The median of the estimated distribution function.
90TH QUANTILE	Based on the estimated distribution function, there is a 10% chance this consequence magnitude will be exceeded.
95TH QUANTILE	Based on the estimated distribution function, there is a 5% chance this consequence magnitude will be exceeded.
99TH QUANTILE	Based on the estimated distribution function, there is a 1% chance this consequence magnitude will be exceeded.
99.5TH QUANTILE	Based on the estimated distribution function, there is a 0.5% chance this consequence magnitude will be exceeded.
PEAK CONS	The largest consequence magnitude obtained from the full set of weather trials which were examined.
PEAK PROB	The probability associated with the largest consequence magnitude.
PEAK TRIAL	In the series of weather samples, the sequence number of the weather trial that gave rise to the largest consequence magnitude. By going back to the ATMOS output listing, the user can determine the start time (day and hour) of this weather sequence.

6.11 Cases of a Given Health Effect

EARLY can calculate the number of health effect cases that will occur within a range of distances. The risk models for these health effects must have been previously defined in the proper section.

Note: Any cancer results requested here are automatically produced by CHRONC so that the results can be combined by OUTPUT. In the results calculated by CHRONC, the cancer values include direct exposure cancers in the population residing in the region as well as the indirect exposure cancers resulting from both (1) consumption of food and water produced in the region and (2) exposure of decontamination workers working in the region.

Variable Name: NUM1
Variable Type: Integer, Scalar
Allowed Range: $0 \leq \text{value} \leq 40$
Purpose: The number of results of this type to be calculated.
Example Usage:

```
*
* NUMBER OF DESIRED RESULTS OF THIS TYPE
*
TYPE1NUMBER 35
```

Note: The remaining parameters in this section are required only if NUM1 is greater than 0.

Variable Name: NAME
Variable Type: Character, Array
Allowed Range: $10 \leq \text{length} \leq 24$
Purpose: Defines the name of each Type 1 result for which the number of cases will be calculated. Depending on the value of NAME, six different types of results may be produced. They are listed below along with examples of their specification for input.

cases of early fatality:	'ERL FAT/TOTAL'
cases of a given early injury:	'ERL INJ/name of an injury'
cases of a given cancer death:	'CAN FAT/name of a cancer'
total cases of cancer death:	'CAN FAT/TOTAL'
cases of a given cancer injury:	'CAN INJ/name of a cancer'
total cases of cancer injury:	'CAN INJ/TOTAL'

Variable Name: I1DIS1
Variable Type: Integer, Array

Allowed Range: 1 ≤ value ≤ NUMRAD
Purpose: Defines the inner spatial interval of the region of interest for this result. The user must supply NUM1 values in column 2 of the data block.

Variable Name: I2DIS1
Variable Type: Integer, Array
Allowed Range: I1DIS1 ≤ value ≤ NUMRAD
Purpose: Defines the outer spatial interval of the region of interest for this result. The user must supply NUM1 values in column 3 of the data block.

Note: In order to obtain the CCDF tables of a consequence measure requested in this section, append the character string 'CCDF' to the line requesting that result as the fourth item on the data record. The CCDF tables will be printed on the list output file.

Example Usage:

```
*
* NUMBER OF DESIRED RESULTS OF THIS TYPE
*
TYPE1NUMBER 35
*
TYPE1OUT001 'ERL FAT/TOTAL'                1     26 CCDF (0 TO 1000 MILES)
TYPE1OUT002 'ERL INJ/PRODROMAL VOMIT'      1     26 CCDF
TYPE1OUT003 'ERL INJ/DIARRHEA'             1     26
TYPE1OUT004 'ERL INJ/PNEUMONITIS'          1     26
TYPE1OUT005 'ERL INJ/THYROIDITIS'          1     26
TYPE1OUT006 'ERL INJ/HYPOTHYROIDISM'       1     26
TYPE1OUT007 'ERL INJ/SKIN ERYTHEMA'        1     26
TYPE1OUT008 'ERL INJ/TRANSEPIDERMAL'       1     26
TYPE1OUT009 'CAN FAT/TOTAL'                1     26 CCDF
TYPE1OUT010 'CAN FAT/LUNG'                 1     26
TYPE1OUT011 'CAN FAT/THYROID'              1     26
TYPE1OUT012 'CAN FAT/BREAST'               1     26
TYPE1OUT013 'CAN FAT/GI'                   1     26
TYPE1OUT014 'CAN FAT/LEUKEMIA'             1     26
TYPE1OUT015 'CAN FAT/BONE'                 1     26
TYPE1OUT016 'CAN FAT/OTHER'                1     26
TYPE1OUT017 'CAN INJ/TOTAL'                1     26
TYPE1OUT018 'ERL FAT/TOTAL'                1     19 (0 TO 50 MILES)
TYPE1OUT019 'ERL INJ/PRODROMAL VOMIT'      1     19
TYPE1OUT020 'ERL INJ/DIARRHEA'             1     19
TYPE1OUT021 'ERL INJ/PNEUMONITIS'          1     19
TYPE1OUT022 'ERL INJ/THYROIDITIS'          1     19
TYPE1OUT023 'ERL INJ/HYPOTHYROIDISM'       1     19
TYPE1OUT024 'ERL INJ/SKIN ERYTHEMA'        1     19
TYPE1OUT025 'ERL INJ/TRANSEPIDERMAL'       1     19
TYPE1OUT026 'CAN FAT/TOTAL'                1     19
TYPE1OUT027 'ERL FAT/TOTAL'                1     12 (0 TO 10 MILES)
TYPE1OUT028 'ERL INJ/PRODROMAL VOMIT'      1     12
TYPE1OUT029 'ERL INJ/DIARRHEA'             1     12
TYPE1OUT030 'ERL INJ/PNEUMONITIS'          1     12
TYPE1OUT031 'ERL INJ/THYROIDITIS'          1     12
TYPE1OUT032 'ERL INJ/HYPOTHYROIDISM'       1     12
TYPE1OUT033 'ERL INJ/SKIN ERYTHEMA'        1     12
TYPE1OUT034 'ERL INJ/TRANSEPIDERMAL'       1     12
TYPE1OUT035 'CAN FAT/TOTAL'                1     12
```

6.12 Early Fatality Radius

It may be of interest to know the greatest distance at which a specified level of early fatality risk is exceeded. The user can obtain information about the size of the region in which early fatalities are predicted to occur by setting the variable RISTNR (defined below) to 0.

Variable Name: NUM2
Variable Type: Integer, Scalar
Allowed Range: $0 \leq \text{value} \leq 10$
Purpose: The number of results of this type to be calculated.
Example Usage:

```
*
* NUMBER OF DESIRED RESULTS OF THIS TYPE
*
TYPE2NUMBER  3
```

Variable Name: RISTHR
Variable Type: Real, Scalar
Allowed Range: $0.0 \leq \text{value} \leq 1.0$
Purpose: Defines the risk threshold used for calculating the fatality radius (reported in kilometers). The user must supply NUM2 values in column 1 of the data block. This is the only array in the data block.

Note: In order to obtain the CCDF tables of a consequence measure requested in this section, append the character string 'CCDF' to the line requesting that result as the second item on the data record. The CCDF tables will be printed on the list output file.

Example Usage:

```
*
* NUMBER OF DESIRED RESULTS OF THIS TYPE
*
TYPE2NUMBER  3
*
*            FATALITY RISK THRESHOLD
*
TYPE2OUT001 0.0   DISTANCE AT WHICH ANY FATALITIES OCCURRED
TYPE2OUT002 0.005 DISTANCE AT WHICH FATALITY RISK EXCEEDS 0.005
TYPE2OUT003 0.5   DISTANCE AT WHICH FATALITY RISK EXCEEDS 0.5
```

6.13 Population Exceeding a Dose Threshold

Within the EARLY module alone, it may be of interest to know how many people received doses exceeding certain levels. This information can be obtained by requesting the production of the result described below. It is important to remember that this consequence measure is calculated

solely on the basis of the dose calculations performed in the EARLY module. There is no provision for examining an analogous result for the CHRONC module, or for determining the number of people whose total dose from both EARLY and CHRONC exceeded a certain level.

The user can specify two type of doses to be used for the comparison: acute and lifetime. The acute dose is used by the code to calculate early fatality and early injury health effects (see Section 6.7). The lifetime dose is used to calculate cancer fatality and cancer injury health effects (see Section 6.9). The lifetime dose represents the 50-year dose commitment to a reference adult that results from exposure during the emergency phase (EARLY) time period.

Variable Name: NUM3
Variable Type: Integer, Scalar
Allowed Range: $0 \leq \text{value} \leq 10$
Purpose: The number of results of this type to be calculated.

Variable Name: NAME
Variable Type: Character, Scalar
Allowed Range: $2 \leq \text{length} \leq 10$
Purpose: Defines the name of the organ to which the dose threshold applies. This organ must be found on the list of organs, ORGNAM. The user must supply NUM3 values in column 1 of the data block.

Variable Name: DOSTH3
Variable Type: Real, Array
Allowed Range: $0.0 \leq \text{value} \leq 1000.0$ (sieverts)
Purpose: Defines the dose threshold that will be used for counting the population. The user must supply NUM3 values in column 2 of the data block.

Note: In order to obtain the CCDF tables of a consequence measure requested in this section, append the character string 'CCDF' to the line requesting that result as the fourth item on the data record. The CCDF tables will be printed on the list output file.

Example Usage:

```
*
TYPE3NUMBER 3
*
*           ORGAN NAME  DOSE THRESHOLD (SIEVERTS)
*
TYPE3OUT001 'A-RED MARR'      1.5
TYPE3OUT002 'A-LUNGS'         5.0
TYPE3OUT003 'L-EDEWBODY'      0.05
```

6.14 Average Individual Risk

Average individual risk is obtained by taking the sum of the risk values in all sectors at a given distance and dividing it by the number of sectors.

Note: Any cancer results requested here are automatically produced by CHRONC so that the results can be combined by OUTPUT. When this result is produced by CHRONC, it is only a measure of the risk from direct exposure to people at that distance. Direct exposure includes the cloudshine, groundshine, and inhalation dose to the people living around the facility. The risk presented in this result does not include doses from ingestion of food and water by the region's population or doses to decontamination workers working in the region.

Variable Name: NUM4
Variable Type: Integer, Scalar
Allowed Range: $0 \leq$ value ≤ 20
Purpose: The number of results of this type to be calculated.

Variable Name: I1DIS4
Variable Type: Integer, Array
Allowed Range: $1 \leq$ value $\leq$ NUMRAD
Purpose: Radial spatial interval of the distance of interest. The user must supply NUM4 values in column 1 of the data block.

Variable Name: NAME
Variable Type: Character, Array
Allowed Range: $10 \leq$ length ≤ 24
Purpose: Name of the health effect risk. Average individual risk may be calculated for five types of health effects.

risk of early fatality:	'ERL FAT/TOTAL'
risk of a given early injury:	'ERL INJ/name of an injury'
risk of a given cancer death:	'CAN FAT/name of a cancer'
risk of cancer death:	'CAN FAT/TOTAL'
risk of a given cancer injury:	'CAN INJ/name of a cancer'

The user must supply NUM4 values of NAME in column 2 of the data block.

Note: In order to obtain the CCDF tables of a consequence measure requested in this section, append the character string 'CCDF' to the line requesting that result as the third item on the data record. The CCDF tables will be printed on the output file.

Example Usage:

```
*
* 360-DEGREE AVERAGE RISK OF A GIVEN EFFECT AT A GIVEN DISTANCE.
*
*  POSSIBLE TYPES OF EFFECTS ARE:
*     'ERL FAT/TOTAL'
*     'ERL INJ/INJURY NAME'
*     'CAN FAT/CANCER NAME'
*     'CAN INJ/TOTAL'
*
* NUMBER OF DESIRED RESULTS OF THIS TYPE
*
TYPE4NUMBER    5
*     RADIAL INDEX      TYPE OF EFFECT
*
TYPE4OUT001 1           'ERL FAT/TOTAL'
TYPE4OUT002 2           'ERL FAT/TOTAL'
TYPE4OUT003 3           'ERL FAT/TOTAL'
```

6.15 Population Dose

The total long-term population dose to a given organ resulting from the contamination of a specified region can be calculated. The user must supply the name of the target organ as well as the inner and outer spatial intervals of the region of interest. If only the EARLY module is being run, this result reflects only the pathways considered by EARLY. If both EARLY and CHRONC are being run, the population dose from all pathways is included in the calculation. The CHRONC pathways include both (1) food and water ingestion doses resulting from material deposited in the region and (2) doses to decontamination workers working in the region. On the output listing, population dose is presented in units of person-sieverts.

Variable Name: NUM5
Variable Type: Integer, Scalar
Allowed Range: $0 \leq \text{value} \leq 10$
Purpose: The number of results of this type to be calculated.

Variable Name: NAME
Variable Type: Character, Scalar
Allowed Range: $2 \leq \text{length} \leq 10$
Purpose: Defines the name of the organ to which the population dose applies. This organ must be found on the list of organs, ORGNAM. The user must supply NUM5 values in column 1 of the data block.

Variable Name: I1DIS5
Variable Type: Integer, Array
Allowed Range: $1 \leq \text{value} \leq \text{NUMRAD}$

Purpose: Defines the inner spatial interval of the region of interest for this result. The user must supply NUM5 values in column 2 of the data block.

Variable Name: I2DIS5
Variable Type: Integer, Array
Allowed Range: I1DIS5 ≤ value ≤ NUMRAD
Purpose: Defines the outer spatial interval of the region of interest for this result. The user must supply NUM5 values in column 3 of the data block.

Note: In order to obtain the CCDF tables of a consequence measure requested in this section, append the character string 'CCDF' to the line requesting that result as the fourth item on the data record. The CCDF tables will be printed on the list output file.

Example Usage:

```
*
* TOTAL POPULATION DOSE TO A GIVEN ORGAN BETWEEN TWO DISTANCES.
*
* NUMBER OF DESIRED RESULTS OF THIS TYPE
*
TYPE5NUMBER     3
*
*                     ORGAN       I1DIS5   I2DIS5
*
TYPE5OUT001       'L-EDEWBODY'      1        12       CCDF (0-10 MILES)
TYPE5OUT002       'L-EDEWBODY'      1        19       CCDF (0-50 MILES)
TYPE5OUT003       'L-EDEWBODY'      1        26       CCDF (0-1000 MILES)
```

6.16 Centerline Dose vs. Distance

If the straight-line plume model was chosen (IPLUME=1), the code can keep track of the centerline dose between a range of distances for the various pathways. The centerline dose at each distance is treated as a separate result and OUTPUT will generate a set of results for each of the radial spatial intervals within the specified range. The user must supply a value for the pathway name in all cases. The centerline dose vs. distance results may be obtained for the following pathways.

PATHNM	DESCRIPTION
CLD	cloudshine dose (EARLY only)
GRD	groundshine dose (EARLY and CHRONC)
INH ACU	dose from inhalation of the passing plume (EARLY only)
INH LIF	dose from inhalation of the passing plume (EARLY only)
TOT ACU	total dose from all direct exposure pathways (EARLY and CHRONC)
TOT LIF	total dose from all direct exposure pathways (EARLY and CHRONC)
RES LIF	dose from inhalation of resuspended material after plume passage (EARLY and CHRONC)
RES ACU	dose from inhalation of resuspended material after plume passage (EARLY and CHRONC)

Depending on the exposure pathways specified, this result will be calculated by EARLY and/or CHRONC. If both EARLY and CHRONC are being run, then CHRONC will automatically produce all of the results for the pathways it considers. If pathways 'GRD', 'RES LIF', or 'TOT LIF' are chosen, those results are automatically produced by CHRONC so that the results can be combined by OUTPUT. The other pathway values are only produced by EARLY.

The user must specify the organ doses and exposure pathways for which Type 6 results are to be output. In prior versions of MACCS the acute dose and the lifetime dose were specified by requesting RES ACU or RES LIF and INH ACU or INH LIF, for resuspension and direct inhalation, respectively. In MACCS2, the distinction between acute and lifetime doses is made via the organ name prefixes A- or L-. The ACU and LIF references in the pathway name are ignored in MACCS2. The new code does not distinguish between RES ACU and RES LIF; both flags indicate resuspension dose. Likewise, INH ACU and INH LIF both refer to direct inhalation from the cloud.

To illustrate, consider the following fragment from an EARLY input file for prior versions of MACCS which request Type 6 results for (1) the total acute dose to red marrow, (2) the total lifetime effective dose from all pathways, (3) the acute dose from resuspension to red marrow, and (4) the lifetime effective dose from resuspension.

```
TYPE6OUT001    'RED MARR'     'TOT ACU'     1    19
TYPE6OUT002    'EDEWBODY'     'TOT LIF'     1    26
TYPE6OUT003    'RED MARR'     'RES ACU'     1    19
TYPE6OUT004    'EDEWBODY'     'RES LIF'     1    26
```

In a MACCS2 input file this fragment could be rewritten with minimal change as

```
TYPE6OUT001      'A-RED MARR'      'TOT ACU'     1      19
TYPE6OUT002      'L-EDEWBODY'      'TOT LIF'     1      26
TYPE6OUT003      'A-RED MARR'      'RES ACU'     1      19
TYPE6OUT004      'L-EDEWBODY'      'RES LIF'     1      26
```

The A- and L- prefixes of the organ names control whether an acute or lifetime dose is output for the requested pathway. In MACCS2, unlike MACCS, the pathway name controls only the exposure pathway for which the centerline dose is output.

The specification of a LIF pathway with an A- prefixed organ or an ACU pathway with an L-prefixed organ will not result in a calculational error or an error message and termination of code calculations. Since MACCS2 ignores the ACU and LIF components of the pathway code, equivalent numerical output results would be produced if the above-listed fragment is rewritten as

```
TYPE6OUT001      'A-RED MARR'      'TOT LIF'     1      19
TYPE6OUT002      'L-EDEWBODY'      'TOT ACU'     1      26
TYPE6OUT003      'A-RED MARR'      'RES LIF'     1      19
TYPE6OUT004      'L-EDEWBODY'      'RES ACU'     1      26
```

The descriptive titles for these results on the list output file will match the pathway names specified in the EARLY input file. That is, if misleading titles are requested as above, the same misleading titles will be output as follows:

CENTERLINE DOSE AT SOME DISTANCES (SV)

A-RED MARR	TOT LIF	0–0.2 KM
L-EDEWBODY	TOT LIF	0–0.2 KM
A-RED MARR	RES LIF	0–0.2 KM
L-EDEWBODY	RES ACU	0–0.2 KM

The interpretations of the four centerline dose results above are (1) total dose from all pathways to red marrow using the dose reduction factors for acute health effects, (2) total effective dose from all pathways using a 50-year commitment period for inhalation, (3) resuspension dose to red marrow using the dose reduction factors for acute health effects, and (4) EDE from resuspension using a 50-year commitment period for inhalation. In future versions of MACCS2, the definition of pathway names will be revised.

An alternative method for examining centerline dose from EARLY alone is to set the output control variable, IPRINT, to a value greater than 0. If this is done, a listing of dose vs. distance for all the organs will be printed on the list output. Since this is written for each weather trial, it is recommended that this be done only for single weather trial runs.

Variable Name:	NUM6
Variable Type:	Integer, Scalar
Allowed Range:	$0 \leq$ value ≤ 10
Purpose:	The number of results of this type to be calculated. This result is only available when straight-line plume dispersion (IPLUME=1) and radial evacuation (EVATYP='RADIAL') are being utilized. If IPLUME>1 or EVATYP='NETWORK', an input error will be diagnosed and execution terminated.

Note: Unless IPLUME=1, you must specify a value of 0.

The direct exposure pathways are groundshine, cloudshine, plume inhalation, and inhalation of resuspended material. The pathway name is ignored when 'A-SKIN' is specified as the target organ because direct dry deposition is the only exposure pathway considered for skin.

Variable Name:	ORGNAM
Variable Type:	Character, Scalar
Allowed Range:	$2 \leq$ length ≤ 10

Purpose: Defines the names of the organs for which centerline doses are to be reported. These organs must be found on the list of organs, ORGNAM. The user must supply NUM6 values in column 1 of the data block.

Variable Name: PATHNM
Variable Type: Character, Scalar
Allowed Range: 3 ≤ length ≤ 7
Purpose: Defines the names of the pathways for which centerline doses are to be reported. The name of each pathway *must be on the list of pathways*. The user must supply NUM6 values in column 2 of the data block.

Variable Name: I1DIS6
Variable Type: Integer, Array
Allowed Range: 1 ≤ value ≤ NUMRAD
Purpose: Defines the inner spatial interval of the region of interest for this result. The user must supply NUM6 values in column 3 of the data block.

Variable Name: I2DIS6
Variable Type: Integer, Array
Allowed Range: I1DIS6 ≤ value ≤ NUMRAD
Purpose: Defines the outer spatial interval of the region of interest for this result. The user must supply NUM6 values in column 4 of the data block.

Note: In order to obtain the CCDF tables of a consequence measure requested in this section, append the character string 'CCDF' to the line requesting that result as the fifth item on the data record. The CCDF tables will be printed on the list output file.

Example Usage:

```
*
* NUMBER OF DESIRED RESULTS OF THIS TYPE
*
TYPE6NUMBER     3
*
*              ORGNAM           PATHNM      I1DIS6   I2DIS6
*
TYPE6OUT001    'A-RED MARR'     'TOT ACU'      1        19    (0–50 MILES)
TYPE6OUT002    'A-LUNGS'        'TOT ACU'      1        19    (0–50 MILES)
TYPE6OUT003    'L-EDEWBODY'     'TOT LIF'      1        26    (0–1000 MILES)
```

6.17 Centerline Risk vs. Distance

If the straight-line plume model was chosen (IPLUME=1), the code can keep track of centerline risk between two specified spatial intervals for the various types of health effects. Centerline risk

is calculated for hypothetical individuals located directly under the path of the plume who are exposed to the Gaussian peak of the air and ground concentrations. The centerline risk at each distance in the region is treated as a separate result and OUTPUT will generate a distribution of the consequence measure for each of the spatial intervals within the specified range.

Note: Any cancer results requested here are automatically produced by CHRONC so that the results can be combined by OUTPUT. When this result is produced by CHRONC, it is a measure only of the risk from direct exposure to people at those distances. Direct exposure includes the cloudshine, groundshine, and inhalation dose to the resident population in the specified region. The risk presented in this result does not include societal doses from ingestion of any food and water contaminated as a result of the accident or doses to decontamination workers working in the contaminated area.

Variable Name: NUM7
Variable Type: Integer, Scalar
Allowed Range: $0 \leq$ value ≤ 10
Purpose: The number of results of this type to be calculated. This result is available only when straight-line plume dispersion (IPLUME=1) and radial evacuation (EVATYP='RADIAL') are being utilized. If IPLUME>1 or EVATYP='NETWORK', an input error will be diagnosed and execution terminated.

Note: Unless IPLUME=1, you must specify a value of 0.

Variable Name: NAME
Variable Type: Character, Array
Allowed Range: $10 \leq$ length ≤ 24
Purpose: Defines the option for results of Type 7, centerline risk of a given type of health effect. Depending on the value of NAME, six different types of results may be produced. They are listed below along with examples of their use. The user must supply NUM7 values in column 1 of the data block.

risk of early fatality:	'ERL FAT/TOTAL'
risk of a given early injury:	'ERL INJ/name of an injury'
risk of a given cancer death:	'CAN FAT/name of a cancer'
risk of cancer death:	'CAN FAT/TOTAL'
risk of a given cancer injury:	'CAN INJ/name of a cancer'
risk of cancer injury:	'CAN INJ/TOTAL'

Variable Name: I1DIS7
Variable Type: Integer, Array
Allowed Range: $1 \leq$ value $\leq$ NUMRAD

Purpose: Defines the inner spatial interval of the region of interest for this result. The user must supply NUM7 values in column 2 of the data block.

Variable Name: I2DIS7
Variable Type: Integer, Array
Allowed Range: I1DIS7 ≤ value ≤ NUMRAD
Purpose: Defines the outer spatial interval of the region of interest for this result. The user must supply NUM7 values in column 3 of the data block.

Note: In order to obtain the CCDF tables of a consequence measure requested in this section, append the character string 'CCDF' to the line requesting that result as the fourth item on the data record. The CCDF tables will be printed on the list output file.

Example Usage:

```
*
* CENTERLINE RISK OF A GIVEN EFFECT VS DISTANCE
*
* NUMBER OF DESIRED RESULTS OF THIS TYPE
*
TYPE7NUMBER   2
*
*                      NAME       I1DIS7   I2DIS7
*
TYPE7OUT001      'ERL FAT/TOTAL'    1        19      (0-50 MILES)
TYPE7OUT002      'CAN FAT/TOTAL'    1        26      (0-1000 MILES)
```

6.18 Population-Weighted Risk

The population-weighted health effect risk is obtained by calculating the cases of a health effect in a certain region and then dividing by the total population in the region. It takes account of both the population distribution and the wind rose.

Note: Any cancer results requested here are automatically produced by CHRONC so that the results can be combined by OUTPUT. When this result is produced by CHRONC, it is a measure only of the risk from direct exposure to the resident population in the specified region. The direct exposure pathways are cloudshine, groundshine, direct inhalation, and resuspension inhalation.

The population-weighted risk in CHRONC is calculated by estimating the expected cancer cases and dividing that value by the current population in the region. The risk presented in this result does not include the societal pathways of (1) ingestion of contaminated food and water or (2) doses to decontamination workers working in the area.

Variable Name: NUM8
Variable Type: Integer, Scalar

Allowed Range: $0 \leq$ value ≤ 20
Purpose: The number of results of this type to be calculated.

Variable Name: NAME
Variable Type: Character, Array
Allowed Range: $10 \leq$ length ≤ 24
Purpose: Defines the names of the Type 8 results to be calculated: population-weighted risk of a given type of health effect. Depending on the value of NAME, six different types of results may be produced. These six options are listed below along with examples of their use. The user must supply NUM8 values in column one of the data block.

risk of early fatality:	'ERL FAT/TOTAL'
risk of a given early injury:	'ERL INJ/name of an injury'
risk of a given cancer death:	'CAN FAT/name of a cancer'
risk of cancer death:	'CAN FAT/TOTAL'
risk of a given cancer injury:	'CAN INJ/name of a cancer'
risk of cancer injury:	'CAN INJ/TOTAL'

Variable Name: I1DIS8
Variable Type: Integer, Array
Allowed Range: $1 \leq$ value $\leq$ NUMRAD
Purpose: Defines the inner spatial interval of the region of interest for this result. The user must supply NUM8 values in column 2 of the data block.

Variable Name: I2DIS8
Variable Type: Integer, Array
Allowed Range: $1 \leq$ value $\leq$ NUMRAD
Purpose: Defines the outer spatial interval of the region of interest for this result. The user must supply NUM8 values in column 3 of the data block.

Note: In order to obtain the CCDF tables of a consequence measure requested in this section, append the character string 'CCDF' to the line requesting that result as the fourth item on the data record. The CCDF tables will be printed on the list output file.

Example Usage:

```
*
* NUMBER OF DESIRED RESULTS OF THIS TYPE
*
TYPE8NUMBER   2
*
*                    NAME       I1DIS8   I2DIS8
*
TYPE8OUT001    'ERL FAT/TOTAL'    1        5     CCDF (0-EXCL ZONE + 1 MILE)
TYPE8OUT002    'CAN FAT/TOTAL'    1       12     CCDF (0-10 MILES)
```

6.19 Peak Dose at a Distance

The Type A result, peak dose at a distance, was developed as a result of the addition of the network evacuation option. Type 6 results, centerline dose vs. distance, can be output only when the straight-line plume option without rotation (IPLUME=1) is selected. However, the network evacuation model may not be utilized when IPLUME is set to 1. The Type A result was added to allow the reporting of individual doses for network evacuation scenarios. This result is based on the total dose at each distance over a selected range of distances in a manner analogous to the Type 6 results. The implementation of this result differs from Type 6 results in that there is no capability for reporting a breakdown of individual doses by pathway.

This result is requested in the EARLY input file and produced for each emergency response scenario. There is no dependence on population data. The dose is reported for phantom individuals assumed to be present at all locations. If the CHRONC module is exercised, this result is then automatically produced by CHRONC as well.

The overall weighted sum of results represents the combination of doses calculated by EARLY and CHRONC. Caution should be taken with the use of the overall results obtained by combining the emergency response cohorts because peak doses for the various cohorts may occur at different angular locations. Summation of these values is most likely meaningless if multiple plume segments are allowed to travel in different directions (*i.e.*, when NUMREL is greater than 1 *and* IPLUME is equal to 2 or 3).

Variable Name: NUMA
Variable Type: Integer, Scalar
Allowed Range: $1 \leq$ value ≤ 10
Purpose: Defines the number of results of this type being requested.

Variable Name: NAME
Variable Type: Character, Array
Allowed Range: $1 \leq$ length ≤ 10
Purpose: Defines the name of the organ for this dose measure.

Variable Name: I1DISA
Variable Type: Integer, Array
Allowed Range: $1 \leq$ value $\leq$ NUMRAD
Purpose: Defines the inner boundary of the region for which this result is to be calculated.

Variable Name: I2DISA
Variable Type: Integer, Array

Allowed Range: 1 ≤ value ≤ NUMRAD
Purpose: Defines the outer boundary of the region for which this result is to be calculated.
Example Usage:

```
*
* PEAK DOSE FOUND ON THE SPATIAL GRID
*
TYPEANUMBER    2
*                    NAME      I1DISA     I2DISA
*
TYPEAOUT001     'L-EFFECTIVE'    1          26          (0-1609 KM)
TYPEAOUT002      'A-RED MARR'    1          26          (0-1609 KM)
```

6.20 Peak Dose at an (r,θ) Location

The Type B result provides the peak dose at a user-specified (r,θ) location. Type 6 and A results differ from Type B results in that they are limited to specifying the centerline dose under the plume. Type B results report individual doses at locations other than directly under the plume(s). Type B results also differ from Type 6 results in that there is no capability for reporting individual doses by pathway for Type B results.

Although the Type B result is only requested on the EARLY file, if CHRONC is being exercised, the Type B results will be generated by CHRONC as well as by EARLY, and the results obtained presented both separately and in combination. The Type B results correspond to the total dose estimated to be incurred by a representative phantom individual assumed to reside at a particular (r,θ) location on the spatial grid. User input population data have no bearing on the generation of this consequence measure. Only direct exposure is considered in the generation of this result. Exposures resulting from the ingestion of contaminated food and water are not included. Also, the generation of this result takes full account of any mitigative action models activated by exceedance of user-specified dose thresholds.

The location for which this result is to be calculated is specified as a radial index (which can range from 1 to NUMRAD) and an angular index (which can range from 1 to 16). Following the convention used in other parts of the code, an angular index of 1 "points" to an individual assumed to be located north of the release point, with successive directions rotating clockwise around the compass. An angular index of 16 points to the NNW direction.

If the controlling card (record identifier NUMBOUT001) is omitted, the calculations proceed on the assumption that the Type B results are not being requested.

Variable Name: NUMB
Variable Type: Integer, Scalar
Allowed Range: 0 ≤ value ≤ 32
Purpose: Defines the number of results of this type being requested.

Variable Name: NAME
Variable Type: Character, Array
Allowed Range: 1 ≤ length ≤ 10
Purpose: Defines the name of the organ for this dose measure.

Variable Name: IRAD_B
Variable Type: Integer, Array
Allowed Range: 1 ≤ value ≤ NUMRAD
Purpose: Defines the inner boundary of the region for which this result is to be calculated.

Variable Name: IANG_B
Variable Type: Integer, Array
Allowed Range: 1 ≤ value ≤ 16
Purpose: Defines the angular index to the location at which this result is to be calculated.

Example Usage:

```
*
* PEAK DOSE FOUND ON THE SPATIAL GRID
*
TYPEBNUMBER    2
*                    NAME     IRAD_B     IANG_B
*
TYPEBOUT001      'L-EFFECTIVE'   1          1           (0-1609 KM)
TYPEBOUT002       'A-RED MARR'   1          1           (0-1609 KM)
```

7.0 CHRONC Input File

The CHRONC module simulates the events that occur following the emergency-phase time period modeled by EARLY. Various long-term protective actions may be taken during this period to limit radiation doses to acceptable levels. The parameters defining these protective actions are under user control, and all of them are described in this chapter.

CHRONC calculates the individual health effects that result from both (1) direct exposure to contaminated ground and from inhalation of resuspended materials as well as (2) indirect health effects caused by the consumption of contaminated food and water by individuals who could reside both on and off of the computational grid. CHRONC also calculates the economic costs of the long-term protective actions as well as the cost of the emergency response actions that were modeled in the EARLY module.

It is up to the user to specify the various parameters needed for these calculations. There are no default values for the parameters described in this section. In addition to specifying the characteristics of the model, the user has complete control over the output produced by CHRONC and must explicitly specify which results are to be produced. All of this information is supplied through the CHRONC input file, and all of the input parameters are described in this chapter.

Four long-term exposure pathways are modeled in MACCS2 to predict the long-term radiation exposures from accidental radiological releases: groundshine, resuspension inhalation, ingestion of contaminated food, and ingestion of contaminated drinking water. The models utilized in predicting the doses from these four pathways are described individually in the following sections. The dose from each of the long-term pathways is evaluated for each spatial element surrounding the accident site. For the intermediate phase, only the groundshine and resuspension inhalation exposure pathways are considered.

MACCS2 incorporates two options for the user regarding food ingestion models: (1) the food ingestion model of MACCS and (2) the new COMIDA-based food ingestion model. A brief discussion of the differences between these two models is provided in Section 3.1.2 of this document. The MACCS food ingestion model is based on the simple principle that the long-term dose produced by any radionuclide to an organ via a pathway is the product of (1) the ground concentration of the radionuclide, (2) the integrated transfer factor for the radionuclide to human intake for the pathway, and (3) the ingestion dose conversion factor. There are a number of limitations of the MACCS food ingestion model. A main drawback of this model is that the integrated transfer factors for food pathway radionuclides not included in the MACCS sample problems must be derived by the user external to the code. The calculational procedures are difficult and error prone. In contrast, the COMIDA2-based ingestion model is based on a preprocessor that can be exercised by the user, with consideration of site-specific data, if such data are available.

The radiation dose for the exposure pathways of the intermediate and long-term phases is calculated for each of the coarse spatial elements using the initial ground concentration under the

plume centerline calculated by the ATMOS module. Similar to the early exposure pathways, MACCS2 uses an off-centerline correction factor and the ground concentration under the plume centerline to estimate the initial ground concentration at the off-centerline region of various spatial elements. In contrast to EARLY, however, which utilizes a Gaussian histogram subdividing each 22.5-degree compass sector, the CHRONC calculations do *not* utilize the Gaussian histogram subdivisions in any respect.

For all of the CHRONC calculations, relating to both direct exposure (groundshine and resuspension as well as food and water ingestion) the Gaussian is averaged over the entire 22.5-degree compass sector to yield a single off-centerline geometric adjustment factor. A description of the intermediate and long-term phase off-centerline correction factor is provided in Section 3.2.1 of the MACCS *Model Description*.

7.1 Overview of CHRONC Mitigative Action Models

CHRONC incorporates calculations for two distinct periods of time, the intermediate phase and the long-term phase, as follows.

7.1.1 Intermediate Phase

The mitigative action model for the intermediate phase is very simple. If the intermediate-phase dose criterion is satisfied, the resident population is assumed to be present and subject to radiation exposure from groundshine and resuspension for the entire intermediate phase. If the intermediate-phase exposure leads to doses in excess of DSCRTI, then the population is assumed to be relocated to uncontaminated areas for the entire intermediate phase, with a corresponding per-capita economic cost defined by the user through the input variable POPCST (see Section 7.6).

The user can configure the calculations with an intermediate phase having a duration as short as zero (essentially, no intermediate phase, and a long-term phase beginning immediately upon conclusion of the emergency phase), or as long as 1 year. The calculations of food and water ingestion doses are based on the ground contamination levels estimated to be present at the beginning of the intermediate phase.

7.1.2 Long-Term Phase

The mitigative action models for the long-term exposure phase implemented in MACCS2 differ slightly from the corresponding models implemented in MACCS. The reason for this is that the decisions on mitigative action in the long-term phase are based on two sets of independent actions: (1) decisions relating to whether land at a specific location and time is suitable for human habitation, "habitability," and (2) decisions relating to whether land at a specific location and time is suitable for agricultural production, "farmability."

Since the COMIDA2-based food-chain model of MACCS2 differs markedly from the MACCS food-chain model, it is necessary to provide a description of how both of these food-chain models interact with the long-term mitigative actions triggered by habitability considerations. As a start, several concepts fundamental to MACCS2 that are unchanged from MACCS are

discussed: (1) division between farm and population, (2) habitability decision making, (3) farmability decision making, and (4) primacy of habitability over farmability decisions. These are discussed in Sections 7.1.3 through 7.1.6.

7.1.3 Division Between Farm and Population

The long-term phase incorporates a fundamental distinction between the consequences associated with (1) agricultural uses of land (denoted AREA-DEPENDENT on the code output), and (2) habitation of land by humans (denoted POP.-DEPENDENT on the code output).

7.1.4 Habitability Decision Making

Habitability decision making can result in three possible outcomes: (1) land is immediately habitable, (2) land will be habitable after decontamination, and (3) land will be habitable after a combination of decontamination and interdiction. The parameters controlling the choice of these outcomes are described in Sections 7.4 through 7.6.

7.1.4.1 Land Immediately Habitable

The first step in the decision making regarding habitability is a determination of whether, in the absence of any mitigative actions, the land is suitable for habitation during the long-term exposure period. This is done by comparing (1) the projected individual dose calculated by the code for the long-term dose projection period (input variable TMPACT, described in Section 7.4) against (2) the user-specified dose criterion for long-term exposure (input variable DSCRLT, described in Section 7.4). If the projected individual dose does not exceed DSCRLT, then the land is considered immediately habitable, and no further tests regarding habitability are made.

7.1.4.2 Land Habitable after Decontamination

If the land is not immediately habitable, a progressive series of actions are evaluated, beginning with decontamination for the various user-defined decontamination levels. The influence of decontamination is twofold: (1) the decontamination factor (DF) (input variable DSRFCT, described in Section 7.5) is a linear scaling factor by which the doses are reduced, and (2) weathering and radioactive decay occurring during the decontamination period also reduce doses.

The influence of these two factors is considered to be independent. That is, if the user specifies a DF of 3, and a decontamination period of 1 year, the doses to habitants at the conclusion of decontamination will generally be less than one-third of the doses that would be incurred in the absence of decontamination because both decontamination and weathering and decay would ordinarily serve to reduce subsequent doses. Continuing this example, if weathering and decay resulted in a twofold reduction in the level of contamination at the end of the 1-year period, the combined effect of decontamination with a DF of 3 and weathering and decay would be to reduce subsequent doses by a factor of six.

7.1.4.3 Land Habitable after Decontamination and Interdiction

If the maximum-level decontamination effort is insufficient to allow habitability at the conclusion of the decontamination period, then the dose-reduction impacts of decontamination *in*

combination with temporary interdiction are evaluated to determine if the habitability criterion is satisfied at the conclusion of the decontamination and interdiction periods. As above, the DF obtained from decontamination is considered to be independent of the dose reduction obtained from weathering and decay. The maximum interdiction period considered by the code is 30 years.

The effect of weathering and decay over the interdiction period is calculated with an interpolation technique that utilizes precalculated doses for predefined interdiction periods of 1, 5, and 30 years, as fixed in the code. These three predefined interdiction periods all begin at the conclusion of the maximum-level decontamination effort, which is a user-specified parameter that can range up to 1 year.

7.1.4.4 Limits on Interdiction Duration

For the two separate land uses, farm and population, mitigative actions are chosen that will yield the lowest-cost approach to satisfying the applicable criteria. For farms, the criteria define acceptable levels of foodstuff contamination, while for populations, the criteria define acceptable levels of radiation exposures to resident individuals. The maximum duration of temporary farmland interdiction that can be selected by the code is 8 years, while the corresponding maximum duration for interdiction of population is 30 years. If the maximum-duration interdiction of either land use is insufficient to satisfy the respective criteria for use, then that land use is assumed to be permanently interdicted, or condemned.

7.1.4.5 Test for Cost Effectiveness

As described above, the code evaluates potential mitigative actions for both farm and population in order to determine if it is possible to satisfy the applicable criteria for acceptable exposures. If either of these criteria, for farm or land, cannot be satisfied after the maximum-duration interdiction, then that land use is permanently interdicted, or condemned. However, the use of land for farm or population can also be condemned if the total cost involved in restoring it to use would exceed the user-specified value of the property. If this is done, the use of land for either farm or population or both can be condemned. When a land use is condemned for either reason (*i.e.,* the dose criteria cannot be satisfied, or the cost of reclamation exceeds the property's value), the code calculates the corresponding long-term food and population exposures as zero, and assesses an economic cost for the condemnation of the property.

7.1.5 Farmability Decision Making

The decision on whether land is suitable for farming is based on prior evaluations of its suitability for human habitation. The farmland interdiction models differ slightly, depending on which of the two food-chain models is being utilized. For a description of the interdiction model utilized for the COMIDA2-based food-chain model of MACCS2, see Section 7.10.2. For a description of the interdiction model utilized for the MACCS food-chain model, see Section 7.11.3.

7.1.6 Primacy of Habitability over Farmability Decisions

For both food-chain model options, farm production is allowed to occur only when the environmental contamination levels are sufficiently low to allow habitation. However, the converse condition *is* allowed. That is, if land is not suitable for farming, the existence of that condition imposes no constraint on its habitability.

7.2 Problem Identification Data

The problem identification data block is used to identify the CHRONC input file and the calculations that are being performed.

Variable Name:	CHNAME
Variable Type:	Character, Scalar
Allowed Range:	$1 \leq$ length ≤ 80
Purpose:	Describes this particular CHRONC input file. Choose a text string that briefly describes the input data file, the assumptions and the model choices of this particular application of the CHRONC module.

This text will be printed on all of the MACCS2 list output as an aid in identifying the results. It is not necessary to include the date of the run since that information is automatically included.

Example Usage:

```
*
CHCHNAME001  'SURRY CHRONC INPUT FOR FINAL NUREG-1150 CALCULATIONS'
```

7.3 Emergency-Response Cost Data

The emergency-response cost data block is used to define the compensation costs for people who are subject to the emergency actions of evacuation, sheltering, or relocation. Evacuation is solely under the control of models defined in the EARLY module. Relocation of individuals can occur either during the EARLY emergency phase or during the CHRONC intermediate-phase period. In the presentation of economic cost results (see Section 7.15), the costs associated with the emergency phase (*i.e.,* evacuation and short-term relocation) are reported separately from the costs associated with the intermediate phase (*i.e.,* per-diem costs for relocation for the duration of the intermediate phase).

Variable Name:	EVACST
Variable Type:	Real, Scalar
Allowed Range:	$0.0 \leq$ value ≤ 1000.0 (dollars/person-day)
Purpose:	Defines the daily cost of compensation for evacuees and short-term relocatees who are removed from their homes as a result of radiation

exposure during the emergency-phase period. This value could include the following components: food, housing, transportation, and lost income.

Example Usage:

```
*
CHEVACST001    27.00
```

Variable Name: RELCST
Variable Type: Real, Scalar
Allowed Range: 0.0 ≤ value ≤ 1000.0 (dollars/person-day)
Purpose: Defines the daily cost of compensation for individuals removed from their homes due to intermediate-phase relocation modeled by CHRONC. The costs should include the following components: food, housing, transportation, lost income, and replacement of lost personal property.

Example Usage:

```
*
CHRELCST001    27.00
```

7.4 Long-Term Protective Action Data

The long-term protective action data block defines the intermediate and long-term action time periods as well as the maximum doses that people are allowed to receive during these periods. The maximum allowable doses defined here are used to determine the need for relocation, decontamination, interdiction, or condemnation.

In all versions of MACCS, the exposure period considered by CHRONC was fixed within the code to a value of one million years. That is, the code calculated both individual and collective doses assuming that the population remained present for the entire million-year exposure period. The principal reason for this was to be consistent with the assumptions used in the CRAC2 code (Ritchie *et al.* 1984).

MACCS2 allows the user to define the long-term exposure period through the TMPACT input variable. It is suggested that 30 years is a reasonable value since that is the value used by the EPA in its Superfund guidance (EPA 1991).

Variable Name: DUR_INTPHAS
Variable Type: Real, Scalar
Allowed Range: 0.0 ≤ value ≤ 3.1536E+7 (seconds) (1 year)
Purpose: Defines the duration of the intermediate-phase period. This period follows the emergency-phase period, EARLY variable ENDEMP. The value of ENDEMP is defined in the EARLY input file and passed to CHRONC.

The MACCS input variable TMIPND is no longer utilized to define the intermediate-phase period. Previously, this phase was defined as ending at TMIPND seconds after arrival of the

plume at a spatial interval. TMIPND is no longer processed from the CHRONC input file. Within the code however, the variable TMIPND remains, and it is calculated as follows:

TMIPND = DUR_INTPHAS + ENDEMP

Example Usage:

```
*
DUR_INTPHAS    604800.   (7 DAYS, NO INTERMEDIATE PHASE)
```

Variable Name: TMPACT
Variable Type: Real, Scalar
Allowed Range: TMIPND ≤ value ≤ 1.E+10 (seconds)
Purpose: Defines the long-term dose projection period. Protective actions such as decontamination, or decontamination followed by interdiction are evaluated to determine if the exposure of an individual during this period can be reduced so that it does not exceed the long-term phase allowable dose (DSCRLT) to the long-term phase critical organ (CRTOCR).

If temporary interdiction is required, individuals are returned to their homes at a time when it is estimated that they will receive a dose of exactly DSCRLT to the critical organ over an exposure period of this duration.

Once individuals are returned to their home, their long-term doses are integrated over an exposure period specified by input variable EXPTIM.

Example Usage:

```
*
CHTMPACT001    1.58E8  (5 YEARS)
```

Variable Name: DSCRTI
Variable Type: Real, Scalar
Allowed Range: 0.0 ≤ value ≤ 1.E+5 (sieverts)
Purpose: Defines the intermediate-phase dose criterion. This is the maximum allowable direct exposure dose commitment to the long-term critical organ (CRTOCR) during the intermediate-phase period (TMIPND). The direct exposure pathways considered in this evaluation are groundshine and resuspension inhalation.

If the intermediate-phase dose criterion (DSCRTI) is exceeded for an individual remaining at some location for the entire intermediate-phase period, the resident population there is relocated for the entire intermediate-phase period.

Example Usage:

```
*
CHDSCRTI001    1.0E5  (NO INTERMEDIATE-PHASE RELOCATION)
```

Variable Name: DSCRLT
Variable Type: Real, Scalar
Allowed Range: 1.E–20 ≤ value ≤ 1.E+5 (sieverts)
Purpose: Defines the long-term phase dose criterion. This is the maximum allowable direct exposure dose commitment to the long-term critical organ (CRTOCR) during the long-term phase action period (TMPACT).

Direct exposure in the CHRONC module is defined as the sum of the groundshine and resuspension doses. The user-specified value of DSCRLT determines whether land is considered suitable for habitation during the long-term phase period. This parameter affects the food ingestion pathway indirectly since the code does not model agricultural production in locations (and time periods) where the land is uninhabitable.

If this dose criterion is exceeded in any spatial element during the long-term action period, mitigative actions such as decontamination or decontamination followed by temporary interdiction are employed to limit the dose to the critical organ so that the allowable dose level is not exceeded in that spatial grid element. The long-term critical organ is defined below in this data block.

If it is not possible to reduce doses to this level in a cost-effective manner, the property is condemned and the resident population is permanently relocated.

Example Usage:

```
*
CHDSCRLT001    0.04   (2 REM IN FIRST YEAR, 0.5 REM PER YEAR FOR YEARS 2-5)
```

Variable Name: EXPTIM
Variable Type: Real, Scalar
Allowed Range: 0.0 ≤ value ≤ 1.E10 (seconds) (a period of from 0 to 317 years)
Purpose: Specifies the duration of the long-term exposure period considered by CHRONC.

If a zero is assigned to the EXPTIM parameter, then no long-term phase is defined, and only exposures incurred during the intermediate phase are assessed by CHRONC.

The CHRONC exposure period is *not* measured from the start of the long-term phase. The period begins when people are allowed to return to their property. For example, if the code utilizes 5 years of interdiction (referenced to the beginning of the long-term phase) at a specific location to satisfy the dose criterion, and EXPTIM is set to 30 years, the doses to resident population will be calculated for an exposure period that begins at t=5 years, and ends at t=35 years.

The accrual of doses from food and water ingestion is not affected by the user-specified value of EXPTIM. This accrual is not strictly associated with the population surrounding the facility.

The ingestion of contaminated food and water is assumed to result in doses to an unspecified population.

Example Usage:

```
*
CHEXPTIM001    9.45E8  (30 YEARS PER EPA STANDARD DEFAULT EXPOSURE FACTORS)
```

Variable Name: CRTOCR
Variable Type: Character, Scalar
Allowed Range: $2 \leq \text{length} \leq 10$
Purpose: Defines the long-term phase critical organ. If the total direct exposure dose commitment to this organ in a grid element would exceed the dose criteria in either the intermediate phase period (TMIPND) or the long-term phase period (TMPACT), protective actions would be taken to limit that dose to acceptable levels.

Example Usage:

```
*
CHCRTOCR001    'L-EFFECTIVE'
```

7.5 Decontamination Plan Data

The decontamination plan data block defines the decontamination actions that may be taken during the long-term period to reduce doses to acceptable levels. These data define the decontamination strategies that are possible, their effectiveness, and their cost. Each decontamination level represents an alternative strategy that would reduce the projected long-term groundshine and resuspension doses by a factor called the "dose reduction factor. " Up to three levels of decontamination can be defined.

The objective of decontamination is to reduce projected doses below the long -term dose criterion in a cost-effective manner. If the maximum decontamination level is insufficient to restore an area to immediate habitability, a period of temporary interdiction following the maximum decontamination level is considered in order to allow for dose reduction through radioactive decay and weathering. If the property cannot be made habitable within 30 years or if the cost of reclaiming the habitability of the property exceeds the cost of condemning it, the property will be condemned and permanently withdrawn from use.

Decontamination cost is divided into two categories and these two types of cost are calculated separately. Farm-dependent decontamination cost represents the cost of farmland decontamination in a grid element. Farm-dependent decontamination cost is a function of the area of the grid element devoted to agriculture. Population-dependent decontamination represents the cost of nonfarmland decontamination. Population-dependent decontamination cost is a function of the population residing in the grid element. The strategy of decontamination within a grid element is independent of the type of area being decontaminated.

For a given decontamination level, the same decontamination time and effectiveness apply to both farmland and nonfarmland, but the two costs are unique and are maintained independently for each type of decontamination. Owing to the requirement that the recovery of property must be cost-effective, it is possible, in a given element, that decontamination of nonfarmland is not performed, but farmland is instead condemned.

Decontamination of a grid element serves to reduce the contamination level in that element by the dose reduction factor associated with the decontamination effort being applied. Everything else being equal, a decontamination factor of 10 will cause the integrated dose over any exposure period to be reduced by a factor of 10.

During the decontamination period, which is assumed to begin at the end of the intermediate-phase time period (beginning of the long-term phase period), the population from areas that will be decontaminated is assumed to be relocated to uncontaminated areas, and the associated cost from loss of use is calculated in the same manner as temporary interdiction.

While engaged in cleanup efforts, decontamination workers are assumed to wear respiratory protection devices. Therefore, they accumulate only groundshine doses. These doses and the cancer fatalities that they induce contribute to the aggregated doses and cases of cancer fatalities tabulated in the MACCS2 output.

Decontamination reduces direct exposure doses (both groundshine and resuspension) caused by contamination of land and buildings. Many decontamination processes (*e.g.*, plowing, fire-hosing) reduce groundshine and resuspension doses by washing surface contamination down into the ground. Since these processes may not move contamination out of the root zone, the WASH-1400-based economic cost model of MACCS2 assumes that farmland decontamination reduces direct exposure doses to farmers without reducing uptake of radioactivity by root systems. Thus, decontamination of farmland does not reduce the ingestion doses produced by consumption of crops that are contaminated by root uptake.

Variable Name: LVLDEC
Variable Type: Integer, Scalar
Allowed Range: 1 ≤ value ≤ 3
Purpose: Defines the number of decontamination levels that can be utilized.
Example Usage:

```
*
CHLVLDEC001    2
```

Variable Name: TIMDEC
Variable Type: Real, Array
Allowed Range: 1.E–6 ≤ value ≤ 3.15E7 (seconds) (1 year)
Purpose: Defines the time required for completion of each of the decontamination levels. The user must define a decontamination time for each of the LVLDEC decontamination levels. Decontamination begins at the end of the

intermediate phase (TMIPND). The values must be monotonically increasing.

Example Usage:

```
*
CHTIMDEC001    5.184E6   1.0368E7   (60, 120 DAYS)
```

Variable Name: DSRFCT
Variable Type: Real, Array
Allowed Range: 1.01 ≤ value ≤ 100.0 (unitless)
Purpose: Defines the effectiveness of the various decontamination levels in reducing dose. A dose reduction factor of 3 means that the resulting population dose at that location will be reduced to one-third of what it would be without decontamination. The values specified must be monotonically increasing.

Example Usage:

```
*
CHDSRFCT001    3.  15.
```

Variable Name: CDFRM
Variable Type: Real, Array
Allowed Range: 1.0 ≤ value ≤ 1.E+5 (dollars/hectare)
Purpose: Defines the farmland decontamination cost. A value must be supplied for each of the LVLDEC decontamination levels and the values must be monotonically increasing.

Example Usage:

```
*
CHCDFRM0001    562.5  1250.
```

Variable Name: CDNFRM
Variable Type: Real, Array
Allowed Range: 1.0 ≤ value ≤ 1.E+5 (dollars/person)
Purpose: Defines the nonfarmland decontamination cost. A value must be supplied for each of the LVLDEC decontamination levels and the values must be monotonically increasing.

Example Usage:

```
*
CHCDNFRM001    3000.  8000.
```

Note: The remaining parameters in this section are used only to calculate the dose received from decontamination activities.

Variable Name: FRFDL
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0 (unitless)

Purpose: Defines the fraction of the farmland decontamination cost that is due to labor. A value must be supplied for each of the LVLDEC decontamination levels.

Example Usage:

```
*
CHFRFDL0001    .3  .35
```

Variable Name: FRNFDL
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0 (unitless)
Purpose: Defines the fraction of the nonfarmland decontamination cost that is due to labor. A value must be supplied for each of the LVLDEC decontamination levels.

Example Usage:

```
*
CHFRNFDL001    .7  .5
```

Variable Name: TFWKF
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0 (unitless)
Purpose: Defines the fraction of the decontamination period (TIMDEC) that a farmland decontamination worker spends in the contaminated area. A value must be supplied for each of the LVLDEC decontamination levels.

Example Usage:

```
*
CHTFWKF0001    .10  .33
```

Variable Name: TFWKNF
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0 (unitless)
Purpose: Defines the fraction of the decontamination period (ITMDEC) that a nonfarmland decontamination worker spends in the contaminated area during the decontamination period. A value must be supplied for each of the LVLDEC decontamination levels.

Example Usage:

```
*
CHTFWKNF001    .33  .33
```

Variable Name: DLBCST
Variable Type: Real, Scalar
Allowed Range: 1.0 ≤ value ≤ 1.E+6 (dollars/man-year)
Purpose: Defines the labor cost of a decontamination worker.

Example Usage:

```
*
CHDLBCST001    35000.
```

7.6 Interdiction Plan Cost Data

The interdiction plan cost data block defines the parameters needed to calculate the cost of interdiction. The data supplied here are combined with data in the Site Data file and the regional characteristics data in the course of the calculations.

The model used in MACCS2 for assessing the cost of interdiction is based on the model described in WASH-1400, Appendix 6. It is currently used to calculate the economic cost of loss of use during both decontamination and temporary interdiction periods.

Variable Name: DPRATE
Variable Type: Real, Scalar
Allowed Range: 0.0 ≤ value ≤ 1.0 (per year)
Purpose: Defines the depreciation rate that applies to property improvements during a period of interdiction. This depreciation rate is intended to account for the loss of value of buildings and other structures resulting from a lack of habitation and maintenance.

Example Usage:

```
*
CHDPRATE001    .20
```

Variable Name: DSRATE
Variable Type: Real, Scalar
Allowed Range: 0.0 ≤ value ≤ 1.0 (per year)
Purpose: Defines the expected rate of return from land, buildings, equipment, *etc.* For example, the inflation-adjusted real mortgage rate for land and buildings could be used.

Example Usage:

```
*
CHDSRATE001    .12
```

Variable Name: POPCST
Variable Type: Real, Scalar
Allowed Range: 1.E–6 ≤ value ≤ 1.E+6 (dollars/person)
Purpose: Defines the per capita removal cost for temporary or permanent relocation of population and businesses in a region rendered uninhabitable during the long-term phase time period. This cost is assessed if any of the following actions are required: decontamination alone, decontamination followed by

interdiction, or condemnation. This value should be derived in a way that takes account of both personal and corporate income losses for a transitional period as well as moving expenses.

Example Usage:

```
*
CHPOPCST001    5000.
```

7.7 Groundshine Weathering Data

The groundshine weathering definition data block defines the groundshine weathering equation from Gale, Miller, and Fisher (1964). The groundshine weathering relationship is defined as

$$GW(t) = GWCOEF(1) \bullet \exp[-\ln(2) \bullet t/TGWHLF(1)] + \ldots + GWCOEF(n) \bullet \exp[-\ln(2) \bullet t/TGWHLF(n)]$$

where $GW(t)$ represents the groundshine weathering at time t, given the weathering coefficients, GWCOEF, and the weathering half-lives, TGWHLF. The user must specify the number of terms, n, in the relationship and the values for the weathering coefficients and weathering half-lives.

Variable Name: NGWTRM
Variable Type: Integer, Scalar
Allowed Range: $1 \leq$ value ≤ 2
Purpose: Defines the number of terms in the groundshine weathering relationship.
Example Usage:

```
*
CHNGWTRM001    2
```

Variable Name: GWCOEF
Variable Type: Real, Array
Allowed Range: $1.0E{-}20 \leq$ value ≤ 1.0 (unitless)
Purpose: Defines the array of NGWTRM coefficients in the groundshine weathering equation.
Example Usage:

```
*
CHGWCOEF001    0.5  0.5
```

Variable Name: TGWHLF
Variable Type: Real, Array
Allowed Range: $1.E{-}6 \leq$ value $\leq 1.E{+}12$ (seconds)
Purpose: Defines the array of NGWTRM half-lives in the groundshine weathering equation.

Example Usage:

```
*
CHTGWHLF001    1.6E7   2.8E9
```

7.8 Resuspension Weathering Data

The resuspension weathering definition data block defines the resuspension weathering equation. The resuspension weathering relationship is defined as:

$$RW(t) = RWCOEF(1) \bullet \exp[-\ln(2) \bullet t/TRWHLF(1)] + \ldots + RWCOEF(n) \bullet \exp[-\ln(2) \bullet t/TRWHLF(n)]$$

where $RW(t)$ represents the resuspension weathering at time t, given the weathering coefficients, RWCOEF, and the weathering half-lives, TRWHLF. The user must specify the number of terms, n, in the relationship and the values for the weathering coefficients and weathering half-lives. The user must specify the number of terms, n, in the relationship and the values for the weathering coefficients and weathering half-lives.

Variable Name: NRWTRM
Variable Type: Integer, Scalar
Allowed Range: $1 \leq$ value ≤ 3
Purpose: Defines the number of terms in the resuspension weathering relationship.
Example Usage:

```
*
CHNRWTRM001    3
```

Variable Name: RWCOEF
Variable Type: Real, Array
Allowed Range: 1.0E–20 ≤ value ≤ 1.0 (per meter)
Purpose: Defines the array of NRWTRM coefficients in the resuspension weathering equation.
Example Usage:

```
*
CHRWCOEF001  1.0E-5   1.0E-7  1.0E-9
```

Variable Name: TRWHLF
Variable Type: Real, Array
Allowed Range: 1.E–6 ≤ value ≤ 1.E+12 (seconds)
Purpose: Defines the array of NRWTRM half-lives in the resuspension weathering equation.
Example Usage:

```
*
CHTRWHLF001  1.6E7  1.6E8  1.6E9      (6 MONTHS, 5 YEARS, 50 YEARS)
```

7.9 Regional Characteristics Data

The regional characteristics data block defines the aggregate economic and agricultural characteristics of the area surrounding the accident site.

If mitigative actions are necessary to restrict exposure to allowable levels, these data are used to evaluate the cost-effectiveness of those actions. For instance, if the average property values supplied here indicate that reclaiming a piece of land will cost more than the cost of condemning it, the land will be condemned instead of reclaimed.

Once a set of actions at a certain distance is decided upon, these actions may be "rotated" around the circle if the user has chosen the option of IPLUME=1 or IPLUME=2 as defined in Section 6.2.2. In some of these wind directions, there could be an extremely valuable property. It is implicit in our calculation method that the cost-effectiveness test cannot take account of this nonhomogeneity of the valuation field because of the need for performing a rotation of the chosen actions around the circle.

The choice of actions is always determined by the aggregate characteristics of the region, but the calculation of the resulting consequence measures can be done in two different ways, depending on the value of the input variable POPFLG, which is defined in Section 6.3.

When a uniform population distribution is being used (POPFLG='UNIFORM'), all of the data in this section are used for the calculation of the CHRONC consequence measures. However, if the user requests that a Site Data file be utilized (POPFLG='FILE'), the first four parameters defined in this section are not actually used in the calculations though they all must be supplied. The values corresponding to these four parameters are obtained from the Site Data file for each spatial element on the computational grid.

Variable Name: FRACLD
Variable Type: Real, Scalar
Allowed Range: 1.E-6 ≤ value ≤ 1.0 (unitless)
Purpose: Defines the fraction of the site region covered by land. The remainder is assumed to be water.

Note: If a Site Data file is being used (POPFLG='FILE'), the value of this input parameter is not used by the code; nevertheless a valid parameter value must be supplied.

Example Usage:

```
*
CHFRACLD001    0.95
```

Variable Name: FRCFRM

Variable Type: Real, Scalar
Allowed Range: 1.E–6 ≤ value ≤ 1.0 (unitless)
Purpose: Defines the average fraction of land in the region devoted to farm production. The land area under cultivation is as follows:

cultivated area = total area • FRACLD • FRCFRM.

Note: If a Site Data file is being used (POPFLG='FILE'), the value of this input parameter is not used by the code; nevertheless a valid parameter value must be supplied.

Example Usage:

```
*
CHFRCFRM001    0.382   VIRGINIA
```

Variable Name: FRMPRD
Variable Type: Real, Scalar
Allowed Range: 0.0 ≤ value ≤ 1.E+5 (dollars/hectare)
Purpose: Defines the value of the average annual farm production (gross sales) in the region.

Note: If a Site Data file is being used (POPFLG=FILE), the value of this input parameter is not used by the code; nevertheless a valid parameter value must be supplied.

Example Usage:

```
*
CHFRMPRD001    371.0  VIRGINIA
```

Variable Name: DPFRCT
Variable Type: Real, Scalar
Allowed Range: 0.0 ≤ value ≤ 1.0 (unitless)
Purpose: Defines the fraction of annual farm production (gross sales) in the region resulting from dairy production.

Note: If a Site Data file is being used (POPFLG=FILE), the value of this input parameter is not used by the code; nevertheless a valid parameter value must be supplied.

Example Usage:

```
*
CHDPFRCT001    0.198  VIRGINIA
```

Variable Name: VALWF
Variable Type: Real, Scalar
Allowed Range: 1.E–6 ≤ value ≤ 1.E+6 (dollars/hectare)
Purpose: Defines the value of farm wealth in the region. This value should include both publicly and privately owned grazing lands, farmland, farm buildings,

and nonrecoverable farm machinery, as well as any publicly owned infrastructure serving the farm industry.

Example Usage:

```
*
CHVALWF0001    2613.0  SURRY
```

Variable Name: FRFIM
Variable Type: Real, Scalar
Allowed Range: 0.0 ≤ value ≤ 1.0 (unitless)
Purpose: Defines the fraction of farm wealth in the region due to improvements. This value includes farm buildings, and nonrecoverable machinery, as well as any infrastructure such as silos or irrigation, which is devoted exclusively to the support of farming.

Example Usage:

```
*
CHFRFIM0001    0.25  SURRY
```

Variable Name: VALWNF
Variable Type: Real, Scalar
Allowed Range: 1.E–6 ≤ value ≤ 1.E+6 (dollars/person)
Purpose: Defines the value of the nonfarm wealth in the region. Nonfarm wealth includes all public and private property not associated with farming that would be unusable if the region was rendered either temporarily or permanently uninhabitable. This value should include the cost of land, buildings, infrastructure, and the cost of any nonrecoverable equipment or machinery.

Example Usage:

```
*
CHVALWNF001    84000.  VIRGINIA
```

Variable Name: FRNFIM
Variable Type: Real, scalar
Allowed Range: 0.0 ≤ value ≤ 1.0 (unitless)
Purpose: Defines the fraction of nonfarm wealth in the region due to improvements. This value includes buildings and infrastructure such as roads and utilities, as well as any nonrecoverable equipment or machinery.

Example Usage:

```
*
CHFRNFIM001    0.8
```

7.10 New COMIDA2-Based Food Ingestion Model

If the user wishes to use the newly implemented COMIDA2-based food ingestion model, this is accomplished by setting FDPATH='NEW'. When this is done, MACCS2 utilizes a binary data file written by COMIDA2, the .BIN file, which contains the results of the COMIDA2 food-chain

modeling calculations. The MACCS2 user chooses which .BIN file to use with the input variable BIN_FILE.

The farmland interdiction and cost model implemented in conjunction with the COMIDA-based food chain model was developed with the intention that it be as close as possible to the farmland interdiction and cost model of WASH-1400, as preserved in the present version of MACCS2.

7.10.1 Modeling of Agricultural Countermeasures

Aside from the specification of the name of the binary file, only three input variables are used in the CHRONC input file to control the operation of the COMIDA2-based food-chain model. These are DOSEMILK, DOSEOTHR, and DOSELONG—loosely equivalent to the input parameters PSCMILK, PSCOTH, and GCMAXR of the MACCS food-chain model, which define the farmland interdiction criteria.

DOSEMILK and DOSEOTHR define the maximum allowable food ingestion dose from milk crops and nonmilk crops respectively during the year of the accident. DOSELONG defines the maximum allowable long-term annual dose to an individual from ingestion of the combination of milk and nonmilk crops.

The MACCS food model input variables PSCMILK, PSCOTH, and GCMAXR are specified in terms of maximum allowable ground concentrations for each food radionuclide. The new variables DOSEMILK, DOSEOTHR, and DOSELONG are specified in terms of maximum individual dose resulting from all food pathway radionuclides combined.

LASTACUM, a COMIDA2 input parameter, specifies the duration of the ingestion dose period. MACCS2 calculates the accumulated societal dose starting with the year that the land satisfies the human consumption criteria DOSEMILK and DOSEOTHR, with the exposure period ending in the LASTACUM year after the accident. The allowable range for the LASTACUM variable is from 1 to 50 years. The value of the LASTACUM variable is defined in the COMIDA2 user input file. It is communicated to MACCS2 as part of the header information on the .BIN file written by COMIDA2.

Consistent with the MACCS interdiction model, the maximum farmland interdiction period considered by MACCS2 is 8 years. Land that cannot be returned to production after 8 years is condemned. MACCS2 will also condemn land that cannot be returned to production within LASTACUM years when the COMIDA2 model is used and the LASTACUM input variable is assigned a value less than 9.

To preserve the functionality of the MACCS food-chain model, agricultural countermeasures are always subordinate to the code's evaluation of habitability. That is, if land is uninhabitable because projected groundshine and resuspension doses exceed the long-term dose criterion DSCRLT, agricultural production at that location is not allowed.

Furthermore, if the resident population is never allowed to return, either because of a failure to meet the dose criterion, or because the costs of allowing the population to return would exceed the value of the property, then the farmland is also assumed to be condemned, irrespective of the

projected doses from food ingestion. If the farmland is condemned, none of the additional tests described below are performed. The costs associated with the condemnation of the farmland are based on the value of the property, input variable VALWF.

If the habitability dose criterion specified by the user is met, the following tests are performed by the code to determine the level of interdiction of agricultural production. The second year following the accident, year 2, is the first year for which the long-term ingestion dose criterion (DOSELONG) is evaluated. Milk and crop disposal during the year of the accident are triggered if the habitability criterion (DSCRLT) is exceeded in the year of the accident or if the DOSELONG criterion is exceeded in year 2 following the accident. If neither DSCRLT or DOSELONG lead to the triggering of milk and nonmilk crop disposal, then the individual criteria for the first year's milk (DOSEMILK) and the first year's nonmilk crops (DOSEOTHR) are examined separately to find if either is exceeded. The disposal of milk and/or nonmilk crops is triggered if the projected ingestion dose for these two categories exceeds the DOSEMILK and/or DOSEOTHR criteria. The first-year dose criteria are evaluated using the consumption rates specified by the COMIDA2 input variable CONSUM_RATES.

Milk and crop disposal costs are calculated only for the year of the accident. Beginning in the second year after the accident, acceptability of food production is evaluated by comparing the projected individual dose for year 2 with DOSELONG.

Note: For the purposes of this section, and MACCS2, "years" are defined as successive periods with a duration of 365.25 days, each beginning on the anniversary of the fallout event. COMIDA (and COMIDA2), however, both utilize "years" with durations of exactly 365 days.

If the projected individual dose for the second year does not exceed the dose criterion DOSELONG, the production of that year's agricultural production and the production from all subsequent years is allowed. Implicit in the model is the assumption that the food doses resulting from successive years of production do not increase with time. Also, just as with the MACCS food-chain model, the long-term interdiction of farmland applies to *all* crop categories, and there is no provision for long-term interdiction of a subset of the crops.

If the projected individual dose from the second year of agricultural production exceeds the dose criterion, the projected doses from up to eight successive annual periods are each examined in order to determine if production can be resumed within the first 9 years after the accident.

If the projected doses in each of the years 2 through 9 exceed DOSELONG, no further tests are performed and the farmland is treated as if it were condemned. When farmland is condemned, the associated cost is the market value of the farmland, VALWF, with the dollar values for market value reported on the output listing as FARM DEPENDENT CONDEMNATION COST.

If the projected doses for one of the years examined satisfy the long-term dose criterion, agricultural production is assumed to resume in that year. In that case, societal ingestion doses are assessed for the period ending with the LASTACUM'th year.

For example, if DOSELONG is satisfied in year 3, and LASTACUM has a value of 10, societal doses are accrued for the period denoted as years 3–10, an exposure period with a duration of 8 years. Since agricultural production was not allowed in the first and second years, economic costs for 2 years of interdiction are assessed using the WASH-1400 economic cost model for farmland. The WASH-1400 model calculates the cost of temporary interdiction as the depreciation of the farm's land and improvements (see variables VALWF and FRFIM), and as specified by the depreciation rates for land and improvements (see input variables DSRATE and DPRATE).

First-Year Crop Disposal Costs

The economic cost of milk and/or nonmilk crop disposal during year 1 is modeled as the economic costs assessed for the loss of sales. The two crop disposal cost calculations, however, consistent with CRAC2, are treated differently, as follows.

If the disposal of the first year's milk production is triggered because the dose criterion DOSEMILK is exceeded, milk disposal costs are assessed as 0.25 of annual milk sales (see variables FRMPRD and DPFRCT). The rationale for the reduction in milk disposal costs by the application of the 0.25 adjustment factor was based on the assumption that cows would be taken off pasture and fed uncontaminated feed, allowing dairy production to resume after one-quarter of a year. In order to maintain consistency with the MACCS food-chain model, the application of the fixed 0.25 adjustment factor on milk disposal costs has also been implemented for the COMIDA2 food-chain model implemented in MACCS2.

It is noted that the model implemented in MACCS and MACCS2 for crop disposal costs, and the 0.25 fudge factor for lost dairy sales, is not based on WASH-1400 because WASH-1400 did not account for crop disposal costs. CRAC2, in contrast to WASH-1400, *did* implement separate milk and nonmilk crop disposal costs, providing the technical basis for the MACCS model to assess such costs. CRAC2, however, in assessing the costs of milk and nonmilk crop disposal, assessed a milk disposal cost based on the full year's dairy sales, and not the 0.25 of dairy sales used in the MACCS cost model.

The technical basis for the 0.25 adjustment factor for milk disposal is not mentioned in the MACCS *Model Description*, but it was based on the assumption that dairy cows spend only a fraction of the year on pasture and obtain most of their food from stored feed. The 0.25 adjustment factor is preserved in MACCS2 in order to maintain consistency with MACCS.

7.10.2 Input Variables for COMIDA2-Based Food Model

This section describes the specification of MACCS2 input parameters that are used to control the code's operation when the COMIDA2-based food-chain model is being used. Very few input variables are defined on the CHRONC input file and appear below. The majority of the input parameters of interest are defined on the COMIDA2 input files, described in Section 3 of Volume 2 of this report.

Variable Name: FDPATH
Variable Type: Character, Scalar

Allowed Value: 'NEW' or 'OLD'
Purpose: Specifies whether the "old" food-chain model of MACCS, or the "new" COMIDA2-based food model of MACCS2 is to be used in the calculations. If the value NEW is specified, the remaining data records in this section must be supplied. If the value OLD is specified, the remaining data records in this section are not processed.

Note: If NEW is specified, the user must ensure that lifetime dose (L-) calculations for two organs, effective and thyroid, have been requested in the organ definition data (see Section 6.4).

Example Usage:

```
*
CHFDPATH001  'NEW'
```

Variable Name: BIN_FILE
Variable Type: Character, Scalar
Allowed Range: 1 ≤ length ≤ 40
Purpose: Identifies the COMIDA2 binary to be used for the MACCS2 calculations. This filename can include a directory path; the file need not be in the current directory. It must, however, be a valid filename on the host computer.

The DCF file that was used in the COMIDA2 calculations needs to be the same file that is currently being used in MACCS2. If MACCS2 detects a discrepancy by comparing the two-line header of the DCF files, an error will be diagnosed and MACCS2 execution terminated.

Example Usage:

```
*
* NAME OF THE COMIDA2 BINARY OUTPUT FILE
*
BIN_FILE001  'C:\COMIDA2\COM_A.BIN'
```

Variable Name: DOSEMILK
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.E10 (sieverts)
Purpose: Defines the maximum allowable food ingestion dose from milk crops during the year of the accident. This variable is intended to fulfill a purpose similar to that served by the variable PSCMILK of the MACCS food-chain model. The dose limit for effective dose is obtained from column 1 of the data record; the dose limit for thyroid dose is obtained from column 2.

Variable Name: DOSEOTHR
Variable Type: Real, Array

Allowed Range: 0.0 ≤ value ≤ 1.E10 (sieverts)

Purpose: Defines the maximum allowable food ingestion dose from nonmilk crops during the year of the accident. This variable is intended to fulfill a purpose similar to that served by the variable PSCOTHR of the MACCS food-chain model. The dose limit for effective dose is obtained from column 1 of the data record; the dose limit for thyroid dose is obtained from column 2.

Example Usage:

```
*
* DOSE LIMITS TRIGGERING FIRST YEAR CROP DISPOSAL OF THE SEPARATE
* MILK AND NONMILK COMPONENTS OF THE DIET, CORRESPONDING IN PURPOSE,
* AS MUCH AS POSSIBLE, TO THE MACCS 1.5 INPUT VARIABLES PSCMLK AND PSCOTH
*
*                 L-EFFECTIVE     L-THYROID
DOSEMILK001          0.005          0.015
DOSEOTHR001          0.005          0.015
```

Variable Name: DOSELONG

Variable Type: Real, Array

Allowed Range: 0.0 ≤ value ≤ 1.E10 (sieverts)

Purpose: Defines the maximum allowable "long-term" annual dose to an individual from ingestion of the *combination* of milk and nonmilk crops when the COMIDA2-based food model is being used. These parameter values are used for determining if agricultural production is suitable for consumption in years subsequent to the year of the accident (*i.e.*, from years 2 to LASTACUM).

If not acceptable, production is interdicted for up to LASTACUM–1 years, until such time as the dose criterion is satisfied. If LASTACUM–1 years of interdiction is insufficient, then the farmland is considered condemned. The dose limit for effective dose is obtained from column 1 of the data record; the dose limit for thyroid dose is obtained from column 2.

Example Usage:

```
*
* ANNUAL DOSE LIMITS FOR THE SUBSEQUENT YEAR'S (I.E., AFTER THE FIRST YEAR)
* INTERDICTION OF BOTH THE MILK AND NONMILK (COMBINED) COMPONENTS OF THE DIET
*
*                L-EFFECTIVE    L-THYROID
DOSELONG001         0.005         0.015
```

7.11 MACCS Food-Chain Model

If the user wishes to use the unitless transfer factor food-chain model of MACCS, this is accomplished by setting FDPATH='OLD'. When that model is selected, MACCS2 performs food and water ingestion calculations in exactly the same manner as MACCS.

When FDPATH='OLD', the input parameters described in Sections 7.11.1 to 7.11.3 must be supplied, and the allowable values for those parameters are the same as for MACCS. If the

COMIDA2-based ingestion model is being utilized, *none* of the input parameters in Sections 7.11.1 through 7.11.3 must be supplied, except for the variable FDPATH.

In the following text, the predecessor food-chain model will be referred to as the "MACCS" model and the new COMIDA2-based food-chain model will be referred to as the "MACCS2" model.

Variable Name: FDPATH
Variable Type: Character, Scalar
Allowed Value: 'NEW' or 'OLD'
Purpose: Specifies whether the MACCS food-chain model or the new COMIDA2-based MACCS2 food-chain model is to be used in the calculations.
Example Usage:

```
*
CHFDPATH001  'OLD'  (USING MACCS FOOD-CHAIN MODEL)
```

7.11.1 Ingestion Transfer Factors Data

When radioactive material is deposited on land, some fraction of this material may make its way through the food chain and ultimately be consumed by man in the form of contaminated food or drinking water. The ingestion pathway is modeled in MACCS as a series of transfer processes that the material must undergo between the time of deposition and the consumption of the contaminated food products by humans; these processes decrease the amount of material passed on to the next step.

To calculate the population dose resulting from the accumulated contamination of an area, it is necessary to know the efficiency of the entire food chain taken as a whole in transferring material from the ground to man. MACCS calculates the overall efficiency of the two ingestion pathways (food and water) by multiplication of all of the individual transfer factors which are described below, yielding an overall weight sum representing the effectiveness of the pathway in transferring material from the ground to human consumption.

Variable Name: NFICRP
Variable Type: Integer, Scalar
Allowed Range: $1 \leq \text{value} \leq 10$
Purpose: Defines the number of crop categories that will be used by the food pathway model.

Variable Name: NAMCRP
Variable Type: Character, Array
Allowed Range: $6 \leq \text{length} \leq 20$

Purpose: Defines the name of a crop category used in the food pathway model. The user must supply NFICRP names in column 1 of the data block.

Note: Within the code, there is a distinction between two types of crops: those harvested at the end of the growing season, and those harvested continuously over the entire growing season. The first seven letters of the crop names supplied here are used to distinguish between these two types of crops.

If a crop's name begins with 'PASTURE', it is harvested continuously; if it doesn't, it is harvested at the end of the growing season.

Variable Name: FRCTCH
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1. (unitless)
Purpose: Specifies the fraction of the edible portion of the harvested crop that is consumed by humans. The user must supply NFICRP values for this variable in column 2 of the data block.

Variable Name: FRCTCM
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1. (unitless)
Purpose: Specifies the fraction of the edible portion of the harvested crop that is consumed by milk-producing animals. The user must supply NFICRP values for this variable in column 3 of the data block.

Variable Name: FRCTCB
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1. (unitless)
Purpose: Specifies the fraction of the edible portion of the harvested crop that is consumed by meat-producing animals. The user must supply NFICRP values for this variable in column 4 of the data block.

Example Usage:

```
*
CHNFICRP001    7   (UP TO 10 ALLOWED)
*                              FRACTION OF CROP CONSUMED BY
*                                                DAIRY              MEAT
*           CROP NAME                MAN         ANIMALS            ANIMALS
*
*           NAMCRP                   FRCTCH      FRCTCM             FRCTCB
CHCRPTBL001 'PASTURE'                0.0         0.1                0.9
CHCRPTBL002 'STORED FORAGE'          0.0         0.13               0.87
CHCRPTBL003 'GRAINS'                 0.35        0.04               0.61
CHCRPTBL004 'GRN LEAFY VEG.'         1.0         0.0                0.0
CHCRPTBL005 'OTHER FOOD CROPS'       1.0         0.0                0.0
CHCRPTBL006 'LEGUMES AND SEEDS'      0.24        0.046              0.714
CHCRPTBL007 'ROOTS AND TUBERS'       1.0         0.0                0.0
```

Variable Name: NFIISO
Variable Type: Integer, Scalar
Allowed Range: NUMWPI ≤ value ≤ 10
Purpose: Defines the number of radionuclides for which data will be specified for the food ingestion pathway.

Note: There is no provision for accounting for the food ingestion dose resulting from radioactive daughter products of the food pathway radionuclides defined in NAMIPI.

Variable Name: NAMIPI
Variable Type: Character, Array
Allowed Range: 3 ≤ length ≤ 8
Purpose: Defines the name of a radionuclide used in the food pathway model. The user must supply NFIISO radionuclide names in column 1 of the data block. This list must include all of the radionuclides that were specified for the drinking water pathway. The drinking water pathway radionuclides must appear first in this data list and in the same order as they occurred in the radionuclide list for the drinking water pathway, variable NAMWPI.

Variable Name: DCYPMH
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0 (unitless)
Purpose: Transfer factor describing the processing losses and radioactive decay that occur between the production and the consumption of milk products.

Specifically, DCYPMH is the ratio of the amount of a radionuclide in milk products at the time of consumption to the amount of that radionuclide in the milk at the time of its production (milking).

The values given here will be multiplied by the values given for TFMLK in order to define the efficiency of the milk-to-man food pathway. The user must supply NFIISO values for this variable in column 2 of the data block.

Variable Name: DCYPBH
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0 (unitless)
Purpose: Transfer factor describing the processing losses and radioactive decay that occur between the production and the consumption of meat products.

Specifically, DCYPBH is the ratio of the amount of a radionuclide in meat products at the time of consumption to the amount of that radionuclide in the meat at the time of its production (slaughter).

The values given here will be multiplied by the values given for TFBF in order to define the efficiency of the meat-to-man pathway. The user must supply NFIISO names in column 3 of the data block.

Variable Name: TFMLK
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0 (unitless)
Purpose: Transfer factor describing how much of the material ingested by milk-producing animals ends up in milk products consumed by humans.

Specifically, TFMLK is the ratio of the amount of a radionuclide in fresh milk to the amount of the radionuclide consumed by milk-producing animals. It takes account of biological transport within the animal as well as excretion and radioactive decay.

This factor defines the fraction of the radioactive material ingested by an animal that is transferred to the milk produced by an animal. The values given here will be multiplied by the values given for DCYPMH in order to define the efficiency of the milk-to-man food pathway. The user must supply NFIISO values for this variable in column 4 of the data block.

Variable Name: TFBF
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0 (unitless)
Purpose: Transfer factor describing how much of the material ingested by meat-producing animals ends up in meat products consumed by humans.

Specifically, TFBF is the ratio of the amount of a radionuclide in edible meat at the time of slaughter to the amount of the radionuclide that was consumed by the meat-producing animals. It takes account of biological transport within the animals as well as excretion and radioactive decay.

This factor defines the fraction of the radioactive material ingested by the animal that is transferred to the meat products produced from the animal. The values given here will be multiplied by the values given for DCYBH to define the efficiency of the meat-to-man food pathway. The user must supply NFIISO values for this variable in column 5 of the data block.

Example Usage:

```
*
* NUMBER OF NUCLIDES IN THE CHRONC FOOD INGESTION MODEL
*
CHNFIISO001  6  (UP TO 10 ALLOWED, DAUGHTER BUILDUP IS NOT TREATED)
*
* NUCLIDES THAT WERE DEFINED IN THE WATER PATHWAY DATA ABOVE MUST
* BE A SUBSET OF THE CHRONC INGESTION PATHWAY NUCLIDES.  THE WATER
* PATHWAY NUCLIDES MUST BE LISTED FIRST IN THIS DATA BLOCK AND IN
* THE SAME ORDER AS THEY WERE LISTED IN THE WATER PATHWAY DATA
* BLOCK
*                                                TRANSFER FACTORS
*                        RETENTION FACTORS       [(BQ TRANSFERRED)/
*           INGESTION    PROCESSING AND DECAY     (BQ INGESTED)]
*           NUCLIDE      MILK/MAN    MEAT/MAN    MILK        MEAT
```

```
*
*            NAMIPI      DCYPMH      DCYPBH      TFMLK        TFBF
CHISODEF001 Sr-89       0.66        0.77        0.022       0.00022
CHISODEF002 Sr-90       1.0         1.0         0.022       0.00022
CHISODEF003 Cs-134      1.0         1.0         0.11        0.023
CHISODEF004 Cs-137      1.0         1.0         0.11        0.024
CHISODEF005 I-131       0.28        0.18        0.13        0.0024
CHISODEF006 I-133       0.002       0.0         0.062       0.0011
```

Variable Name: TCROOT
Variable Type: Real, Array
Allowed Range: $0.0 \leq$ value ≤ 1.0 (unitless)
Purpose: Defines the transfer factor for the long-term transfer of radionuclides from soil to edible crops.

Specifically, TCROOT is the ratio of the amount of a radionuclide ultimately taken up from soil into edible portions of a crop to the amount of that radionuclide that was deposited onto the soil.

The long-term transfer of radionuclides from soil to plants occurs principally by uptake (sorption) by plant root systems. Transfer to plant surfaces by rainsplash and by deposition of materials resuspended from surface soil can also contribute to this pathway. Ingestion of contaminated soil by animals grazing on pastureland may also contribute to the overall dose.

The values of TCROOT supplied in the data block should be calculated by integrating the overall uptake rate over the period from t=0 to infinity. In other words, TCROOT incorporates the total uptake over all time after the initial deposition. Since radionuclides are removed from the soil compartment not only by root uptake but also by radioactive decay, percolation, and irreversible chemical binding, all of these processes should be incorporated into the derivation of TCROOT. Values of TCROOT must be specified for each crop category for all radionuclides treated by the food pathway model (*i.e.*, for all possible radionuclide/crop combinations).

The annual rate at which the material is made unavailable by these processes is specified by the input variable QROOT, defined at the end of this section. The required data are entered in a block as a two-dimensional array. The first column of the block repeats the list of food pathway radionuclides. This list must be ordered exactly the same as the original definition of the variable NAMIPI.

All the other columns of the data block present values of TCROOT for one crop category and all food radionuclides. The order of the columns in going from left to right is assumed to be the same as is specified by NAMCRP as described earlier.

Example Usage:

```
*
*                                                GREEN    OTHER    LEGUMES  ROOTS
*                                STORED          LEAFY    FOOD     AND      AND
*            RADIONUCLIDE PASTURE FORAGE   GRAINS  VEG.     CROPS    SEEDS    TUBERS
*
*            NAMISO       CROOT   TCROOT   TCROOT  TCROOT   TCROOT   TCROOT   TCROOT
CHTCROOT001  Sr-89        4.1E-4  1.3E-3   4.3E-5  1.7E-4   8.6E-6   3.7E-4   1.1E-4
CHTCROOT002  Sr-90        2.6E-2  9.0E-2   3.3E-3  1.3E-2   6.6E-4   2.8E-2   8.4E-3
CHTCROOT003  Cs-134       1.3E-3  7.1E-4   3.5E-5  1.4E-5   1.1E-4   9.3E-5   5.6E-5
```

```
CHTCROOT004  Cs-137       6.9E-3   1.5E-3   7.6E-5  3.0E-5   2.3E-4   2.0E-4   1.2E-4
CHTCROOT005  I-131        1.6E-4   0.0      0.0     0.0      0.0      0.0      0.0
CHTCROOT006  I-133        1.7E-6   0.0      0.0     0.0      0.0      0.0      0.0
```

Variable Name: DCYPCH
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0 (unitless)
Purpose: This factor characterizes the loss due to radioactive decay occurring between the time of harvest and the time of the crop's consumption by humans.

Specifically, DCYPCH is the ratio between the amount of a radionuclide present in a crop at the time of its consumption and the amount of that radionuclide in the crop at the time of harvest after taking account of losses due to radioactive decay. The data supplied here are used in calculating ingestion dose arising from both direct deposition onto growing crops and the long-term uptake processes of subsequent growing seasons.

This factor is applied only to crops that are directly consumed by humans (*e.g.*, grains, vegetables, and legumes). Any values supplied for crops not consumed by humans will have no impact on the calculations. The values given here are multiplied by the corresponding values of FPLSCH, which characterizes processing losses, to obtain the overall transfer factor for this part of the food chain. Values of DCYPCH must be specified for each crop category for all radionuclides treated by the food pathway model (*i.e.*, for all possible radionuclide/crop combinations).

The required data are entered in a block as a two-dimensional array. The first column of the block repeats the list of food pathway radionuclides. This list must be ordered exactly the same as the original definition of the variable NAMIPI. All the other columns of the data block present values of DCYPCH for one crop category and all food radionuclides. The order of the columns in going from left to right is assumed to be the same as previously specified for NAMCRP.

Example Usage:

```
*
*                                      GREEN            OTHER    LEGUMES     ROOTS
*                                STORED LEAFY            FOOD      AND         AND
*             NUCLIDE  PASTURE FORAGE GRAINS   VEG.    CROPS     SEEDS       TUBERS
*
*             NAMISO   DCYPCH DCYPCH  DCYPCH   DCYPCH DCYPCH    DCYPCH      DCYPCH
CHDCYPCH001    Sr-89     0.0     0.0     0.18    0.67    0.21      0.18        0.18
CHDCYPCH002    Sr-90     0.0     0.0     0.99    1.0     0.99      0.99        0.99
CHDCYPCH003    Cs-134    0.0     0.0     0.84    0.96    0.85      0.84        0.84
CHDCYPCH004    Cs-137    0.0     0.0     0.99    1.0     0.99      0.99        0.99
CHDCYPCH005    I-131     0.0     0.0     0.0099  0.21    0.024     0.0099      0.0099
CHDCYPCH006    I-133     0.0     0.0     0.0     0.0     0.0       0.0         0.0
```

Variable Name: DCYPCM
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0 (unitless)

Purpose: This factor characterizes the loss due to radioactive decay occurring between the time of harvest and the time of the crop's consumption by meat-producing animals.

Specifically, DCYPCM is the ratio of the amount of a radionuclide in the crop at the time of its consumption to the amount of that radionuclide in the crop at the time of harvest. The data supplied here are used in calculating ingestion dose arising from both direct deposition onto growing crops and the long-term uptake processes of subsequent growing seasons.

This factor is applied only to crops that are directly consumed by milk-producing animals (*e.g.*, pasture and forage). Any values supplied for crops not consumed by milk-producing animals will have no impact on the calculations.

For pasture crops, harvest and consumption are simultaneous and so DCYPCM should be set to 1.0 for the pasture crop categories. Values of DCYPCM must be specified for each crop category for all radionuclides treated by the food pathway model (*i.e.*, for all possible radionuclide-crop combinations).

The required data are entered in a block as a two-dimensional array. The first column of the block repeats the list of food pathway radionuclides. This list must be ordered exactly the same as the original definition of the variable NAMIPI. All the other columns of the data block present values of DCYPCM for one crop category and all food radionuclides. The order of the columns in going from left to right is assumed to be the same as previously specified for NAMCRP.

Example Usage:

```
*
*                                        GREEN            OTHER    LEGUMES     ROOTS
*                                STORED  LEAFY            FOOD       AND         AND
*             NUCLIDE  PASTURE  FORAGE  GRAINS   VEG.    CROPS     SEEDS       TUBERS
*
*             NAMISO   DCYPCH   DCYPCH  DCYPCH   DCYPCH  DCYPCH    DCYPCH      DCYPCH
CHDCYPCM001  Sr-89      1.0     0.37    0.20       0.0     0.0      0.20        0.0
CHDCYPCM002  Sr-90      1.0     0.99    0.99       0.0     0.0      0.99        0.0
CHDCYPCM003  Cs-134     1.0     0.92    0.85       0.0     0.0      0.85        0.0
CHDCYPCM004  Cs-137     1.0     0.99    0.99       0.0     0.0      0.99        0.0
CHDCYPCM005  I-131      1.0     0.063   0.032      0.0     0.0      0.032       0.0
CHDCYPCM006  I-133      1.0     0.0068  0.0034     0.0     0.0      0.0034      0.0
```

Variable Name: DCYPCB
Variable Type: Real, Array
Allowed Range: $0.0 \leq$ value ≤ 1.0 (unitless)
Purpose: This factor specifies the retention of material after radioactive decay occurs between the time of harvest and the time of consumption by meat-producing animals.

Specifically, DCYPCB is the ratio of the amount of a radionuclide in the crop at the time of its consumption to the amount of that radionuclide in the crop at the time of harvest. This factor is applied only to crops that are directly consumed by meat-producing animals (*e.g.* pasture and forage). Any values supplied for crops not consumed by meat-producing animals will have no impact on the calculations.

Values of DCYPCB must be specified for each crop category for all radionuclides treated by the food pathway model (*i.e.*, for all possible radionuclide-crop combinations). The required data are entered in a block as a two-dimensional array. The first column of the block repeats the list of food pathway radionuclides. This list must be ordered exactly the same as the original definition of the variable NAMIPI.

All the other columns of the data block present values of DCYPCB for one crop category and all food radionuclides. The order of the columns in going from left to right is assumed to be the same as previously specified for NAMCRP.

Example Usage:

```
*
*                                        GREEN            OTHER    LEGUMES     ROOTS
*                                STORED  LEAFY            FOOD       AND         AND
*             NUCLIDE  PASTURE  FORAGE  GRAINS   VEG.    CROPS     SEEDS       TUBERS
*
*             NAMISO   DCYPCH   DCYPCH  DCYPCH   DCYPCH  DCYPCH    DCYPCH      DCYPCH
CHDCYPCB001  Sr-89      1.0     0.37    0.20       0.0     0.0      0.20        0.0
CHDCYPCB002  Sr-90      1.0     0.99    0.99       0.0     0.0      0.99        0.0
CHDCYPCB003  Cs-134     1.0     0.92    0.85       0.0     0.0      0.85        0.0
CHDCYPCB004  Cs-137     1.0     0.99    0.99       0.0     0.0      0.99        0.0
CHDCYPCB005  I-131      1.0     0.063   0.032      0.0     0.0      0.032       0.0
CHDCYPCB006  I-133      1.0     0.0068  0.0034     0.0     0.0      0.0034      0.0
```

Variable Name: FPLSCH
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0 (unitless)
Purpose: This factor specifies the fraction of material retained in the harvested crop after accounting for the losses resulting from its preparation for consumption by humans.

Specifically, FPLSCH is the ratio of the amount of a radionuclide in the crop after it has been processed for human consumption to the amount of that radionuclide in the crop before processing. The retention factor reflects the fraction of radioactive material in the edible portion of the plant that is retained after washing, peeling, or cooking. The values supplied here apply only to crops that are directly consumed by humans. Any values specified for crops such as pasture which are supplied here will have no impact on the calculations.

Values of FPLSCH must be specified for each crop category for all radionuclides treated by the food pathway model (*i.e.*, for all possible radionuclide-crop combinations). The values are multiplied with the corresponding values of DCYPCH in order to obtain the overall transfer factor for this part of the food chain.

The data are entered in a block as a two-dimensional array. The first column of the block repeats the list of food pathway radionuclides. This list must be ordered exactly the same as the original definition of the variable NAMIPI. All the other columns present values of FPLSCH for one crop category and all food radionuclides. The order of the columns in going from left to right is assumed to be the same as previously specified for NAMCRP.

Example Usage:

```
*
*                                        GREEN            OTHER    LEGUMES      ROOTS
*                                STORED  LEAFY            FOOD      AND          AND
*             NUCLIDE  PASTURE  FORAGE  GRAINS   VEG.    CROPS     SEEDS       TUBERS
*
*             NAMISO   DCYPCH   DCYPCH   DCYPCH   DCYPCH  DCYPCH    DCYPCH      DCYPCH
CHFPLSCH001  Sr-89       0.0     0.0      0.25     0.5    0.71      0.8          0.8
CHFPLSCH002  Sr-90       0.0     0.0      0.25     0.5    0.71      0.8          0.8
CHFPLSCH003  Cs-134      0.0     0.0      0.25     0.5    0.71      0.8          0.8
CHFPLSCH004  Cs-137      0.0     0.0      0.25     0.5    0.71      0.8          0.8
CHFPLSCH005  I-131       0.0     0.0      0.33     0.5    0.71      0.8          0.8
CHFPLSCH006  I-133       0.0     0.0      0.33     0.5    0.71      0.8          0.8
```

When an accident occurs during the growing season, part of the radioactive material deposited on farmland will be retained on plant surfaces and the remainder will fall on the ground. Between the time of deposition and the time of harvest, radioactive material can be lost from plant surfaces due to weathering, radioactive decay, translocation to interior portions of the plant, and the harvesting process.

The fraction of radioactive material that is removed from the air due to dry and wet deposition that ends up in edible portions of the harvested plant is here called the growing crop retention factor. Specifically, this factor is defined to be the ratio between the amount of a radionuclide

present in the crop at harvest and the total amount of material initially deposited onto the land used for producing that crop.

For all crops except pasture, harvesting occurs at the end of the growing season. The harvesting of pasture differs from the other crops in that it is a continuous process. In MACCS it is assumed that grazing takes exactly one growing season to harvest the year's entire production of the pasture crop. The numerical integration used in the pasture dose calculations is therefore different from that used for the other crop categories. The type of integration performed by the code is determined by the name given to the crop categories. Crop names beginning with PASTURE are treated differently from the rest.

For crops where the edible portion of the plant is exposed to the environment, weathering losses over the period from deposition to harvesting will decrease the amount of radionuclides retained as a function of time. That is, the longer the time between deposition and harvesting, the lower the resultant dose.

Crops such as grains and legumes, which have the edible portions internal to the plant, may show the opposite behavior, with material being absorbed into the plant over time. Since this is a slow process and data on the translocation rate are hard to obtain, the user should try to define an average retention factor appropriate for deposition onto crops that is independent of time in the growing season, and not use the weathering model for these types of crops. The situation is further complicated by the fact that the available data suggest that total retention for grains is greatest when the deposition occurs near the middle of the growing season rather than at the end of it.

Both types of crops are modeled with a weathering equation that can have up to three exponential terms, each with a different weathering rate. For the types of crops not subject to weathering losses (that is, grains and legumes), a very long half-life can be specified for the weathering rate as a way of replacing the weathering function with a constant transfer fraction.

In MACCS the removal of radioactivity from plant surfaces by weathering is treated as a sum of terms that have the following form:

$$\text{CTCOEF} \cdot \exp(-\lambda \cdot t),$$

where CTCOEF represents the fraction of material deposited on a cultivated field that is removed by weathering with a decay rate of $\lambda = 0.693 / \text{CTHALF}$.

CTCOEF equals the product of two quantities: the interception fraction and the availability fraction. The interception fraction is the fraction of material deposited onto a field that is intercepted by crop surfaces and the availability fraction is the fraction of material deposited onto crop surfaces that is weathered away with the half-life CTHALF.

Because translocation from the plant surface to interior portions influences the retention of radioactivity for grains, legumes, and root crops, the weathering model just described is not appropriate for these crop categories, but as discussed in the next paragraph, the model can be

modified through user-defined input parameters to in effect yield a transfer function that is constant with respect to time.

For the sample data presented in this section, the efficiency of grains, legumes, and root crops in transferring radioactivity was not derived in the same way as the data were derived for the other types of crops. For the grain, legume, and "other" categories, an empirical transfer factor derived from fallout studies was used in which the empirical factor represents the combined effects of interception, weathering, translocation to seeds, and root uptake.

Since long-term uptake is treated separately from the growing-season pathway, this may cause the long-term uptake dose from grains and legumes to be double counted in the first growing season. However, since root uptake in a single season is typically small relative to the contamination resulting from direct deposition, the potential impact of such a double counting is unlikely to be significant.

For convenience, this empirical factor is input as a value of CTCOEF. Since this empirical value includes the effects of weathering, the exponential part of the weathering decay expression associated with this empirical value for CTCOEF is reduced to unity by setting CTHALF to the maximum allowable value, 3.15E13 s.

For all food pathway radionuclides, values of CTCOEF and CTHALF are required for each term in the weathering expression for each crop category. Unnecessary weathering terms are eliminated by setting CTCOEF equal to 0 and CTHALF equal to unity for those terms.

Variable Name: NTTRM
Variable Type: Integer, Scalar
Allowed Range: 1 ≤ value ≤ 3
Purpose: Defines the number of terms used in the growing crop retention model.
Example Usage:

```
*
* NUMBER OF TERMS IN THE GROWING CROP RETENTION MODEL
*
CHNTRTRM001    2
```

Variable Name: CTCOEF
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0 (unitless)
Purpose: For crops with exposed edible portions, defines the product of the interception fraction and the availability fraction for each term in the weathering model. For plants with edible portions internal to the plant, defines the combined transfer fraction for interception, weathering, and translocation to seeds averaged over an entire growing season.

For each term of the weathering equation (and there can be up to three of them), values of CTCOEF must be specified for each crop category for all radionuclides treated by the food

pathway model. The required data are entered in up to three data blocks for each of the possible terms of the weathering equation, with each of the data blocks being arranged in the same manner as the variables described earlier (FPLSCH, DCYPCH, *etc.*).

The values of CTCOEF entered in different data blocks are distinguished from each other by the ninth character in the record identifier. For variable CTCOEF, the record identifier has the form CHCTCOEFNMM where N is 1 for the first weathering term, 2 for the second weathering term, and 3 for the third weathering term, and MM varies from 01 for the first food pathway radionuclide to NN for the last food pathway radionuclide.

The data format for CTCOEF is identical to that used for the subsequent variable CTHALF. There should be a one-to-one correspondence between the data supplied for these two variables.

Example Usage:

```
*
*                                                GREEN   OTHER  LEGUMES    ROOTS
*                                   STORED       LEAFY   FOOD     AND      AND
*            RADIONUCLIDE  PASTURE  FORAGE  GRAINS  VEG.   CROPS   SEEDS    TUBERS
*
CHCTCOEF101  Sr-89         0.3      0.2      0.01   0.24    0.2    0.005    0.0006
CHCTCOEF102  Sr-90         0.3      0.2      0.01   0.24    0.2    0.005    0.0006
CHCTCOEF103  Cs-134        0.3      0.2      0.05   0.24    0.2     0.01    0.025
CHCTCOEF104  Cs-137        0.3      0.2      0.05   0.24    0.2     0.01    0.025
CHCTCOEF105  I-131         0.3      0.2       0.0   0.24    0.2      0.0     0.0
CHCTCOEF106  I-133         0.3      0.2       0.0   0.24    0.2      0.0     0.0
*
*  TERM 2
CHCTCOEF201  Sr-89         0.076    0.05      0.0   0.06    0.05     0.0     0.0
CHCTCOEF202  Sr-90         0.076    0.05      0.0   0.06    0.05     0.0     0.0
CHCTCOEF203  Cs-134        0.076    0.05      0.0   0.06    0.05     0.0     0.0
CHCTCOEF204  Cs-137        0.076    0.05      0.0   0.06    0.05     0.0     0.0
CHCTCOEF205  I-131         0.076    0.05      0.0   0.06    0.05     0.0     0.0
CHCTCOEF206  I-133         0.076    0.05      0.0   0.06    0.05     0.0     0.0
```

Variable Name: CTHALF
Variable Type: Real, Array
Allowed Range: 1. ≤ value ≤ 1.E14 (seconds)
Purpose: Half-life values for the various terms of the weathering model. The values supplied for CTHALF in this data block must be properly paired with the corresponding values of CTCOEF defined in the previous data block.

For each term of the weathering equation (there can be up to three), values of CTHALF must be specified for each crop category for all radionuclides treated by the food pathway model. The required data are entered in up to three data blocks for each of the possible terms of the weathering equation, with each of the data blocks being arranged in the same manner as the variables described earlier (FPLSCH, DCYPCH, *etc.*).

The values of CTHALF entered in different data blocks are distinguished from each other by the ninth character in the record identifier. For variable CTHALF, the record identifier has the form CHCTHALFNMM where N is 1 for the first weathering term, 2 for the second weathering term,

and 3 for the third weathering term, and MM varies from 01 for the first food pathway radionuclide to NN for the last food pathway radionuclide. The data format for CTHALF is identical to that used for the preceding variable CTCOEF. There should be a one-to-one correspondence between the data supplied for these two variables.

Example Usage:

```
*
* CROP TRANSFER HALF-LIVES BY NUCLIDE (SECONDS)
*                                                   GREEN   OTHER  LEGUMES ROOTS
*                                     STORED        LEAFY   FOOD    AND     AND
*            RADIONUCLIDE   PASTURE   FORAGE  GRAINS VEG.    CROPS   SEEDS  TUBERS
*
* TERM1
CHCTHALF101     Sr-89      1.21E6   1.21E6   1E13    1.21E6 1.21E6  1E13    1E13
CHCTHALF102     Sr-90      1.21E6   1.21E6   1E13    1.21E6 1.21E6  1E13    1E13
CHCTHALF103     Cs-134     1.21E6   1.21E6   1E13    1.21E6 1.21E6  1E13    1E13
CHCTHALF104     Cs-137     1.21E6   1.21E6   1E13    1.21E6 1.21E6  1E13    1E13
CHCTHALF105     I-131      1.21E6   1.21E6   1.0     1.21E6 1.21E6  1.0     1.0
CHCTHALF106     I-133      1.21E6   1.21E6   1.0     1.21E6 1.21E6  1.0     1.0
*
*  TERM2
CHCTHALF201     SR-89      4.32E6   4.32E6   1.0     4.32E6 4.32E6  1.0     1.0
CHCTHALF202     SR-90      4.32E6   4.32E6   1.0     4.32E6 4.32E6  1.0     1.0
CHCTHALF203     CS-134     4.32E6   4.32E6   1.0     4.32E6 4.32E6  1.0     1.0
CHCTHALF204     CS-137     4.32E6   4.32E6   1.0     4.32E6 4.32E6  1.0     1.0
CHCTHALF205     I-131      4.32E6   4.32E6   1.0     4.32E6 4.32E6  1.0     1.0
CHCTHALF206     I-133      4.32E6   4.32E6   1.0     4.32E6 4.32E6  1.0     1.0
```

7.11.2 Crop Share and Growing Season Data

In the previous section, the user has defined the characteristics of a number of different crop categories with regard to their efficiency in transferring radioactive material to man through the food chain. If MACCS2 is being used without a Site Data file (see Section 6.3), the data in this section are used to supply the information necessary to calculate the doses resulting from the food ingestion pathway.

Note: When FDPATH='NEW', the data in this section must always be supplied. If the user is supplying a Site Data file (POPFLG = 'FILE' in Section 6.3), then the data supplied here will have no impact on the calculations because they will be superseded by the corresponding data on that file.

Variable Name:	NAMCRP
Variable Type:	Character, Array
Allowed Range:	$6 \leq \text{length} \leq 20$
Purpose:	Specifies the crop categories for which this set of growing season and farm fraction data will apply. The user must supply NFICRP crop category names in column 1 of the data block.

Note: The list of crop names specified here must be identical to the list of names specified in the previous section.

Variable Name: TGSBEG
Variable Type: Real, Array
Allowed Range: 1.0 ≤ value ≤ 365.0
Purpose: Defines the start of the growing season for the named crop category in terms of the Julian day (January 1 is day 1). The user must supply NFICRP values in column 2 of the data block.

Variable Name: TGSEND
Variable Type: Real, Array
Allowed Range: TGSBEG ≤ value ≤ 365.0
Purpose: Defines the end of the growing season for the named crop category in terms of the Julian day. The user must supply NFICRP values in column 3 of the data block.

Variable Name: FRCTFL
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0
Purpose: Defines the fraction of cultivated farmland that is used to grow the named crop category. The user must supply NFICRP values in column 4 of the data block.

Example Usage:

```
*
*              NAMCRP                TGSBEG   TGSEND   FRCTFL
CHCRPRGN001 'PASTURE'                90.      270.     0.41
CHCRPRGN002 'STORED FORAGE'          150.     240.     0.13
CHCRPRGN003 'GRAINS'                 150.     240.     0.21
CHCRPRGN004 'GRN LEAFY VEGETABLES'   150.     240.     0.002
CHCRPRGN005 'OTHER FOOD CROPS'       150.     240.     0.004
CHCRPRGN006 'LEGUMES AND SEEDS'      150.     240.     0.15
CHCRPRGN007 'ROOTS AND TUBERS'       150.     240.     0.003
```

7.11.3 Protective Action Guide for MACCS Food Pathway Model

In the event of an accident at a nuclear facility, it is likely that an assessment of the accident's impact on agricultural production in the surrounding region will be performed. Based on a projection of dose to an individual consuming locally produced food products, the local authorities will determine if these food products are safe to eat. If the food product is judged to be unsafe, two kinds of actions can be taken: disposal of already growing crops and long-term restriction of agricultural production in subsequent growing seasons.

The MACCS food-chain model divides agricultural activities into four components representing two sets of binary pairs:

MILK DIRECT-DEPOSITION
CROP DIRECT-DEPOSITION
MILK ROOT-UPTAKE
CROP ROOT-UPTAKE

This terminology is defined as follows. MILK refers to both fresh milk as well as to dairy products such as cheese and butter. CROP refers to all other foodstuffs. DIRECT-DEPOSITION refers to doses that result when an accident occurs during the growing season and the doses are incurred in the single annual period following the accident. If an accident occurs outside of the growing season, the code does not evaluate the need for disposal of growing crops, and the corresponding doses from the milk and crop pathways will be reported as zero. In contrast, ROOT-UPTAKE refers to food doses that result irrespective of whether the accident occurs during the growing season, and these are calculated for an integration period with an endpoint of t=infinity. These two periods may overlap. That is, for accidents that occur during the growing season, doses may be incurred from *both* the direct-deposition and root-uptake components of the MACCS food-chain model.

The stringency (degree of protection) for both types of mitigative actions is specified by the user through input parameters described in this section. All of these parameters are specified in terms of allowable ground concentration and will be referred to as "action guides."

For an accident that occurs during the growing season, there are two types of actions that can occur: disposal of milk and its products and disposal of crops other than milk (nonmilk crops). All agricultural production is divided between these two categories. The action guides used for determining if these two actions are necessary are the input variables PSCMLK and PSCOTH, which are defined below.

For high levels of contamination, it may be necessary to restrict agricultural production for a number of years after the accident. In order to determine if this is necessary, a single set of values for allowable ground concentration (variable GCMAXR) is used. During the long-term interdiction period, either all crops (both milk and nonmilk) can be produced or no crops can be produced.

For accidents that occur outside of the growing season, MACCS2 will, in all cases, evaluate only the long-term action guide (GCMAXR). Outside of the growing season, the growing season action guides PSCMLK and PSCOTH are never evaluated since crop disposal can only occur during the growing season.

For accidents that occur during the growing season, however, both types of criteria (growing season and long-term) may be evaluated by the code. It is up to the user to determine whether these two types of evaluation are performed either independently of each other (uncoupled) or in such a way that the exceedance of one type of criteria will automatically force the exceedance of the other criteria (coupled). The choice of these two options is defined by the user-specified input parameter, COUPLD, described below.

When the two types of criteria are chosen to be evaluated independently, there are no interactions between the growing season pathway and the long-term pathway. The resultant doses and economic costs from these two components of the food model are calculated in a completely independent manner.

If the user chooses the option of a coupled evaluation, the following rules define the interactions between two types of actions. Whenever the long-term criteria (GCMAXR) are exceeded, the disposal of any growing crops (both milk and nonmilk) will automatically be triggered. Alternatively, whenever both milk and nonmilk crop disposal are called for as a result of exceeding both the PSCMLK and PSCOTH criteria, the code will automatically impose at least 1 year of long-term farmland interdiction.

Variable Name: COUPLD
Variable Type: Logical
Allowed Value: .TRUE. or .FALSE.
Purpose: Defines whether the growing season and the long-term action guides are evaluated in a coupled manner (COUPLD=.TRUE.) or in a totally independent manner (COUPLD=.FALSE.)
Example Usage:

```
*
CHCOUPLD001 .FALSE.  (THE TWO TYPES OF TESTS ARE INDEPENDENT)
```

Variable Name: NAMIPI
Variable Type: Character, Array
Allowed Range: 3 ≤ length ≤ 8
Purpose: Defines the names of the ingestion model radionuclides for which growing season protective action guides will be specified. The user must supply all of the NFIISO names in column 1 of the data block in the same order as they were originally defined for variable NAMIPI in the previous section.

Variable Name: PSCMLK
Variable Type: Real, Array
Allowed Range: 1.E–6 ≤ value ≤ 1.E20 (becquerels/square meter)
Purpose: Defines the growing season protective action guide (*i.e.,* maximum permissible surface concentration), for milk and milk products for the named radionuclide. The user must define NFIISO protective action guide values in column 2 of the data block.

Variable Name: PSCOTH
Variable Type: Real, Array
Allowed Range: 1.E–6 ≤ value ≤ 1.E20 (becquerels/square meter)

Purpose: Defines the growing season protective action guide, maximum permissible surface concentration, for nonmilk crops and their products for the named radionuclide. The user must define NFIISO protective action guide values in column 3 of the data block.

Example Usage:

```
*
*                                MILK AND         OTHER CROPS
*                                PRODUCTS         AND PRODUCTS
*
*                       NAMIPI          PSCMLK          PSCOTH
CHPAGMCP001             Sr-89           2.2E07          2.2E07
CHPAGMCP002             Sr-90           2.4E05          2.4E05
CHPAGMCP003             Cs-134          2.2E05          2.2E05
CHPAGMCP004             Cs-137          2.7E05          2.7E05
CHPAGMCP005             I-131           1.3E06          8.0E06
CHPAGMCP006             I-133           1.0E10          1.0E20
```

The long-term uptake fractions for root uptake and soil ingestion by animals have been previously defined by variable TCROOT. These uptake fractions are integrated over all time, that is, from t=0 to t=infinity. MACCS allows the user to define a model for the temporary interdiction of the long-term uptake pathway if certain ground contamination levels are exceeded at the time of the accident. If this model is activated, and temporary interdiction of long-term uptake is needed, the period of temporary interdiction is the shortest number of whole years that allows the long-term criteria to be met. The longest allowed period of long-term interdiction is 8 years. If 8 years of weathering and radioactive decay are insufficient, the farmland is condemned and permanently removed from production.

The data defining this interdiction model are given below. They consist of two parts: the criteria to be met for each ingestion radionuclide and a rate constant for the decrease of the radionuclide's availability over the temporary interdiction period. Values for these parameters must be supplied in the same order as originally used to define the list of radionuclides in the ingestion model, the initial definition of NAMIPI.

Variable Name: NAMIPI
Variable Type: Character, Array
Allowed Range: 3 ≤ length ≤ 8
Purpose: Defines the name of the food ingestion radionuclide whose maximum permissible surface concentration for long-term production and weathering depletion rate are being defined in the adjacent two columns. The user must name the NFIISO food ingestion radionuclides in column 1 of the data block in the same order as they were originally defined.

Variable Name: GCMAXR
Variable Type: Real, Array
Allowed Range: 1.E–6 ≤ value ≤ 1.E35 (becquerels/square meter)

Purpose: Defines the protective action guide(*i.e.*, maximum permissible surface concentration) for long-term crop production for the named radionuclide. The user must supply NFIISO values for this parameter in column 2 of the data block.

Variable Name: QROOT
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.E+35 (per year)
Purpose: Defines the rate constant for the decrease in availability of the named radionuclide. The following processes should be considered in the specification of the value for this parameter:

1. radioactive decay,
2. irreversible chemical binding to the soil,
3. percolation downward into the soil,
4. uptake into plants or ingestion by animals.

The value assigned to QROOT is used to determine how effective temporary interdiction of the long-term agricultural pathway will be in reducing ingestion doses. For example, if the depletion rate is 0.5 per year (*i.e.*, 50%/annum), a year of temporary interdiction will cause the integrated dose to be EXP(–0.5) of what it would be if there were no interdiction.

The user must define NFIISO values for this parameter in column 3 of the data block.

Example Usage:

```
*
*                       NAMIPI      GCMAXR      QROOT
CHPAGLTS001             Sr-89       1.8E08      4.9
CHPAGLTS002             Sr-90       3.7E04      0.065
CHPAGLTS003             Cs-134      4.1E06      0.59
CHPAGLTS004             Cs-137      1.8E06      0.28
CHPAGLTS005             I-131       1.0E20      32.0
CHPAGLTS006             I-133       1.0E20      290.0
```

7.12 Water Ingestion Data

When radioactive material is deposited on the ground, it is expected that some fraction of this material will make its way into drinking water consumed by humans (Helton, Muller, and Bayer, 1985). MACCS2 models this uptake into drinking water as two separate paths: (1) deposition of material directly onto freshwater bodies and (2) deposition of material onto land with subsequent washoff into freshwater bodies.

The water ingestion model assumes that the area surrounding the site is divided into two categories: water and land. The radioactive material deposited on a spatial element is apportioned between water and land according to the fraction of the region covered by land (see variable FRACLD in the previous section).

For coastal sites, where both fresh water and ocean water need to be treated, it is recommended that the user supply a Site Data file where the limitation of having only one kind of watershed can be overcome. A Site Data file can define up to four types of watersheds. One of those watersheds (*e.g.*, ocean) can be defined to have a 0 uptake fraction.

The user is required to supply three numeric parameters in the following section. They define the behavior of the single watershed that is utilized if a uniform population density has been specified.

Of the material deposited directly onto water or transferred from land to water, the fraction represented by WINGF determines how much of that material will eventually be consumed by humans. There is no adjustment of WINGF within the code to account for radioactive decay.

Of the material that has been deposited on land, some fraction makes its way through runoff into the freshwater supply over a relatively short period after deposition. This fraction is specified by the value of WSHRTI.

The remainder of the material deposited on land is assumed to be washed off to the freshwater supply at a constant fractional rate over the time from t=0 to t=infinity. The rate at which this subsequent washoff occurs is specified by the value of the rate constant WSHRTA.

The code uses the values of the two variables, WSHRTI and WSHRTA, and evaluates the integral of the washoff fraction in a way that takes account of radioactive decay for the material deposited on land surfaces. The model is described by Helton, Muller, and Bayer (1985). The evaluation of this integral produces a numeric value, F, which represents the fraction of material falling on land that will be eventually transferred to surface water bodies that supply drinking water.

With this value of F, we can now calculate the uptake fraction for material deposited on solid ground. It is simply WINGF• F. The input variable WINGF is the ratio between the total amount of a radionuclide consumed via the drinking water pathway (*i.e.*, by the entire population of the region surrounding the facility) and the amount entering potable surface-water bodies. Typically, WINGF would be derived by the MACCS2 user from a model for radionuclide movement in the surface-water system in the surrounding region.

The models used to determine WINGF can vary in complexity from the very simple (*e.g.*, a single uniformly mixed cell) to the very complex (*e.g.*, three-dimensional fluid transport with temporal and spatial variability). The value of WINGF supplied with the sample problems has been derived in a very simple manner.

Note: The data in this section describing the water ingestion factors must be supplied on the CHRONC input file, but they are used in the calculations only if the user has chosen the

option of a uniform population density surrounding the site (in Section 6.3, POPFLG='UNIFORM').

Variable Name: NUMWPI
Variable Type: Integer, Scalar
Allowed Range: 1 ≤ value ≤ 10
Purpose: Defines the number of radionuclides to be considered in the drinking water pathway. If the MACCS food-chain model is being utilized, the drinking water radionuclides must be a subset of the food ingestion radionuclides (defined by NFIISO and NAMIPI as described in Section 7.11.1).

Variable Name: NAMWPI
Variable Type: Character, Array
Allowed Range: 2 ≤ length ≤ 10
Purpose: Defines the name of a radionuclide used in the drinking water pathway. The user must supply NUMWPI radionuclide names in column 1 of the data block.

Note: For the purpose of calculating water ingestion doses, there is no provision for modeling the buildup of any radioactive daughter products that result from decay. There is no provision for accounting for the water ingestion dose resulting from radioactive daughter products of the water pathway radionuclides defined in NAMWPI.

Variable Name: WSHFRI
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0 (unitless)
Purpose: Defines the initial washoff fraction for the specified radionuclide. This is the fraction of material deposited on land that is easily washed off into the watershed drainage system immediately following the deposition of that radionuclide. The user must supply NUMWPI values for this variable in column 2 of the data block.

Variable Name: WSHRTA
Variable Type: Real, Array
Allowed Range: 0.0 ≤ value ≤ 1.0 (per year)
Purpose: Defines the annual washoff rate for the specified radionuclide. This is the rate at which material deposited on land is washed off into the watershed drainage system following the initial deposition. The user must supply NUMWPI values for this variable in column 3 of the data block.
Variable Name: WINGF
Variable Type: Real, Array

Allowed Range: 0.0 ≤ value ≤ 1.0 (unitless)

Purpose: Defines the water ingestion factor for the radionuclide specified in column 1 of the data block. This factor specifies the fraction of the radioactivity washed into the drainage system of the watershed that is ultimately consumed by humans. The user must supply NUMWPI values for this variable in column 4 of the data block.

Note: If a site file is being used (POPFLG=FILE), the value of WINGF is not used by the code; nevertheless a valid parameter value must be supplied.

Example Usage:

```
*
CHNUMWPI001    4
*
*                          INITIAL     ANNUAL      INGESTION FACTOR
*              WATER       WASHOFF     WASHOFF     [(BQ INGESTED)/
*              NUCLIDE     FRACTION    RATE         (BQ IN WATER)]
*
*              NAMWPI      WSHFRI      WSHRTA         WINGF
CHWTRISO001    Sr-89       0.01        0.004          5.0E-6
CHWTRISO002    Sr-90       0.01        0.004          5.0E-6
CHWTRISO003    Cs-134      0.005       0.001          5.0E-6
CHWTRISO004    Cs-137      0.005       0.001          5.0E-6
```

7.13 Diagnostic Trace Option

The diagnostic options data block allows the user to print a detailed listing of values for intermediate variables used in CHRONC calculations. The output for this option is written to the output file. Most of the variables output are CHRONC internal FORTRAN variables. The user will need to examine the definitions of these variables provided in the MACCS2 FORTRAN coding in order to fully understand the output listing generated with this option.

Variable Name: KSWTCH

Variable Type: Integer, Scalar

Allowed Range: 0 ≤ value ≤ 1

Purpose: Defines the set of special diagnostics to be printed by CHRONC. This variable is used to enable the generation and printing of intermediate calculations on the output listing. It is recommended that the user set the value of each of these options to 0 for normal calculations. Specification of any value greater than 0 will generate a large amount of printed output. Therefore, the trace output option should be used only for single weather trial runs.

Example Usage:

```
*
CHKSWTCH001    1   (TURNS ON DEBUG PRINT STATEMENTS FOR CHRONC)
```

7.14 Population Dose Results

The CHRONC module calculates the long-term population dose broken down by pathway for a list of organs defined by the user through the EARLY input file (see Section 6.4). The option to examine this breakdown of long-term population doses for organs selected from the set of available organs is controlled by the user as defined in this section. The breakdown of long-term population dose results has no corresponding result in the EARLY module. The EARLY module produces only one consequence measure relating to population dose, the Type 5 result, total population dose.

No long-term population dose results for a defined cancer organ are produced on the output listing unless the user specifically requests them. Each request for the breakdown of the long-term population dose to an organ produces the block of either 12 or 15 dose results (depending on which food model is being used) identified below. All of the dose results are reported in person-sieverts although the units are listed simply as sieverts (Sv) in the output file.

TOTAL LONG-TERM PATHWAYS DOSE—total long-term population dose from groundshine and resuspension, from the consumption of contaminated food, from the ingestion of contaminated surface water, and from decontamination work.

LONG-TERM DIRECT EXPOSURE PATHWAYS—total long-term population dose to resident population from groundshine and resuspension.

TOTAL INGESTION PATHWAYS DOSE—total long-term population dose from the consumption of contaminated dairy products, contaminated nondairy products, and contaminated water.

LONG-TERM GROUNDSHINE DOSE—total long-term population dose received by resident population from groundshine.

LONG-TERM RESUSPENSION DOSE—total long-term population dose received by resident population from resuspension.

POP.-DEPENDENT DECONTAMINATION DOSE—total long-term population dose received from groundshine by workers performing "population dependent" (nonfarm) decontamination (decontamination workers receive no inhalation dose).

FARM-DEPENDENT DECONTAMINATION DOSE—total long-term population dose received from groundshine by workers performing "farm dependent" (farmland) decontamination (decontamination workers receive no inhalation dose).

WATER INGESTION DOSE—total long-term population dose from ingestion of contaminated surface water.

If the MACCS food-chain model is being utilized, the following food pathway results are reported:

MILK GROWING SEASON DOSE—total long-term population dose resulting from consumption of milk and dairy products contaminated as a result of deposition onto crops during the growing season.

CROP GROWING SEASON DOSE—total long-term population dose resulting from consumption of nonmilk food products contaminated as a result of deposition onto crops during the growing season.

MILK LONG-TERM DOSE—total long-term population dose resulting from consumption of milk and dairy products contaminated by long-term uptake in the period following the accident.

CROP LONG-TERM DOSE—total long-term population dose resulting from consumption of nondairy crops and their products contaminated by long-term uptake in the period following the accident.

If the COMIDA2 food-chain model is being utilized, the following food pathway results are reported:

INGESTION OF GRAINS—total long-term population dose resulting from consumption of grains by humans.

INGESTION OF LEAF VEG—total long-term population dose resulting from consumption of leafy vegetables by humans.

INGESTION OF ROOT CROPS—total long-term population dose resulting from consumption of root crops by humans.

INGESTION OF FRUITS—total long-term population dose resulting from consumption of fruits by humans.

INGESTION OF LEGUMES—total long-term population dose resulting from consumption of legumes by humans.

INGESTION OF BEEF—total long-term population dose resulting from consumption of beef by humans.

INGESTION OF MILK—total long-term population dose resulting from consumption of milk by humans.

INGESTION OF POULTRY—total long-term population dose resulting from consumption of poultry by humans.

INGESTION OF OTHER MEAT CROPS—total long-term population dose resulting from consumption of other meat crops by humans.

Variable Name: NXUM9
Variable Type: Integer, Scalar

Allowed Range: $0 \leq \text{value} \leq 10$
Purpose: Specifies the number of long-term population dose result blocks to be printed.

Variable Name: ORGNAM
Variable Type: Character, Scalar
Allowed Range: $2 \leq \text{length} \leq 10$
Purpose: Defines the name of the organ for which the long-term dose breakdown is to be reported. The user must supply NXUM9 organ names in column 1 of the data block.

Variable Name: IX1DS9
Variable Type: Integer, Scalar
Allowed Range: $1 \leq \text{value} \leq \text{NUMRAD}$
Purpose: Defines the inner spatial interval of the region of interest for this result block. The user must supply NXUM9 values in column 2 of the data block.

Variable Name: IX2DS9
Variable Type: Integer, Scalar
Allowed Range: $\text{IX1DS9} \leq \text{value} \leq \text{NUMRAD}$
Purpose: Defines the outer spatial interval of the region of interest for this result block. The user must supply NXUM9 values in column 3 of the data block.

Note: The region of interest, as specified earlier, is used to determine the size of the potentially contaminated area being evaluated. In the context of this consequence measure, the population dose within a region is the population dose that occurs as a result of material deposited within the region. For the direct exposure pathways of groundshine and resuspension, the dose is received by the resident population, but for the indirect exposure pathways of ingestion and decontamination, the dose could be received by individuals who reside elsewhere.

In order to obtain the CCDF tables of a consequence measure requested in this section, append the character string 'CCDF' to the line requesting that result as the fourth item on the data card. The CCDF tables will be printed on the output file (unit 6).

Example Usage:

```
*
TYPE9NUMBER   2      (UP TO 10 ALLOWED)
*
*              ORGNAM        INNER         OUTER
*
TYPE9OUT001    L-EDEWBODY     1            26    CCDF   (0-1000 MILES)
TYPE9OUT002    L-EDEWBODY     1            19           (0-50 MILES)
```

7.15 Economic Cost Results

The CHRONC module calculates the economic costs of all the long-term protective actions as well as the cost of the emergency response actions that were modeled by EARLY. The option to print these economic results is controlled by the user.

No economic costs are printed unless the user specifically requests them. Each request for economic results produces the block of 13 economic results described below. All of the economic cost measures are reported in dollars.

TOTAL ECONOMIC COSTS—the sum of population- and farm-dependent costs.

POP.-DEPENDENT COSTS—the sum of population-dependent decontamination, interdiction, and condemnation costs.

FARM-DEPENDENT COSTS—the sum of farm-dependent decontamination, interdiction, and condemnation costs as well as milk and crop disposal costs.

POP.-DEPENDENT DECONTAMINATION COST—nonfarm property (*i.e.*, property associated with resident population) decontamination cost.

FARM-DEPENDENT DECONTAMINATION COST—farm property decontamination cost.

POP.-DEPENDENT INTERDICTION COST—depreciation and deterioration of nonfarm property during the period it cannot be used during both decontamination and interdiction plus the cost of population removal (see POPCST in Section 7.6).

FARM-DEPENDENT INTERDICTION COST—depreciation and deterioration of farm property during the period it cannot be used during both decontamination and interdiction.

POP.-DEPENDENT CONDEMNATION COST—compensation paid for permanent loss of nonfarm property plus the cost of population removal.

FARM-DEPENDENT CONDEMNATION COST—compensation paid for permanent loss of farm property because it could not be returned to production within 8 years of the accident.

EMERGENCY PHASE COSTS—per-diem costs to compensate people for being away from home due to evacuation and relocation during the emergency phase.

Note: When more than one emergency-response scenario is being evaluated by the EARLY module, the presentation of evacuation and relocation cost is calculated on the basis of the scenario that was defined last in sequence on the EARLY input file.

INTERMEDIATE PHASE COSTS—per-diem costs to compensate people for being away from home due to relocation for the duration of the intermediate phase if DSCRTI is exceeded.

MILK DISPOSAL COSTS—compensation for lost milk sales during a quarter of a year if the first year's crops require disposal. This cost is incurred if the accident occurs during the growing season *and* any of the following conditions are found:

1. the growing-season milk action guide is exceeded, or
2. any decontamination actions are required, or
3. (for MACCS food model only) if COUPLD=.TRUE. *and* any long-term interdiction is required.

CROP DISPOSAL COSTS—compensation for lost nonmilk crop sales during a full year. This cost is incurred if the accident occurs during the growing season and any of the following conditions are found:

1. the growing-season nonmilk action guide is exceeded, or
2. any decontamination actions are required, or
3. (for MACCS food model only) if COUPLD=.TRUE. *and* any long-term interdiction is required.

Variable Name: NXUM10
Variable Type: Integer, Scalar
Allowed Range: $0 \leq$ value ≤ 10
Purpose: Specifies the number of economic result blocks to be printed.

Variable Name: I1DS10
Variable Type: Integer, Scalar
Allowed Range: $1 \leq$ value $\leq$ NUMRAD
Purpose: Defines the inner spatial interval of the region of interest for this result block. The user must supply NXUM10 values in column 1 of the data block.

Variable Name: I2DS10
Variable Type: Integer, Scalar
Allowed Range: I1DS10 $\leq$ value $\leq$ NUMRAD
Purpose: Defines the outer spatial interval of the region of interest for this result block. The user must supply NXUM10 values in column 2 of the data block.

Note: In order to obtain the CCDF tables of a consequence measure requested in this section, append the character string 'CCDF' to the line requesting that result as the third item on the data record. The CCDF tables will be printed on the output file.

Example Usage:

```
*
* ECONOMIC COST RESULTS BROKEN DOWN BY 13 TYPES OF COSTS
*
```

```
* NUMBER OF RESULTS OF THIS TYPE THAT ARE BEING REQUESTED
* FOR EACH RESULT YOU REQUEST, THE CODE WILL PRODUCE A SET OF 13
*
TYP10NUMBER   2      (UP TO 10 ALLOWED)
*
*              INNER    OUTER
*
TYP10OUT001       1       26     CCDF   (0-1000 MILES)
TYP10OUT002       1       19            (0-50 MILES)
```

7.16 Action Distance Results

The long-term protective actions that result from the calculations of the CHRONC module depend on the data supplied by the user. Associated with the long-term actions of decontamination, interdiction, and crop disposal are the maximum distances to which these actions are implemented. The user must specify whether these maximum action distance results are to be printed.

The option to print or not print these long-term action distances is controlled by a flag specified by the user. The flag value .TRUE. will produce the eight maximum action distance results that are described below. Each result is identified by the result name used on the output file together with a description of the result. All of the distances are reported in kilometers.

FARM-DEPENDENT DECONTAMINATION DIST.—maximum distance at which farmland decontamination is required.

POP.-DEPENDENT DECONTAMINATION DIST.—maximum distance at which nonfarmland decontamination is required.

FARM-DEPENDENT INTERDICTION DIST.—maximum distance at which farmland decontamination or interdiction is required.

POP.-DEPENDENT INTERDICTION DIST.—maximum distance at which nonfarmland decontamination or interdiction is required.

FARM-DEPENDENT CONDEMNATION DIST.—maximum distance at which farmland condemnation is required.

POP.-DEPENDENT CONDEMNATION DIST.—maximum distance at which nonfarmland condemnation is required.

MILK DISPOSAL DIST.—maximum distance at which the loss of 3 months of milk and dairy products sales is required.

CROP DISPOSAL DIST.—maximum distance at which the loss of 1 year of nonmilk crop sales is required.

The flag value .FALSE. will eliminate the maximum action distance results from the output.

Variable Name: FLAG11
Variable Type: Logical, Scalar
Allowed Value: .TRUE. or .FALSE.
Purpose: Specifies the print flag for the maximum action distance results.

Note: In order to obtain the CCDF tables of a consequence measure requested in this section, append the character string 'CCDF' to the line requesting that result as the second item on the data record. The CCDF tables will be printed on the output file.

Example Usage:

```
*
TYP11FLAG11 .TRUE.
```

7.17 Impacted Area/Population Results

The long-term protective actions that result from the calculations of the CHRONC module depend on the data supplied by the user. Associated with the long-term actions of decontamination, interdiction, condemnation, and crop disposal are the farm areas and populations that are affected by these actions. The option to print these impacted area/population results is controlled by the user.

No impacted farm-area/population results are printed unless the user specifically requests them. Each request for impacted farm-area/population results produces the block of eight results identified below. All farm-area results are reported in hectares and all population results are reported as number of individuals.

FARM DECONTAMINATION (HECTARES)—area within which farmland decontamination was required.

POP. DECONTAMINATION (INDIVIDUALS)—population of areas that required decontamination of nonfarm property.

FARM INTERDICTION (HECTARES)—farmland area which required either decontamination or interdiction.

POP. INTERDICTION (INDIVIDUALS)—population of areas that required either decontamination or interdiction of nonfarm property.

FARM CONDEMNATION (HECTARES)—area within which farmland condemnation was required.

POP. CONDEMNATION (INDIVIDUALS)—population of areas that required condemnation of nonfarm property.

MILK DISPOSAL AREA (HECTARES)—affected area requiring the loss of milk and dairy products sales for 3 months.

CROP DISPOSAL AREA (HECTARES)—affected area requiring the loss of nonmilk crop sales for a year.

Variable Name: NUM12
Variable Type: Integer, Scalar
Allowed Range: 0 ≤ value ≤ 10
Purpose: Specifies the number of impacted farm-area/population result blocks to be printed.

Variable Name: I1DS12
Variable Type: Integer, Scalar
Allowed Range: 1 ≤ value ≤ NUMRAD
Purpose: Defines the inner spatial interval of the region of interest for this result block. The user must supply NUM12 values in column 1 of the data block.

Variable Name: I2DS12
Variable Type: Integer, Scalar
Allowed Range: I1DS12 ≤ value ≤ NUMRAD
Purpose: Defines the outer spatial interval of the region of interest for this result block. The user must supply NUM12 values in column 2 of the data block.

Note: In order to obtain the CCDF tables of a consequence measure requested in this section, append the character string 'CCDF' to the line requesting that result as the third item on the data record. The CCDF tables will be printed on the output file.

Example Usage:

```
*
TYP12NUMBER   2      (UP TO 10 ALLOWED)
*
*              INNER       OUTER
TYP12OUT001      1           26        CCDF (0-1000 MILES)
TYP12OUT002      1           19             (0-50 MILES)
```

7.18 Maximum Individual Food Ingestion Dose at a Distance

This result is available only when the COMIDA2-based food model option is specified (FDPATH='NEW'). If requested, MACCS2 will report statistics on the maximum food ingestion dose calculated for the 16 wind directions within a user-specified spatial interval, for effective dose or thyroid dose. No other organs are available for this result.

The maximum dose is the dose calculated using the food consumption rates specified in the COMIDA2 input file for a representative individual. The projected doses in years 1 through 9 are examined in turn, and the maximum value found is used in generating this result.

Variable Name:	NUM13
Variable Type:	Integer, Scalar
Allowed Range:	0 ≤ value ≤ 20
Purpose:	Specifies the number of maximum dose from food ingestion result blocks to be calculated.

Variable Name:	IRAD13
Variable Type:	Integer, Scalar
Allowed Range:	1 ≤ value ≤ NUMRAD
Purpose:	Defines the spatial interval of the distance of interest for this result block. The user must supply NUM13 values in column 1 of the data block.

Variable Name:	ORGN13
Variable Type:	Character, Scalar
Allowed Value:	'EFFECTIVE' or 'THYROID'
Purpose:	Defines the organ to be used for each requested result. The user must supply NUM13 values in column 2 of the data block.

Note: In order to obtain the CCDF tables of a consequence measure requested in this section, append the character string 'CCDF' to the line requesting that result as the third item on the data record. The CCDF tables will be printed on the list output file.

Example Usage:

```
*
* MAXIMUM ANNUAL FOOD INGESTION DOSE TO AN INDIVIDUAL, REQUESTED BY IXOT13
*
* THIS RESULT IS CALCULATED AFTER ACCOUNTING FOR TEMPORARY OR PERMANENT
INTERDICTION.
* IT IS ONLY AVAILABLE FOR THE COMIDA2-BASED FOOD MODEL.
*
* NUMBER OF RESULTS OF THIS TYPE THAT ARE BEING REQUESTED
*
TYP13NUMBER   7   (UP TO 20 ALLOWED)
*
* IRAD13 IS THE RADIAL SPATIAL INTERVAL AT WHICH RESULTS ARE REQUESTED
*
* ORGN13 IS THE NAME OF THE ORGAN FOR WHICH RESULTS ARE REQUESTED
*  (ALLOWABLE VALUES FOR ORGN13 ARE 'EFFECTIVE' OR 'THYROID')
*
*              IRAD13      ORGN13
TYP13OUT001       1        EFFECTIVE
TYP13OUT002       2        EFFECTIVE
TYP13OUT003       3        EFFECTIVE
TYP13OUT004       4        EFFECTIVE
```

```
TYP13OUT005       5        EFFECTIVE
TYP13OUT006       1        THYROID
TYP13OUT007       2        THYROID
```

References

Abbott, M. L., and A. S. Rood (1993), *COMIDA: A Radionuclide Food-Chain Model for Acute Fallout Deposition*, EGG-GEO-10367, available from OSTI, Idaho National Engineering Laboratory, Idaho Falls, ID.

Abbott, M. L., and A. S. Rood (1994), "COMIDA: A Radionuclide Food-Chain Model," *Health Physics*, Vol. 66, No. 1, pp. 17–29.

Abrahamson, S., M. A. Bender, B. B. Boecker, E. S. Gilbert, and B. R. Scott (1991), *Health Effects Models for Nuclear Power Plant Accident Consequence Analysis, Modifications of Models Resulting from Recent Reports of Health Effects of Ionizing Radiation, Low LET Radiation, Part II: Scientific Bases for Health Effects Models*, NUREG/CR-4214, Rev. 1, Part II, Addendum 1, LMF-132, Inhalation Toxicology Research Institute, Albuquerque, NM.

Aldrich, D. C., J. L. Sprung, D. J. Alpert, K. Diegert, R. M. Ostmeyer, L. T. Ritchie, and D. R. Strip (1982), *Technical Guidance for Siting Criteria Development*, NUREG/CR-2239, SAND81-1539, Sandia National Laboratories, Albuquerque, NM.

Alonso, A., and E. Gallego (1987), *Cost-Effectiveness Analysis of Countermeasures Using Accident Consequence Assessment Models*, CTN-36-87, Universidad Politécnica de Madrid, Madrid, Spain.

Alonso, A., E. Gallego, and J. E. Martin (1990), *The Modeling of Off-Site Economic Consequences of Nuclear Accidents*, CTN-29-90, Universidad Politécnica de Madrid, Madrid, Spain.

Alpert, D. J., D. I. Chanin, and L. T. Ritchie (1987), "Relative Importance of Individual Elements to LWR Accident Consequence Estimates Using Equal Release Fractions," *Nuclear Safety*, Vol. 28, No. 1, pp. 77–86.

American Nuclear Society and Institute of Electrical and Electronic Engineers (1983), *PRA Procedures Guide*, NUREG/CR-2300, Nuclear Regulatory Commission, Washington, DC.

Amos, C. N., W. H. Baker, M. D. Brandyberry, D. P. Kearnaghan, K. R. O'Kula, J. J. Weingardt, and N. D. Woody (1991), *Savannah River Site Reactor Safety Assessment*, WSRC-RP-91-041-DRAFT, Westinghouse Savannah River Company, Aiken, SC.

American National Standards Institute (1966), *FORTRAN*, ANSI X3.9-1966, New York.

American National Standards Institute (1978), *Programming Language FORTRAN*, ANSI X3.9-1978, ISO 1539-1980(E), New York.

Birchall, A. (1986), "A Microcomputer Algorithm for Solving Compartmental Models Involving Radionuclide Transformations," *Health Physics*, Vol. 50, No. 3 (March), pp. 389–397.

Briggs, G. A. (1975), "Plume Rise Predictions," in *Lectures on Air Pollution and Environmental Impact Analysis*, Workshop proceedings, American Meteorological Association, Boston, MA.

Briggs, G. A. (1984), "Plume Rise and Buoyancy Effects," in *Atmospheric Science and Power Production*, DOE/TIC-27601, Department of Energy, Washington, DC.

Brown, T. D., A. C. Payne, Jr., L. A. Miller, J. D. Johnson, D. I. Chanin, A. W. Shiver, S. J. Higgins, and T. T. Sype (1993), *Integrated Risk Assessment for the LaSalle Unit 2 Nuclear Power Plant*, NUREG/CR-5305, SAND90-2765, Vol. 2, Part 2, Sandia National Laboratories, Albuquerque, NM.

Brown, T. D., L. N. Kmetyk, D. Whitehead, J. Forester, L. Miller, and J. Johnson (1995), *Evaluation of Potential Severe Accidents During Low Power and Shutdown Operations at Grand Gulf, Unit 1*, NUREG/CR-6143, SAND93-2440, Vol. 6, Part 1, Sandia National Laboratories, Albuquerque, NM.

Bureau of the Census (1994), *Statistical Abstract of the United States: 1994*, Government Printing Office, Washington, DC.

Camp, A. L., D. M. Kunsman, L. A. Miller, J. L. Sprung, T. A. Wheeler, and G. D. Wyss (1990), *Level III Probabilistic Risk Assessment for N Reactor*, WHC-MR-0045, SAND89-2102, Westinghouse Hanford Company, Richland, WA.

Chanin, D. I. (1992), *A New Emergency Response Model for MACCS*, LA-SUB-94-67, DE94017051, available from NTIS, Los Alamos National Laboratory, Los Alamos, NM.

Chanin, D. I., and M. L. Young (1997), *Code Manual for MACCS2*. Vol. 2, *Pre-Processor Codes COMIDA2, FGRDCF, IDCF2*, to appear as SAND report, Sandia National Laboratories, Albuquerque, NM.

Chanin, D. I., J. L. Sprung, L. T. Ritchie, and H.-N. Jow (1990), *MELCOR Accident Consequence Code System (MACCS), User's Guide*, NUREG/CR-4691, SAND86-1562, Vol. 1, Sandia National Laboratories, Albuquerque, NM.

Chanin, D., J. Rollstin, J. Foster, and L. Miller (1993), *MACCS Version 1.5.11.1: A Maintenance Release of the Code*, NUREG/CR-6059, SAND92-2146, Sandia National Laboratories, Albuquerque, NM.

Commission of the European Communities (1991), *COSYMA: A New Programme Package for Accident Consequence Assessment*, EUR 13028, Commission of the European Communities, Luxembourg.

Dobbe, C. A., E. R. Carlson, N. H. Marshall, E. S. Marwil, and J. E. Tolli (1990), *Quality Assurance and Verification of the MACCS Code, Version 1.5*, NUREG/CR-5376, Idaho National Engineering Laboratory, Idaho Falls, ID.

Dobbins, R. A. (1979), *Atmospheric Motion and Air Pollution*, John Wiley & Sons, New York.

DOE (1988), *External Dose-Rate Conversion Factors for Calculation of Dose to the Public* , DOE/EH 0070, DE88 014691, Washington, DC.

DOE (1989), *General Design Criteria*, Order 6430.1A, issued April 6, 1989, Department of Energy, Washington, DC.

DOE (1991a), *Draft Environmental Impact Statement for the Siting, Construction, and Operation of New Production Reactor Capacity*, DOE/EIS-0144D, Washington, DC.

DOE (1991b), *Unreviewed Safety Questions*, Order 5480.21, issued December 24, 1991, Department of Energy, Washington, DC.

DOE (1992a), "National Environmental Policy Act Implementing Procedures: Final Rule, 10 CFR 1021," *Federal Register*, Vol. 57, pp. 15122–15159, April 24, 1992.

DOE (1992b), *Safety Analysis Reports*, Order 5480.23, issued April 30, 1992, Department of Energy, Washington, DC.

DOE (1993), *Guidelines for Preparation of Environmental Impact Statements and Environmental Assessments*, no doc. number, issued May 27, 1993, NEPA Oversight Office, Department of Energy, Washington, DC.

DOE (1994a), *F-Canyon Plutonium Solutions Environmental Impact Statement*, DOE/EIS-0219, Department of Energy, Aiken, SC.

DOE (1994b), *Environmental Assessment for the Proposed Interim Storage of Highly Enriched Uranium Above the Maximum Historical Storage Level at the Y-12 Plant, Oak Ridge, TN*, DOE/EA-0929, Department of Energy, Oak Ridge, TN.

DOE (1995a), *Dual Axis Radiographic Hydrodynamic Test Facility Final Environmental Impact Statement*, DOE/EIS-0228, Department of Energy, Albuquerque, NM.

DOE (1995b), *Final Programmatic Environmental Impact Statement for Tritium Supply and Recycling*, DOE/EIS-0161, Department of Energy, Washington, DC.

DOE (1995c), *Disposition of Surplus Highly Enriched Uranium Draft Environmental Impact Statement*, DOE/EIS-0240-D, Department of Energy, Washington, DC.

DOE (1996a), *Final Environmental Impact Statement on a Proposed Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel*, DOE/EIS-0218F, Department of Energy, Washington, DC.

DOE (1996b), *Draft Programmatic Environmental Impact Statement for Stockpile Stewardship and Management*, DOE/EIS-0236, Department of Energy, Washington, DC.

DOE (1996c), *Draft Environmental Impact Statement for the Continued Operation of the Pantex Plant and Associated Storage of Nuclear Weapon Components*, DOE/EIS-0225D, Department of Energy, Washington, DC.

DOE (1996d), *Storage and Disposition of Weapons-Usable Fissile Materials Draft Programmatic Environmental Impact Statement*, DOE/EIS-0229-D, Department of Energy, Washington, DC.

DOE (1996e), "National Environmental Policy Act Implementing Procedures: Proposed Rule, 10 CFR 1021," *Federal Register*, Vol. 61, No. 34, p. 6413 *et seq.*, February 20, 1996.

East, J. M. (1996), *Benchmark of MACCS2 Against MACCS Using DWPF SAR Chapter 9 Integrated Risk Analyses*, WSRC-RP-94-61, Westinghouse Savannah River Company, Aiken, SC.

Eckerman, K. F., and J. C. Ryman (1993), *External Exposure to Radionuclides in Air, Water, and Soil, Federal Guidance Report 12*, EPA 402-R-93-081, Environmental Protection Agency, Washington, DC.

Eckerman, K. F., A. B. Wolbarst, and A. C. B. Richardson (1989), *Limiting Values for Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion, Federal Guidance Report 11*, EPA 520/1-88-020, second printing with corrections, Environmental Protection Agency, Washington, DC.

EPA (Environmental Protection Agency) (1991), *Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors*, OSWER Directive 9285.6-03, PB91-921314, Washington, DC.

EPA (Environmental Protection Agency) (1992), *Manual of Protective Action Guides and Protective Actions for Nuclear Incidents*, EPA 400-R-92-001, PB92-164763, Washington, DC.

EPA (Environmental Protection Agency) (1994), *Estimating Radiogenic Cancer Risks*, EPA 402-R-93-076, Washington, DC.

Evans, J. S. (1990), *Health Effects Models for Nuclear Power Plant Accident Consequence Analysis*, Part I, *Introduction, Integration, and Summary*, NUREG/CR-4214, SAND85-7185, Rev. 1, Part I, Sandia National Laboratories, Albuquerque, NM.

Evans, J. S., D. W. Moeller, and D. W. Cooper (1985), *Health Effects Model for Nuclear Power Plant Accident Consequence Analysis*, Parts I and II, NUREG/CR-4214, SAND85-7185, Sandia National Laboratories, Albuquerque, NM.

Fetter, S. (1988), *Internal Dose Conversion Factors for 19 Target Organs and 9 Irradiation Times and External Dose-Rate Conversion Factors for 21 Target Organs for 259 Radionuclides Produced in Potential Fusion Materials*, EGG-FSP-8036, Idaho National Engineering Laboratory, Idaho Falls, ID.

Fetter, S. (1991), *Internal Dose Conversion Factors for 19 Target Organs and 9 Irradiation Times and External Dose-Rate Conversion Factors for 21 Target Organs for 144 Radionuclides*, EGG-FSP-9875, Idaho National Engineering Laboratory, Idaho Falls, ID.

Fisher, S. E., and K. E. Lenox (1995), *An Assessment of the Radiological Doses Resulting from Accidental Uranium Aerosol Releases and Fission Product Releases from a Postulated Criticality Accident at the Oak Ridge Y-12 Plant*, ORNL/TM-12782, Oak Ridge Y-12 Plant, Oak Ridge, TN.

Gale, H. J., D. L. O. Miller, and E. M. R. Fisher (1964), "Weathering of Caesium-137 in Soil," *Nature*, Vol. 201, pp. 257–261.

Gifford, F. J. (1960), "Atmospheric Dispersion Calculations Using the Generalized Gaussian Plume Model," *Nuclear Safety*, Vol. 2, No. 2, pp. 56–59.

Gifford, F. J. (1976), "Turbulent Diffusion-Typing Schemes: A Review," *Nuclear Safety*, Vol. 1, No. 1, pp. 68–86.

Hall, D. J., and R. A. Waters (1986), *Further Experiments on a Buoyant Emission from a Building*, LR 567 (PA), Warren Spring Laboratory, Stevenage, England.

Hanna, S. R., G. A. Briggs, and R. P. Hosker, Jr. (1982), *Handbook on Atmospheric Diffusion*, DOE/TIC-11223, Department of Energy, Washington, DC.

Hanson, A. L., R. E. Davis, and V. Mubayi (1994), *Calculations in Support of a Potential Definition of a Large Release*, NUREG/CR-6094, Brookhaven National Laboratory, Upton, NY.

Harper, F. T., S. C. Hora, M. L. Young, L. A. Miller, C. H. Lui, M. D. McKay, J. C. Helton, L. H. J. Goossens, R. M. Cooke, J. Päsler-Sauer, B. Kraan, and J. A. Jones (1995), *Probabilistic Accident Consequence Uncertainty Analysis: Dispersion and Deposition Uncertainty Assessment*, Vols. 1–3, NUREG/CR-6244, EUR 15855EN, Commission of the European Communities, Brussels-Luxembourg.

Helton, J. C., A. B. Muller, and A. Bayer (1985), "Contamination of Surface Water Bodies After Reactor Accidents by Erosion of Atmospherically Deposited Radionuclides," *Health Physics*, Vol. 48, No. 6, p. 757.

Helton, J. C., *et al.* (1989), "An Uncertainty/Sensitivity Analysis of MACCS Code Predictions for Severe Nuclear Reactor Accident Consequences," SAND88-1688c, *Proceedings: PSA '89–International Topical Meeting on Probability, Reliability and Safety Assessment*, Sandia National Laboratories, Albuquerque, NM.

Helton, J. C., J. D. Johnson, J. A. Rollstin, A. W. Shiver, and J. L. Sprung (1995a), *Uncertainty and Sensitivity Analysis of Chronic Exposure Results with the MACCS Reactor Accident Consequence Model*, NUREG/CR-6134, SAND93-2370, Sandia National Laboratories, Albuquerque, NM.

Helton, J. C., J. D. Johnson, M. D. McKay, A. W. Shiver, and J. L. Sprung (1995b), *Uncertainty and Sensitivity Analysis of Early Exposure Results with the MACCS Reactor Accident Consequence Model*, NUREG/CR-6135, SAND93-2371, Sandia National Laboratories, Albuquerque, NM.

Helton, J. C., J. D. Johnson, J. A. Rollstin, A. W. Shiver, and J. L. Sprung (1995c), *Uncertainty and Sensitivity Analysis of Food Exposure Results with the MACCS Reactor Accident Consequence Model*, NUREG/CR-6136, SAND93-2372, Sandia National Laboratories, Albuquerque, NM.

Helton, J. C., J. D. Johnson, and J. L. Sprung (1995d), "Robustness of an Uncertainty and Sensitivity Analysis of Early Exposure Results with the MACCS Reactor Accident Consequence Model," *Reliability Engineering and System Safety*, Vol. 48, No. 2, p. 129.

International Commission on Radiological Protection (1977), *Recommendations of the International Commission on Radiological Protection*, Vol. 1, No. 3, ICRP 26, Pergamon Press, New York.

International Commission on Radiological Protection (1989), "Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 1," *Annals of the ICRP*, ICRP Publication 56, Vol. 20, No. 2, Pergamon Press, New York.

International Commission on Radiological Protection (1991), "1990 Recommendations of the International Commission on Radiological Protection," *Annals of the ICRP*, ICRP Publication 60, Vol. 21, Nos. 1–3, Pergamon Press, New York.

Jones, J. A. (1983), *Models to Allow for the Effects of Coastal Sites, Plume Rise and Buildings on Dispersion of Radionuclides and Guidance on the Value of Deposition Velocity and Washout Coefficients*, NRPB-R157, National Radiological Protection Board, England.

Jones, K. R., C. A. Dobbe, and D. L. Knudson (1991), *INEL Personal Computer Version of MACCS 1.5*, NUREG/CR-5667, Idaho National Engineering Laboratory, Idaho Falls, ID.

Jow, H.-N., J. L. Sprung, J. A. Rollstin, L. T. Ritchie, and D. I. Chanin (1990), *MELCOR Accident Consequence Code System (MACCS), Model Description*, NUREG/CR-4691, SAND86-1562, Vol. 2, Sandia National Laboratories, Albuquerque, NM.

Kahaner, D., C. Moler, and S. Nash (1989) *Numerical Methods and Software*, Prentice Hall, Englewood Cliffs, NJ.

Kaplan, S., and B. J. Garrick (1981), "On the Quantitative Definition of Risk," *Risk Analysis*, Vol. 1, No. 1, pp. 11–27.

Lonergan, S. C., R. L. Goble, and C. Cororaton (1990), "Estimating the Financial Consequences of a Severe Reactor Accident in Canada," *Energy*, Vol. 15, No. 6, pp. 507–522.

Mubayi, V., V. Sailor, and G. Anandalingam (1995), *Cost-Benefit Considerations in Regulatory Analysis*, NUREG/CR-6349, Brookhaven National Laboratory, Upton, NY.

National Academy of Sciences (1990), *Health Effects of Exposure to Low Levels of Ionizing Radiation: BEIR V*, National Research Council, National Academy Press, Washington, DC.

Neuhauser, K. S., and F. L. Kanipe (1996), *RADTRAN 4:* Vol. 2, *Technical Manual*, SAND89-2370, Sandia National Laboratories, Albuquerque, NM.

Neymotin, L. (1994), *Comparisons of MACCS Users Calculations for the International Comparison Exercise on Probabilistic Consequence Assessment Codes*, NUREG/CR-6053, Brookhaven National Laboratory, Upton, NY.

NRC (1975), *Reactor Safety Study: Calculation of Reactor Accident Consequences*, WASH-1400, NUREG 75/014, Appendix 6, Nuclear Regulatory Commission, Washington, DC.

NRC (1983), *Atmospheric Dispersion Models for Potential Accident Consequence Assessment at Nuclear Power Plants*, Reg. Guide 1.145, Rev. 1, Nuclear Regulatory Commission, Washington, DC.

NRC (1986), "Safety Goals for the Operations of Nuclear Power Plants; Policy Statement," *Federal Register*, Vol. 51, No. 149, August 4, 1986, Nuclear Regulatory Commission, Washington, DC

NRC (1987), *Reactor Risk Reference Document*, NUREG-1150 (public draft for comment), Nuclear Regulatory Commission, Washington, DC.

NRC (1990), *Formulation of a Large Release Definition and Supporting Rationale*, SECY-90-405, Policy Issue (Notation Vote), December 14, 1990, Nuclear Regulatory Commission, Washington, DC.

NRC (1991), *Severe Accident Risks: An Assessment for Five Commercial Nuclear Power Plants*, NUREG-1150, Nuclear Regulatory Commission, Washington, DC.

Nuclear Energy Agency of the Organization for Economic Cooperation and Development (NEA OECD), and the Commission of the European Communities (1994), *Probabilistic Accident Consequence Assessment Codes: Second International Comparison Overview Report*, Paris, France.

O'Kula, K. R. (1991), "Recommendations for MACCS 1.5 Improvements: Modifications to Improve Applicability to DOE Facilities," SRL-PRA-910018, Letter Report to Ken Murphy of DOE/DP dated January 15, 1991, Westinghouse Savannah River Company, Aiken, SC.

O'Kula, K. R., and J. M. East (1990), *Comparison of MACCS 1.4 and 1.5 With Basis Data from the Savannah River SID*, WSRC-RP-90-1322, Rev. 0, Westinghouse Savannah River Company, Aiken, SC.

O'Kula, K. R., and Z. T. Mendoza (1989), *SRP PRA of Reactor Operation–Level 3 Phase 1 Off-Site Consequence Analysis*, DPST-88-1043, Savannah River Laboratory, Aiken, SC [UCNI report].

Ostmeyer, R. M. (1986), *An Approach to Estimating Food Ingestion Exposures for Nuclear Waste Transportation Accidents*, SAND85-1722, Sandia National Laboratories, Albuquerque, NM.

Panitz, H.-J. (1989), *Accident Consequence Assessments with Different Atmospheric Dispersion Models, A Benchmark Study*, KfK 4445, Kerforschungszentrum, Karlsruhe, Germany.

Payne, A. C., Jr. (1992), *Analysis of the LaSalle Unit 2 Nuclear Power Plant: Risk Methods Integration and Evaluation Program (RMIEP)*, NUREG/CR-4832, SAND92-0537, Vol. 1, Sandia National Laboratories, Albuquerque, NM.

Peterson, V. L. (1993a), *Population Distribution and Building Specifications Relevant to Atmospheric Modeling for Rocky Flats Plant, 1993*, NSTR-016-93, Rocky Flats Plant, Golden, CO [report not for public distribution: may contain UCNI].

Peterson, V. L. (1993b), *Reference Computations of Public Dose and Cancer Risk from Airborne Releases of Plutonium*, RFP-4910, Rocky Flats Plant, Golden, CO.

Peterson, V. L. (1994a), *Verification and Validation of the MELCOR Accident Consequence Code System (MACCS)*, NSTR-017-94, Rev. 0, Rocky Flats Plant, Golden, CO.

Peterson, V. L. (1994b), *Tools and Methodology for Collocated-Worker Consequence Assessments*, RFP-4911, Rev. 0, Rocky Flats Plant, Golden, CO.

Peterson, V. L. (1995), *Reference Computations of Public Dose and Cancer Risk from Airborne Releases of Uranium and Class W Plutonium*, RFP-4965, Rev. 0, Rocky Flats Plant, Golden, CO.

Radiation Shielding Information Center (1994), *FGR-DOSE: Dose Coefficients from Federal Guidance Reports 11 and 12*, DLC-167, Oak Ridge National Laboratory, Oak Ridge, TN.

Ramsdell, J. V., Jr. (1990), "Diffusion in Building Wakes for Ground-Level Releases," *Atmospheric Environment*, Vol. 24B, No. 3, pp. 377–388.

Raytheon Systems Services (1995), *Draft Safety Analysis Report for the Device Assembly Facility at the Nevada Test Site*, DAF-SAR-001-193-5394C, M. H. Chew & Associates, Livermore, CA [UCNI report].

Ritchie, L. T., J. D. Johnson, and R. M. Blond (1983), *Calculations of Reactor Accident Consequences Version 2 CRAC2: Computer Code, User's Guide*, NUREG/CR-2326, SAND81-1994, Sandia National Laboratories, Albuquerque, NM.

Ritchie, L. T., D. J. Alpert, R. P. Burke, J. D. Johnson, R. M. Ostmeyer, D. C. Aldrich, and R. M. Blond (1984), *CRAC2 Model Description*, NUREG/CR-2552, SAND82-0342, Sandia National Laboratories, Albuquerque, NM.

Rollstin, J.A., D. I. Chanin, and H.-N. Jow (1990), *MELCOR Accident Consequence Code System (MACCS)*, Programmer's Reference Manual, NUREG/CR-4691, SAND86-1562, Sandia National Laboratories, Albuquerque, NM.

Rood, A. S., and M. L. Abbott (1991), *A Comparison of Dose and Dose-Rate Conversion Factors from the Soviet Union, United Kingdom, U.S. Department of Energy, and the Idaho National Engineering Laboratory Fusion Safety Program*, EGG-FSP-9865, Idaho National Engineering Laboratory, Idaho Falls, ID.

Runkle, G. E., and R. M. Ostmeyer (1985), *An Assessment of Dosimetry Data for Accidental Radionuclide Releases from Nuclear Reactors*, NUREG/CR-4185, SAND85-0283, Sandia National Laboratories, Albuquerque, NM.

Science Applications International Corporation (SAIC) (1993), *U.S. Department of Energy Defense Programs Safety Survey Report*–Vol. I: *Main Report*, DOE/DP-70056-H1, D. Pinkston, ed., SAIC, Germantown, MD.

Skrable, K., C. French, G. Chabot, and A. Major (1974), "A General Equation for the Kinetics of Linear First Order Phenomena and Suggested Applications," *Health Physics*, Vol. 27 (July), pp. 155–157.

Snell, W. G., and R. W. Jubach (1981), *Technical Basis for Regulatory Guide 1.145: Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants*, NUREG/CR-2260, NUS Corp.

Sprung, J. L., J. A. Rollstin, J. C. Helton, and H.-N. Jow (1990), *Evaluation of Severe Accident Risks: Quantification of Major Input Parameters, MACCS Input*, NUREG/CR-4551, SAND86-1309, Vol. 2, Rev. 1, Part 7, Sandia National Laboratories, Albuquerque, NM.

Stone and Webster (1991), *FSAR Review Team Report on Rocky Flats Plant Building 707*, no doc. number, Stone & Webster Engineering Corp., Boston, MA [UCNI report].

Systems Applications, Inc. (1982), *Survey of Plume Models for Atmospheric Application*, EPRI EA-2243, Electric Power Research Institute, Palo Alto, CA.

Tadmor, J., and Y. Gur (1969), "Analytical Expressions for the Vertical and Lateral Dispersion Coefficients in Atmospheric Diffusion," *Atmospheric Environment*, Vol. 3, pp. 688–689.

Turner, D. B. (1970), *Workbook of Atmospheric Dispersion Estimates*, PSH-999-AP-26, Department of Health, Education, and Welfare, Washington, DC.

Tveten, U. (1990a), *Radionuclide Behavior in the Environment*, NUREG/CR-5304, SAND90-7116, Institutt for Energiteknikk, Kjeller, Norway.

Tveten, U. (1990b), *Review of the Chronic Exposure Pathway Models in MACCS and Several Other Well-Known Probabilistic Risk Assessment Models*, NUREG/CR-5377, Institutt for Energiteknikk, Kjeller, Norway.

Tveten, U. (1995), "Use of Post-Chernobyl Data from Norway to Validate the Long-Term Exposure Models of the Accident Consequence Code MACCS," *Nuclear Technology*, Vol. 65, No. 3, p. 322.

Vogt, K.-J. (1977), "Empirical Investigations of the Diffusion of Waste Air Plumes in the Atmosphere," *Nuclear Technology*, Vol. 34, pp. 43–57.

Wenzel, D. R. (1994), *The Radiological Safety Analysis Computer Program (RSAC-5) User's Manual*, WINCO-1123, Rev. 1, Idaho National Engineering Laboratory, Idaho Falls, ID.

Westinghouse Savannah River Company (1990), *Reactor Operation Safety Information Document*, WSRC-RP-89-820, Westinghouse Savannah River Company, Aiken, SC.

Whicker, F. W., and T. B. Kirchner (1987), "PATHWAY: A Dynamic Food-Chain Model to Predict Radionuclide Ingestion After Fallout Deposition," *Health Physics*, Vol. 52, No. 6, pp. 717–737.

Whicker, F. W., T. B. Kirchner, D. D. Breshears, and M. D. Otis (1990), "Estimation of Radionuclide Ingestion: The PATHWAY Food-Chain Model," *Health Physics*, Vol. 59, pp. 645–657.

Young, M. (1994), *Evaluation of Population Density and Distribution Criteria in Nuclear Power Plant Siting*, SAND93-0848, Sandia National Laboratories, Albuquerque, NM.

Young, M., and D. Chanin (1997), *DOSFAC2: User's Guide*, NUREG/CR-6547, SAND97-2776, Sandia National Laboratories, Albuquerque, NM.

Yuan, Y. C., S. Y. Chen, B. M. Biwer, and D. J. LePoire (1995), *RISKIND—A Computer Program for Calculating Radiological Consequences and Health Risks from Transportation of Spent Nuclear Fuel*, ANL/EAD-1, Argonne National Laboratory, Argonne, IL.

Appendix A: Auxiliary Input Files

A.1 Meteorological Data File Format

For METCOD values of 1, 2 or 5 (see Section 5.13), a meteorological data file must be provided by the user. The file consists of 1 year of hourly recordings (8760) of the wind direction, wind speed, atmospheric stability, and accumulated precipitation. Generally, the data are taken from either the facility site or from a nearby weather station.

The meteorological data file used in MACCS2 is a formatted text file. The format of this file is identical to that used with MACCS and similar to that used in the CRAC2 code.

There are a total of 8763 records in the meteorological data file. The first two records contain identification information. Up to 80 characters may be used on each line. This header information is printed on the output listing. If an additional identification record is added at the beginning of the file, CRAC2 meteorological data files may be used with MACCS2. Records 3 through 8762 contain hourly meteorological observations, one hour per line. The hourly meteorological data is input as integers. The format of the information is as follows:

Columns	Format	Variable	Information	Range
2-4	I3	ISTRDY	Julian day of the year	1 to 365
6-7	I2	ISTRHR	Hour of the day	1 to 24
9-10	I2	WINDIR	Direction the wind is blowing toward (N to NNW)	1 to 16
11-13	I3	WINDSPD	Wind speed (10ths of meters per second)	1 to 300*
14	I1	ISTAB	Stability Category (Pasquill A through G)	1 to 7**
15-17	I3	RNMM	Accumulated precipitation (100ths of inches)	-1 to 999***

*Values between 1 and 4 are automatically changed to 5 (0.5 m/s).
**A value of 7 is automatically changed to 6 by the code.
***Some meteorological data files use –1 to indicate a trace of precipitation during the hour. MACCS2 assumes these values to be 0.

The 8763rd record contains a table of eight values of mixing layer height. Two values of mixing height are supplied for each of the four seasons of the year. The first of these two values corresponds to the morning mixing height and the second to the afternoon height. In the current implementation, the larger of these two values and the value of the boundary weather mixing height is used by the code.

In its present form, that atmospheric model implemented in MACCS2 does not allow a change in mixing layer to occur during transport of the plume. Mixing layer height is assumed to be

constant and therefore only a single value is used by the code. Only seasonal variability can be considered for this parameter. The start day of each weather sequence determines the season in which that sequence lies.

Note: The following data are supplied in units of hundreds of meters and as real numbers.

Columns	Format	Variable	Information	Range
1-10	F10.0	HEIGHT(1,1)	Morning-winter mixing height	0. to 999.
11-20	F10.0	HEIGHT(2,1)	Morning-spring mixing height	0. to 999.
21-30	F10.0	HEIGHT(3,1)	Morning-summer mixing height	0. to 999.
31-40	F10.0	HEIGHT(4,1)	Morning-autumn mixing height	0. to 999.
41-50	F10.0	HEIGHT(1,2)	Afternoon-winter mixing height	0. to 999.
51-60	F10.0	HEIGHT(2,2)	Afternoon-spring mixing height	0. to 999.
61-70	F10.0	HEIGHT(3,2)	Afternoon-summer mixing height	0. to 999.
71-80	F10.0	HEIGHT(4,2)	Afternoon-autumn mixing height	0. to 999.

A sample set of records from the meteorological data file is provided in Figure A-1, which shows the first and last ten records of the file. For example, the weather conditions for day one, hour one (record number three) are: wind direction—blowing toward the SE, wind speed of 2.6 m/s, stability 4 (category D), and accumulated precipitation of 0.07 inches (1.8 mm) in the hour. The winter, spring, summer, and autumn mixing heights for neutral and unstable conditions (record 8763) are all 1200 m.

```
U.S. NATIONAL WEATHER SERVICE METEOROLOGICAL DATA FILE
Sample Input for the MACCS2 Documentation
 1    1  70264  7
 1    2  60624  7
 1    3  80414  2
 1    4  80364 -1
 1    5  90314  0
 1    6 110464  0
 1    7 110264 -1
 1    8 110414 -1
 .
 .
 .
 365 16 120154  4
 365 17 110154  4
 365 18 130214  4
 365 19 130154  3
 365 20 130104  2
 365 21 130154  2
 365 22 140104  2
 365 23 130104  2
 365 24 140104  2
       12.       12.       12.       12.        12        12        12        12
```

Figure A-1. The first and last ten records from a MACCS/MACCS2 meterological file.

A.2 Dose Conversion Factors File Format

A dose conversion factor (DCF) file is required for both the EARLY and CHRONC modules. The format of this file is identical to that of MACCS, allowing both codes to be used with identical DCF data for purposes of code comparison.

In contrast to MACCS, however, where the name of the DCF file is specified in the batch file controlling execution, MACCS2 requires the user to specify a DCF filename as input variable DCF_FILE defined in Section 6.2.1. Also, in contrast to MACCS, which utilizes the DCF file's values for 8-hr and 7-day groundshine dose, MACCS2 does not process those columns of data, and they may be omitted.

MACCS2 utilizes the following data from the DCF file:

1. cloudshine dose-rate factor [Sv /(Bq-s/m^3)],

2. groundshine dose-rate factor [Sv/(Bq-s/m^2)],

3. "acute" short-term inhalation doses (Sv/Bq) used for calculation of deterministic health effects,

4. "lifetime" 50-year committed inhalation doses (Sv/Bq) used for calculation of individual and societal doses and stochastic health effects, and

5. 50-year committed ingestion doses (Sv/Bq) used for calculation of individual and societal doses and stochastic health effects from food and water ingestion.

If an organ is not considered in the deterministic health effects models, no internal dose for early exposure from inhalation is given, or needed; the values on the file are set to –1.0.

The DCF data file used in MACCS2 is a formatted file. An example of a MACCS2 DCF file is provided in Figure A-2. The first two records contain identification information. Up to 80 characters may be used on each line. This header information is printed on the output listing. The next line gives the number of organs included in the file. The format for this line is I10. The organ names are specified next, one name per line. The spelling must be the same as that used in all other program data files. Next the number of radionuclides included in the file is given. The format is again I10.

The names of the radionuclides are given on the following lines, one name per line. The spelling of the radionuclide names must again be the same as in all other program modules. Following the list of radionuclides, there are two lines in the dosimetry data file that are not read but aid user understanding of the file. On the next line is the name of the first radionuclide followed on the next lines by the organ names and the associated dosimetry data. The format of the dosimetry data is as follows:

Column	Variable	Format	Identification
1-10	FILORG	A10	Name of the Organ
11-20	CDCF	F10.0	Cloudshine Dose-Rate Factor
21-30	IGDCF(I,J,1)	F10.0	Not Applicable—Not Used by MACCS2
31-40	IGDCF(I,J,2)	F10.0	Not Applicable—Not Used by MACCS2
41-50	GRDCF	F10.0	Groundshine Dose-Rate Factor
51-60	IDCF(I,J,1)	F10.0	Inhalation Dose Factor Used Only with the Deterministic Health Effects Models
61-70	IDCF(I,J,2)	F10.0	50-year Inhalation Dose Commitment
71-80	DFING	F10.0	50-year Inhalation Dose Commitment

```
MACCS2 DCF File
Sample DCF File For MACCS2 Documentation
        17 ORGANS DEFINED IN THIS FILE:
STOMACH
SMALL IN
LUNGS
RED MARR
THYROID
LOWER LI
BONE SUR
BREAST
TESTES
OVARIES
EDEWBODY
THYROIDH
ADRENALS
BLAD WAL
KIDNEYS
LIVER
PANCREAS
         2 NUCLIDES DEFINED IN THIS FILE:
CO-58
CO-60

          CLOUDSHINE  GROUND    GROUND    GROUND    INHALED   INHALED  INGESTION
                      SHINE 8HR SHINE 7DAY SHINE RATE ACUTE    CHRONIC
CO-58
STOMACH    3.520E-14 1.979E-11 4.023E-10 6.881E-16 1.558E-10 1.394E-09 3.853E-10
SMALL IN   3.203E-14 1.796E-11 3.652E-10 6.247E-16 3.307E-10 7.495E-10 1.130E-09
LUNGS      3.805E-14 2.143E-11 4.356E-10 7.452E-16 7.599E-10 1.601E-08 8.510E-11
RED MARR   3.869E-14 2.179E-11 4.430E-10 7.579E-16 1.577E-10 9.228E-10 2.601E-10
THYROID    4.788E-14 2.690E-11 5.469E-10 9.354E-16-1.000E+00 8.704E-10 6.308E-11
LOWER LI   3.456E-14 1.942E-11 3.948E-10 6.754E-16 9.144E-10 1.989E-09 3.962E-09
BONE SUR   4.249E-14 2.389E-11 4.857E-10 8.308E-16-1.000E+00 6.926E-10 1.252E-10
BREAST     4.566E-14 2.571E-11 5.228E-10 8.942E-16-1.000E+00 9.367E-10 1.788E-10
TESTES     5.074E-14 2.845E-11 5.784E-10 9.894E-16-1.000E+00 1.060E-10 1.614E-10
OVARIES    3.456E-14 1.942E-11 3.948E-10 6.754E-16-1.000E+00 6.166E-10 1.041E-09
EDEWBODY   4.398E-14 2.459E-11 5.000E-10 8.553E-16-1.000E+00 3.088E-09 8.206E-10
THYROIDH   4.788E-14 2.690E-11 5.469E-10 9.354E-16 6.142E-11 8.704E-10 6.308E-11
ADRENALS   3.742E-14 2.097E-11 4.264E-10 7.293E-16-1.000E+00 1.601E-09 1.509E-10
BLAD WAL   3.583E-14 2.015E-11 4.097E-10 7.008E-16-1.000E+00 2.387E-10 3.643E-10
KIDNEYS    3.742E-14 2.106E-11 4.282E-10 7.325E-16-1.000E+00 7.523E-10 2.094E-10
LIVER      3.583E-14 2.006E-11 4.078E-10 6.976E-16-1.000E+00 1.637E-09 2.456E-10
PANCREAS   3.079E-14 1.723E-11 3.504E-10 5.993E-16-1.000E+00 1.675E-09 1.997E-10
CO-60
STOMACH    9.132E-14 4.602E-11 9.655E-10 1.598E-15 3.840E-10 2.726E-08 1.611E-09
SMALL IN   8.530E-14 4.301E-11 9.022E-10 1.494E-15 8.077E-10 7.046E-09 3.591E-09
LUNGS      9.862E-14 4.986E-11 1.046E-09 1.731E-15 3.511E-09 3.448E-07 8.768E-10
RED MARR   9.957E-14 5.032E-11 1.055E-09 1.747E-15 3.986E-10 1.718E-08 1.311E-09
THYROID    1.230E-13 6.219E-11 1.305E-09 2.159E-15-1.000E+00 1.615E-08 7.843E-10
LOWER LI   9.069E-14 4.575E-11 9.597E-10 1.589E-15 2.386E-09 7.916E-09 1.113E-08
BONE SUR   1.056E-13 5.333E-11 1.119E-09 1.852E-15-1.000E+00 1.353E-08 9.415E-10
BREAST     1.164E-13 5.872E-11 1.232E-09 2.039E-15-1.000E+00 1.843E-08 1.100E-09
TESTES     1.297E-13 6.548E-11 1.373E-09 2.274E-15-1.000E+00 1.697E-09 1.075E-09
OVARIES    8.879E-14 4.484E-11 9.406E-10 1.557E-15-1.000E+00 4.753E-09 3.187E-09
EDEWBODY   1.125E-13 5.666E-11 1.189E-09 1.968E-15-1.000E+00 5.948E-08 2.839E-09
THYROIDH   1.230E-13 6.219E-11 1.305E-09 2.159E-15 1.465E-10 1.615E-08 7.843E-10
ADRENALS   9.418E-14 4.749E-11 9.961E-10 1.649E-15-1.000E+00 2.990E-08 1.586E-09
BLAD WAL   9.354E-14 4.721E-11 9.904E-10 1.639E-15-1.000E+00 2.949E-09 1.771E-09
KIDNEYS    9.830E-14 4.959E-11 1.040E-09 1.722E-15-1.000E+00 1.557E-08 1.355E-09
LIVER      9.323E-14 4.703E-11 9.865E-10 1.633E-15-1.000E+00 3.352E-08 2.326E-09
PANCREAS   8.086E-14 4.073E-11 8.544E-10 1.414E-15-1.000E+00 3.179E-08 1.290E-09
```

Figure A-2. Sample MACCS2 DCF file.

A.3 Site Data File Format

In the Site Data file, the user specifies the population distribution and land use information for the region surrounding the site. Contained in the Site Data file are the geometry data used for the site (spatial intervals), population distribution, fraction of the area that is land, watershed data for the liquid pathways model, information on agricultural land use and growing seasons, and regional economic information. An example of a Site Data file is provided in NUREG/CR-4691, Volume 1, Appendix D.2.

The user specifies in the EARLY input file whether a Site Data file is to be used (see variable POPFLG in Section 6.3). If a Site Data file is not being used, the population density applied in the EARLY and CHRONC modules is specified in the EARLY input file. It is not possible for the user to supply differing population data for the two modules.

The Site Data file used in MACCS2 is a formatted file. The data must appear exactly as described below and in exactly the same order. In contrast to the input files for MACCS2, which are processed by a free-format input processor, the Site Data file is processed with fixed format FORTRAN READ statements.

The use of fixed format READ statements requires that the user exercise special attention to line up the data items in their proper fields. Any numeric items specified in exponential format (*e.g.*, 1.E–6) must be right-justified in the field because trailing blanks are processed as zeroes in the FORTRAN READ statements.

In contrast to the ATMOS, EARLY, and CHRONC user input files, where every value is validated by the code to ensure that it lies within a range of allowable values, the validation performed on the Site Data is only partially complete. Some of the input parameters on this file are rigorously checked to ensure that they fall within the allowed range, while other values are not checked at all.

It is recommended that the user exercise scrupulous care in constructing a Site Data file. It is very important that all items appear in their proper fields and that all numeric values lie within the range of acceptable values. Failure to conform to these requirements may lead to the generation of spurious results.

When code users edited the population counts in the Site Data file using text editors, there were several occurrences where the code diagnosed an input conversion error and aborted execution, and it has proved very difficult to identify and remedy the problem. A possible explanation for these problems is the inadvertent inclusion of nonprintable ASCII characters or control codes in the file. A likely culprit appears to be the TAB character (ASCII code decimal 9). Control codes such as the TAB can be treated differently by different text editors, or their handling can vary, depending on user-specified editor settings.

In order to aid users in identifying the cause of these problems, and maximize the portability of the Site Data file across computer platforms, MACCS2 incorporates a test for nonprintable

characters in the site data file. If any such characters are found to be present, their location on the input data line is indicated, and further execution is terminated.

The ANSI standard for FORTRAN 77 does not specify how the TAB and other control codes should be handled if they are encountered during formatted input operations. The set of processor characters handled by standard FORTRAN 77 is limited to the blank, numeric digits, upper case letters, and the following twelve symbols: '+-*/(),.:=$. However, it seems logical to extend this set to include all of the printable characters that can be generated by a IBM PC-AT-compatible keyboard; that is, the characters with decimal ASCII control codes between 32 (blank) and 126 (~). As a result, the definition of allowable characters in the site data file is that it can be allowed to contain all of the characters having decimal ASCII control codes between 32 and 126, inclusive.

A sample MACCS2 site data file is listed in Figure A-3. The first two records of the site data file contain identification information. Up to 80 characters may be used on each line. This header information is printed on the output listing.

Following the descriptive text fields, there are six data records that specify the amount of data that is being supplied on the file. The values defined on these data records must be consistent with the MACCS2 model definition data defined by the ATMOS, EARLY, and CHRONC input files. The value of the Site Data file input variable and the corresponding ATMOS, EARLY, and CHRONC variable must be identical. If any inconsistencies are detected, execution of the program will be terminated.

The data are input as integers and the format is as follows:

Line	Columns	Fortran Format Descriptor	Site-File Variable	Identification	MACCS2 Variable	Allowed Range
3	1-4	I4	NSPDTS	No. of spatial intervals	NUMRAD	2-35
4	1-4	I4	NWNDIR	No. of wind directions	NUMCOR	16-16
5	1-4	I4	NCPGZN	No. of food crops	NFICRP	1-10
6	1-4	I4	NWPISO	No. of water radionuclides	NUMWPI	1-10
7	1-4	I4	NWTRSH	No. of watersheds	NUMWPA	1-4
8	1-4	I4	NECRGN	No. of economic regions	N.A.	1-99

Eight blocks of site data follow the introductory block described above. Each of these data blocks is introduced by a separator line that identifies the block of data to follow. The first line of each data block must be the separator for that block. The first character (column 1) of the separator line is ignored and the following 22 characters must match the identification field for that specific data block. The eight blocks of data are identified by the following character separators:

SPATIAL DISTANCES
POPULATION
LAND FRACTION
REGION INDEX
WATERSHED INDEX
CROP SEASON AND SHARE
WATERSHED DEFINITION
REGIONAL ECONOMIC DATA

```
MACCS SITE DATA FILE
 SAMPLE SITE FILE FOR MACCS2 DOCUMENTATION
  26 SPATIAL INTERVALS
  16 WIND DIRECTIONS
   7 CROP CATEGORIES
   4 WATER PATHWAY ISOTOPES
   2 WATERSHEDS
  59 ECONOMIC REGIONS
 SPATIAL DISTANCES
      0.16      0.52      1.21     1.61       2.13      3.22      4.02      4.83
      5.63      8.05     11.27    16.09      20.92     25.75     32.19     40.23
     48.28     64.37     80.47   112.65     160.93    241.14    321.87    563.27
   804.67    1609.34
 POPULATION
        0.        0.        0.        0.        0.        0.        4.        5.
        6.       25.     3341.     7107.     2173.        0.     1305.      474.
     2252.     2945.     5403.    20169.   112004.  3431358.  1355700.  2742710.
  2487346.   104331.
        0.        0.        0.        0.        1.        2.        9.       13.
       15.       63.     1667.     3550.     1330.     1072.     3198.     2425.
      515.     9469.     5317.     7120.    13586.   198785.  1058744. 20508438.
  3290082.   830354.
        0.        0.        0.        0.        0.        0.        5.        6.
        8.       31.      822.     1752.     4543.     1713.     1597.     2296.
     6535.     1775.        0.     8555.    48596.   119411.   233382.  3003954.
  7620063.  1169436.
        0.        0.        0.        0.        0.        0.        1.        1.
        2.       11.      543.     1157.     3820.     1621.     3364.        0.
        0.      129.     6679.    11858.        0.        0.        0.        0.
        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.     4798.    10202.    10348.    10480.     9570.        0.
        0.     2317.     1756.        0.        0.        0.        0.        0.
        0.        0.
        0.        0.        0.        0.        0.        0.        1.        1.
        1.        7.     8316.    17684.    16340.    30419.    39474.    74998.
    24195.    80412.    57477.        0.        0.        0.        0.        0.
        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.     1722.     6433.    36763.    20632.
   126203.   372471.    68327.     8599.     6339.     1057.        0.        0.
        0.        0.
        0.        0.        0.        0.        0.        0.        2.        2.
```

Figure A-3. MACCS/MACCS2 sample Site Data file (continued on following page).

```
      3.       13.      127.      273.     1649.     4571.     3441.     7838.
  11747.    19019.     3360.    36387.    10447.    12402.        0.        0.
      0.        0.
      0.        0.        5.        4.        8.       23.       14.       20.
     23.       93.      301.      650.        0.        0.     1264.     4065.
   1106.    14665.     4071.    18006.    37417.    89072.    81626.        0.
      0.        0.
      0.        0.        0.        0.        0.        0.       19.       25.
     29.      117.       45.      105.        0.      510.      951.     1521.
   1223.    17636.     4926.    30765.    53265.   289674.   216165.   479431.
 280809.  8801784.
      0.        0.        0.        0.        1.        2.       14.       20.
     23.       93.      155.      338.      125.     1079.        0.     1355.
   2765.      154.     5296.    21409.    62228.   523803.   479588.  1538059.
1526840.  3099458.
      0.        0.        0.        0.        1.        2.       14.       20.
     23.       93.      110.      240.     1056.        0.       50.     1396.
    915.     3153.     4132.    16295.    35596.   239712.   709522.  2845970.
3957581. 10560254.
      0.        0.        0.        0.        0.        0.       25.       33.
     38.      154.       30.       70.      450.        0.      980.      517.
    155.    66531.    40902.     9557.    44818.   194801.   376828.  1492286.
2250273. 12145932.
      0.        0.        0.        0.        0.        0.        7.        9.
     12.       47.       31.       69.        0.      380.      281.      445.
   1986.    32459.   183133.   193630.    30369.   203275.    94113.  1328987.
5086913. 19537940.
      0.        0.        0.        0.        0.        0.        0.        0.
      0.        0.      223.      477.        0.     1026.      609.     2575.
   2794.     6593.    96857.   107328.    47585.   156826.   101785.  4175263.
7535605.  9667977.
      0.        0.        0.        0.        0.        0.       15.       20.
     23.       92.     2503.     5326.     3508.     1826.     1884.      275.
   3965.     2084.     6270.    10765.   103787.   970659.   472558.  1396088.
1969210.    73968.
LAND FRACTION
1.00 1.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.80 1.00 1.00 0.95 0.75 0.70 0.85
1.00 0.85 0.70 0.75 0.55 0.70 0.60 1.00 1.00 0.95
1.00 1.00 1.00 1.00 0.90 0.70 0.40 0.00 0.00 0.45 1.00 0.95 0.40 0.60 1.00 1.00
0.90 0.45 0.60 0.20 0.50 0.50 0.30 0.25 0.50 0.60
1.00 1.00 1.00 1.00 1.00 1.00 0.00 0.00 0.00 0.05 1.00 1.00 0.20 1.00 0.70 0.30
0.85 0.20 0.00 0.20 0.00 0.00 0.00 0.00 0.00 0.00
1.00 1.00 1.00 1.00 1.00 0.80 0.10 0.00 0.00 0.00 1.00 1.00 0.75 0.30 0.40 0.00
0.15 0.00 0.45 0.30 0.00 0.00 0.00 0.00 0.00 0.00
1.00 1.00 1.00 1.00 1.00 0.60 0.00 0.00 0.00 0.00 0.95 1.00 1.00 0.70 0.40 0.10
0.00 0.50 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
1.00 1.00 1.00 1.00 1.00 0.70 0.00 0.00 0.00 0.80 0.90 0.75 0.85 1.00 1.00 0.70
0.15 0.25 0.25 0.00 0.00 0.00 0.00 0.00 0.00 0.00
1.00 1.00 1.00 1.00 1.00 1.00 0.55 0.50 0.25 0.15 0.00 0.10 0.00 0.10 0.50 0.60
0.85 1.00 1.00 0.40 0.40 0.05 0.00 0.00 0.00 0.00
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 0.90 0.35 0.40 0.80 1.00 1.00 1.00
1.00 1.00 1.00 1.00 0.95 0.20 0.00 0.00 0.00 0.00
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 0.80 0.40 0.00 0.00 0.20
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 1.00 1.00 0.75 0.50 0.40
1.00 1.00 0.70 0.40 0.20 0.75 0.95 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 0.95 1.00 1.00 1.00 1.00 0.80
1.00 1.00 0.00 0.00 0.00 0.00 0.05 0.70 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 0.95 0.90 1.00 1.00 1.00 1.00
1.00 1.00 0.00 0.00 0.00 0.00 0.00 0.15 0.70 0.90 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 0.00 0.00 0.00 0.00 0.00 0.00 0.20 0.50 0.40 0.30 0.25 0.75 0.80 0.85
0.85 0.95 1.00 1.00 1.00 1.00 1.00 1.00 0.90 0.85
1.00 1.00 0.00 0.00 0.00 0.00 0.00 0.15 0.80 0.75 0.80 0.85 0.95 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 0.50 0.45
1.00 1.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.90 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 0.95 0.80 0.85 1.00 1.00 0.55 0.95
REGION INDEX
```

Figure A-3. MACCS/MACCS2 sample Site Data file (continued on following page).

```
444450505050505044444444444444444444441818 7283054
4444444444444450504444444444444444444444418 728301917
44444444444450505044444444444444444450441850505050
444444444444445050504444444444450445044445050505050
444444444444505050504444444444445044505050505050505050
444444444444505050504444444444444444444450505050505050
444444444444444444445044504444444444444443131505050 50
444444444444444444444444444444444444444431313150505050
444444444444444444444444444444444444443131313131505 0 8
444444444444444444444444444444444444444443131313138 9 8
444444444444444444444444444444444444444431313138 9 1
444450505050444444444444444444444444444444444444314040
444450505050504444444444444444444444444444444444461511
4444505050505050444444444444444444444444444444444463347
444450505050504444444444444444444444444444444444365320
4444505050505050504444444444444444444444441818363053
 WATERSHED INDEX
 1 1 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 2 2 2 2 1 1 2 1 1 1 1 1 1 2 2 2 2 2 2 1
 1 1 1 1 1 1 2 2 2 2 1 1 2 1 1 2 1 2 2 2 2 2 2 2 2 2
 1 1 1 1 1 1 2 2 2 2 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2
 1 1 1 1 1 1 2 2 2 2 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2
 1 1 1 1 1 1 2 2 2 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2
 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 1 1 1 1 2 2 2 2 2 2 2
 1 1 1 1 1 1 1 1 1 1 2 2 1 1 1 1 1 1 1 1 1 2 2 2 2 2
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2
 1 1 1 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 CROP SEASON AND SHARE
   1 PASTURE               90. 270.   0.41
   2 STORED FORAGE        150. 240.   0.13
   3 GRAINS               150. 240.   0.21
   4 GRN LEAFY VEGETABLES 150. 240.   0.002
   5 OTHER FOOD CROPS     150. 240.   0.004
   6 LEGUMES AND SEEDS    150. 240.   0.15
   7 ROOTS AND TUBERS     150. 240.   0.003
 WATERSHED DEFINITION              1111111111222222222233333333334444444444
   1 SR-89                             5.0E-6    0.0
   2 SR-90                             5.0E-6    0.0
   3 CS-134                            5.0E-6    0.0
   4 CS-137                            5.0E-6    0.0
 REGIONAL ECONOMIC DATA
   1 ALA             .354 .040      459.     1824.    62000.
   2 ARIZ            .516 .104      110.      682.    74000.
   3 ARK             .483 .041      466.     2049.    61000.
   4 CALIF           .330 .144     1022.     4394.    93000.
   5 COLO            .522 .048      211.      971.    83000.
   6 CONN            .160 .294     1605.     4980.   107000.
   7 DEL             .534 .042     1723.     3428.    82000.
   8 FLA             .375 .080      832.     3341.    80000.
   9 GA              .363 .060      613.     1885.    73000.
  10 IDAHO           .279 .144      343.     1562.    61000.
  11 ILL             .806 .044      709.     3900.    86000.
  12 IND             .713 .079      611.     3283.    72000.
  13 IOWA            .938 .060      695.     3133.    73000.
  14 KANS            .917 .035      281.     1204.    81000.
  15 KY              .571 .112      482.     1838.    61000.
  16 LA              .354 .074      459.     3284.    61000.
  17 MAINE           .079 .260      662.     1133.    70000.
  18 MD              .429 .216      956.     4489.    93000.
  19 MASS            .136 .249     1349.     2563.    97000.
  20 MICH            .313 .247      658.     2187.    81000.
  21 MINN            .597 .223      516.     2111.    82000.
  22 MISS            .470 .054      403.     2084.    53000.
```

Figure A-3. MACCS/MACCS2 sample Site Data file (continued on following page).

```
 23 MO              .703 .102      322.     1647.    76000.
 24 MONT            .657 .030       61.      563.    65000.
 25 NEBR            .962 .031      318.     1148.    75000.
 26 NEV             .127 .139       63.      601.    84000.
 27 N.H.            .096 .482      518.     2018.    87000.
 28 N.J.            .203 .129     1399.     6477.   102000.
 29 N.MEX           .590 .144       53.      473.    63000.
 30 N.Y.            .310 .589      711.     1378.    94000.
 31 N.C.            .352 .065      860.     2658.    68000.
 32 N.DAK           .924 .048      164.      948.    69000.
 33 OHIO            .602 .175      581.     2686.    76000.
 34 OKLA            .751 .060      204.     1508.    67000.
 35 OREG            .292 .111      236.     1203.    73000.
 36 PA              .303 .447      855.     2534.    78000.
 37 R.I.            .108 .213     1062.     6438.    80000.
 38 S.C.            .290 .084      472.     1843.    62000.
 39 S.DAK           .915 .091      145.      587.    65000.
 40 TENN            .509 .153      360.     1850.    66000.
 41 TEX             .816 .064      164.     1492.    74000.
 42 UTAH            .225 .259      123.     1286.    60000.
 43 VT              .286 .789      628.     1472.    73000.
 44 VA              .382 .198      371.     2075.    84000.
 45 WASH            .377 .154      476.     1948.    82000.
 46 W.VA            .246 .224      150.     1728.    58000.
 47 WIS             .517 .591      723.     1751.    76000.
 48 WYO             .561 .028       43.      380.    70000.
 49 BRIT COL        .377 .154      476.     1948.    60000.
 50 OCEAN           .000 .000        0.        0.        0.
 51 SASKAT          .657 .030       61.      563.    60000.
 52 MANITOBA        .924 .048      164.      948.    60000.
 53 ONTARIO         .597 .223      516.     2111.    60000.
 54 QUEBEC          .310 .589      711.     1378.    60000.
 55 NOVA SCOT       .079 .260      662.     1133.    60000.
 56 BAJA CAL        .330 .144     1022.     4394.    10000.
 57 SONORA          .516 .104      110.      682.    10000.
 58 CHIHUAHUA       .590 .144       53.      473.    10000.
 59 COAHUILA        .816 .064      164.     1492.    10000.
END
```

Figure A-3. MACCS/MACCS2 sample Site Data file.

A.3.1 Spatial Distances Data Block

The spatial distance data define the spatial grid for which the population and land use data are specified. The data define the distance in kilometers to the endpoints of the spatial intervals. The areas between the spatial interval endpoints within each of the 16 wind direction sectors are referred to as spatial elements. This grid definition must agree with the grid defined in the ATMOS input file (see the variable SPAEND in Section 5.3). A relative error of 10% in the endpoint distances is allowed. For larger discrepancies in the geometry data, the error flag will be set and execution will terminate upon completion of the Site Data file input processing.

The first line of the spatial distance data block contains the 22-character separator beginning with SPATIAL DISTANCES in column 2. Next, the endpoint distances in kilometers are specified, eight values per line, using the format described below. As many lines as are needed to define the spatial distances are used. The miminum spacing between adjacent spatial intervals is 0.1 km.

A maximum of eight interval endpoints may be input per line within ten column intervals; *i.e.*, the first interval endpoint would be input in columns 1–10, the second interval endpoint would be input in columns 11–20, etc. The data are read as a real numbers with two decimal places. The format used to process the data is as follows:

Columns	Fortran Format Descriptor	Site-File Variable	Identification	MACCS2 Variable	Allowed Range
1-80	8E10.2	SPDSTS	Spatial interval endpoints (km)	SPAEND	0.001—999.0

A.3.2 Population Data Block

The population data for each element in the spatial grid is defined here. The first line of the data block contains the 22-character separator beginning with POPULATION in column 2. Next, the number of people in each element is given for the first wind sector. (The first wind sector is assumed to be centered on north.) The population data are specified, eight values per line, using the format described below. As many lines as needed to cover all the spatial elements in the sector are used. Proceeding in a clockwise rotation, the population data for the second (NNE) and subsequent sectors follow. Data for all 16 wind directions (sectors) must be provided. Data for each sector begin on a new line.

The population data are input as a real number although no fractional numbers are stored. The population data for up to eight spatial elements may be defined per line and the data are input per ten column intervals; *i.e.*, the population in the first element would be input in columns 1–10, the population in the second element would be input in columns 11–20, etc. The format used to process the data is as follows:

Columns	Fortran Format Descriptor	Site-File Variable	Identification	Allowed Range
1-80	8E10.0	POPDAT	Population data	0.0 - 1.E9

If the user specifies that fraction of the people or fraction of the time weighting is to be performed (see variable WTNAME in Section 6.6.8, the new code functions exactly the same as MACCS 1.5.11.1. In cases where the SUMPOP option is selected, the processing and interpretation of population data are treated in a different manner, as described below.

For each emergency response scenario (of the up to three allowed) defined in the EARLY input file, a distinct population distribution must be supplied in the Site Data file. In MACCS 1.5.11.1, the population data block is delimited with the header record POPULATION (see Figure B.3.1 in Appendix B) beginning at column 2, followed by the population data.

When the SUMPOP option is selected, the header cards for each population data block are POPULATION1, POPULATION2, and POPULATION3, corresponding to the respective emergency-response scenarios, all beginning at column 2. An error will result if the number of population data blocks does not equal the number of emergency-response scenarios defined in the EARLY input file.

A.3.3 Land Fraction Data Block

The fraction of each spatial element that is land (as opposed to lakes, oceans, *etc.*) must be defined. The first line of the data block contains the 22-character separator beginning with LAND FRACTION in column 2. Next, the fraction of area that is land in each radial spatial interval of the first sector is given. All values must be between 0 and 1. A value of 0 means the element has no land, a value of 1 means the element is all land. The land fraction data are specified, 16 values per line, with the format described below. As many lines as needed to define all the spatial intervals in the sector are used. The land fraction data for the second and subsequent sectors follow in a clockwise rotation. Data for all 16 wind direction sectors must be provided. The data for each sector begin on a new line.

The land fraction data are read as a real number and land fractions are input every five columns. The format used to process the data is as follows:

Columns	Fortran Format Descriptor	Variable	Identification	Allowed Range
1-80	16F5.2	FRCLND	Land Fraction	0.0-1.0

A.3.4 Region Index Data Block

In this data block the user assigns a user-defined economic region to each of the spatial intervals. The economic regions are defined in the Regional Economic data block. Section A.3.8 contains a description of the types of economic data that can be defined for each economic region.

The first line in the Region Index data block contains the 22-character separator beginning with REGION INDEX in column 2. The next line contains two-digit integers associating a region index with each of the spatial elements in the first sector. The data are specified with the format defined below. All of the region indices for one sector are input on one line. The region indices for the second and subsequent sectors are on the following lines, a new line for each sector in a clockwise rotation. A total of 16 lines are required. For example, a region index of 09 means that economic data for region number nine will be used for the spatial element.

The format used to process the data is as follows:

Columns	Fortran Format Descriptor	Site-File Variable	Identification	Allowed Range
1-80	40I2	INDREG	Region Index	1 - NECRGN

A.3.5 Watershed Index Data Block

Each of the spatial intervals in the grid must be associated with one of the watershed classes. The definition of the watershed classes is provided in Section A.3.7. The watershed identification data block begins with the 22-character separator beginning with WATERSHED INDEX in column 2. The next line contains two-digit integers associating a watershed type with

each of the spatial elements in the first sector. The data are specified with the format defined below.

All of the watershed type indices for one wind sector will fit on a single line. The watershed indices for the second and subsequent sectors are on the following lines, a new line for each sector in a clockwise rotation. A total of 16 lines are required. For example, a watershed index of 1 means that the water ingestion factor for watershed type 1 will be used for all material deposited on that spatial element. A watershed index of 2 means that the water ingestion factor for watershed type 2 will be used for all material deposited on that spatial element.

The format used to process the data is as follows:

Columns	Fortran Format Descriptor	Site-File Variable	Identification	Allowed Range
1-80	40I2	INDWTR	Watershed Index	1—NWTRSH

A.3.6 Crop and Season Share Data Block

The length of the growing season and the average fraction of the farmland area at the site devoted to each crop type must be specified. These fractions need not sum to exactly 1, but their sum should not exceed a value of 1. If these values sum to a value less than 1, that sum indicates the fraction of farmland in production in an average year (some fraction of farmland may be fallow). Data must be given for each of the crop categories. The data block begins with the separator CROP SEASON AND SHARE in column 2.

The format used to process the data is as follows:

Columns	Fortran Format Descriptor	Site-File Variable	Identification	Allowed Range
1-4	I4	I	Crop Index	1—NCPGZN
6-25	A20	CROP	Crop Name	Not Applicable
26-30	F5.0	GBEG	Day of the Year the Growing Season Begins	1.0—GEND
31-35	F5.0	GEND	Day of the Year the Growing Season Ends	GBEG—365.0
36-45	F10.0	FRCLCP	Fraction of the Site-Averaged Farmland Devoted to this Crop	0.0—1.0

A.3.7 Watershed Definition Data Block

The data block begins with the 22-character separator beginning with WATERSHED DEFINITION in column 2. For each of the radionuclides considered in the liquid pathways model, an initial washoff fraction and an annual washoff rate (year^{-1}) must be specified together with an ingestion factor (Bq ingested/Bq in water) for each of the NUMWPA (NWTRSH) watershed classes.

The format used to process the data is as follows:

Columns	Fortran Format Descriptor	Site-File Variable	Identification	Allowed Range
1-4	I4	I	Radionuclide Index	1—NWPISO
6-13	A8	NMISO	Radionuclide Name	Not Applicable
16-25	E10.1	DUMMY	Obsolete: No Longer Used	Not Applicable
26-35	E10.1	DUMMY	Obsolete: No Longer Used	Not Applicable
36-45	E10.1	WTRINF(1)	Ingestion Factor for Watershed Class 1	0.0—1.0
46-55	E10.1	WTRINF(2)	Ingestion Factor for Watershed Class 2	0.0—1.0
56-65	E10.1	WTRINF(3)	Ingestion Factor for Watershed Class 3	0.0—1.0
66-75	E10.1	WTRINF(4)	Ingestion Factor for Watershed Class 4	0.0—1.0

A.3.8 Regional Economic Data Block

Economic data must be specified for each of the economic regions. The data block begins with the separator REGIONAL ECONOMIC DATA in column 2. An economic region is typically identified with an existing county, a state, or country to provide an indication of the source of the data or the type of geographical area it is intended to represent. The economic regions defined in this section are identified with spatial elements in the Region Index data block.

The format used to process this data is as follows:

Columns	Format Edit Descriptor	Site-File Variable	Identification	Allowed Range
1-4	I4	I	Region Index Number	1—NECRGN
6-15	A10	NMRGN	Name of the Region	Not Applicable

21-25	F5.3	FRMFRC	Fraction of Land Devoted to Farming in Region	0.0—1.0
26-30	F5.3	DPF	Fraction of Farm Sales Resulting from Dairy Production in Region	0.0—1.0
31-40	F10.1	ASFP	Total Annual Farm Sales for the Region (dollars/hectare)	0.0—1.E9
41-50	F10.1	VFRM	Farmland Property Value for the Region (dollars/hectare)	0.0—1.E9
51-60	F10.1	VNFRM	Nonfarm Property Value for the Region (dollars/person)	0.0—1.E9

Appendix B: READMAC2.TXT FILE

---------- MACCS2 VERSION 1.12 ----------

OVERVIEW

The complete MACCS2 package includes the MACCS2 code and four preprocessors. The package is distributed as six ZIP files:

MAC2ZIPA.ZIP
MAC2ZIPB.ZIP
COMIDA2.ZIP
FGRDCF
IDCF2.ZIP
DOSFAC2

MAC2ZIPA.ZIP and MAC2ZIPB.ZIP contain the MACCS2 code and the files required to exercise the 14 MACCS2 sample problems. The preprocessors are not required to exercise the code. The preprocessors may be used to create input files containing dose conversion factor (DCF) or food pathway data not contained in the sample problem files.

HARDWARE AND SOFTWARE REQUIREMENTS

IBM-compatible 486 or Pentium PC with 8 MB of RAM

The MACCS2 package ZIP files require approximately the following disk space when decompressed:
MAC2ZIPA.ZIP 6 MB
MAC2ZIPB.ZIP 5 MB
COMIDA2.ZIP 7 MB
FGRDCF 3 MB
IDCF2.ZIP 5 MB
DOSFAC2 5 MB

The files may be decompressed using PKZIP version 2.04g (or higher). Norton Utilities can also be used to decompress the archives. The MACCS2 software requires Microsoft DOS 3.3 or higher (or a DOS-compatible operating system).

The MACCS2.EXE file included in this package was compiled using the 486 instruction set option. This option reduces the MACCS2 computer run time but

requires that the code be exercised on a 486 or Pentium CPU.

The provided executables include the Phar-Lap DOS extender, and, as a result, successful operation of the MACCS2 software does not require the use of any memory managers such as Microsoft EMM386.EXE or HIMEM.SYS. In fact, the use of the Microsoft memory managers sometimes results in conflicts with the Phar-Lap DOS extender used by Lahey FORTRAN to access extended memory.

The Phar-Lap DOS-extender executables of the MACCS2 software package do not run in conventional memory. For that reason, the amount of free conventional memory is less important for the installation of MACCS2 than the amount of EMS or XMS available. Approximately 6 MB of extended memory (XMS) or 6 MB of expanded memory (EMS) must be available for MACCS2 execution. When the MACCS2.EXE file is invoked, a pop-up screen will appear indicating how much memory the DOS extender can access. If it shows that 5860 kB or more is available, there is sufficient RAM available to execute MACCS2 and all of the preprocessors.

The use of a Microsoft disk cache may interfere with the successful operation of MACCS2. Default settings for the Microsoft SMARTDRV disk cache may allocate one-half of the available RAM for the disk cache. A disk cache size of 512 kB of RAM is sufficient for most operations. A 512-kB disk cache can be specified for SMARTDRV by invoking it on the AUTOEXEC.BAT file as,

SMARTDRV 512

MACCS2 can be tested on systems started up with a "clean boot" disk if it is suspected that memory managers or memory-resident software is interfering with the successful operation of MACCS2. A clean boot disk would include a set of startup files, CONFIG.SYS and AUTOEXEC.BAT, which contain no references to the HIMEM.SYS and EMM386.EXE drivers from Microsoft. For MACCS2 sessions, the substitute startup files might need to be used instead of the startup files that are set up by the WINDOWS installation process.

No conflicts have ever been encountered when using the Quarterdeck Office Systems QEMM memory manager software. However, sometimes the use of third-party memory managers like QEMM can result in problems running WINDOWS.

INSTALLATION INSTRUCTIONS FOR MACCS2

Create a MACCS2 subdirectory. The MACCS2 subdirectory can be created using the following command:

MD MACCS2

Copy MAC2ZIPA.ZIP and MAC2ZIPB.ZIP into the MACCS2 subdirectory.

Decompress using Norton Utilities or PKZIP (version 2.04g). Using PKZIP the files may be decompressed using the PKUNZIP command.

The MAC2ZIPA.ZIP and MAC2ZIPB.ZIP files contains 14 sample problems. All of the files required to run the sample problems are included in these two ZIP files. The MACCS2 output from the 14 sample problem runs is provided in the .OUT files on the distribution disk. The contents of the ATMOS, EARLY, and CHRONC input files are echoed in the .OUT files generated for each MACCS2 run. A description of the sample problems is provided in Section 4.4 of the code manual for MACCS2: Volume 1, User's Guide.

On a Pentium 133 MHz PC, the complete set of MACCS2 sample problems, performed using the provided RUNEM.BAT, required approximately 2.5 hrs to execute. The last sample problem executed by RUNEM.BAT, LISTF_RND, required 60 percent of the total run time. To execute the MACCS2 sample problems, type the following command:

RUNEM

which will regenerate the .OUT files in the MACCS2 directory, overwriting the provided set of output files.

A single MACCS2 run is initiated by calling the RUNMAX2.BAT file and specifying six MACCS2 input file names. On the command line, the user must specify the ATMOS, EARLY, CHRONC, meteorological, and Site Data file names. Sample problem A_O, for example, may be initiated with the following command line:

RUNMAX2 IN1A IN2A IN3A_O METSUR SURSIT LISTA_O

IN1A is the ATMOS input file
IN2A is the EARLY input file
IN3A_O is the CHRONC input file
METSUR is the meteorological data input file
SURSIT contains site-specific data
LISTA_O is the name of the output file to which the MACCS2 output is to be written

Double quotes "" must be specified as a place holder when a null argument is being supplied.
.....
DOSE CONVERSION FACTOR FILES
.....
The MAC2ZIPB.ZIP file contains seven DCF files:

DOSDATA.INP - Created by DOSFAC2 and contains the 60 radionuclides considered important to commercial reactor accidents.

DOSD825.INP - Created by FGRDCF and contains all of the radionuclides accessed by FGRDCF.

DOSD60.INP - Created by FGRDCF and contains the 60 radionuclides contained in DOSDATA.INP.

IDCF2_1.INP, IDCF2_2.INP, IDCF2_3.INP - Combined, these files contain all of the radionuclides that can be accessed by IDCF2.

IDCF2_4.INP - Created by IDCF2 and contains the 60 radionuclides contained in DOSDATA.INP.

The external DCFs produced by IDCF2 are obtained from DOE/EH-0070. A number of radionuclides listed in the IDCF2-produced files are assigned values of 0 for external DCFs for which Federal Guidance Report 12 lists DCF values greater than 0 (provided in the FGRDCF produced files).

INSTALLATION INSTRUCTIONS FOR MACCS2 PREPROCESSORS

Create subdirectories for each preprocessor to be installed on the system. Decompress the preprocessor ZIP files into the subdirectories.

The MACCS2 DCF input file name is specified by the user in the EARLY input file as the DCF_FILE input parameter. The COMIDA2-generated MACCS2 input file name is user specified in the CHRONC input file as the BIN_FILE input parameter. The user must specify the drive and directory containing the DCF and COMIDA2 MACCS2 input files if the files are not contained in MACCS2 subdirectory.

If COMIDA2-generated MACCS2 input files are used in MACCS2 analyses, the DCF file specified in the EARLY input file must be the same DCF file used to generate the COMIDA2 MACCS2 input file.

The input files required for the FGRDCF and DOSFAC2 preprocessor sample problems can be identified by the .SEL extension. The FGRDCF and DOSFAC2 preprocessors may be exercised using the following commands:

FGRDCF: RUNFGR "filename".SEL
DOSFAC2: DOSFACPC "filename".SEL
The MACCS2 DCF input files created by these two preprocessors are "filename".inp.

All of the DOSFAC2 sample problems can also be run by simply using the RUNEM.BAT file included in the DOSFAC2.ZIP archive.

The IDCF2 sample problem input file, TEST.INP, may be run with the command:

RUNIDCF2 TEST

The name of the MACCS2 DCF file produced by IDCF2 is fixed in the FORTRAN coding as DOSDATAX.INP.

The input files for the COMIDA2 sample problems can be identified by the .INP extension. (The DOSDATA.INP file included in the COMIDA2 archive is not a COMIDA2 sample problem. It is a DCF file required by the COMIDA2 sample problems.) The COMIDA2 sample problems may be run using the RUNEM.BAT file or by using the following command:

RUNCOM2 "filename".INP

EXECUTION IN THE DOS WINDOW OF WINDOWS 3.1 AND WINDOWS_95

The MACCS2 software package was developed in a DOS environment. MACCS2 version 1.12 was compiled with Lahey FORTRAN F77L-EM/32 Version 5.20 and can be successfully executed in the DOS window of Microsoft WINDOWS 3.1 and WINDOWS 95.

No information is available on the use of MACCS2 in the IBM OS/2 multitasking environment. However, if MACCS2 is successfully installed and made operational in multitasking environments other than Microsoft WINDOWS, please inform the code developers so that the information can be shared with other code users.

CODE COMPILATION UNDER LAHEY FORTRAN

The MACCS2.EXE file provided in this archive was generated using Lahey FORTRAN. To recompile MACCS2 using Lahey FORTRAN, execute the DOS command

LAHEY MACCS2

which will recompile (and use machine-dependent routines in MXXLAHEY.FOR), creating an executable named MACCS2.EXE.

The MACCS2.EXE included in this distribution package was compiled with the following options of Lahey FORTRAN F77L/EM32, version 5.20:

OPTION	DESCRIPTION	OPTION	DESCRIPTION
/n0	- Standard FORTRAN 77 IMPLICIT	/ L	- Line-number traceback table
/n2	- Generate 387 constants and code	/ P	- Protect constant arguments
/ 4	- Optimize for 80486 processor	/ Q1	- Limit NDP stack entries
/n7	- Optimize interstatement	/nQ2	- No protected-mode RPC
/nA2	- No allocatable array checking	/nQ3	- No real-mode RPC
/ B	- Check array subscript bounds	/nR	- No remembering local items
/nC	- Ignore nonstandard usage	/ S	- Create filename.SLD for SOLD
/nC1	- INTEGER constants 4 bytes	/nT	- INTEGER*4, LOGICAL*4 default
/ D	- DIRECT files without headers	/nV	- Not VAX interpretation
/nH	- No hardcopy source listing	/ W	- Display warning messages
/ I	- Check subprogram Interfaces	/nX	- No Xref listing
/nK	- Generate 80×87 code	/ Z1	- Production optimiZations

and it was linked with the following linker statement:

386link %1,MXXLAHEY -pack -checksum -stack 300000 -symbols -stub runb

---

CODE COMPILATION UNDER MICROSOFT POWERSTATION FORTRAN

MACCS2 version 1.12 can also be recompiled using the Microsoft Powerstation FORTRAN compiler version 1.0a. If MACCS2 is recompiled with the Microsoft compiler, COMIDA2 will also require recompilation because the binary file formats used by the two languages are incompatible.

Under Microsoft FORTRAN, MACCS2 can be recompiled using the MICROSOF.BAT file enclosed as part of this archive, by executing the DOS command

MICROSOF MACCS2

which will recompile the program and its machine-dependent routines (found in the file MXXMICRO.FOR), and then LINK the program into an executable named MACCS2.EXE. The MICROSOF.BAT file in the MACCS2 archive is different from the file of the same name provided in the COMIDA2 archive. The reason for this is that MACCS2 can be exercised (while COMIDA2 cannot) using the full run-time error checking features of Microsoft FORTRAN.

COMPILING FOR NON-PC SYSTEMS

The MACCS2 package includes a file of machine-dependent subroutines that must be modified for non-PC environments. These subroutines are provided in MXXLAHEY.FOR and MXXMICRO.FOR for code complilation under Lahey FORTRAN and Microsoft Powerstation FORTRAN respectively. The subroutines include the coding required for VAX/VMS, IBM S/6000, SUN UNIX workstations, and CRAY UNICOS systems. The user who intends to exercise MACCS2 on a non-PC platform must delete the comment characters for the coding required by the platform to be used and comment out the coding required by the PC platform.

Appendix C: Sample Problem A LISTA_N.OUT Output Listing

```
MACCS2 09/26/96   08:40:08   Version 1.12, Last Modified 9/25/96 by D. Chanin
P1:  ATMOS USER INPUT (UNIT 24) = IN1A.INP
P2:  EARLY USER INPUT (UNIT 25) = IN2A.INP
P3: CHRONC USER INPUT (UNIT 26) = IN3A_N.INP
P4:  METEOROLOGY DATA (UNIT 28) = METSUR.INP
P5:   SITE DATA INPUT (UNIT 29) = SURSIT.INP
P6:       LIST OUTPUT (UNIT 06) = LISTA_N.OUT


USER INPUT IS READ FROM UNIT 24
RECORD IDENTIFIER FIELDS  11 CHARACTERS LONG ARE EXPECTED.
THE FIRST 100 COLUMNS OF EACH INPUT RECORD ARE PROCESSED.
THE MAXIMUM NUMBER OF IDENTIFIER RECORDS THAT MAY BE SAVED AS THE BASE CASE IS  1000.

RECORD
NUMBER                                  RECORD

       * GENERAL DESCRIPTIVE TITLE DESCRIBING THIS "ATMOS" INPUT
       *
    1  RIATNAM1001 'IN1A.INP, Sample Problem A--Using Table-Lookup Sigmas, ATMOS input'
       ******************************************************************************
       * GEOMETRY DATA BLOCK, LOADED BY INPGEO, STORED IN /GEOM/
       *
       * NUMBER OF RADIAL SPATIAL ELEMENTS
       *
    2  GENUMRAD001  26
       *
       *  SURRY
       *
    3  GESPAEND001      .16       .52      1.21      1.61      2.13
    4  GESPAEND002     3.22      4.02      4.83      5.63      8.05
    5  GESPAEND003    11.27     16.09     20.92     25.75     32.19
    6  GESPAEND004    40.23     48.28     64.37     80.47    112.65
    7  GESPAEND005   160.93    241.14    321.87    563.27    804.67
    8  GESPAEND006  1609.34
       ******************************************************************************
       * NUCLIDE DATA BLOCK, LOADED BY INPISO, STORED IN /ISOGRP/, /ISONAM/
       *
       * Number of pseudo-stable nuclides (used to truncate the decay chains)
       *
    9  ISNUMSTB001      27
       *
       * List of pseudo-stable nuclides
       *
   10  ISNAMSTB001     I-129    (daughter of Te-129 and Te-129m)
   11  ISNAMSTB002     Xe-131m  (daughter of I-131)
   12  ISNAMSTB003     Xe-133m  (daughter of I-133)
   13  ISNAMSTB004     Xe-135m  (daughter of I-135)
   14  ISNAMSTB005     Cs-135   (daughter of Xe-135 and Xe-135m)
   15  ISNAMSTB006     Sm-147   (daughter of Pm-147)
   16  ISNAMSTB007     U-234    (daughter of Pu-238)
   17  ISNAMSTB008     U-235    (daughter of Pu-239)
   18  ISNAMSTB009     U-236    (daughter of Pu-240)
   19  ISNAMSTB010     U-237    (daughter of Pu-241)
   20  ISNAMSTB011     Np-237   (daughter of Am-241)
   21  ISNAMSTB012     Rb-87    (daughter of Kr-87)
```

```
22  ISNAMSTB013     Ba-137m  (daughter of Cs-137)
23  ISNAMSTB014     Rb-88    (daughter of Kr-88)
24  ISNAMSTB015     Y-91m    (daughter of Sr-91)
25  ISNAMSTB016     Zr-93    (daughter of Y-93)
26  ISNAMSTB017     Nb-93m   (daughter of Zr-93)
27  ISNAMSTB018     Nb-95m   (daughter of Zr-95)
28  ISNAMSTB019     Nb-97    (daughter of Zr-97 and Nb-97m)
29  ISNAMSTB020     Nb-97m   (daughter of Zr-97)
30  ISNAMSTB021     Tc-99    (daughter of Mo-99)
31  ISNAMSTB022     Rh-103m  (daughter of Ru-103)
32  ISNAMSTB023     Rh-106   (daughter of Ru-106)
33  ISNAMSTB024    Te-131    (daughter of Te-131m)
34  ISNAMSTB025     Pr-144   (daughter of Ce-144 and Pr-144m)
35  ISNAMSTB026     Pr-144m  (daughter of Ce-144)
36  ISNAMSTB027     Pm-147   (daughter of Nd-147)
    *
    * Number of radioactive nuclides to be considered
    *
37  ISNUMISO001 60
    *
    * NUMBER OF NUCLIDE GROUPS
    *
38  ISMAXGRP001  9
    *
    * WET AND DRY DEPOSITION FLAGS FOR EACH NUCLIDE GROUP
    *
    *              WETDEP     DRYDEP
    *
39  ISDEPFLA001    .FALSE.   .FALSE.
40  ISDEPFLA002    .TRUE.    .TRUE.
41  ISDEPFLA003    .TRUE.    .TRUE.
42  ISDEPFLA004    .TRUE.    .TRUE.
43  ISDEPFLA005    .TRUE.    .TRUE.
44  ISDEPFLA006    .TRUE.    .TRUE.
45  ISDEPFLA007    .TRUE.    .TRUE.
46  ISDEPFLA008    .TRUE.    .TRUE.
47  ISDEPFLA009    .TRUE.    .TRUE.
    *
    * NUCLIDE GROUP DATA FOR 9 NUCLIDE GROUPS
    *
    *               NUCNAM    IGROUP
    *
48  ISOTPGRP001     Co-58        6
49  ISOTPGRP002     Co-60        6
50  ISOTPGRP003     Kr-85        1
51  ISOTPGRP004     Kr-85m       1
52  ISOTPGRP005     Kr-87        1
53  ISOTPGRP006     Kr-88        1
54  ISOTPGRP007     Rb-86        3
55  ISOTPGRP008     Sr-89        5
56  ISOTPGRP009     Sr-90        5
57  ISOTPGRP010     Sr-91        5
58  ISOTPGRP011     Sr-92        5
59  ISOTPGRP012     Y-90         7
60  ISOTPGRP013     Y-91         7
61  ISOTPGRP014     Y-92         7
62  ISOTPGRP015     Y-93         7
63  ISOTPGRP016     Zr-95        7
64  ISOTPGRP017     Zr-97        7
65  ISOTPGRP018     Nb-95        7
66  ISOTPGRP019     Mo-99        6
67  ISOTPGRP020     Tc-99m       6
```

```
 68  ISOTPGRP021     Ru-103       6
 69  ISOTPGRP022     Ru-105       6
 70  ISOTPGRP023     Ru-106       6
 71  ISOTPGRP024     Rh-105       6
 72  ISOTPGRP025     Sb-127       4
 73  ISOTPGRP026     Sb-129       4
 74  ISOTPGRP027     Te-127       4
 75  ISOTPGRP028     Te-127m      4
 76  ISOTPGRP029     Te-129       4
 77  ISOTPGRP030     Te-129m      4
 78  ISOTPGRP031     Te-131m      4
 79  ISOTPGRP032     Te-132       4
 80  ISOTPGRP033     I-131        2
 81  ISOTPGRP034     I-132        2
 82  ISOTPGRP035     I-133        2
 83  ISOTPGRP036     I-134        2
 84  ISOTPGRP037     I-135        2
 85  ISOTPGRP038     Xe-133       1
 86  ISOTPGRP039     Xe-135       1
 87  ISOTPGRP040     Cs-134       3
 88  ISOTPGRP041     Cs-136       3
 89  ISOTPGRP042     Cs-137       3
 90  ISOTPGRP043     Ba-139       9
 91  ISOTPGRP044     Ba-140       9
 92  ISOTPGRP045     La-140       7
 93  ISOTPGRP046     La-141       7
 94  ISOTPGRP047     La-142       7
 95  ISOTPGRP048     Ce-141       8
 96  ISOTPGRP049     Ce-143       8
 97  ISOTPGRP050     Ce-144       8
 98  ISOTPGRP051     Pr-143       7
 99  ISOTPGRP052     Nd-147       7
100  ISOTPGRP053     Np-239       8
101  ISOTPGRP054     Pu-238       8
102  ISOTPGRP055     Pu-239       8
103  ISOTPGRP056     Pu-240       8
104  ISOTPGRP057     Pu-241       8
105  ISOTPGRP058     Am-241       7
106  ISOTPGRP059     Cm-242       7
107  ISOTPGRP060     Cm-244       7
     ******************************************************************************
     * WET DEPOSITION DATA BLOCK, LOADED BY INPWET, STORED IN /WETCON/
     *
     * WASHOUT COEFFICIENT NUMBER ONE, LINEAR FACTOR
     *
108  WDCWASH1001  9.5E-5   (JON HELTON AFTER JONES, 1986)
     *
     * WASHOUT COEFFICIENT NUMBER TWO, EXPONENTIAL FACTOR
     *
109  WDCWASH2001  0.8      (JON HELTON AFTER JONES, 1986)
     ******************************************************************************
     * DRY DEPOSITION DATA BLOCK, LOADED BY INPDRY, STORED IN /DRYCON/
     *
     * NUMBER OF PARTICLE SIZE GROUPS
     *
110  DDNPSGRP001   1
     *
     * DEPOSITION VELOCITY OF EACH PARTICLE SIZE GROUP (M/S)
     *
111  DDVDEPOS001   0.01   (VALUE SELECTED BY S. ACHARYA, NRC)
     ******************************************************************************
     * DISPERSION PARAMETER DATA BLOCK, LOADED BY INPDIS, STORED IN /DISPY/, /DISPZ/
```

```
     *
     * # of distances in plume-size tables--which can be used as an alternative to the power-law model:
     * (to utilize the power-law model, set NUM_DIST to zero or delete the following data card)
     *
112  NUM_DIST001   50
     *
     * A-stability      Distance (m)  Sigma-y (m)    Sigma-z (m)
113  A-STB/DIS01        1.000E+00     3.6580E-01     2.5000E-04  Tadmor/Gur (0.5-5 km)
114  A-STB/DIS02        1.400E+00     4.9569E-01     5.1105E-04  Tadmor/Gur (0.5-5 km)
115  A-STB/DIS03        2.000E+00     6.8408E-01     1.0905E-03  Tadmor/Gur (0.5-5 km)
116  A-STB/DIS04        3.000E+00     9.8658E-01     2.5812E-03  Tadmor/Gur (0.5-5 km)
117  A-STB/DIS05        4.000E+00     1.2793E+00     4.7568E-03  Tadmor/Gur (0.5-5 km)
118  A-STB/DIS06        5.000E+00     1.5649E+00     7.6428E-03  Tadmor/Gur (0.5-5 km)
119  A-STB/DIS07        6.000E+00     1.8450E+00     1.1259E-02  Tadmor/Gur (0.5-5 km)
120  A-STB/DIS08        8.000E+00     2.3923E+00     2.0749E-02  Tadmor/Gur (0.5-5 km)
121  A-STB/DIS09        1.000E+01     2.9265E+00     3.3338E-02  Tadmor/Gur (0.5-5 km)
122  A-STB/DIS10        1.000E+02     2.3412E+01     4.4457E+00  Tadmor/Gur (0.5-5 km)
123  A-STB/DIS11        1.400E+02     3.1726E+01     9.0879E+00  Tadmor/Gur (0.5-5 km)
124  A-STB/DIS12        2.000E+02     4.3783E+01     1.9392E+01  Tadmor/Gur (0.5-5 km)
125  A-STB/DIS13        3.000E+02     6.3144E+01     4.5901E+01  Tadmor/Gur (0.5-5 km)
126  A-STB/DIS14        4.000E+02     8.1877E+01     8.4590E+01  Tadmor/Gur (0.5-5 km)
127  A-STB/DIS15        5.000E+02     1.0016E+02     1.3591E+02  Tadmor/Gur (0.5-5 km)
128  A-STB/DIS16        6.000E+02     1.1808E+02     2.0022E+02  Tadmor/Gur (0.5-5 km)
129  A-STB/DIS17        8.000E+02     1.5312E+02     3.6898E+02  Tadmor/Gur (0.5-5 km)
130  A-STB/DIS18        1.000E+03     1.8730E+02     5.9284E+02  Tadmor/Gur (0.5-5 km)
131  A-STB/DIS19        1.400E+03     2.5381E+02     1.2119E+03  Tadmor/Gur (0.5-5 km)
132  A-STB/DIS20        2.000E+03     3.5027E+02     2.5860E+03  Tadmor/Gur (0.5-5 km)
133  A-STB/DIS21        3.000E+03     5.0516E+02     6.1210E+03  Tadmor/Gur (0.5-5 km)
134  A-STB/DIS22        4.000E+03     6.5503E+02     1.1280E+04  Tadmor/Gur (0.5-5 km)
135  A-STB/DIS23        5.000E+03     8.0128E+02     1.8124E+04  Tadmor/Gur (0.5-5 km)
136  A-STB/DIS24        6.000E+03     9.4470E+02     2.6700E+04  Tadmor/Gur (0.5-5 km)
137  A-STB/DIS25        8.000E+03     1.2250E+03     4.9205E+04  Tadmor/Gur (0.5-5 km)
138  A-STB/DIS26        1.000E+04     1.4985E+03     7.9057E+04  Tadmor/Gur (0.5-5 km)
139  A-STB/DIS27        1.400E+04     2.0305E+03     1.6161E+05  Tadmor/Gur (0.5-5 km)
140  A-STB/DIS28        2.000E+04     2.8022E+03     3.4485E+05  Tadmor/Gur (0.5-5 km)
141  A-STB/DIS29        3.000E+04     4.0414E+03     8.1625E+05  Tadmor/Gur (0.5-5 km)
142  A-STB/DIS30        4.000E+04     5.2404E+03     1.5042E+06  Tadmor/Gur (0.5-5 km)
143  A-STB/DIS31        5.000E+04     6.4104E+03     2.4169E+06  Tadmor/Gur (0.5-5 km)
144  A-STB/DIS32        6.000E+04     7.5577E+03     3.5605E+06  Tadmor/Gur (0.5-5 km)
145  A-STB/DIS33        8.000E+04     9.8000E+03     6.5615E+06  Tadmor/Gur (0.5-5 km)
146  A-STB/DIS34        1.000E+05     1.1988E+04     1.0542E+07  Tadmor/Gur (0.5-5 km)
147  A-STB/DIS35        1.400E+05     1.6245E+04     2.1551E+07  Tadmor/Gur (0.5-5 km)
148  A-STB/DIS36        2.000E+05     2.2418E+04     4.5986E+07  Tadmor/Gur (0.5-5 km)
149  A-STB/DIS37        3.000E+05     3.2332E+04     1.0885E+08  Tadmor/Gur (0.5-5 km)
150  A-STB/DIS38        4.000E+05     4.1924E+04     2.0059E+08  Tadmor/Gur (0.5-5 km)
151  A-STB/DIS39        5.000E+05     5.1284E+04     3.2229E+08  Tadmor/Gur (0.5-5 km)
152  A-STB/DIS40        6.000E+05     6.0463E+04     4.7480E+08  Tadmor/Gur (0.5-5 km)
153  A-STB/DIS41        8.000E+05     7.8401E+04     8.7500E+08  Tadmor/Gur (0.5-5 km)
154  A-STB/DIS42        1.000E+06     9.5906E+04     1.4059E+09  Tadmor/Gur (0.5-5 km)
155  A-STB/DIS43        1.400E+06     1.2996E+05     2.8738E+09  Tadmor/Gur (0.5-5 km)
156  A-STB/DIS44        2.000E+06     1.7935E+05     6.1324E+09  Tadmor/Gur (0.5-5 km)
157  A-STB/DIS45        3.000E+06     2.5866E+05     1.4515E+10  Tadmor/Gur (0.5-5 km)
158  A-STB/DIS46        4.000E+06     3.3540E+05     2.6750E+10  Tadmor/Gur (0.5-5 km)
159  A-STB/DIS47        5.000E+06     4.1028E+05     4.2979E+10  Tadmor/Gur (0.5-5 km)
160  A-STB/DIS48        6.000E+06     4.8372E+05     6.3316E+10  Tadmor/Gur (0.5-5 km)
161  A-STB/DIS49        8.000E+06     6.2723E+05     1.1668E+11  Tadmor/Gur (0.5-5 km)
162  A-STB/DIS50        1.000E+07     7.6726E+05     1.8747E+11  Tadmor/Gur (0.5-5 km)
     *
     * B-stability      Distance (m)  Sigma-y (m)    Sigma-z (m)
163  B-STB/DIS01        1.000E+00     2.7510E-01     1.9000E-03  Tadmor/Gur (0.5-5 km)
164  B-STB/DIS02        1.400E+00     3.7279E-01     3.2574E-03  Tadmor/Gur (0.5-5 km)
165  B-STB/DIS03        2.000E+00     5.1446E-01     5.7681E-03  Tadmor/Gur (0.5-5 km)
```

166	B-STB/DIS04	3.000E+00	7.4196E-01	1.1045E-02	Tadmor/Gur (0.5-5 km)
167	B-STB/DIS05	4.000E+00	9.6208E-01	1.7511E-02	Tadmor/Gur (0.5-5 km)
168	B-STB/DIS06	5.000E+00	1.1769E+00	2.5036E-02	Tadmor/Gur (0.5-5 km)
169	B-STB/DIS07	6.000E+00	1.3875E+00	3.3530E-02	Tadmor/Gur (0.5-5 km)
170	B-STB/DIS08	8.000E+00	1.7992E+00	5.3161E-02	Tadmor/Gur (0.5-5 km)
171	B-STB/DIS09	1.000E+01	2.2009E+00	7.6007E-02	Tadmor/Gur (0.5-5 km)
172	B-STB/DIS10	1.000E+02	1.7607E+01	3.0406E+00	Tadmor/Gur (0.5-5 km)
173	B-STB/DIS11	1.400E+02	2.3859E+01	5.2127E+00	Tadmor/Gur (0.5-5 km)
174	B-STB/DIS12	2.000E+02	3.2927E+01	9.2307E+00	Tadmor/Gur (0.5-5 km)
175	B-STB/DIS13	3.000E+02	4.7487E+01	1.7675E+01	Tadmor/Gur (0.5-5 km)
176	B-STB/DIS14	4.000E+02	6.1576E+01	2.8023E+01	Tadmor/Gur (0.5-5 km)
177	B-STB/DIS15	5.000E+02	7.5323E+01	4.0066E+01	Tadmor/Gur (0.5-5 km)
178	B-STB/DIS16	6.000E+02	8.8805E+01	5.3657E+01	Tadmor/Gur (0.5-5 km)
179	B-STB/DIS17	8.000E+02	1.1515E+02	8.5073E+01	Tadmor/Gur (0.5-5 km)
180	B-STB/DIS18	1.000E+03	1.4086E+02	1.2163E+02	Tadmor/Gur (0.5-5 km)
181	B-STB/DIS19	1.400E+03	1.9088E+02	2.0853E+02	Tadmor/Gur (0.5-5 km)
182	B-STB/DIS20	2.000E+03	2.6342E+02	3.6926E+02	Tadmor/Gur (0.5-5 km)
183	B-STB/DIS21	3.000E+03	3.7991E+02	7.0705E+02	Tadmor/Gur (0.5-5 km)
184	B-STB/DIS22	4.000E+03	4.9262E+02	1.1210E+03	Tadmor/Gur (0.5-5 km)
185	B-STB/DIS23	5.000E+03	6.0260E+02	1.6028E+03	Tadmor/Gur (0.5-5 km)
186	B-STB/DIS24	6.000E+03	7.1046E+02	2.1465E+03	Tadmor/Gur (0.5-5 km)
187	B-STB/DIS25	8.000E+03	9.2124E+02	3.4033E+03	Tadmor/Gur (0.5-5 km)
188	B-STB/DIS26	1.000E+04	1.1269E+03	4.8658E+03	Tadmor/Gur (0.5-5 km)
189	B-STB/DIS27	1.400E+04	1.5271E+03	8.3419E+03	Tadmor/Gur (0.5-5 km)
190	B-STB/DIS28	2.000E+04	2.1074E+03	1.4772E+04	Tadmor/Gur (0.5-5 km)
191	B-STB/DIS29	3.000E+04	3.0393E+03	2.8285E+04	Tadmor/Gur (0.5-5 km)
192	B-STB/DIS30	4.000E+04	3.9410E+03	4.4845E+04	Tadmor/Gur (0.5-5 km)
193	B-STB/DIS31	5.000E+04	4.8209E+03	6.4117E+04	Tadmor/Gur (0.5-5 km)
194	B-STB/DIS32	6.000E+04	5.6838E+03	8.5868E+04	Tadmor/Gur (0.5-5 km)
195	B-STB/DIS33	8.000E+04	7.3701E+03	1.3614E+05	Tadmor/Gur (0.5-5 km)
196	B-STB/DIS34	1.000E+05	9.0155E+03	1.9465E+05	Tadmor/Gur (0.5-5 km)
197	B-STB/DIS35	1.400E+05	1.2217E+04	3.3371E+05	Tadmor/Gur (0.5-5 km)
198	B-STB/DIS36	2.000E+05	1.6860E+04	5.9093E+05	Tadmor/Gur (0.5-5 km)
199	B-STB/DIS37	3.000E+05	2.4315E+04	1.1315E+06	Tadmor/Gur (0.5-5 km)
200	B-STB/DIS38	4.000E+05	3.1529E+04	1.7940E+06	Tadmor/Gur (0.5-5 km)
201	B-STB/DIS39	5.000E+05	3.8568E+04	2.5649E+06	Tadmor/Gur (0.5-5 km)
202	B-STB/DIS40	6.000E+05	4.5471E+04	3.4350E+06	Tadmor/Gur (0.5-5 km)
203	B-STB/DIS41	8.000E+05	5.8962E+04	5.4462E+06	Tadmor/Gur (0.5-5 km)
204	B-STB/DIS42	1.000E+06	7.2126E+04	7.7867E+06	Tadmor/Gur (0.5-5 km)
205	B-STB/DIS43	1.400E+06	9.7737E+04	1.3350E+07	Tadmor/Gur (0.5-5 km)
206	B-STB/DIS44	2.000E+06	1.3488E+05	2.3639E+07	Tadmor/Gur (0.5-5 km)
207	B-STB/DIS45	3.000E+06	1.9453E+05	4.5264E+07	Tadmor/Gur (0.5-5 km)
208	B-STB/DIS46	4.000E+06	2.5224E+05	7.1765E+07	Tadmor/Gur (0.5-5 km)
209	B-STB/DIS47	5.000E+06	3.0855E+05	1.0261E+08	Tadmor/Gur (0.5-5 km)
210	B-STB/DIS48	6.000E+06	3.6378E+05	1.3741E+08	Tadmor/Gur (0.5-5 km)
211	B-STB/DIS49	8.000E+06	4.7171E+05	2.1787E+08	Tadmor/Gur (0.5-5 km)
212	B-STB/DIS50	1.000E+07	5.7702E+05	3.1150E+08	Tadmor/Gur (0.5-5 km)
	*				
	* C-stability	Distance (m)	Sigma-y (m)	Sigma-z (m)	
213	C-STB/DIS01	1.000E+00	2.0890E-01	2.0000E-01	Tadmor/Gur (0.5-5 km)
214	C-STB/DIS02	1.400E+00	2.8308E-01	2.6660E-01	Tadmor/Gur (0.5-5 km)
215	C-STB/DIS03	2.000E+00	3.9066E-01	3.6158E-01	Tadmor/Gur (0.5-5 km)
216	C-STB/DIS04	3.000E+00	5.6341E-01	5.1125E-01	Tadmor/Gur (0.5-5 km)
217	C-STB/DIS05	4.000E+00	7.3056E-01	6.5369E-01	Tadmor/Gur (0.5-5 km)
218	C-STB/DIS06	5.000E+00	8.9367E-01	7.9097E-01	Tadmor/Gur (0.5-5 km)
219	C-STB/DIS07	6.000E+00	1.0536E+00	9.2428E-01	Tadmor/Gur (0.5-5 km)
220	C-STB/DIS08	8.000E+00	1.3662E+00	1.1818E+00	Tadmor/Gur (0.5-5 km)
221	C-STB/DIS09	1.000E+01	1.6712E+00	1.4300E+00	Tadmor/Gur (0.5-5 km)
222	C-STB/DIS10	1.000E+02	1.3370E+01	1.0224E+01	Tadmor/Gur (0.5-5 km)
223	C-STB/DIS11	1.400E+02	1.8118E+01	1.3629E+01	Tadmor/Gur (0.5-5 km)
224	C-STB/DIS12	2.000E+02	2.5003E+01	1.8484E+01	Tadmor/Gur (0.5-5 km)
225	C-STB/DIS13	3.000E+02	3.6060E+01	2.6136E+01	Tadmor/Gur (0.5-5 km)

226	C-STB/DIS14	4.000E+02	4.6758E+01	3.3417E+01	Tadmor/Gur (0.5-5 km)
227	C-STB/DIS15	5.000E+02	5.7198E+01	4.0435E+01	Tadmor/Gur (0.5-5 km)
228	C-STB/DIS16	6.000E+02	6.7435E+01	4.7250E+01	Tadmor/Gur (0.5-5 km)
229	C-STB/DIS17	8.000E+02	8.7442E+01	6.0414E+01	Tadmor/Gur (0.5-5 km)
230	C-STB/DIS18	1.000E+03	1.0696E+02	7.3102E+01	Tadmor/Gur (0.5-5 km)
231	C-STB/DIS19	1.400E+03	1.4495E+02	9.7447E+01	Tadmor/Gur (0.5-5 km)
232	C-STB/DIS20	2.000E+03	2.0003E+02	1.3216E+02	Tadmor/Gur (0.5-5 km)
233	C-STB/DIS21	3.000E+03	2.8849E+02	1.8687E+02	Tadmor/Gur (0.5-5 km)
234	C-STB/DIS22	4.000E+03	3.7408E+02	2.3893E+02	Tadmor/Gur (0.5-5 km)
235	C-STB/DIS23	5.000E+03	4.5759E+02	2.8911E+02	Tadmor/Gur (0.5-5 km)
236	C-STB/DIS24	6.000E+03	5.3949E+02	3.3784E+02	Tadmor/Gur (0.5-5 km)
237	C-STB/DIS25	8.000E+03	6.9955E+02	4.3196E+02	Tadmor/Gur (0.5-5 km)
238	C-STB/DIS26	1.000E+04	8.5573E+02	5.2267E+02	Tadmor/Gur (0.5-5 km)
239	C-STB/DIS27	1.400E+04	1.1596E+03	6.9673E+02	Tadmor/Gur (0.5-5 km)
240	C-STB/DIS28	2.000E+04	1.6003E+03	9.4493E+02	Tadmor/Gur (0.5-5 km)
241	C-STB/DIS29	3.000E+04	2.3080E+03	1.3361E+03	Tadmor/Gur (0.5-5 km)
242	C-STB/DIS30	4.000E+04	2.9927E+03	1.7083E+03	Tadmor/Gur (0.5-5 km)
243	C-STB/DIS31	5.000E+04	3.6608E+03	2.0671E+03	Tadmor/Gur (0.5-5 km)
244	C-STB/DIS32	6.000E+04	4.3161E+03	2.4155E+03	Tadmor/Gur (0.5-5 km)
245	C-STB/DIS33	8.000E+04	5.5965E+03	3.0884E+03	Tadmor/Gur (0.5-5 km)
246	C-STB/DIS34	1.000E+05	6.8460E+03	3.7371E+03	Tadmor/Gur (0.5-5 km)
247	C-STB/DIS35	1.400E+05	9.2770E+03	4.9816E+03	Tadmor/Gur (0.5-5 km)
248	C-STB/DIS36	2.000E+05	1.2803E+04	6.7562E+03	Tadmor/Gur (0.5-5 km)
249	C-STB/DIS37	3.000E+05	1.8464E+04	9.5529E+03	Tadmor/Gur (0.5-5 km)
250	C-STB/DIS38	4.000E+05	2.3942E+04	1.2214E+04	Tadmor/Gur (0.5-5 km)
251	C-STB/DIS39	5.000E+05	2.9287E+04	1.4780E+04	Tadmor/Gur (0.5-5 km)
252	C-STB/DIS40	6.000E+05	3.4529E+04	1.7270E+04	Tadmor/Gur (0.5-5 km)
253	C-STB/DIS41	8.000E+05	4.4773E+04	2.2082E+04	Tadmor/Gur (0.5-5 km)
254	C-STB/DIS42	1.000E+06	5.4769E+04	2.6720E+04	Tadmor/Gur (0.5-5 km)
255	C-STB/DIS43	1.400E+06	7.4218E+04	3.5618E+04	Tadmor/Gur (0.5-5 km)
256	C-STB/DIS44	2.000E+06	1.0242E+05	4.8306E+04	Tadmor/Gur (0.5-5 km)
257	C-STB/DIS45	3.000E+06	1.4772E+05	6.8302E+04	Tadmor/Gur (0.5-5 km)
258	C-STB/DIS46	4.000E+06	1.9154E+05	8.7331E+04	Tadmor/Gur (0.5-5 km)
259	C-STB/DIS47	5.000E+06	2.3430E+05	1.0567E+05	Tadmor/Gur (0.5-5 km)
260	C-STB/DIS48	6.000E+06	2.7624E+05	1.2348E+05	Tadmor/Gur (0.5-5 km)
261	C-STB/DIS49	8.000E+06	3.5819E+05	1.5788E+05	Tadmor/Gur (0.5-5 km)
262	C-STB/DIS50	1.000E+07	4.3817E+05	1.9104E+05	Tadmor/Gur (0.5-5 km)
	*				
	* D-stability	Distance (m)	Sigma-y (m)	Sigma-z (m)	
263	D-STB/DIS01	1.000E+00	1.4740E-01	3.0000E-01	Tadmor/Gur (0.5-5 km)
264	D-STB/DIS02	1.400E+00	1.9974E-01	3.7374E-01	Tadmor/Gur (0.5-5 km)
265	D-STB/DIS03	2.000E+00	2.7565E-01	4.7180E-01	Tadmor/Gur (0.5-5 km)
266	D-STB/DIS04	3.000E+00	3.9754E-01	6.1486E-01	Tadmor/Gur (0.5-5 km)
267	D-STB/DIS05	4.000E+00	5.1549E-01	7.4197E-01	Tadmor/Gur (0.5-5 km)
268	D-STB/DIS06	5.000E+00	6.3058E-01	8.5840E-01	Tadmor/Gur (0.5-5 km)
269	D-STB/DIS07	6.000E+00	7.4344E-01	9.6696E-01	Tadmor/Gur (0.5-5 km)
270	D-STB/DIS08	8.000E+00	9.6400E-01	1.1669E+00	Tadmor/Gur (0.5-5 km)
271	D-STB/DIS09	1.000E+01	1.1792E+00	1.3500E+00	Tadmor/Gur (0.5-5 km)
272	D-STB/DIS10	1.000E+02	9.4340E+00	6.0746E+00	Tadmor/Gur (0.5-5 km)
273	D-STB/DIS11	1.400E+02	1.2784E+01	7.5678E+00	Tadmor/Gur (0.5-5 km)
274	D-STB/DIS12	2.000E+02	1.7642E+01	9.5533E+00	Tadmor/Gur (0.5-5 km)
275	D-STB/DIS13	3.000E+02	2.5444E+01	1.2450E+01	Tadmor/Gur (0.5-5 km)
276	D-STB/DIS14	4.000E+02	3.2993E+01	1.5024E+01	Tadmor/Gur (0.5-5 km)
277	D-STB/DIS15	5.000E+02	4.0359E+01	1.7382E+01	Tadmor/Gur (0.5-5 km)
278	D-STB/DIS16	6.000E+02	4.7582E+01	1.9580E+01	Tadmor/Gur (0.5-5 km)
279	D-STB/DIS17	8.000E+02	6.1699E+01	2.3628E+01	Tadmor/Gur (0.5-5 km)
280	D-STB/DIS18	1.000E+03	7.5474E+01	2.7335E+01	Tadmor/Gur (0.5-5 km)
281	D-STB/DIS19	1.400E+03	1.0227E+02	3.4054E+01	Tadmor/Gur (0.5-5 km)
282	D-STB/DIS20	2.000E+03	1.4114E+02	4.2989E+01	Tadmor/Gur (0.5-5 km)
283	D-STB/DIS21	3.000E+03	2.0356E+02	5.6024E+01	Tadmor/Gur (0.5-5 km)
284	D-STB/DIS22	4.000E+03	2.6395E+02	6.7606E+01	Tadmor/Gur (0.5-5 km)
285	D-STB/DIS23	5.000E+03	3.2288E+02	7.8215E+01	Tadmor/Gur (0.5-5 km)

286	D-STB/DIS24	6.000E+03	3.8067E+02	8.8107E+01	Tadmor/Gur (0.5-5 km)
287	D-STB/DIS25	8.000E+03	4.9360E+02	1.0632E+02	Tadmor/Gur (0.5-5 km)
288	D-STB/DIS26	1.000E+04	6.0381E+02	1.2300E+02	Tadmor/Gur (0.5-5 km)
289	D-STB/DIS27	1.400E+04	8.1821E+02	1.5324E+02	Tadmor/Gur (0.5-5 km)
290	D-STB/DIS28	2.000E+04	1.1292E+03	1.9344E+02	Tadmor/Gur (0.5-5 km)
291	D-STB/DIS29	3.000E+04	1.6285E+03	2.5210E+02	Tadmor/Gur (0.5-5 km)
292	D-STB/DIS30	4.000E+04	2.1116E+03	3.0422E+02	Tadmor/Gur (0.5-5 km)
293	D-STB/DIS31	5.000E+04	2.5831E+03	3.5196E+02	Tadmor/Gur (0.5-5 km)
294	D-STB/DIS32	6.000E+04	3.0454E+03	3.9647E+02	Tadmor/Gur (0.5-5 km)
295	D-STB/DIS33	8.000E+04	3.9489E+03	4.7843E+02	Tadmor/Gur (0.5-5 km)
296	D-STB/DIS34	1.000E+05	4.8306E+03	5.5350E+02	Tadmor/Gur (0.5-5 km)
297	D-STB/DIS35	1.400E+05	6.5458E+03	6.8956E+02	Tadmor/Gur (0.5-5 km)
298	D-STB/DIS36	2.000E+05	9.0335E+03	8.7047E+02	Tadmor/Gur (0.5-5 km)
299	D-STB/DIS37	3.000E+05	1.3028E+04	1.1344E+03	Tadmor/Gur (0.5-5 km)
300	D-STB/DIS38	4.000E+05	1.6893E+04	1.3689E+03	Tadmor/Gur (0.5-5 km)
301	D-STB/DIS39	5.000E+05	2.0665E+04	1.5838E+03	Tadmor/Gur (0.5-5 km)
302	D-STB/DIS40	6.000E+05	2.4364E+04	1.7841E+03	Tadmor/Gur (0.5-5 km)
303	D-STB/DIS41	8.000E+05	3.1592E+04	2.1529E+03	Tadmor/Gur (0.5-5 km)
304	D-STB/DIS42	1.000E+06	3.8645E+04	2.4907E+03	Tadmor/Gur (0.5-5 km)
305	D-STB/DIS43	1.400E+06	5.2368E+04	3.1029E+03	Tadmor/Gur (0.5-5 km)
306	D-STB/DIS44	2.000E+06	7.2270E+04	3.9170E+03	Tadmor/Gur (0.5-5 km)
307	D-STB/DIS45	3.000E+06	1.0423E+05	5.1048E+03	Tadmor/Gur (0.5-5 km)
308	D-STB/DIS46	4.000E+06	1.3515E+05	6.1601E+03	Tadmor/Gur (0.5-5 km)
309	D-STB/DIS47	5.000E+06	1.6532E+05	7.1267E+03	Tadmor/Gur (0.5-5 km)
310	D-STB/DIS48	6.000E+06	1.9492E+05	8.0280E+03	Tadmor/Gur (0.5-5 km)
311	D-STB/DIS49	8.000E+06	2.5274E+05	9.6877E+03	Tadmor/Gur (0.5-5 km)
312	D-STB/DIS50	1.000E+07	3.0917E+05	1.1208E+04	Tadmor/Gur (0.5-5 km)
	*				
	* E-stability	Distance (m)	Sigma-y (m)	Sigma-z (m)	
313	E-STB/DIS01	1.000E+00	1.0460E-01	4.0000E-01	Tadmor/Gur (0.5-5 km)
314	E-STB/DIS02	1.400E+00	1.4174E-01	4.8983E-01	Tadmor/Gur (0.5-5 km)
315	E-STB/DIS03	2.000E+00	1.9561E-01	6.0717E-01	Tadmor/Gur (0.5-5 km)
316	E-STB/DIS04	3.000E+00	2.8211E-01	7.7506E-01	Tadmor/Gur (0.5-5 km)
317	E-STB/DIS05	4.000E+00	3.6581E-01	9.2164E-01	Tadmor/Gur (0.5-5 km)
318	E-STB/DIS06	5.000E+00	4.4748E-01	1.0542E+00	Tadmor/Gur (0.5-5 km)
319	E-STB/DIS07	6.000E+00	5.2757E-01	1.1765E+00	Tadmor/Gur (0.5-5 km)
320	E-STB/DIS08	8.000E+00	6.8409E-01	1.3990E+00	Tadmor/Gur (0.5-5 km)
321	E-STB/DIS09	1.000E+01	8.3682E-01	1.6001E+00	Tadmor/Gur (0.5-5 km)
322	E-STB/DIS10	1.000E+02	6.6947E+00	6.4012E+00	Tadmor/Gur (0.5-5 km)
323	E-STB/DIS11	1.400E+02	9.0719E+00	7.8387E+00	Tadmor/Gur (0.5-5 km)
324	E-STB/DIS12	2.000E+02	1.2520E+01	9.7165E+00	Tadmor/Gur (0.5-5 km)
325	E-STB/DIS13	3.000E+02	1.8056E+01	1.2403E+01	Tadmor/Gur (0.5-5 km)
326	E-STB/DIS14	4.000E+02	2.3413E+01	1.4749E+01	Tadmor/Gur (0.5-5 km)
327	E-STB/DIS15	5.000E+02	2.8640E+01	1.6870E+01	Tadmor/Gur (0.5-5 km)
328	E-STB/DIS16	6.000E+02	3.3766E+01	1.8827E+01	Tadmor/Gur (0.5-5 km)
329	E-STB/DIS17	8.000E+02	4.3784E+01	2.2388E+01	Tadmor/Gur (0.5-5 km)
330	E-STB/DIS18	1.000E+03	5.3559E+01	2.5607E+01	Tadmor/Gur (0.5-5 km)
331	E-STB/DIS19	1.400E+03	7.2577E+01	3.1358E+01	Tadmor/Gur (0.5-5 km)
332	E-STB/DIS20	2.000E+03	1.0016E+02	3.8870E+01	Tadmor/Gur (0.5-5 km)
333	E-STB/DIS21	3.000E+03	1.4445E+02	4.9617E+01	Tadmor/Gur (0.5-5 km)
334	E-STB/DIS22	4.000E+03	1.8731E+02	5.9001E+01	Tadmor/Gur (0.5-5 km)
335	E-STB/DIS23	5.000E+03	2.2912E+02	6.7485E+01	Tadmor/Gur (0.5-5 km)
336	E-STB/DIS24	6.000E+03	2.7013E+02	7.5316E+01	Tadmor/Gur (0.5-5 km)
337	E-STB/DIS25	8.000E+03	3.5028E+02	8.9559E+01	Tadmor/Gur (0.5-5 km)
338	E-STB/DIS26	1.000E+04	4.2848E+02	1.0244E+02	Tadmor/Gur (0.5-5 km)
339	E-STB/DIS27	1.400E+04	5.8063E+02	1.2544E+02	Tadmor/Gur (0.5-5 km)
340	E-STB/DIS28	2.000E+04	8.0129E+02	1.5549E+02	Tadmor/Gur (0.5-5 km)
341	E-STB/DIS29	3.000E+04	1.1556E+03	1.9849E+02	Tadmor/Gur (0.5-5 km)
342	E-STB/DIS30	4.000E+04	1.4985E+03	2.3603E+02	Tadmor/Gur (0.5-5 km)
343	E-STB/DIS31	5.000E+04	1.8330E+03	2.6997E+02	Tadmor/Gur (0.5-5 km)
344	E-STB/DIS32	6.000E+04	2.1611E+03	3.0129E+02	Tadmor/Gur (0.5-5 km)
345	E-STB/DIS33	8.000E+04	2.8023E+03	3.5827E+02	Tadmor/Gur (0.5-5 km)

346	E-STB/DIS34	1.000E+05	3.4279E+03	4.0979E+02	Tadmor/Gur (0.5-5 km)
347	E-STB/DIS35	1.400E+05	4.6452E+03	5.0182E+02	Tadmor/Gur (0.5-5 km)
348	E-STB/DIS36	2.000E+05	6.4105E+03	6.2203E+02	Tadmor/Gur (0.5-5 km)
349	E-STB/DIS37	3.000E+05	9.2453E+03	7.9403E+02	Tadmor/Gur (0.5-5 km)
350	E-STB/DIS38	4.000E+05	1.1988E+04	9.4419E+02	Tadmor/Gur (0.5-5 km)
351	E-STB/DIS39	5.000E+05	1.4665E+04	1.0800E+03	Tadmor/Gur (0.5-5 km)
352	E-STB/DIS40	6.000E+05	1.7289E+04	1.2053E+03	Tadmor/Gur (0.5-5 km)
353	E-STB/DIS41	8.000E+05	2.2419E+04	1.4332E+03	Tadmor/Gur (0.5-5 km)
354	E-STB/DIS42	1.000E+06	2.7424E+04	1.6393E+03	Tadmor/Gur (0.5-5 km)
355	E-STB/DIS43	1.400E+06	3.7162E+04	2.0074E+03	Tadmor/Gur (0.5-5 km)
356	E-STB/DIS44	2.000E+06	5.1285E+04	2.4883E+03	Tadmor/Gur (0.5-5 km)
357	E-STB/DIS45	3.000E+06	7.3964E+04	3.1764E+03	Tadmor/Gur (0.5-5 km)
358	E-STB/DIS46	4.000E+06	9.5907E+04	3.7771E+03	Tadmor/Gur (0.5-5 km)
359	E-STB/DIS47	5.000E+06	1.1732E+05	4.3203E+03	Tadmor/Gur (0.5-5 km)
360	E-STB/DIS48	6.000E+06	1.3832E+05	4.8215E+03	Tadmor/Gur (0.5-5 km)
361	E-STB/DIS49	8.000E+06	1.7935E+05	5.7334E+03	Tadmor/Gur (0.5-5 km)
362	E-STB/DIS50	1.000E+07	2.1940E+05	6.5578E+03	Tadmor/Gur (0.5-5 km)
	*				
	* F-stability	Distance (m)	Sigma-y (m)	Sigma-z (m)	
363	F-STB/DIS01	1.000E+00	7.2200E-02	2.0000E-01	Tadmor/Gur (0.5-5 km)
364	F-STB/DIS02	1.400E+00	9.7838E-02	2.4491E-01	Tadmor/Gur (0.5-5 km)
365	F-STB/DIS03	2.000E+00	1.3502E-01	3.0356E-01	Tadmor/Gur (0.5-5 km)
366	F-STB/DIS04	3.000E+00	1.9473E-01	3.8749E-01	Tadmor/Gur (0.5-5 km)
367	F-STB/DIS05	4.000E+00	2.5250E-01	4.6076E-01	Tadmor/Gur (0.5-5 km)
368	F-STB/DIS06	5.000E+00	3.0887E-01	5.2700E-01	Tadmor/Gur (0.5-5 km)
369	F-STB/DIS07	6.000E+00	3.6415E-01	5.8814E-01	Tadmor/Gur (0.5-5 km)
370	F-STB/DIS08	8.000E+00	4.7219E-01	6.9934E-01	Tadmor/Gur (0.5-5 km)
371	F-STB/DIS09	1.000E+01	5.7761E-01	7.9989E-01	Tadmor/Gur (0.5-5 km)
372	F-STB/DIS10	1.000E+02	4.6210E+00	3.1991E+00	Tadmor/Gur (0.5-5 km)
373	F-STB/DIS11	1.400E+02	6.2619E+00	3.9174E+00	Tadmor/Gur (0.5-5 km)
374	F-STB/DIS12	2.000E+02	8.6417E+00	4.8557E+00	Tadmor/Gur (0.5-5 km)
375	F-STB/DIS13	3.000E+02	1.2463E+01	6.1981E+00	Tadmor/Gur (0.5-5 km)
376	F-STB/DIS14	4.000E+02	1.6161E+01	7.3700E+00	Tadmor/Gur (0.5-5 km)
377	F-STB/DIS15	5.000E+02	1.9769E+01	8.4297E+00	Tadmor/Gur (0.5-5 km)
378	F-STB/DIS16	6.000E+02	2.3307E+01	9.4076E+00	Tadmor/Gur (0.5-5 km)
379	F-STB/DIS17	8.000E+02	3.0222E+01	1.1186E+01	Tadmor/Gur (0.5-5 km)
380	F-STB/DIS18	1.000E+03	3.6969E+01	1.2795E+01	Tadmor/Gur (0.5-5 km)
381	F-STB/DIS19	1.400E+03	5.0096E+01	1.5667E+01	Tadmor/Gur (0.5-5 km)
382	F-STB/DIS20	2.000E+03	6.9135E+01	1.9420E+01	Tadmor/Gur (0.5-5 km)
383	F-STB/DIS21	3.000E+03	9.9707E+01	2.4789E+01	Tadmor/Gur (0.5-5 km)
384	F-STB/DIS22	4.000E+03	1.2929E+02	2.9476E+01	Tadmor/Gur (0.5-5 km)
385	F-STB/DIS23	5.000E+03	1.5815E+02	3.3714E+01	Tadmor/Gur (0.5-5 km)
386	F-STB/DIS24	6.000E+03	1.8646E+02	3.7625E+01	Tadmor/Gur (0.5-5 km)
387	F-STB/DIS25	8.000E+03	2.4178E+02	4.4739E+01	Tadmor/Gur (0.5-5 km)
388	F-STB/DIS26	1.000E+04	2.9576E+02	5.1172E+01	Tadmor/Gur (0.5-5 km)
389	F-STB/DIS27	1.400E+04	4.0078E+02	6.2661E+01	Tadmor/Gur (0.5-5 km)
390	F-STB/DIS28	2.000E+04	5.5309E+02	7.7669E+01	Tadmor/Gur (0.5-5 km)
391	F-STB/DIS29	3.000E+04	7.9767E+02	9.9142E+01	Tadmor/Gur (0.5-5 km)
392	F-STB/DIS30	4.000E+04	1.0343E+03	1.1789E+02	Tadmor/Gur (0.5-5 km)
393	F-STB/DIS31	5.000E+04	1.2653E+03	1.3484E+02	Tadmor/Gur (0.5-5 km)
394	F-STB/DIS32	6.000E+04	1.4917E+03	1.5048E+02	Tadmor/Gur (0.5-5 km)
395	F-STB/DIS33	8.000E+04	1.9343E+03	1.7893E+02	Tadmor/Gur (0.5-5 km)
396	F-STB/DIS34	1.000E+05	2.3661E+03	2.0466E+02	Tadmor/Gur (0.5-5 km)
397	F-STB/DIS35	1.400E+05	3.2063E+03	2.5061E+02	Tadmor/Gur (0.5-5 km)
398	F-STB/DIS36	2.000E+05	4.4248E+03	3.1063E+02	Tadmor/Gur (0.5-5 km)
399	F-STB/DIS37	3.000E+05	6.3815E+03	3.9651E+02	Tadmor/Gur (0.5-5 km)
400	F-STB/DIS38	4.000E+05	8.2748E+03	4.7149E+02	Tadmor/Gur (0.5-5 km)
401	F-STB/DIS39	5.000E+05	1.0122E+04	5.3927E+02	Tadmor/Gur (0.5-5 km)
402	F-STB/DIS40	6.000E+05	1.1934E+04	6.0183E+02	Tadmor/Gur (0.5-5 km)
403	F-STB/DIS41	8.000E+05	1.5475E+04	7.1563E+02	Tadmor/Gur (0.5-5 km)
404	F-STB/DIS42	1.000E+06	1.8929E+04	8.1852E+02	Tadmor/Gur (0.5-5 km)
405	F-STB/DIS43	1.400E+06	2.5651E+04	1.0023E+03	Tadmor/Gur (0.5-5 km)

```
406  F-STB/DIS44        2.000E+06     3.5400E+04     1.2424E+03  Tadmor/Gur (0.5-5 km)
407  F-STB/DIS45        3.000E+06     5.1053E+04     1.5858E+03  Tadmor/Gur (0.5-5 km)
408  F-STB/DIS46        4.000E+06     6.6200E+04     1.8857E+03  Tadmor/Gur (0.5-5 km)
409  F-STB/DIS47        5.000E+06     8.0980E+04     2.1568E+03  Tadmor/Gur (0.5-5 km)
410  F-STB/DIS48        6.000E+06     9.5474E+04     2.4070E+03  Tadmor/Gur (0.5-5 km)
411  F-STB/DIS49        8.000E+06     1.2380E+05     2.8621E+03  Tadmor/Gur (0.5-5 km)
412  F-STB/DIS50        1.000E+07     1.5144E+05     3.2736E+03  Tadmor/Gur (0.5-5 km)
     *
     *  LINEAR SCALING FACTOR FOR SIGMA-Y FUNCTION, NORMALLY 1
     *
413  DPYSCALE001    1.
     *
     *  LINEAR SCALING FACTOR FOR SIGMA-Z FUNCTION,
     *  NORMALLY USED FOR SURFACE ROUGHNESS LENGTH CORRECTION.
     *  (Z1 / Z0) ** 0.2,   FROM CRAC2 WE HAVE  (10 CM / 3 CM) ** 0.2 = 1.27
     *
414  DPZSCALE001    1.27
     ************************************************************************** *
     * EXPANSION FACTOR DATA BLOCK, LOADED BY INPEXP, STORED IN /EXPAND/
     *
     * TIME BASE FOR EXPANSION FACTOR (SECONDS)
     *
415  PMTIMBAS001    600.   (10 MINUTES)
     *
     * BREAK POINT FOR FORMULA CHANGE (SECONDS)
     *
416  PMBRKPNT001   3600.   (1 HOUR)
     *
     * EXPONENTIAL EXPANSION FACTOR NUMBER 1
     *
417  PMXPFAC1001      0.2
     *
     * EXPONENTIAL EXPANSION FACTOR NUMBER 2
     *
418  PMXPFAC2001      0.25
     ******************************************************************************
     * PLUME RISE DATA BLOCK, LOADED BY INPLRS, STORED IN /PLUMRS/
     *
     * SCALING FACTOR FOR THE CRITICAL WIND SPEED FOR ENTRAINMENT OF A BOUYANT PLUME
     * (USED BY FUNCTION CAUGHT)
     *
419  PRSCLCRW001   1.
     *
     * SCALING FACTOR FOR THE A-D STABILITY PLUME RISE FORMULA
     * (USED BY FUNCTION PLMRIS)
     *
420  PRSCLADP001   1.
     *
     * SCALING FACTOR FOR THE E-F STABILITY PLUME RISE FORMULA
     * (USED BY FUNCTION PLMRIS)
     *
421  PRSCLEFP001   1.
     ******************************************************************************
     * RELEASE DATA BLOCK, LOADED BY INPREL, STORED IN /ATNAM2/, /MULREL/
     *
422  RDATNAM2001 'SECOND DRAFT 1150, WORST CASE SOURCE TERM FOR EARLY FATALITIES'
     *
     * TIME AFTER ACCIDENT INITIATION WHEN THE ACCIDENT REACHES GENERAL EMERGENCY
     * CONDITIONS (AS DEFINED IN NUREG-0654), OR WHEN PLANT PERSONNEL CAN RELIABLY
     * PREDICT THAT GENERAL EMERGENCY CONDITIONS WILL BE ATTAINED
     *
423  RDOALARM001      1300.
```

```
     *
     * NUMBER OF PLUME SEGMENTS THAT ARE RELEASED
     *
424  RDNUMREL001          2
     *
     * SELECTION OF RISK DOMINANT PLUME
     *
425  RDMAXRIS001          1
     *
     * REFERENCE TIME FOR DISPERSION AND RADIOACTIVE DECAY
     *
426  RDREFTIM001       0.00      0.50
     *
     * HEAT CONTENT OF THE RELEASE SEGMENTS (W)
     * A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS
     *
427  RDPLHEAT001     3.7E+6     1.7E5
     *
     * HEIGHT OF THE PLUME SEGMENTS AT RELEASE (M)
     * A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS
     *
428  RDPLHITE001         0.        0.
     *
     * DURATION OF THE PLUME SEGMENTS (S)
     * A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS
     *
429  RDPLUDUR001      1800.    22000.
     *
     * TIME OF RELEASE FOR EACH PLUME (S AFTER SCRAM)
     * A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS
     *
430  RDPDELAY001      3700.    10000.
     *
     * Initial value of sigma-y for each plume--Note: values required for each plume
     *
431  SIGYINIT001  9.302  9.302 (initial sigma-y, calculated for 40 meter wide bldg.)
     *
     * Initial value of sigma-z for each plume--Note: values required for each plume
     *
432  SIGZINIT001  23.26  23.26 (initial sigma-z, calculated for 50 meter high bldg.)
     *
     * Building height (meters)--Note: values required for each plume
     *
433  WEBUILDH001   50.0  50.0  (Surry)
     *
     * PARTICLE SIZE DISTRIBUTION OF EACH NUCLIDE GROUP
     * YOU MUST SPECIFY A COLUMN OF DATA FOR EACH OF THE PARTICLE SIZE GROUPS
     *
434  RDPSDIST001      1.
435  RDPSDIST002      1.
436  RDPSDIST003      1.
437  RDPSDIST004      1.
438  RDPSDIST005      1.
439  RDPSDIST006      1.
440  RDPSDIST007      1.
441  RDPSDIST008      1.
442  RDPSDIST009      1.
     *
     * 3412 MWTH PWR CORE INVENTORY, END-OF-CYCLE
     *           SUPPLIED BY D.E. BENNETT, 5/14/86
     *
     *               NUCNAM        CORINV (Bq)
```

```
     *
443  RDCORINV001     Co-58         3.223E+16
444  RDCORINV002     Co-60         2.465E+16
445  RDCORINV003     Kr-85         2.475E+16
446  RDCORINV004     Kr-85m        1.159E+18
447  RDCORINV005     Kr-87         2.118E+18
448  RDCORINV006     Kr-88         2.864E+18
449  RDCORINV007     Rb-86         1.888E+15
450  RDCORINV008     Sr-89         3.590E+18
451  RDCORINV009     Sr-90         1.938E+17
452  RDCORINV010     Sr-91         4.616E+18
453  RDCORINV011     Sr-92         4.803E+18
454  RDCORINV012     Y-90          2.079E+17
455  RDCORINV013     Y-91          4.374E+18
456  RDCORINV014     Y-92          4.821E+18
457  RDCORINV015     Y-93          5.454E+18
458  RDCORINV016     Zr-95         5.526E+18
459  RDCORINV017     Zr-97         5.759E+18
460  RDCORINV018     Nb-95         5.224E+18
461  RDCORINV019     Mo-99         6.098E+18
462  RDCORINV020     Tc-99m        5.263E+18
463  RDCORINV021     Ru-103        4.542E+18
464  RDCORINV022     Ru-105        2.954E+18
465  RDCORINV023     Ru-106        1.032E+18
466  RDCORINV024     Rh-105        2.046E+18
467  RDCORINV025     Sb-127        2.787E+17
468  RDCORINV026     Sb-129        9.872E+17
469  RDCORINV027     Te-127        2.692E+17
470  RDCORINV028     Te-127m       3.564E+16
471  RDCORINV029     Te-129        9.267E+17
472  RDCORINV030     Te-129m       2.443E+17
473  RDCORINV031     Te-131m       4.680E+17
474  RDCORINV032     Te-132        4.658E+18
475  RDCORINV033     I-131         3.206E+18
476  RDCORINV034     I-132         4.725E+18
477  RDCORINV035     I-133         6.779E+18
478  RDCORINV036     I-134         7.440E+18
479  RDCORINV037     I-135         6.392E+18
480  RDCORINV038     Xe-133        6.782E+18
481  RDCORINV039     Xe-135        1.273E+18
482  RDCORINV040     Cs-134        4.324E+17
483  RDCORINV041     Cs-136        1.316E+17
484  RDCORINV042     Cs-137        2.417E+17
485  RDCORINV043     Ba-139        6.282E+18
486  RDCORINV044     Ba-140        6.216E+18
487  RDCORINV045     La-140        6.352E+18
488  RDCORINV046     La-141        5.826E+18
489  RDCORINV047     La-142        5.616E+18
490  RDCORINV048     Ce-141        5.651E+18
491  RDCORINV049     Ce-143        5.494E+18
492  RDCORINV050     Ce-144        3.405E+18
493  RDCORINV051     Pr-143        5.395E+18
494  RDCORINV052     Nd-147        2.412E+18
495  RDCORINV053     Np-239        6.464E+19
496  RDCORINV054     Pu-238        3.664E+15
497  RDCORINV055     Pu-239        8.263E+14
498  RDCORINV056     Pu-240        1.042E+15
499  RDCORINV057     Pu-241        1.755E+17
500  RDCORINV058     Am-241        1.159E+14
501  RDCORINV059     Cm-242        4.436E+16
502  RDCORINV060     Cm-244        2.596E+15
     *
```

```
     *  SCALING FACTOR TO ADJUST THE CORE INVENTORY FOR POWER LEVEL
     *
503  RDCORSCA001   0.715  *  SURRY
     *
     *
504  RDAPLFRC001   PARENT      (apply rel fracs the same as prior versions)
     *
     * RELEASE FRACTIONS FOR ISOTOPE GROUPS IN RELEASE
     *
     *  ISOTOPE GROUPS:
     *
     *            XE/KR    I     CS     TE     SR     RU     LA     CE     BA
     *
505  RDRELFRC001 1.0E+0 6.8E-1 6.4E-1 1.7E-1 4.2E-3 2.3E-3 1.6E-4 4.0E-4 6.3E-3
506  RDRELFRC002 4.3E-3 9.5E-3 2.4E-3 1.4E-1 6.8E-2 4.7E-4 6.8E-3 7.1E-3 5.4E-2
     ******************************************************************************
     * OUTPUT CONTROL DATA BLOCK, LOADED BY INPOPT, STORED IN /STOPME/, /ATMOPT/
     *
     * FLAG TO INDICATE THAT THIS IS THE LAST PROGRAM IN THE SERIES TO BE RUN
     *
507  OCENDAT1001  .FALSE. (SET THIS VALUE TO .TRUE. TO SKIP EARLY AND CHRONC)
     *
508  OCIDEBUG001  0
     *
     * NAME OF THE NUCLIDE TO BE LISTED ON THE DISPERSION LISTINGS
     *
509  OCNUCOUT001  Cs-137
     *
     *              NUM0
510  TYPE0NUMBER      2
     *
     *              INDREL   INDRAD
511  TYPE0OUT001      1        9
512  TYPE0OUT002      1       10         XCCDF
     ******************************************************************************
     * METEOROLOGICAL SAMPLING DATA BLOCK
     *
     * METEOROLOGICAL SAMPLING OPTION CODE:
     *
     * METCOD = 1, USER SPECIFIED DAY AND HOUR IN THE YEAR (FROM MET FILE),
     *          2, WEATHER CATEGORY BIN SAMPLING,
     *          3, 120 HOURS OF WEATHER SPECIFIED ON THE ATMOS USER INPUT FILE,
     *          4, CONSTANT MET (BOUNDARY WEATHER USED FROM THE START),
     *          5, STRATIFIED RANDOM SAMPLES FOR EACH DAY OF THE YEAR.
     *
513  M1METCOD001  2
     *
     * LAST SPATIAL INTERVAL FOR MEASURED WEATHER
     *
514  M2LIMSPA001  25
     *
     * BOUNDARY WEATHER MIXING LAYER HEIGHT
     *
515  M2BNDMXH001  1000.  (METERS)
     *
     * BOUNDARY WEATHER STABILITY CLASS INDEX
     *
516  M2IBDSTB001  4      (D-STABILITY)
     *
     * BOUNDARY WEATHER RAIN RATE
     *
517  M2BNDRAN001  5.     (MM/HR)
```

```
       *
       * BOUNDARY WEATHER WIND SPEED
       *
  518  M2BNDWND001  5.     (M/S)
       *
       * NUMBER OF RAIN DISTANCE INTERVALS FOR BINNING
       *
  519  M4NRNINT001  5
       *
       * ENDPOINTS OF THE RAIN DISTANCE INTERVALS (KILOMETERS)
       *
       * NOTE: THESE MUST BE CHOSEN TO MATCH THE SPATIAL ENDPOINT DISTANCES
       *       SPECIFIED FOR THE ARRAY SPAEND (10 % ERROR IS ALLOWED).
       *
  520  M4RNDSTS001  3.22  5.63  11.27  20.92  32.19
       *
       * NUMBER OF RAIN INTENSITIY BREAKPOINTS
       *
  521  M4NRINTN001   3
       *
       * RAIN INTENSITY BREAKPOINTS FOR WEATHER BINNING (MILLIMETERS PER HOUR)
       *
  522  M4RNRATE001   2.  4.  6.
       *
       * NUMBER OF SAMPLES PER BIN
       *
  523  M4NSMPLS001  4  (THIS NUMBER SHOULD BE SET TO 4 FOR RISK ASSESSMENT)
       *
       * INITIAL SEED FOR RANDOM NUMBER GENERATOR
       *
  524  M4IRSEED001   79
       .
******** TERMINATOR RECORD ENCOUNTERED -- END OF BASE CASE USER INPUT ********


USER INPUT PROCESSING SUMMARY - BASE CASE

NUMBER OF RECORDS READ                        =  753
NUMBER OF BLANK OR COMMENT RECORDS READ       =  228
NUMBER OF TERMINATOR RECORDS                  =    1
NUMBER OF RECORDS PROCESSED                   =  524
     NUMBER OF PROCESSED RECORDS DUPLICATED   =    0
     NUMBER OF PROCESSED RECORDS SORTED       =  524
*****************************************************************************************



Decay Chain #  Ba-139

Decay Chain #  Ba-140   La-140
Fraction of Ba-140  going to La-140  in this chain = 1.000000

Decay Chain #  Ce-143   Pr-143
Fraction of Ce-143  going to Pr-143  in this chain = 1.000000

Decay Chain #  Ce-144

Decay Chain #  Cm-242   Pu-238
Fraction of Cm-242  going to Pu-238  in this chain = 1.000000

Decay Chain #  Cm-244   Pu-240
Fraction of Cm-244  going to Pu-240  in this chain = 1.000000
```

```
Decay Chain #  Co-58

Decay Chain #  Co-60

Decay Chain #  Cs-134

Decay Chain #  Cs-136

Decay Chain #  Cs-137

Decay Chain #  I-133    Xe-133
Fraction of I-133   going to Xe-133  in this chain = 0.971000

Decay Chain #  I-134

Decay Chain #  I-135    Xe-135
Fraction of I-135   going to Xe-135  in this chain = 0.846000

Decay Chain #  Kr-85m   Kr-85
Fraction of Kr-85m  going to Kr-85   in this chain = 0.211000

Decay Chain #  Kr-87

Decay Chain #  Kr-88

Decay Chain #  La-141   Ce-141
Fraction of La-141  going to Ce-141  in this chain = 1.000000

Decay Chain #  La-142

Decay Chain #  Mo-99    Tc-99m
Fraction of Mo-99   going to Tc-99m  in this chain = 0.876000

Decay Chain #  Nd-147

Decay Chain #  Np-239   Pu-239
Fraction of Np-239  going to Pu-239  in this chain = 1.000000

Decay Chain #  Pu-241   Am-241
Fraction of Pu-241  going to Am-241  in this chain = 1.000000

Decay Chain #  Rb-86

Decay Chain #  Ru-103

Decay Chain #  Ru-105   Rh-105
Fraction of Ru-105  going to Rh-105  in this chain = 1.000000

Decay Chain #  Ru-106

Decay Chain #  Sb-127   Te-127
Fraction of Sb-127  going to Te-127  in this chain = 0.824000

Decay Chain #  Sb-127   Te-127m  Te-127
Fraction of Sb-127  going to Te-127m in this chain = 0.176000
Fraction of Sb-127  going to Te-127  in this chain = 0.171776
Fraction of Te-127m going to Te-127  in this chain = 0.976000

Decay Chain #  Sb-129   Te-129
Fraction of Sb-129  going to Te-129  in this chain = 0.775000
```

```
Decay Chain #  Sb-129   Te-129m  Te-129
Fraction of Sb-129  going to Te-129m in this chain = 0.225000
Fraction of Sb-129  going to Te-129  in this chain = 0.146250
Fraction of Te-129m going to Te-129  in this chain = 0.650000

Decay Chain #  Sr-89

Decay Chain #  Sr-90    Y-90
Fraction of Sr-90   going to Y-90    in this chain = 1.000000

Decay Chain #  Sr-91    Y-91
Fraction of Sr-91   going to Y-91    in this chain = 0.422000

Decay Chain #  Sr-92    Y-92
Fraction of Sr-92   going to Y-92    in this chain = 1.000000

Decay Chain #  Te-131m  I-131
Fraction of Te-131m going to I-131   in this chain = 0.778000

Decay Chain #  Te-132   I-132
Fraction of Te-132  going to I-132   in this chain = 1.000000

Decay Chain #  Y-93

Decay Chain #  Zr-95    Nb-95
Fraction of Zr-95   going to Nb-95   in this chain = 0.993000

Decay Chain #  Zr-97

Using new table-lookup scheme for sigma-y/sigma-z


RELEASED INVENTORY OF ALL PLUMES
Co-58      5.30E+13   1.08E+13
Co-60      4.05E+13   8.28E+12
Kr-85      1.77E+16   7.61E+13
Kr-85m     7.07E+17   1.45E+15
Kr-87      8.65E+17   2.71E+14
Kr-88      1.59E+18   2.12E+15
Rb-86      8.63E+14   3.21E+12
Sr-89      1.08E+16   1.74E+17
Sr-90      5.82E+14   9.42E+15
Sr-91      1.29E+16   1.47E+17
Sr-92      1.11E+16   5.25E+16
Y-90       3.00E+13   1.53E+15
Y-91       5.03E+14   2.14E+16
Y-92       2.75E+15   7.93E+16
Y-93       5.81E+14   1.78E+16
Zr-95      6.32E+14   2.68E+16
Zr-97      6.32E+14   2.20E+16
Nb-95      5.98E+14   2.54E+16
Mo-99      9.92E+15   1.93E+15
Tc-99m     8.66E+15   1.75E+15
Ru-103     7.46E+15   1.52E+15
Ru-105     4.14E+15   3.99E+14
Ru-106     1.70E+15   3.47E+14
Rh-105     3.39E+15   6.83E+14
Sb-127     3.36E+16   2.67E+16
Sb-129     1.02E+17   3.88E+16
Te-127     3.27E+16   2.66E+16
Te-127m    4.33E+15   3.57E+15
```

Te-129	1.09E+17	5.61E+16
Te-129m	2.97E+16	2.44E+16
Te-131m	5.56E+16	4.09E+16
Te-132	5.61E+17	4.43E+17
I-131	1.55E+18	2.20E+16
I-132	1.84E+18	3.79E+17
I-133	3.18E+18	3.79E+16
I-134	1.60E+18	5.02E+14
I-135	2.79E+18	2.36E+16
Xe-133	4.84E+18	2.15E+16
Xe-135	1.03E+18	1.22E+16
Cs-134	1.98E+17	7.42E+14
Cs-136	6.01E+16	2.23E+14
Cs-137	1.11E+17	4.15E+14
Ba-139	1.69E+16	1.29E+16
Ba-140	2.79E+16	2.37E+17
La-140	1.20E+15	5.07E+16
La-141	5.56E+14	1.01E+16
La-142	4.05E+14	1.98E+15
Ce-141	1.62E+15	2.86E+16
Ce-143	1.54E+15	2.47E+16
Ce-144	9.74E+14	1.73E+16
Pr-143	6.19E+14	2.62E+16
Nd-147	2.75E+14	1.15E+16
Np-239	1.83E+16	3.05E+17
Pu-238	1.05E+12	1.86E+13
Pu-239	2.36E+11	4.20E+12
Pu-240	2.98E+11	5.29E+12
Pu-241	5.02E+13	8.91E+14
Am-241	1.33E+10	5.64E+11
Cm-242	5.07E+12	2.15E+14
Cm-244	2.97E+11	1.26E+13

```
READING FROM A WEATHER FILE WITH THE FOLLOWING HEADER:
SURRY MET, NRC-12/12/88, CREATED 12/22/88
 MACCS FORMAT--NUREG-1150
     METEOROLOGICAL DATA FILE CONTAINS  451 HOURS OF OBSERVED RAIN DATA.
            ACCUMULATED RAIN MEASUREMENTS TOTALED  29.21 INCHES FOR THE YEAR.
            CONSTANT LID HEIGHTS (M) FOR 4 SEASONS =    1054   1890   1924   1412
            NON-ZERO WINDSPEEDS LESS THAN 0.5 M/S ARE SET TO 0.5 M/S
```

* * * * METEOROLOGICAL BIN SUMMARY * * * *

```
  BIN PRIORITIES
    RI XX - RAIN INTENSITY I WITHIN THE INTERVAL ENDING AT XX
              INTERVAL ENDPOINTS ARE IN KILOMETERS FROM THE ACCIDENT SITE, THE 5 INTERVAL ENDPOINTS ARE    3   6  11  21  32
              RAIN INTENSITIES ARE IN MILLIMETERS OF RAIN PER HOUR, THE 3 INTENSITY BREAKPOINTS ARE         2.0  4.0  6.0
    S   V - INITIAL WEATHER CONDITIONS WITH STABILITY CLASS S AND WIND SPEED INTERVAL V
              STABILITY CLASSES ARE B = A/B, D = C/D, E = E, AND F = F
              WIND SPEED INTERVALS ARE IN METERS PER SECOND, 1 (0-1), 2 (1-2), 3 (2-3), 4 (3-5), 5 (5-7), 6 (GT 7)
```

			WIND DIRECTION																
METBIN			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	TOTAL	PER CENT
1	B	3	0.032	0.041	0.037	0.029	0.077	0.088	0.080	0.055	0.060	0.046	0.039	0.069	0.089	0.090	0.130	0.039	957	10.9247
2	B	4	0.008	0.075	0.122	0.080	0.042	0.093	0.088	0.094	0.094	0.067	0.053	0.091	0.066	0.011	0.013	0.004	946	10.7991
3	D	1	0.058	0.093	0.047	0.047	0.116	0.047	0.023	0.058	0.081	0.047	0.047	0.035	0.047	0.070	0.128	0.058	86	0.9817
4	D	2	0.035	0.040	0.054	0.063	0.052	0.080	0.052	0.072	0.070	0.072	0.075	0.059	0.084	0.096	0.052	0.042	572	6.5297
5	D	3	0.015	0.063	0.066	0.037	0.059	0.066	0.057	0.063	0.083	0.083	0.131	0.079	0.114	0.050	0.031	0.006	544	6.2100
6	D	4	0.011	0.088	0.103	0.074	0.036	0.020	0.030	0.149	0.120	0.109	0.093	0.094	0.056	0.003	0.008	0.005	658	7.5114
7	D	5	0.014	0.110	0.076	0.076	0.034	0.021	0.083	0.241	0.145	0.028	0.083	0.062	0.028	0.000	0.000	0.000	145	1.6553
8	D	6	0.000	0.364	0.000	0.000	0.091	0.000	0.000	0.000	0.000	0.000	0.000	0.545	0.000	0.000	0.000	0.000	11	0.1256

9	E	1	0.101	0.081	0.054	0.041	0.108	0.041	0.041	0.041	0.020	0.034	0.034	0.054	0.054	0.095	0.095	0.108	148	1.6895
10	E	2	0.060	0.063	0.063	0.063	0.081	0.058	0.037	0.028	0.057	0.069	0.046	0.031	0.100	0.156	0.048	0.039	668	7.6256
11	E	3	0.063	0.135	0.080	0.057	0.036	0.036	0.040	0.078	0.135	0.077	0.090	0.018	0.063	0.053	0.015	0.026	758	8.6530
12	E	4	0.055	0.240	0.130	0.088	0.052	0.037	0.065	0.120	0.073	0.052	0.035	0.020	0.013	0.002	0.010	0.007	599	6.8379
13	F	1	0.138	0.101	0.071	0.039	0.041	0.049	0.056	0.039	0.037	0.028	0.018	0.031	0.027	0.079	0.090	0.155	774	8.8356
14	F	2	0.163	0.149	0.065	0.071	0.069	0.049	0.058	0.046	0.082	0.034	0.013	0.013	0.008	0.022	0.053	0.105	759	8.6644
15	F	3	0.207	0.290	0.124	0.103	0.076	0.069	0.007	0.014	0.028	0.007	0.007	0.014	0.000	0.007	0.007	0.041	145	1.6553
16	F	4	0.167	0.333	0.167	0.000	0.083	0.000	0.000	0.167	0.083	0.000	0.000	0.000	0.000	0.000	0.000	0.000	12	0.1370
17	R1	3	0.074	0.031	0.037	0.026	0.034	0.074	0.085	0.097	0.071	0.040	0.060	0.105	0.111	0.043	0.063	0.051	352	4.0183
18	R1	6	0.171	0.024	0.073	0.049	0.024	0.073	0.073	0.049	0.024	0.049	0.024	0.024	0.122	0.049	0.098	0.073	41	0.4680
19	R1	11	0.097	0.049	0.049	0.010	0.010	0.058	0.039	0.039	0.049	0.029	0.087	0.068	0.165	0.010	0.097	0.146	103	1.1758
20	R1	21	0.098	0.076	0.045	0.015	0.008	0.053	0.068	0.053	0.030	0.038	0.045	0.098	0.144	0.038	0.106	0.083	132	1.5068
21	R1	32	0.110	0.055	0.039	0.008	0.031	0.031	0.047	0.071	0.039	0.031	0.047	0.126	0.142	0.063	0.071	0.087	127	1.4498
22	R2	3	0.108	0.041	0.027	0.068	0.041	0.000	0.014	0.068	0.068	0.068	0.108	0.135	0.081	0.081	0.068	0.027	74	0.8447
23	R2	6	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.000	0.000	0.000	0.000	0.000	0.333	3	0.0342
24	R2	11	0.125	0.000	0.125	0.000	0.000	0.000	0.000	0.063	0.125	0.063	0.063	0.000	0.063	0.063	0.250	0.063	16	0.1826
25	R2	21	0.125	0.042	0.167	0.000	0.083	0.000	0.042	0.042	0.083	0.042	0.000	0.042	0.083	0.000	0.125	0.125	24	0.2740
26	R2	32	0.148	0.000	0.074	0.037	0.074	0.037	0.000	0.000	0.000	0.000	0.037	0.037	0.185	0.037	0.074	0.259	27	0.3082
27	R3	3	0.059	0.059	0.059	0.059	0.118	0.000	0.059	0.059	0.000	0.059	0.059	0.118	0.000	0.118	0.059	0.118	17	0.1941
29	R3	11	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.000	0.333	3	0.0342
30	R3	21	0.200	0.000	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.200	0.000	0.000	0.200	0.200	5	0.0571
31	R3	32	0.571	0.000	0.000	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.143	0.143	7	0.0799
32	R4	3	0.211	0.000	0.000	0.000	0.053	0.053	0.000	0.000	0.000	0.053	0.105	0.000	0.211	0.105	0.053	0.158	19	0.2169
33	R4	6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1	0.0114
34	R4	11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.400	0.000	0.200	0.400	5	0.0571
35	R4	21	0.071	0.071	0.000	0.000	0.000	0.071	0.143	0.000	0.071	0.000	0.000	0.000	0.143	0.071	0.143	0.214	14	0.1598
36	R4	32	0.125	0.000	0.000	0.000	0.125	0.000	0.125	0.000	0.000	0.125	0.000	0.000	0.125	0.125	0.250	0.000	8	0.0913
37	ALL		0.066	0.095	0.075	0.056	0.054	0.057	0.057	0.074	0.077	0.057	0.055	0.056	0.066	0.054	0.052	0.050	8760	

* * * * METEOROLOGICAL BIN SUMMARY * * * *

BIN PRIORITIES

RI XX - RAIN INTENSITY I WITHIN THE INTERVAL ENDING AT XX
INTERVAL ENDPOINTS ARE IN KILOMETERS FROM THE ACCIDENT SITE, THE 5 INTERVAL ENDPOINTS ARE 3 6 11 21 32
RAIN INTENSITIES ARE IN MILLIMETERS OF RAIN PER HOUR, THE 3 INTENSITY BREAKPOINTS ARE 2.0 4.0 6.0

S V - INITIAL WEATHER CONDITIONS WITH STABILITY CLASS S AND WIND SPEED INTERVAL V
STABILITY CLASSES ARE B = A/B, D = C/D, E = E, AND F = F
WIND SPEED INTERVALS ARE IN METERS PER SECOND (M/S), 1 (0-1), 2 (1-2), 3 (2-3), 4 (3-5), 5 (5-7), 6 (GT 7)

			WIND DIRECTION																
METBIN			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	TOTAL	PER CENT
1	B	3	31	39	35	28	74	84	77	53	57	44	37	66	85	86	124	37	957	10.9247
2	B	4	8	71	115	76	40	88	83	89	89	63	50	86	62	10	12	4	946	10.7991
3	D	1	5	8	4	4	10	4	2	5	7	4	4	3	4	6	11	5	86	0.9817
4	D	2	20	23	31	36	30	46	30	41	40	41	43	34	48	55	30	24	572	6.5297
5	D	3	8	34	36	20	32	36	31	34	45	45	71	43	62	27	17	3	544	6.2100
6	D	4	7	58	68	49	24	13	20	98	79	72	61	62	37	2	5	3	658	7.5114
7	D	5	2	16	11	11	5	3	12	35	21	4	12	9	4	0	0	0	145	1.6553
8	D	6	0	4	0	0	1	0	0	0	0	0	0	6	0	0	0	0	11	0.1256
9	E	1	15	12	8	6	16	6	6	6	3	5	5	8	8	14	14	16	148	1.6895
10	E	2	40	42	42	42	54	39	25	19	38	46	31	21	67	104	32	26	668	7.6256
11	E	3	48	102	61	43	27	27	30	59	102	58	68	14	48	40	11	20	758	8.6530
12	E	4	33	144	78	53	31	22	39	72	44	31	21	12	8	1	6	4	599	6.8379
13	F	1	107	78	55	30	32	38	43	30	29	22	14	24	21	61	70	120	774	8.8356
14	F	2	124	113	49	54	52	37	44	35	62	26	10	10	6	17	40	80	759	8.6644
15	F	3	30	42	18	15	11	10	1	2	4	1	1	2	0	1	1	6	145	1.6553
16	F	4	2	4	2	0	1	0	0	2	1	0	0	0	0	0	0	0	12	0.1370
17	R1	3	26	11	13	9	12	26	30	34	25	14	21	37	39	15	22	18	352	4.0183
18	R1	6	7	1	3	2	1	3	3	2	1	2	1	1	5	2	4	3	41	0.4680
19	R1	11	10	5	5	1	1	6	4	4	5	3	9	7	17	1	10	15	103	1.1758

20	R1	21	13	10	6	2	1	7	9	7	4	5	6	13	19	5	14	11	132	1.5068
21	R1	32	14	7	5	1	4	4	6	9	5	4	6	16	18	8	9	11	127	1.4498
22	R2	3	8	3	2	5	3	0	1	5	5	5	8	10	6	6	5	2	74	0.8447
23	R2	6	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	3	0.0342
24	R2	11	2	0	2	0	0	0	0	1	2	1	1	0	1	1	4	1	16	0.1826
25	R2	21	3	1	4	0	2	0	1	1	2	1	0	1	2	0	3	3	24	0.2740
26	R2	32	4	0	2	1	2	1	0	0	0	0	1	1	5	1	2	7	27	0.3082
27	R3	3	1	1	1	1	2	0	1	1	0	1	1	2	0	2	1	2	17	0.1941
28	R3	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0000
29	R3	11	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	3	0.0342
30	R3	21	1	0	1	0	0	0	0	0	0	0	0	1	0	0	1	1	5	0.0571
31	R3	32	4	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	7	0.0799
32	R4	3	4	0	0	0	1	1	0	0	0	1	2	0	4	2	1	3	19	0.2169
33	R4	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0.0114
34	R4	11	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	2	5	0.0571
35	R4	21	1	1	0	0	0	1	2	0	1	0	0	0	2	1	2	3	14	0.1598
36	R4	32	1	0	0	0	1	0	1	0	0	1	0	0	1	1	2	0	8	0.0913

* * * * SUMMARIES * * * *

R	101	40	44	23	30	49	58	64	50	39	56	89	121	46	82	86	978	11.1644
B	39	110	150	104	114	172	160	142	146	107	87	152	147	96	136	41	1903	21.7237
D	42	143	150	120	102	102	95	213	192	166	191	157	155	90	63	35	2016	23.0137
E	136	300	189	144	128	94	100	156	187	140	125	55	131	159	63	66	2173	24.8059
F	263	237	124	99	96	85	88	69	96	49	25	36	27	79	111	206	1690	19.2922
1	127	98	67	40	58	48	51	42	39	31	23	35	34	81	95	141	1010	11.5297
2	199	186	127	138	156	141	122	108	154	124	89	82	143	198	132	146	2245	25.6279
3	102	209	145	100	124	138	116	134	194	137	172	108	172	132	123	50	2156	24.6119
4	45	255	228	166	82	112	126	242	204	165	128	156	100	13	23	11	2056	23.4703
5	7	37	45	23	19	14	28	54	30	5	16	13	11	0	0	0	302	3.4475
6	0	5	1	0	1	0	0	0	0	0	0	6	0	0	0	0	13	0.1484

* * * * * BIN WINDROSE SUMMARY * * * * *

BIN	DIRECTION																TOTAL
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
1	0.032	0.041	0.037	0.029	0.077	0.088	0.080	0.055	0.060	0.046	0.039	0.069	0.089	0.090	0.130	0.039	1.000000
2	0.008	0.075	0.122	0.080	0.042	0.093	0.088	0.094	0.094	0.067	0.053	0.091	0.066	0.011	0.013	0.004	1.000000
3	0.058	0.093	0.047	0.047	0.116	0.047	0.023	0.058	0.081	0.047	0.047	0.035	0.047	0.070	0.128	0.058	1.000000
4	0.035	0.040	0.054	0.063	0.052	0.080	0.052	0.072	0.070	0.072	0.075	0.059	0.084	0.096	0.052	0.042	1.000000
5	0.015	0.063	0.066	0.037	0.059	0.066	0.057	0.063	0.083	0.083	0.131	0.079	0.114	0.050	0.031	0.006	1.000000
6	0.011	0.088	0.103	0.074	0.036	0.020	0.030	0.149	0.120	0.109	0.093	0.094	0.056	0.003	0.008	0.005	1.000000
7	0.014	0.110	0.076	0.076	0.034	0.021	0.083	0.241	0.145	0.028	0.083	0.062	0.028	0.000	0.000	0.000	1.000000
8	0.000	0.364	0.000	0.000	0.091	0.000	0.000	0.000	0.000	0.000	0.000	0.545	0.000	0.000	0.000	0.000	1.000000
9	0.101	0.081	0.054	0.041	0.108	0.041	0.041	0.041	0.020	0.034	0.034	0.054	0.054	0.095	0.095	0.108	1.000000
10	0.060	0.063	0.063	0.063	0.081	0.058	0.037	0.028	0.057	0.069	0.046	0.031	0.100	0.156	0.048	0.039	1.000000
11	0.063	0.135	0.080	0.057	0.036	0.036	0.040	0.078	0.135	0.077	0.090	0.018	0.063	0.053	0.015	0.026	1.000000
12	0.055	0.240	0.130	0.088	0.052	0.037	0.065	0.120	0.073	0.052	0.035	0.020	0.013	0.002	0.010	0.007	1.000000
13	0.138	0.101	0.071	0.039	0.041	0.049	0.056	0.039	0.037	0.028	0.018	0.031	0.027	0.079	0.090	0.155	1.000000
14	0.163	0.149	0.065	0.071	0.069	0.049	0.058	0.046	0.082	0.034	0.013	0.013	0.008	0.022	0.053	0.105	1.000000
15	0.207	0.290	0.124	0.103	0.076	0.069	0.007	0.014	0.028	0.007	0.007	0.014	0.000	0.007	0.007	0.041	1.000000
16	0.167	0.333	0.167	0.000	0.083	0.000	0.000	0.167	0.083	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000000
17	0.103	0.041	0.045	0.024	0.031	0.050	0.059	0.065	0.051	0.040	0.057	0.091	0.124	0.047	0.084	0.088	1.000000
18	0.103	0.041	0.045	0.024	0.031	0.050	0.059	0.065	0.051	0.040	0.057	0.091	0.124	0.047	0.084	0.088	1.000000
19	0.103	0.041	0.045	0.024	0.031	0.050	0.059	0.065	0.051	0.040	0.057	0.091	0.124	0.047	0.084	0.088	1.000000
20	0.103	0.041	0.045	0.024	0.031	0.050	0.059	0.065	0.051	0.040	0.057	0.091	0.124	0.047	0.084	0.088	1.000000
21	0.103	0.041	0.045	0.024	0.031	0.050	0.059	0.065	0.051	0.040	0.057	0.091	0.124	0.047	0.084	0.088	1.000000
22	0.103	0.041	0.045	0.024	0.031	0.050	0.059	0.065	0.051	0.040	0.057	0.091	0.124	0.047	0.084	0.088	1.000000
23	0.103	0.041	0.045	0.024	0.031	0.050	0.059	0.065	0.051	0.040	0.057	0.091	0.124	0.047	0.084	0.088	1.000000
24	0.103	0.041	0.045	0.024	0.031	0.050	0.059	0.065	0.051	0.040	0.057	0.091	0.124	0.047	0.084	0.088	1.000000
25	0.103	0.041	0.045	0.024	0.031	0.050	0.059	0.065	0.051	0.040	0.057	0.091	0.124	0.047	0.084	0.088	1.000000

```
   26  0.103  0.041  0.045  0.024  0.031  0.050  0.059  0.065  0.051  0.040  0.057  0.091  0.124  0.047  0.084  0.088  1.000000
   27  0.103  0.041  0.045  0.024  0.031  0.050  0.059  0.065  0.051  0.040  0.057  0.091  0.124  0.047  0.084  0.088  1.000000
   28  0.103  0.041  0.045  0.024  0.031  0.050  0.059  0.065  0.051  0.040  0.057  0.091  0.124  0.047  0.084  0.088  1.000000
   29  0.103  0.041  0.045  0.024  0.031  0.050  0.059  0.065  0.051  0.040  0.057  0.091  0.124  0.047  0.084  0.088  1.000000
   30  0.103  0.041  0.045  0.024  0.031  0.050  0.059  0.065  0.051  0.040  0.057  0.091  0.124  0.047  0.084  0.088  1.000000
   31  0.103  0.041  0.045  0.024  0.031  0.050  0.059  0.065  0.051  0.040  0.057  0.091  0.124  0.047  0.084  0.088  1.000000
   32  0.103  0.041  0.045  0.024  0.031  0.050  0.059  0.065  0.051  0.040  0.057  0.091  0.124  0.047  0.084  0.088  1.000000
   33  0.103  0.041  0.045  0.024  0.031  0.050  0.059  0.065  0.051  0.040  0.057  0.091  0.124  0.047  0.084  0.088  1.000000
   34  0.103  0.041  0.045  0.024  0.031  0.050  0.059  0.065  0.051  0.040  0.057  0.091  0.124  0.047  0.084  0.088  1.000000
   35  0.103  0.041  0.045  0.024  0.031  0.050  0.059  0.065  0.051  0.040  0.057  0.091  0.124  0.047  0.084  0.088  1.000000
   36  0.103  0.041  0.045  0.024  0.031  0.050  0.059  0.065  0.051  0.040  0.057  0.091  0.124  0.047  0.084  0.088  1.000000
   37  0.066  0.095  0.075  0.056  0.054  0.057  0.057  0.074  0.077  0.057  0.055  0.056  0.066  0.054  0.052  0.050  1.000000


******** BEGINNING OF CHANGE CASE   1 USER INPUT ********
       ********************** RELEASE DATA BLOCK *************
       * SOURCE TERM NUMBER 2 OF 2
       *
  525  RDATNAM2001 'RELEASE FRACTIONS OF SOURCE TERM 1 REDUCED BY A FACTOR OF TEN'
********   RECORD NUMBER   525 REPLACES RECORD NUMBER   422   ********
       *
       *            XE/KR    I     CS     TE     SR     RU     LA     CE     BA
       *
  526  RDRELFRC001 1.0E-1 6.8E-2 6.4E-2 1.7E-2 4.2E-4 2.3E-4 1.6E-5 4.0E-5 6.3E-4
********   RECORD NUMBER   526 REPLACES RECORD NUMBER   505   ********
  527  RDRELFRC002 4.3E-4 9.5E-4 2.4E-4 1.4E-2 6.8E-3 4.7E-5 6.8E-4 7.1E-4 5.4E-3
********   RECORD NUMBER   527 REPLACES RECORD NUMBER   506   ********
       .
******** TERMINATOR RECORD ENCOUNTERED -- END OF CHANGE CASE   1 USER INPUT ********

USER INPUT PROCESSING SUMMARY - CHANGE CASE   1
NUMBER OF RECORDS CHANGED              =    3
NUMBER OF RECORDS ADDED                =    0
*****************************************************************************************


RELEASED INVENTORY OF ALL PLUMES
Co-58      5.30E+12   1.08E+12
Co-60      4.05E+12   8.28E+11
Kr-85      1.77E+15   7.61E+12
Kr-85m     7.07E+16   1.45E+14
Kr-87      8.65E+16   2.71E+13
Kr-88      1.59E+17   2.12E+14
Rb-86      8.63E+13   3.21E+11
Sr-89      1.08E+15   1.74E+16
Sr-90      5.82E+13   9.42E+14
Sr-91      1.29E+15   1.47E+16
Sr-92      1.11E+15   5.25E+15
Y-90       3.00E+12   1.53E+14
Y-91       5.03E+13   2.14E+15
Y-92       2.75E+14   7.93E+15
Y-93       5.81E+13   1.78E+15
Zr-95      6.32E+13   2.68E+15
Zr-97      6.32E+13   2.20E+15
Nb-95      5.98E+13   2.54E+15
Mo-99      9.92E+14   1.93E+14
Tc-99m     8.66E+14   1.75E+14
Ru-103     7.46E+14   1.52E+14
Ru-105     4.14E+14   3.99E+13
Ru-106     1.70E+14   3.47E+13
Rh-105     3.39E+14   6.83E+13
```

```
Sb-127     3.36E+15   2.67E+15
Sb-129     1.02E+16   3.88E+15
Te-127     3.27E+15   2.66E+15
Te-127m    4.33E+14   3.57E+14
Te-129     1.09E+16   5.61E+15
Te-129m    2.97E+15   2.44E+15
Te-131m    5.56E+15   4.09E+15
Te-132     5.61E+16   4.43E+16
I-131      1.55E+17   2.20E+15
I-132      1.84E+17   3.79E+16
I-133      3.18E+17   3.79E+15
I-134      1.60E+17   5.02E+13
I-135      2.79E+17   2.36E+15
Xe-133     4.84E+17   2.15E+15
Xe-135     1.03E+17   1.22E+15
Cs-134     1.98E+16   7.42E+13
Cs-136     6.01E+15   2.23E+13
Cs-137     1.11E+16   4.15E+13
Ba-139     1.69E+15   1.29E+15
Ba-140     2.79E+15   2.37E+16
La-140     1.20E+14   5.07E+15
La-141     5.56E+13   1.01E+15
La-142     4.05E+13   1.98E+14
Ce-141     1.62E+14   2.86E+15
Ce-143     1.54E+14   2.47E+15
Ce-144     9.74E+13   1.73E+15
Pr-143     6.19E+13   2.62E+15
Nd-147     2.75E+13   1.15E+15
Np-239     1.83E+15   3.05E+16
Pu-238     1.05E+11   1.86E+12
Pu-239     2.36E+10   4.20E+11
Pu-240     2.98E+10   5.29E+11
Pu-241     5.02E+12   8.91E+13
Am-241     1.33E+09   5.64E+10
Cm-242     5.07E+11   2.15E+13
Cm-244     2.97E+10   1.26E+12


USER INPUT IS READ FROM UNIT 25
RECORD IDENTIFIER FIELDS  11 CHARACTERS LONG ARE EXPECTED.
THE FIRST 100 COLUMNS OF EACH INPUT RECORD ARE PROCESSED.
THE MAXIMUM NUMBER OF IDENTIFIER RECORDS THAT MAY BE SAVED AS THE BASE CASE IS  1000.

RECORD
NUMBER                                  RECORD

       * GENERAL DESCRIPTIVE TITLE DESCRIBING THIS "EARLY" INPUT FILE
       *
    1  MIEANAM1001 'IN2A.INP, Sample Problem A of NUREG/CR-4691, Vol. 1, EARLY input'
    2  DCF_FILE001 'DOSDATA.INP'  (DCF file of MACCS 1.5.11.1)
       *
       *             ORGNAM         ORGFLG
       *
    3  MIORGDEF001  'A-SKIN'        .TRUE.
    4  MIORGDEF002  'A-RED MARR'    .TRUE.
    5  MIORGDEF003  'A-LUNGS'       .TRUE.
    6  MIORGDEF004  'A-THYROIDH'    .TRUE.
    7  MIORGDEF005  'A-STOMACH'     .TRUE.
    8  MIORGDEF006  'A-LOWER LI'    .FALSE.  (does not contribute to early fatalities)
    9  MIORGDEF007  'L-EDEWBODY'    .TRUE.
   10  MIORGDEF008  'L-RED MARR'    .TRUE.
   11  MIORGDEF009  'L-BONE SUR'    .TRUE.
```

```
12  MIORGDEF010  'L-BREAST'      .TRUE.
13  MIORGDEF011  'L-LUNGS'       .TRUE.
14  MIORGDEF012  'L-THYROID'     .TRUE.
15  MIORGDEF013  'L-LOWER LI'    .TRUE.
16  MIORGDEF014  'L-BLAD WAL'    .TRUE.
17  MIORGDEF015  'L-LIVER'       .FALSE.
18  MIORGDEF016  'L-THYROIDH'    .TRUE.
    *
    * FLAG TO INDICATE THAT THIS IS THE LAST PROGRAM IN THE SERIES TO BE RUN
    *
19  MIENDAT2001  .FALSE.    (SET THIS VALUE TO .TRUE. TO SKIP CHRONC)
    *
    * DISPERSION MODEL OPTION CODE:  1  *  STRAIGHT LINE
    *                                2  *  WIND-SHIFT WITH ROTATION
    *                                3  *  WIND-SHIFT WITHOUT ROTATION
    *
20  MIIPLUME001  2
    *
    * NUMBER OF FINE GRID SUBDIVISIONS USED BY THE MODEL
    *
21  MINUMFIN001  7    (3, 5 OR 7 ALLOWED)
    *
    * LEVEL OF DEBUG OUTPUT REQUIRED, NORMAL RUNS SHOULD SPECIFY ZERO
    *
22  MIIPRINT001  0
    *
    * LOGICAL FLAG SIGNIFYING THAT THE BREAKDOWN OF RISK BY WEATHER CATEGORY
    * BIN ARE TO BE PRESENTED TO SHOW THEIR RELATIVE CONTRIBUTION TO THE MEAN
    *
    *             RISBIN
    *
23  MIRISCAT001   .FALSE.
    *
    * FLAG INDICATING IF WIND-ROSES FROM ATMOS ARE TO BE OVERRIDDEN
    *
24  MIOVRRID001  .FALSE.  (USE THE WIND ROSE CALCULATED FOR EACH WEATHER BIN)
    ******************************************************************************
    * POPULATION DISTRIBUTION DATA BLOCK, LOADED BY INPOPU, STORED IN /POPDAT/
    *
25  PDPOPFLG001  FILE
    *
    *PDPOPFLG001  UNIFORM
    *PDIBEGIN001  1   (SPATIAL INTERVAL AT WHICH POPULATION BEGINS)
    *PDPOPDEN001  50. (POPULATION DENSITY (PEOPLE PER SQUARE KILOMETER))
    ******************************************************************************
    * SHIELDING AND EXPOSURE FACTORS, LOADED BY INDFAC, STORED IN /EADFAC/
    *
    * THREE VALUES OF EACH PROTECTION FACTOR ARE SUPPLIED,
    * ONE FOR EACH TYPE OF ACTIVTY:
    *
    * ACTIVITY TYPE:
    *     1 - EVACUEES WHILE MOVING
    *     2 - NORMAL ACTIVITY IN SHELTERING AND EVACUATION ZONE
    *     3 - SHELTERED ACTIVITY
    *
    * CLOUD SHIELDING FACTOR
    *
    *    SITE        GG   PB   SEQ  SUR  ZION
    *    SHELTERING  0.7  0.5  0.65 0.6  0.5
    *
    *            EVACUEES  NORMAL  SHELTER
    *
```

```
26  SECSFACT001      1.     0.75     0.6   *  SURRY SHELTERING VALUE
    *
    * PROTECTION FACTOR FOR INHALATION
    *
27  SEPROTIN001      1.     0.41      0.33  * VALUES FOR NORMAL ACTIVITY AND
    *                                          SHELTERING SELECTED BY NRC STAFF
    *
    * BREATHING RATE (CUBIC METERS PER SECOND)
    *
28  SEBRRATE001  2.66E-4  2.66E-4  2.66E-4
    *
    * SKIN PROTECTION FACTOR
    *
29  SESKPFAC001  1.0      0.41     0.33    * VALUES FOR NORMAL ACTIVITY AND
    *                                         SHELTERING SELECTED BY NRC STAFF
    *
    * GROUND SHIELDING FACTOR
    *
    *    SITE        GG   PB   SEQ  SUR  ZION
    *    SHELTERING  0.25 0.1  0.2  0.2  0.1
    *
30  SEGSHFAC001      0.5    0.33    0.2   * VALUE FOR NORMAL ACTIVITY SELECTED BY
    *                                        NRC STAFF
    *
    * RESUSPENSION INHALATION MODEL CONCENTRATION COEFFICIENT (/METER)
    *
    *   RESCON = 1.E-4 IS APPROPRIATE FOR MECHANICAL RESUSPENSION BY VEHICLES.
    *   RESHAF = 2.11 DAYS CAUSES 1.E-4 TO DECAY IN ONE WEEK TO 1.E-5, THE VALUE
    *   OF RESCON USED IN THE FIRST TERM OF THE LONG-TERM RESUSPENSION EQUATION
    *   USED IN CHRONC.
    *
31  SERESCON001   1.E-4     (RESUSPENSION IS TURNED ON)
    *
    * RESUSPENSION CONCENTRATION COEFFICIENT HALF-LIFE (SEC)
    *
32  SERESHAF001   1.82E5    (2.11 DAYS)
    ******************************************************************************
    * EVACUATION ZONE DATA BLOCK, LOADED BY EVNETW, STORED IN /NETWOR/, /EOPTIO/
    *
    * SPECIFIC DESCRIPTION OF THE EMERGENCY RESPONSE SCENARIO BEING USED
    *
33  EZEANAM2001  'EVACUATION WITHIN 10 MILES, RELOCATION MODELS APPLY ELSEWHERE'
    *
    * THE TYPE OF WEIGHTING TO BE APPLIED TO THE EMERGENCY RESPONSE SCENARIOS
    * YOU MUST SUPPLY A VALUE OF 'TIME' OR 'PEOPLE'
    *
34  EZWTNAME001  'PEOPLE'
    *
    * WEIGHTING FRACTION APPLICABLE TO THIS SCENARIO
    *
35  EZWTFRAC001  0.95
    *
    * LAST RING IN THE MOVEMENT ZONE
    *
36  EZLASMOV001     15    (EVACUEES DISAPPEAR AFTER TRAVELING TO 20 MILES)
    *
    *  Flag defining the time at which evacuees "enter" the destination element
    *
    *TRAVELPOINT   'CENTERPOINT' (new option implemented at MACCS2 v. 1.11f)
37  TRAVELPOINT   'BOUNDARY'    (functionality derived from MACCS circa 1984)
    *
    * RADIAL EVACUATION SPEED (M/S)
```

```
    *
38  EZESPEED001    1.8   1.8    1.8          (SURRY)
39  EZEVATYP001     'RADIAL'
40  EZDURBEG001    86400.0
41  EZDURMID001    0.0
42  EZREFPNT001     'ALARM'
43  EZNUMEVA001      12
44  EZDLTSHL001   7200.  7200.  7200.  7200.  7200.  7200.
45  EZDLTSHL002   7200.  7200.  7200.  7200.  7200.  7200.
46  EZDLTEVA001      0.     0.     0.     0.     0.     0.
47  EZDLTEVA002      0.     0.     0.     0.     0.     0.
    ********************************************************************
    * SHELTER AND RELOCATION ZONE DATA BLOCK, LOADED BY INPEMR,
    *                                         STORED IN /INPSRZ/, /RELOCA/
    *
    * DURATION OF THE EMERGENCY PHASE (SECONDS FROM PLUME ARRIVAL)
    *
48  SRENDEMP001  604800.   (ONE WEEK)
    *
    * CRITICAL ORGAN FOR RELOCATION DECISIONS
    *
49  SRCRIORG001 'L-EDEWBODY'
    *
    * HOT SPOT RELOCATION TIME (SECONDS FROM PLUME ARRIVAL)
    *
50  SRTIMHOT001  43200.    (ONE-HALF DAY)
    *
    * NORMAL RELOCATION TIME (SECONDS FROM PLUME ARRIVAL)
    *
51  SRTIMNRM001  86400.    (ONE DAY)
    *
    * HOT SPOT RELOCATION DOSE CRITERION THRESHOLD (SIEVERTS)
    *
52  SRDOSHOT001  0.5    (50 REM DOSE TO WHOLE BODY IN 1 WEEK TRIGGERS RELOCATION)
    *
    * NORMAL RELOCATION DOSE CRITERION THRESHOLD (SIEVERTS)
    *
53  SRDOSNRM001  0.25   (25 REM DOSE TO WHOLE BODY IN 1 WEEK TRIGGERS RELOCATION)
    ***************************************************************************
    * EARLY FATALITY MODEL PARAMETERS, LOADED BY INEFAT, STORED IN /EFATAL/
    *
    * NUMBER OF EARLY FATALITY EFFECTS
    *
54  EFNUMEFA001   2
    *
    *            ORGNAM       EFFACA   EFFACB   EFFTHR
    *
55  EFATAGRP001 'A-RED MARR'      3.8      5.0    1.5
56  EFATAGRP002 'A-LUNGS'        10.0      7.0    5.0
    ***************************************************************************
    * EARLY INJURY MODEL PARAMETERS, LOADED BY INEINJ, STORED IN /EINJUR/
    *
    * NUMBER OF EARLY INJURY EFFECTS
    *
57  EINUMEIN001  7
    *
    *            EINAME           ORGNAM   EISUSC EITHRE EIFACA EIFACB
    *
58  EINJUGRP001 'PRODROMAL VOMIT' 'A-STOMACH'  1.     .5     2.     3.
59  EINJUGRP002 'DIARRHEA'        'A-STOMACH'  1.     1.     3.     2.5
60  EINJUGRP003 'PNEUMONITIS'     'A-LUNGS'    1.     5.    10.     7.
61  EINJUGRP004 'SKIN ERYTHEMA'   'A-SKIN'     1.     3.     6.     5.
```

```
 62  EINJUGRP005 'TRANSEPIDERMAL'  'A-SKIN'     1.    10.    20.     5.
 63  EINJUGRP006 'THYROIDITIS'     'A-THYROIDH' 1.    40.   240.     2.
 64  EINJUGRP007 'HYPOTHYROIDISM'  'A-THYROIDH' 1.     2.    60.     1.3
     ***************************************************************************
     * ACUTE EXPOSURE CANCER PARAMETERS, LOADED BY INACAN STORED IN /ACANCR/.
     *
     * NUMBER OF ACUTE EXPOSURE CANCER EFFECTS
     *
 65  LCNUMACA001   7
     *
     * THRESHOLD DOSE FOR APPLYING THE DOSE DEPENDENT REDUCTION FACTOR
     *
 66  LCDDTHRE001   0.2  (LOWEST DOSE FOR WHICH DDREFA WILL BE APPLIED)
     *
     * DOSE THRESHOLD FOR LINEAR DOSE RESPONSE (Sv)
     *
 67  LCACTHRE001   0.0  (LINEAR-QUADRATIC MODEL IS NOT BEING USED)
     *
     *            ACNAME     ORGNAM  ACSUSC DOSEFA DOSEFB CFRISK   CIRISK  DDREFA
     *
 68  LCANCERS001 'LEUKEMIA' 'L-RED MARR'  1.0   1.0   0.0   9.70E-3   0.0     2.0
 69  LCANCERS002 'BONE'     'L-BONE SUR'  1.0   1.0   0.0   9.00E-4   0.0     2.0
 70  LCANCERS003 'BREAST'   'L-BREAST'    1.0   1.0   0.0   5.40E-3   1.7E-2  1.0
 71  LCANCERS004 'LUNG'     'L-LUNGS'     1.0   1.0   0.0   1.55E-2   0.0     2.0
 72  LCANCERS005 'THYROID'  'L-THYROIDH'  1.0   1.0   0.0   7.20E-4   7.2E-3  1.0
 73  LCANCERS006 'GI'       'L-LOWER LI'  1.0   1.0   0.0   3.36E-2   0.0     2.0
 74  LCANCERS007 'OTHER'    'L-EDEWBODY'  1.0   1.0   0.0   2.76E-2   0.0     2.0
     ***************************************************************************
     * RESULT 1 OPTIONS BLOCK, LOADED BY INOUT1, STORED IN /INOUT1/
     * TOTAL NUMBER OF A GIVEN EFFECT (LATENT CANCER, EARLY DEATH, EARLY INJURY)
     *
     * NUMBER OF DESIRED RESULTS OF THIS TYPE
     *
 75  TYPE1NUMBER    28
     *
 76  TYPE1OUT001    'ERL FAT/TOTAL'                1  26   NOCCDF (0 TO 1000 MILES)
 77  TYPE1OUT002    'ERL INJ/PRODROMAL VOMIT'      1  26   NOCCDF
 78  TYPE1OUT003    'ERL INJ/DIARRHEA'             1  26
 79  TYPE1OUT004    'ERL INJ/PNEUMONITIS'          1  26
 80  TYPE1OUT005    'ERL INJ/THYROIDITIS'          1  26
 81  TYPE1OUT006    'ERL INJ/HYPOTHYROIDISM'       1  26
 82  TYPE1OUT007    'ERL INJ/SKIN ERYTHEMA'        1  26
 83  TYPE1OUT008    'ERL INJ/TRANSEPIDERMAL'       1  26
 84  TYPE1OUT009    'CAN FAT/TOTAL'                1  26   NOCCDF
 85  TYPE1OUT010    'CAN FAT/LUNG'                 1  26
 86  TYPE1OUT011    'CAN FAT/THYROID'              1  26
 87  TYPE1OUT012    'CAN FAT/BREAST'               1  26
 88  TYPE1OUT013    'CAN FAT/GI'                   1  26
 89  TYPE1OUT014    'CAN FAT/LEUKEMIA'             1  26
 90  TYPE1OUT015    'CAN FAT/BONE'                 1  26
 91  TYPE1OUT016    'CAN FAT/OTHER'                1  26
 92  TYPE1OUT017    'CAN INJ/THYROID'              1  26
 93  TYPE1OUT018    'CAN INJ/BREAST'               1  26
 94  TYPE1OUT019    'CAN FAT/TOTAL'                1  19  CCDF  (0 TO 50 MILES)
 95  TYPE1OUT020    'ERL FAT/TOTAL'                1  12        (0 TO 10 MILES)
 96  TYPE1OUT021    'ERL INJ/PRODROMAL VOMIT'      1  12
 97  TYPE1OUT022    'ERL INJ/DIARRHEA'             1  12
 98  TYPE1OUT023    'ERL INJ/PNEUMONITIS'          1  12
 99  TYPE1OUT024    'ERL INJ/THYROIDITIS'          1  12
100  TYPE1OUT025    'ERL INJ/HYPOTHYROIDISM'       1  12
101  TYPE1OUT026    'ERL INJ/SKIN ERYTHEMA'        1  12
102  TYPE1OUT027    'ERL INJ/TRANSEPIDERMAL'       1  12
```

```
103  TYPE1OUT028    'CAN FAT/TOTAL'                1  12
     ******************************************************************************
     * RESULT 2 OPTIONS BLOCK, LOADED BY INOUT2, STORED IN /INOUT2/
     * FURTHEST DISTANCE AT WHICH A GIVEN RISK OF EARLY DEATH IS EXCEEDED.
     *
     * NUMBER OF DESIRED RESULTS OF THIS TYPE
     *
104  TYPE2NUMBER  1
     *
     *            FATALITY RISK THRESHOLD
     *
105  TYPE2OUT001  0.
     ******************************************************************************
     * RESULT 3 OPTIONS BLOCK, LOADED BY INOUT3, STORED IN /INOUT3/
     * NUMBER OF PEOPLE WHOSE DOSE TO A GIVEN ORGAN EXCEEDS A GIVEN THRESHOLD.
     *
     * NUMBER OF DESIRED RESULTS OF THIS TYPE
     *
106  TYPE3NUMBER  3
     *
     *               ORGAN NAME   DOSE THRESHOLD (Sv)
     *
107  TYPE3OUT001    'A-RED MARR'        1.5
108  TYPE3OUT002    'A-LUNGS'           5.0
109  TYPE3OUT003    'L-EDEWBODY'        0.05
     ******************************************************************************
     * RESULT 4 OPTIONS BLOCK, LOADED BY INOUT4, STORED IN /INOUT4/
     * 360 DEGREE AVERAGE RISK OF A GIVEN EFFECT AT A GIVEN DISTANCE.
     *
     * POSSIBLE TYPES OF EFFECTS ARE:
     *
     *   'ERL FAT/TOTAL'
     *   'ERL INJ/INJURY NAME'
     *   'CAN FAT/CANCER NAME'
     *   'CAN FAT/TOTAL'
     *
     * NUMBER OF DESIRED RESULTS OF THIS TYPE
     *
110  TYPE4NUMBER  5
     *
     *            RADIAL INDEX   TYPE OF EFFECT
     *
111  TYPE4OUT001       1         'ERL FAT/TOTAL'
112  TYPE4OUT002       2         'ERL FAT/TOTAL'
113  TYPE4OUT003       3         'ERL FAT/TOTAL'
114  TYPE4OUT004       4         'ERL FAT/TOTAL'
115  TYPE4OUT005       5         'ERL FAT/TOTAL'
     ******************************************************************************
     * RESULT 5 OPTIONS BLOCK, LOADED BY INOUT5, STORED IN /INOUT5/
     *
     * TOTAL POPULATION DOSE TO A GIVEN ORGAN BETWEEN TWO DISTANCES.
     *
     * NUMBER OF DESIRED RESULTS OF THIS TYPE
     *
116  TYPE5NUMBER     3
     *
     *             ORGAN      I1DIS5     I2DIS5
     *
117  TYPE5OUT001 'L-EDEWBODY'      1         12          (0-10 MILES)
118  TYPE5OUT002 'L-EDEWBODY'      1         19    NOCCDF  (0-50 MILES)
119  TYPE5OUT003 'L-EDEWBODY'      1         26    NOCCDF  (0-1000 MILES)
     ******************************************************************************
```

```
      * RESULT 6 OPTIONS BLOCK, LOADED BY INOUT6, STORED IN /INOUT6/
      *
      * CENTERLINE DOSE TO AN ORGAN VS DIST BY PATHWAY, PATHWAY NAMES ARE AS FOLLOWS:
      *
      *  PATHWAY NAME:
      *    'CLD'     - CLOUDSHINE
      *    'GRD'     - GROUNDSHINE
      *    'INH ACU' - "ACUTE DOSE EQUIVALENT" FROM DIRECT INHALATION OF THE CLOUD
      *    'INH LIF' - "LIFETIME DOSE COMMITMENT" FROM DIRECT INHALATION OF THE CLOUD
      *    'RES ACU' - "ACUTE DOSE EQUIVALENT" FROM RESUSPENSION INHALATION
      *    'RES LIF' - "LIFETIME DOSE COMMITMENT" FROM RESUSPENSION INHALATION
      *    'TOT ACU' - "ACUTE DOSE EQUIVALENT" FROM ALL PATHWAYS
      *    'TOT LIF' - "LIFETIME DOSE COMMITMENT" FROM ALL PATHWAYS
      *
      * NUMBER OF DESIRED RESULTS OF THIS TYPE
      *
  120 TYPE6NUMBER     0
      *
      *             ORGNAM        PATHNM      I1DIS6   I2DIS6
      *
      *TYPE6OUT001  'A-RED MARR'    'TOT ACU'      1       19     (0-50 MILES)
      *TYPE6OUT002  'A-LUNGS'       'TOT ACU'      1       19     (0-50 MILES)
      *TYPE6OUT003  'L-EDEWBODY'    'TOT LIF'      1       26     (0-1000 MILES)
      ******************************************************************************
      * RESULT 7 OPTIONS BLOCK, LOADED BY INOUT7, STORED IN /INOUT7/
      *
      * CENTERLINE RISK OF A GIVEN EFFECT VS DISTANCE
      *
      * NUMBER OF DESIRED RESULTS OF THIS TYPE
      *
  121 TYPE7NUMBER   0
      *
      *                    NAME           I1DIS7       I2DIS7
      *
      *TYPE7OUT001     'ERL FAT/TOTAL'        1           19       (0-50 MILES)
      *TYPE7OUT002     'CAN FAT/TOTAL'        1           26       (0-1000 MILES)
      ******************************************************************************
      * RESULT 8 OPTIONS BLOCK, LOADED BY INOUT8, STORED IN /INOUT8/
      *
      * POPULATION WEIGHTED FATALITY RISK BETWEEN 2 DISTANCES
      *
      * NUMBER OF DESIRED RESULTS OF THIS TYPE
      *
  122 TYPE8NUMBER   2
      *
      *                NAME       I1DIS8  I2DIS8
      *
  123 TYPE8OUT001 'ERL FAT/TOTAL'   1       5     NOCCDF  (0-EXCL ZONE + 1 MI)
  124 TYPE8OUT002 'CAN FAT/TOTAL'   1      12     NOCCDF  (0-10 MILES)
      ******************************************************************************
      * RESULT A OPTIONS BLOCK, LOADED BY INOUTA, STORED IN /INOUTA/
      *
      * peak dose to a given organ
      *
      *            NUMA
  125 TYPEANUMBER   1
      *
      *              ORGNAM    I1DISA  I2DISA
  126 TYPEAOUT001 'L-EDEWBODY'  1       26
      .
******** TERMINATOR RECORD ENCOUNTERED -- END OF BASE CASE USER INPUT ********
```

```
USER INPUT PROCESSING SUMMARY - BASE CASE

NUMBER OF RECORDS READ                          =  386
NUMBER OF BLANK OR COMMENT RECORDS READ         =  259
NUMBER OF TERMINATOR RECORDS                    =    1
NUMBER OF RECORDS PROCESSED                     =  126
     NUMBER OF PROCESSED RECORDS DUPLICATED     =    0
     NUMBER OF PROCESSED RECORDS SORTED         =  126
*******************************************************************************************


The list of defined organs is as follows (A- is ACUTE and L- is LIFETIME):
   A-SKIN
   A-RED MARR
   A-LUNGS
   A-THYROIDH
   A-STOMACH
   L-EDEWBODY
   L-RED MARR
   L-BONE SUR
   L-BREAST
   L-LUNGS
   L-THYROID
   L-LOWER LI
   L-BLAD WAL
   L-THYROIDH

READING FROM A DOSE CONVERSION FILE WITH THE FOLLOWING HEADER:
MACCS File DOSDATA.INP: Changed by D. CHANIN25-JUN-92, 09:53:47
Seven new organs added with MACCS Version 1.5.11.1


USING THE FOLLOWING SITE DATA FILE:

 MACCS SITE DATA FILE FOR SURRY (JLS, 11/10/88)
 SECPOP POP DISTRIBUTION FROM 1980 CENSUS DATA ALTERED USING 0-10 MI NRC DATA
  26 SPATIAL INTERVALS
  16 WIND DIRECTIONS
   7 CROP CATEGORIES
   4 WATER PATHWAY ISOTOPES
   2 WATERSHEDS
  59 ECONOMIC REGIONS
 SPATIAL DISTANCES
      0.16      0.52      1.21     1.61       2.13      3.22      4.02      4.83
      5.63      8.05     11.27    16.09      20.92     25.75     32.19     40.23
     48.28     64.37     80.47   112.65     160.93    241.14    321.87    563.27
   804.67    1609.34
 POPULATION
        0.        0.        0.        0.        0.        0.        4.        5.
        6.       25.     3341.     7107.     2173.        0.     1305.      474.
      2252.     2945.     5403.    20169.   112004.  3431358.  1355700.  2742710.
  2487346.   104331.
        0.        0.        0.        0.        1.        2.        9.       13.
       15.       63.     1667.     3550.     1330.     1072.     3198.     2425.
      515.     9469.     5317.     7120.    13586.   198785.  1058744. 20508438.
  3290082.   830354.
        0.        0.        0.        0.        0.        0.        5.        6.
        8.       31.      822.     1752.     4543.     1713.     1597.     2296.
     6535.     1775.        0.     8555.    48596.   119411.   233382.  3003954.
```

```
 7620063.  1169436.
       0.        0.        0.        0.        0.        0.        1.        1.
       2.       11.      543.     1157.     3820.     1621.     3364.        0.
       0.      129.     6679.    11858.        0.        0.        0.        0.
       0.        0.
       0.        0.        0.        0.        0.        0.        0.        0.
       0.        0.     4798.    10202.    10348.    10480.     9570.        0.
       0.     2317.     1756.        0.        0.        0.        0.        0.
       0.        0.
       0.        0.        0.        0.        0.        0.        1.        1.
       1.        7.     8316.    17684.    16340.    30419.    39474.    74998.
   24195.    80412.    57477.        0.        0.        0.        0.        0.
       0.        0.
       0.        0.        0.        0.        0.        0.        0.        0.
       0.        0.        0.        0.     1722.     6433.    36763.    20632.
  126203.   372471.    68327.     8599.     6339.     1057.        0.        0.
       0.        0.
       0.        0.        0.        0.        0.        0.        2.        2.
       3.       13.      127.      273.     1649.     4571.     3441.     7838.
   11747.    19019.     3360.    36387.    10447.    12402.        0.        0.
       0.        0.
       0.        0.        5.        4.        8.       23.       14.       20.
      23.       93.      301.      650.        0.        0.     1264.     4065.
    1106.    14665.     4071.    18006.    37417.    89072.    81626.        0.
       0.        0.
       0.        0.        0.        0.        0.        0.       19.       25.
      29.      117.       45.      105.        0.      510.      951.     1521.
    1223.    17636.     4926.    30765.    53265.   289674.   216165.   479431.
  280809.  8801784.
       0.        0.        0.        0.        1.        2.       14.       20.
      23.       93.      155.      338.      125.     1079.        0.     1355.
    2765.      154.     5296.    21409.    62228.   523803.   479588.  1538059.
 1526840.  3099458.
       0.        0.        0.        0.        1.        2.       14.       20.
      23.       93.      110.      240.     1056.        0.       50.     1396.
     915.     3153.     4132.    16295.    35596.   239712.   709522.  2845970.
 3957581. 10560254.
       0.        0.        0.        0.        0.        0.       25.       33.
      38.      154.       30.       70.      450.        0.      980.      517.
     155.    66531.    40902.     9557.    44818.   194801.   376828.  1492286.
 2250273. 12145932.
       0.        0.        0.        0.        0.        0.        7.        9.
      12.       47.       31.       69.        0.      380.      281.      445.
    1986.    32459.   183133.   193630.    30369.   203275.    94113.  1328987.
 5086913. 19537940.
       0.        0.        0.        0.        0.        0.        0.        0.
       0.        0.      223.      477.        0.     1026.      609.     2575.
    2794.     6593.    96857.   107328.    47585.   156826.   101785.  4175263.
 7535605.  9667977.
       0.        0.        0.        0.        0.        0.       15.       20.
      23.       92.     2503.     5326.     3508.     1826.     1884.      275.
    3965.     2084.     6270.    10765.   103787.   970659.   472558.  1396088.
 1969210.    73968.
LAND FRACTION
1.00 1.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.80 1.00 1.00 0.95 0.75 0.70 0.85
1.00 0.85 0.70 0.75 0.55 0.70 0.60 1.00 1.00 0.95
1.00 1.00 1.00 1.00 0.90 0.70 0.40 0.00 0.00 0.45 1.00 0.95 0.40 0.60 1.00 1.00
0.90 0.45 0.60 0.20 0.50 0.50 0.30 0.25 0.50 0.60
1.00 1.00 1.00 1.00 1.00 1.00 0.00 0.00 0.00 0.05 1.00 1.00 0.20 1.00 0.70 0.30
0.85 0.20 0.00 0.20 0.00 0.00 0.00 0.00 0.00 0.00
1.00 1.00 1.00 1.00 1.00 0.80 0.10 0.00 0.00 0.00 1.00 1.00 0.75 0.30 0.40 0.00
0.15 0.00 0.45 0.30 0.00 0.00 0.00 0.00 0.00 0.00
```

```
 1.00 1.00 1.00 1.00 1.00 0.60 0.00 0.00 0.00 0.00 0.95 1.00 1.00 0.70 0.40 0.10
 0.00 0.50 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
 1.00 1.00 1.00 1.00 1.00 0.70 0.00 0.00 0.00 0.80 0.90 0.75 0.85 1.00 1.00 0.70
 0.15 0.25 0.25 0.00 0.00 0.00 0.00 0.00 0.00 0.00
 1.00 1.00 1.00 1.00 1.00 1.00 0.55 0.50 0.25 0.15 0.00 0.10 0.00 0.10 0.50 0.60
 0.85 1.00 1.00 0.40 0.40 0.05 0.00 0.00 0.00 0.00
 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 0.90 0.35 0.40 0.80 1.00 1.00 1.00
 1.00 1.00 1.00 1.00 0.95 0.20 0.00 0.00 0.00 0.00
 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
 1.00 1.00 1.00 1.00 1.00 0.80 0.40 0.00 0.00 0.20
 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
 1.00 1.00 1.00 1.00 1.00 1.00 1.00 0.75 0.50 0.40
 1.00 1.00 0.70 0.40 0.20 0.75 0.95 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
 1.00 1.00 1.00 1.00 0.95 1.00 1.00 1.00 1.00 0.80
 1.00 1.00 0.00 0.00 0.00 0.00 0.05 0.70 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
 1.00 1.00 1.00 1.00 0.95 0.90 1.00 1.00 1.00 1.00
 1.00 1.00 0.00 0.00 0.00 0.00 0.00 0.15 0.70 0.90 1.00 1.00 1.00 1.00 1.00 1.00
 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
 1.00 1.00 0.00 0.00 0.00 0.00 0.00 0.00 0.20 0.50 0.40 0.30 0.25 0.75 0.80 0.85
 0.85 0.95 1.00 1.00 1.00 1.00 1.00 1.00 0.90 0.85
 1.00 1.00 0.00 0.00 0.00 0.00 0.00 0.15 0.80 0.75 0.80 0.85 0.95 1.00 1.00 1.00
 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 0.50 0.45
 1.00 1.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.90 1.00 1.00 1.00 1.00 1.00 1.00
 1.00 1.00 1.00 0.95 0.80 0.85 1.00 1.00 0.55 0.95
 REGION INDEX
444450505050505050444444444444444444444441818 7283054
4444444444444450504444444444444444444444418 728301917
444444444444450505044444444444444444444504418505050505 0
444444444444450505044444444444504450444450505050505 0
4444444444445050505044444444444450445050505050505050
4444444444445050505044444444444444444444505050505050
444444444444444444444504450444444444444444313150505050
4444444444444444444444444444444444444431313150505050
444444444444444444444444444444444444431313131315050 8
4444444444444444444444444444444444444444313131313 8 8
4444444444444444444444444444444444444444431313138 9 1
444450505050444444444444444444444444444444444444314040
4444505050505044444444444444444444444444444444444461511
444450505050505044444444444444444444444444444444444463347
4444505050505044444444444444444444444444444444444365320
444450505050505050444444444444444444444444441818363053
 WATERSHED INDEX
 1 1 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 2 2 2 2 1 1 2 1 1 1 1 1 1 2 2 2 2 2 2 1
 1 1 1 1 1 1 2 2 2 2 1 1 2 1 1 2 1 2 2 2 2 2 2 2 2 2
 1 1 1 1 1 1 2 2 2 2 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2
 1 1 1 1 1 1 2 2 2 2 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2
 1 1 1 1 1 1 2 2 2 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2
 1 1 1 1 1 1 2 2 2 2 2 2 2 2 1 1 1 1 2 2 2 2 2 2 2 2
 1 1 1 1 1 1 1 1 1 1 2 2 1 1 1 1 1 1 1 1 1 2 2 2 2 2
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2
 1 1 1 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 CROP SEASON AND SHARE
   1 PASTURE               90. 270.   0.41
   2 STORED FORAGE        150. 240.   0.13
   3 GRAINS               150. 240.   0.21
```

```
  4 GRN LEAFY VEGETABLES 150. 240.   0.002
  5 OTHER FOOD CROPS     150. 240.   0.004
  6 LEGUMES AND SEEDS    150. 240.   0.15
  7 ROOTS AND TUBERS     150. 240.   0.003
WATERSHED DEFINITION              1111111111222222222233333333334444444444
  1 Sr-89                             5.0E-6    0.0
  2 Sr-90                             5.0E-6    0.0
  3 Cs-134                            5.0E-6    0.0
  4 Cs-137                            5.0E-6    0.0
REGIONAL ECONOMIC DATA
  1 ALA             .354 .040      459.     1824.    62000.
  2 ARIZ            .516 .104      110.      682.    74000.
  3 ARK             .483 .041      466.     2049.    61000.
  4 CALIF           .330 .144     1022.     4394.    93000.
  5 COLO            .522 .048      211.      971.    83000.
  6 CONN            .160 .294     1605.     4980.   107000.
  7 DEL             .534 .042     1723.     3428.    82000.
  8 FLA             .375 .080      832.     3341.    80000.
  9 GA              .363 .060      613.     1885.    73000.
 10 IDAHO           .279 .144      343.     1562.    61000.
 11 ILL             .806 .044      709.     3900.    86000.
 12 IND             .713 .079      611.     3283.    72000.
 13 IOWA            .938 .060      695.     3133.    73000.
 14 KANS            .917 .035      281.     1204.    81000.
 15 KY              .571 .112      482.     1838.    61000.
 16 LA              .354 .074      459.     3284.    61000.
 17 MAINE           .079 .260      662.     1133.    70000.
 18 MD              .429 .216      956.     4489.    93000.
 19 MASS            .136 .249     1349.     2563.    97000.
 20 MICH            .313 .247      658.     2187.    81000.
 21 MINN            .597 .223      516.     2111.    82000.
 22 MISS            .470 .054      403.     2084.    53000.
 23 MO              .703 .102      322.     1647.    76000.
 24 MONT            .657 .030       61.      563.    65000.
 25 NEBR            .962 .031      318.     1148.    75000.
 26 NEV             .127 .139       63.      601.    84000.
 27 N.H.            .096 .482      518.     2018.    87000.
 28 N.J.            .203 .129     1399.     6477.   102000.
 29 N.MEX           .590 .144       53.      473.    63000.
 30 N.Y.            .310 .589      711.     1378.    94000.
 31 N.C.            .352 .065      860.     2658.    68000.
 32 N.DAK           .924 .048      164.      948.    69000.
 33 OHIO            .602 .175      581.     2686.    76000.
 34 OKLA            .751 .060      204.     1508.    67000.
 35 OREG            .292 .111      236.     1203.    73000.
 36 PA              .303 .447      855.     2534.    78000.
 37 R.I.            .108 .213     1062.     6438.    80000.
 38 S.C.            .290 .084      472.     1843.    62000.
 39 S.DAK           .915 .091      145.      587.    65000.
 40 TENN            .509 .153      360.     1850.    66000.
 41 TEX             .816 .064      164.     1492.    74000.
 42 UTAH            .225 .259      123.     1286.    60000.
 43 VT              .286 .789      628.     1472.    73000.
 44 VA              .382 .198      371.     2075.    84000.
 45 WASH            .377 .154      476.     1948.    82000.
 46 W.VA            .246 .224      150.     1728.    58000.
 47 WIS             .517 .591      723.     1751.    76000.
 48 WYO             .561 .028       43.      380.    70000.
 49 BRIT COL        .377 .154      476.     1948.    60000.
 50 OCEAN           .000 .000        0.        0.        0.
 51 SASKAT          .657 .030       61.      563.    60000.
 52 MANITOBA        .924 .048      164.      948.    60000.
```

```
  53 ONTARIO         .597 .223      516.     2111.    60000.
  54 QUEBEC          .310 .589      711.     1378.    60000.
  55 NOVA SCOT       .079 .260      662.     1133.    60000.
  56 BAJA CAL        .330 .144     1022.     4394.    10000.
  57 SONORA          .516 .104      110.      682.    10000.
  58 CHIHUAHUA       .590 .144       53.      473.    10000.
  59 COAHUILA        .816 .064      164.     1492.    10000.
 END
POPULATION

>>The Record Identifier TYPEBNUMBER was not found:
>>Type B results not being generated



******** BEGINNING OF CHANGE CASE   1 USER INPUT ********
       ****************************************************************************
       * EMERGENCY RESPONSE SCENARIO NUMBER 2
       ****************************************************************************
       * EVACUATION ZONE DATA BLOCK, LOADED BY EVNETW, STORED IN /NETWOR/, /EOPTIO/
       *
       * SPECIFIC DESCRIPTION OF THE EMERGENCY RESPONSE SCENARIO BEING USED
       *
  127  EZEANAM2001  'NO EVACUATION, RELOCATION MODELS APPLY EVERYWHERE'
********   RECORD NUMBER   127 REPLACES RECORD NUMBER    33   ********
       *
       * WEIGHTING FRACTION APPLICABLE TO THIS SCENARIO
       *
  128  EZWTFRAC001  0.05
********   RECORD NUMBER   128 REPLACES RECORD NUMBER    35   ********
       *
       * LAST RING IN THE MOVEMENT ZONE
       *
  129  EZLASMOV001     0   (A ZERO TURNS OFF THE EVACUATION MODEL)
********   RECORD NUMBER   129 REPLACES RECORD NUMBER    36   ********
       .
******** TERMINATOR RECORD ENCOUNTERED -- END OF CHANGE CASE   1 USER INPUT ********

USER INPUT PROCESSING SUMMARY - CHANGE CASE   1
NUMBER OF RECORDS CHANGED             =    3
NUMBER OF RECORDS ADDED               =    0
*****************************************************************************************


NO EVACUATION REQUESTED


USER INPUT IS READ FROM UNIT 26
RECORD IDENTIFIER FIELDS  11 CHARACTERS LONG ARE EXPECTED.
THE FIRST 100 COLUMNS OF EACH INPUT RECORD ARE PROCESSED.
THE MAXIMUM NUMBER OF IDENTIFIER RECORDS THAT MAY BE SAVED AS THE BASE CASE IS  1000.

RECORD
NUMBER                                  RECORD

       * GENERAL DESCRIPTIVE TITLE DESCRIBING THIS "CHRONC" INPUT FILE
       *
    1  CHCHNAME001 'IN3A_N.INP, Sample Problem A, "New" COMIDA2-Based Food Model'
       ****************************************************************************
       * EMERGENCY RESPONSE COST DATA BLOCK
       *
       * DAILY COST FOR A PERSON WHO IS EVACUATED (DOLLARS/PERSON-DAY)
```

```
    *
 2  CHEVACST001  27.00   (INCLUDES FOOD AND HOUSING COSTS BUT NOT LOST INCOME)
    *
    * DAILY COST FOR A PERSON WHO IS RELOCATED (DOLLARS/PERSON-DAY)
    *
 3  CHRELCST001  27.00   (INCLUDES FOOD AND HOUSING COSTS BUT NOT LOST INCOME)
    ******************************************************************************
    * LONG TERM PROTECTIVE ACTION DATA BLOCK
    *
    * Duration of the intermediate phase period--at version 1.11c TMIPND is no
    * longer processed.  The new input variable DUR_INTPHAS is the period's
    * duration, not the time after plume arrival at which the period ends.
    *
 4  DUR_INTPHAS   0.0    (in seconds)   (no intermediate phase)
    *
    * LONG-TERM PHASE DOSE PROJECTION PERIOD, THE DURATION OF THE EXPOSURE
    * PERIOD OVER WHICH THE LONG-TERM DOSE CRITERION IS EVALUATED (SECONDS)
    *
 5  CHTMPACT001   1.58E8             (5 YEARS)
    *
    * DOSE CRITERION FOR INTERMEDIATE PHASE RELOCATION (Sv)
    *
 6  CHDSCRTI001   1.0E5              (NO INTERMEDIATE PHASE RELOCATION)
    *
    * DOSE CRITERION FOR LONG-TERM PHASE RELOCATION (Sv)
    *
 7  CHDSCRLT001    0.04
    *
    * CRITICAL ORGAN NAME FOR LONG-TERM ACTIONS
    *
 8  CHCRTOCR001 'L-EDEWBODY'
    *
    * Long Term Exposure Period    Previously permanently set to:
    *    one million years = 3.15 E13 seconds
    *    MACCS2 allowable range is 3.15E7 to 1.E10
    *
 9  CHEXPTIM001    1.E10
    ******************************************************************************
    * DECONTAMINATION PLAN DATA BLOCK
    *
    * NUMBER OF LEVELS OF DECONTAMINATION
    *
10  CHLVLDEC001  2
    *
    * DECONTAMINATION TIMES CORRESPONDING TO THE LVLDEC LEVELS OF DECONTAMINATION
    *  (SECONDS)
    *
11  CHTIMDEC001   5.184E6  1.0368E7    (60, 120 DAYS)
    *
    * DOSE REDUCTION FACTORS CORRESPONDING TO THE LVLDEC LEVELS OF DECONTAMINATION
    *
12  CHDSRFCT001   3.      15.
    *
    * COST OF FARM DECONTAMINATION PER FARMLAND UNIT AREA (DOLLARS/HECTARE)
    *  FOR THE VARIOUS LEVELS OF DECONTAMINATION
    *
13  CHCDFRM0001   562.5   1250.
    *
    * COST OF NONFARM DECONTAMINATION PER RESIDENT PERSON (DOLLARS/PERSON)
    *  FOR THE VARIOUS LEVELS OF DECONTAMINATION
    *
14  CHCDNFRM001   3000.   8000.
```

```
    *
    * FRACTION OF FARMLAND DECONTAMINATION COST DUE TO LABOR
    *  FOR THE VARIOUS DECONTAMINATION LEVELS
    *
15  CHFRFDL0001  .3      .35
    *
    * FRACTION OF NON-FARM DECONTAMINATION COST DUE TO LABOR
    *  FOR THE VARIOUS DECONTAMINATION LEVELS
    *
16  CHFRNFDL001  .7      .5
    *
    * FRACTION OF TIME WORKERS IN FARM AREAS SPEND IN CONTAMINATED AREAS
    *  FOR THE VARIOUS DECONTAMINATION LEVELS
    *
17  CHTFWKF0001  .10     .33
    *
    * FRACTION OF TIME WORKERS IN NON-FARM AREAS SPEND IN CONTAMINATED AREAS
    *  FOR THE VARIOUS DECONTAMINATION LEVELS
    *
18  CHTFWKNF001  .33     .33
    *
    * AVERAGE COST OF DECONTAMINATION LABOR (DOLLARS/MAN-YEAR)
    *
19  CHDLBCST001   35000.
    ******************************************************************************
    * INTERDICTION COST DATA BLOCK
    *
    * DEPRECIATION (DETERIORATION) RATE DURING INTERDICTION PERIOD (PER YEAR)
    *
20  CHDPRATE001    .20   (VALUE OBTAINED FROM WASH-1400, APPENDIX 6)
    *
    * INVESTMENT INCOME RETURN (DISCOUNT RATE) DURING INTERDICTION PERIOD (PER YEAR)
    * THIS VALUE SHOULD BE DERIVED AS A REAL RETURN RATE ADJUSTED FOR INFLATION
    *
21  CHDSRATE001    .12   (VALUE OBTAINED FROM WASH-1400, APPENDIX 6)
    *
    * POPULATION RELOCATION COST (DOLLARS/PERSON):
    *  ALTERNATIVE HOUSING, MOVING COSTS, AND LOST INCOME FOR PEOPLE IN
    *  AREAS WHICH REQUIRE DECONTAMINATION, INTERDICTION, OR CONDEMNATION
    *
22  CHPOPCST001   5000.
    ******************************************************************************
    * GROUNDSHINE WEATHERING DEFINITION DATA BLOCK
    *
    * NUMBER OF TERMS IN THE GROUNDSHINE WEATHERING RELATIONSHIP (EITHER 1 OR 2)
    *
23  CHNGWTRM001   2
    *
    * GROUNDSHINE WEATHERING COEFFICIENTS
    *
24  CHGWCOEF001   0.5    0.5            (JON HELTON)
    *
    * HALF LIVES CORRESPONDING TO THE GROUNDSHINE WEATHERING COEFFICIENTS (S)
    *
25  CHTGWHLF001   1.6E7  2.8E9          (JON HELTON)
    ******************************************************************************
    * RESUSPENSION WEATHERING DEFINITION DATA BLOCK
    *
    * NUMBER OF TERMS IN THE RESUSPENSION WEATHERING RELATIONSHIP
    *
26  CHNRWTRM001    3
    *
```

```
    * RESUSPENSION CONCENTRATION COEFFICIENTS   (/ METER)
    *  RELATIONSHIP BETWEEN GROUND CONCENTRATION AND INSTANTANEOUS AIR CONC.
    *
27  CHRWCOEF001  1.0E-5   1.0E-7   1.0E-9  (VALUES HERE SELECTED BY JON HELTON)
    *
    * HALF-LIVES CORRESPONDING TO THE RESUSPENSION CONCENTRATION COEFFICIENTS (S)
    *
28  CHTRWHLF001  1.6E7    1.6E8    1.6E9   (6 MONTHS, 5 YEARS, 50 YEARS)
    ******************************************************************************
    * SITE REGION DESCRIPTION DATA BLOCK
    *
    * FRACTION OF AREA THAT IS LAND IN THE REGION
    *
29  CHFRACLD001   0.95   (ROUGH GUESS VALUE, SITE FILE OVERRIDES THIS VALUE)
    *
    * FRACTION OF LAND DEVOTED TO FARMING IN THE REGION
    *
30  CHFRCFRM001   0.382  (VIRGINIA STATE VALUE, SITE FILE OVERRIDES THIS VALUE)
    *
    * AVERAGE VALUE OF ANNUAL FARM PRODUCTION IN THE REGION (DOLLARS/HECTARE)
    *  (CASH RECEIPTS FROM FARMING PLUS VALUE OF HOME CONSUMPTION)/(LAND IN FARMS)
    *
31  CHFRMPRD001   371.0  (VIRGINIA STATE VALUE, SITE FILE OVERRIDES THIS VALUE)
    *
    * FRACTION OF FARM PRODUCTION RESULTING FROM DAIRY PRODUCTION IN THE REGION
    *  (VALUE OF MILK PRODUCED)/(CASH RECEIPTS FROM FARMING PLUS HOME CONSUMPTION)
    *
32  CHDPFRCT001   0.198  (VIRGINIA STATE VALUE, SITE FILE OVERRIDES THIS VALUE)
    *
    * VALUE OF FARM WEALTH (DOLLARS/HECTARE)
    *  (AVERAGE VALUE PER HECTARE OF FARM LAND AND BUILDINGS TO 100 MILES)
    *
33  CHVALWF0001   2613.  *  SURRY
    *
    * FRACTION OF FARM WEALTH IN IMPROVEMENTS FOR THE REGION
    *
34  CHFRFIM0001   0.25  *  SURRY
    *
    * NON-FARM WEALTH, PROPERTY AND IMPROVEMENTS FOR THE REGION (DOLLARS/PERSON)
    *  THE VALUE OF ALL RESIDENTIAL, BUSINESS, AND PUBLIC ASSETS WHICH WOULD BE
    *  LOST IN THE EVENT OF PERMANENT INTERDICTION (CONDEMNATION) OF THE AREA
    *
35  CHVALWNF001   84000.  *  SURRY
    *
    * FRACTION OF NON-FARM WEALTH IN IMPROVEMENTS FOR THE REGION
    *
36  CHFRNFIM001   0.8
    ***************************************************************************
37  CHFDPATH001 'NEW'
    *
    * name of the COMIDA2 binary output file
    *
38  BIN_FILE001 'C:\COMIDA2A\SAMP_A.BIN'   (revised data file of 8/12/95)
    *
    * Dose limits triggering first year crop disposal of the separate
    * milk and non-milk components of the diet, corresponding in purpose,
    * more or less, to the MACCS 1.5 input variables PSCMLK and PSCOTH
    *
    * For NUREG-1150 calculations, the maximum allowable ground concentrations for
    * production of milk and non-milk crops contaminated by an accident occurring
    * in the growing season were derived based on an assumed maximum allowable
    * dose of 5 rem effective or 15 rem thyroid, per the 1982 FDA guidance that's
```

```
    * reprinted in the 1992 EPA PAG Manual.  For purposes of comparison against
    * the prior results, it is being assumed, for simplicity, that milk and
    * non-milk crops contribute equally to the first year dose.  Thus, the 5 rem
    * effective dose limit used in NUREG-1150 is equally split between milk and
    * non-milk crops, with 2.5 rem allowed for each.  Similarly, the 15 rem
    * thyroid limit is split into 7.5 and 7.5 rem for the milk and non-milk
    * portions of the diet.
    *
    *             effective     thyroid  (doses in sieverts)
39  DOSEMILK001    0.025          0.075
40  DOSEOTHR001    0.025          0.075
    *
    * Annual dose limits for the subsequent year's (i.e., after the first year)
    * interdiction of BOTH the milk and non-milk (combined) components of the diet
    *
    * Note: the long-term food critera, GCMAXR, used for NUREG-1150 wre based on
    * an ingestion dose integrated from zero to infinity.  It is not possible to
    * translate those parameter values into corresponding annual dose limits, as is
    * required by the COMIDA2-based food model.  The "total" dose limits used in
    * NUREG-1150 for "root uptake", 0.5 rem effective and 1.5 rem thyroid, are used
    * here as annual dose limits for interdiction of food production in years the
    * years subsequent to the accident.
    *
    *             effective     thyroid  (doses in sieverts)
41  DOSELONG001    0.005          0.015
    *
    * NUMBER OF NUCLIDES IN THE WATER INGESTION PATHWAY MODEL
    *
42  CHNUMWPI001    4
    *
    * TABLE OF NUCLIDE DEFINITIONS IN THE WATER INGESTION PATHWAY MODEL
    *
    * IF A SITE DATA FILE IS DEFINED, THE DATA DEFINING THE WATERSHED INGESTION
    *  FACTOR IS SUPERSEDED BY THE CORRESPONDING DATA IN THE SITE DATA FILE
    *
    *                        INITIAL     ANNUAL    INGESTION FACTOR
    *             WATER      WASHOFF     WASHOFF    ((Bq INGESTED)/
    *            NUCLIDE     FRACTION     RATE       (Bq IN WATER))
    *
    *             NAMWPI      WSHFRI      WSHRTA         WINGF
43  CHWTRISO001   Sr-89        0.01       0.004          5.0E-6
44  CHWTRISO002   Sr-90        0.01       0.004          5.0E-6
45  CHWTRISO003   Cs-134       0.005      0.001          5.0E-6
46  CHWTRISO004   Cs-137       0.005      0.001          5.0E-6
    ******************************************************************************
    * SPECIAL OPTIONS DATA BLOCK
    *
    * DETAILED PRINT OPTION CONTROL SWITCHES, LOOK AT THE CODE BEFORE TURNING ON!!
    *          KSWDSC
    *
47  CHKSWTCH001   0
    ******************************************************************************
    * DEFINE THE TYPE 9 RESULTS
    *
    * LONG-TERM POPULATION DOSE IN A GIVEN REGION BROKEN DOWN BY THE 12 PATHWAYS
    *
    * NUMBER OF RESULTS OF THIS TYPE THAT ARE BEING REQUESTED
    * FOR EACH RESULT YOU REQUEST, THE CODE WILL PRODUCE A SET OF 12
    *
48  TYPE9NUMBER   2      (UP TO 10 ALLOWED)
    *
    *              ORGNAM        INNER      OUTER
```

```
    *
49  TYPE9OUT001   'L-EDEWBODY'       1          26    (0-1000 MILES)
50  TYPE9OUT002   'L-EDEWBODY'       1          19    (0-50 MILES)
    ******************************************************************************
    * ECONOMIC COST RESULTS IN A REGION BROKEN DOWN BY 12 TYPES OF COSTS
    *
    * NUMBER OF RESULTS OF THIS TYPE THAT ARE BEING REQUESTED
    * FOR EACH RESULT YOU REQUEST, THE CODE WILL PRODUCE A SET OF 12
    *
51  TYP10NUMBER   2      (UP TO 10 ALLOWED)
    *
    *              INNER      OUTER
    *
52  TYP10OUT001      1          26    (0-1000 MILES)
53  TYP10OUT002      1          19    (0-50 MILES)
    ******************************************************************************
    * DEFINE A FLAG THAT CONTROLS THE PRODUCTION OF THE ACTION DISTANCE RESULTS
    *
    * SPECIFYING A VALUE OF .TRUE. TURNS ON ALL 8 OF THE ACTION DISTANCE RESULTS,
    * A VALUE OF .FALSE. WILL ELIMINATE THE ACTION DISTANCE RESULTS FROM THE OUTPUT.
    *
54  TYP11FLAG11  .TRUE.
    ******************************************************************************
    * IMPACTED AREA/POPULATION RESULTS IN A REGION BROKEN DOWN BY 6 TYPES OF IMPACTS
    *
    * NUMBER OF RESULTS OF THIS TYPE THAT ARE BEING REQUESTED
    * FOR EACH RESULT YOU REQUEST, THE CODE WILL PRODUCE A SET OF 8
    *
55  TYP12NUMBER   2      (UP TO 10 ALLOWED)
    *
    *              INNER      OUTER
    *
56  TYP12OUT001      1          26    (0-1000 MILES)
57  TYP12OUT002      1          19    (0-50 MILES)
    ******************************************************************************
    * Maximal annual food ingestion dose to an individual, requested by IXOT13
    *
    * This result is calculated after accounting for temporary or
    * permanent interdiction.  It is only available for the "new" food model.
    *
    * NUMBER OF RESULTS OF THIS TYPE THAT ARE BEING REQUESTED
    *
58  TYP13NUMBER   20   (UP TO 10 ALLOWED)
    *
    * IRAD13 is the radial spatial interval at which results are requested
    *
    * ORGN13 is the name of the organ for which results are requested
    *  (allowable values for ORGN13 are 'EFFECTIVE' or 'THYROID')
    *
    *          IRAD13   ORGN13
    *
59  TYP13OUT001   2    EFFECTIVE
60  TYP13OUT002   4    EFFECTIVE
61  TYP13OUT003   6    EFFECTIVE
62  TYP13OUT004   8    EFFECTIVE
63  TYP13OUT005  10    EFFECTIVE
64  TYP13OUT006  12    EFFECTIVE
65  TYP13OUT007  14    EFFECTIVE
66  TYP13OUT008  16    EFFECTIVE
67  TYP13OUT009  18    EFFECTIVE
68  TYP13OUT010  20    EFFECTIVE
69  TYP13OUT011   2    THYROID
```

```
   70  TYP13OUT012   4    THYROID
   71  TYP13OUT013   6    THYROID
   72  TYP13OUT014   8    THYROID
   73  TYP13OUT015  10    THYROID
   74  TYP13OUT016  12    THYROID
   75  TYP13OUT017  14    THYROID
   76  TYP13OUT018  16    THYROID
   77  TYP13OUT019  18    THYROID
   78  TYP13OUT020  20    THYROID
        .
******** TERMINATOR RECORD ENCOUNTERED -- END OF BASE CASE USER INPUT ********


USER INPUT PROCESSING SUMMARY - BASE CASE

NUMBER OF RECORDS READ                          =  327
NUMBER OF BLANK OR COMMENT RECORDS READ         =  248
NUMBER OF TERMINATOR RECORDS                    =    1
NUMBER OF RECORDS PROCESSED                     =   78
     NUMBER OF PROCESSED RECORDS DUPLICATED     =    0
     NUMBER OF PROCESSED RECORDS SORTED         =   78
*****************************************************************************************


COMIDA2 binary file header =
COMIDA2 12/17/95   11:50:38   Beta-Test Ver. 1.11, 12/17/95: allow for HTO input
COMIDA2 descriptive title  =
MACCS File DOSDATA.INP: Changed by D. CHANIN25-JUN-92, 09:53:47
Seven new organs added with MACCS Version 1.5.11.1

A SITE DATA FILE IS BEING USED FOR BOTH "EARLY" AND "CHRONC"

 7 CANCER EFFECTS ARE DEFINED IN THE MODEL.
    INDEX  CANCER EFFECT                 ORGAN       ALPHA       BETA     CFRISK     CIRISK
       1                       LEUKEMIA     L-RED MARR   1.000E+00  0.000E+00  9.700E-03  0.000E+00
       2                       BONE         L-BONE SUR   1.000E+00  0.000E+00  9.000E-04  0.000E+00
       3                       BREAST       L-BREAST     1.000E+00  0.000E+00  5.400E-03  1.700E-02
       4                       LUNG         L-LUNGS      1.000E+00  0.000E+00  1.550E-02  0.000E+00
       5                       THYROID      L-THYROIDH   1.000E+00  0.000E+00  7.200E-04  7.200E-03
       6                       GI           L-LOWER LI   1.000E+00  0.000E+00  3.360E-02  0.000E+00
       7                       OTHER        L-EDEWBODY   1.000E+00  0.000E+00  2.760E-02  0.000E+00

  TIME OF HOTSPOT RELOCATION IS 4.3200E+04.
  TIME OF NORMAL RETURN IS  8.640E+04 AND THE EMERGENCY PHASE ENDS AT  6.048E+05.


GROUNDSHINE SHIELDING FACTOR   = 0.330

RESUSPENSION PROTECTION FACTOR = 0.410

BREATHING RATE (CUBIC M/S) =   2.660E-04

  DISPERSION MODEL FLAG IS  2

 WINDROSE PROBABILITIES BY WIND DIRECTION AND MET BIN NUMBER
 BIN     1      2      3      4      5      6      7      8      9     10     11     12     13     14     15     16
    1 0.0324 0.0408 0.0366 0.0293 0.0773 0.0878 0.0805 0.0554 0.0596 0.0460 0.0387 0.0690 0.0888 0.0899 0.1296 0.0387
    2 0.0085 0.0751 0.1216 0.0803 0.0423 0.0930 0.0877 0.0941 0.0941 0.0666 0.0529 0.0909 0.0655 0.0106 0.0127 0.0042
    3 0.0581 0.0930 0.0465 0.0465 0.1163 0.0465 0.0233 0.0581 0.0814 0.0465 0.0465 0.0349 0.0465 0.0698 0.1279 0.0581
    4 0.0350 0.0402 0.0542 0.0629 0.0524 0.0804 0.0524 0.0717 0.0699 0.0717 0.0752 0.0594 0.0839 0.0962 0.0524 0.0420
    5 0.0147 0.0625 0.0662 0.0368 0.0588 0.0662 0.0570 0.0625 0.0827 0.0827 0.1305 0.0790 0.1140 0.0496 0.0313 0.0055
    6 0.0106 0.0881 0.1033 0.0745 0.0365 0.0198 0.0304 0.1489 0.1201 0.1094 0.0927 0.0942 0.0562 0.0030 0.0076 0.0046
```

```
    7 0.0138 0.1103 0.0759 0.0759 0.0345 0.0207 0.0828 0.2414 0.1448 0.0276 0.0828 0.0621 0.0276 0.0000 0.0000 0.0000
    8 0.0000 0.3636 0.0000 0.0000 0.0909 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.5455 0.0000 0.0000 0.0000 0.0000
    9 0.1014 0.0811 0.0541 0.0405 0.1081 0.0405 0.0405 0.0405 0.0203 0.0338 0.0338 0.0541 0.0541 0.0946 0.0946 0.1081
   10 0.0599 0.0629 0.0629 0.0629 0.0808 0.0584 0.0374 0.0284 0.0569 0.0689 0.0464 0.0314 0.1003 0.1557 0.0479 0.0389
   11 0.0633 0.1346 0.0805 0.0567 0.0356 0.0356 0.0396 0.0778 0.1346 0.0765 0.0897 0.0185 0.0633 0.0528 0.0145 0.0264
   12 0.0551 0.2404 0.1302 0.0885 0.0518 0.0367 0.0651 0.1202 0.0735 0.0518 0.0351 0.0200 0.0134 0.0017 0.0100 0.0067
   13 0.1382 0.1008 0.0711 0.0388 0.0413 0.0491 0.0556 0.0388 0.0375 0.0284 0.0181 0.0310 0.0271 0.0788 0.0904 0.1550
   14 0.1634 0.1489 0.0646 0.0711 0.0685 0.0487 0.0580 0.0461 0.0817 0.0343 0.0132 0.0132 0.0079 0.0224 0.0527 0.1054
   15 0.2069 0.2897 0.1241 0.1034 0.0759 0.0690 0.0069 0.0138 0.0276 0.0069 0.0069 0.0138 0.0000 0.0069 0.0069 0.0414
   16 0.1667 0.3333 0.1667 0.0000 0.0833 0.0000 0.0000 0.1667 0.0833 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
   17 0.1033 0.0409 0.0450 0.0235 0.0307 0.0501 0.0593 0.0654 0.0511 0.0399 0.0573 0.0910 0.1237 0.0470 0.0838 0.0879
   18 0.1033 0.0409 0.0450 0.0235 0.0307 0.0501 0.0593 0.0654 0.0511 0.0399 0.0573 0.0910 0.1237 0.0470 0.0838 0.0879
   19 0.1033 0.0409 0.0450 0.0235 0.0307 0.0501 0.0593 0.0654 0.0511 0.0399 0.0573 0.0910 0.1237 0.0470 0.0838 0.0879
   20 0.1033 0.0409 0.0450 0.0235 0.0307 0.0501 0.0593 0.0654 0.0511 0.0399 0.0573 0.0910 0.1237 0.0470 0.0838 0.0879
   21 0.1033 0.0409 0.0450 0.0235 0.0307 0.0501 0.0593 0.0654 0.0511 0.0399 0.0573 0.0910 0.1237 0.0470 0.0838 0.0879
   22 0.1033 0.0409 0.0450 0.0235 0.0307 0.0501 0.0593 0.0654 0.0511 0.0399 0.0573 0.0910 0.1237 0.0470 0.0838 0.0879
   23 0.1033 0.0409 0.0450 0.0235 0.0307 0.0501 0.0593 0.0654 0.0511 0.0399 0.0573 0.0910 0.1237 0.0470 0.0838 0.0879
   24 0.1033 0.0409 0.0450 0.0235 0.0307 0.0501 0.0593 0.0654 0.0511 0.0399 0.0573 0.0910 0.1237 0.0470 0.0838 0.0879
   25 0.1033 0.0409 0.0450 0.0235 0.0307 0.0501 0.0593 0.0654 0.0511 0.0399 0.0573 0.0910 0.1237 0.0470 0.0838 0.0879
   26 0.1033 0.0409 0.0450 0.0235 0.0307 0.0501 0.0593 0.0654 0.0511 0.0399 0.0573 0.0910 0.1237 0.0470 0.0838 0.0879
   27 0.1033 0.0409 0.0450 0.0235 0.0307 0.0501 0.0593 0.0654 0.0511 0.0399 0.0573 0.0910 0.1237 0.0470 0.0838 0.0879
   28 0.1033 0.0409 0.0450 0.0235 0.0307 0.0501 0.0593 0.0654 0.0511 0.0399 0.0573 0.0910 0.1237 0.0470 0.0838 0.0879
   29 0.1033 0.0409 0.0450 0.0235 0.0307 0.0501 0.0593 0.0654 0.0511 0.0399 0.0573 0.0910 0.1237 0.0470 0.0838 0.0879
   30 0.1033 0.0409 0.0450 0.0235 0.0307 0.0501 0.0593 0.0654 0.0511 0.0399 0.0573 0.0910 0.1237 0.0470 0.0838 0.0879
   31 0.1033 0.0409 0.0450 0.0235 0.0307 0.0501 0.0593 0.0654 0.0511 0.0399 0.0573 0.0910 0.1237 0.0470 0.0838 0.0879
   32 0.1033 0.0409 0.0450 0.0235 0.0307 0.0501 0.0593 0.0654 0.0511 0.0399 0.0573 0.0910 0.1237 0.0470 0.0838 0.0879
   33 0.1033 0.0409 0.0450 0.0235 0.0307 0.0501 0.0593 0.0654 0.0511 0.0399 0.0573 0.0910 0.1237 0.0470 0.0838 0.0879
   34 0.1033 0.0409 0.0450 0.0235 0.0307 0.0501 0.0593 0.0654 0.0511 0.0399 0.0573 0.0910 0.1237 0.0470 0.0838 0.0879
   35 0.1033 0.0409 0.0450 0.0235 0.0307 0.0501 0.0593 0.0654 0.0511 0.0399 0.0573 0.0910 0.1237 0.0470 0.0838 0.0879
   36 0.1033 0.0409 0.0450 0.0235 0.0307 0.0501 0.0593 0.0654 0.0511 0.0399 0.0573 0.0910 0.1237 0.0470 0.0838 0.0879
   37 0.0663 0.0947 0.0750 0.0559 0.0537 0.0573 0.0572 0.0735 0.0766 0.0572 0.0553 0.0558 0.0663 0.0537 0.0519 0.0495
   38 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
   39 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
   40 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
   41 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000


Processing a Site Data File with Header:  MACCS SITE DATA FILE FOR SURRY (JLS, 11/10/88)
  SECPOP POP DISTRIBUTION FROM 1980 CENSUS DATA ALTERED USING 0-10 MI NRC DATA

 THIS PROGRAM CURRENTLY ALLOWS THE GENERATION OF UP TO  394 RESULTS

YOU HAVE REQUESTED  68 RESULTS FROM "EARLY" COMPOSED OF:

  28 RESULTS OF TYPE 1
   1 RESULTS OF TYPE 2
   3 RESULTS OF TYPE 3
   5 RESULTS OF TYPE 4
   3 RESULTS OF TYPE 5
   0 RESULTS OF TYPE 6
   0 RESULTS OF TYPE 7
   2 RESULTS OF TYPE 8
  26 RESULTS OF TYPE A
   0 RESULTS OF TYPE B

YOU HAVE REQUESTED  104 RESULTS FROM "CHRONC" COMPOSED OF:

  34 RESULTS OF TYPE 9
  26 RESULTS OF TYPE 10
   8 RESULTS OF TYPE 11
  16 RESULTS OF TYPE 12
  20 RESULTS OF TYPE 13
```

TRIAL	DAY	HOUR	BIN	PRBMET
1	153	15	24	4.57E-04
2	157	10	1	2.73E-02
3	163	14	21	3.62E-03
4	166	7	9	4.22E-03
5	167	17	2	2.70E-02
6	168	4	12	1.71E-02
7	171	7	6	1.88E-02
8	171	13	36	2.28E-04
9	171	15	35	4.00E-04
10	171	16	32	5.42E-04
11	179	24	31	2.00E-04
12	180	2	30	1.43E-04
13	180	23	10	1.91E-02
14	181	15	25	6.85E-04
15	188	8	4	1.63E-02
16	193	3	18	1.17E-03
17	195	22	15	4.14E-03
18	200	14	36	2.28E-04
19	201	21	34	1.43E-04
20	203	6	31	2.00E-04
21	203	8	31	2.00E-04
22	203	9	31	2.00E-04
23	203	10	30	1.43E-04
24	203	11	29	1.14E-04
25	204	9	36	2.28E-04
26	204	11	35	4.00E-04
27	204	12	34	1.43E-04
28	204	14	32	5.42E-04
29	205	24	11	2.16E-02
30	215	18	3	2.45E-03
31	220	5	5	1.55E-02
32	222	21	16	3.42E-04
33	224	4	27	4.85E-04
34	228	5	13	2.21E-02
35	229	24	7	4.14E-03
36	231	2	20	3.77E-03
37	232	14	30	1.43E-04
38	232	16	22	2.11E-03
39	232	22	35	4.00E-04
40	232	23	34	1.43E-04
41	235	19	14	2.17E-02
42	240	3	26	7.71E-04
43	244	21	19	2.94E-03
44	248	20	9	4.22E-03
45	250	22	26	7.71E-04
46	251	2	25	6.85E-04
47	253	2	13	2.21E-02
48	263	16	17	1.00E-02
49	268	8	4	1.63E-02
50	270	3	14	2.17E-02

TRIAL	DAY	HOUR	BIN	PRBMET
51	271	20	10	1.91E-02
52	272	10	1	2.73E-02
53	282	6	18	1.17E-03
54	286	22	24	4.57E-04
55	288	10	2	2.70E-02
56	299	10	32	5.42E-04

57	299	11	27	4.85E-04
58	301	2	11	2.16E-02
59	301	15	5	1.55E-02
60	307	5	6	1.88E-02
61	309	11	21	3.62E-03
62	309	14	19	2.94E-03
63	309	20	9	4.22E-03
64	311	18	3	2.45E-03
65	315	21	20	3.77E-03
66	319	5	10	1.91E-02
67	321	9	4	1.63E-02
68	330	9	19	2.94E-03
69	330	10	18	1.17E-03
70	330	18	36	2.28E-04
71	335	23	8	3.14E-04
72	335	24	8	3.14E-04
73	336	7	22	2.11E-03
74	336	21	23	1.14E-04
75	342	16	3	2.45E-03
76	346	13	1	2.73E-02
77	347	22	11	2.16E-02
78	348	9	9	4.22E-03
79	357	21	17	1.00E-02
80	358	12	22	2.11E-03
81	358	14	27	4.85E-04
82	358	17	32	5.42E-04
83	365	16	3	2.45E-03
84	8	16	5	1.55E-02
85	9	6	15	4.14E-03
86	12	23	12	1.71E-02
87	12	24	16	3.42E-04
88	13	5	14	2.17E-02
89	15	10	2	2.70E-02
90	23	9	7	4.14E-03
91	25	6	20	3.77E-03
92	25	10	18	1.17E-03
93	29	14	17	1.00E-02
94	32	5	13	2.21E-02
95	37	18	8	3.14E-04
96	47	11	4	1.63E-02
97	48	2	16	3.42E-04
98	49	10	26	7.71E-04
99	50	18	24	4.57E-04
100	51	19	5	1.55E-02

TRIAL	DAY	HOUR	BIN	PRBMET
101	53	1	6	1.88E-02
102	53	13	21	3.62E-03
103	57	22	17	1.00E-02
104	59	20	13	2.21E-02
105	65	14	7	4.14E-03
106	69	2	12	1.71E-02
107	71	24	25	6.85E-04
108	72	3	25	6.85E-04
109	72	4	23	1.14E-04
110	72	14	20	3.77E-03
111	74	20	23	1.14E-04
112	78	9	8	3.14E-04
113	83	17	6	1.88E-02
114	84	19	10	1.91E-02
115	85	2	14	2.17E-02

116	87	21	15	4.14E-03
117	101	4	16	3.42E-04
118	107	14	19	2.94E-03
119	107	20	21	3.62E-03
120	112	22	7	4.14E-03
121	115	13	2	2.70E-02
122	122	19	11	2.16E-02
123	124	23	15	4.14E-03
124	125	6	12	1.71E-02
125	127	18	26	7.71E-04
126	133	24	24	4.57E-04
127	134	1	22	2.11E-03
128	139	22	35	4.00E-04
129	139	23	34	1.43E-04
130	139	24	33	1.14E-04
131	140	2	30	1.43E-04
132	140	3	29	1.14E-04
133	140	7	27	4.85E-04
134	140	19	29	1.14E-04
135	151	9	1	2.73E-02

DATE AND TIME OF RUN = MACCS2 09/26/96 08:40:08 Version 1.12, Last Modified 9/25/96 by D. Chanin
"ATMOS" DESCRIPTION = IN1A.INP, Sample Problem A--Using Table-Lookup Sigmas, ATMOS input

	PROB NON-ZERO	MEAN	QUANTILES 50TH	90TH	95TH	99TH	99.5TH	PEAK CONS	PEAK PROB	PEAK TRIAL
Source Term 1: Plume 1, at 4.8-5.6 km										
Cs-137 Center Air Conc. (Bq-s/m3)	1.0000	4.07E+11	2.40E+11	1.07E+12	1.49E+12	2.09E+12	2.16E+12	2.35E+12	7.71E-04	45
Cs-137 Ground Air Conc. (Bq-s/m3)	1.0000	3.63E+11	2.16E+11	1.02E+12	1.10E+12	1.30E+12	1.41E+12	1.72E+12	7.71E-04	45
Cs-137 Center Ground Conc. (Bq/m2)	0.9872	3.89E+09	2.31E+09	1.03E+10	1.12E+10	1.35E+10	1.47E+10	3.04E+10	1.14E-04	130
Total Center Ground Conc. (Bq/m2)	0.9872	3.69E+11	2.37E+11	9.30E+11	1.07E+12	1.31E+12	1.43E+12	2.90E+12	1.14E-04	130
Ground-Level Dilution, X/Q (s/m3)	1.0000	4.49E-06	2.42E-06	1.27E-05	1.61E-05	NOT-FOUND	NOT-FOUND	2.36E-05	2.21E-02	34
Cs-137 Adjusted Source, Q (Bq)	1.0000	9.21E+16	8.81E+16	1.03E+17	1.04E+17	1.07E+17	1.09E+17	1.11E+17	2.45E-03	75
Plume Sigma-y (m)	1.0000	4.96E+02	3.92E+02	NOT-FOUND	NOT-FOUND	NOT-FOUND	NOT-FOUND	1.04E+03	1.81E-01	2
Plume Sigma-z (m)	1.0000	2.66E+02	1.09E+02	7.33E+02	8.06E+02	NOT-FOUND	NOT-FOUND	2.40E+03	1.06E-02	28
Plume Height (m)	0.4148	1.24E+02	0.00E+00	7.06E+02	8.84E+02	1.02E+03	1.04E+03	1.11E+03	2.00E-04	21
Plume Arrival Time (s)	1.0000	6.86E+03	6.06E+03	9.90E+03	1.08E+04	1.30E+04	1.41E+04	1.42E+04	4.94E-03	36
Source Term 1: Plume 1, at 5.6-8.1 km										
Cs-137 Center Air Conc. (Bq-s/m3)	1.0000	2.51E+11	1.37E+11	6.76E+11	9.86E+11	NOT-FOUND	NOT-FOUND	1.26E+12	2.21E-02	47
Cs-137 Ground Air Conc. (Bq-s/m3)	1.0000	2.46E+11	1.25E+11	7.73E+11	9.66E+11	NOT-FOUND	NOT-FOUND	1.12E+12	2.21E-02	47
Cs-137 Center Ground Conc. (Bq/m2)	0.9975	2.61E+09	1.40E+09	7.76E+09	9.72E+09	1.14E+10	1.21E+10	1.63E+10	1.43E-04	129
Total Center Ground Conc. (Bq/m2)	0.9975	2.39E+11	1.40E+11	6.81E+11	7.33E+11	8.27E+11	8.70E+11	1.49E+12	1.43E-04	129
Ground-Level Dilution, X/Q (s/m3)	1.0000	3.37E-06	1.46E-06	9.63E-06	1.26E-05	NOT-FOUND	NOT-FOUND	1.73E-05	2.21E-02	34
Cs-137 Adjusted Source, Q (Bq)	1.0000	8.83E+16	8.60E+16	1.02E+17	1.04E+17	1.07E+17	1.09E+17	1.11E+17	2.45E-03	75
Plume Sigma-y (m)	1.0000	6.34E+02	5.16E+02	NOT-FOUND	NOT-FOUND	NOT-FOUND	NOT-FOUND	1.33E+03	1.77E-01	2
Plume Sigma-z (m)	1.0000	2.96E+02	1.51E+02	7.60E+02	8.57E+02	1.31E+03	1.71E+03	1.82E+03	4.22E-03	4
Plume Height (m)	0.4148	1.27E+02	0.00E+00	7.33E+02	8.96E+02	1.02E+03	1.04E+03	1.11E+03	2.00E-04	21
Plume Arrival Time (s)	1.0000	7.78E+03	6.78E+03	1.10E+04	1.20E+04	1.49E+04	1.63E+04	1.69E+04	3.77E-03	36

DATE AND TIME OF RUN = MACCS2 09/26/96 08:40:08 Version 1.12, Last Modified 9/25/96 by D. Chanin
"ATMOS" DESCRIPTION = IN1A.INP, Sample Problem A--Using Table-Lookup Sigmas, ATMOS input
"EARLY" DESCRIPTION = IN2A.INP, Sample Problem A of NUREG/CR-4691, Vol. 1, EARLY input
"CHRONC" DESCRIPTION = IN3A_N.INP, Sample Problem A, "New" COMIDA2-Based Food Model

SOURCE TERM 1 OF 2:
SECOND DRAFT 1150, WORST CASE SOURCE TERM FOR EARLY FATALITIES

OVERALL RESULTS OBTAINED BY COMBINING 2 EMERGENCY RESPONSE COHORTS FROM "EARLY" WITH THE WEIGHTING FRACTIONS BELOW APPLIED TO THEM:

	FRACTION OF THE PEOPLE
COHORT 1 = EVACUATION WITHIN 10 MILES, RELOCATION MODELS APPLY ELSEWHERE	0.950
COHORT 2 = NO EVACUATION, RELOCATION MODELS APPLY EVERYWHERE	0.050

AND THEN MERGING THE 2 RESULTS ABOVE WITH THE SINGLE SET OF RESULTS FROM "CHRONC" DESCRIBED BELOW:

COHORT 3 = IN3A_N.INP, Sample Problem A, "New" COMIDA2-Based Food Model

RESULTS WHICH ARE PRODUCED ONLY BY "EARLY" OR ONLY BY "CHRONC" ARE PRESENTED IN LATER SECTIONS.

09/26/96 08:40:08 PAGE 1

		PROB NON-ZERO	MEAN	QUANTILES 50TH	90TH	95TH	99TH	99.5TH	PEAK CONS	PEAK PROB	PEAK TRIAL
HEALTH EFFECTS CASES											
ERL FAT/TOTAL	0-1609 km	0.6836	1.34E+01	2.38E-01	2.77E+01	4.76E+01	1.57E+02	3.35E+02	3.18E+03	2.85E-04	85
ERL INJ/PRODROMAL VOMIT	0-1609 km	0.8218	8.84E+01	5.58E+00	1.57E+02	3.12E+02	1.58E+03	2.51E+03	8.03E+03	2.85E-04	85
ERL INJ/DIARRHEA	0-1609 km	0.7422	4.00E+01	1.34E+00	7.58E+01	1.41E+02	6.54E+02	1.23E+03	5.19E+03	2.85E-04	85
ERL INJ/PNEUMONITIS	0-1609 km	0.5941	5.65E+00	6.33E-03	1.14E+01	2.63E+01	9.41E+01	1.26E+02	8.76E+02	2.85E-04	85
ERL INJ/THYROIDITIS	0-1609 km	0.5735	9.94E+00	2.88E-02	1.87E+01	4.50E+01	1.85E+02	2.62E+02	1.23E+03	2.85E-04	85
ERL INJ/HYPOTHYROIDISM	0-1609 km	0.9600	2.00E+02	4.19E+01	4.12E+02	9.07E+02	3.10E+03	3.80E+03	9.30E+03	5.71E-04	123
ERL INJ/SKIN ERYTHEMA	0-1609 km	0.9967	5.02E+03	1.04E+03	1.11E+04	1.99E+04	7.07E+04	1.05E+05	1.80E+05	7.13E-04	114
ERL INJ/TRANSEPIDERMAL	0-1609 km	0.9321	1.38E+03	1.52E+02	3.67E+03	6.81E+03	1.88E+04	2.40E+04	4.22E+04	7.71E-04	29
CAN FAT/TOTAL	0-1609 km	1.0000	1.13E+04	6.85E+03	2.59E+04	3.56E+04	6.07E+04	7.15E+04	1.01E+05	1.11E-03	135
CAN FAT/LUNG	0-1609 km	1.0000	1.77E+03	1.12E+03	4.01E+03	5.61E+03	9.21E+03	1.09E+04	1.55E+04	1.11E-03	135
CAN FAT/THYROID	0-1609 km	1.0000	2.75E+02	1.76E+02	5.95E+02	8.56E+02	1.20E+03	1.33E+03	2.47E+03	2.85E-04	123
CAN FAT/BREAST	0-1609 km	1.0000	1.22E+03	6.63E+02	2.86E+03	4.23E+03	8.10E+03	9.51E+03	1.23E+04	1.11E-03	135
CAN FAT/GI	0-1609 km	1.0000	3.25E+03	1.89E+03	7.64E+03	1.04E+04	1.68E+04	2.05E+04	2.93E+04	1.11E-03	135
CAN FAT/LEUKEMIA	0-1609 km	1.0000	1.05E+03	6.10E+02	2.37E+03	3.28E+03	6.03E+03	7.14E+03	9.59E+03	1.11E-03	135
CAN FAT/BONE	0-1609 km	1.0000	1.40E+02	9.80E+01	3.09E+02	4.04E+02	6.53E+02	7.57E+02	1.10E+03	1.11E-03	135
CAN FAT/OTHER	0-1609 km	1.0000	3.57E+03	2.24E+03	7.98E+03	1.10E+04	2.10E+04	2.35E+04	3.15E+04	1.11E-03	135
CAN INJ/THYROID	0-1609 km	1.0000	2.75E+03	1.76E+03	5.95E+03	8.56E+03	1.20E+04	1.33E+04	2.47E+04	2.85E-04	123
CAN INJ/BREAST	0-1609 km	1.0000	3.85E+03	2.19E+03	9.10E+03	1.30E+04	2.50E+04	3.04E+04	3.89E+04	1.11E-03	135
CAN FAT/TOTAL	0-80.5 km	1.0000	1.72E+03	9.55E+02	4.07E+03	5.93E+03	9.56E+03	1.11E+04	2.07E+04	2.85E-04	123
ERL FAT/TOTAL	0-16.1 km	0.6823	1.34E+01	2.32E-01	2.73E+01	4.69E+01	1.57E+02	3.35E+02	3.18E+03	2.85E-04	85
ERL INJ/PRODROMAL VOMIT	0-16.1 km	0.8169	8.04E+01	4.60E+00	1.31E+02	2.34E+02	1.49E+03	2.43E+03	7.84E+03	2.85E-04	85
ERL INJ/DIARRHEA	0-16.1 km	0.7402	3.85E+01	1.30E+00	7.00E+01	1.25E+02	6.54E+02	1.23E+03	5.19E+03	2.85E-04	85
ERL INJ/PNEUMONITIS	0-16.1 km	0.5941	5.65E+00	6.33E-03	1.14E+01	2.63E+01	9.41E+01	1.26E+02	8.76E+02	2.85E-04	85
ERL INJ/THYROIDITIS	0-16.1 km	0.5735	9.94E+00	2.88E-02	1.87E+01	4.50E+01	1.85E+02	2.62E+02	1.23E+03	2.85E-04	85
ERL INJ/HYPOTHYROIDISM	0-16.1 km	0.9515	1.65E+02	2.35E+01	2.77E+02	8.13E+02	2.88E+03	3.68E+03	9.09E+03	5.71E-04	123
ERL INJ/SKIN ERYTHEMA	0-16.1 km	0.9941	1.69E+03	3.26E+02	4.78E+03	9.41E+03	2.03E+04	2.09E+04	2.60E+04	2.29E-05	99
ERL INJ/TRANSEPIDERMAL	0-16.1 km	0.9296	8.56E+02	9.28E+01	2.06E+03	4.89E+03	1.48E+04	2.04E+04	2.59E+04	1.82E-04	61
CAN FAT/TOTAL	0-16.1 km	1.0000	3.87E+02	1.38E+02	7.68E+02	1.61E+03	4.86E+03	5.76E+03	1.50E+04	2.85E-04	123
EARLY FATALITY DISTANCE (km)											
ERL FAT/TOTAL RISK > 0.000		1.0000	4.48E+00	3.69E+00	8.81E+00	1.15E+01	NOT-FOUND	NOT-FOUND	2.09E+01	2.17E-02	50

09/26/96 08:40:08 PAGE 2

	PROB NON-ZERO	MEAN	QUANTILES 50TH	90TH	95TH	99TH	99.5TH	PEAK CONS	PEAK PROB	PEAK TRIAL
POPULATION EXCEEDING DOSE										
EARLY dose A-RED MARR > 1.50 Sv	0.6836	1.01E+02	2.35E+00	1.32E+02	2.54E+02	2.54E+03	3.68E+03	1.05E+04	2.85E-05	87
EARLY dose A-LUNGS > 5.00 Sv	0.5941	4.45E+01	1.49E-01	6.28E+01	1.18E+02	7.03E+02	1.94E+03	7.96E+03	2.85E-04	85
EARLY dose L-EDEWBODY > 5.000E-02 Sv	1.0000	7.57E+04	2.92E+04	2.18E+05	3.19E+05	5.46E+05	6.43E+05	7.47E+05	4.06E-05	108
AVERAGE INDIVIDUAL RISK										
ERL FAT/TOTAL 0-0.2 km	1.0000	1.76E-01	1.41E-01	2.10E-01	2.19E-01	2.39E-01	2.48E-01	2.94E-01	2.28E-04	18
ERL FAT/TOTAL 0.2-0.5 km	1.0000	6.71E-02	6.59E-02	1.02E-01	1.08E-01	1.25E-01	1.33E-01	1.61E-01	5.42E-04	82
ERL FAT/TOTAL 0.5-1.2 km	0.8572	3.76E-02	4.35E-02	5.44E-02	5.65E-02	6.18E-02	6.43E-02	9.40E-02	5.42E-04	28
ERL FAT/TOTAL 1.2-1.6 km	0.8032	2.71E-02	3.11E-02	5.16E-02	5.40E-02	6.00E-02	6.27E-02	6.39E-02	3.77E-03	36
ERL FAT/TOTAL 1.6-2.1 km	0.7380	2.15E-02	2.12E-02	5.18E-02	5.62E-02	NOT-FOUND	NOT-FOUND	6.19E-02	2.17E-02	115

POPULATION DOSE (Sv)

L-EDEWBODY	TOT LIF	0-16.1 km	1.0000	7.13E+03	3.01E+03	1.40E+04	2.70E+04	8.68E+04	1.13E+05	2.56E+05	2.85E-04	123
L-EDEWBODY	TOT LIF	0-80.5 km	1.0000	3.54E+04	1.99E+04	8.82E+04	1.18E+05	1.96E+05	2.19E+05	3.70E+05	2.85E-04	123
L-EDEWBODY	TOT LIF	0-1609 km	1.0000	2.50E+05	1.43E+05	5.76E+05	7.90E+05	1.39E+06	1.75E+06	2.28E+06	1.11E-03	135

POPULATION WEIGHTED RISK

ERL FAT/TOTAL	0-2.1 km	0.3627	3.10E-02	0.00E+00	2.73E-02	1.61E-01	6.57E-01	7.36E-01	8.40E-01	1.44E-03	79
CAN FAT/TOTAL	0-16.1 km	0.9993	4.53E-03	1.11E-03	9.66E-03	1.92E-02	6.79E-02	8.12E-02	2.03E-01	2.85E-04	123

PEAK DOSE FOUND ON SPATIAL GRID (Sv)

L-EDEWBODY	0-0.2 km	1.0000	7.43E+02	6.01E+02	1.33E+03	1.58E+03	NOT-FOUND	NOT-FOUND	1.93E+03	2.21E-02	47
L-EDEWBODY	0.2-0.5 km	1.0000	1.49E+02	1.06E+02	3.31E+02	3.96E+02	5.91E+02	6.94E+02	7.35E+02	4.14E-03	17
L-EDEWBODY	0.5-1.2 km	1.0000	7.07E+01	5.88E+01	1.33E+02	1.57E+02	2.40E+02	2.97E+02	3.18E+02	4.14E-03	17
L-EDEWBODY	1.2-1.6 km	1.0000	4.98E+01	3.76E+01	1.06E+02	1.20E+02	1.57E+02	1.77E+02	1.83E+02	4.14E-03	17
L-EDEWBODY	1.6-2.1 km	1.0000	3.99E+01	3.19E+01	1.02E+02	1.23E+02	NOT-FOUND	NOT-FOUND	1.53E+02	2.21E-02	94
L-EDEWBODY	2.1-3.2 km	1.0000	2.69E+01	1.80E+01	7.05E+01	9.48E+01	NOT-FOUND	NOT-FOUND	1.48E+02	2.21E-02	94
L-EDEWBODY	3.2-4.0 km	1.0000	1.80E+01	8.54E+00	6.34E+01	7.22E+01	7.90E+01	8.21E+01	1.11E+02	1.43E-04	129
L-EDEWBODY	4.0-4.8 km	1.0000	1.46E+01	6.53E+00	4.38E+01	7.41E+01	NOT-FOUND	NOT-FOUND	8.87E+01	2.17E-02	88
L-EDEWBODY	4.8-5.6 km	1.0000	1.21E+01	2.76E+00	3.72E+01	6.21E+01	NOT-FOUND	NOT-FOUND	8.82E+01	2.17E-02	88
L-EDEWBODY	5.6-8.1 km	1.0000	7.34E+00	1.83E+00	2.35E+01	2.95E+01	NOT-FOUND	NOT-FOUND	4.37E+01	2.17E-02	88
L-EDEWBODY	8.1-11.3 km	1.0000	2.54E+00	8.14E-01	8.30E+00	1.15E+01	1.89E+01	2.56E+01	2.81E+01	4.14E-03	85
L-EDEWBODY	11.3-16.1 km	1.0000	9.81E-01	3.70E-01	3.09E+00	3.47E+00	4.53E+00	5.08E+00	1.62E+01	3.42E-04	87
L-EDEWBODY	16.1-20.9 km	1.0000	1.37E+00	9.11E-01	3.25E+00	3.95E+00	NOT-FOUND	NOT-FOUND	6.04E+00	2.17E-02	50
L-EDEWBODY	20.9-25.8 km	1.0000	8.85E-01	7.16E-01	1.86E+00	2.68E+00	NOT-FOUND	NOT-FOUND	3.33E+00	1.91E-02	51
L-EDEWBODY	25.8-32.2 km	1.0000	5.62E-01	4.85E-01	9.07E-01	1.16E+00	NOT-FOUND	NOT-FOUND	1.85E+00	1.91E-02	51
L-EDEWBODY	32.2-40.2 km	1.0000	3.84E-01	3.20E-01	6.81E-01	7.96E-01	NOT-FOUND	NOT-FOUND	1.07E+00	1.71E-02	86
L-EDEWBODY	40.2-48.3 km	1.0000	2.76E-01	2.33E-01	5.36E-01	6.43E-01	NOT-FOUND	NOT-FOUND	8.19E-01	1.91E-02	114
L-EDEWBODY	48.3-64.4 km	1.0000	2.14E-01	1.95E-01	4.06E-01	5.04E-01	NOT-FOUND	NOT-FOUND	6.25E-01	1.91E-02	114
L-EDEWBODY	64.4-80.5 km	1.0000	1.60E-01	1.30E-01	2.69E-01	3.17E-01	NOT-FOUND	NOT-FOUND	3.89E-01	1.71E-02	86
L-EDEWBODY	80.5-113 km	1.0000	1.17E-01	9.94E-02	2.00E-01	2.38E-01	NOT-FOUND	NOT-FOUND	3.63E-01	1.88E-02	7
L-EDEWBODY	113-161 km	1.0000	8.15E-02	7.64E-02	1.17E-01	1.31E-01	1.67E-01	1.86E-01	2.68E-01	3.14E-04	72
L-EDEWBODY	161-241 km	1.0000	6.52E-02	6.57E-02	9.00E-02	1.00E-01	1.13E-01	1.20E-01	1.22E-01	3.77E-03	65
L-EDEWBODY	241-322 km	1.0000	5.40E-02	4.76E-02	8.96E-02	1.03E-01	NOT-FOUND	NOT-FOUND	1.12E-01	2.70E-02	55
L-EDEWBODY	322-563 km	1.0000	3.56E-02	3.12E-02	7.12E-02	8.54E-02	NOT-FOUND	NOT-FOUND	1.03E-01	2.73E-02	135
L-EDEWBODY	563-805 km	1.0000	1.18E-02	7.48E-03	2.75E-02	3.22E-02	4.07E-02	4.51E-02	5.67E-02	2.45E-03	64
L-EDEWBODY	805-1609 km	1.0000	1.70E-03	7.40E-04	4.00E-03	7.12E-03	8.87E-03	9.75E-03	1.54E-02	4.14E-03	105

```
  DATE AND TIME OF RUN = MACCS2 09/26/96   08:40:08   Version 1.12, Last Modified 9/25/96 by D. Chanin
  "ATMOS"  DESCRIPTION = IN1A.INP, Sample Problem A--Using Table-Lookup Sigmas, ATMOS input
  "EARLY"  DESCRIPTION = IN2A.INP, Sample Problem A of NUREG/CR-4691, Vol. 1, EARLY input

SOURCE TERM  1 OF  2:
    SECOND DRAFT 1150, WORST CASE SOURCE TERM FOR EARLY FATALITIES

RESULTS FOR A SINGLE EMERGENCY RESPONSE COHORT WITHOUT ANY WEIGHTING FRACTIONS BEING APPLIED

    COHORT 1 = EVACUATION WITHIN 10 MILES, RELOCATION MODELS APPLY ELSEWHERE
```

09/26/96 08:40:08 PAGE 3

		PROB NON-ZERO	MEAN	QUANTILES 50TH	90TH	95TH	99TH	99.5TH	PEAK CONS	PEAK PROB	PEAK TRIAL
HEALTH EFFECTS CASES											
ERL FAT/TOTAL	0-1609 km	0.4947	1.25E+01	0.00E+00	2.22E+01	4.60E+01	1.71E+02	3.45E+02	3.31E+03	2.85E-04	85
ERL INJ/PRODROMAL VOMIT	0-1609 km	0.6277	8.54E+01	1.75E+00	1.47E+02	2.83E+02	1.61E+03	2.51E+03	8.31E+03	2.85E-04	85
ERL INJ/DIARRHEA	0-1609 km	0.5283	3.84E+01	1.17E-01	7.15E+01	1.32E+02	7.70E+02	1.23E+03	5.40E+03	2.85E-04	85
ERL INJ/PNEUMONITIS	0-1609 km	0.4015	5.73E+00	0.00E+00	1.15E+01	3.07E+01	9.55E+01	1.26E+02	9.22E+02	2.85E-04	85
ERL INJ/THYROIDITIS	0-1609 km	0.4800	1.03E+01	0.00E+00	2.06E+01	4.61E+01	1.98E+02	2.85E+02	1.29E+03	2.85E-04	85
ERL INJ/HYPOTHYROIDISM	0-1609 km	0.8494	2.02E+02	3.83E+01	4.01E+02	8.91E+02	3.15E+03	3.85E+03	9.72E+03	1.34E-03	123
ERL INJ/SKIN ERYTHEMA	0-1609 km	0.9015	4.97E+03	9.84E+02	1.12E+04	1.94E+04	7.07E+04	1.05E+05	1.80E+05	7.13E-04	114
ERL INJ/TRANSEPIDERMAL	0-1609 km	0.7818	1.37E+03	1.37E+02	3.59E+03	6.70E+03	1.89E+04	2.40E+04	4.17E+04	7.71E-04	29
CAN FAT/TOTAL	0-1609 km	1.0000	1.47E+03	1.02E+03	2.95E+03	3.72E+03	7.26E+03	8.86E+03	1.90E+04	2.85E-04	123
CAN FAT/LUNG	0-1609 km	1.0000	3.01E+02	2.13E+02	6.34E+02	7.90E+02	1.23E+03	1.51E+03	3.35E+03	2.85E-04	123
CAN FAT/THYROID	0-1609 km	1.0000	1.32E+02	7.53E+01	2.95E+02	4.08E+02	9.35E+02	1.20E+03	2.54E+03	2.85E-04	123
CAN FAT/BREAST	0-1609 km	1.0000	8.88E+01	6.61E+01	1.77E+02	2.24E+02	3.19E+02	3.52E+02	6.62E+02	1.14E-04	112
CAN FAT/GI	0-1609 km	1.0000	3.01E+02	2.14E+02	5.98E+02	7.45E+02	1.18E+03	1.45E+03	3.32E+03	2.85E-04	123
CAN FAT/LEUKEMIA	0-1609 km	1.0000	9.46E+01	7.09E+01	1.95E+02	2.34E+02	3.46E+02	4.08E+02	8.79E+02	2.85E-04	123
CAN FAT/BONE	0-1609 km	1.0000	2.35E+01	1.57E+01	5.11E+01	7.10E+01	1.02E+02	1.13E+02	1.72E+02	2.85E-04	123
CAN FAT/OTHER	0-1609 km	1.0000	5.31E+02	3.40E+02	1.09E+03	1.45E+03	3.10E+03	3.73E+03	8.20E+03	2.85E-04	123
CAN INJ/THYROID	0-1609 km	1.0000	1.32E+03	7.53E+02	2.95E+03	4.08E+03	9.35E+03	1.20E+04	2.54E+04	2.85E-04	123
CAN INJ/BREAST	0-1609 km	1.0000	2.80E+02	2.09E+02	5.79E+02	7.20E+02	1.04E+03	1.15E+03	2.08E+03	1.14E-04	112
CAN FAT/TOTAL	0-80.5 km	1.0000	9.26E+02	4.27E+02	2.28E+03	3.13E+03	7.11E+03	8.79E+03	1.90E+04	2.85E-04	123
ERL FAT/TOTAL	0-16.1 km	0.4919	1.24E+01	0.00E+00	2.19E+01	4.58E+01	1.71E+02	3.45E+02	3.31E+03	2.85E-04	85
ERL INJ/PRODROMAL VOMIT	0-16.1 km	0.5895	7.74E+01	7.60E-01	1.26E+02	2.39E+02	1.61E+03	2.51E+03	8.12E+03	2.85E-04	85
ERL INJ/DIARRHEA	0-16.1 km	0.5233	3.68E+01	9.33E-02	6.63E+01	1.22E+02	7.70E+02	1.23E+03	5.40E+03	2.85E-04	85
ERL INJ/PNEUMONITIS	0-16.1 km	0.4015	5.73E+00	0.00E+00	1.15E+01	3.07E+01	9.55E+01	1.26E+02	9.22E+02	2.85E-04	85
ERL INJ/THYROIDITIS	0-16.1 km	0.4800	1.03E+01	0.00E+00	2.06E+01	4.61E+01	1.98E+02	2.85E+02	1.29E+03	2.85E-04	85
ERL INJ/HYPOTHYROIDISM	0-16.1 km	0.7970	1.67E+02	1.55E+01	2.80E+02	8.21E+02	3.03E+03	3.77E+03	9.51E+03	5.71E-04	123
ERL INJ/SKIN ERYTHEMA	0-16.1 km	0.8409	1.64E+03	2.11E+02	4.93E+03	9.67E+03	2.13E+04	2.45E+04	2.60E+04	3.67E-03	11
ERL INJ/TRANSEPIDERMAL	0-16.1 km	0.7357	8.42E+02	3.90E+01	2.03E+03	4.74E+03	1.53E+04	2.04E+04	2.60E+04	2.95E-04	11
CAN FAT/TOTAL	0-16.1 km	0.9074	3.03E+02	3.45E+01	6.36E+02	1.53E+03	4.86E+03	5.76E+03	1.55E+04	2.85E-04	123
EARLY FATALITY DISTANCE (km)											
ERL FAT/TOTAL RISK > 0.000		1.0000	4.32E+00	3.59E+00	8.81E+00	1.15E+01	NOT-FOUND	NOT-FOUND	2.09E+01	2.17E-02	50
POPULATION EXCEEDING DOSE											
EARLY dose A-RED MARR > 1.50 Sv		0.4947	9.66E+01	0.00E+00	1.17E+02	2.31E+02	2.54E+03	3.68E+03	1.09E+04	2.85E-05	87
EARLY dose A-LUNGS > 5.00 Sv		0.4015	4.47E+01	0.00E+00	6.29E+01	1.18E+02	7.03E+02	1.94E+03	8.32E+03	2.85E-04	85
EARLY dose L-EDEWBODY > 5.000E-02 Sv		1.0000	7.53E+04	2.92E+04	2.18E+05	3.19E+05	5.46E+05	6.43E+05	7.47E+05	4.06E-05	108
AVERAGE INDIVIDUAL RISK											
ERL FAT/TOTAL	0-0.2 km	1.0000	1.70E-01	1.41E-01	NOT-FOUND	NOT-FOUND	NOT-FOUND	NOT-FOUND	2.77E-01	1.27E-01	2
ERL FAT/TOTAL	0.2-0.5 km	0.9885	6.33E-02	6.44E-02	9.24E-02	1.03E-01	1.20E-01	1.28E-01	1.59E-01	5.42E-04	82
ERL FAT/TOTAL	0.5-1.2 km	0.6964	3.61E-02	3.92E-02	5.36E-02	5.56E-02	6.03E-02	6.25E-02	9.19E-02	5.42E-04	28
ERL FAT/TOTAL	1.2-1.6 km	0.6902	2.64E-02	3.02E-02	NOT-FOUND	NOT-FOUND	NOT-FOUND	NOT-FOUND	6.25E-02	1.21E-01	20

09/26/96 08:40:08 PAGE 4

		PROB NON-ZERO	MEAN	QUANTILES 50TH	90TH	95TH	99TH	99.5TH	PEAK CONS	PEAK PROB	PEAK TRIAL
AVERAGE INDIVIDUAL RISK											
ERL FAT/TOTAL	1.6-2.1 km	0.6573	2.12E-02	2.06E-02	6.00E-02	NOT-FOUND	NOT-FOUND	NOT-FOUND	6.25E-02	9.35E-02	20

POPULATION DOSE (Sv)

L-EDEWBODY TOT LIF	0-16.1 km	0.9074	5.44E+03	8.19E+02	1.12E+04	2.54E+04	8.81E+04	1.15E+05	2.65E+05	2.85E-04	123
L-EDEWBODY TOT LIF	0-80.5 km	1.0000	1.77E+04	8.73E+03	4.48E+04	6.55E+04	1.08E+05	1.37E+05	3.27E+05	2.85E-04	123
L-EDEWBODY TOT LIF	0-1609 km	1.0000	3.03E+04	2.14E+04	6.16E+04	7.63E+04	1.17E+05	1.44E+05	3.27E+05	2.85E-04	123

POPULATION WEIGHTED RISK

ERL FAT/TOTAL	0-2.1 km	0.2092	3.01E-02	0.00E+00	2.63E-02	1.25E-01	6.60E-01	7.84E-01	8.50E-01	3.56E-03	20
CAN FAT/TOTAL	0-16.1 km	0.9074	4.12E-03	4.62E-04	8.50E-03	1.92E-02	6.81E-02	8.14E-02	2.11E-01	2.85E-04	123

PEAK DOSE FOUND ON SPATIAL GRID (Sv)

L-EDEWBODY	0-0.2 km	1.0000	7.23E+02	5.79E+02	1.34E+03	1.60E+03	NOT-FOUND	NOT-FOUND	1.89E+03	2.59E-02	36
L-EDEWBODY	0.2-0.5 km	1.0000	1.44E+02	1.06E+02	3.31E+02	3.96E+02	5.91E+02	6.94E+02	7.25E+02	4.14E-03	17
L-EDEWBODY	0.5-1.2 km	1.0000	6.92E+01	5.43E+01	1.30E+02	1.55E+02	2.39E+02	2.97E+02	3.14E+02	4.14E-03	17
L-EDEWBODY	1.2-1.6 km	1.0000	4.93E+01	3.76E+01	1.06E+02	1.19E+02	1.56E+02	1.75E+02	1.81E+02	4.14E-03	17
L-EDEWBODY	1.6-2.1 km	1.0000	3.95E+01	3.19E+01	1.02E+02	1.24E+02	NOT-FOUND	NOT-FOUND	1.56E+02	2.21E-02	94
L-EDEWBODY	2.1-3.2 km	0.9730	2.65E+01	1.75E+01	7.05E+01	9.48E+01	NOT-FOUND	NOT-FOUND	1.51E+02	2.21E-02	94
L-EDEWBODY	3.2-4.0 km	0.9401	1.77E+01	7.82E+00	6.34E+01	7.22E+01	7.90E+01	8.21E+01	1.14E+02	1.43E-04	129
L-EDEWBODY	4.0-4.8 km	0.9082	1.43E+01	5.47E+00	4.38E+01	7.46E+01	NOT-FOUND	NOT-FOUND	9.14E+01	2.17E-02	88
L-EDEWBODY	4.8-5.6 km	0.8435	1.19E+01	1.98E+00	3.73E+01	7.46E+01	NOT-FOUND	NOT-FOUND	9.12E+01	2.17E-02	88
L-EDEWBODY	5.6-8.1 km	0.8015	7.16E+00	1.47E+00	2.40E+01	2.95E+01	NOT-FOUND	NOT-FOUND	4.46E+01	2.17E-02	88
L-EDEWBODY	8.1-11.3 km	0.7120	2.36E+00	5.81E-01	8.30E+00	1.19E+01	2.15E+01	2.71E+01	2.89E+01	4.14E-03	85
L-EDEWBODY	11.3-16.1 km	0.5447	8.34E-01	6.67E-02	3.09E+00	3.47E+00	4.53E+00	5.08E+00	1.67E+01	3.42E-04	87
L-EDEWBODY	16.1-20.9 km	1.0000	1.30E+00	8.29E-01	3.25E+00	3.95E+00	NOT-FOUND	NOT-FOUND	6.02E+00	2.17E-02	50
L-EDEWBODY	20.9-25.8 km	1.0000	8.02E-01	5.18E-01	1.85E+00	2.68E+00	NOT-FOUND	NOT-FOUND	3.33E+00	1.91E-02	51
L-EDEWBODY	25.8-32.2 km	1.0000	4.46E-01	3.35E-01	8.21E-01	9.58E-01	NOT-FOUND	NOT-FOUND	1.85E+00	1.91E-02	51
L-EDEWBODY	32.2-40.2 km	1.0000	2.74E-01	1.94E-01	5.81E-01	7.39E-01	NOT-FOUND	NOT-FOUND	8.92E-01	1.71E-02	86
L-EDEWBODY	40.2-48.3 km	1.0000	1.88E-01	1.34E-01	3.61E-01	4.57E-01	NOT-FOUND	NOT-FOUND	6.51E-01	1.91E-02	114
L-EDEWBODY	48.3-64.4 km	1.0000	1.42E-01	1.12E-01	2.56E-01	3.06E-01	NOT-FOUND	NOT-FOUND	4.82E-01	1.91E-02	114
L-EDEWBODY	64.4-80.5 km	1.0000	9.68E-02	7.62E-02	2.01E-01	2.28E-01	NOT-FOUND	NOT-FOUND	2.77E-01	1.71E-02	86
L-EDEWBODY	80.5-113 km	1.0000	5.90E-02	4.75E-02	1.25E-01	1.53E-01	NOT-FOUND	NOT-FOUND	2.25E-01	1.88E-02	7
L-EDEWBODY	113-161 km	1.0000	2.77E-02	2.53E-02	5.22E-02	6.31E-02	8.40E-02	9.31E-02	1.66E-01	3.14E-04	72
L-EDEWBODY	161-241 km	1.0000	1.29E-02	1.10E-02	2.38E-02	2.87E-02	3.93E-02	4.48E-02	6.24E-02	2.45E-03	83
L-EDEWBODY	241-322 km	1.0000	7.39E-03	6.65E-03	1.60E-02	2.03E-02	2.50E-02	2.74E-02	3.51E-02	2.45E-03	83
L-EDEWBODY	322-563 km	1.0000	2.88E-03	2.50E-03	5.68E-03	6.43E-03	7.65E-03	8.07E-03	1.90E-02	3.14E-04	112
L-EDEWBODY	563-805 km	1.0000	7.69E-04	5.61E-04	1.66E-03	2.07E-03	2.52E-03	2.75E-03	3.37E-03	2.45E-03	64
L-EDEWBODY	805-1609 km	1.0000	9.73E-05	5.32E-05	2.36E-04	5.09E-04	7.98E-04	9.01E-04	9.31E-04	4.14E-03	105

DATE AND TIME OF RUN = MACCS2 09/26/96 08:40:08 Version 1.12, Last Modified 9/25/96 by D. Chanin
"ATMOS" DESCRIPTION = IN1A.INP, Sample Problem A--Using Table-Lookup Sigmas, ATMOS input
"EARLY" DESCRIPTION = IN2A.INP, Sample Problem A of NUREG/CR-4691, Vol. 1, EARLY input

SOURCE TERM 1 OF 2:
SECOND DRAFT 1150, WORST CASE SOURCE TERM FOR EARLY FATALITIES

RESULTS FOR A SINGLE EMERGENCY RESPONSE COHORT WITHOUT ANY WEIGHTING FRACTIONS BEING APPLIED

COHORT 2 = NO EVACUATION, RELOCATION MODELS APPLY EVERYWHERE

09/26/96 08:40:08 PAGE 5

		PROB NON-ZERO	MEAN	QUANTILES 50TH	90TH	95TH	99TH	99.5TH	PEAK CONS	PEAK PROB	PEAK TRIAL
HEALTH EFFECTS CASES											
ERL FAT/TOTAL	0-1609 km	0.6836	3.18E+01	2.19E+00	7.12E+01	1.86E+02	4.55E+02	5.99E+02	2.73E+03	2.00E-05	128
ERL INJ/PRODROMAL VOMIT	0-1609 km	0.8218	1.46E+02	2.28E+01	4.10E+02	8.51E+02	1.88E+03	2.36E+03	5.72E+03	2.00E-05	39
ERL INJ/DIARRHEA	0-1609 km	0.7404	7.14E+01	8.59E+00	1.87E+02	4.31E+02	9.60E+02	1.09E+03	3.64E+03	2.00E-05	128
ERL INJ/PNEUMONITIS	0-1609 km	0.5934	4.06E+00	8.81E-02	1.42E+01	2.22E+01	3.19E+01	3.38E+01	4.15E+02	7.15E-06	129
ERL INJ/THYROIDITIS	0-1609 km	0.5640	2.43E+00	4.70E-02	9.08E+00	1.31E+01	2.59E+01	3.29E+01	5.66E+01	1.06E-03	115
ERL INJ/HYPOTHYROIDISM	0-1609 km	0.9325	1.53E+02	3.13E+01	4.58E+02	7.33E+02	1.63E+03	2.12E+03	2.98E+03	1.11E-03	51
ERL INJ/SKIN ERYTHEMA	0-1609 km	0.9555	5.97E+03	8.94E+02	1.41E+04	2.70E+04	8.02E+04	1.09E+05	1.81E+05	7.13E-04	114
ERL INJ/TRANSEPIDERMAL	0-1609 km	0.8175	1.64E+03	1.42E+02	5.23E+03	7.65E+03	2.14E+04	2.73E+04	5.20E+04	7.71E-04	29

CAN FAT/TOTAL	0-1609 km	1.0000	1.58E+03	1.16E+03	3.05E+03	3.74E+03	5.43E+03	5.94E+03	9.00E+03	1.11E-03	51
CAN FAT/LUNG	0-1609 km	1.0000	3.57E+02	2.67E+02	7.31E+02	9.23E+02	1.21E+03	1.34E+03	1.88E+03	4.57E-04	44
CAN FAT/THYROID	0-1609 km	1.0000	1.22E+02	8.01E+01	2.52E+02	3.41E+02	6.07E+02	7.19E+02	1.04E+03	1.11E-03	51
CAN FAT/BREAST	0-1609 km	1.0000	9.34E+01	7.48E+01	1.85E+02	2.25E+02	3.09E+02	3.33E+02	6.65E+02	1.14E-04	112
CAN FAT/GI	0-1609 km	1.0000	3.27E+02	2.56E+02	6.29E+02	7.67E+02	1.12E+03	1.28E+03	1.74E+03	1.11E-03	51
CAN FAT/LEUKEMIA	0-1609 km	1.0000	1.07E+02	8.60E+01	2.10E+02	2.50E+02	3.27E+02	3.49E+02	5.58E+02	1.14E-04	112
CAN FAT/BONE	0-1609 km	1.0000	3.05E+01	2.19E+01	6.37E+01	8.50E+01	1.11E+02	1.18E+02	2.08E+02	1.28E-05	56
CAN FAT/OTHER	0-1609 km	1.0000	5.44E+02	3.93E+02	1.06E+03	1.38E+03	2.19E+03	2.42E+03	3.86E+03	1.11E-03	51
CAN INJ/THYROID	0-1609 km	1.0000	1.22E+03	8.01E+02	2.52E+03	3.41E+03	6.07E+03	7.19E+03	1.04E+04	1.11E-03	51
CAN INJ/BREAST	0-1609 km	1.0000	2.94E+02	2.28E+02	5.80E+02	7.04E+02	1.02E+03	1.13E+03	2.09E+03	1.14E-04	112
CAN FAT/TOTAL	0-80.5 km	1.0000	1.03E+03	5.93E+02	2.40E+03	3.36E+03	5.42E+03	5.94E+03	9.00E+03	1.11E-03	51
ERL FAT/TOTAL	0-16.1 km	0.6823	3.17E+01	2.15E+00	7.00E+01	1.76E+02	4.55E+02	5.99E+02	2.73E+03	2.00E-05	128
ERL INJ/PRODROMAL VOMIT	0-16.1 km	0.8168	1.38E+02	2.20E+01	3.91E+02	7.80E+02	1.73E+03	2.17E+03	5.72E+03	2.00E-05	39
ERL INJ/DIARRHEA	0-16.1 km	0.7384	6.98E+01	8.38E+00	1.80E+02	4.11E+02	9.03E+02	1.07E+03	3.64E+03	2.00E-05	128
ERL INJ/PNEUMONITIS	0-16.1 km	0.5934	4.06E+00	8.81E-02	1.42E+01	2.22E+01	3.19E+01	3.38E+01	4.15E+02	7.15E-06	129
ERL INJ/THYROIDITIS	0-16.1 km	0.5640	2.43E+00	4.70E-02	9.08E+00	1.31E+01	2.59E+01	3.29E+01	5.66E+01	1.06E-03	115
ERL INJ/HYPOTHYROIDISM	0-16.1 km	0.9241	1.18E+02	2.10E+01	3.79E+02	6.12E+02	1.09E+03	1.32E+03	2.10E+03	1.06E-03	41
ERL INJ/SKIN ERYTHEMA	0-16.1 km	0.9529	2.65E+03	5.22E+02	8.66E+03	1.29E+04	2.18E+04	2.38E+04	3.98E+04	5.03E-04	103
ERL INJ/TRANSEPIDERMAL	0-16.1 km	0.8151	1.11E+03	1.21E+02	3.54E+03	5.83E+03	1.20E+04	1.40E+04	2.60E+04	1.89E-04	91
CAN FAT/TOTAL	0-16.1 km	0.9993	4.11E+02	1.53E+02	1.16E+03	1.59E+03	2.90E+03	3.12E+03	4.44E+03	2.00E-05	39
EARLY FATALITY DISTANCE (km)											
ERL FAT/TOTAL RISK > 0.000		1.0000	7.38E+00	7.49E+00	1.35E+01	1.61E+01	NOT-FOUND	NOT-FOUND	2.09E+01	2.17E-02	50
POPULATION EXCEEDING DOSE											
EARLY dose A-RED MARR > 1.50 Sv		0.6836	1.94E+02	1.52E+01	4.81E+02	1.16E+03	2.85E+03	3.49E+03	1.11E+04	2.00E-05	128
EARLY dose A-LUNGS > 5.00 Sv		0.5934	4.05E+01	1.57E+00	5.60E+01	2.62E+02	5.65E+02	1.01E+03	1.19E+03	3.86E-05	125
EARLY dose L-EDEWBODY > 5.000E-02 Sv		1.0000	8.19E+04	3.37E+04	2.29E+05	3.34E+05	5.65E+05	6.50E+05	7.73E+05	8.56E-04	96
AVERAGE INDIVIDUAL RISK											
ERL FAT/TOTAL	0-0.2 km	1.0000	2.88E-01	2.69E-01	3.92E-01	4.46E-01	5.24E-01	5.41E-01	6.24E-01	2.28E-04	18
ERL FAT/TOTAL	0.2-0.5 km	1.0000	1.39E-01	1.13E-01	1.77E-01	2.03E-01	2.26E-01	2.36E-01	2.73E-01	5.42E-04	10
ERL FAT/TOTAL	0.5-1.2 km	0.8567	6.49E-02	6.88E-02	1.06E-01	1.14E-01	1.34E-01	1.43E-01	1.79E-01	5.42E-04	10
ERL FAT/TOTAL	1.2-1.6 km	0.8032	3.91E-02	3.96E-02	7.11E-02	7.56E-02	8.72E-02	9.27E-02	1.27E-01	5.42E-04	82

09/26/96 08:40:08 PAGE 6

		PROB NON-ZERO	MEAN	QUANTILES 50TH	90TH	95TH	99TH	99.5TH	PEAK CONS	PEAK PROB	PEAK TRIAL
AVERAGE INDIVIDUAL RISK											
ERL FAT/TOTAL	1.6-2.1 km	0.7380	2.79E-02	3.03E-02	5.14E-02	5.96E-02	7.74E-02	8.38E-02	1.08E-01	5.42E-04	28
POPULATION DOSE (Sv)											
L-EDEWBODY TOT LIF	0-16.1 km	0.9993	6.30E+03	2.71E+03	1.66E+04	2.48E+04	4.83E+04	5.49E+04	7.38E+04	1.06E-03	41
L-EDEWBODY TOT LIF	0-80.5 km	1.0000	1.85E+04	1.07E+04	4.46E+04	6.26E+04	1.02E+05	1.13E+05	1.42E+05	1.11E-03	51
L-EDEWBODY TOT LIF	0-1609 km	1.0000	3.12E+04	2.41E+04	6.06E+04	7.47E+04	1.04E+05	1.11E+05	1.54E+05	1.14E-04	112
POPULATION WEIGHTED RISK											
ERL FAT/TOTAL	0-2.1 km	0.3627	4.68E-02	0.00E+00	4.53E-02	4.30E-01	6.85E-01	7.17E-01	8.50E-01	8.32E-05	28
CAN FAT/TOTAL	0-16.1 km	0.9993	5.59E-03	2.07E-03	1.41E-02	2.10E-02	3.41E-02	3.88E-02	6.05E-02	2.00E-05	39
PEAK DOSE FOUND ON SPATIAL GRID (Sv)											
L-EDEWBODY	0-0.2 km	1.0000	1.11E+03	9.48E+02	1.99E+03	2.24E+03	NOT-FOUND	NOT-FOUND	2.57E+03	2.21E-02	47
L-EDEWBODY	0.2-0.5 km	1.0000	2.51E+02	2.11E+02	5.10E+02	5.87E+02	7.51E+02	8.02E+02	9.67E+02	6.85E-04	46
L-EDEWBODY	0.5-1.2 km	1.0000	9.52E+01	9.13E+01	2.11E+02	2.43E+02	3.17E+02	3.38E+02	4.09E+02	6.85E-04	46
L-EDEWBODY	1.2-1.6 km	1.0000	5.83E+01	5.83E+01	1.07E+02	1.28E+02	1.94E+02	2.06E+02	2.30E+02	6.85E-04	46
L-EDEWBODY	1.6-2.1 km	1.0000	4.49E+01	3.87E+01	8.10E+01	8.83E+01	1.09E+02	1.20E+02	1.60E+02	6.85E-04	46
L-EDEWBODY	2.1-3.2 km	1.0000	3.16E+01	2.52E+01	7.38E+01	8.37E+01	NOT-FOUND	NOT-FOUND	9.72E+01	2.21E-02	34
L-EDEWBODY	3.2-4.0 km	1.0000	2.21E+01	1.49E+01	5.35E+01	6.18E+01	7.35E+01	7.61E+01	9.16E+01	1.14E-04	130
L-EDEWBODY	4.0-4.8 km	1.0000	1.74E+01	1.19E+01	3.92E+01	4.99E+01	NOT-FOUND	NOT-FOUND	6.75E+01	2.21E-02	34
L-EDEWBODY	4.8-5.6 km	1.0000	1.35E+01	9.08E+00	3.83E+01	4.94E+01	5.23E+01	5.33E+01	5.62E+01	7.71E-04	45
L-EDEWBODY	5.6-8.1 km	1.0000	8.95E+00	5.34E+00	2.55E+01	3.13E+01	NOT-FOUND	NOT-FOUND	3.53E+01	2.21E-02	47
L-EDEWBODY	8.1-11.3 km	1.0000	4.48E+00	2.83E+00	1.13E+01	1.36E+01	NOT-FOUND	NOT-FOUND	1.69E+01	2.17E-02	115

L-EDEWBODY	11.3-16.1 km	1.0000	2.34E+00	1.30E+00	6.69E+00	7.76E+00	NOT-FOUND	NOT-FOUND	8.95E+00	2.17E-02	41
L-EDEWBODY	16.1-20.9 km	1.0000	1.30E+00	8.29E-01	3.25E+00	3.95E+00	NOT-FOUND	NOT-FOUND	6.02E+00	2.17E-02	50
L-EDEWBODY	20.9-25.8 km	1.0000	8.02E-01	5.18E-01	1.85E+00	2.68E+00	NOT-FOUND	NOT-FOUND	3.33E+00	1.91E-02	51
L-EDEWBODY	25.8-32.2 km	1.0000	4.46E-01	3.35E-01	8.21E-01	9.58E-01	NOT-FOUND	NOT-FOUND	1.85E+00	1.91E-02	51
L-EDEWBODY	32.2-40.2 km	1.0000	2.74E-01	1.94E-01	5.81E-01	7.39E-01	NOT-FOUND	NOT-FOUND	8.92E-01	1.71E-02	86
L-EDEWBODY	40.2-48.3 km	1.0000	1.88E-01	1.34E-01	3.61E-01	4.57E-01	NOT-FOUND	NOT-FOUND	6.51E-01	1.91E-02	114
L-EDEWBODY	48.3-64.4 km	1.0000	1.42E-01	1.12E-01	2.56E-01	3.06E-01	NOT-FOUND	NOT-FOUND	4.82E-01	1.91E-02	114
L-EDEWBODY	64.4-80.5 km	1.0000	9.68E-02	7.62E-02	2.01E-01	2.28E-01	NOT-FOUND	NOT-FOUND	2.77E-01	1.71E-02	86
L-EDEWBODY	80.5-113 km	1.0000	5.90E-02	4.75E-02	1.25E-01	1.53E-01	NOT-FOUND	NOT-FOUND	2.25E-01	1.88E-02	7
L-EDEWBODY	113-161 km	1.0000	2.77E-02	2.53E-02	5.22E-02	6.31E-02	8.40E-02	9.31E-02	1.66E-01	3.14E-04	72
L-EDEWBODY	161-241 km	1.0000	1.29E-02	1.10E-02	2.38E-02	2.87E-02	3.93E-02	4.48E-02	6.24E-02	2.45E-03	83
L-EDEWBODY	241-322 km	1.0000	7.39E-03	6.65E-03	1.60E-02	2.03E-02	2.50E-02	2.74E-02	3.51E-02	2.45E-03	83
L-EDEWBODY	322-563 km	1.0000	2.88E-03	2.50E-03	5.68E-03	6.43E-03	7.65E-03	8.07E-03	1.90E-02	3.14E-04	112
L-EDEWBODY	563-805 km	1.0000	7.69E-04	5.61E-04	1.66E-03	2.07E-03	2.52E-03	2.75E-03	3.37E-03	2.45E-03	64
L-EDEWBODY	805-1609 km	1.0000	9.73E-05	5.32E-05	2.36E-04	5.09E-04	7.98E-04	9.01E-04	9.31E-04	4.14E-03	105

```
  DATE AND TIME OF RUN = MACCS2 09/26/96   08:40:08   Version 1.12, Last Modified 9/25/96 by D. Chanin
  "ATMOS"  DESCRIPTION = IN1A.INP, Sample Problem A--Using Table-Lookup Sigmas, ATMOS input
  "EARLY"  DESCRIPTION = IN2A.INP, Sample Problem A of NUREG/CR-4691, Vol. 1, EARLY input
  "CHRONC" DESCRIPTION = IN3A_N.INP, Sample Problem A, "New" COMIDA2-Based Food Model

SOURCE TERM  1 OF  2:
    SECOND DRAFT 1150, WORST CASE SOURCE TERM FOR EARLY FATALITIES

RESULTS FROM THE "CHRONC" MODULE ALONE

    COHORT 3 = IN3A_N.INP, Sample Problem A, "New" COMIDA2-Based Food Model
```

09/26/96 08:40:08 PAGE 7

		PROB NON-ZERO	MEAN	QUANTILES 50TH	90TH	95TH	99TH	99.5TH	PEAK CONS	PEAK PROB	PEAK TRIAL
HEALTH EFFECTS CASES											
CAN FAT/TOTAL	0-1609 km	1.0000	9.79E+03	5.37E+03	2.32E+04	3.29E+04	6.03E+04	7.14E+04	9.74E+04	1.11E-03	135
CAN FAT/LUNG	0-1609 km	1.0000	1.47E+03	7.69E+02	3.46E+03	4.99E+03	8.65E+03	1.02E+04	1.47E+04	1.11E-03	135
CAN FAT/THYROID	0-1609 km	1.0000	1.44E+02	7.17E+01	3.39E+02	4.94E+02	1.06E+03	1.22E+03	1.65E+03	1.11E-03	135
CAN FAT/BREAST	0-1609 km	1.0000	1.13E+03	5.77E+02	2.76E+03	3.99E+03	7.63E+03	9.07E+03	1.20E+04	1.11E-03	135
CAN FAT/GI	0-1609 km	1.0000	2.94E+03	1.56E+03	7.25E+03	1.02E+04	1.67E+04	2.04E+04	2.84E+04	1.11E-03	135
CAN FAT/LEUKEMIA	0-1609 km	1.0000	9.52E+02	5.34E+02	2.25E+03	3.23E+03	5.94E+03	7.09E+03	9.29E+03	1.11E-03	135
CAN FAT/BONE	0-1609 km	1.0000	1.16E+02	7.02E+01	2.73E+02	3.65E+02	6.03E+02	7.15E+02	1.03E+03	1.11E-03	135
CAN FAT/OTHER	0-1609 km	1.0000	3.04E+03	1.55E+03	7.35E+03	1.03E+04	1.67E+04	2.05E+04	3.03E+04	1.11E-03	135
CAN INJ/THYROID	0-1609 km	1.0000	1.44E+03	7.17E+02	3.39E+03	4.94E+03	1.06E+04	1.22E+04	1.65E+04	1.11E-03	135
CAN INJ/BREAST	0-1609 km	1.0000	3.57E+03	1.77E+03	8.85E+03	1.27E+04	2.38E+04	2.87E+04	3.78E+04	1.11E-03	135
CAN FAT/TOTAL	0-80.5 km	1.0000	7.87E+02	4.07E+02	1.93E+03	2.70E+03	3.89E+03	4.43E+03	6.79E+03	2.15E-04	102
CAN FAT/TOTAL	0-16.1 km	1.0000	7.85E+01	5.57E+01	1.63E+02	2.17E+02	3.12E+02	3.40E+02	5.78E+02	1.88E-05	39
POPULATION DOSE (Sv)											
L-EDEWBODY TOT LIF	0-16.1 km	1.0000	1.65E+03	1.09E+03	3.66E+03	5.08E+03	7.15E+03	7.60E+03	1.23E+04	1.82E-04	102
L-EDEWBODY TOT LIF	0-80.5 km	1.0000	1.77E+04	8.96E+03	4.33E+04	6.29E+04	9.69E+04	1.07E+05	1.52E+05	2.15E-04	102
L-EDEWBODY TOT LIF	0-1609 km	1.0000	2.20E+05	1.12E+05	5.33E+05	7.52E+05	1.36E+06	1.71E+06	2.19E+06	1.11E-03	135
POPULATION WEIGHTED RISK											
CAN FAT/TOTAL	0-16.1 km	0.9797	3.29E-04	1.19E-04	8.44E-04	1.31E-03	2.57E-03	3.00E-03	3.13E-03	3.71E-04	113
PEAK DOSE FOUND ON SPATIAL GRID (Sv)											
L-EDEWBODY	0-0.2 km	0.2034	2.64E-02	0.00E+00	1.14E-01	1.33E-01	1.87E-01	2.03E-01	2.18E-01	6.85E-04	108
L-EDEWBODY	0.2-0.5 km	0.3463	4.73E-02	0.00E+00	1.42E-01	1.79E-01	2.05E-01	2.08E-01	2.19E-01	4.57E-04	126
L-EDEWBODY	0.5-1.2 km	0.8822	1.10E-01	1.08E-01	1.68E-01	2.01E-01	NOT-FOUND	NOT-FOUND	2.18E-01	2.73E-02	76
L-EDEWBODY	1.2-1.6 km	0.9532	9.61E-02	9.08E-02	1.53E-01	1.87E-01	NOT-FOUND	NOT-FOUND	2.18E-01	2.16E-02	122
L-EDEWBODY	1.6-2.1 km	0.8069	8.79E-02	8.18E-02	1.36E-01	1.58E-01	2.02E-01	2.05E-01	2.19E-01	1.43E-04	12
L-EDEWBODY	2.1-3.2 km	0.8583	1.09E-01	1.08E-01	2.02E-01	2.04E-01	2.10E-01	2.12E-01	2.19E-01	7.71E-04	42
L-EDEWBODY	3.2-4.0 km	0.9014	1.07E-01	1.07E-01	1.71E-01	2.00E-01	2.05E-01	2.08E-01	2.19E-01	1.43E-04	129

L-EDEWBODY	4.0-4.8 km	0.9801	1.10E-01	1.06E-01	1.47E-01	1.69E-01	NOT-FOUND	NOT-FOUND	2.06E-01	2.21E-02	47
L-EDEWBODY	4.8-5.6 km	0.9801	1.01E-01	1.04E-01	1.45E-01	1.68E-01	NOT-FOUND	NOT-FOUND	1.91E-01	2.73E-02	135
L-EDEWBODY	5.6-8.1 km	0.9805	9.11E-02	8.23E-02	1.19E-01	1.31E-01	1.64E-01	1.80E-01	1.94E-01	2.94E-03	118
L-EDEWBODY	8.1-11.3 km	0.9805	7.80E-02	7.18E-02	1.16E-01	1.30E-01	1.66E-01	1.84E-01	1.94E-01	3.62E-03	102
L-EDEWBODY	11.3-16.1 km	0.9805	7.18E-02	4.97E-02	1.28E-01	1.49E-01	NOT-FOUND	NOT-FOUND	1.90E-01	1.55E-02	84
L-EDEWBODY	16.1-20.9 km	0.9806	6.93E-02	4.02E-02	1.11E-01	1.17E-01	1.33E-01	1.40E-01	1.89E-01	1.14E-04	132
L-EDEWBODY	20.9-25.8 km	1.0000	8.30E-02	9.27E-02	1.15E-01	1.22E-01	1.41E-01	1.50E-01	1.88E-01	4.00E-04	26
L-EDEWBODY	25.8-32.2 km	1.0000	1.16E-01	1.03E-01	1.18E-01	1.26E-01	1.44E-01	1.53E-01	1.89E-01	4.57E-04	126
L-EDEWBODY	32.2-40.2 km	1.0000	1.10E-01	1.02E-01	1.23E-01	1.33E-01	1.60E-01	1.73E-01	1.90E-01	2.11E-03	127
L-EDEWBODY	40.2-48.3 km	1.0000	8.78E-02	9.68E-02	1.32E-01	1.49E-01	NOT-FOUND	NOT-FOUND	1.81E-01	1.63E-02	67
L-EDEWBODY	48.3-64.4 km	1.0000	7.25E-02	6.72E-02	1.14E-01	1.26E-01	1.58E-01	1.75E-01	1.83E-01	3.62E-03	102

09/26/96 08:40:08 PAGE 8

		PROB NON-ZERO	MEAN	QUANTILES 50TH	90TH	95TH	99TH	99.5TH	PEAK CONS	PEAK PROB	PEAK TRIAL
PEAK DOSE FOUND ON SPATIAL GRID (Sv)											
L-EDEWBODY	64.4-80.5 km	1.0000	6.31E-02	5.99E-02	9.75E-02	1.08E-01	1.33E-01	1.45E-01	1.75E-01	1.17E-03	92
L-EDEWBODY	80.5-113 km	1.0000	5.80E-02	5.19E-02	8.57E-02	9.82E-02	1.16E-01	1.24E-01	1.43E-01	1.17E-03	69
L-EDEWBODY	113-161 km	1.0000	5.38E-02	4.84E-02	8.79E-02	1.00E-01	1.01E-01	1.01E-01	1.02E-01	3.14E-04	72
L-EDEWBODY	161-241 km	1.0000	5.23E-02	5.20E-02	7.36E-02	7.79E-02	8.91E-02	9.43E-02	9.66E-02	3.77E-03	65
L-EDEWBODY	241-322 km	1.0000	4.67E-02	4.21E-02	7.38E-02	7.82E-02	8.94E-02	9.47E-02	9.61E-02	4.22E-03	63
L-EDEWBODY	322-563 km	1.0000	3.27E-02	3.00E-02	7.11E-02	8.44E-02	NOT-FOUND	NOT-FOUND	9.80E-02	2.73E-02	135
L-EDEWBODY	563-805 km	1.0000	1.10E-02	7.33E-03	2.56E-02	3.17E-02	4.04E-02	4.49E-02	5.33E-02	2.45E-03	64
L-EDEWBODY	805-1609 km	1.0000	1.60E-03	6.92E-04	4.00E-03	7.12E-03	8.87E-03	9.75E-03	1.45E-02	4.14E-03	105
L-EDEWBODY POP. DOSE (Sv) 0-1609 km											
TOTAL LONG-TERM PATHWAYS DOSE		1.0000	2.20E+05	1.12E+05	5.33E+05	7.52E+05	1.36E+06	1.71E+06	2.19E+06	1.11E-03	135
LONG-TERM DIRECT EXPOSURE PATHWAYS		1.0000	1.88E+05	8.83E+04	4.46E+05	6.82E+05	1.22E+06	1.43E+06	2.16E+06	1.11E-03	135
TOTAL INGESTION PATHWAYS DOSE		1.0000	2.89E+04	1.04E+04	7.36E+04	1.21E+05	2.66E+05	3.14E+05	4.71E+05	2.28E-04	4
LONG-TERM GROUNDSHINE DOSE		1.0000	1.83E+05	8.50E+04	4.43E+05	6.82E+05	1.22E+06	1.42E+06	2.13E+06	1.11E-03	135
LONG-TERM RESUSPENSION DOSE		1.0000	4.54E+03	2.95E+03	9.92E+03	1.38E+04	2.29E+04	2.56E+04	3.60E+04	6.85E-04	15
WATER INGESTION DOSE		1.0000	1.77E+03	1.31E+03	3.47E+03	4.60E+03	6.41E+03	7.14E+03	1.23E+04	1.88E-05	39
POP.-DEPENDENT DECONTAMINATION DOSE		1.0000	3.14E+03	1.66E+03	7.69E+03	1.07E+04	1.91E+04	2.13E+04	4.32E+04	2.15E-04	102
FARM-DEPENDENT DECONTAMINATION DOSE		1.0000	1.01E+02	6.82E+01	2.25E+02	2.68E+02	3.36E+02	3.59E+02	4.69E+02	3.14E-04	83
INGESTION OF GRAINS		1.0000	2.05E+03	3.63E+02	6.47E+03	1.03E+04	2.22E+04	2.84E+04	4.00E+04	2.43E-03	52
INGESTION OF LEAF VEG		1.0000	2.05E+03	3.63E+02	6.47E+03	1.03E+04	2.22E+04	2.84E+04	4.00E+04	2.43E-03	52
INGESTION OF ROOT CROPS		1.0000	1.37E+03	2.37E+02	3.82E+03	7.26E+03	1.57E+04	2.09E+04	3.39E+04	2.28E-04	4
INGESTION OF FRUITS		1.0000	1.93E+03	2.60E+02	5.29E+03	1.05E+04	2.38E+04	3.05E+04	4.94E+04	2.28E-04	4
INGESTION OF LEGUMES		1.0000	1.35E+03	3.96E+02	3.48E+03	6.42E+03	1.33E+04	1.67E+04	2.93E+04	2.28E-04	4
INGESTION OF BEEF		1.0000	9.60E+03	2.62E+03	2.31E+04	4.40E+04	1.10E+05	1.42E+05	2.35E+05	2.28E-04	4
INGESTION OF MILK		1.0000	6.76E+03	2.30E+03	1.59E+04	2.90E+04	6.44E+04	8.71E+04	1.29E+05	2.28E-04	6
INGESTION OF POULTRY		1.0000	2.40E+03	5.09E+02	7.08E+03	1.14E+04	2.59E+04	3.26E+04	4.39E+04	1.77E-03	5
INGESTION OF OTHER MEAT CROPS		1.0000	7.39E+02	3.24E+02	1.99E+03	2.57E+03	5.40E+03	6.73E+03	8.33E+03	2.43E-03	52
L-EDEWBODY POP. DOSE (Sv) 0-80.5 km											
TOTAL LONG-TERM PATHWAYS DOSE		1.0000	1.77E+04	8.96E+03	4.33E+04	6.29E+04	9.69E+04	1.07E+05	1.52E+05	2.15E-04	102
LONG-TERM DIRECT EXPOSURE PATHWAYS		1.0000	1.33E+04	5.97E+03	3.48E+04	5.30E+04	7.47E+04	7.88E+04	1.06E+05	2.15E-04	102
TOTAL INGESTION PATHWAYS DOSE		1.0000	1.87E+03	1.45E+03	3.16E+03	4.05E+03	6.41E+03	7.22E+03	1.26E+04	3.22E-05	107
LONG-TERM GROUNDSHINE DOSE		1.0000	1.24E+04	5.40E+03	3.34E+04	5.10E+04	7.47E+04	7.88E+04	1.05E+05	2.15E-04	102
LONG-TERM RESUSPENSION DOSE		1.0000	9.30E+02	4.16E+02	2.42E+03	3.83E+03	6.47E+03	7.21E+03	1.26E+04	5.84E-06	109
WATER INGESTION DOSE		1.0000	1.18E+03	8.16E+02	2.34E+03	3.05E+03	5.71E+03	6.92E+03	1.22E+04	1.88E-05	39
POP.-DEPENDENT DECONTAMINATION DOSE		1.0000	2.41E+03	1.00E+03	6.59E+03	1.01E+04	1.83E+04	2.10E+04	4.32E+04	2.15E-04	102
FARM-DEPENDENT DECONTAMINATION DOSE		1.0000	5.79E+01	5.25E+01	1.03E+02	1.08E+02	1.21E+02	1.27E+02	1.56E+02	2.16E-04	110
INGESTION OF GRAINS		1.0000	1.26E+02	1.02E+02	2.53E+02	3.24E+02	5.11E+02	5.43E+02	6.18E+02	1.14E-03	50
INGESTION OF LEAF VEG		1.0000	1.26E+02	1.02E+02	2.53E+02	3.24E+02	5.11E+02	5.43E+02	6.18E+02	1.14E-03	50
INGESTION OF ROOT CROPS		1.0000	7.31E+01	6.30E+01	1.25E+02	1.46E+02	2.04E+02	2.15E+02	3.56E+02	1.41E-05	109
INGESTION OF FRUITS		1.0000	6.26E+01	5.53E+01	1.03E+02	1.08E+02	1.18E+02	1.23E+02	1.78E+02	1.04E-05	109
INGESTION OF LEGUMES		1.0000	1.25E+02	1.05E+02	2.27E+02	2.67E+02	3.45E+02	3.76E+02	6.62E+02	1.41E-05	109
INGESTION OF BEEF		1.0000	1.01E+02	6.33E+01	2.11E+02	3.48E+02	5.36E+02	5.61E+02	7.10E+02	3.92E-05	107
INGESTION OF MILK		1.0000	1.32E+02	9.69E+01	2.72E+02	3.55E+02	5.16E+02	5.36E+02	7.08E+02	5.37E-06	109
INGESTION OF POULTRY		1.0000	1.84E+01	1.05E+01	4.70E+01	6.75E+01	1.05E+02	1.10E+02	1.19E+02	1.14E-03	50
INGESTION OF OTHER MEAT CROPS		1.0000	2.62E+01	1.39E+01	6.94E+01	8.58E+01	1.16E+02	1.28E+02	1.80E+02	4.00E-04	78

ECONOMIC COST MEASURES ($) 0-1609 km										
TOTAL ECONOMIC COSTS	1.0000	1.18E+10	6.46E+09	2.33E+10	3.54E+10	6.48E+10	9.38E+10	2.69E+11	1.11E-03	76
POP.-DEPENDENT COSTS	1.0000	1.07E+10	5.45E+09	2.15E+10	3.26E+10	6.35E+10	8.23E+10	2.68E+11	1.11E-03	76
FARM-DEPENDENT COSTS	1.0000	1.17E+09	5.50E+08	3.36E+09	5.05E+09	6.69E+09	7.21E+09	8.59E+09	4.00E-04	4
POP.-DEPENDENT DECONTAMINATION COST	1.0000	2.71E+09	1.32E+09	5.97E+09	9.02E+09	1.77E+10	2.50E+10	6.60E+10	1.11E-03	76
FARM-DEPENDENT DECONTAMINATION COST	1.0000	2.33E+08	1.31E+08	5.36E+08	6.59E+08	1.13E+09	1.21E+09	1.42E+09	9.70E-04	15

09/26/96 08:40:08 PAGE 9

	PROB NON-ZERO	MEAN	QUANTILES 50TH	90TH	95TH	99TH	99.5TH	PEAK CONS	PEAK PROB	PEAK TRIAL
ECONOMIC COST MEASURES ($) 0-1609 km										
POP.-DEPENDENT INTERDICTION COST	1.0000	7.31E+09	3.51E+09	1.56E+10	2.59E+10	4.41E+10	7.29E+10	2.02E+11	1.11E-03	76
FARM-DEPENDENT INTERDICTION COST	1.0000	4.73E+08	1.22E+08	1.36E+09	2.22E+09	3.22E+09	3.39E+09	4.26E+09	2.28E-04	4
POP.-DEPENDENT CONDEMNATION COST	0.9121	6.35E+08	1.26E+08	1.50E+09	3.33E+09	6.70E+09	7.80E+09	4.44E+10	5.71E-05	75
FARM-DEPENDENT CONDEMNATION COST	1.0000	1.45E+07	1.18E+07	2.90E+07	3.38E+07	4.68E+07	5.25E+07	7.91E+07	1.45E-04	92
EMERGENCY PHASE COST	1.0000	6.03E+06	2.49E+06	1.26E+07	3.09E+07	6.16E+07	8.41E+07	1.11E+08	1.11E-03	86
INTERMEDIATE PHASE COST	0.0000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0
MILK DISPOSAL COST	1.0000	3.38E+07	4.87E+06	9.63E+07	1.84E+08	2.98E+08	3.71E+08	1.91E+09	4.00E-04	4
CROP DISPOSAL COST	1.0000	4.12E+08	1.42E+08	1.23E+09	1.89E+09	2.14E+09	2.21E+09	2.60E+09	1.43E-04	4
ECONOMIC COST MEASURES ($) 0-80.5 km										
TOTAL ECONOMIC COSTS	1.0000	4.44E+09	2.09E+09	1.15E+10	1.73E+10	2.62E+10	3.01E+10	5.74E+10	2.15E-04	102
POP.-DEPENDENT COSTS	1.0000	4.30E+09	1.87E+09	1.12E+10	1.69E+10	2.61E+10	3.01E+10	5.72E+10	2.15E-04	102
FARM-DEPENDENT COSTS	1.0000	1.35E+08	1.14E+08	2.32E+08	2.84E+08	3.22E+08	3.33E+08	3.57E+08	1.26E-03	52
POP.-DEPENDENT DECONTAMINATION COST	1.0000	1.02E+09	3.71E+08	2.68E+09	5.06E+09	6.45E+09	7.05E+09	7.34E+09	2.37E-03	55
FARM-DEPENDENT DECONTAMINATION COST	1.0000	5.39E+07	5.01E+07	1.00E+08	1.04E+08	1.14E+08	1.18E+08	1.65E+08	1.04E-05	109
POP.-DEPENDENT INTERDICTION COST	1.0000	2.64E+09	1.05E+09	7.85E+09	1.11E+10	1.71E+10	2.05E+10	3.73E+10	2.15E-04	102
FARM-DEPENDENT INTERDICTION COST	1.0000	4.20E+07	3.23E+07	9.12E+07	1.05E+08	1.22E+08	1.30E+08	1.49E+08	1.17E-03	49
POP.-DEPENDENT CONDEMNATION COST	0.9121	6.35E+08	1.26E+08	1.50E+09	3.33E+09	6.70E+09	7.80E+09	4.44E+10	5.71E-05	75
FARM-DEPENDENT CONDEMNATION COST	1.0000	1.45E+07	1.18E+07	2.90E+07	3.38E+07	4.68E+07	5.25E+07	7.91E+07	1.45E-04	92
EMERGENCY PHASE COST	1.0000	5.94E+06	2.40E+06	1.24E+07	3.08E+07	6.16E+07	8.41E+07	1.11E+08	1.11E-03	86
INTERMEDIATE PHASE COST	0.0000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0
MILK DISPOSAL COST	1.0000	1.33E+06	9.85E+05	2.57E+06	3.05E+06	3.29E+06	3.40E+06	4.61E+06	9.57E-06	24
CROP DISPOSAL COST	1.0000	2.29E+07	1.71E+07	4.65E+07	5.59E+07	7.24E+07	7.58E+07	8.54E+07	8.28E-04	34
MAXIMUM LONG-TERM ACTION DISTANCE (km)										
FARM-DEPENDENT DECONTAMINATION DIST.	1.0000	2.00E+02	1.78E+02	3.77E+02	4.69E+02	NOT-FOUND	NOT-FOUND	5.63E+02	4.07E-02	2
POP.-DEPENDENT DECONTAMINATION DIST.	1.0000	2.10E+02	1.96E+02	3.88E+02	4.79E+02	NOT-FOUND	NOT-FOUND	5.63E+02	4.36E-02	2
FARM-DEPENDENT INTERDICTION DIST.	1.0000	2.99E+02	2.30E+02	6.90E+02	NOT-FOUND	NOT-FOUND	NOT-FOUND	8.05E+02	9.61E-02	1
POP.-DEPENDENT INTERDICTION DIST.	1.0000	2.10E+02	1.96E+02	3.88E+02	4.79E+02	NOT-FOUND	NOT-FOUND	5.63E+02	4.36E-02	2
FARM-DEPENDENT CONDEMNATION DIST.	1.0000	2.79E+01	2.81E+01	3.67E+01	4.03E+01	4.99E+01	5.54E+01	8.05E+01	1.08E-03	92
POP.-DEPENDENT CONDEMNATION DIST.	0.9121	1.81E+01	2.06E+01	3.13E+01	3.42E+01	4.19E+01	4.57E+01	6.44E+01	2.45E-03	75
MILK DISPOSAL DIST.	1.0000	3.24E+02	2.21E+02	7.61E+02	8.49E+02	NOT-FOUND	NOT-FOUND	1.61E+03	1.78E-02	4
CROP DISPOSAL DIST.	1.0000	2.90E+02	2.21E+02	6.89E+02	NOT-FOUND	NOT-FOUND	NOT-FOUND	8.05E+02	9.61E-02	1
AFFECTED AREA/POPULATION 0-1609 km										
FARM DECONTAMINATION (HECTARES)	1.0000	3.19E+05	1.70E+05	7.65E+05	9.25E+05	2.05E+06	2.12E+06	2.29E+06	9.70E-04	15
POP. DECONTAMINATION (INDIVIDUALS)	1.0000	6.62E+05	3.04E+05	1.40E+06	2.62E+06	4.69E+06	7.29E+06	2.19E+07	1.11E-03	76
FARM INTERDICTION (HECTARES)	1.0000	8.41E+05	3.03E+05	2.51E+06	3.86E+06	5.36E+06	5.59E+06	5.92E+06	1.88E-03	52
POP. INTERDICTION (INDIVIDUALS)	1.0000	6.62E+05	3.04E+05	1.40E+06	2.62E+06	4.69E+06	7.29E+06	2.19E+07	1.11E-03	76
FARM CONDEMNATION (HECTARES)	1.0000	6.98E+03	5.99E+03	1.28E+04	1.53E+04	2.35E+04	2.82E+04	3.81E+04	1.45E-04	92
POP. CONDEMNATION (INDIVIDUALS)	0.9121	7.19E+03	1.33E+03	1.60E+04	3.34E+04	9.36E+04	1.07E+05	4.99E+05	5.71E-05	75
MILK DISPOSAL AREA (HECTARES)	1.0000	1.20E+06	2.71E+05	3.75E+06	5.36E+06	9.34E+06	2.18E+07	3.69E+07	2.28E-04	4
CROP DISPOSAL AREA (HECTARES)	1.0000	8.09E+05	2.78E+05	2.49E+06	3.86E+06	5.36E+06	5.59E+06	5.92E+06	1.88E-03	52
AFFECTED AREA/POPULATION 0-80.5 km										
FARM DECONTAMINATION (HECTARES)	1.0000	5.73E+04	4.57E+04	1.04E+05	1.10E+05	1.27E+05	1.35E+05	2.22E+05	1.04E-05	109
POP. DECONTAMINATION (INDIVIDUALS)	1.0000	1.75E+05	6.86E+04	5.20E+05	7.38E+05	1.00E+06	1.01E+06	1.11E+06	7.47E-06	109
FARM INTERDICTION (HECTARES)	1.0000	7.37E+04	5.69E+04	1.36E+05	1.72E+05	2.17E+05	2.28E+05	2.58E+05	8.28E-04	34
POP. INTERDICTION (INDIVIDUALS)	1.0000	1.75E+05	6.86E+04	5.20E+05	7.38E+05	1.00E+06	1.01E+06	1.11E+06	7.47E-06	109
FARM CONDEMNATION (HECTARES)	1.0000	6.98E+03	5.99E+03	1.28E+04	1.53E+04	2.35E+04	2.82E+04	3.81E+04	1.45E-04	92

POP. CONDEMNATION (INDIVIDUALS)	0.9121	7.19E+03	1.33E+03	1.60E+04	3.34E+04	9.36E+04	1.07E+05	4.99E+05	5.71E-05	75
MILK DISPOSAL AREA (HECTARES)	1.0000	7.27E+04	5.71E+04	1.34E+05	1.71E+05	2.07E+05	2.11E+05	2.51E+05	9.57E-06	24
CROP DISPOSAL AREA (HECTARES)	1.0000	7.39E+04	5.85E+04	1.36E+05	1.77E+05	2.19E+05	2.29E+05	2.60E+05	8.28E-04	34

	PROB NON-ZERO	MEAN	QUANTILES 50TH	90TH	95TH	99TH	99.5TH	PEAK CONS	PEAK PROB	PEAK TRIAL
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE)										
PROJECTED FOR INDIVIDUAL 0.2-0.5 km	0.0358	4.47E-05	0.00E+00	0.00E+00	0.00E+00	1.95E-03	2.20E-03	3.28E-03	4.57E-04	126
PROJECTED FOR INDIVIDUAL 1.2-1.6 km	0.1928	6.84E-04	0.00E+00	3.17E-03	3.51E-03	4.46E-03	4.94E-03	9.83E-03	4.14E-03	90
PROJECTED FOR INDIVIDUAL 2.1-3.2 km	0.3295	1.46E-03	0.00E+00	3.81E-03	4.71E-03	1.09E-02	1.18E-02	1.84E-02	1.14E-04	109
PROJECTED FOR INDIVIDUAL 4.0-4.8 km	0.4487	1.65E-03	0.00E+00	3.79E-03	4.45E-03	8.59E-03	9.97E-03	1.71E-02	6.85E-04	108
PROJECTED FOR INDIVIDUAL 5.6-8.1 km	0.7930	4.72E-03	3.19E-03	1.03E-02	1.10E-02	1.28E-02	1.36E-02	1.94E-02	1.14E-04	109
PROJECTED FOR INDIVIDUAL 11.3-16.1 km	0.8727	5.05E-03	3.78E-03	9.89E-03	1.44E-02	NOT-FOUND	NOT-FOUND	2.25E-02	2.73E-02	52
PROJECTED FOR INDIVIDUAL 20.9-25.8 km	0.8807	4.34E-03	3.26E-03	9.87E-03	1.08E-02	1.31E-02	1.42E-02	1.89E-02	4.57E-04	99
PROJECTED FOR INDIVIDUAL 32.2-40.2 km	0.9845	5.45E-03	4.27E-03	1.04E-02	1.15E-02	1.46E-02	1.62E-02	2.48E-02	1.17E-03	53
PROJECTED FOR INDIVIDUAL 48.3-64.4 km	1.0000	5.86E-03	3.88E-03	1.26E-02	1.68E-02	NOT-FOUND	NOT-FOUND	2.47E-02	1.63E-02	96
PROJECTED FOR INDIVIDUAL 80.5-113 km	1.0000	4.39E-03	3.12E-03	8.18E-03	9.35E-03	2.23E-02	2.41E-02	3.05E-02	6.85E-04	108
MAXIMUM ANNUAL FOOD DOSE (THYROID)										
PROJECTED FOR INDIVIDUAL 0.2-0.5 km	0.0358	6.67E-05	0.00E+00	0.00E+00	0.00E+00	2.09E-03	2.56E-03	9.13E-03	2.94E-03	62
PROJECTED FOR INDIVIDUAL 1.2-1.6 km	0.1928	3.15E-04	0.00E+00	1.24E-04	1.57E-04	2.81E-03	4.65E-03	9.96E-02	4.57E-04	126
PROJECTED FOR INDIVIDUAL 2.1-3.2 km	0.3295	4.52E-03	0.00E+00	2.31E-03	5.45E-02	8.23E-02	9.63E-02	1.01E-01	4.22E-03	78
PROJECTED FOR INDIVIDUAL 4.0-4.8 km	0.4487	3.06E-03	0.00E+00	2.15E-03	2.18E-02	NOT-FOUND	NOT-FOUND	8.73E-02	1.63E-02	67
PROJECTED FOR INDIVIDUAL 5.6-8.1 km	0.7930	1.63E-02	6.40E-04	5.58E-02	7.27E-02	9.67E-02	1.06E-01	1.09E-01	4.14E-03	105
PROJECTED FOR INDIVIDUAL 11.3-16.1 km	0.8727	3.64E-02	2.21E-02	1.06E-01	1.20E-01	NOT-FOUND	NOT-FOUND	1.39E-01	2.16E-02	29
PROJECTED FOR INDIVIDUAL 20.9-25.8 km	0.8807	3.36E-02	2.24E-02	8.24E-02	1.07E-01	NOT-FOUND	NOT-FOUND	1.34E-01	2.21E-02	47
PROJECTED FOR INDIVIDUAL 32.2-40.2 km	0.9845	3.84E-02	2.90E-02	9.03E-02	1.02E-01	1.13E-01	1.18E-01	1.38E-01	3.42E-04	117
PROJECTED FOR INDIVIDUAL 48.3-64.4 km	1.0000	4.03E-02	2.18E-02	1.07E-01	1.26E-01	NOT-FOUND	NOT-FOUND	1.46E-01	2.70E-02	89
PROJECTED FOR INDIVIDUAL 80.5-113 km	1.0000	3.17E-02	1.37E-02	9.30E-02	1.03E-01	1.14E-01	1.19E-01	1.44E-01	2.28E-04	18

SOURCE TERM 1 OF 2:
SECOND DRAFT 1150, WORST CASE SOURCE TERM FOR EARLY FATALITIES

RESULT NAME = HEALTH EFFECTS CASES
CAN FAT/TOTAL 0-80.5 km

PEOPLE FRACTION = 0.9500 0.0500

OVERALL		EMER. RESP. # 1		EMER. RESP. # 2		CHRONC RESULTS	
X	PROB>=X	X	PROB>=X	X	PROB>=X	X	PROB>=X
1.00E-04	1.00E+00	1.00E-04	1.00E+00	1.00E-04	1.00E+00	1.00E-04	1.00E+00
2.00E-04	1.00E+00	2.00E-04	1.00E+00	2.00E-04	1.00E+00	2.00E-04	1.00E+00
3.00E-04	1.00E+00	3.00E-04	1.00E+00	3.00E-04	1.00E+00	3.00E-04	1.00E+00
5.00E-04	1.00E+00	5.00E-04	1.00E+00	5.00E-04	1.00E+00	5.00E-04	1.00E+00
7.00E-04	1.00E+00	7.00E-04	1.00E+00	7.00E-04	1.00E+00	7.00E-04	1.00E+00
1.00E-03	1.00E+00	1.00E-03	1.00E+00	1.00E-03	1.00E+00	1.00E-03	1.00E+00
2.00E-03	1.00E+00	2.00E-03	1.00E+00	2.00E-03	1.00E+00	2.00E-03	1.00E+00
3.00E-03	1.00E+00	3.00E-03	1.00E+00	3.00E-03	1.00E+00	3.00E-03	1.00E+00
5.00E-03	1.00E+00	5.00E-03	1.00E+00	5.00E-03	1.00E+00	5.00E-03	1.00E+00
7.00E-03	1.00E+00	7.00E-03	1.00E+00	7.00E-03	1.00E+00	7.00E-03	1.00E+00
1.00E-02	1.00E+00	1.00E-02	1.00E+00	1.00E-02	1.00E+00	1.00E-02	1.00E+00
2.00E-02	1.00E+00	2.00E-02	1.00E+00	2.00E-02	1.00E+00	2.00E-02	1.00E+00
3.00E-02	1.00E+00	3.00E-02	1.00E+00	3.00E-02	1.00E+00	3.00E-02	1.00E+00
5.00E-02	1.00E+00	5.00E-02	1.00E+00	5.00E-02	1.00E+00	5.00E-02	1.00E+00
7.00E-02	1.00E+00	7.00E-02	1.00E+00	7.00E-02	1.00E+00	7.00E-02	1.00E+00
1.00E-01	1.00E+00	1.00E-01	1.00E+00	1.00E-01	1.00E+00	1.00E-01	1.00E+00

```
 2.00E-01  1.00E+00    2.00E-01  1.00E+00    2.00E-01  1.00E+00    2.00E-01  1.00E+00
 3.00E-01  1.00E+00    3.00E-01  1.00E+00    3.00E-01  1.00E+00    3.00E-01  1.00E+00
 5.00E-01  1.00E+00    5.00E-01  1.00E+00    5.00E-01  1.00E+00    5.00E-01  1.00E+00
 7.00E-01  1.00E+00    7.00E-01  1.00E+00    7.00E-01  1.00E+00    7.00E-01  1.00E+00
 1.00E+00  1.00E+00    1.00E+00  1.00E+00    1.00E+00  1.00E+00    1.00E+00  1.00E+00
 2.00E+00  1.00E+00    2.00E+00  1.00E+00    2.00E+00  1.00E+00    2.00E+00  1.00E+00
 3.00E+00  1.00E+00    3.00E+00  1.00E+00    3.00E+00  1.00E+00    3.00E+00  1.00E+00
 5.00E+00  1.00E+00    5.00E+00  1.00E+00    5.00E+00  1.00E+00    5.00E+00  1.00E+00
 7.00E+00  1.00E+00    7.00E+00  1.00E+00    7.00E+00  1.00E+00    7.00E+00  1.00E+00
 1.00E+01  1.00E+00    1.00E+01  1.00E+00    1.00E+01  1.00E+00    1.00E+01  1.00E+00
 2.00E+01  1.00E+00    2.00E+01  9.99E-01    2.00E+01  1.00E+00    2.00E+01  1.00E+00
 3.00E+01  1.00E+00    3.00E+01  9.99E-01    3.00E+01  1.00E+00    3.00E+01  1.00E+00
 5.00E+01  1.00E+00    5.00E+01  9.90E-01    5.00E+01  1.00E+00    5.00E+01  1.00E+00
 7.00E+01  1.00E+00    7.00E+01  9.71E-01    7.00E+01  9.98E-01    7.00E+01  9.99E-01
 1.00E+02  9.99E-01    1.00E+02  9.43E-01    1.00E+02  9.91E-01    1.00E+02  9.97E-01
 2.00E+02  9.92E-01    2.00E+02  7.98E-01    2.00E+02  8.87E-01    2.00E+02  8.60E-01
 3.00E+02  9.57E-01    3.00E+02  6.54E-01    3.00E+02  7.57E-01    3.00E+02  6.40E-01
 5.00E+02  8.00E-01    5.00E+02  4.44E-01    5.00E+02  5.79E-01    5.00E+02  4.23E-01
 7.00E+02  6.32E-01    7.00E+02  3.28E-01    7.00E+02  4.34E-01    7.00E+02  3.28E-01
 1.00E+03  4.83E-01    1.00E+03  2.42E-01    1.00E+03  3.03E-01    1.00E+03  2.40E-01
 2.00E+03  2.36E-01    2.00E+03  1.34E-01    2.00E+03  1.40E-01    2.00E+03  9.54E-02
 3.00E+03  1.54E-01    3.00E+03  5.48E-02    3.00E+03  6.61E-02    3.00E+03  3.98E-02
 5.00E+03  7.47E-02    5.00E+03  1.73E-02    5.00E+03  1.86E-02    5.00E+03  2.64E-03
 7.00E+03  3.39E-02    7.00E+03  1.05E-02    7.00E+03  1.43E-03    6.79E+03  2.15E-04
 1.00E+04  8.40E-03    1.00E+04  3.27E-03    9.00E+03  1.11E-03       N.D.      N.D.
 2.00E+04  2.85E-04    1.90E+04  2.85E-04       N.D.      N.D.       N.D.      N.D.
 2.07E+04  2.85E-04       N.D.      N.D.       N.D.      N.D.       N.D.      N.D.
    N.D.      N.D.       N.D.      N.D.       N.D.      N.D.       N.D.      N.D.
    N.D.      N.D.       N.D.      N.D.       N.D.      N.D.       N.D.      N.D.
    N.D.      N.D.       N.D.      N.D.       N.D.      N.D.       N.D.      N.D.

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX


  DATE AND TIME OF RUN = MACCS2 09/26/96   08:40:08   Version 1.12, Last Modified 9/25/96 by D. Chanin
  "ATMOS"  DESCRIPTION = IN1A.INP, Sample Problem A--Using Table-Lookup Sigmas, ATMOS input
  "EARLY"  DESCRIPTION = IN2A.INP, Sample Problem A of NUREG/CR-4691, Vol. 1, EARLY input
  "CHRONC" DESCRIPTION = IN3A_N.INP, Sample Problem A, "New" COMIDA2-Based Food Model

SOURCE TERM  2 OF  2:
    RELEASE FRACTIONS OF SOURCE TERM 1 REDUCED BY A FACTOR OF TEN

OVERALL RESULTS OBTAINED BY COMBINING 2 EMERGENCY RESPONSE COHORTS FROM "EARLY" WITH THE WEIGHTING FRACTIONS BELOW APPLIED TO THEM:

                                                                                   FRACTION OF THE PEOPLE
                                                                                                   ------
    COHORT 1 = EVACUATION WITHIN 10 MILES, RELOCATION MODELS APPLY ELSEWHERE                        0.950

    COHORT 2 = NO EVACUATION, RELOCATION MODELS APPLY EVERYWHERE                                    0.050

AND THEN MERGING THE 2 RESULTS ABOVE WITH THE SINGLE SET OF RESULTS FROM "CHRONC" DESCRIBED BELOW:

    COHORT 3 = IN3A_N.INP, Sample Problem A, "New" COMIDA2-Based Food Model

RESULTS WHICH ARE PRODUCED ONLY BY "EARLY" OR ONLY BY "CHRONC" ARE PRESENTED IN LATER SECTIONS.

09/26/96   08:40:08    PAGE  12          PROB                         QUANTILES                             PEAK      PEAK  PEAK
                                       NON-ZERO   MEAN      50TH      90TH      95TH      99TH     99.5TH     CONS      PROB  TRIAL
HEALTH EFFECTS CASES
 ERL FAT/TOTAL               0-1609 km  0.1958  4.54E-03  0.00E+00  1.24E-03  8.52E-03  1.52E-01  2.11E-01  1.08E+00  1.14E-04   17
```

ERL INJ/PRODROMAL VOMIT	0-1609 km	0.4849	1.48E-01	0.00E+00	3.20E-01	8.49E-01	2.94E+00	3.66E+00	6.90E+00	8.28E-04	94
ERL INJ/DIARRHEA	0-1609 km	0.3026	3.57E-02	0.00E+00	3.81E-02	1.31E-01	1.06E+00	1.31E+00	2.68E+00	1.14E-04	17
ERL INJ/PNEUMONITIS	0-1609 km	0.0312	3.92E-04	0.00E+00	0.00E+00	0.00E+00	1.18E-02	1.72E-02	4.25E-01	1.14E-04	17
ERL INJ/THYROIDITIS	0-1609 km	0.0872	6.48E-03	0.00E+00	0.00E+00	3.12E-02	1.39E-01	1.85E-01	1.03E+00	8.28E-04	94
ERL INJ/HYPOTHYROIDISM	0-1609 km	0.6486	7.68E+00	1.12E-01	1.37E+01	2.73E+01	1.48E+02	2.16E+02	6.39E+02	2.85E-04	85
ERL INJ/SKIN ERYTHEMA	0-1609 km	0.7985	4.31E+02	1.76E+01	7.88E+02	1.92E+03	7.90E+03	1.03E+04	2.51E+04	2.85E-04	123
ERL INJ/TRANSEPIDERMAL	0-1609 km	0.6705	8.72E+01	4.15E-01	1.26E+02	2.33E+02	1.82E+03	3.24E+03	8.80E+03	3.14E-04	87
CAN FAT/TOTAL	0-1609 km	1.0000	1.95E+03	1.32E+03	4.13E+03	5.45E+03	9.04E+03	1.06E+04	1.95E+04	1.14E-04	112
CAN FAT/LUNG	0-1609 km	1.0000	2.97E+02	2.15E+02	6.35E+02	8.19E+02	1.21E+03	1.38E+03	2.98E+03	1.14E-04	112
CAN FAT/THYROID	0-1609 km	1.0000	3.86E+01	2.74E+01	7.88E+01	1.04E+02	1.68E+02	2.02E+02	3.58E+02	1.14E-04	112
CAN FAT/BREAST	0-1609 km	1.0000	2.17E+02	1.43E+02	4.68E+02	6.36E+02	1.01E+03	1.12E+03	2.41E+03	1.14E-04	112
CAN FAT/GI	0-1609 km	1.0000	5.81E+02	3.97E+02	1.25E+03	1.71E+03	2.75E+03	3.13E+03	5.65E+03	1.14E-04	112
CAN FAT/LEUKEMIA	0-1609 km	1.0000	1.83E+02	1.25E+02	3.91E+02	5.26E+02	8.09E+02	9.90E+02	1.84E+03	1.14E-04	112
CAN FAT/BONE	0-1609 km	1.0000	2.26E+01	1.59E+01	4.61E+01	5.99E+01	9.26E+01	1.06E+02	2.04E+02	1.14E-04	112
CAN FAT/OTHER	0-1609 km	1.0000	6.15E+02	4.44E+02	1.26E+03	1.66E+03	2.75E+03	3.14E+03	6.08E+03	1.14E-04	112
CAN INJ/THYROID	0-1609 km	1.0000	3.86E+02	2.74E+02	7.88E+02	1.04E+03	1.68E+03	2.02E+03	3.58E+03	1.14E-04	112
CAN INJ/BREAST	0-1609 km	1.0000	6.83E+02	4.89E+02	1.46E+03	2.03E+03	3.15E+03	3.57E+03	7.58E+03	1.14E-04	112
CAN FAT/TOTAL	0-80.5 km	1.0000	4.68E+02	2.37E+02	1.17E+03	1.76E+03	2.59E+03	2.95E+03	4.08E+03	2.15E-04	102
ERL FAT/TOTAL	0-16.1 km	0.1958	4.54E-03	0.00E+00	1.24E-03	8.52E-03	1.52E-01	2.11E-01	1.08E+00	1.14E-04	17
ERL INJ/PRODROMAL VOMIT	0-16.1 km	0.4849	1.48E-01	0.00E+00	3.20E-01	8.49E-01	2.94E+00	3.66E+00	6.90E+00	8.28E-04	94
ERL INJ/DIARRHEA	0-16.1 km	0.3026	3.57E-02	0.00E+00	3.81E-02	1.31E-01	1.06E+00	1.31E+00	2.68E+00	1.14E-04	17
ERL INJ/PNEUMONITIS	0-16.1 km	0.0312	3.92E-04	0.00E+00	0.00E+00	0.00E+00	1.18E-02	1.72E-02	4.25E-01	1.14E-04	17
ERL INJ/THYROIDITIS	0-16.1 km	0.0872	6.48E-03	0.00E+00	0.00E+00	3.12E-02	1.39E-01	1.85E-01	1.03E+00	8.28E-04	94
ERL INJ/HYPOTHYROIDISM	0-16.1 km	0.6474	7.59E+00	1.09E-01	1.34E+01	2.72E+01	1.48E+02	2.16E+02	6.39E+02	2.85E-04	85
ERL INJ/SKIN ERYTHEMA	0-16.1 km	0.7985	3.87E+02	1.54E+01	5.27E+02	1.74E+03	7.76E+03	9.96E+03	2.51E+04	2.85E-04	123
ERL INJ/TRANSEPIDERMAL	0-16.1 km	0.6705	8.72E+01	4.15E-01	1.26E+02	2.33E+02	1.82E+03	3.24E+03	8.80E+03	3.14E-04	87
CAN FAT/TOTAL	0-16.1 km	1.0000	7.22E+01	3.86E+01	1.52E+02	2.39E+02	6.70E+02	8.20E+02	1.77E+03	2.85E-04	123
EARLY FATALITY DISTANCE (km)											
ERL FAT/TOTAL RISK > 0.000		0.9998	7.61E-01	5.28E-01	2.03E+00	2.44E+00	NOT-FOUND	NOT-FOUND	3.22E+00	2.25E-02	94

09/26/96 08:40:08 PAGE 13

		PROB NON-ZERO	MEAN	QUANTILES 50TH	90TH	95TH	99TH	99.5TH	PEAK CONS	PEAK PROB	PEAK TRIAL
POPULATION EXCEEDING DOSE											
EARLY dose A-RED MARR > 1.50 Sv		0.1958	8.72E-02	0.00E+00	8.39E-02	2.71E-01	2.52E+00	3.41E+00	7.20E+00	8.48E-04	94
EARLY dose A-LUNGS > 5.00 Sv		0.0312	1.00E-02	0.00E+00	0.00E+00	0.00E+00	5.77E-01	7.56E-01	2.83E+00	1.49E-04	17
EARLY dose L-EDEWBODY > 5.000E-02 Sv		0.9999	6.74E+03	2.00E+03	1.56E+04	2.74E+04	8.65E+04	1.04E+05	1.78E+05	5.71E-05	75
AVERAGE INDIVIDUAL RISK											
ERL FAT/TOTAL	0-0.2 km	0.9998	7.98E-02	8.32E-02	1.12E-01	1.19E-01	1.36E-01	1.45E-01	1.76E-01	5.42E-04	28
ERL FAT/TOTAL	0.2-0.5 km	0.7557	6.76E-03	1.80E-03	3.01E-02	3.16E-02	3.55E-02	3.73E-02	4.41E-02	4.85E-04	57
ERL FAT/TOTAL	0.5-1.2 km	0.6682	5.71E-04	9.39E-05	1.79E-03	2.37E-03	7.71E-03	9.87E-03	1.08E-02	4.14E-03	17
ERL FAT/TOTAL	1.2-1.6 km	0.5240	1.08E-04	3.57E-06	4.45E-04	5.69E-04	1.18E-03	1.67E-03	1.83E-03	4.14E-03	17
ERL FAT/TOTAL	1.6-2.1 km	0.3664	3.65E-05	0.00E+00	1.28E-04	2.34E-04	NOT-FOUND	NOT-FOUND	5.86E-04	1.00E-02	79
POPULATION DOSE (Sv)											
L-EDEWBODY TOT LIF	0-16.1 km	1.0000	1.50E+03	7.91E+02	3.20E+03	4.81E+03	1.09E+04	1.38E+04	3.10E+04	2.85E-04	85
L-EDEWBODY TOT LIF	0-80.5 km	1.0000	1.04E+04	5.22E+03	2.81E+04	3.92E+04	6.02E+04	6.81E+04	9.24E+04	2.15E-04	102
L-EDEWBODY TOT LIF	0-1609 km	1.0000	4.41E+04	3.18E+04	9.90E+04	1.22E+05	1.94E+05	2.20E+05	4.41E+05	1.14E-04	112
POPULATION WEIGHTED RISK											
ERL FAT/TOTAL	0-2.1 km	0.1249	2.09E-04	0.00E+00	1.43E-05	2.56E-04	8.33E-03	1.08E-02	5.29E-02	1.14E-04	17
CAN FAT/TOTAL	0-16.1 km	0.9993	8.14E-04	4.02E-04	1.69E-03	2.76E-03	7.41E-03	9.17E-03	2.32E-02	2.85E-04	123
PEAK DOSE FOUND ON SPATIAL GRID (Sv)											
L-EDEWBODY	0-0.2 km	1.0000	7.44E+01	6.01E+01	1.33E+02	1.58E+02	NOT-FOUND	NOT-FOUND	1.93E+02	2.21E-02	47
L-EDEWBODY	0.2-0.5 km	1.0000	1.50E+01	1.06E+01	3.31E+01	3.96E+01	5.91E+01	6.94E+01	7.36E+01	6.85E-04	46
L-EDEWBODY	0.5-1.2 km	1.0000	7.18E+00	6.34E+00	1.34E+01	1.57E+01	2.40E+01	2.97E+01	3.21E+01	4.14E-03	17
L-EDEWBODY	1.2-1.6 km	1.0000	5.08E+00	3.76E+00	1.06E+01	1.20E+01	1.58E+01	1.78E+01	1.84E+01	4.14E-03	17
L-EDEWBODY	1.6-2.1 km	1.0000	4.07E+00	3.19E+00	1.02E+01	1.23E+01	NOT-FOUND	NOT-FOUND	1.54E+01	2.21E-02	94

L-EDEWBODY	2.1-3.2 km	1.0000	2.76E+00	1.80E+00	7.05E+00	9.48E+00	NOT-FOUND	NOT-FOUND	1.48E+01	2.21E-02	94
L-EDEWBODY	3.2-4.0 km	1.0000	1.86E+00	8.63E-01	6.34E+00	7.22E+00	7.90E+00	8.21E+00	1.11E+01	1.43E-04	129
L-EDEWBODY	4.0-4.8 km	1.0000	1.51E+00	6.83E-01	4.38E+00	7.41E+00	NOT-FOUND	NOT-FOUND	8.88E+00	2.17E-02	88
L-EDEWBODY	4.8-5.6 km	1.0000	1.26E+00	4.06E-01	3.72E+00	7.40E+00	NOT-FOUND	NOT-FOUND	8.85E+00	2.17E-02	88
L-EDEWBODY	5.6-8.1 km	1.0000	8.02E-01	2.58E-01	2.35E+00	2.95E+00	NOT-FOUND	NOT-FOUND	4.39E+00	2.17E-02	88
L-EDEWBODY	8.1-11.3 km	1.0000	3.44E-01	1.64E-01	9.45E-01	1.25E+00	2.17E+00	2.79E+00	2.99E+00	4.14E-03	85
L-EDEWBODY	11.3-16.1 km	1.0000	1.94E-01	1.42E-01	3.95E-01	5.19E-01	6.41E-01	7.03E-01	1.76E+00	3.42E-04	87
L-EDEWBODY	16.1-20.9 km	1.0000	2.47E-01	2.17E-01	4.00E-01	4.75E-01	NOT-FOUND	NOT-FOUND	7.47E-01	2.17E-02	50
L-EDEWBODY	20.9-25.8 km	1.0000	1.90E-01	1.70E-01	3.44E-01	3.88E-01	NOT-FOUND	NOT-FOUND	4.61E-01	1.91E-02	51
L-EDEWBODY	25.8-32.2 km	1.0000	1.33E-01	1.10E-01	2.28E-01	2.88E-01	3.20E-01	3.30E-01	3.80E-01	2.00E-04	21
L-EDEWBODY	32.2-40.2 km	1.0000	9.74E-02	9.31E-02	1.56E-01	1.91E-01	2.22E-01	2.33E-01	2.91E-01	2.28E-04	25
L-EDEWBODY	40.2-48.3 km	1.0000	8.36E-02	7.79E-02	1.22E-01	1.38E-01	1.84E-01	2.23E-01	2.56E-01	3.77E-03	110
L-EDEWBODY	48.3-64.4 km	1.0000	7.04E-02	6.73E-02	1.07E-01	1.20E-01	1.58E-01	1.77E-01	2.23E-01	2.45E-03	75
L-EDEWBODY	64.4-80.5 km	1.0000	5.97E-02	5.46E-02	8.69E-02	1.00E-01	NOT-FOUND	NOT-FOUND	1.32E-01	1.71E-02	86
L-EDEWBODY	80.5-113 km	1.0000	4.83E-02	4.14E-02	8.20E-02	9.71E-02	1.06E-01	1.09E-01	1.23E-01	3.14E-04	95
L-EDEWBODY	113-161 km	1.0000	3.25E-02	2.62E-02	7.01E-02	7.96E-02	NOT-FOUND	NOT-FOUND	9.76E-02	1.63E-02	67
L-EDEWBODY	161-241 km	1.0000	1.69E-02	1.27E-02	2.95E-02	5.03E-02	5.58E-02	5.84E-02	7.76E-02	3.14E-04	71
L-EDEWBODY	241-322 km	1.0000	9.72E-03	7.57E-03	2.17E-02	2.61E-02	3.62E-02	4.08E-02	4.61E-02	2.45E-03	83
L-EDEWBODY	322-563 km	1.0000	4.14E-03	3.17E-03	9.91E-03	1.09E-02	1.32E-02	1.43E-02	2.17E-02	3.14E-04	112
L-EDEWBODY	563-805 km	1.0000	1.18E-03	7.48E-04	2.75E-03	3.22E-03	4.07E-03	4.51E-03	5.67E-03	2.45E-03	64
L-EDEWBODY	805-1609 km	1.0000	1.70E-04	7.40E-05	4.00E-04	7.12E-04	8.87E-04	9.75E-04	1.54E-03	4.14E-03	105

DATE AND TIME OF RUN = MACCS2 09/26/96 08:40:08 Version 1.12, Last Modified 9/25/96 by D. Chanin
"ATMOS" DESCRIPTION = IN1A.INP, Sample Problem A--Using Table-Lookup Sigmas, ATMOS input
"EARLY" DESCRIPTION = IN2A.INP, Sample Problem A of NUREG/CR-4691, Vol. 1, EARLY input

SOURCE TERM 2 OF 2:
RELEASE FRACTIONS OF SOURCE TERM 1 REDUCED BY A FACTOR OF TEN

RESULTS FOR A SINGLE EMERGENCY RESPONSE COHORT WITHOUT ANY WEIGHTING FRACTIONS BEING APPLIED

COHORT 1 = EVACUATION WITHIN 10 MILES, RELOCATION MODELS APPLY ELSEWHERE

09/26/96 08:40:08 PAGE 14

		PROB NON-ZERO	MEAN	QUANTILES 50TH	90TH	95TH	99TH	99.5TH	PEAK CONS	PEAK PROB	PEAK TRIAL
HEALTH EFFECTS CASES											
ERL FAT/TOTAL	0-1609 km	0.0440	1.97E-03	0.00E+00	0.00E+00	0.00E+00	8.04E-02	1.07E-01	8.99E-01	1.14E-04	17
ERL INJ/PRODROMAL VOMIT	0-1609 km	0.2548	1.31E-01	0.00E+00	2.43E-01	7.57E-01	2.71E+00	3.32E+00	6.90E+00	8.28E-04	94
ERL INJ/DIARRHEA	0-1609 km	0.1215	2.80E-02	0.00E+00	8.54E-03	1.04E-01	8.39E-01	1.08E+00	2.44E+00	1.14E-04	17
ERL INJ/PNEUMONITIS	0-1609 km	0.0104	1.77E-04	0.00E+00	0.00E+00	0.00E+00	3.17E-03	7.33E-03	3.58E-01	1.14E-04	17
ERL INJ/THYROIDITIS	0-1609 km	0.0844	6.71E-03	0.00E+00	0.00E+00	3.12E-02	1.35E-01	1.84E-01	1.08E+00	8.28E-04	94
ERL INJ/HYPOTHYROIDISM	0-1609 km	0.5385	7.88E+00	3.06E-02	1.42E+01	2.93E+01	1.55E+02	2.17E+02	6.70E+02	2.85E-04	85
ERL INJ/SKIN ERYTHEMA	0-1609 km	0.6186	4.28E+02	1.21E+01	7.27E+02	2.00E+03	8.01E+03	1.06E+04	2.60E+04	2.85E-04	123
ERL INJ/TRANSEPIDERMAL	0-1609 km	0.5092	8.95E+01	2.06E-02	1.30E+02	2.53E+02	1.82E+03	3.24E+03	9.26E+03	3.14E-04	87
CAN FAT/TOTAL	0-1609 km	1.0000	1.54E+02	1.05E+02	3.08E+02	4.05E+02	7.79E+02	1.00E+03	1.97E+03	2.85E-04	123
CAN FAT/LUNG	0-1609 km	1.0000	2.97E+01	2.14E+01	6.16E+01	7.89E+01	1.26E+02	1.53E+02	3.35E+02	2.85E-04	123
CAN FAT/THYROID	0-1609 km	1.0000	1.41E+01	8.08E+00	3.05E+01	4.38E+01	1.05E+02	1.34E+02	2.67E+02	2.85E-04	123
CAN FAT/BREAST	0-1609 km	1.0000	1.09E+01	7.76E+00	2.22E+01	2.90E+01	4.69E+01	5.42E+01	1.25E+02	2.15E-04	102
CAN FAT/GI	0-1609 km	1.0000	3.27E+01	2.26E+01	6.62E+01	8.34E+01	1.50E+02	1.97E+02	3.59E+02	2.85E-04	123
CAN FAT/LEUKEMIA	0-1609 km	1.0000	1.04E+01	7.44E+00	2.12E+01	2.59E+01	4.24E+01	5.19E+01	9.54E+01	2.15E-04	102
CAN FAT/BONE	0-1609 km	1.0000	2.21E+00	1.52E+00	4.65E+00	6.07E+00	8.68E+00	9.82E+00	1.56E+01	2.85E-04	123
CAN FAT/OTHER	0-1609 km	1.0000	5.44E+01	3.48E+01	1.09E+02	1.50E+02	3.13E+02	3.75E+02	8.52E+02	2.85E-04	123
CAN INJ/THYROID	0-1609 km	1.0000	1.41E+02	8.08E+01	3.05E+02	4.38E+02	1.05E+03	1.34E+03	2.67E+03	2.85E-04	123
CAN INJ/BREAST	0-1609 km	1.0000	3.44E+01	2.39E+01	6.94E+01	9.10E+01	1.35E+02	1.57E+02	3.92E+02	2.15E-04	102
CAN FAT/TOTAL	0-80.5 km	1.0000	9.97E+01	4.67E+01	2.45E+02	3.55E+02	7.47E+02	1.00E+03	1.97E+03	2.85E-04	123
ERL FAT/TOTAL	0-16.1 km	0.0440	1.97E-03	0.00E+00	0.00E+00	0.00E+00	8.04E-02	1.07E-01	8.99E-01	1.14E-04	17
ERL INJ/PRODROMAL VOMIT	0-16.1 km	0.2548	1.31E-01	0.00E+00	2.43E-01	7.57E-01	2.71E+00	3.32E+00	6.90E+00	8.28E-04	94
ERL INJ/DIARRHEA	0-16.1 km	0.1215	2.80E-02	0.00E+00	8.54E-03	1.04E-01	8.39E-01	1.08E+00	2.44E+00	1.14E-04	17
ERL INJ/PNEUMONITIS	0-16.1 km	0.0104	1.77E-04	0.00E+00	0.00E+00	0.00E+00	3.17E-03	7.33E-03	3.58E-01	1.14E-04	17

ERL INJ/THYROIDITIS	0-16.1 km	0.0844	6.71E-03	0.00E+00	0.00E+00	3.12E-02	1.35E-01	1.84E-01	1.08E+00	8.28E-04	94
ERL INJ/HYPOTHYROIDISM	0-16.1 km	0.5358	7.79E+00	2.75E-02	1.39E+01	2.93E+01	1.55E+02	2.17E+02	6.70E+02	2.85E-04	85
ERL INJ/SKIN ERYTHEMA	0-16.1 km	0.6051	3.84E+02	5.29E+00	4.96E+02	1.83E+03	7.86E+03	9.98E+03	2.60E+04	2.85E-04	123
ERL INJ/TRANSEPIDERMAL	0-16.1 km	0.5092	8.95E+01	2.06E-02	1.30E+02	2.53E+02	1.82E+03	3.24E+03	9.26E+03	3.14E-04	87
CAN FAT/TOTAL	0-16.1 km	0.9074	2.93E+01	3.74E+00	5.09E+01	1.41E+02	4.81E+02	5.82E+02	1.61E+03	2.85E-04	123
EARLY FATALITY DISTANCE (km)											
ERL FAT/TOTAL RISK > 0.000		0.9973	7.13E-01	5.28E-01	2.03E+00	2.44E+00	NOT-FOUND	NOT-FOUND	3.22E+00	2.25E-02	94
POPULATION EXCEEDING DOSE											
EARLY dose A-RED MARR > 1.50 Sv		0.0440	6.38E-02	0.00E+00	0.00E+00	0.00E+00	2.50E+00	3.21E+00	7.14E+00	8.48E-04	94
EARLY dose A-LUNGS > 5.00 Sv		0.0104	8.32E-03	0.00E+00	0.00E+00	0.00E+00	7.03E-01	7.62E-01	2.71E+00	3.77E-04	17
EARLY dose L-EDEWBODY > 5.000E-02 Sv		0.9418	6.66E+03	1.91E+03	1.51E+04	2.78E+04	8.65E+04	1.04E+05	1.78E+05	5.71E-05	75
AVERAGE INDIVIDUAL RISK											
ERL FAT/TOTAL	0-0.2 km	0.9973	7.46E-02	7.81E-02	1.11E-01	1.18E-01	1.35E-01	1.43E-01	1.73E-01	5.42E-04	28
ERL FAT/TOTAL	0.2-0.5 km	0.5397	5.72E-03	2.92E-04	3.01E-02	3.14E-02	3.49E-02	3.64E-02	4.23E-02	4.85E-04	57
ERL FAT/TOTAL	0.5-1.2 km	0.3217	3.33E-04	0.00E+00	1.06E-03	1.36E-03	6.35E-03	9.16E-03	9.99E-03	4.14E-03	17
ERL FAT/TOTAL	1.2-1.6 km	0.1390	5.79E-05	0.00E+00	2.44E-04	4.38E-04	6.24E-04	6.96E-04	1.14E-03	4.14E-03	17

09/26/96 08:40:08 PAGE 15

		PROB NON-ZERO	MEAN	QUANTILES 50TH	90TH	95TH	99TH	99.5TH	PEAK CONS	PEAK PROB	PEAK TRIAL
AVERAGE INDIVIDUAL RISK											
ERL FAT/TOTAL	1.6-2.1 km	0.1065	1.49E-05	0.00E+00	7.26E-05	1.14E-04	NOT-FOUND	NOT-FOUND	2.29E-04	2.21E-02	104
POPULATION DOSE (Sv)											
L-EDEWBODY TOT LIF	0-16.1 km	0.9074	5.44E+02	8.19E+01	1.12E+03	2.54E+03	8.81E+03	1.15E+04	2.65E+04	2.85E-04	123
L-EDEWBODY TOT LIF	0-80.5 km	1.0000	2.15E+03	1.03E+03	5.31E+03	7.91E+03	1.53E+04	2.00E+04	3.47E+04	2.85E-04	123
L-EDEWBODY TOT LIF	0-1609 km	1.0000	3.42E+03	2.32E+03	7.06E+03	8.91E+03	1.57E+04	2.00E+04	3.48E+04	2.85E-04	123
POPULATION WEIGHTED RISK											
ERL FAT/TOTAL	0-2.1 km	0.0440	9.69E-05	0.00E+00	0.00E+00	0.00E+00	3.55E-03	5.16E-03	4.49E-02	1.14E-04	17
CAN FAT/TOTAL	0-16.1 km	0.9074	3.99E-04	5.16E-05	6.84E-04	1.75E-03	6.68E-03	8.23E-03	2.19E-02	2.85E-04	123
PEAK DOSE FOUND ON SPATIAL GRID (Sv)											
L-EDEWBODY	0-0.2 km	1.0000	7.23E+01	5.79E+01	1.34E+02	1.60E+02	NOT-FOUND	NOT-FOUND	1.89E+02	2.59E-02	36
L-EDEWBODY	0.2-0.5 km	1.0000	1.44E+01	1.06E+01	3.31E+01	3.96E+01	5.91E+01	6.94E+01	7.25E+01	4.14E-03	17
L-EDEWBODY	0.5-1.2 km	1.0000	6.92E+00	5.43E+00	1.30E+01	1.55E+01	2.39E+01	2.97E+01	3.14E+01	4.14E-03	17
L-EDEWBODY	1.2-1.6 km	1.0000	4.93E+00	3.76E+00	1.06E+01	1.19E+01	1.56E+01	1.75E+01	1.81E+01	4.14E-03	17
L-EDEWBODY	1.6-2.1 km	1.0000	3.95E+00	3.19E+00	1.02E+01	1.24E+01	NOT-FOUND	NOT-FOUND	1.56E+01	2.21E-02	94
L-EDEWBODY	2.1-3.2 km	0.9730	2.65E+00	1.75E+00	7.05E+00	9.48E+00	NOT-FOUND	NOT-FOUND	1.51E+01	2.21E-02	94
L-EDEWBODY	3.2-4.0 km	0.9401	1.77E+00	7.82E-01	6.34E+00	7.22E+00	7.90E+00	8.21E+00	1.14E+01	1.43E-04	129
L-EDEWBODY	4.0-4.8 km	0.9082	1.43E+00	5.47E-01	4.38E+00	7.46E+00	NOT-FOUND	NOT-FOUND	9.14E+00	2.17E-02	88
L-EDEWBODY	4.8-5.6 km	0.8435	1.19E+00	1.98E-01	3.73E+00	7.46E+00	NOT-FOUND	NOT-FOUND	9.12E+00	2.17E-02	88
L-EDEWBODY	5.6-8.1 km	0.8015	7.16E-01	1.47E-01	2.40E+00	2.95E+00	NOT-FOUND	NOT-FOUND	4.46E+00	2.17E-02	88
L-EDEWBODY	8.1-11.3 km	0.7120	2.36E-01	5.81E-02	8.30E-01	1.19E+00	2.15E+00	2.71E+00	2.89E+00	4.14E-03	85
L-EDEWBODY	11.3-16.1 km	0.5447	8.34E-02	6.67E-03	3.09E-01	3.47E-01	4.53E-01	5.08E-01	1.67E+00	3.42E-04	87
L-EDEWBODY	16.1-20.9 km	1.0000	1.64E-01	1.30E-01	3.25E-01	3.95E-01	NOT-FOUND	NOT-FOUND	6.02E-01	2.17E-02	50
L-EDEWBODY	20.9-25.8 km	1.0000	1.22E-01	1.03E-01	2.46E-01	2.87E-01	NOT-FOUND	NOT-FOUND	3.33E-01	1.91E-02	51
L-EDEWBODY	25.8-32.2 km	1.0000	8.08E-02	7.02E-02	1.49E-01	1.86E-01	2.12E-01	2.18E-01	2.45E-01	3.42E-04	87
L-EDEWBODY	32.2-40.2 km	1.0000	4.87E-02	3.25E-02	1.03E-01	1.10E-01	1.29E-01	1.37E-01	1.87E-01	2.00E-04	11
L-EDEWBODY	40.2-48.3 km	1.0000	3.09E-02	1.70E-02	7.51E-02	9.32E-02	1.23E-01	1.36E-01	1.42E-01	3.77E-03	110
L-EDEWBODY	48.3-64.4 km	1.0000	1.82E-02	1.15E-02	3.50E-02	7.06E-02	8.50E-02	9.21E-02	1.33E-01	2.45E-03	75
L-EDEWBODY	64.4-80.5 km	1.0000	1.05E-02	7.64E-03	2.10E-02	2.47E-02	5.20E-02	5.44E-02	5.98E-02	1.17E-03	92
L-EDEWBODY	80.5-113 km	1.0000	6.31E-03	4.75E-03	1.42E-02	1.95E-02	2.87E-02	3.32E-02	4.43E-02	1.17E-03	69
L-EDEWBODY	113-161 km	1.0000	2.77E-03	2.53E-03	5.22E-03	6.31E-03	8.40E-03	9.31E-03	1.66E-02	3.14E-04	72
L-EDEWBODY	161-241 km	1.0000	1.29E-03	1.10E-03	2.38E-03	2.87E-03	3.93E-03	4.48E-03	6.24E-03	2.45E-03	83
L-EDEWBODY	241-322 km	1.0000	7.39E-04	6.65E-04	1.60E-03	2.03E-03	2.50E-03	2.74E-03	3.51E-03	2.45E-03	83
L-EDEWBODY	322-563 km	1.0000	2.88E-04	2.50E-04	5.68E-04	6.43E-04	7.65E-04	8.07E-04	1.90E-03	3.14E-04	112

L-EDEWBODY	563-805 km	1.0000	7.69E-05	5.61E-05	1.66E-04	2.07E-04	2.52E-04	2.75E-04	3.37E-04	2.45E-03	64
L-EDEWBODY	805-1609 km	1.0000	9.73E-06	5.32E-06	2.36E-05	5.09E-05	7.98E-05	9.01E-05	9.31E-05	4.14E-03	105

DATE AND TIME OF RUN = MACCS2 09/26/96 08:40:08 Version 1.12, Last Modified 9/25/96 by D. Chanin
"ATMOS" DESCRIPTION = IN1A.INP, Sample Problem A--Using Table-Lookup Sigmas, ATMOS input
"EARLY" DESCRIPTION = IN2A.INP, Sample Problem A of NUREG/CR-4691, Vol. 1, EARLY input

SOURCE TERM 2 OF 2:
RELEASE FRACTIONS OF SOURCE TERM 1 REDUCED BY A FACTOR OF TEN

RESULTS FOR A SINGLE EMERGENCY RESPONSE COHORT WITHOUT ANY WEIGHTING FRACTIONS BEING APPLIED

COHORT 2 = NO EVACUATION, RELOCATION MODELS APPLY EVERYWHERE

09/26/96 08:40:08 PAGE 16

		PROB NON-ZERO	MEAN	QUANTILES 50TH	90TH	95TH	99TH	99.5TH	PEAK CONS	PEAK PROB	PEAK TRIAL
HEALTH EFFECTS CASES											
ERL FAT/TOTAL	0-1609 km	0.1958	5.34E-02	0.00E+00	2.35E-02	1.52E-01	2.10E+00	2.38E+00	6.57E+00	5.84E-06	130
ERL INJ/PRODROMAL VOMIT	0-1609 km	0.4849	4.70E-01	0.00E+00	1.26E+00	2.78E+00	6.34E+00	7.56E+00	4.80E+01	7.15E-06	129
ERL INJ/DIARRHEA	0-1609 km	0.3026	1.81E-01	0.00E+00	3.90E-01	1.13E+00	3.41E+00	3.91E+00	1.16E+01	5.84E-06	130
ERL INJ/PNEUMONITIS	0-1609 km	0.0303	4.49E-03	0.00E+00	0.00E+00	0.00E+00	2.21E-01	2.75E-01	1.90E+00	3.50E-05	46
ERL INJ/THYROIDITIS	0-1609 km	0.0355	2.27E-03	0.00E+00	0.00E+00	0.00E+00	1.05E-01	1.22E-01	4.72E-01	3.50E-05	46
ERL INJ/HYPOTHYROIDISM	0-1609 km	0.6262	3.81E+00	1.50E-01	9.53E+00	2.32E+01	5.23E+01	6.70E+01	1.01E+02	1.06E-03	41
ERL INJ/SKIN ERYTHEMA	0-1609 km	0.7347	4.88E+02	1.53E+01	1.37E+03	3.07E+03	7.09E+03	1.06E+04	1.74E+04	1.06E-03	50
ERL INJ/TRANSEPIDERMAL	0-1609 km	0.5891	4.49E+01	5.26E-01	8.66E+01	2.24E+02	8.22E+02	1.04E+03	2.31E+03	1.06E-03	115
CAN FAT/TOTAL	0-1609 km	1.0000	1.69E+02	1.23E+02	3.30E+02	4.21E+02	6.50E+02	7.29E+02	1.11E+03	2.15E-04	102
CAN FAT/LUNG	0-1609 km	1.0000	3.57E+01	2.66E+01	7.27E+01	8.84E+01	1.11E+02	1.18E+02	2.30E+02	1.28E-05	56
CAN FAT/THYROID	0-1609 km	1.0000	1.32E+01	8.45E+00	2.62E+01	3.64E+01	7.26E+01	8.03E+01	1.07E+02	1.11E-03	51
CAN FAT/BREAST	0-1609 km	1.0000	1.22E+01	9.13E+00	2.45E+01	3.15E+01	4.60E+01	5.34E+01	1.26E+02	2.15E-04	102
CAN FAT/GI	0-1609 km	1.0000	3.63E+01	2.73E+01	7.40E+01	9.48E+01	1.32E+02	1.50E+02	3.01E+02	2.15E-04	102
CAN FAT/LEUKEMIA	0-1609 km	1.0000	1.19E+01	9.04E+00	2.38E+01	3.04E+01	4.03E+01	4.56E+01	9.71E+01	2.15E-04	102
CAN FAT/BONE	0-1609 km	1.0000	2.98E+00	2.17E+00	6.08E+00	7.80E+00	1.26E+01	1.53E+01	2.83E+01	1.28E-05	56
CAN FAT/OTHER	0-1609 km	1.0000	5.68E+01	4.11E+01	1.13E+02	1.50E+02	2.35E+02	2.67E+02	3.56E+02	2.15E-04	102
CAN INJ/THYROID	0-1609 km	1.0000	1.32E+02	8.45E+01	2.62E+02	3.64E+02	7.26E+02	8.03E+02	1.07E+03	1.11E-03	51
CAN INJ/BREAST	0-1609 km	1.0000	3.83E+01	2.86E+01	7.62E+01	1.02E+02	1.38E+02	1.57E+02	3.98E+02	2.15E-04	102
CAN FAT/TOTAL	0-80.5 km	1.0000	1.14E+02	6.50E+01	2.73E+02	3.93E+02	6.50E+02	7.29E+02	1.11E+03	2.15E-04	102
ERL FAT/TOTAL	0-16.1 km	0.1958	5.34E-02	0.00E+00	2.35E-02	1.52E-01	2.10E+00	2.38E+00	6.57E+00	5.84E-06	130
ERL INJ/PRODROMAL VOMIT	0-16.1 km	0.4849	4.70E-01	0.00E+00	1.26E+00	2.78E+00	6.34E+00	7.56E+00	4.80E+01	7.15E-06	129
ERL INJ/DIARRHEA	0-16.1 km	0.3026	1.81E-01	0.00E+00	3.90E-01	1.13E+00	3.41E+00	3.91E+00	1.16E+01	5.84E-06	130
ERL INJ/PNEUMONITIS	0-16.1 km	0.0303	4.49E-03	0.00E+00	0.00E+00	0.00E+00	2.21E-01	2.75E-01	1.90E+00	3.50E-05	46
ERL INJ/THYROIDITIS	0-16.1 km	0.0355	2.27E-03	0.00E+00	0.00E+00	0.00E+00	1.05E-01	1.22E-01	4.72E-01	3.50E-05	46
ERL INJ/HYPOTHYROIDISM	0-16.1 km	0.6250	3.72E+00	1.47E-01	9.35E+00	2.32E+01	4.98E+01	6.18E+01	1.01E+02	1.06E-03	41
ERL INJ/SKIN ERYTHEMA	0-16.1 km	0.7347	4.45E+02	1.44E+01	1.26E+03	3.02E+03	6.15E+03	8.33E+03	1.72E+04	1.89E-04	36
ERL INJ/TRANSEPIDERMAL	0-16.1 km	0.5891	4.49E+01	5.26E-01	8.66E+01	2.24E+02	8.22E+02	1.04E+03	2.31E+03	1.06E-03	115
CAN FAT/TOTAL	0-16.1 km	0.9993	4.39E+01	1.84E+01	1.16E+02	1.59E+02	2.91E+02	3.43E+02	4.84E+02	1.06E-03	41
EARLY FATALITY DISTANCE (km)											
ERL FAT/TOTAL RISK > 0.000		0.9998	1.68E+00	1.40E+00	3.19E+00	3.37E+00	3.84E+00	4.06E+00	5.63E+00	3.71E-04	40
POPULATION EXCEEDING DOSE											
EARLY dose A-RED MARR > 1.50 Sv		0.1958	5.31E-01	0.00E+00	1.48E+00	4.23E+00	8.65E+00	1.05E+01	3.27E+01	5.84E-06	130
EARLY dose A-LUNGS > 5.00 Sv		0.0303	4.26E-02	0.00E+00	0.00E+00	0.00E+00	2.13E+00	2.32E+00	5.00E+00	1.49E-04	17
EARLY dose L-EDEWBODY > 5.000E-02 Sv		0.9990	8.34E+03	3.14E+03	2.02E+04	3.37E+04	8.61E+04	1.04E+05	1.94E+05	5.71E-05	75
AVERAGE INDIVIDUAL RISK											
ERL FAT/TOTAL	0-0.2 km	0.9998	1.79E-01	1.54E-01	2.34E-01	2.57E-01	NOT-FOUND	NOT-FOUND	3.14E-01	1.55E-02	59
ERL FAT/TOTAL	0.2-0.5 km	0.7557	2.66E-02	2.13E-02	5.91E-02	6.72E-02	8.03E-02	8.60E-02	1.33E-01	5.42E-04	28
ERL FAT/TOTAL	0.5-1.2 km	0.6640	5.09E-03	1.89E-03	2.03E-02	2.18E-02	2.59E-02	2.79E-02	6.68E-02	5.42E-04	28
ERL FAT/TOTAL	1.2-1.6 km	0.5240	1.05E-03	7.80E-05	2.72E-03	3.99E-03	1.17E-02	1.37E-02	2.79E-02	4.85E-04	33

09/26/96 08:40:08 PAGE 17

		PROB NON-ZERO	MEAN	QUANTILES 50TH	90TH	95TH	99TH	99.5TH	PEAK CONS	PEAK PROB	PEAK TRIAL
AVERAGE INDIVIDUAL RISK											
ERL FAT/TOTAL	1.6-2.1 km	0.3664	4.46E-04	0.00E+00	1.03E-03	1.51E-03	NOT-FOUND	NOT-FOUND	1.17E-02	1.00E-02	79
POPULATION DOSE (Sv)											
L-EDEWBODY TOT LIF	0-16.1 km	0.9993	7.72E+02	3.26E+02	2.10E+03	2.78E+03	4.85E+03	5.49E+03	7.99E+03	1.06E-03	41
L-EDEWBODY TOT LIF	0-80.5 km	1.0000	2.38E+03	1.28E+03	5.64E+03	8.35E+03	1.25E+04	1.41E+04	2.58E+04	2.15E-04	102
L-EDEWBODY TOT LIF	0-1609 km	1.0000	3.65E+03	2.73E+03	7.19E+03	9.40E+03	1.28E+04	1.44E+04	2.58E+04	2.15E-04	102
POPULATION WEIGHTED RISK											
ERL FAT/TOTAL	0-2.1 km	0.1249	2.33E-03	0.00E+00	2.99E-04	3.61E-03	1.05E-01	1.19E-01	3.19E-01	2.48E-05	33
CAN FAT/TOTAL	0-16.1 km	0.9993	5.98E-04	2.57E-04	1.52E-03	2.18E-03	3.54E-03	4.19E-03	6.59E-03	1.06E-03	41
PEAK DOSE FOUND ON SPATIAL GRID (Sv)											
L-EDEWBODY	0-0.2 km	1.0000	1.11E+02	9.48E+01	1.99E+02	2.24E+02	NOT-FOUND	NOT-FOUND	2.57E+02	2.21E-02	47
L-EDEWBODY	0.2-0.5 km	1.0000	2.51E+01	2.11E+01	5.10E+01	5.87E+01	7.51E+01	8.02E+01	9.67E+01	6.85E-04	46
L-EDEWBODY	0.5-1.2 km	1.0000	9.53E+00	9.13E+00	2.11E+01	2.43E+01	3.17E+01	3.38E+01	4.09E+01	6.85E-04	46
L-EDEWBODY	1.2-1.6 km	1.0000	5.84E+00	5.83E+00	1.07E+01	1.28E+01	1.94E+01	2.06E+01	2.30E+01	6.85E-04	46
L-EDEWBODY	1.6-2.1 km	1.0000	4.50E+00	3.87E+00	8.10E+00	8.83E+00	1.09E+01	1.20E+01	1.60E+01	6.85E-04	46
L-EDEWBODY	2.1-3.2 km	1.0000	3.17E+00	2.52E+00	7.38E+00	8.37E+00	NOT-FOUND	NOT-FOUND	9.72E+00	2.21E-02	34
L-EDEWBODY	3.2-4.0 km	1.0000	2.22E+00	1.49E+00	5.35E+00	6.18E+00	7.35E+00	7.61E+00	9.16E+00	1.14E-04	130
L-EDEWBODY	4.0-4.8 km	1.0000	1.75E+00	1.19E+00	3.92E+00	4.99E+00	NOT-FOUND	NOT-FOUND	6.75E+00	2.21E-02	34
L-EDEWBODY	4.8-5.6 km	1.0000	1.36E+00	9.08E-01	3.83E+00	4.94E+00	5.23E+00	5.33E+00	5.62E+00	7.71E-04	45
L-EDEWBODY	5.6-8.1 km	1.0000	9.07E-01	5.34E-01	2.55E+00	3.13E+00	NOT-FOUND	NOT-FOUND	3.53E+00	2.21E-02	47
L-EDEWBODY	8.1-11.3 km	1.0000	4.67E-01	2.88E-01	1.13E+00	1.36E+00	NOT-FOUND	NOT-FOUND	1.69E+00	2.17E-02	115
L-EDEWBODY	11.3-16.1 km	1.0000	2.62E-01	2.02E-01	6.69E-01	7.76E-01	NOT-FOUND	NOT-FOUND	8.95E-01	2.17E-02	41
L-EDEWBODY	16.1-20.9 km	1.0000	1.64E-01	1.30E-01	3.25E-01	3.95E-01	NOT-FOUND	NOT-FOUND	6.02E-01	2.17E-02	50
L-EDEWBODY	20.9-25.8 km	1.0000	1.22E-01	1.03E-01	2.46E-01	2.87E-01	NOT-FOUND	NOT-FOUND	3.33E-01	1.91E-02	51
L-EDEWBODY	25.8-32.2 km	1.0000	8.08E-02	7.02E-02	1.49E-01	1.86E-01	2.12E-01	2.18E-01	2.45E-01	3.42E-04	87
L-EDEWBODY	32.2-40.2 km	1.0000	4.87E-02	3.25E-02	1.03E-01	1.10E-01	1.29E-01	1.37E-01	1.87E-01	2.00E-04	11
L-EDEWBODY	40.2-48.3 km	1.0000	3.09E-02	1.70E-02	7.51E-02	9.32E-02	1.23E-01	1.36E-01	1.42E-01	3.77E-03	110
L-EDEWBODY	48.3-64.4 km	1.0000	1.82E-02	1.15E-02	3.50E-02	7.06E-02	8.50E-02	9.21E-02	1.33E-01	2.45E-03	75
L-EDEWBODY	64.4-80.5 km	1.0000	1.05E-02	7.64E-03	2.10E-02	2.47E-02	5.20E-02	5.44E-02	5.98E-02	1.17E-03	92
L-EDEWBODY	80.5-113 km	1.0000	6.31E-03	4.75E-03	1.42E-02	1.95E-02	2.87E-02	3.32E-02	4.43E-02	1.17E-03	69
L-EDEWBODY	113-161 km	1.0000	2.77E-03	2.53E-03	5.22E-03	6.31E-03	8.40E-03	9.31E-03	1.66E-02	3.14E-04	72
L-EDEWBODY	161-241 km	1.0000	1.29E-03	1.10E-03	2.38E-03	2.87E-03	3.93E-03	4.48E-03	6.24E-03	2.45E-03	83
L-EDEWBODY	241-322 km	1.0000	7.39E-04	6.65E-04	1.60E-03	2.03E-03	2.50E-03	2.74E-03	3.51E-03	2.45E-03	83
L-EDEWBODY	322-563 km	1.0000	2.88E-04	2.50E-04	5.68E-04	6.43E-04	7.65E-04	8.07E-04	1.90E-03	3.14E-04	112
L-EDEWBODY	563-805 km	1.0000	7.69E-05	5.61E-05	1.66E-04	2.07E-04	2.52E-04	2.75E-04	3.37E-04	2.45E-03	64
L-EDEWBODY	805-1609 km	1.0000	9.73E-06	5.32E-06	2.36E-05	5.09E-05	7.98E-05	9.01E-05	9.31E-05	4.14E-03	105

DATE AND TIME OF RUN = MACCS2 09/26/96 08:40:08 Version 1.12, Last Modified 9/25/96 by D. Chanin
"ATMOS" DESCRIPTION = IN1A.INP, Sample Problem A--Using Table-Lookup Sigmas, ATMOS input
"EARLY" DESCRIPTION = IN2A.INP, Sample Problem A of NUREG/CR-4691, Vol. 1, EARLY input
"CHRONC" DESCRIPTION = IN3A_N.INP, Sample Problem A, "New" COMIDA2-Based Food Model

SOURCE TERM 2 OF 2:
RELEASE FRACTIONS OF SOURCE TERM 1 REDUCED BY A FACTOR OF TEN

RESULTS FROM THE "CHRONC" MODULE ALONE

COHORT 3 = IN3A_N.INP, Sample Problem A, "New" COMIDA2-Based Food Model

09/26/96 08:40:08 PAGE 18

		PROB NON-ZERO	MEAN	QUANTILES 50TH	90TH	95TH	99TH	99.5TH	PEAK CONS	PEAK PROB	PEAK TRIAL
HEALTH EFFECTS CASES											

CAN FAT/TOTAL	0-1609 km	1.0000	1.80E+03	1.20E+03	3.94E+03	5.30E+03	8.22E+03	1.00E+04	1.89E+04	1.14E-04	112
CAN FAT/LUNG	0-1609 km	1.0000	2.67E+02	1.81E+02	5.89E+02	7.80E+02	1.18E+03	1.36E+03	2.86E+03	1.14E-04	112
CAN FAT/THYROID	0-1609 km	1.0000	2.46E+01	1.62E+01	5.08E+01	7.00E+01	1.30E+02	1.56E+02	3.23E+02	1.14E-04	112
CAN FAT/BREAST	0-1609 km	1.0000	2.06E+02	1.34E+02	4.55E+02	6.07E+02	9.97E+02	1.11E+03	2.34E+03	1.14E-04	112
CAN FAT/GI	0-1609 km	1.0000	5.48E+02	3.69E+02	1.24E+03	1.70E+03	2.58E+03	2.98E+03	5.48E+03	1.14E-04	112
CAN FAT/LEUKEMIA	0-1609 km	1.0000	1.73E+02	1.16E+02	3.75E+02	5.15E+02	7.86E+02	9.30E+02	1.79E+03	1.14E-04	112
CAN FAT/BONE	0-1609 km	1.0000	2.03E+01	1.40E+01	4.24E+01	5.56E+01	9.01E+01	1.06E+02	1.96E+02	1.14E-04	112
CAN FAT/OTHER	0-1609 km	1.0000	5.61E+02	3.76E+02	1.21E+03	1.63E+03	2.75E+03	3.14E+03	5.87E+03	1.14E-04	112
CAN INJ/THYROID	0-1609 km	1.0000	2.46E+02	1.62E+02	5.08E+02	7.00E+02	1.30E+03	1.56E+03	3.23E+03	1.14E-04	112
CAN INJ/BREAST	0-1609 km	1.0000	6.48E+02	4.39E+02	1.43E+03	2.00E+03	3.03E+03	3.47E+03	7.37E+03	1.14E-04	112
CAN FAT/TOTAL	0-80.5 km	1.0000	3.68E+02	1.67E+02	1.02E+03	1.32E+03	2.22E+03	2.56E+03	3.02E+03	2.37E-03	55
CAN FAT/TOTAL	0-16.1 km	1.0000	4.21E+01	2.55E+01	9.50E+01	1.25E+02	2.09E+02	2.24E+02	3.39E+02	7.15E-06	37
POPULATION DOSE (Sv)											
L-EDEWBODY TOT LIF	0-16.1 km	1.0000	9.44E+02	5.78E+02	2.14E+03	2.90E+03	4.89E+03	5.16E+03	7.64E+03	7.15E-06	37
L-EDEWBODY TOT LIF	0-80.5 km	1.0000	8.27E+03	3.91E+03	2.24E+04	3.15E+04	4.96E+04	5.78E+04	6.82E+04	2.37E-03	55
L-EDEWBODY TOT LIF	0-1609 km	1.0000	4.06E+04	2.82E+04	9.31E+04	1.18E+05	1.87E+05	2.16E+05	4.25E+05	1.14E-04	112
POPULATION WEIGHTED RISK											
CAN FAT/TOTAL	0-16.1 km	0.9993	4.05E-04	2.33E-04	9.98E-04	1.27E-03	2.03E-03	2.11E-03	2.99E-03	5.72E-06	24
PEAK DOSE FOUND ON SPATIAL GRID (Sv)											
L-EDEWBODY	0-0.2 km	0.4675	7.17E-02	0.00E+00	2.00E-01	2.02E-01	2.07E-01	2.09E-01	2.18E-01	2.28E-04	18
L-EDEWBODY	0.2-0.5 km	0.9107	1.04E-01	1.07E-01	1.59E-01	1.88E-01	2.06E-01	2.10E-01	2.19E-01	7.71E-04	98
L-EDEWBODY	0.5-1.2 km	0.9995	1.30E-01	1.09E-01	1.74E-01	2.01E-01	2.05E-01	2.07E-01	2.17E-01	1.14E-04	134
L-EDEWBODY	1.2-1.6 km	0.9995	1.10E-01	1.06E-01	1.35E-01	1.49E-01	1.90E-01	2.05E-01	2.16E-01	2.45E-03	83
L-EDEWBODY	1.6-2.1 km	0.9801	9.49E-02	9.82E-02	1.32E-01	1.50E-01	NOT-FOUND	NOT-FOUND	1.98E-01	1.00E-02	48
L-EDEWBODY	2.1-3.2 km	0.9801	7.48E-02	7.79E-02	1.32E-01	1.59E-01	NOT-FOUND	NOT-FOUND	1.87E-01	2.73E-02	76
L-EDEWBODY	3.2-4.0 km	0.9806	6.52E-02	6.00E-02	1.09E-01	1.34E-01	NOT-FOUND	NOT-FOUND	1.88E-01	1.55E-02	59
L-EDEWBODY	4.0-4.8 km	0.9806	5.93E-02	4.74E-02	1.02E-01	1.13E-01	1.41E-01	1.55E-01	1.90E-01	1.17E-03	92
L-EDEWBODY	4.8-5.6 km	0.9806	5.48E-02	3.94E-02	1.04E-01	1.10E-01	1.27E-01	1.36E-01	1.86E-01	1.43E-04	37
L-EDEWBODY	5.6-8.1 km	0.9806	7.65E-02	5.80E-02	1.28E-01	1.48E-01	NOT-FOUND	NOT-FOUND	1.90E-01	1.55E-02	100
L-EDEWBODY	8.1-11.3 km	1.0000	9.69E-02	9.61E-02	1.30E-01	1.46E-01	NOT-FOUND	NOT-FOUND	1.90E-01	1.00E-02	93
L-EDEWBODY	11.3-16.1 km	1.0000	1.02E-01	1.02E-01	1.15E-01	1.21E-01	1.36E-01	1.44E-01	1.88E-01	1.43E-04	37
L-EDEWBODY	16.1-20.9 km	1.0000	8.29E-02	8.16E-02	1.11E-01	1.17E-01	1.33E-01	1.40E-01	1.86E-01	1.43E-04	23
L-EDEWBODY	20.9-25.8 km	1.0000	6.74E-02	6.32E-02	1.01E-01	1.10E-01	1.31E-01	1.41E-01	1.74E-01	7.71E-04	42
L-EDEWBODY	25.8-32.2 km	1.0000	5.23E-02	4.58E-02	8.15E-02	9.21E-02	1.18E-01	1.31E-01	1.72E-01	7.71E-04	42
L-EDEWBODY	32.2-40.2 km	1.0000	4.87E-02	4.07E-02	7.22E-02	7.55E-02	8.38E-02	8.77E-02	1.27E-01	2.28E-04	25
L-EDEWBODY	40.2-48.3 km	1.0000	5.26E-02	4.69E-02	7.80E-02	8.40E-02	9.98E-02	1.10E-01	1.22E-01	2.45E-03	75
L-EDEWBODY	48.3-64.4 km	1.0000	5.21E-02	4.88E-02	7.86E-02	8.57E-02	NOT-FOUND	NOT-FOUND	9.86E-02	1.63E-02	49

09/26/96 08:40:08 PAGE 19

		PROB NON-ZERO	MEAN	QUANTILES 50TH	90TH	95TH	99TH	99.5TH	PEAK CONS	PEAK PROB	PEAK TRIAL
PEAK DOSE FOUND ON SPATIAL GRID (Sv)											
L-EDEWBODY	64.4-80.5 km	1.0000	4.92E-02	4.79E-02	7.40E-02	7.74E-02	8.59E-02	8.98E-02	9.40E-02	2.45E-03	30
L-EDEWBODY	80.5-113 km	1.0000	4.20E-02	3.64E-02	7.68E-02	8.69E-02	NOT-FOUND	NOT-FOUND	9.67E-02	2.73E-02	76
L-EDEWBODY	113-161 km	1.0000	2.97E-02	2.40E-02	6.36E-02	7.64E-02	NOT-FOUND	NOT-FOUND	9.20E-02	1.63E-02	67
L-EDEWBODY	161-241 km	1.0000	1.57E-02	1.17E-02	2.94E-02	5.03E-02	5.58E-02	5.84E-02	7.17E-02	3.14E-04	71
L-EDEWBODY	241-322 km	1.0000	8.99E-03	7.11E-03	1.86E-02	2.46E-02	3.50E-02	3.85E-02	4.26E-02	2.45E-03	83
L-EDEWBODY	322-563 km	1.0000	3.85E-03	3.13E-03	8.11E-03	9.68E-03	1.23E-02	1.35E-02	1.98E-02	3.14E-04	112
L-EDEWBODY	563-805 km	1.0000	1.10E-03	7.33E-04	2.56E-03	3.17E-03	4.04E-03	4.49E-03	5.33E-03	2.45E-03	64
L-EDEWBODY	805-1609 km	1.0000	1.60E-04	6.92E-05	4.00E-04	7.12E-04	8.87E-04	9.75E-04	1.45E-03	4.14E-03	105
L-EDEWBODY POP. DOSE (Sv)	0-1609 km										
TOTAL LONG-TERM PATHWAYS DOSE		1.0000	4.06E+04	2.82E+04	9.31E+04	1.18E+05	1.87E+05	2.16E+05	4.25E+05	1.14E-04	112
LONG-TERM DIRECT EXPOSURE PATHWAYS		1.0000	3.22E+04	2.21E+04	6.60E+04	9.10E+04	1.81E+05	2.16E+05	4.21E+05	1.14E-04	112
TOTAL INGESTION PATHWAYS DOSE		1.0000	8.02E+03	2.59E+03	2.50E+04	3.70E+04	7.09E+04	8.22E+04	1.10E+05	1.77E-03	5
LONG-TERM GROUNDSHINE DOSE		1.0000	3.15E+04	2.13E+04	6.53E+04	9.01E+04	1.80E+05	2.16E+05	4.16E+05	1.14E-04	112
LONG-TERM RESUSPENSION DOSE		1.0000	7.11E+02	5.03E+02	1.50E+03	2.04E+03	2.67E+03	2.99E+03	5.31E+03	1.14E-04	112

WATER INGESTION DOSE	1.0000	1.77E+02	1.31E+02	3.47E+02	4.60E+02	6.41E+02	7.14E+02	1.23E+03	1.88E-05	39
POP.-DEPENDENT DECONTAMINATION DOSE	1.0000	3.65E+02	1.79E+02	8.29E+02	1.44E+03	2.95E+03	3.63E+03	1.05E+04	5.71E-05	75
FARM-DEPENDENT DECONTAMINATION DOSE	1.0000	1.01E+01	8.96E+00	2.06E+01	2.55E+01	3.22E+01	3.37E+01	4.42E+01	8.56E-05	75
INGESTION OF GRAINS	1.0000	5.85E+02	6.16E+01	1.68E+03	2.59E+03	7.95E+03	1.03E+04	1.15E+04	1.88E-03	52
INGESTION OF LEAF VEG	1.0000	5.85E+02	6.16E+01	1.68E+03	2.59E+03	7.95E+03	1.03E+04	1.15E+04	1.88E-03	52
INGESTION OF ROOT CROPS	1.0000	3.87E+02	3.89E+01	1.31E+03	2.11E+03	3.60E+03	4.77E+03	6.12E+03	1.77E-03	5
INGESTION OF FRUITS	1.0000	5.59E+02	4.75E+01	2.00E+03	3.14E+03	5.35E+03	6.74E+03	8.96E+03	1.77E-03	5
INGESTION OF LEGUMES	1.0000	3.55E+02	6.67E+01	1.16E+03	1.75E+03	2.83E+03	3.51E+03	5.24E+03	1.77E-03	5
INGESTION OF BEEF	1.0000	2.66E+03	8.96E+02	7.89E+03	1.17E+04	2.10E+04	2.94E+04	3.95E+04	2.28E-04	4
INGESTION OF MILK	1.0000	2.01E+03	7.58E+02	5.79E+03	9.18E+03	1.69E+04	2.17E+04	3.41E+04	2.28E-04	4
INGESTION OF POULTRY	1.0000	8.00E+02	1.82E+02	2.26E+03	3.48E+03	9.41E+03	1.17E+04	1.42E+04	2.43E-03	52
INGESTION OF OTHER MEAT CROPS	1.0000	2.08E+02	1.05E+02	4.69E+02	6.53E+02	1.76E+03	2.17E+03	2.61E+03	1.88E-03	52
L-EDEWBODY POP. DOSE (Sv) 0-80.5 km										
TOTAL LONG-TERM PATHWAYS DOSE	1.0000	8.27E+03	3.91E+03	2.24E+04	3.15E+04	4.96E+04	5.78E+04	6.82E+04	2.37E-03	55
LONG-TERM DIRECT EXPOSURE PATHWAYS	1.0000	7.42E+03	3.03E+03	2.10E+04	3.06E+04	4.84E+04	5.67E+04	6.66E+04	2.37E-03	55
TOTAL INGESTION PATHWAYS DOSE	1.0000	4.85E+02	3.86E+02	8.33E+02	1.01E+03	1.17E+03	1.25E+03	2.04E+03	3.22E-05	108
LONG-TERM GROUNDSHINE DOSE	1.0000	7.13E+03	2.86E+03	2.02E+04	3.05E+04	4.84E+04	5.64E+04	6.59E+04	2.37E-03	55
LONG-TERM RESUSPENSION DOSE	1.0000	2.82E+02	1.36E+02	6.31E+02	1.10E+03	2.10E+03	2.30E+03	5.11E+03	3.64E-04	68
WATER INGESTION DOSE	1.0000	1.18E+02	8.16E+01	2.34E+02	3.05E+02	5.71E+02	6.92E+02	1.22E+03	1.88E-05	39
POP.-DEPENDENT DECONTAMINATION DOSE	0.9999	3.58E+02	1.64E+02	8.22E+02	1.44E+03	2.95E+03	3.63E+03	1.05E+04	5.71E-05	75
FARM-DEPENDENT DECONTAMINATION DOSE	1.0000	9.60E+00	8.35E+00	1.88E+01	2.33E+01	3.15E+01	3.31E+01	4.42E+01	8.56E-05	75
INGESTION OF GRAINS	1.0000	4.59E+01	2.59E+01	8.33E+01	1.72E+02	3.21E+02	3.61E+02	4.64E+02	1.14E-03	49
INGESTION OF LEAF VEG	1.0000	4.59E+01	2.59E+01	8.33E+01	1.72E+02	3.21E+02	3.61E+02	4.64E+02	1.14E-03	49
INGESTION OF ROOT CROPS	1.0000	2.32E+01	1.61E+01	4.90E+01	6.03E+01	9.58E+01	1.01E+02	1.05E+02	1.14E-03	49
INGESTION OF FRUITS	1.0000	2.79E+01	2.03E+01	6.18E+01	8.27E+01	1.13E+02	1.22E+02	1.45E+02	1.14E-03	49
INGESTION OF LEGUMES	1.0000	3.27E+01	2.97E+01	5.59E+01	6.78E+01	9.47E+01	1.01E+02	1.04E+02	1.14E-03	49
INGESTION OF BEEF	1.0000	1.03E+02	7.39E+01	2.23E+02	3.04E+02	3.63E+02	3.93E+02	5.67E+02	3.92E-05	108
INGESTION OF MILK	1.0000	8.51E+01	6.98E+01	1.72E+02	2.24E+02	3.12E+02	3.28E+02	4.59E+02	3.92E-05	108
INGESTION OF POULTRY	1.0000	2.18E+01	1.33E+01	4.70E+01	6.41E+01	1.12E+02	1.30E+02	1.85E+02	9.70E-04	49
INGESTION OF OTHER MEAT CROPS	1.0000	1.55E+01	1.09E+01	3.25E+01	3.83E+01	6.47E+01	7.23E+01	7.91E+01	1.14E-03	49
ECONOMIC COST MEASURES ($) 0-1609 km										
TOTAL ECONOMIC COSTS	1.0000	1.46E+09	8.07E+08	3.22E+09	5.96E+09	8.64E+09	9.63E+09	1.50E+10	2.15E-04	102
POP.-DEPENDENT COSTS	1.0000	1.24E+09	5.87E+08	2.95E+09	5.85E+09	8.60E+09	9.61E+09	1.49E+10	2.15E-04	102
FARM-DEPENDENT COSTS	1.0000	2.24E+08	7.05E+07	6.89E+08	9.57E+08	2.05E+09	2.28E+09	2.64E+09	1.88E-03	2
POP.-DEPENDENT DECONTAMINATION COST	1.0000	3.33E+08	1.36E+08	7.66E+08	1.48E+09	2.53E+09	2.89E+09	5.28E+09	2.15E-04	102
FARM-DEPENDENT DECONTAMINATION COST	1.0000	2.38E+07	1.82E+07	5.16E+07	5.99E+07	7.96E+07	8.80E+07	1.18E+08	2.46E-04	68

	PROB NON-ZERO	MEAN	QUANTILES 50TH	90TH	95TH	99TH	99.5TH	PEAK CONS	PEAK PROB	PEAK TRIAL
ECONOMIC COST MEASURES ($) 0-1609 km										
POP.-DEPENDENT INTERDICTION COST	1.0000	8.71E+08	4.00E+08	2.34E+09	4.07E+09	6.09E+09	6.76E+09	9.95E+09	2.23E-04	110
FARM-DEPENDENT INTERDICTION COST	1.0000	9.80E+07	2.19E+07	3.16E+08	4.70E+08	1.02E+09	1.08E+09	1.17E+09	1.88E-03	2
POP.-DEPENDENT CONDEMNATION COST	0.6064	3.24E+07	5.08E+05	4.66E+07	2.18E+08	4.97E+08	7.61E+08	2.71E+09	1.14E-05	18
FARM-DEPENDENT CONDEMNATION COST	1.0000	1.34E+06	1.09E+06	3.12E+06	3.54E+06	4.76E+06	5.33E+06	1.06E+07	5.04E-05	42
EMERGENCY PHASE COST	0.8625	8.59E+05	1.48E+05	2.29E+06	3.54E+06	9.90E+06	1.10E+07	2.12E+07	5.71E-05	75
INTERMEDIATE PHASE COST	0.0000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0
MILK DISPOSAL COST	1.0000	7.92E+06	8.43E+05	2.05E+07	3.44E+07	1.10E+08	1.21E+08	1.59E+08	6.85E-04	15
CROP DISPOSAL COST	1.0000	9.25E+07	1.36E+07	2.93E+08	4.63E+08	9.12E+08	1.13E+09	1.74E+09	8.85E-04	2
ECONOMIC COST MEASURES ($) 0-80.5 km										
TOTAL ECONOMIC COSTS	1.0000	1.22E+09	5.58E+08	2.82E+09	5.73E+09	8.60E+09	9.62E+09	1.50E+10	2.15E-04	102
POP.-DEPENDENT COSTS	0.9999	1.16E+09	5.05E+08	2.78E+09	5.73E+09	8.60E+09	9.61E+09	1.49E+10	2.15E-04	102
FARM-DEPENDENT COSTS	1.0000	5.75E+07	5.37E+07	9.89E+07	1.06E+08	1.22E+08	1.30E+08	1.74E+08	1.85E-04	3
POP.-DEPENDENT DECONTAMINATION COST	0.9999	3.13E+08	1.21E+08	7.12E+08	1.45E+09	2.53E+09	2.89E+09	5.28E+09	2.15E-04	102
FARM-DEPENDENT DECONTAMINATION COST	1.0000	1.91E+07	1.58E+07	3.48E+07	3.99E+07	5.13E+07	5.35E+07	6.46E+07	2.16E-04	110
POP.-DEPENDENT INTERDICTION COST	0.9999	8.16E+08	3.51E+08	2.23E+09	4.00E+09	6.09E+09	6.76E+09	9.95E+09	2.23E-04	110
FARM-DEPENDENT INTERDICTION COST	1.0000	2.33E+07	1.72E+07	4.88E+07	6.28E+07	7.68E+07	8.06E+07	9.00E+07	1.06E-03	135

POP.-DEPENDENT CONDEMNATION COST	0.6064	3.24E+07	5.08E+05	4.66E+07	2.18E+08	4.97E+08	7.61E+08	2.71E+09	1.14E-05	18
FARM-DEPENDENT CONDEMNATION COST	1.0000	1.34E+06	1.09E+06	3.12E+06	3.54E+06	4.76E+06	5.33E+06	1.06E+07	5.04E-05	42
EMERGENCY PHASE COST	0.8625	8.59E+05	1.48E+05	2.29E+06	3.54E+06	9.90E+06	1.10E+07	2.12E+07	5.71E-05	75
INTERMEDIATE PHASE COST	0.0000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0
MILK DISPOSAL COST	1.0000	8.17E+05	7.13E+05	1.73E+06	2.08E+06	2.38E+06	2.52E+06	2.87E+06	1.06E-03	52
CROP DISPOSAL COST	1.0000	1.30E+07	1.04E+07	2.59E+07	3.27E+07	4.66E+07	5.10E+07	5.48E+07	1.26E-03	52
MAXIMUM LONG-TERM ACTION DISTANCE (km)										
FARM-DEPENDENT DECONTAMINATION DIST.	1.0000	6.83E+01	5.95E+01	1.14E+02	1.34E+02	NOT-FOUND	NOT-FOUND	1.61E+02	2.26E-02	13
POP.-DEPENDENT DECONTAMINATION DIST.	1.0000	6.87E+01	6.14E+01	1.14E+02	1.35E+02	NOT-FOUND	NOT-FOUND	1.61E+02	2.42E-02	13
FARM-DEPENDENT INTERDICTION DIST.	1.0000	1.38E+02	9.89E+01	3.29E+02	4.05E+02	NOT-FOUND	NOT-FOUND	5.63E+02	2.47E-02	2
POP.-DEPENDENT INTERDICTION DIST.	1.0000	6.87E+01	6.14E+01	1.14E+02	1.35E+02	NOT-FOUND	NOT-FOUND	1.61E+02	2.42E-02	13
FARM-DEPENDENT CONDEMNATION DIST.	1.0000	8.63E+00	9.42E+00	1.24E+01	1.37E+01	1.72E+01	1.89E+01	3.22E+01	9.99E-04	25
POP.-DEPENDENT CONDEMNATION DIST.	0.6064	4.74E+00	5.43E+00	1.07E+01	1.17E+01	1.46E+01	1.60E+01	2.58E+01	1.44E-04	18
MILK DISPOSAL DIST.	1.0000	1.67E+02	1.01E+02	NOT-FOUND	NOT-FOUND	NOT-FOUND	NOT-FOUND	5.63E+02	1.00E-01	2
CROP DISPOSAL DIST.	1.0000	1.37E+02	9.84E+01	3.29E+02	4.05E+02	NOT-FOUND	NOT-FOUND	5.63E+02	2.47E-02	2
AFFECTED AREA/POPULATION 0-1609 km										
FARM DECONTAMINATION (HECTARES)	1.0000	3.18E+04	2.30E+04	6.82E+04	8.55E+04	1.12E+05	1.21E+05	1.72E+05	1.71E-04	72
POP. DECONTAMINATION (INDIVIDUALS)	1.0000	7.57E+04	2.79E+04	2.13E+05	3.71E+05	5.55E+05	5.89E+05	8.21E+05	2.15E-04	102
FARM INTERDICTION (HECTARES)	1.0000	1.87E+05	4.98E+04	5.62E+05	8.09E+05	1.85E+06	2.10E+06	2.29E+06	1.88E-03	2
POP. INTERDICTION (INDIVIDUALS)	1.0000	7.57E+04	2.79E+04	2.13E+05	3.71E+05	5.55E+05	5.89E+05	8.21E+05	2.15E-04	102
FARM CONDEMNATION (HECTARES)	1.0000	6.48E+02	5.42E+02	1.24E+03	1.52E+03	2.19E+03	2.41E+03	5.13E+03	5.04E-05	42
POP. CONDEMNATION (INDIVIDUALS)	0.6064	3.72E+02	1.36E+01	6.33E+02	2.63E+03	6.34E+03	7.85E+03	3.04E+04	1.14E-05	18
MILK DISPOSAL AREA (HECTARES)	1.0000	2.99E+05	4.33E+04	8.79E+05	1.54E+06	2.17E+06	2.27E+06	2.41E+06	1.88E-03	135
CROP DISPOSAL AREA (HECTARES)	1.0000	1.85E+05	4.35E+04	5.62E+05	8.09E+05	1.85E+06	2.10E+06	2.29E+06	1.88E-03	2
AFFECTED AREA/POPULATION 0-80.5 km										
FARM DECONTAMINATION (HECTARES)	1.0000	2.46E+04	1.85E+04	5.07E+04	5.40E+04	6.24E+04	6.65E+04	7.64E+04	1.45E-04	102
POP. DECONTAMINATION (INDIVIDUALS)	0.9999	7.00E+04	2.35E+04	2.06E+05	3.59E+05	5.55E+05	5.89E+05	8.21E+05	2.15E-04	102
FARM INTERDICTION (HECTARES)	1.0000	4.28E+04	3.59E+04	7.97E+04	1.04E+05	1.24E+05	1.33E+05	1.58E+05	1.06E-03	52
POP. INTERDICTION (INDIVIDUALS)	0.9999	7.00E+04	2.35E+04	2.06E+05	3.59E+05	5.55E+05	5.89E+05	8.21E+05	2.15E-04	102
FARM CONDEMNATION (HECTARES)	1.0000	6.48E+02	5.42E+02	1.24E+03	1.52E+03	2.19E+03	2.41E+03	5.13E+03	5.04E-05	42
POP. CONDEMNATION (INDIVIDUALS)	0.6064	3.72E+02	1.36E+01	6.33E+02	2.63E+03	6.34E+03	7.85E+03	3.04E+04	1.14E-05	18
MILK DISPOSAL AREA (HECTARES)	1.0000	4.47E+04	3.48E+04	9.25E+04	1.06E+05	1.25E+05	1.34E+05	1.56E+05	1.06E-03	52
CROP DISPOSAL AREA (HECTARES)	1.0000	4.19E+04	3.45E+04	7.97E+04	1.04E+05	1.24E+05	1.33E+05	1.58E+05	1.06E-03	52

09/26/96 08:40:08 PAGE 21

	PROB NON-ZERO	MEAN	QUANTILES 50TH	90TH	95TH	99TH	99.5TH	PEAK CONS	PEAK PROB	PEAK TRIAL
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE)										
PROJECTED FOR INDIVIDUAL 0.2-0.5 km	0.4165	1.15E-03	0.00E+00	2.54E-03	4.16E-03	NOT-FOUND	NOT-FOUND	1.63E-02	1.63E-02	96
PROJECTED FOR INDIVIDUAL 1.2-1.6 km	0.6819	3.45E-03	2.08E-03	1.00E-02	1.32E-02	NOT-FOUND	NOT-FOUND	1.83E-02	2.17E-02	115
PROJECTED FOR INDIVIDUAL 2.1-3.2 km	0.7828	4.96E-03	4.18E-03	1.09E-02	1.30E-02	NOT-FOUND	NOT-FOUND	1.68E-02	1.88E-02	101
PROJECTED FOR INDIVIDUAL 4.0-4.8 km	0.8553	4.37E-03	3.27E-03	1.03E-02	1.26E-02	NOT-FOUND	NOT-FOUND	1.60E-02	2.21E-02	94
PROJECTED FOR INDIVIDUAL 5.6-8.1 km	0.8920	4.48E-03	3.10E-03	1.06E-02	1.38E-02	NOT-FOUND	NOT-FOUND	2.21E-02	1.88E-02	113
PROJECTED FOR INDIVIDUAL 11.3-16.1 km	0.9809	7.35E-03	5.76E-03	1.22E-02	1.40E-02	1.89E-02	2.54E-02	3.10E-02	3.77E-03	110
PROJECTED FOR INDIVIDUAL 20.9-25.8 km	1.0000	4.95E-03	3.56E-03	1.07E-02	1.36E-02	NOT-FOUND	NOT-FOUND	2.43E-02	1.63E-02	49
PROJECTED FOR INDIVIDUAL 32.2-40.2 km	1.0000	4.89E-03	3.23E-03	9.39E-03	1.37E-02	NOT-FOUND	NOT-FOUND	3.12E-02	2.21E-02	94
PROJECTED FOR INDIVIDUAL 48.3-64.4 km	1.0000	4.49E-03	2.27E-03	1.07E-02	1.19E-02	1.54E-02	1.72E-02	2.88E-02	7.71E-04	98
PROJECTED FOR INDIVIDUAL 80.5-113 km	1.0000	5.90E-03	3.98E-03	1.32E-02	1.88E-02	NOT-FOUND	NOT-FOUND	2.63E-02	1.63E-02	96
MAXIMUM ANNUAL FOOD DOSE (THYROID)										
PROJECTED FOR INDIVIDUAL 0.2-0.5 km	0.4165	3.27E-03	0.00E+00	1.53E-03	2.77E-03	NOT-FOUND	NOT-FOUND	9.52E-02	2.05E-02	96
PROJECTED FOR INDIVIDUAL 1.2-1.6 km	0.6819	9.17E-03	8.01E-04	4.27E-02	5.70E-02	7.61E-02	8.16E-02	1.03E-01	3.42E-04	97
PROJECTED FOR INDIVIDUAL 2.1-3.2 km	0.7828	3.47E-02	1.58E-03	9.58E-02	1.06E-01	1.27E-01	1.37E-01	1.40E-01	4.22E-03	4
PROJECTED FOR INDIVIDUAL 4.0-4.8 km	0.8553	2.93E-02	2.62E-02	7.27E-02	7.79E-02	9.11E-02	9.76E-02	1.17E-01	1.14E-04	24
PROJECTED FOR INDIVIDUAL 5.6-8.1 km	0.8920	3.34E-02	2.04E-02	1.04E-01	1.17E-01	NOT-FOUND	NOT-FOUND	1.41E-01	1.55E-02	59
PROJECTED FOR INDIVIDUAL 11.3-16.1 km	0.9809	5.13E-02	5.03E-02	1.03E-01	1.11E-01	1.32E-01	1.42E-01	1.47E-01	3.77E-03	110
PROJECTED FOR INDIVIDUAL 20.9-25.8 km	1.0000	3.37E-02	2.58E-02	7.43E-02	9.15E-02	NOT-FOUND	NOT-FOUND	1.27E-01	1.63E-02	49

PROJECTED FOR INDIVIDUAL 32.2-40.2 km	1.0000	3.16E-02	2.60E-02	6.77E-02	9.94E-02	NOT-FOUND	NOT-FOUND	1.46E-01	2.21E-02	94
PROJECTED FOR INDIVIDUAL 48.3-64.4 km	1.0000	3.37E-02	1.71E-02	9.33E-02	1.05E-01	1.22E-01	1.30E-01	1.37E-01	2.94E-03	118
PROJECTED FOR INDIVIDUAL 80.5-113 km	1.0000	3.78E-02	2.61E-02	9.14E-02	1.04E-01	1.16E-01	1.22E-01	1.43E-01	4.85E-04	133

MACCS2 09/26/96 08:40:08 Version 1.12, Last Modified 9/25/96 by D. Chanin PAGE 22

SOURCE TERM 2 OF 2:
RELEASE FRACTIONS OF SOURCE TERM 1 REDUCED BY A FACTOR OF TEN

RESULT NAME = HEALTH EFFECTS CASES
CAN FAT/TOTAL 0-80.5 km

PEOPLE FRACTION = 0.9500 0.0500

OVERALL		EMER. RESP. # 1		EMER. RESP. # 2		CHRONC RESULTS	
X	PROB>=X	X	PROB>=X	X	PROB>=X	X	PROB>=X
1.00E-04	1.00E+00	1.00E-05	1.00E+00	1.00E-05	1.00E+00	1.00E-04	1.00E+00
2.00E-04	1.00E+00	2.00E-05	1.00E+00	2.00E-05	1.00E+00	2.00E-04	1.00E+00
3.00E-04	1.00E+00	3.00E-05	1.00E+00	3.00E-05	1.00E+00	3.00E-04	1.00E+00
5.00E-04	1.00E+00	5.00E-05	1.00E+00	5.00E-05	1.00E+00	5.00E-04	1.00E+00
7.00E-04	1.00E+00	7.00E-05	1.00E+00	7.00E-05	1.00E+00	7.00E-04	1.00E+00
1.00E-03	1.00E+00	1.00E-04	1.00E+00	1.00E-04	1.00E+00	1.00E-03	1.00E+00
2.00E-03	1.00E+00	2.00E-04	1.00E+00	2.00E-04	1.00E+00	2.00E-03	1.00E+00
3.00E-03	1.00E+00	3.00E-04	1.00E+00	3.00E-04	1.00E+00	3.00E-03	1.00E+00
5.00E-03	1.00E+00	5.00E-04	1.00E+00	5.00E-04	1.00E+00	5.00E-03	1.00E+00
7.00E-03	1.00E+00	7.00E-04	1.00E+00	7.00E-04	1.00E+00	7.00E-03	1.00E+00
1.00E-02	1.00E+00	1.00E-03	1.00E+00	1.00E-03	1.00E+00	1.00E-02	1.00E+00
2.00E-02	1.00E+00	2.00E-03	1.00E+00	2.00E-03	1.00E+00	2.00E-02	1.00E+00
3.00E-02	1.00E+00	3.00E-03	1.00E+00	3.00E-03	1.00E+00	3.00E-02	1.00E+00
5.00E-02	1.00E+00	5.00E-03	1.00E+00	5.00E-03	1.00E+00	5.00E-02	1.00E+00
7.00E-02	1.00E+00	7.00E-03	1.00E+00	7.00E-03	1.00E+00	7.00E-02	1.00E+00
1.00E-01	1.00E+00	1.00E-02	1.00E+00	1.00E-02	1.00E+00	1.00E-01	1.00E+00
2.00E-01	1.00E+00	2.00E-02	1.00E+00	2.00E-02	1.00E+00	2.00E-01	1.00E+00
3.00E-01	1.00E+00	3.00E-02	1.00E+00	3.00E-02	1.00E+00	3.00E-01	1.00E+00
5.00E-01	1.00E+00	5.00E-02	1.00E+00	5.00E-02	1.00E+00	5.00E-01	1.00E+00
7.00E-01	1.00E+00	7.00E-02	1.00E+00	7.00E-02	1.00E+00	7.00E-01	1.00E+00
1.00E+00	1.00E+00	1.00E-01	1.00E+00	1.00E-01	1.00E+00	1.00E+00	1.00E+00
2.00E+00	1.00E+00	2.00E-01	1.00E+00	2.00E-01	1.00E+00	2.00E+00	1.00E+00
3.00E+00	1.00E+00	3.00E-01	1.00E+00	3.00E-01	1.00E+00	3.00E+00	1.00E+00
5.00E+00	1.00E+00	5.00E-01	1.00E+00	5.00E-01	1.00E+00	5.00E+00	1.00E+00
7.00E+00	1.00E+00	7.00E-01	1.00E+00	7.00E-01	1.00E+00	7.00E+00	1.00E+00
1.00E+01	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+01	9.99E-01
2.00E+01	9.99E-01	2.00E+00	9.99E-01	2.00E+00	1.00E+00	2.00E+01	9.99E-01
3.00E+01	9.99E-01	3.00E+00	9.99E-01	3.00E+00	1.00E+00	3.00E+01	9.98E-01
5.00E+01	9.96E-01	5.00E+00	9.95E-01	5.00E+00	1.00E+00	5.00E+01	9.82E-01
7.00E+01	9.78E-01	7.00E+00	9.81E-01	7.00E+00	9.98E-01	7.00E+01	9.29E-01
1.00E+02	9.15E-01	1.00E+01	9.57E-01	1.00E+01	9.96E-01	1.00E+02	8.17E-01
2.00E+02	5.99E-01	2.00E+01	8.27E-01	2.00E+01	9.28E-01	2.00E+02	4.22E-01
3.00E+02	3.91E-01	3.00E+01	6.97E-01	3.00E+01	8.06E-01	3.00E+02	3.09E-01
5.00E+02	2.45E-01	5.00E+01	4.75E-01	5.00E+01	6.23E-01	5.00E+02	1.90E-01
7.00E+02	1.78E-01	7.00E+01	3.57E-01	7.00E+01	4.70E-01	7.00E+02	1.41E-01
1.00E+03	1.29E-01	1.00E+02	2.44E-01	1.00E+02	3.21E-01	1.00E+03	1.06E-01
2.00E+03	4.03E-02	2.00E+02	1.42E-01	2.00E+02	1.54E-01	2.00E+03	1.64E-02
3.00E+03	4.58E-03	3.00E+02	7.02E-02	3.00E+02	8.78E-02	3.00E+03	2.37E-03
4.08E+03	2.15E-04	5.00E+02	2.50E-02	5.00E+02	3.01E-02	3.02E+03	2.37E-03
N.D.	N.D.	7.00E+02	1.16E-02	7.00E+02	7.32E-03	N.D.	N.D.
N.D.	N.D.	1.00E+03	5.11E-03	1.00E+03	2.72E-04	N.D.	N.D.
N.D.	N.D.	1.97E+03	2.85E-04	1.11E+03	2.15E-04	N.D.	N.D.
N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

```
    N.D.      N.D.        N.D.      N.D.        N.D.      N.D.        N.D.      N.D.
    N.D.      N.D.        N.D.      N.D.        N.D.      N.D.        N.D.      N.D.
    N.D.      N.D.        N.D.      N.D.        N.D.      N.D.        N.D.      N.D.

Successful completion of MACCS2 was achieved!
This job required a total of   2708.588 CPU seconds

   Input processing required     10.209 CPU seconds
         Simulation required   2579.520 CPU seconds
  Output processing required    118.859 CPU seconds
```

Appendix D: Glossary of Input File Variables

This appendix is a glossary of the input variable names for the MACCS2 code. The name of the user input file in which each variable belongs is noted. The location in the user's guide where the variable is defined is given by section number. Each variable name is also briefly described.

VARIABLE NAME	INPUT FILE	SECT.	DESCRIPTION
ACNAME	EARLY	6.9.3	Latent Cancer Effect
ACSUSC	EARLY	6.9.3	Population Susceptible to Cancer
ACTHRE	EARLY	6.9.3	Linear Dose-Response Threshold
APLFRC	ATMOS	5.11	Method of Applying Release Fractions
ATNAM1	ATMOS	5.2	Title Describing the ATMOS Assumptions
ATNAM2	ATMOS	5.11	Title Describing the Source Term
BIN_FILE	CHRONC	7.10.2	Name of COMIDA2 Ingestion Data File
BNDMXH	ATMOS	5.14	Boundary Weather Mixing Layer Height
BNDRAN	ATMOS	5.14	Boundary Weather Rain Rate
BNDWND	ATMOS	5.14	Boundary Weather Wind Speed
BRKPNT	ATMOS	5.8	Breakpoint Time for Plume Meander
BRRATE	EARLY	6.5	Breathing Rate
BUILDH	ATMOS	5.10	Reactor Building Height
CDFRM	CHRONC	7.5	Farmland Decontamination Cost
CDNFRM	CHRONC	7.5	Nonfarm Decontamination Cost
CFRISK	EARLY	6.9.3	Lifetime Cancer Fatality Risk Factors
CHNAME	CHRONC	7.2	CHRONC Problem Identification
CIRISK	EARLY	6.9.3	Lifetime Cancer Injury Risk Factors
CORINV	ATMOS	5.11	Core Inventory by Radionuclide
CORSCA	ATMOS	5.11	Linear Scaling Factor on Core Inventory
COUPLD	CHRONC	7.11.3	Coupling Flag for Food Actions
CRIORG	EARLY	6.6.8	Critical Organ for EARLY Phase
CRTOCR	CHRONC	7.4	Critical Organ for CHRONC Phase
CSFACT	EARLY	6.5	Cloudshine Shielding Factor
CTCOEF	CHRONC	7.11.1	Growing Season Transfer Coefficient
CTHALF	CHRONC	7.11.1	Growing Season Weathering Half-Life
CWASH1	ATMOS	5.5	Linear Coefficient for Washout
CWASH2	ATMOS	5.5	Exponential Term for Washout
CYSIGA	ATMOS	5.7	Linear Coefficient for σ_y
CYSIGB	ATMOS	5.7	Exponential Term for σ_y
CZSIGA	ATMOS	5.7	Linear Coefficient for σ_z
CZSIGB	ATMOS	5.7	Exponential Term for σ_z
DCF_FILE	EARLY	6.2.1	Name of Dose Conversion Factor File
DCYPBH	CHRONC	7.11.1	Decay/Processing Retention Meat to Humans
DCYPCB	CHRONC	7.11.1	Decay/Processing Retention Crops to Meat

DCYPCH	CHRONC	7.11.1	Decay/Processing Retention Crops to Humans
DCYPCM	CHRONC	7.11.1	Decay/Processing Retention Crops to Milk
DCYPMH	CHRONC	7.11.1	Decay/Processing Retention Milk to Humans
DDREFA	EARLY	6.9.3	Dose-Dependent Reduction Factor
DDTHRE	EARLY	6.9.3	Threshold for Applying Dose-Dependent Reduction Factor
DISTANCE	ATMOS	7.5.2	Downwind Distance for σ_y and σ_z Parameters
DLBCST	CHRONC	7.5	Decontamination Worker Labor Cost
DLTEVA	EARLY	6.6.8	Delay to Evacuation for Each Ring
DLTSHL	EARLY	6.6.8	Delay to Take Shelter for Each Ring
DOSEFA	EARLY	6.9.3	Cancer Dose-Response Alpha Factors
DOSEFB	EARLY	6.9.3	Cancer Dose-Response Beta Factors
DOSELONG	CHRONC	7.10.2	COMIDA2 Model Long-Term Dose Limit
DOSEMILK	CHRONC	7.10.2	COMIDA2 Model First-Year Milk Dose Limit
DOSEOTHR	CHRONC	7.10.2	COMIDA2 Model First-Year Nonmilk Dose Limit
DOSHOT	EARLY	6.6.8	Normal Relocation Dose Threshold
DOSNRM	EARLY	6.6.8	Hot-Spot Relocation Dose Threshold
DOSTH3	EARLY	6.13	Dose Threshold for Result 3
DPFRCT	CHRONC	7.9	Farm Production Dairy Fraction
DPRATE	CHRONC	7.6	Property Depreciation Rate
DRYDEP	ATMOS	5.4	Dry Deposition Flag
DSCRLT	CHRONC	7.4	Long-Term Phase Dose Criterion
DSCRTI	CHRONC	7.4	Intermediate-Phase Dose Criterion
DSRATE	CHRONC	7.6	Societal Discount Rate for Property
DSRFCT	CHRONC	7.5	Decontamination Factors
DURBEG	EARLY	6.6.8	Duration of Beginning of Evacuation Phase
DUR_INTPHAS	CHRONC	7.4	Duration of Intermediate-Phase Period
DURMID	EARLY	6.6.8	Duration of Middle of Evacuation Phase
EANAM1	EARLY	6.2.2	Text Describing the EARLY Assumptions
EANAM2	EARLY	6.6.8	Text Describing the Emergency Response
EFFACA	EARLY	6.7	Hazard Function Fatal Alpha Factors
EFFACB	EARLY	6.8	Hazard Function Fatal Beta Factors
EIFACA	EARLY	6.8	Hazard Function Injury Alpha Factors
EIFACB	EARLY	6.8	Hazard Function Injury Beta Factors
EINAME	EARLY	6.8	Early Injury Effect Names
EISUSC	EARLY	6.8	Susceptible Population Fraction
EITHRE	EARLY	6.8	Early Injury Dose Threshold
EFFTHR	EARLY	6.7	Threshold Dose to Target Organ
ENDAT1	ATMOS	5.12	Control Flag Indicating Only ATMOS Is to be Run
ENDAT2	EARLY	6.2.2	Control Flag Indicating Only ATMOS and EARLY Are to be Run
ENDEMP	EARLY	6.6.8	Duration of the Early Phase
ESPEED	EARLY	6.6	Radial Evacuation Speed Array
EVACST	CHRONC	7.3	Emergency-Phase Cost of Evacuation/Relocation
EVATYP	EARLY	6.6.8	Type of Evacuation
EXPTIM	CHRONC	7.4	Maximum Exposure Time for CHRONC Calculations

FDPATH	CHRONC	7.10.2	COMIDA2 vs. MACCS Food Model Switch
FDPATH	CHRONC	7.11	COMIDA2 vs. MACCS Food Model Switch
FLAG11	CHRONC	7.16	Flag to Request Maximum Distance Results
FPLSCH	CHRONC	7.11.1	Losses in Processing Crops for Human Consumption
FRACLD	CHRONC	7.9	Fraction of Site Area that is Land
FRCFRM	CHRONC	7.9	Fraction of Site Land Used for Farming
FRCTCB	CHRONC	7.11.1	Fraction of Crop Consumed by Meat Animals
FRCTCH	CHRONC	7.11.1	Fraction of Crop Consumed by Humans
FRCTCM	CHRONC	7.11.1	Fraction of Crop Consumed by Milk Animals
FRCTFL	CHRONC	7.11.2	Fraction of Farmland Used for Each Crop
FRFDL	CHRONC	7.5	Farm Labor Cost Fraction
FRFIM	CHRONC	7.9	Farm Wealth Improvements Fraction
FRMPRD	CHRONC	7.9	Average Annual Farm Production Value
FRNFDL	CHRONC	7.5	Nonfarm Labor Cost Fraction
FRNFIM	CHRONC	7.9	Nonfarm Wealth Improvements Fraction
GCMAXR	CHRONC	7.11.3	Protective Action Guides for Long-Term Uptake to Milk or Crops
GSHFAC	EARLY	6.5	Groundshine Shielding Factor Table
GWCOEF	CHRONC	7.7	Long-Term Groundshine Coefficients
HRMXHT	ATMOS	5.17	Mixing Layer Heights
HRRAIN	ATMOS	5.17	Rain Rates
HRWNDV	ATMOS	5.17	Wind Speeds
I1DIS1	EARLY	6.11	Inner Spatial Interval for Result 1
I1DIS4	EARLY	6.14	Spatial Interval for Result 4
I1DIS5	EARLY	6.15	Inner Spatial Interval for Result 5
I1DIS6	EARLY	6.16	Inner Spatial Interval for Result 6
I1DIS7	EARLY	6.17	Inner Spatial Interval for Result 7
I1DIS8	EARLY	6.18	Inner Spatial Interval for Result 8
I1DISA	EARLY	6.19	Inner Spatial Interval for Result A
I1DS10	CHRONC	7.15	Inner Spatial Interval for Result 10
I1DS12	CHRONC	7.17	Inner Spatial Interval for Result 12
I2DIS1	EARLY	6.11	Outer Spatial Interval for Result 1
I2DIS5	EARLY	6.15	Outer Spatial Interval for Result 5
I2DIS6	EARLY	6.16	Outer Spatial Interval for Result 6
I2DIS7	EARLY	6.17	Outer Spatial Interval for Result 7
I2DIS8	EARLY	6.18	Outer Spatial Interval for Result 8
I2DISA	EARLY	6.19	Outer Spatial Interval for Result A
I2DS10	CHRONC	7.15	Outer Spatial Interval for Result 10
I2DS12	CHRONC	7.17	Outer Spatial Interval for Result 12
IANG_B	EARLY	6.20	Angular Index for Type B Results
IBDSTB	ATMOS	5.14	Boundary Weather Stability Class
IBEGIN	EARLY	6.3	Interval at Which Population Begins
IDEBUG	ATMOS	5.12	Debug Switch for Dispersion Print
IDIREC	EARLY	6.6.8	Array of Exit Directions for Network Evacuation
IGROUP	ATMOS	5.4	Radionuclide Groups

IHRDIR	ATMOS	5.17	Wind Directions
IHRSTB	ATMOS	5.17	Stability Classes
INDRAD	ATMOS	5.18	Distance Index for ATMOS CCDFs
INDREL	ATMOS	5.18	Plume Index for ATMOS CCDFs
INDXBN	ATMOS	5.16	Index to Bin Number Used for Met Sample
INWGHT	ATMOS	5.16	Number of Samples to Take from the Bin
IORG13	CHRONC	7.18	Organ Index for Maximum Food Dose Result
IPLUME	EARLY	6.2.2	Plume Model Dispersion Code
IPRINT	EARLY	6.2.2	Quantity of Early Debug Output
IRAD13	CHRONC	7.18	Distance Index for Maximum Food Dose Result
IRAD_B	EARLY	6.20	Inner Radial Boundary for Type B Results
IRSEED	ATMOS	5.16	Seed for Random Number Generator
ISTRDY	ATMOS	5.15	Starting Day of the Accident
ISTRHR	ATMOS	5.15	Starting Hour of the Accident
IX1DS9	CHRONC	7.14	Inner Spatial Interval for Result 9
IX2DS9	CHRONC	7.14	Outer Spatial Interval for Result 9
KSWTCH	CHRONC	7.13	Diagnostic Output Option Switch
LASMOV	EARLY	6.6.8	Last Evacuation Movement Interval
LIMSPA	ATMOS	5.14	Last Spatial Interval for Recorded Weather
LVLDEC	CHRONC	7.5	Number of Decontamination Strategies
MAXGRP	ATMOS	5.4	Number of Radionuclide Groups
MAXRIS	ATMOS	5.11	Selection of Risk Dominant Plume
METCOD	ATMOS	5.13	Meteorological Sampling Option Code
NAMCRP	CHRONC	7.11.1	Names of the Crop Categories
NAMCRP	CHRONC	7.11.2	Names of the Crop Categories
NAME	EARLY	6.11	Result Type 1 Health Effect Name
NAME	EARLY	6.13	Result Type 3 Organ Name
NAME	EARLY	6.14	Result Type 4 Health Effect Name
NAME	EARLY	6.15	Result Type 5 Organ Name
NAME	EARLY	6.17	Result Type 7 Health Effect Name
NAME	EARLY	6.18	Result Type 8 Health Effect Name
NAME	EARLY	6.19	Result Type A Organ Name
NAME	EARLY	6.20	Result Type B Organ Name
NAMIPI	CHRONC	7.11.1	Names of Food Ingestion Radionuclides
NAMIPI	CHRONC	7.11.3	Names of Food Ingestion Radionuclides
NAMSTB	ATMOS	5.4	List of Pseudostable Nuclides
NAMWPI	CHRONC	7.12	Names of Water Ingestion Radionuclides
NFICRP	CHRONC	7.11.1	Number of Crop Categories
NFIISO	CHRONC	7.11.1	Number of Radionuclides for Food Ingestion
NGWTRM	CHRONC	7.7	Number of Terms in Groundshine Weathering Equation
NPSGRP	ATMOS	5.6	Number of Particle Size Groups
NRINTN	ATMOS	5.16	Number of Rain Intensity Breakpoints
NRNINT	ATMOS	5.16	Number of Rain Distance Intervals
NRWTRM	CHRONC	7.8	Number of Terms in Resuspension Weathering Equation
NSBINS	ATMOS	5.16	Number of Weather Bins to Sample

NSMPLS	ATMOS	5.16	Number of Weather Samples per Bin
NTTRM	CHRONC	7.11.1	Number of Terms in Growing-Season Food Model
NUCNAM	ATMOS	5.4	Radionuclide Names
NUCOUT	ATMOS	5.12	Radionuclide Used in Dispersion Print
NUM0	ATMOS	5.18	Number of Requests for ATMOS CCDFs
NUM1	EARLY	6.11	Number of Health Effect Results
NUM2	EARLY	6.12	Number of Early Fatality Radius Results
NUM3	EARLY	6.13	Number of Early Dose Threshold Results
NUM4	EARLY	6.14	Number of Avg. Individual Risk Results
NUM5	EARLY	6.15	Number of Population Dose Results
NUM6	EARLY	6.16	Number of Centerline Dose/Distance Results
NUM7	EARLY	6.17	Number of Centerline Risk/Distance Results
NUM8	EARLY	6.18	Number of Population-Weighted Risk Results
NUM12	CHRONC	7.17	Number of Affected Area Results
NUM13	CHRONC	7.18	Number of Ingestion Dose Results
NUMA	EARLY	6.19	Number of Peak Dose at a Distance Results
NUMACA	EARLY	6.9.3	Number of Latent Cancer Effects
NUMB	EARLY	6.20	Peak Dose at an (r, θ) Location
NUMEFA	EARLY	6.7	Number of Early Fatality Effects
NUMEIN	EARLY	6.8	Number of Early Injury Effects
NUMEVA	EARLY	6.6.8	Outer Boundary of Evacuation/Shelter Region
NUMFIN	EARLY	6.2.2	Number of Fine Grid Subdivisions
NUMISO	ATMOS	5.4	Number of Defined Radionuclides
NUMRAD	ATMOS	5.3	Number of Radial Spatial Intervals
NUMREL	ATMOS	5.11	Number of Released Plume Segments
NUMSTB	ATMOS	5.4	Number of Defined Pseudostable Radionuclides
NUMWPI	CHRONC	7.12	Number of Radionuclides for Water Ingestion
NUM_DST	ATMOS	5.7.2	Number of Distances Defined in Dispersion Table
NXUM9	CHRONC	7.14	Number of Population Dose Results
NXUM10	CHRONC	7.15	Number of Economic Block Results
OALARM	ATMOS	5.11	Off-Site Alarm Time
ORGFLG	EARLY	6.4	Doses to be Calculated for Specified Organ
ORGNAM	EARLY	6.4	Defined Organ Names
ORGNAM	EARLY	6.7	Early Fatality Target Organs
ORGNAM	EARLY	6.8	Early Injury Target Organs
ORGNAM	EARLY	6.9.3	Latent Cancer Target Organs
ORGNAM	EARLY	6.16	Organ Name of the Centerline Doses
ORGNAM	CHRONC	7.14	Organ Name for Population Dose Results
ORGN13	CHRONC	7.18	Organ Name for Type 13 Results
OVRRID	EARLY	6.2.2	Wind Rose Probability Override
PATHNM	EARLY	6.16	Pathway Code for Result 6
PDELAY	ATMOS	5.11	Plume Release Times
PLHEAT	ATMOS	5.11	Plume Heat Contents
PLHITE	ATMOS	5.11	Plume Release Heights
PLUDUR	ATMOS	5.11	Plume Segment Durations

POPCST	CHRONC	7.6	Per Capita Cost of Long-Term Relocation
POPDEN	EARLY	6.3	Average Regional Population Density
POPFLG	EARLY	6.3	Population Distribution Flag
PROTIN	EARLY	6.5	Inhalation Protection Factor
PSCMLK	CHRONC	7.11.3	Growing-Season Protective Action Criteria for Milk
PSCOTH	CHRONC	7.11.3	Growing-Season Protective Action Criteria for Crops
PSDIST	ATMOS	5.11	Particle Size Distribution by Group
QROOT	CHRONC	7.11.3	Decay Rate for Long-Term Food Dose
REFPNT	EARLY	6.6.8	Reference Time Point (ARRIVAL or SCRAM)
REFTIM	ATMOS	5.11	Plume Reference Time Point
RELCST	CHRONC	7.3	Relocation Cost per Person-Day
RELFRC	ATMOS	5.11	Release Fractions of the Source Term
RESCON	EARLY	6.5	Resuspension Concentration Coefficient
RESHAF	EARLY	6.5	Resuspension Concentration Half-Life
RISCAT	EARLY	6.2.2	Risk by Weather-Category Flag
RISTHR	EARLY	6.12	Risk Threshold for Fatality Radius
RNDSTS	ATMOS	5.16	Rain Distances Used for Binning
RNRATE	ATMOS	5.16	Rain Intensities Used for Binning
RWCOEF	CHRONC	7.8	Long-Term Resuspension Factor Coefficients
SCLADP	ATMOS	5.9	Scaling Factor for A–D Plume Rise
SCLCRW	ATMOS	5.9	Scaling Factor for Critical Wind Speed
SCLEFP	ATMOS	5.9	Scaling Factor for E–F Plume Rise
SIGMA_Y	ATMOS	5.7.2	Gaussian Crosswind Dispersion Parameter (σ_y)
SIGMA_Z	ATMOS	5.7.2	Gaussian Vertical Dispersion Parameter (σ_z)
SIGYINIT	ATMOS	5.10	Initial Value of σ_y
SIGZINIT	ATMOS	5.10	Initial Value of σ_z
SKPFAC	EARLY	6.5	Skin Protection Factors
SPAEND	ATMOS	5.3	Endpoints of Spatial Intervals
TCROOT	CHRONC	7.11.1	Transfer Factor Long-Term Root Uptake
TFBF	CHRONC	7.11.1	Transfer Factor Animal to Meat
TFMILK	CHRONC	7.11.1	Transfer Factor Animal to Milk
TFWKF	CHRONC	7.5	Farm Worker's Work Fraction
TFWKNF	CHRONC	7.5	Nonfarm Workers Work Fraction
TGSBEG	CHRONC	7.11.2	Growing Season Start Time for Each Crop
TGSEND	CHRONC	7.11.2	Growing Season End Time for Each Crop
TGWHLF	CHRONC	7.7	Groundshine Weathering Half-Lives
TIMBAS	ATMOS	5.8	Time Base for Plume Expansion Factor
TIMDEC	CHRONC	7.5	Decontamination Times
TIMHOT	EARLY	6.6.8	Hot Spot Relocation Time
TIMNRM	EARLY	6.6.8	Normal Relocation Time
TMIPND	CHRONC	7.4	Time Intermediate Phase Ends
TMPACT	CHRONC	7.4	Time Action Period Ends
TRAVELPOINT	EARLY	6.6.8	Evacuee Movement Option
TRWHLF	CHRONC	7.8	Resuspension Weathering Half-Lives
VALWF	CHRONC	7.9	Value of Farm Wealth (per Hectare)

VALWNF	CHRONC	7.9	Value of Nonfarm Wealth (per Capita)
VDEPOS	ATMOS	5.6	Dry Deposition Velocities
WETDEP	ATMOS	5.4	Wet Deposition Flag
WINGF	CHRONC	7.12	Water Transfer Fraction to Humans
WINROS	EARLY	6.2.2	Wind Rose Probabilities
WSHFRI	CHRONC	7.12	Initial Water Washoff Fraction
WSHRTA	CHRONC	7.12	Annual Water Washoff Fraction
WTFRAC	EARLY	6.6.8	Weighting Fraction for Combined Results
WTNAME	EARLY	6.6.8	Type of Weighting (PEOPLE, TIME, or SUMPOP)
XPFAC1	ATMOS	5.8	Base Time for Meander Expansion Factor
XPFAC2	ATMOS	5.8	Breakpoint for Expansion Factor Model
YSCALE	ATMOS	5.7.3	Scale Factor for Horizontal Dispersion
ZSCALE	ATMOS	5.7.3	Scale Factor for Vertical Dispersion

ATTACHMENT 20

Excerpt from Electric Power Research Institute ("EPRI") Report 1020236, "MAAP4 Applications Guidance: Desktop Reference for Using MAAP4 Software, Revision 2" (2010)

ELECTRIC POWER
RESEARCH INSTITUTE

MAAP4 Applications Guidance

Desktop Reference for Using MAAP4 Software, Revision 2

WARNING:
Please read the Export Control Agreement on the back cover.

PORTIONS
TRANSLATED

MAAP4 Applications Guidance

Desktop Reference for Using MAAP4 Software, Revision 2

1020236

Final Report, July 2010

EPRI Project Manager
F. Rahn

This document does **NOT** meet the requirements of
10CFR50 Appendix B, 10CFR Part 21,
ANSI N45.2-1977 and/or the intent of ISO-9001 (1994)

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

THE FOLLOWING ORGANIZATION, UNDER CONTRACT TO EPRI, PREPARED THIS REPORT:

ERIN Engineering and Research, Inc.

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

ACKNOWLEDGMENTS

The following organization, under contract to the Electric Power Research Institute (EPRI), prepared this report:

ERIN Engineering and Research, Inc.
158 West Gay Street, Suite 400
West Chester, PA 19380

Principal Investigator
B. Schlenger-Faber

This report describes research sponsored by EPRI.

This publication is a corporate document that should be cited in the literature in the following manner:

MAAP4 Applications Guidance: Desktop Reference for Using MAAP4 Software, Revision 2. EPRI, Palo Alto, CA: 2010. 1020236.

PRODUCT DESCRIPTION

The existing Modular Accident Analysis Program Version 4 (MAAP4) documentation consists of the MAAP4 User's Manual, the MAAP4 user's guides for input preparation, and transmittal documents that describe individual revisions. These components contain detailed information on the mechanics of running the code as well as detailed descriptions of the individual models, but they do not include specific applications guidance. This applications guidance document is intended to fill that gap by providing sufficient information to enable users to optimize their efforts and generate high-quality Level 1 probabilistic risk assessment (PRA) analyses.

Results and Findings

MAAP4 is a computer code used by nuclear utilities and research organizations to predict the progression of light water reactor accidents. This applications guidance document provides the following:

- A description of the MAAP4 code
- Guidance for ensuring the quality of MAAP4 analyses
- Guidance on how to apply MAAP4 for Level 1 PRAs
- A compilation of summary information on the benchmarking of MAAP4 models
- An assessment of MAAP4's ability to adequately predict significant Level 1 PRA phenomena

Challenges and Objectives

Two prior efforts that were related to the previous version of the code, MAAP3B, generated particularly useful information regarding the validation of the thermal-hydraulic models, code application guidance, and recommended sensitivity analyses. The first effort was a set of thermal-hydraulic qualification studies. The objectives of the studies were to evaluate the thermal-hydraulic modeling in MAAP3B and provide guidance on code use. The resultant reports contain detailed descriptions of relevant plant features, accident sequences, benchmarks, and input file components, as well as guidance on applications and limitations. The second effort was the creation of a set of recommended sensitivity analyses for an individual plant examination (IPE). The resultant document contains a review of key accident sequences and phenomena and recommended approaches for treating phenomenological uncertainties in IPEs. There is a consensus among current code users that similar thermal-hydraulic assessments, applications guidance, and recommendations for sensitivity analyses for MAAP4 would be advantageous. This report aims to satisfy these needs for Level 1 PRA risk-informed applications.

Applications, Value, and Use

It is anticipated that this report will be used by analysts responsible for running the code, analysts responsible for incorporating MAAP4 results into PRA models, and others interested in MAAP4's capabilities (for example, utility personnel, regulators, reactor vendors, and researchers).

EPRI Perspective

This guidance document provides sufficient information to enable users to optimize their efforts and generate high-quality Level 1 PRA MAAP4 analyses.

Approach

The information in this report was primarily assembled from extensive experience using the MAAP4 code, from the MAAP4 User's Manual and user's guides, from the MAAP3B thermal-hydraulic qualification studies and sensitivity guidance described previously, from benchmark descriptions, and from the results of exploratory MAAP4 calculations performed to investigate specific topics for this effort.

Keywords

Probabilistic risk assessment
ASME PRA standard
PRA scope and quality
Success criteria
Thermal-hydraulic analysis
MAAP4

1
OVERVIEW

The Modular Accident Analysis Program Version 4 (MAAP4) is a computer code used by nuclear utilities and research organizations to predict the progression of light water reactor (LWR) accidents. This applications guidance document provides the following:

- A description of the MAAP4 code
- Guidance for ensuring the quality of MAAP4 analyses
- Guidance on how to apply MAAP4 for Level 1[1] probabilistic risk assessments (PRAs)
- A compilation of summary information on the benchmarking of MAAP4 models
- An assessment of MAAP4's ability to adequately predict significant Level 1 PRA phenomena

It is anticipated that this report will be used by analysts responsible for running the code, analysts responsible for incorporating MAAP4 results into PRA models, and others interested in MAAP4's capabilities (for example, utility personnel, regulators, reactor vendors, and researchers).

1.1 Creation of the Applications Guidance Document: Motivation and Method

The existing MAAP4 documentation consists of the MAAP4 User's Manual [1], the MAAP4 user's guides for input preparation, and transmittal documents that describe individual revisions. These components contain detailed information on the mechanics of running the code as well as detailed descriptions of the individual models, but they do not include specific applications guidance. This applications guidance document is intended to fill that gap by providing sufficient information to enable users to optimize their efforts and generate high-quality Level 1 PRA analyses. (The existing documentation is further described in Section 2.4 of this report.)

Two prior efforts that were related to the previous version of the code, MAAP3B, generated particularly useful information regarding the validation of the thermal-hydraulic models, code application guidance, and recommended sensitivity analyses. The first effort was the set of thermal-hydraulic qualification studies conducted by Gabor, Kenton & Associates (GKA) and S. Levy [2–5]. The objectives of the studies were to evaluate the thermal-hydraulic modeling in MAAP3B and provide guidance on code use. The resultant reports contain detailed descriptions

[1] Level 1 PRA analysis relates to the progression of an accident from its initiating events to plant damage, for example, core damage. Level 2 analysis extends to the potential for release of fission products from the primary system and from the containment.

of relevant plant features, accident sequences, benchmarks, and input file components, as well as guidance on applications and limitations. The second effort was the creation of a set of recommended sensitivity analyses for an individual plant examination (IPE) by GKA [6]. The resultant document contains a review of key accident sequences and phenomena and recommended approaches for treating phenomenological uncertainties in IPEs. Use of the latter document was endorsed by the U.S. Nuclear Regulatory Commission (NRC) as part of the Brookhaven National Laboratory review of MAAP3B's applicability for IPEs. There is a consensus among current code users that similar thermal-hydraulic assessments, applications guidance, and recommendations for sensitivity analyses for MAAP4 would be advantageous. This report aims to satisfy these needs for Level 1 PRA risk-informed applications.

The MAAP4 code has been extensively benchmarked, and information about benchmarks is included in the MAAP4 User's Manual. However, only a portion of the benchmarks are discussed in the manual. Of those presented, not all are described in a format that readily allows for the systematic assessment of MAAP4's capabilities. As part of the preparation of this report, benchmarking information was gathered from a variety of sources and reviewed by a team of MAAP4 experts. Summaries of the benchmarks and results from the review were compiled so that they can be used for thermal-hydraulic assessments of significant Level 1 phenomena; that is, they can be used to understand MAAP4's capabilities, identify particular applications in which caution is advised, and provide a basis for determining areas and/or phenomena for which additional benchmarks would be beneficial. The benchmark compilation supported the identification of the ranges of code applicability, code limitations, and usage precautions. These identified items are included in this report.

The American Society of Mechanical Engineers (ASME) has issued a standard that contains requirements for PRAs that are used to support risk-informed decisions and prescribes a method for applying the requirements for specific applications [7]. In addition, the NRC has issued Regulatory Guide (RG) 1.200 [8]. It provides guidance on determining the technical adequacy of a PRA, and it endorses the ASME standard and method with limited exceptions and clarifications. This report contains suggestions on how the overall intent and the individual elements of both the standard and the regulatory guide that apply to MAAP4 can be met.

The need for a succinct description of MAAP4 was identified so that utilities, regulatory agencies, and research organizations would have a convenient tool for communicating pertinent information about MAAP4. The summary contained in this report concisely presents the phenomena modeled in the code, the structure of the code, and how the code has been applied.

The information in this report was primarily assembled from extensive experience using the MAAP4 code, from the MAAP4 User's Manual and user's guides, from the MAAP3B thermal-hydraulic qualification studies and sensitivity guidance described previously, from benchmark descriptions, and from the results of exploratory MAAP4 calculations performed to investigate specific topics for this effort. The report was authored by ERIN Engineering and Research, Inc. (ERIN), with contributions from Fauske & Associates, LLC (FAI), the Electric Power Research Institute (EPRI), and Erigo Technologies. It was reviewed by a peer review team that included Chan Paik, Robert Hammersley, and Robert Reeves of FAI, Ken Canavan and Frank Rahn of EPRI, and Marc Kenton of Erigo Technologies. The preparation of the report was funded by the MAAP Users Group (MUG) and EPRI.

1.2 Structure of the Applications Guidance Document

This MAAP4 applications guidance document is designed to be used as a reference when performing MAAP4 analyses and incorporating the results from the analyses into PRA models. The following is an outline of the contents of this report:

Section 1: Introductory information including the purpose, motivation, applicability, and scope of the report.

Section 2: Descriptive summary information about MAAP4, including general information about the code, the history of its development and use, a summary of the Level 1 PRA phenomena that are modeled, and a synopsis of the code's computational structure and design philosophy.

Section 3: Suggested practices for ensuring the quality of MAAP4 analyses. These address the development and testing of input files, code execution, documentation and review of sequences, control and traceability of results, training and certification of analysts, and communication with end users. Section 3 also contains a cross-reference of sections of this report with the intent and elements of the ASME standard and RG 1.200.

Section 4: An approach for conducting uncertainty and sensitivity analyses, including suggestions for investigating the effects of input parameters that control the phenomenological models in the code.

Section 5: Specific guidance on how to apply MAAP4 to Level 1 PRA analyses for boiling water reactors (BWRs). The guidance provides information on dominant plant features, controlling phenomena, and code logic that affect Level 1 sequences. It also addresses the determination of core damage, and it presents specific considerations for defining and analyzing sequences as a function of the type of initiating event.

Section 6: Specific guidance on how to apply MAAP4 to Level 1 PRA analyses for pressurized water reactors (PWRs). The guidance provides information on dominant plant features, controlling phenomena, and code logic that affect Level 1 sequences. It also addresses the determination of core damage, and it presents specific considerations for defining and analyzing sequences as a function of the type of initiating event.

Section 7: A compilation of summaries of MAAP benchmarks and a review of the results of the benchmarks with respect to the performance of the major thermal-hydraulic models and code capabilities.

Section 8: Guidance on the range of applicability of the code, its limitations, and usage precautions.

Section 9: References.

Appendix A: MAAP4 units labels, units conversion factors, and guidance for handling units in input files; guidance for user-defined input calculations.

Appendix B: MAAP4 modeling of BWR systems: input, output, and logic features.

Appendix C: MAAP4 modeling of PWR systems: input, output, and logic features.

Appendix D: Sample MAAP4 analyst certification guide.

Appendix E: ASME PRA requirements applicable to MAAP4 analyses.

Appendix F: Summaries of benchmarks that pertain to the MAAP4 modeling of Level 1 phenomena.

2
INTRODUCTION TO MAAP4

The Modular Accident Analysis Program Version 4 (MAAP4) is a computer code that simulates the response of light water reactor (LWR) power plants during severe accidents. Given a set of initiating events and operator actions, MAAP4 predicts the plant's response as the accident progresses. The code is used to do the following:

- Predict the timing of key events (for example, core uncovery, core damage, core relocation to the lower plenum, and vessel failure)
- Evaluate the influence of mitigative systems, including the impact of the timing of their operation
- Evaluate the effects of operator actions
- Predict the magnitude and timing of fission product releases
- Investigate uncertainties in severe accident phenomena

MAAP4 results are primarily used to determine Level 1 and 2 success criteria and accident timing for probabilistic risk assessments (PRAs). They are also used for equipment qualification analyses, fission product large early release frequency (LERF) determinations, integrated leak rate test evaluations, emergency planning and training, simulator verification, analyses to support plant modifications, generic plant issue assessments (for example, significance determinations), and other similar applications.

MAAP4 is an integral code. It treats the full spectrum of important phenomena that could occur during an accident, simultaneously modeling those that relate to the thermal hydraulics and to the fission products. It also simultaneously models the primary system and the containment and reactor/auxiliary building.

Parallel versions of MAAP4 support boiling water reactors (BWRs) and pressurized water reactors (PWRs), and there are also unique versions for CANDU, VVER, and ATR reactor designs. Although much of the information presented in this section and in other parts of this report is applicable to all versions of the MAAP4 code, the information primarily applies to the BWR and PWR versions. These two versions contain the same core model, containment and reactor/auxiliary building model, fission product model, and input and output schemes. They have distinct primary system models and engineered safeguards models. The code is applicable to both current and advanced LWR designs, with models that represent the passive features of the latter.

MAAP4 requires two input files. The first is the parameter file, which contains plant-specific information, output specifications, and user-controlled phenomenological parameters. The second is the sequence input file, which specifies the accident initiators, operator actions, and

sequence control times (that is, end time and print interval). After processing the information in the two files, the code predicts the sequence of events and corresponding plant conditions. It generates approximately 25 output files, including a synopsis of the sequence, a summary of events, tables of time-dependent results in a form suitable for plotting, and tabulated results that provide the details of the plant's status at selected times. The input and output files are described in more detail in Section 3 of this report.

2.1 MAAP Development History and the MAAP Users Group

MAAP was originally developed for the Industry Degraded Core Rulemaking (IDCOR) program in the early 1980s by Fauske & Associates, LLC (FAI). At the completion of IDCOR, ownership of MAAP was transferred to the Electric Power Research Institute (EPRI), which was charged with maintaining and improving the code. Starting in the late 1980s, the MAAP3B version became widely used, first in the United States and then worldwide, to support success criteria determination, human action timing evaluations, and Level 2 analyses for individual plant examinations (IPEs). IPEs were used to identify plant vulnerabilities and to facilitate an increased understanding of severe accident phenomena. Therefore, the code has been applied to numerous containment designs and sequences for approximately 20 years.

The code was updated to the current version, MAAP4, in the mid-1990s. It extended MAAP's capabilities for accident management evaluations, primarily with refined core and lower plenum models. Other improvements include a generalized node and junction containment model and models that represent unique features of advanced LWRs. As part of the development process, MAAP4 was reviewed by a committee of independent experts to ensure that it is state-of-the-art and applicable for accident management evaluations. The development of MAAP4 was sponsored by several organizations, including EPRI and the U.S. Department of Energy (DOE). EPRI licenses MAAP4 to utilities, vendors, and research organizations, including universities.

The majority of MAAP4 users are members of the MAAP Users Group (MUG). The MUG provides direction and funding for code maintenance, enhancements, and benchmarking; facilitates information transfer through biannual meetings and the issuance of various communications on code problems and best practices; and supports industry and regulatory acceptance. As of April 2009, the MUG membership consists of approximately 50 organizations from 12 countries. FAI is the maintenance contractor for the code, and ERIN Engineering and Research, Inc. performs an independent review of maintenance activities.

The code has been developed and is maintained under FAI's quality assurance program, which is in compliance with U.S. 10CFR50 Appendix B and ISO 9001 quality assurance requirements.

2.2 Phenomena Modeled in MAAP4

MAAP4 treats the spectrum of physical processes that could occur during an accident. Level 1 PRA phenomena include the following:

- Gas and water flow
- Natural circulation

- Steam evaporation and condensation
- Boiling
- Critical flow
- Conduction, convection, and radiation heat transfer
- Countercurrent flow

Level 2 PRA phenomena include the following:

- Cladding oxidation and hydrogen evolution
- Core material eutectic formation
- Core relocation
- Lower head–core debris dynamics
- Failure of vessel penetrations and/or the lower head
- Debris entrainment
- Debris-concrete interactions
- Ignition of combustible gases
- pH and iodine chemistry in containment
- Fission product release, transport, and deposition

The subsequent sections describe the MAAP4 models that relate to Level 1 PRA phenomena. Each section includes the names of the principal subroutines; detailed information about the models is contained in the corresponding subroutine descriptions in the MAAP4 User's Manual [1]. Also included are the sections of the parameter files that contain the input parameters specific to each group of models.

2.2.1 Primary System Thermal Hydraulics

2.2.1.1 BWR Primary System Thermal Hydraulics

The BWR primary system model calculates the thermal-hydraulic conditions in the reactor pressure vessel. It tracks the mass and energy of water pools in the downcomer (including the water inside jet pumps and in the recirculation loops), in the core (including the water above the active core extending into the standpipes, separators, and upper plenum), in the control rod drive (CRD) tubes, and in the lower plenum. The remaining free volume constitutes a single gas space. The gas pressure is imposed on the water pools, and the individual water masses and energies are then used to determine the temperature of each pool. MAAP4 also tracks the two-phase mixture volume in each water region. The gas space is divided into eight nodes for heat transfer and gas flow calculations. The code tracks the gas temperature, mass fraction of hydrogen, and fission product masses in each of the gas nodes. Eleven primary system heat sinks are modeled, each as a two-dimensional slab.

7
MAAP BENCHMARKS

The MAAP4 code has been extensively benchmarked, and information about the benchmarks has been presented and published in a variety of forums. To facilitate an assessment of the abilities of the code to model Level 1 phenomena based on the results of the benchmarks, the documentation of relevant benchmarks was collected and reviewed by a team of MAAP4 experts.[8] The benchmarks were gathered from the MAAP4 User's Manual, technical journals, conference proceedings, MUG meeting presentations, and technical reports. More than 30 benchmarks were collected; they fall into the following categories:

- Comparisons to plant events (PE entries)
- Comparisons to integral codes (IC entries)
- Comparisons to integral experiments (IE entries)
- Comparisons to separate effects experiments (SE entries)

7.1 Method for the Review of the MAAP Benchmarks

The team of experts—each member having extensive experience with the development and application of MAAP3B and MAAP4 as well as extensive knowledge of severe accident phenomena and plant response—reviewed the individual benchmarks in two stages. The first stage consisted of a preliminary review of the documentation of each benchmark to determine if 1) it contains adequate information on the method and results so that conclusions could be drawn and 2) the code was used in an appropriate manner (for example, not in a regime determined to be outside the range of applicability according to the limitations posted on the MAAP4 web site). The major code models—primary system thermal hydraulics, steam generator thermal hydraulics, core heat-up, and containment thermal response—evaluated by each benchmark were identified. Similarly, significant code capabilities validated by each benchmark were identified. These include critical flow through valves and breaks, ECCS injection, condenser heat transfer, voiding in the core, and hot leg natural circulation (HLNC).

The second stage consisted of an in-depth review of each of the benchmarks that met the preliminary criteria to determine the agreement between the MAAP4 results and the corresponding data and comparative analyses. The team studied the documented information and discussed the strength of the benchmark, the specific results, the conclusions drawn by the authors, and so on. To provide a framework for the collective assessment of the code's capabilities, the review was structured to 1) rate the degree of agreement between the sets

[8] The team consisted of Jeff Gabor and Barbara Schlenger-Faber of ERIN, Chan Paik and Robert Reeves of FAI, and Marc Kenton of Erigo Technologies.

of comparative results and 2) capture pertinent information on code performance, limitations, and options for modeling particular phenomena.

The degree of agreement for the major code models is based on the following representative quantities. They were selected because of their importance to the success criteria and human reliability components of PRA analysis:

- BWR primary system thermal hydraulics: primary system pressure and water level in the vessel
- PWR primary system thermal hydraulics: primary system pressure, water level in the pressurizer, and water level in the vessel
- Steam generator thermal hydraulics: secondary side pressure and water level in the steam generators
- Core heat-up (generic to BWR and PWR): maximum core temperature
- Containment thermal response (generic to BWR and PWR): containment pressure

The team jointly rated the agreement for each of the major models as well as the overall degree of agreement as *very good*, *good*, *fair*, *qualitative*, or *inconclusive*. No *poor* agreements were identified. By necessity, the rating process was qualitative rather than quantitative. Consideration was given to whether the uncertainties associated with the documented sequence definitions and boundary conditions tended to be greater than those associated with the modeling approaches and phenomenological uncertainties.

The team also assessed the validation of the specific code capabilities as *validated by explicit results* or *qualitative or indirect validation*. No *inconclusive* or *negative* validations were identified.

Details about each of the benchmarks are assembled in Appendix F and include the following:

- Identifying information: authoring organizations, plant types (BWR, PWR, containment type, and so on), PRA levels, sequence types, time frames of the analyses, and MAAP code versions
- Agreement for major code models: elaboration and observations
- Validation of significant code capabilities: elaboration and observations
- Exemplified limitations and precautions
- Issues for further code development and user support
- Notes and recommendations for the users
- Conclusions drawn by the authors of the benchmark
- Documentation: reference citations

The entries in Appendix F have a consistent format; only the applicable or available details are included for each individual benchmark.

7.2 Benchmark Review Results

Tables 7-1 and 7-2 list the benchmarks that met the preliminary criteria of the first stage of the review process and contain the summary results from the team's in-depth review. The first table contains the degree of agreement for the major code models and the overall code. The second table contains the extent of the validation of the significant code capabilities.

Compilations of the degree of agreement for the major code models and the validation of the code capabilities are presented in Tables 7-3 and 7-4, respectively. Compilations of the benchmarks as a function of sequence type are presented in Tables 7-5 and 7-6 for BWRs and PWRs, respectively. Because not all of the benchmarks are of the same technical caliber and because some contain multiple independent sequences while others contain variations of a base sequence, the compilations should be viewed as general versus rigorous.

7.3 Conclusions from the Benchmark Review

Three sets of conclusions were drawn from the review of the benchmarks. First, the compilations in Tables 7-3 through 7-6 were examined to identify particular areas in which additional benchmarks would be beneficial for filling in gaps in the overall matrix of major code models, code capabilities, and sequences that are supported by benchmarks. Recommendations for additional benchmarks based on this examination of the number and level of agreement of the existing benchmarks are as follows:

- Major code models: steam generator thermal hydraulics for OTSGs
- Significant code capabilities: drywell/fan cooler heat and mass transfer
- BWR sequences:
  - SLOCAs and MLOCAs
  - Stuck-open SRVs with discharge to the suppression pool
  - ATWS conditions
- PWR sequences:
  - LLOCAs
  - SGTRs (These are in part supported by the SLOCA benchmark sequences, but additional benchmarks that focus on the secondary side response would be of value because of the complex coupling of the primary and secondary sides and the importance of SGTRs in Level 1 analysis.)
  - Mid-loop operation

Second, specific details of the benchmarks assembled in Appendix F that affect code applications were collected. These details include limitations, precautions, notes and recommendations for users, and issues for further code development and user support. They are listed in Section 8 along with additional items known to the team and the code maintenance contractor.

Table 7-1
Collected Benchmarks and Agreement for the Major Code Models Related to Level 1 Phenomena

Benchmark Type (entry in Appendix F)	Identifier, Sequences, and Plant Type	Agreement for Major Code Models						Principal Sources of Documentation for the Benchmark
		Overall Code	Primary System Thermal Hydraulics (pressure and water level)		SG Thermal Hydraulics (pressure and water level)	Core Heat-Up (core temperature)	Containment Thermal Response (pressure)	
			BWR	PWR				
Plant event (PE1)	TMI-2 LOFW; B&W	Very good given uncertainty in boundary conditions	—	Good	Fair (OTSG, one-region model)	Indirect support	Qualitative	MAAP4 User's Manual and conference proceedings
Plant event (PE2)	Davis-Besse LOFW; B&W	Fair	—	Fair to good	—	—	—	MAAP4 User's Manual
Plant event (PE3)	Oyster Creek LOFW; BWR with isolation condenser	Very good given uncertainty in boundary conditions	Good	—	—	—	—	MAAP4 User's Manual
Plant event (PE4)	Prairie Island SGTR; WLD	Good	—	Good	—	—	—	MAAP4 User's Manual
Plant event (PE5)	Maanshan SBO; WLD	Good	—	Good to very good	—	—	—	Presentation to the NRC

Table 7-1 (continued)
Collected Benchmarks and Agreement for the Major Code Models Related to Level 1 Phenomena

Benchmark Type (entry in Appendix F)	Identifier, Sequences, and Plant Type	Agreement for Major Code Models						Principal Sources of Documentation for the Benchmark
		Overall Code	Primary System Thermal Hydraulics (pressure and water level)		SG Thermal Hydraulics (pressure and water level)	Core Heat-Up (core temperature)	Containment Thermal Response (pressure)	
			BWR	PWR				
Plant event (PE6)	Oconee plant trip; B&W	Good	—	Very good with code change to model plants with hot water in dome	—	—	—	Presentation to the MUG
Plant event (PE7)	LOOP and plant trip in 1992 MAAP3B Qualification Studies; Westing-house four-loop	Generally but not specifically applicable; good agreement with MAAP3B	—	—	—	—	—	EPRI technical report
Integral code–compared to CENTS (IC1)	SBO and LOFW with F&B; CE	Good	—	Good	Fair to very good (U-tube, two-region model)	—	—	Conference proceedings

Table 7-1 (continued)
Collected Benchmarks and Agreement for the Major Code Models Related to Level 1 Phenomena

Benchmark Type (entry in Appendix F)	Identifier, Sequences, and Plant Type	Agreement for Major Code Models						Principal Sources of Documentation for the Benchmark
		Overall Code	Primary System Thermal Hydraulics (pressure and water level)		SG Thermal Hydraulics (pressure and water level)	Core Heat-Up (core temperature)	Containment Thermal Response (pressure)	
			BWR	PWR				
Integral code–compared to SR5 (IC2)	LOFW and S/MLOCAs; U.S. EPR	Good	—	Good to very good[a]	Fair to good (U-tube, one-region model)	Fair to very good	—	Conference proceedings
Integral code–compared to TRACG02 (IC3)	LOOPs with LLOCAs; BWR	Good	Good	—	—	Fair	—	GE technical report
Integral code–compared to RELAP5 (IC4)	SBO with F&B for Palisades; CE	Good	—	Fair to good	Good (U-tube, one-region model)[b]	—	—	Erigo letter report and presentations to the MUG
Integral code–compared to SR5 and MELCOR (IC5 1 of 2)	LLOCA for Kuonsheng; BWR	Good	Fair to good	—	—	Good	—	Journal paper and doctoral dissertation

Table 7-1 (continued)
Collected Benchmarks and Agreement for the Major Code Models Related to Level 1 Phenomena

Benchmark Type (entry in Appendix F)	Identifier, Sequences, and Plant Type	Agreement for Major Code Models						Principal Sources of Documentation for the Benchmark
		Overall Code	Primary System Thermal Hydraulics (pressure and water level)		SG Thermal Hydraulics (pressure and water level)	Core Heat-Up (core temperature)	Containment Thermal Response (pressure)	
			BWR	PWR				
Integral code–compared to SR5 and MELCOR (IC5 2 of 2)	SBO for Maanshan; WLD	Good	—	Fair to good	Good (U-tube, region model not specified)	Good	—	Journal paper and doctoral dissertation
Integral code–compared to CENTS (IC6)	MLOCA for Palo Verde; WLD	Inconclusive	—	Inconclusive	Inconclusive (U-tube, region model not specified)	—	—	Presentation to the MUG
Integral code–compared to CATHARE (IC7)	S/M LOCAs; EDF/ Framatome PWR 900	Good	—	Good to very good	Very good (U-tube, one-region model)	—	—	EDF technical report
Integral code–compared to SR5 and MELCOR (IC8)	TMLB′ (SBO with no RCP seal leak); WLD	Good	—	Fair to good	Good (U-tube, one-region model)	Indirect support	—	Journal paper

Table 7-1 (continued)
Collected Benchmarks and Agreement for the Major Code Models Related to Level 1 Phenomena

Benchmark Type (entry in Appendix F)	Identifier, Sequences, and Plant Type	Agreement for Major Code Models						Principal Sources of Documentation for the Benchmark
		Overall Code	Primary System Thermal Hydraulics (pressure and water level)		SG Thermal Hydraulics (pressure and water level)	Core Heat-Up (core temperature)	Containment Thermal Response (pressure)	
			BWR	PWR				
Integral code–compared to RELAP5 (IC9)	LOOP with F&B for Millstone; CE	Good	—	Fair to good	Good (U-tube, one-region model)	Good	—	Presentation to the MUG
Integral code–compared to MELCOR (IC10)	TMLB, LLOCAs and SLOCA; WLD SBO, transients, and LLOCA; BWR	Good	Not available	Good	—	—	—	Conference proceedings
Integral code–compared to SAFE (IC11)	Transients, SLOCA, and MSLB in 1992 MAAP3B Qualification Studies; BWR	Generally but not specifically applicable; good agreement with MAAP3B	—	—	—	—	—	EPRI technical report

Table 7-1 (continued)
Collected Benchmarks and Agreement for the Major Code Models Related to Level 1 Phenomena

Benchmark Type (entry in Appendix F)	Identifier, Sequences, and Plant Type	Agreement for Major Code Models						Principal Sources of Documentation for the Benchmark
		Overall Code	Primary System Thermal Hydraulics (pressure and water level)		SG Thermal Hydraulics (pressure and water level)	Core Heat-Up (core temperature)	Containment Thermal Response (pressure)	
			BWR	PWR				
Integral code–compared to RELAP and RETRAN (IC12)	Transients, failed-open PORV, SGTRs, SLOCAs, and MSLB in 1992 MAAP3B Qualification Studies; Westing-house four-loop	Generally but not specifically applicable; good agreement with MAAP3B	—	—	—	—	—	EPRI technical report
Integral experiments (IE1)	BETHSY LOFWs with F&B and SLOCA; EDF/ Framatome PWR 900	Very good	—	Very good	Very good (U-tube, one- and two-region models)	—	—	Presentation to the MUG
Integral experiments (IE2)	IIST SBO; WLD	Very good	—	Very good	Very good (U-tube, one-region model)	Very good	—	Conference proceedings

Table 7-1 (continued)
Collected Benchmarks and Agreement for the Major Code Models Related to Level 1 Phenomena

Benchmark Type (entry in Appendix F)	Identifier, Sequences, and Plant Type	Agreement for Major Code Models						Principal Sources of Documentation for the Benchmark
		Overall Code	Primary System Thermal Hydraulics (pressure and water level)		SG Thermal Hydraulics (pressure and water level)	Core Heat-Up (core temperature)	Containment Thermal Response (pressure)	
			BWR	PWR				
Integral experiments (IE3)	MB-2 LOFWs, MSLBs, and MSLB with SGTR; WLD	Very good	—	—	Very good (U-tube, two-region model)	—	—	Conference proceedings
Integral experiment (IE4)	OSU SLOCAs and failed-open PORVs; AP600	Very good	—	Very good	Very good (U-tube, two-region model)	—	—	Conference proceedings
Integral experiment (IE5)	Waltz Mill containment; generic	—	—	—	—	—	Fair	MAAP4 User's Manual
Integral experiment (IE7; see Table 7-2 for IE6)	CSTF containment; generic	—	—	—	—	—	Very good	MAAP4 User's Manual
Integral experiment (IE8)	HDR containment; generic	—	—	—	—	—	Very good	Journal paper and conference proceedings
Integral experiment (IE9)	ISP-35 containment; generic	—	—	—	—	—	Very good	Conference proceedings

Table 7-1 (continued)
Collected Benchmarks and Agreement for the Major Code Models Related to Level 1 Phenomena

Benchmark Type (entry in Appendix F)	Identifier, Sequences, and Plant Type	Agreement for Major Code Models						Principal Sources of Documentation for the Benchmark
		Overall Code	Primary System Thermal Hydraulics (pressure and water level)		SG Thermal Hydraulics (pressure and water level)	Core Heat-Up (core temperature)	Containment Thermal Response (pressure)	
			BWR	PWR				
integral experiment (IE10)	Semiscale: SLOCAs, LOOPs, and SGTRs in 1992 MAAP3B Qualification Studies for PWR	Generally but not specifically applicable; good agreement with MAAP3B	—	—	—	—	—	EPRI technical report
Integral experiment (IE11)	FIST: LOFWs and MLOCA in 1992 MAAP3B Qualification Studies for BWR	Generally but not specifically applicable; good agreement with MAAP3B	—	—	—	—	—	EPRI technical report
Integral experiment (IE12)	MIST: SLOCAs in 1992 MAAP3B Qualification Studies for B&W	Generally but not specifically applicable; good agreement with MAAP3B	—	—	—	—	—	EPRI technical report

[a] One exception to the agreement is suspected to be the result of input differences.

[b] The exception to the agreement is a minor limitation in MAAP4 related to condensation in the steam generators.

Table 7-2
Collected Benchmarks and Validation of Significant Code Capabilities Related to Level 1 Phenomena

Benchmark Type (entry in Appendix F)	Identifier and Plant Type	Capabilities					Principal Sources of Documentation for the Benchmark
		Critical Flow Model	ECCS Injection	Condenser Heat Transfer	Voiding in Core	HLNC	
Plant event (PE3)	Oyster Creek LOFW; BWR with isolation condenser	—	—	BWR isolation condenser validated	—	—	MAAP4 User's Manual
Plant event (PE4)	Prairie Island SGTR; WLD	—	PWR hardwired model validated	—	—	—	MAAP4 User's Manual
Integral code–compared to CENTS (IC1)	SBO and LOFW with F&B; CE	Qualitative support (PORV flow)	PWR generalized model validated	—	—	—	Conference proceedings
Integral code–compared to SR5 (IC2)	LOFW and S/MLOCAs; U.S. EPR	Qualitative support (safety valve flow); validated (break flow)	—	—	—	—	Conference proceedings
Integral code–compared to TRACG02 (IC3)	LOOPs with LLOCAs; BWR	Validated (break flow)	BWR model validated	—	—	—	GE technical report

Table 7-2 (continued)
Collected Benchmarks and Validation of Significant Code Capabilities Related to Level 1 Phenomena

Benchmark Type (entry in Appendix F)	Identifier and Plant Type	Capabilities					Principal Sources of Documentation for the Benchmark
		Critical Flow Model	ECCS Injection	Condenser Heat Transfer	Voiding in Core	HLNC	
Integral code–compared to RELAP5 (IC4)	SBO with F&B for Palisades; CE	Qualitative support (PORV flow)	PWR generalized model validated	—	—	—	Erigo letter report and presentations to the MUG
Integral code–compared to CENTS (IC6)	MLOCA for Palo Verde; WLD	Validated (break flow)	—	—	—	—	Presentation to the MUG
Integral code–compared to CATHARE (IC7)	S/M LOCAs; EDF/ Framatome PWR 900	Validated (break flow)	—	—	—	—	EDF technical report
Integral code–compared to SR5 and MELCOR (IC8)	TMLB' (SBO with no RCP seal leak); WLD	Qualitative support (PORV flow)	—	—	—	—	Journal paper

Table 7-2 (continued)
Collected Benchmarks and Validation of Significant Code Capabilities Related to Level 1 Phenomena

Benchmark Type (entry in Appendix F)	Identifier and Plant Type	Capabilities					Principal Sources of Documentation for the Benchmark
		Critical Flow Model	ECCS Injection	Condenser Heat Transfer	Voiding in Core	HLNC	
Integral code–compared to RELAP5 (IC9)	LOOP with F&B for Millstone; CE	Validated (PORV flow)	PWR validated (model not specified)	—	—	—	Presentation to the MUG
Integral experiment (IE1)	BETHSY LOFWs with F&B and SLOCA; EDF/ Framatome PWR 900	Validated (break and PORV flow)	PWR generalized model validated	—	Qualitative support	—	Presentation to the MUG
Integral experiment (IE3)	MB-2 LOFWs, MSLBs, and MSLB with SGTR; WLD	Validated (break flow)	—	—	—	—	Conference proceedings
Integral experiment (IE4)	OSU SLOCAs and failed-open PORVs; AP600	Validated (break and PORV flow)	PWR validated (passive systems)	—	—	—	Conference proceedings

Table 7-2 (continued)
Collected Benchmarks and Validation of Significant Code Capabilities Related to Level 1 Phenomena

Benchmark Type (entry in Appendix F)	Identifier and Plant Type	Capabilities					Principal Sources of Documentation for the Benchmark
		Critical Flow Model	ECCS Injection	Condenser Heat Transfer	Voiding in Core	HLNC	
Integral experiment (IE5)	Waltz Mill containment; generic	—	—	PWR ice condenser validated	—	—	MAAP4 User's Manual
Integral experiment (IE6)	PNL ice containment; WICE	—	—	PWR ice condenser validated	—	—	MAAP4 User's Manual
Separate effects experiment (SE1)	THTF; generic	—	—	—	Validation of void fraction subroutine	—	MAAP4 User's Manual
Separate effects experiments (SE2)	Westing-house 1/7th scale; PWR	—	—	—	—	Validation of HLNC subroutine	MAAP4 User's Manual and EPRI technical report
Separate effects experiment (SE3)	Marviken and FAI blowdown; PWR	Validated (PORV flow, also pressurizer model)	—	—	—	—	MAAP4 User's Manual

Table 7-3
Compilation of the Agreement for the Major Code Models Related to Level 1 Phenomena[a]

Major Code Model	Number of Benchmarks Reviewed by Experts	Agreement[b]						
		Very Good	Good to Very Good	Good and Fair to Very Good	Fair to Good	Fair	Qualitative or Indirect	Inconclusive
Overall code for BWR analysis	4	1	—	3	—	—	—	—
BWR primary system thermal hydraulics	3	—	—	2	1	—	—	—
Overall code for PWR analysis	18	5	—	11	—	1	—	1
PWR primary system thermal hydraulics	17	4	3	4	5	—	—	1
PWR steam generator thermal hydraulics	13	5 U-tube	—	5 U-tube	1 U-tube	1 OTSG	—	1 U-tube
Core heat-up (generic to BWR and PWR)	8	1	—	4	—	1	2	—
Containment (generic to BWR and PWR)	5	3	—	—	—	1	1	—

[a] Does not include the MAAP3B benchmarks that are generally but not specifically applicable (good agreement obtained with MAAP3B).

[b] No poor agreement with the benchmarks was identified for any of the major code models.

Third, all of the assembled benchmark information was reviewed to determine in an overall sense either that MAAP4 is an appropriate tool for Level 1 analysis or that there are significant issues that adversely affect the adequacy of the code for such applications. It was concluded that the benchmarks support the use of MAAP4 for Level 1 analysis as long as users are aware of and follow the guidance in the other sections of this report, particularly Sections 3–6 and 8, and the corresponding appendices.

Table 7-4
Compilation of the Validation of Significant Code Capabilities Related to Level 1 Phenomena

Code Capability		Number of Benchmarks Reviewed by Experts	
		Explicit Validation	Qualitative or Indirect Validation
Critical flow model	PORV and SRV flow applications	4 (including pressurizer model)	4
	Break flow applications	7	—
ECCS injection	BWR model	1	—
	PWR models	6	—
Condenser heat transfer	BWR isolation condenser	1	—
	PWR ice condenser	2	—
Voiding in the core		1	1
HLNC		1	—
Drywell/fan cooler heat and mass transfer		0	—

Table 7-5
BWR Sequences Supported by Benchmarks

Sequence Initiating Event	Type of Benchmark (entry in Appendix F)	Number and Types of Sequences	Overall Agreement	Sequence Time Frame
BWR transients (including SBOs, LOFW, and turbine trips) ***Total with MAAP4: 3 + 4 minor support*** ***Total with MAAP3B: 6***	Plant event: Oyster Creek (PE3)	1 LOFW	Very good	30 min
	Integral code comparison to TRACG02 (IC3)	2 LOOPs with LLOCAs	Good	8 min
	Integral code comparison to SAFE (IC11)—MAAP3B	4 LOFW	Good agreement with MAAP3B	15 min–2 hr
	Integral experiment comparison to FIST (IE11)—MAAP3B	2 LOFW	Good agreement with MAAP3B	15–50 min
	Integral code comparison to MELCOR (IC10)	1 SBO and 3 transients	Good: only a minor supporting benchmark for Level 1 applications	40 hr
BWR LLOCAs (excluding MSLBs) ***Total with MAAP4: 3 + 1 minor support***	Integral code comparison to TRACG02 (IC3)	2 LOOPs with LLOCA	Good	8 min
	Integral code comparison to SR5 and MELCOR (IC5)	1 LLOCA	Good	4 hr
	Integral code comparison to MELCOR (IC10)	1 LLOCA	Good: only a minor supporting benchmark for Level 1 applications	40 hr
BWR MLOCAs and SLOCAs ***None with MAAP4*** ***Total with MAAP3B: 2***	Integral code comparison to SAFE (IC11)—MAAP3B	1 SLOCA	Good agreement with MAAP3B	1 hr
	Integral experiment comparison to FIST (IE11)—MAAP3B	1 MLOCA	Good agreement with MAAP3B	8 min
BWR MSLBs ***None with MAAP4*** ***Total with MAAP3B: 1*** Can be considered a subset of LLOCAs	Integral code comparison to SAFE (IC11)—MAAP3B	1 MSLB	Good agreement with MAAP3B	7 min

Table 7-5 (continued)
BWR Sequences Supported by Benchmarks

Sequence Initiating Event	Type of Benchmark (entry in Appendix F)	Number and Types of Sequences	Overall Agreement	Sequence Time Frame
BWR interfacing system LOCAs (discharge outside of containment)	No supporting benchmarks, but essentially covered by LLOCA and S/MLOCA benchmarks.			
BWR stuck-open SRVs	No supporting benchmarks with stuck-open SRVs as an initiator, but similar to SLOCAs if discharge is to the gas space (versus to the suppression pool). Sequences are also supported by benchmarks in which stuck-open or manually opened SRVs are subsequent conditions.			
BWR feedwater line breaks	No supporting benchmarks, but essentially covered by S/MLOCA benchmarks.			
BWR ATWS	No supporting benchmarks.			

Table 7-6
PWR Sequences Supported by Benchmarks

Sequence Initiating Event	Type of Benchmark (entry in Appendix F)	Number and Types of Sequences	Plant Type	Steam Generator Type and Model	Overall Agreement	Sequence Time Frame
PWR transients (including SBOs, LOFW, and turbine trips) ***Total with MAAP4: 19 + 1 minor support*** ***Total with MAAP3B: 6***	Plant event: TMI-2 (PE1)	1 LOFW with stuck-open PORV	B&W	OTSG, one-region model	Very good	5 hr
	Plant event: Davis-Besse (PE2)	1 LOFW	B&W	—	Fair	30 min
	Plant event: Maanshan (PE5)	1 SBO	WLD	—	Good	3 hr
	Plant event: Oconee (PE6)	1 plant trip	B&W	—	Good	15 min
	Plant event: four-loop (PE7)—MAAP3B	1 LOOP and 1 plant trip	Westing-house	—	Good agreement with MAAP3B	3–5 min
	Integral code comparison to CENTS (IC1)	1 SBO and 1 LOFW with feed and bleed	CE	U-tube, two-region model	Good	3 hr
	Integral code comparison to SR5 (IC2)	3 LOFWs	U.S. EPR	U-tube, one-region model	Good	2 hr
	Integral code comparison to RELAP5 (IC4)	2 SBOs with feed and bleed	CE	U-tube, one-region model	Good	5–10 hr
	Integral code comparison to SR5 and MELCOR (IC5)	1 SBO	WLD	U-tube, region model not specified	Good	5 hr
	Integral code comparison to SR5 and MELCOR (IC8)	1 TMLB' (SBO, no RCP seal leak)	WLD	U-tube, one-region model	Good	5 hr
	Integral code comparison to RELAP5 (IC9)	1 LOOP with feed and bleed	CE	U-tube, one-region model	Good	3 hr

Table 7-6 (continued)
PWR Sequences Supported by Benchmarks

Sequence Initiating Event	Type of Benchmark (entry in Appendix F)	Number and Types of Sequences	Plant Type	Steam Generator Type and Model	Overall Agreement	Sequence Time Frame
	Integral code comparison to MELCOR (IC10)	1 TMLB (SBO with RCP seal leak)	WLD	—	Good: only a minor supporting benchmark for Level 1 applications	40 hr
	Integral code comparison to RELAP and RETRAN (IC12)—MAAP3B	2 transients	Westing-house	—	Good agreement with MAAP3B plus code changes that were incorporated into MAAP4	5 min–1.4 hr
	Integral experiment comparison to BETHSY (IE1)	2 LOFWs with feed and bleed	900 MWe EDF/ Framatome	U-tube, one-region model	Very good	1–2 hr
	Integral experiment to IIST (IE2)	1 SBO	WLD	U-tube, one-region model	Very good	3 hr
	Integral experiment comparison to MB-2 (IE3)	2 LOFWs	WLD	U-tube, two-region model	Very good	2–12 min
	Integral experiment comparison to Semiscale (IE10)—MAAP3B	2 LOOPs	Generic PWR	—	Good agreement with MAAP3B	3–5 hr
PWR LLOCAs (excluding MSLBs) ***Total with MAAP4: 2 minor support***	Integral code comparison to MELCOR (IC10)	2 LLOCAs: location not identified	WLD	—	Good: only a minor supporting benchmark for Level 1 applications	40 hr

Table 7-6 (continued)
PWR Sequences Supported by Benchmarks

Sequence Initiating Event	Type of Benchmark (entry in Appendix F)	Number and Types of Sequences	Plant Type	Steam Generator Type and Model	Overall Agreement	Sequence Time Frame
PWR MLOCAs and SLOCAs ***Total with MAAP4: 12 + 1 minor support*** ***Total with MAAP3B: 8***	Integral code comparison to SR5 (IC2)	1 SLOCA: location not identified 1 MLOCA: location not identified	U.S. EPR	U-tube, one-region model	Good	2 hr
	Integral code comparison to CENTS (IC6)	1 MLOCA: break in the intermediate leg	WLD	U-tube, region model not specified	Inconclusive	5 hr
	Integral code comparison to CATHARE (IC7)	1 SLOCA: break in the hot leg 1 MLOCA: break in the hot leg 3 SLOCAs: breaks in the cold leg 1 MLOCA: break in the cold leg	900 MWe EDF/ Framatome	U-tube, one-region model	Good	2–12 hr
	Integral code comparison to MELCOR (IC10)	1 SLOCA: location not identified	WLD	—	Good: only a minor supporting benchmark for Level 1 applications	40 hr
	Integral code comparison to RELAP and RETRAN (IC12)—MAAP3B	2 SLOCAs: breaks in the cold leg	Westing-house	—	Good agreement with MAAP3B plus code changes that were incorporated into MAAP4	30 min–1 hr

Table 7-6 (continued)
PWR Sequences Supported by Benchmarks

Sequence Initiating Event	Type of Benchmark (entry in Appendix F)	Number and Types of Sequences	Plant Type	Steam Generator Type and Model	Overall Agreement	Sequence Time Frame
	Integral experiment comparison to BETHSY (IE1)	1 SLOCA: break in the cold leg	900 MWe EDF/ Framatome	U-tube, two-region model	Very good	2 hr
	Integral experiment comparison to OSU (IE4)	2 SLOCAs: breaks in an injection line	AP600	U-tube, two-region model	Very good	Not provided
	Integral experiment comparison to Semiscale (IE10)—MAAP3B	4 SLOCAs: breaks in the cold leg	Generic PWR	—	Good agreement with MAAP3B	13–50 min
	Integral experiment comparison to MIST (IE12)—MAAP3B	2 SLOCAs: breaks in the cold leg	B&W	—	Good agreement with MAAP3B	1–12 hr
PWR interfacing system LOCAs (discharge outside of containment)	No supporting benchmarks, but essentially covered by LLOCA and S/MLOCA benchmarks.					
PWR stuck-open PORVs ***Total with MAAP4: 2*** ***Total with MAAP3B: 1***	Integral code comparison to RELAP and RETRAN (IC12)—MAAP3B	1 failed-open PORV	Westing-house	—	Good agreement with MAAP3B plus code changes that were incorporated into MAAP4	8 min
	Integral experiment comparison to OSU (IE4)	2 failed-open PORVs	AP600	U-tube, two-region model	Very good	Not provided

Table 7-6 (continued)
PWR Sequences Supported by Benchmarks

Sequence Initiating Event	Type of Benchmark (entry in Appendix F)	Number and Types of Sequences	Plant Type	Steam Generator Type and Model	Overall Agreement	Sequence Time Frame
PWR SGTR ***Total with MAAP4: 1*** ***Total with MAAP3B: 5***	Plant event: Prairie Island (PE4)	1 SGTR	WLD	—	Good	8 min
	Integral code comparison to RELAP and RETRAN (IC12)—MAAP3B	2 SGTRs	Westing-house	—	Good agreement with MAAP3B plus code changes that were incorporated into MAAP4	50 min
	Integral experiment comparison to Semiscale (IE10)—MAAP3B	3 SGTRs	Generic PWR	—	Good agreement with MAAP3B	5–40 min
PWR MSLBs ***Total with MAAP4: 3*** ***Total with MAAP3B: 1***	Integral code comparison to RELAP and RETRAN (IC12)—MAAP3B	1 MSLB	Westing-house	—	Good agreement with MAAP3B plus code changes that were incorporated into MAAP4	5 min
	Integral experiment comparison to MB-2 (IE3)	2 MSLBs 1 MSLB with SGTR	WLD	U-tube, two-region model	Very good	2–3 min 17 min for SGTR
PWR feedwater line breaks	No supporting benchmarks, but similar to LOCAs and, to a lesser extent, MSLBs.					
PWR mid-loop operation	No supporting benchmarks.					
PWR ATWS	No supporting benchmarks, but typically a very low contributor to core damage frequencies.					

F
SUMMARIES OF MAAP BENCHMARKS

This appendix contains summaries of benchmarks that pertain to the MAAP4 modeling of Level 1 phenomena. The benchmarks fall into the following categories:

- Comparisons to plant events (PE entries)
- Comparisons to integral codes (IC entries)
- Comparisons to integral experiments (IE entries)
- Comparisons to separate effects experiments (SE entries)

The summaries contain identifying information about the benchmarks, including the authors, plant types, PRA levels, time frames, MAAP4 code versions, comparison codes and experiments, number and types of sequences, and references for the documentation. The summaries also contain the degree of agreement for the major code models and the validation of code capabilities, as determined by the team of MAAP4 experts introduced in Section 7 of this report. Related notes, exemplified limitations and precautions, recommendations for users, and issues for further code development identified by the team are included, as are the documented conclusions drawn by the authors of the benchmarks. The summaries are presented in a common format to facilitate the drawing of conclusions regarding the overall extent and success of the benchmarking of MAAP4; only relevant components are included in each individual summary. Copies of the benchmark documentation and the references in the report will be maintained by EPRI and made available under separate cover.

Comparison to Plant Event:
PE1. TMI-2 LOFW with Stuck-Open PORV

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Versions	Principal Sources of Documentation
FAI	PWR, B&W	1 and 2	5 hr	4.0.0, 4.0.2, 4.0.6, 4.0.7	MAAP4 User's Manual (1994), conference proceedings (1995); also code transmittal documents (2005, 2007)

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Very good agreement given that there are uncertainties in some of the boundary conditions and corresponding assumptions had to be made	—
PWR primary system thermal hydraulics	Pressure	Good agreement	—
	Water level in the pressurizer	Good agreement	
Steam generator: one-region OTSG	Pressure	Fair agreement	Does not uncover any issue that calls the model into question
	Water level	Not applicable (boundary condition)	
Core heat-up	Core temperature	Core temperature is not available; however, agreement indirectly supported by the timing of hydrogen generation	Code predicts that hydrogen was generated early enough to shut off condensation in the steam generators, which is consistent with the data

Comparison to Plant Event:
PE1. TMI-2 LOFW with Stuck-Open PORV, continued

Model	Indicator	Agreement Based on Expert Review	Notes
Containment	Pressure	Qualitative agreement; overall trends are reasonable	Boundary conditions and plant details are uncertain (for example, fan cooler performance and flow from the quench tank)

Conclusions from the Authors of the Benchmark

Conference proceedings: "Comparisons of the MAAP4 model predictions with the TMI-2 data show that the MAAP4 code calculations are in good agreement with the overall plant response during the accident. … MAAP4 provided a reasonable simulation of the TMI-2 system response in terms of the behavior before the core was uncovered, the response of the primary system while the core degraded, the response of the RCS when the core was reflooded at 174 minutes as well as the lower head response after 224 minutes."

Documentation

MAAP4 User's Manual [1]: Volume III, Section 4, Rev. 0, May 1994. (using Rev. 4.0.0, includes predicted containment response)

C. Paik, R. Henry, and M. McCartney, "MAAP4.0 Benchmarking with the TMI-2 Experience," *Proceedings of the International Conference on Probabilistic Safety Assessment Methodology and Applications, PSA '95.* Seoul, Korea (November 26–30, 1995). (using Rev. 4.0.2)

MAAP4 transmittal documents for Rev. 4.0.6 and Rev. 4.0.7 [12, 13]. (plotted results only, 2005 and 2007)

Comparison to Plant Event:
PE2. Davis-Besse LOFW

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Versions	Principal Sources of Documentation
FAI	PWR, B&W	1	0.5 hr	4.0.3, 4.0.6, 4.0.7	MAAP4 User's Manual (1996); also code transmittal documents (2005, 2007)

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Fair agreement	Steam generator terms (pressure and water level) are boundary conditions, so this benchmark does not test the steam generator model.
PWR primary system thermal hydraulics	Pressure	Fair agreement	There is evidence that the code overestimates the heat transfer to the pressurizer sprays.
	Water level in the pressurizer	Good agreement	

Conclusions from the Authors of the Benchmark

"MAAP4 agrees with the measured data over the entire duration of the incident. … There are some differences in the pressurizer response, but all of the appropriate trends are observed in terms of the initial level increase, a decrease in the level and a subsequent increase as the system overheats and the pressure increases. Once the auxiliary feedwater has been reestablished to the steam generators and the RCS depressurizes, the pressurizer level also decreases. … Given the secondary side conditions, the MAAP4 models follow the dynamic response of the RCS."

Comparison to Plant Event:
PE2. Davis-Besse LOFW, continued

Documentation

MAAP4 User's Manual [1]: Volume III, Section B, Rev. 0, August 1996.
MAAP4 transmittal documents for Rev. 4.0.6 and Rev. 4.0.7 [12, 13]. (plotted results only, 2005 and 2007)

Comparison to Plant Event:
PE3. Oyster Creek LOFW

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Principal Source of Documentation
FAI	BWR with isolation condenser	1	0.5 hr	4.0.7	MAAP4 User's Manual (2007)

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Very good agreement given that there are uncertainties in some of the boundary conditions and corresponding assumptions had to be made	—
BWR primary system thermal hydraulics	Pressure	Good agreement	—
	Water level in the vessel	Good agreement	

Validation of Code Capabilities

Isolation condenser heat transfer: hardwired model	Validated based on pressure in the primary system being well predicted

Note

The extent of steam voiding in the core and the resulting water displacement into the downcomer are somewhat under-predicted during the early portion of the sequence (the first 4 minutes in this benchmark). The calculated water level has the expected trend, but it rises more slowly than the data during this period. This might also be because the model for water circulation between the downcomer, core, and core bypass is somewhat simplified, with only one node for the combined downcomer, jet pump, and recirculation pump water and one node for the combined core, core bypass, shroud head, riser, and separator water.

Comparison to Plant Event:
PE3. Oyster Creek LOFW, continued

Conclusions from the Authors of the Benchmark

"With some reasonable sensitivities included to refine boundary conditions that are either absent or in conflict with plant data, the MAAP4 model provides an excellent characterization of the RCS pressure response following the reactor scram and loss-of-feedwater initiators. The downcomer level response provides good long-term agreement, so total water mass and energy in the vessel are properly represented. However, additional improvement in the short-term dynamic level response is necessary. Specifically, the model for core voiding and subsequent displacement of water from the core to the downcomer needs improvement. Given the simplified model for water (one combined node for downcomer, jet pump and recirculation loop water and one combined node for core and core bypass water), this may be the best agreement possible in the context of the current model."

Documentation

MAAP4 User's Manual [1]: Volume III, Section B, Rev. 0.1, March 2007.

Comparison to Plant Event:
PE4. Prairie Island SGTR

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Versions	Principal Sources of Documentation
FAI	PWR, WLD	1	8 min	4.0.4, 4.0.6, 4.0.7	MAAP4 User's Manual (1997); also code transmittal documents (2005, 2007)

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Good agreement	Steam generator terms (pressure and water level) are boundary conditions, so this benchmark does not test the steam generator model
PWR primary system thermal hydraulics	Pressure	Good agreement	—
	Water level in the pressurizer	Not available	

Validation of Code Capabilities

PWR ECCS injection: hardwired model	Validated based on the effect of injection on the pressure in the primary system being appropriately predicted

Comparison to Plant Event:
PE4. Prairie Island SGTR, continued

Conclusions from the Authors of the Benchmark

Primary system pressure: "Agreement is excellent between transient initiation and the time of reactor scram. ... Post-scram depressurization and the subsequent pressurization due to safety injection (HPI) flow were predicted well for the remainder of the benchmark."

Primary system water temperatures: "Agreement is quite good during the period prior to scram. ... MAAP4 predicted well the hot and cold leg temperatures.... After the 10% power reduction, MAAP4 properly predicted the slight decrease in the hot leg temperature and the corresponding increase in the cold leg temperature. Upon scram initiation, MAAP4 properly predicted the substantial decrease in the hot leg temperature and subsequent convergence with the cold leg temperature in response to the step change in thermal power. ... Initial post-scram cooling rate was somewhat higher than that in the actual transient, which was probably due to a secondary side boiling heat transfer coefficient that was larger than expected. However, as the primary side temperature approached the secondary side saturation temperature, boiling was diminished due to the decrease [in] tube wall superheat. Consequently, while the initial cooldown was too rapid, the total energy removed from the RCS during the entire post-scram period was similar, as reflected in the average temperature prediction that was only a few degrees lower than that for the actual transient."

Overall: "MAAP4 provides a reasonable characterization of the reactor coolant system response to the steam generator tube rupture given the synchronized boundary conditions for the thermal power runback, reactor scram, feedwater flow rate, and steam generator secondary side pressure."

Documentation

MAAP4 User's Manual [1]: Volume III, Section B, Rev. 0, October 1997.
MAAP4 transmittal documents for Rev. 4.0.6 and Rev. 4.0.7 [12, 13]. (plotted results only, 2005 and 2007)

Comparison to Plant Event:
PE5. Maanshan SBO

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Principal Source of Documentation
FAI, also INER, Taiwan Power Co.	PWR, WLD	1	3 hr	4.0.5	Presentation to the NRC (2004)

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Good agreement	—
PWR primary system thermal hydraulics	Pressure	Very good agreement	Sensitivity cases consisted of 1) using a lower value of HTSTAG and 2) simulating natural convection with the RCP coastdown curve. Using the coastdown curve instead of HTSTAG means that the code will calculate the primary side to secondary side heat transfer coefficient using the forced convection heat transfer correlation instead of HTSTAG. These sensitivity cases were selected because the sequence starts 23 hours after reactor trip.
	Water level in the pressurizer	Good agreement Very good agreement with a value of HTSTAG[a] that is appropriate for the sequence (lower than the nominal value because the initial power is low) Very good agreement with natural convection simulated by the RCP coastdown curve	

[a] HTSTAG is the coefficient for the primary side to secondary side heat transfer when single- or two-phase natural circulation is occurring in the coolant loops.

Comparison to Plant Event:
PE5. Maanshan SBO, continued

Notes

The benchmark includes MELCOR code predictions of the event as well as the MAAP4 predictions.

The steam generator terms (pressure and water level) are boundary conditions, so this benchmark does not test the steam generator model.

Using the RCP coastdown curve did not yield better agreement with the data than using the smaller value for input parameter HTSTAG. The smaller value was selected because the power is relatively low due to the long elapsed time since reactor trip.

Exemplified Limitation

PWR sequences without makeup or loss from the primary system in which the primary system is cooling down by heat transfer to the steam generators can result in a minor over-prediction of the rate of depressurization in the primary system at the time that the pressurizer drains completely. This is due to the fact that steam flow from the pressurizer into the water-filled RCS condenses in the water, which is in a homogenous, subcooled state. In actuality, the water in the reactor vessel dome is somewhat hotter than the rest of the RCS, and a portion of that water flashes into steam as the RCS depressurizes, keeping the system at a higher pressure. The calculated faster depressurization might lead to slightly earlier pressure activation of safety systems, such as accumulator injection. This is a minor limitation and affects only the detailed behavior of the primary system.

Conclusions from the Authors of the Benchmark

"MAAP4 results generally agree with the plant data for the SBO sequence. With adjustments of MAAP input parameters (sensitivity studies), comparisons with the details of the plant data can be improved. In this case, this is primarily a result of the low decay heat.... These sensitivity parameters have very little effect on overall time to when the core is uncovered."

Comparison to Plant Event:
PE5. Maanshan SBO, continued

Documentation

Presentation to the NRC by FAI, September 2004. (supersedes 2001 presentation)
Presentation to the MAAP Users Group by INER and Taiwan Power Co., May 2001.

Comparison to Plant Event:
PE6. Oconee Plant Trip

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Versions	Principal Source of Documentation
Duke	PWR, B&W	1	15 min	4.0.5, 4.0.6 plus code change	Presentation to the MUG (2006)
Code change made regarding the option for specifying if the water in the PWR vessel dome region is considered hot or cold (added in Rev. 4.0.7)					

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Good agreement	—
PWR primary system thermal hydraulics	Pressure	Very good agreement after change made to model plants with hot water in the dome	—
	Water level in the pressurizer	Not available	

Exemplified Limitation

Through Rev. 4.0.6, the code always models the water in the vessel dome as cold water, representing *T-cold* plants. The code might under-predict the decrease in the water volume in the primary system as the plant depressurizes for plants with hot water in the vessel dome, *T-hot* plants, resulting in a smaller predicted pressure drop. One impact of this limitation is that emergency system low pressure setpoints might not be hit in T-hot plants if they are modeled as T-cold plants.

Conclusions from the Authors of the Benchmark

"The additional shrinkage that results when the reactor vessel upper head water is designated as hot causes the pressure to drop to the emergency system setpoint."

Comparison to Plant Event:
PE6. Oconee Plant Trip, continued

Documentation

Presentation to the MAAP Users Group by Duke, November 2006.

Comparison to Plant Event:
PE7. 1992 MAAP3B Qualification Studies–LOOP and Plant Trip

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Principal Source of Documentation
GKA	PWR, Westinghouse four-loop plant (ice condenser containment)	1	3, 5 min	MAAP3B Rev. 16	EPRI technical report (1992)

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Good agreement with MAAP3B plus code changes that were identified as part of the MAAP3B benchmark activity. The changes were incorporated into MAAP4.	The benchmark is generally but not specifically applicable to MAAP4 because it was done with MAAP3B.

Documentation

1992 MAAP Thermal-Hydraulic Qualification Studies [2, 5].

Comparison to Integral Codes:
IC1. SBO and LOFW with Feed and Bleed for CE Plants; CENTS Code

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Comparison Code Version	Number of Sequences	Principal Source of Documentation
Westinghouse	PWR, CE	1	3 hr	4.0.6 plus code change, also 4.0.5 for LOFW	CENTS Version 06100	1 SBO, 1 LOFW	Conference proceedings (2009), presentation to the MUG (2006)
Code change made regarding the option for specifying if the water in the PWR vessel dome region is considered hot or cold (added in Rev. 4.0.7)							

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Good agreement	The cases demonstrate the need to check the secondary side water mass versus level and adjust the geometry terms as needed. The 4.0.5 LOFW case also demonstrates the importance of checking that the input parameter values result in accurate, self-consistent initial conditions by testing with a steady-state sequence.
PWR primary system thermal hydraulics	Pressure	Good agreement	The RCP coastdown curve was used to simulate single-phase primary side natural convection in the LOFW sequence. There are differences in the predicted quality of the fluid flowing through the surge line and therefore through the PORVs. These differences do not indicate problems with the MAAP4 model, and they do not affect the agreement of the key quantities.
	Water level in the pressurizer	Good agreement (available in MUG presentation for LOFW)	

Comparison to Integral Codes:
IC1. SBO and LOFW with Feed and Bleed for CE Plants; CENTS Code, continued

Model	Indicator	Agreement Based on Expert Review	Notes
Steam generator: two-region U-tube	Pressure	Very good agreement	The MAAP4 steam generator level model is more simplified than the one in CENTS. Secondary side benchmarking was performed to ensure consistency between the two codes for the timing of the reactor trip signal and the initiation of feed and bleed. This involved adjusting the MAAP4 setpoints to correspond to the appropriate steam generator inventory.
	Water level (represented by mass)	Fair to good agreement	

Validation of Code Capabilities

Critical flow: pressurizer PORVs	Qualitative agreement inferred from primary system response
PWR ECCS injection: generalized model	Validated based on the effect of injection on the primary system response

Exemplified Precaution

Loss-of-feedwater sequences are particularly sensitive to mismatches between the core power, feedwater flow, and secondary side volume versus height input values. It is important to accurately determine the time of reactor trip, which in turn means determining appropriate secondary side water level setpoints if the water level is the trigger for reactor trip.

Comparison to Integral Codes:
IC1. SBO and LOFW with Feed and Bleed for CE Plants; CENTS Code, continued

Conclusions from the Authors of the Benchmark

Conference proceedings: "The results of the analyses presented in this paper provide several useful insights. The simplified single-phase natural circulation model utilized by MAAP4 drives differences in the thermal-hydraulic response of the SGs as well as the RCS. It should be noted that older generators of MAAP4, such as MAAP 4.0.5, have been known to skew the RCS pressure responses for feed and bleed and SBO transients. MAAP versions 4.0.6 and beyond include a number of enhancements that yield more consistent results for the pressure traces of the SBO and the feed and bleed transients. It is recommended that the user be cautious in the selection of the code version that is employed for SBO and LOFW event analyses.

This paper demonstrates that when care is taken to normalize the MAAP4 and CENTS primary side natural circulation flow rate and SG modeling behaviors, the trends of MAAP4 and CENTS, while not in precise agreement, are sufficiently close to predict similar equipment sets required for mitigation. Although the timings and durations of key occurrences and actuations vary, MAAP4 predictions of core uncovery tend to be conservatively biased. It should also be noted that the use of thermal-hydraulic results in PRA should consider the uncertainties inherent in key models employed in the computer codes."

Minutes and viewgraphs: "MAAP is successful in predicting feed and bleed success criteria with integrated containment response."

Viewgraphs: "Incorporating mass-based secondary side setpoints and steam generator pressure control: earlier SG dryout times, less time for operators to initiate feed and bleed, more realistic SG mass vs. level predictions; ... Low PORV quality predictions lead to: increased RCS coolant loss, earlier core uncovery times; ... MAAP generated success criteria: accurate in terms of minimum requirement equipment set, different in terms of detailed transient response; ... MAAP is successful in predicting feed and bleed success criteria with integrated containment response: important to understand potential MAAP modeling uncertainties."

Comparison to Integral Codes:
IC1. SBO and LOFW with Feed and Bleed for CE Plants; CENTS Code, continued

Documentation

N. LaBarge, R. Schneider, B. Baron, and M. Jacob, "Comparison of Thermal Hydraulic Simulations of Beyond Design Basis Events Using the MAAP4 and CENTS Computer Codes," *Proceedings of the 17th International Conference on Nuclear Engineering (ICONE17).* Brussels, Belgium (July 12–16, 2009).
Presentation to the MAAP Users Group by Westinghouse, November 2006. (preliminary to the 2009 paper, used Rev. 4.0.5, proprietary to Westinghouse)

Comparison to Integral Codes:
IC2. LOFW and S/MLOCAs for U.S. EPR; S-RELAP5 Code

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Comparison Code Version	Number of Sequences	Principal Source of Documentation
AREVA NP	PWR, U.S. EPR	1	2 hr	4.0.7	S-RELAP5 (version not specified)	3 LOFWs, 1 SLOCA, 1 MLOCA	Conference proceedings (2008)

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Good agreement	The agreement between the codes for the various sequences is sensitive to the timing of the RCP trip and the subsequent onset of natural circulation in the primary system, which influences primary to secondary side heat transfer. The MAAP4 model primary system model is less mechanistic than the S-RELAP5 model; the differences in the results due to differences in the modeling are the most pronounced for Case 3c (LOFW with three unvented steam generators) because of the particularly asymmetric conditions in the steam generators.

Comparison to Integral Codes:
IC2. LOFW and S/MLOCAs for U.S. EPR; S-RELAP5 Code, continued

Model	Indicator	Agreement Based on Expert Review	Notes
PWR primary system thermal hydraulics	Pressure	Very good agreement (pressure comparison provided for only one sequence, a LOCA)	Plots of the water level in the vessel are not included in the paper. However, periods of core uncovery were inferred from plots of the cladding temperatures. One LOFW sequence (Case 4g) shows a higher core temperature in MAAP4 compared with S-RELAP5, and the paper contains a postulated explanation of why MAAP4 predicts the more conservative result—that MAAP4 does not explicitly model the "sucking" of water into the core due to the pressurizer PORV being open—which contributes to the homogenization of the two-phase fluid and, therefore, improved heat transfer. Based on the information provided, the review team that assessed the benchmark suspects that the reason for the differences in results is that the RCPs have tripped on a high void fraction condition in MAAP4, while the RCPs continue to run in S-RELAP5, and is not primarily due to differences in the thermal-hydraulic models.
	Water level in the pressurizer	Not available	
	Water level in the vessel	Good agreement, with the exception of one LOFW sequence (Case 4g), which is suspected to be due to differences in input	
Steam generator: one-region U-tube	Pressure	Not available	The review team surmised that the pressures agree well based on the other information provided in the paper. Differences in water level are suspected to be in part due to differences in RCP operation, as noted in the primary system thermal hydraulics discussion.
	Water level	Fair to good agreement	
Core heat-up	Core temperature	Fair to very good agreement	Differences in core temperatures are suspected to be in part due to differences in RCP operation, as noted in the primary system thermal hydraulics discussion.

Comparison to Integral Codes:
IC2. LOFW and S/MLOCAs for U.S. EPR; S-RELAP5 Code, continued

Exemplified Limitation

MAAP4 models one primary system water temperature before the phases separate. This is adequate when all of the steam generators are behaving similarly or when all the RCPs are operating to keep the water circulating. However, in cases where the pressures in the steam generators are very different and the primary system is in a single-phase natural circulation mode, the code will over- or under-predict the heat transfer to the secondary side. Under these circumstances, the code should not be used to calculate detailed results such as the time to steam generator dryout. (This is the situation in Case 3c in this benchmark, in which three of the steam generators are not vented and the code over-predicts the heat transfer to the vented steam generator. This is a highly improbable sequence because all of the valves on three of the generators are assumed to have failed, and it exaggerates the impact of the code limitation.) Note that an asymmetry in the steam generators is different than an asymmetry in the primary system loops, which can be handled with the MAAP4 models. (This limitation relates to the first code-to-code discrepancy noted in the conclusions from the authors, presented below.)

Validation of Code Capabilities

Critical flow: pressurizer safety valves	Qualitative support with one LOFW sequence
Critical flow: break flow	Validated based on good agreement between the calculated break flows for one LOCA sequence

Comparison to Integral Codes:
IC2. LOFW and S/MLOCAs for U.S. EPR; S-RELAP5 Code, continued

Conclusions from the Authors of the Benchmark

"The results of the benchmark between MAAP4 and S-RELAP5 provided insight into the capabilities and limitations of MAAP4 to simulate plant thermal-hydraulic behavior prior to core damage. Overall, the MAAP4 results show a very good agreement to the S-RELAP5 results as summarized in [a table in the paper]. However, two significant discrepancies were identified.

This first significant discrepancy is related to the simulation of primary to secondary side heat transfer. Specifically, this discrepancy is associated with the onset of fully developed natural circulation in the RCS coolant loops. MAAP4 consistently predicts this occurring shortly after the RCPs have tripped, while S-RELAP5 typically showed the development of this loop flow within 20 minutes following the RCP trips. As such, the onset of natural circulation has been identified as a major uncertainty associated with using the MAAP4 code. This only impacts those events in which RCPs are tripped early in an event simulation.

The second significant discrepancy appeared in Case 13d [actually Case 4g, a LOFW] in which the RCPs were allowed to remain operating for the duration of the simulation. Due to the lack of explicit interfacial drag and other code limitations, MAAP4 results exhibited unphysical phase separation. As a result, when a significant amount of RCS coolant is lost, the heat transfer benefits of entrained liquid are absent and in the situation in which the core becomes uncovered, a subsequent clad temperature excursion occurs earlier and lasts longer than that predicted by the best-estimate S-RELAP5 code. As such, in those scenarios MAAP4 results should be considered as being very conservative relative to a best-estimate representation.

Based on the results from the benchmark study, MAAP4 has demonstrated that it is a rather good simulator of nuclear plant transient trends; however, MAAP4's prediction of clad temperature magnitude is not sufficiently accurate to accept without compensation. As such, the following bases for success criteria are to be applied when using MAAP4 for the U.S. EPR: MAAP4 cases resulting in a PCT (peak cladding temperature) of 1400°F or less will be considered a success; cases resulting in a PCT of 1800°F or greater will be considered a failure; and cases resulting in a PCT between 1400°F and 1800°F will be examined in detail, possibly with a corresponding S-RELAP5 calculation."

Documentation

J. Butler, D. Kapitz, R. Martin, F. Seifaee, and R. Sundaram, "MAAP4.0.7 Analysis and Justification for PRA Level 1 Mission Success Criteria," *Proceedings of the 2008 International Congress on Advances in Nuclear Power Plants (ICAPP'08).* Anaheim, CA (June 8–12, 2008).

Comparison to Integral Codes:
IC3. LOOP with LLOCA for BWR Plants; TRACG02 Code

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Comparison Code Version	Number of Sequences	Principal Source of Documen-tation
GE	BWR	1	8 min	4.0.4 plus code change	TRACG02	2 LOOP with LLOCAs	GE technical report (2006)
Code change made for a more mechanistic transition between nuclear and film boiling heat transfer from the cladding to the coolant (added to Rev. 4.0.6)							

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Good agreement	Benchmark required careful attention to ensure that the core peaking factors were the same in both codes so that they would calculate the same linear heat generation rates.
BWR primary system thermal hydraulics	Pressure	Good agreement	Code change results in a higher heat transfer coefficient during the early part of the film boiling phase.
	Water level in the vessel	Good agreement	
Core heat-up	Core temperature	Fair agreement	There is good agreement in the magnitude of the predicted temperatures with an "adder" of ~200°F added to the TRACG02 results to account for known model uncertainties. However, MAAP4 predicts an early temperature increase, and the reason for this difference is unknown.

Comparison to Integral Codes:
IC3. LOOP with LLOCA for BWR Plants; TRACG02 Code, continued

Validation of Code Capabilities

Critical flow: break flow	Validated based on good agreement between the calculated break flows
BWR ECCS injection	Validated based on good agreement between the calculated injection flows

Conclusions from the Authors of the Benchmark

Report: "In the generic analysis, the MAAP4 code was used to identify the most challenging set of plant changes, and subsequently TRACG02 analyses were carried out for these conditions to show that the peak cladding temperature was below the defined criteria. With the benchmark complete, it is shown that the MAAP4 code is adequate for analyzing the large break LOCA/LOOP events. It is also expected that as long as the parameters used in the generic MAAP4 analysis bound the corresponding parameters for the individual licensee's plants, the results of the generic MAAP4 analyses … are applicable for those individual plants."

"The benchmark analyses documented in [the report] showed that the TRACG02 and MAAP4 PCT (peak cladding temperature) values compared reasonably well. … The TRACG02 results showed that MAAP4 results are relatively conservative, i.e., they over-predict the PCT values."

"Sections B.4.2 and B.4.3 compare MAAP4 and TRACG02 predictions of reactor power, reactor vessel pressure, break flow rate, ECCS flow rate, and peak cladding temperature, for the selected BWR4 case and BWR6 case, respectively. Overall, the results compare favorably given the differences in methodology between the two codes. The results of these benchmark analyses conclude that MAAP4 is an acceptable tool for performing the thermal-hydraulic analyses required for the large break LOCA/LOOP exemption for the specific cases analyzed here."

Documentation

GE Nuclear Energy. *Guidance for Separation of Loss of Offsite Power from Large Break LOCA.* Licensing Topical Report, 2006. NEDO-33148, Rev. 2.
Presentation to the MAAP Users Group by NPPD, May 2004. (preliminary to the licensing report)

Comparison to Integral Codes:
IC4. SBO with Feed and Bleed for Palisades CE Plant; RELAP5 Code

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Versions	Comparison Code Version	Number of Sequences	Principal Sources of Documentation
Erigo Technologies	PWR, CE	1	5, 10 hr	4.0.5 plus code change	RELAP5 Ver. 3 Mod. 2	2 SBOs	Erigo letter report (2006), presentation to the MUG (2006)
FAI	PWR, CE	1	5, 10 hr	4.0.6 plus code change	RELAP5 Ver. 3 Mod. 2	2 SBOs	Presentation to the MUG (2008)
Code change made regarding the option for specifying if the water in the PWR vessel dome region is considered hot or cold (added in Rev. 4.0.7)							

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Good agreement	
PWR primary system thermal hydraulics	Pressure	Fair agreement using HTSTAG,[a] good agreement simulating natural circulation with the RCP coastdown curve (results in a later pressurization)	Sensitivity case consisted of simulating natural convection with the RCP coastdown curve. This resulted in a better match for the timing of the primary system pressurization (the pressurization is later with the RCP coastdown). The lumped treatment of natural convection using HTSTAG is conservative with respect to heat transfer from the primary system for this benchmark. It might be conservative or non-conservative for the full sequence depending on the particular results of interest.
	Water level in the pressurizer	Good agreement, taking into account earlier pressurization due to reduced heat transfer to SGs in base case (trends are good in both cases)	

Comparison to Integral Codes:
IC4. SBO with Feed and Bleed for Palisades CE Plant; RELAP5 Code, continued

Model	Indicator	Agreement Based on Expert Review	Notes
PWR primary system thermal hydraulics	Water level in the vessel	Good agreement	See previous note
Steam generator: one-region U-tube	Pressure	Good agreement except as noted	Due to cooling on the primary side because of injection, RELAP5 calculates condensation on the secondary side of the steam generator tubes, and MAAP4 does not model condensation on the secondary side. This is a minor limitation in MAAP4, and is the reason that at the end of the first sequence RELAP5 predicts a water level increase and a pressure decrease in the steam generator that is not predicted by MAAP4.
	Water level	Good agreement	

[a] HTSTAG is the coefficient for the primary side to secondary side heat transfer when single- or two-phase natural circulation is occurring in the coolant loops.

Validation of Code Capabilities

Critical flow: pressurizer PORVs	Qualitative agreement inferred from primary system response
PWR ECCS injection: generalized model	Validated based on good agreement between the calculated injection flows

Comparison to Integral Codes:
IC4. SBO with Feed and Bleed for Palisades CE Plant; RELAP5 Code, continued

Exemplified Limitation

MAAP4 does not model condensation on the secondary side of the steam generators, which can occur when there is substantial cooling on the primary side because of injection. The code will not predict the resulting increase in the water level and decrease in the pressure on the secondary side. This is a minor limitation.

Conclusions from the Authors of the Benchmark

Report: "The trends exhibited by both codes are considered quite consistent for both sequences, and similar conclusions would be made regarding key timing and the adequacy of operator actions in preventing core damage. [The authors] expect that differences in plant models remain, and that these are probably more responsible for the remaining differences than are different thermal-hydraulic modeling approaches. Taken at face value, MAAP exhibited a somewhat faster and more severe response in each of these two sequences. The results from this effort should help resolve concerns about the use of MAAP for non-severe accident sequences, particularly those involving feed and bleed."

Erigo viewgraphs: "Generally good agreement on SBO-001: users can improve agreement by modeling natural circulation heat transfer with a nominal flow rate rather than HTSTAG;" "For SBO-003, differences exist in SG inventory predictions which can partly be attributed to smaller decay heat in RELAP;" "MAAP generally predicts slightly more severe behavior"

FAI viewgraphs: "MAAP4 is in general agreement with RELAP;" "MAAP4 provides a conservative assessment of the potential for core overheating"

Documentation

Presentation to the MAAP Users Group by Erigo, May 2006.

M. Kenton, *Comparison of MAAP and RELAP Predictions for Two Postulated Station Blackout Accidents in Palisades.* Erigo Technologies (2006). FR-0512-01.

Presentation to the MAAP Users Group by FAI, May 2008.

Comparison to Integral Codes:
IC5. LLOCA for Kuosheng BWR Plant and SBO for Maanshan WLD Plant; SCDAP/RELAP5 and MELCOR Codes

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Comparison Code Versions	Number of sequences	Principal Sources of Documentation
INER, Chung Yuan Univ.	BWR	1	4 hr	4.0.4	SCDAP/RELAP5 Mod. 3.3 and MELCOR1.8.5	1 LLOCA	Journal paper (2005), doctoral dissertation (2006)
	PWR, WLD	1	5 hr			1 SBO	

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Good agreement for both BWR and PWR cases	—
BWR primary system thermal hydraulics	Pressure	Good agreement	There are discrepancies in the boil off of the water in the lower plenum, but there is not enough information to determine the reason.
	Water level in the vessel	Fair agreement as noted	
PWR primary system thermal hydraulics	Pressure	Good agreement	Trends in the water level are the same, but different reference elevations inhibit the drawing of conclusions. The levels track well after they are in the same regime.
	Water level in the pressurizer	Not available	
	Water level in the vessel	Fair agreement as noted	
Steam generator: U-tube (region model not specified)	Pressure	Good agreement	—
	Water level	Good agreement	
BWR and PWR core heat-up	Core temperature	Good agreement	—

Comparison to Integral Codes:
IC5. LLOCA for Kuosheng BWR Plant and SBO for Maanshan WLD Plant; SCDAP/RELAP5 and MELCOR Codes, continued

Note

The paper includes Level 2 phenomena, but the extraction of information for benchmarking purposes is limited to Level 1 phenomena (consistent with the scope of this document).

Conclusions from the Authors of the Benchmark

Journal paper: "The important severe accident phenomena including core uncovery, cladding oxidation, … give similar results with SR5, MAAP, and MELCOR."

Documentation

T. Wang, S. Wang, and J. Teng, "Comparison of Severe Accident Results Among SCDAP/RELAP5, MAAP, and MELCOR Codes," *Nuclear Technology.* Vol. 150, p. 145–152 (2005).

T. Wang, *Study on Severe Accident Codes and Their Applications.* Chung Yuan Christian University (Taiwan) Doctoral Dissertation, etd-0725107-155243 (2006).

Comparison to Integral Codes:
IC6. MLOCA for Palo Verde WLD Plant; CENTS Code

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Comparison Code Version	Number of Sequences	Principal Source of Documentation
FAI	PWR, WLD	1	5 hr	4.0.5 plus code change	CENTS (version not specified)	1 MLOCA	Presentation to the MUG (2005)
Code change for venting separated liquid and gas flow with subcooled water (will be added to Rev. 4.0.8, results in a marginally lower RCS pressure)							

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Inconclusive	CENTS predicts that the pressurizer and steam generators depressurize at a much higher rate than the MAAP4 predictions. Significant effort failed to resolve the issue; the differences are associated with small differences in the mass and energy, which make it difficult to find the root cause of the discrepancies. It is suspected that the critical flow model in CENTS might need refinement.
PWR primary system thermal hydraulics	Pressure	Inconclusive	Due to pressure discrepancies
	Water level in the pressurizer	Not available	
Steam generator: U-tube (region model not specified)	Pressure	Inconclusive	Due to pressure discrepancies
	Water level	Not available	

Comparison to Integral Codes:
IC6. MLOCA for Palo Verde WLD Plant; CENTS Code, continued

Validation of Code Capabilities

Critical flow: break flow	Validated based on generally good agreement between the code predictions for mass and energy through the break

Exemplified Limitation

The code uses a single value of VFSEP, the void fraction above which the primary system inventory is no longer modeled as a homogeneous two-phase mixture, during any sequence. For small to medium LOCA sequences with injection, a relatively low value might result in a more realistic primary system inventory but a somewhat higher primary system pressure. The sensitivity of the primary system response to the value of VFSEP should be evaluated routinely, as noted in Sections 4 and 8 of this document.

Conclusions from the Authors of the Benchmark

"Agreement between MAAP4 and CENTS on break flow is generally good, but differences in RCS and SG depressurization could not be resolved, despite significant effort. (It was identified that there might be a need for Henry-Fauske implementation refinement in CENTS.) Despite these differences, both codes reach the same basic conclusion of no core overheating."

Documentation

Presentation to the MAAP Users Group by FAI, May 2005.

Comparison to Integral Codes:
IC7. S/M LOCAs for EDF/Framatome PWR 900 Plant; CATHARE Code

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Comparison Code Version	Number of Sequences	Principal Source of Documentation
EDF	PWR, 900 MWe CPY series, EDF/Framatome	1	2–12 hr	4.0.4	CATHARE v1.5	6 S/MLOCAs	EDF technical report (2004)

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Good agreement after adjustments to the MAAP4 input	Initially, MAAP4 predicted a faster discharge rate from the accumulators than CATHARE. The differences were resolved by reducing the diameter of the accumulator piping in the MAAP4 parameter file, thereby increasing the flow resistance. Recommendations were made to allow the accumulators to discharge in an adiabatic (isentropic) manner as well as in an isothermal manner; this option was added to MAAP4.0.6 along with a coefficient to increase the piping resistance. Also, there were differences in the initial designations of the water pools associated with the cold leg breaks that were resolved by moving the breaks in MAAP4 to the intermediate leg.

Comparison to Integral Codes:
IC7. S/MLOCAs for EDF/Framatome PWR 900 Plant; CATHARE Code, continued

Model	Indicator	Agreement Based on Expert Review	Notes
PWR primary system thermal hydraulics	Pressure	Very good agreement	The agreement in the water level in the vessel is inferred from the mass of water in the primary system plus pressurizer; the calculated levels were not plotted.
	Water level in the pressurizer	Not available	
	Water level in the vessel	Good agreement given the noted differences in the accumulator injection	
Steam generator: one-region U-tube	Pressure	Very good agreement	The agreement in the heat transfer to the steam generators is very good. It is surmised that the agreement in the water levels in the steam generators is very good because of the agreement in the pressure and heat transfer.
	Water level	Not available	

Validation of Code Capabilities

Critical flow: break flow	Validated based on moderate agreement between the calculated break flows

Comparison to Integral Codes:
IC7. S/MLOCAs for EDF/Framatome PWR 900 Plant; CATHARE Code, continued

Notes

Injection into the "cold leg" in MAAP4, as designated by setting the value of input parameter IDISCH to 1 for the hardwired ESF model or by setting the pump discharge location parameters to 2 for the generalized ESF model, is actually into the intermediate leg water pools, which extend from the outlets of the steam generators to the RCPs. Users sometimes misinterpret injection into the "cold leg" as going into the horizontal portions of the cold legs. The water in the horizontal portions of the cold legs is part of the downcomer water pool. This distinction is important for cold leg break sequences because it affects whether injection goes directly out of the break or into the downcomer. See Sections 6.4.3 and 6.6.1 of this report for discussions of break locations and water pools.

It is suggested in this benchmark that the evacuation of water plugs in the cross-over legs be improved. The water plugs affect the pressure calculations such that the code can over-predict the pressure in the core relative to the pressure in the downcomer by the amount of the water head in the legs, potentially leading to a brief period of core uncovery, but this condition is minor and self-correcting.

Exemplified Precaution

The accumulator tanks and the piping to the primary system are not modeled as thermal-hydraulic control volumes. Combined with this is the positive-feedback coupling of a higher accumulator discharge rate with a lower primary system pressure (which allows more discharge). Therefore, the accumulator model has inherent uncertainties that can influence the results of a sequence. Users should evaluate the sensitivity of their results to the accumulator input parameters, including the polytropic constants, the head loss coefficients, and the dimensions of the piping. The largest impact of the parameter values on the results occurs for small LOCA sequences. Note that the larger the value of the polytropic constant the slower the rate of discharge.

Comparison to Integral Codes:
IC7. S/MLOCAs for EDF/Framatome PWR 900 Plant; CATHARE Code, continued

Exemplified Limitations

In sequences with a break in the cold leg, MAAP4 can over-predict the amount of injected water that goes into the downcomer—and therefore into the core—prior to going out of the break if the injection is designated as being into the downcomer water pool (see the note). This occurs because the code does not apportion the injection into that which flows to the downcomer and that which flows out of the break. Users should determine the injection location relative to the break location, and then define the sequence such that the injected water goes into the appropriate water pool. Individual scenarios can be bracketed with one sequence that includes a break in the cold leg and injection into the cold leg (the downcomer water pool) and one that includes a break in the intermediate leg and injection into the intermediate leg at the same elevation as the cold leg break. A workaround for the code limitation is to reduce the amount of injection (including the inventory in the cold leg accumulators), and add the portion of the water that would go out of the break directly into the containment. (Note that the discharge location of the accumulators is always the downcomer water pool.)

A similar but less encountered limitation is that the portion of condensation on the primary side of the steam generator tubes that flows into the hot legs is added to the core water pool and will not flow directly out a hot leg break. This is only a concern if just one steam generator is depressurized and the break is in that loop. An approximate workaround is to locate the break in the intermediate leg such that the portion of the condensate that goes into the intermediate leg water pool is potentially discharged out of the break.

Comparison to Integral Codes:
IC7. S/MLOCAs for EDF/Framatome PWR 900 Plant; CATHARE Code, continued

Conclusions from the Authors of the Benchmark

"Response to the objectives: An initial comparison with CATHARE showed the limits of the modeling of the primary thermo-hydraulics in MAAP. However, following the modifications made to the parameter file to overcome these limits, the difference with CATHARE is greatly reduced in a second comparison. We solved the problems of: excessively fast letdown of the accumulators; evacuation of the condensates in the cold leg; evacuation in the break of part of the injection of the accumulators on scenario B4BF [4" cold leg break]. However, on the other hand, the evacuation of the condensates on the break scenarios in the hot leg [two sequences] is not always modeled. On the other hand, the improvements made are not viable in the long term: it is necessary to take these physical phenomena into account in the models of the code. The comparison with CATHARE only enabled us to assess the validity of the MAAP results on the thermo-hydraulics of the primary system before uncovery of the core. MAAP, the reference code for the study of serious accidents at EDF, is a scenario code representing the nuclear unit as a whole (including the containment).

Prospects: It is necessary to make the following improvements to envisage the use of MAAP as a crisis tool: the injection of the accumulators should be carried out in the cold leg and not directly to the downcomer; for the cold leg break scenarios, the letdown of part of the safety injection in the break should be taken into account; the accumulator letdown routine should be modified: the current isothermic letdown should be replaced by a polytropic letdown with a coefficient that may be modified by the user; the evacuation in the break of condensates produced in the SG tubes in heat pipe operation should be modeled; the modeling of the evacuation of water plugs in the crossover leg should be improved. In addition, this validation of the modeling of the primary thermo-hydraulics in MAAP should be extended to other types of accident scenarios (H2, RTGV ...)"

Documentation

EDF Branche Energies, Service Études et Projets Thermiques et Nucléaires. *Intercomparison of the MAAP/CATHARE codes on 2" and 4" break scenarios.* Design note, 2004. ENTEAG040227 A Prel.

Presentation to the MAAP Users Group by EDF, November 2004.

Comparison to Integral Codes:
IC8. TMLB′ for WLD Plant; SCDAP/RELAP5 and MELCOR Codes

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Comparison Code Versions	Number of Sequences	Principal Source of Documentation
Purdue Univ., Exelon, Creare, SNL	PWR, WLD	1 and 2	5 hr	4.0.5	SCDAP/ RELAP5 Mod. 3.3 and MELCOR1.8.5	1 TMLB' (SBO with no RCP seal leak)	Journal paper (2004), presentation to the MUG (2004)

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Good agreement	—
PWR primary system thermal hydraulics	Pressure	Good agreement except as noted	A pressurizer pressure initial dip of about 1.5 MPa (corresponding to 0.5 m in level) is not calculated in MAAP4. The reason is unclear and is atypical for MAAP4. It might be due to the fact that the code does not calculate the behavior in each loop individually, so it does not calculate a much larger natural circulation flow in the loop that is venting compared to the other loops. The other two codes model this level of detail. The effect of this difference is minor.
	Water level in the pressurizer	Good agreement prior to core damage, fair agreement after core damage	
	Water level in the vessel	Fair agreement inferred from core uncovery time	
Steam generator: one-region U-tube	Pressure	Good agreement	—
	Water level	Not available	
Core heat-up	Core temperature	Good agreement supported by timing and magnitude of hydrogen generation	Core temperature is not available.

Comparison to Integral Codes:
IC8. TMLB′ for WLD Plant; SCDAP/RELAP5 and MELCOR Codes, continued

Validation of Code Capabilities

Critical flow: pressurizer PORVs	Qualitative agreement inferred from primary system response

Note

Models typically used in MAAP4 analysis were disabled for code consistency, including 1) the steam generator/hot leg recirculation flow ratio calculation, 2) the pressure drop caused by cross-flow in the core, 3) thermal radiation between gases and structures in the hot leg and surge line, and 4) hot leg to containment heat transfer.

Exemplified Limitation

Early, temporary primary system pressure drops might not be calculated with MAAP4 because the code does not calculate the behavior in each loop individually. Therefore, low primary system pressure setpoints for ECCS injection might not be hit early in a sequence (on the order of 30 minutes).

Conclusions from the Authors of the Benchmark

Journal paper: "Detailed plots show that the thermal-hydraulic phenomena and major in-vessel severe accident phenomena are in good agreement for the three codes. The integral effect of diversified core models in terms of total hydrogen production and total core debris mass slumping into the reactor vessel lower head are consistent for the three codes. … There are several discrepancies that could be termed as minor and that are possibly due to uncertainties in the numerics and physics models. Several key assumptions were made to account for known differences in heat transfer modeling and the representation of counter-current natural circulation of hot gasses. Given these assumptions, the three codes predict similar temperatures in the various reactor coolant system components."

Comparison to Integral Codes:
IC8. TMLB′ for WLD Plant; SCDAP/RELAP5 and MELCOR Codes, continued

Documentation

K. Vierow, Y. Liao, J. Johnson, M. Kenton, and R. Gauntt, "Severe Accident Analysis of PWR Station Blackout with the MELCOR, MAAP4 and SCDAP/RELAP5 Codes," *Nuclear Engineering and Design.* Vol. 234, No. 1–3, p. 129–145 (2004).
Presentation to the MAAP Users Group by ERIN for Purdue University, May 2004.
Presentation to the NRC staff by Creare, March 2002. (preliminary to the 2004 paper)
M. Kenton, *A Comparison of MAAP and SCDAP/RELAP5 Calculations for a High Pressure PWR Severe Accident.* Creare Incorporated: 2000. 8200.7 TM-2048. (preliminary to the 2004 paper)

Comparison to Integral Codes:
IC9. LOOP with Feed and Bleed for Millstone CE Plant; RELAP5 Code

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Comparison Code Version	Number of Sequences	Principal Source of Documentation
Dominion	PWR, CE	1	3 hr	Not specified	RELAP5 (version not specified)	1 LOOP	Presentation to the MUG (2003)

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Good agreement	—
PWR primary system thermal hydraulics	Pressure	Good agreement	—
	Water level in the pressurizer	Not available	
	Water level in the vessel	Fair agreement	
Steam generator: one-region U-tube	Pressure	Good agreement, taking into account range of RELAP output	—
	Water level	Good agreement	
Core heat-up	Core temperature	Good agreement, taking into account slightly higher initial value	—

Validation of Code Capabilities

Critical flow: pressurizer PORVs	Validated based on good agreement between the calculated vent flows
PWR ECCS injection (model option not specified)	Validated based on fair to good agreement between the calculated injection flows

Comparison to Integral Codes:
IC9. LOOP with Feed and Bleed for Millstone CE Plant; RELAP5 Code, continued

Conclusions from the Authors of the Benchmark

"Comparison shows excellent agreement."

Documentation

Presentation to the MAAP Users Group by Dominion, November 2003.

Comparison to Integral Codes:
IC10. Various Sequences for BWR and WLD PWR Plants; MELCOR Code

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Comparison Code Version	Number of Sequences	Principal Source of Documentation
ITS, SNL, NUPEC	PWR, WLD	1 and 2	40 hr	4.0.2	MELCOR 1.8.3	4 PWRs	Conference proceedings (1996)
	BWR, MI	1 and 2	40 hr			5 BWRs	
PWR Sequences: TMLB (SBO with RCP seal leak), 2 LLOCAs, SLOCA BWR Sequences: SBO, 3 transients, LLOCA							

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Good agreement based on core uncovery times for sequences within range of applicability of MAAP4	—
PWR primary system thermal hydraulics (only available for SBO sequence)	Pressure	Good agreement	—
	Water level	Good agreement, based on core uncovery time	

Note

Comparisons are primarily for Level 2 phenomena. This is a minor supporting benchmark for Level 1 applications given its emphasis on severe accidents and the fact that there is not a large amount of information on specific sequences in the paper.

Comparison to Integral Codes:
IC10. Various Sequences for BWR and WLD PWR Plants; MELCOR Code, continued

Exemplified Limitation

MAAP4 does not predict the appropriate primary system response during the early blowdown phase of a large LOCA in a PWR, and should not be used in this context. This is because the code might over-predict the amount of water retained in the primary system; the phases are separated and the code can under-predict the water flow through the break (more gas flow versus water flow). The water in the primary system is assumed to be in the core region versus partly in the legs, which adversely affects the calculations. Also, the code can over-predict the rate of accumulator discharge because the pressure is under-predicted, contributing to the non-physical response.

Conclusions from the Authors of the Benchmark

None applicable for Level 1.

Documentation

M. Leonard, S. Ashbaugh, R. Cole, K. Bergeron, and K. Nagashima, "A Direct Comparison of MELCOR 1.8.3 and MAAP4 Results for Several PWR and BWR Accident Sequences," *Proceedings of the International Topical Meeting on Probabilistic Safety Assessment, PSA '96.* Park City, UT (September 29–October 3, 1996).

Comparison to Integral Codes:
IC11. 1992 MAAP3B Qualification Studies–Various BWR Sequences; SAFE Code

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Comparison Code Version	Number of Sequences	Principal Source of Documen-tation
GKA	BWR (MI containment)	1	7 min–2 hr	MAAP3B Rev. 6	SAFE (version not specified)	4 transients, 1 SLOCA, 1 MSLB	EPRI technical report (1992)

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Good agreement with MAAP3B	The benchmark is generally but not specifically applicable to MAAP4 because it was done with MAAP3B.

Documentation

1992 MAAP Thermal-Hydraulic Qualification Studies [2, 5].

Comparison to Integral Codes:
IC12. 1992 MAAP3B Qualification Studies–Various PWR Sequences; RELAP and RETRAN Codes

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Comparison Code Versions	Number of Sequences	Principal Source of Documentation
GKA	PWR, Westinghouse (ice condenser containment)	1	5 min–1.4 hr	MAAP3B Rev. 16	RELAP and RETRAN (versions not specified)	8 total: 2 transients, 1 failed-open PORV, 2 SGTRs, 2 SLOCAs, and 1 MSLB	EPRI technical report (1992)

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Good agreement with MAAP3B plus code changes that were identified as part of the MAAP3B benchmark activity. The changes were incorporated into MAAP4.	The benchmark is generally but not specifically applicable to MAAP4 because it was done with MAAP3B.

Documentation

1992 MAAP Thermal-Hydraulic Qualification Studies [2, 5].

Comparison to Integral Experiments:
IE1. BETHSY LOFW with F&B and SLOCA

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Scale/Scope of Experiment	Number of Sequences	Principal Source of Documentation
FAI	PWR, 900 MWe, EDF/ Framatome	1	1, 2 hr	4.0.7	Primary system with 3 loops and steam generators, full height, full pressure, 1/100 power-to-volume ratio	2 LOFWs, 1 SLOCA	Presentation to the MUG (2008)

Major Code Models Compared and Review of Agreement

Model	Indicators	Agreement Based on Expert Review	Notes
Overall code	—	Very good agreement	Agreement obtained with minimal adjustment of input parameters.
PWR primary system thermal hydraulics	Pressure	Very good agreement	Very good agreement was obtained for the primary system inventory.
	Water level in the pressurizer and vessel	Very good agreement	
Steam generator: one- and two-region U-tube	Pressure	Very good agreement	The one-region model was used for the LOFW cases because the power was low; the two-region model was used for the SLOCA case.
	Water level	Very good agreement	—

Comparison to Integral Experiments:
IE1. BETHSY LOFW with F&B and SLOCA, continued

Note for PWR Benchmarking

When initiating a sequence at significantly less than full power and with heat transfer to the steam generators (that is, not a mid-loop sequence), it is important to determine that the initial water levels in the generators are correct. This particularly applies to the two-region steam generator model because the dynamic head is not fully developed. It is also necessary to decrease the value of the calculated steam generator resistance correction factor, FKSEC, to 1.0 after time zero because the code will calculate an unreasonably high value due to the non-standard conditions.

Validation of Code Capabilities

Critical flow: pressurizer PORVs	Validated based on the good agreement of the primary system inventory.
Critical flow: break flow	Validated based on the good agreement of the primary system inventory. There is a slight under-prediction of the break flow due to the MAAP4 modeling of the water distribution in the primary system.
PWR ECCS injection: generalized model	Validated based on the good agreement of the primary system inventory.
Voiding in the core	Qualitative validation based on core temperature and core collapsed water level, which implicitly support the void fraction calculations.

Conclusions from the Authors of the Benchmark

"Good agreement with the experimental results for both the loss of feed with feed-and-bleed, and 2-inch small LOCA sequences. For 2-inch small LOCA, MAAP4 under-predicted overall break flow mass which is mostly due to MAAP4 modeling of water distribution in RCS."

Documentation

Presentation to the MAAP Users Group by FAI, May 2008.

Comparison to Integral Experiments:
IE2. IIST SBO

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Scale/Scope of Experiment	Number of Sequences	Principal Source of Documentation
FAI	PWR, WLD	1	3 hr	4.0.6	Primary system with 3 loops and steam generators, reduced height and reduced pressure	1 SBO	Conference proceedings (2005)

Major Code Models Compared and Review of Agreement

Model	Indicators	Agreement Based on Expert Review	Notes
Overall code	—	Very good agreement	Two values of the volume of the primary system were used because of uncertainties in the data. The specific input parameters that were adjusted to obtain agreement were not identified in the paper. The effect of heat loss is substantial because of the small scale of the test apparatus.
PWR primary system thermal hydraulics	Pressure	Very good agreement	—
	Water level in the pressurizer	Very good agreement	
	Water level in the vessel	Not available	

Comparison to Integral Experiments:
IE2. IIST SBO, continued

Model	Indicators	Agreement Based on Expert Review	Notes
Steam generator: one-region, U-tube	Pressure	Not available	—
	Water level	Very good agreement	
Core heat-up	Core temperature	Very good agreement	The onset of core heat-up is influenced by the defined initial volume of the primary system

Conclusions from the Authors of the Benchmark

"The comparison … with the integral experiment … demonstrates that the MAAP4 code provides a good, yet conservative representation of the timing over which inventory would be lost from both the secondary and RCS under station blackout conditions. In particular, the MAAP4 code, with its geometric representation of the IIST facility, shows agreement with the boildown of water level on the secondary side. The representation for the RCS pressure history is also in good agreement with the measured response. It is noted that one aspect of this and all analyses for reduced size test facilities is to properly represent the heat losses from the scaled RPV, cold legs, hot legs and pressurizer."

Documentation

R. Henry, C. Henry, C. Paik, and G. Hauser, "Comparison of the MAAP4 Code with the Station Blackout Simulation in the IIST Facility," *The 11th International Topical Meeting on Nuclear Reactor Thermal-Hydraulics (NURETH-11).* Avignon, France (October 2–6, 2005), paper 264.

Presentation to the MAAP Users Group by FAI, May 2005.

Comparison to Integral Experiments:
IE3. MB-2 LOFW and MSLBs with and without SGTR

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Scale/Scope of Experiment	Number of Sequences	Principal Source of Documentation
FAI	PWR, WLD	1	1–15 min	4.0.6	Steam generator, 0.8% power	2 LOFWs, 3 MSLBs	Conference proceedings (2005)

Major Code Models Compared and Review of Agreement

Model	Indicators	Agreement Based on Expert Review	Notes
Overall code	—	Very good agreement	The specific input parameters that were adjusted to obtain agreement were not identified in the paper.
Steam generator: two-region, U-tube	Pressure	Very good agreement	—
	Water level	Very good agreement	

Validation of Code Capabilities

Critical flow: break flow	Validated based on MSLB flow agreement

Comparison to Integral Experiments:
IE3. MB-2 LOFW and MSLBs with and without SGTR, continued

Conclusions from the Authors of the Benchmark

"In general, comparisons of the MAAP4 results with the MB-2 test results show that the MAAP4 code calculation is in agreement with the overall test responses for all five tests. This agreement indicates that a simple lumped volume approach and simple models of internal recirculation and void fraction profile can adequately simulate the response of a steam generator during these accident conditions. This conclusion is particularly relevant for the more challenging test of 100% MSLB. Herein, prediction of the substantial liquid discharge is key to a successful benchmark. The model accommodates the relevant physical processes of flow reversal and dynamic level swell."

Documentation

C. Paik and C. Henry, "Benchmarking of MAAP4 Steam Generator Model Against Westinghouse MB-2 Experiments," *The 11th International Topical Meeting on Nuclear Reactor Thermal-Hydraulics (NURETH-11).* Avignon, France (October 2–6, 2005), log number 322.
MAAP4 User's Manual [1]: Volume III-C, Rev. 0, February 2005.
Presentation to the MAAP Users Group by FAI, November 2004.

Comparison to Integral Experiments:
IE4. AP600 OSU SLOCAs and Failed PORVs

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Scale/Scope of Experiment	Number of Sequences	Principal Source of Documen-tation
FAI and Westing-house	PWR, AP600	1	"Short" and "long" but only relative time; actual time frame not in documentation	4.0.5 plus code change	Primary system with 1 loop and steam generators, 1/4 height scale	2 SLOCAs, 2 failed-open PORVs	Conference proceedings (2004)
Code change made to the calculations of heat transfer within the covered nodes of the core to allow oscillations in the two-phase level swell associated with steaming due to injection followed by subcooling (not included in the standard code; see the *issue for code development and user support* discussion that follows)							

Major Code Models Compared and Review of Agreement

Model	Indicators	Agreement Based on Expert Review	Notes
Overall code	—	Very good agreement	—
PWR primary system thermal hydraulics	Pressure and level	Very good agreement	Detailed agreement dependent on code change
	Water level in the pressurizer	Very good agreement	
	Water level in the vessel	Not available	
Steam generator: two-region, U-tube	Pressure	Very good agreement	—
	Water level	Very good agreement	

Comparison to Integral Experiments:
IE4. AP600 OSU SLOCAs and Failed PORVs, continued

Validation of Code Capabilities

Critical flow: pressurizer PORVs	Validated based on primary system response
Critical flow: break flow	Validated based on primary system response
PWR ECCS injection (passive AP600 and AP1000 systems)	Validated based on primary system response

Issue for Code Development and User Support

A code change was made to the subroutine that calculates the heat transfer within the covered nodes of the core (subroutine COVER) to allow oscillations in the two-phase level swell associated with steaming due to injection followed by subcooling, which then allows more injection. In the standard version of the code, these oscillations are suppressed to avoid numerical difficulties. The model deficiency affects only plants with injection that is driven solely by a gravity head (versus a differential gas pressure) such as the AP1000 and the ABWR; it was appropriate to model the oscillations in the benchmark sequences. The code change improved the detailed primary system water level agreement late in the transients after the primary system depressurized. Incorporating the change into the standard version of the code, primarily to improve calculations for sequences in which there is repeated core uncovery with intermittent injection, is under consideration.

Conclusions from the Authors of the Benchmark

"In general, comparisons of the MAAP4 results with the OSU test results show that the MAAP4 code calculation is in agreement with the overall test response for all four tests. This includes reactor coolant system including pressurizer, core makeup tank, accumulator, steam generators, and the IRWST. These benchmarking results demonstrate the use of MAAP4 to simulate a reactor coolant system response and the passive system performance during small LOCAs. These benchmarking results also show that it is essential to have an integral response of the reactor coolant system and the containment to model the AP600 passive core cooling."

Comparison to Integral Experiments:
IE4. AP600 OSU SLOCAs and Failed PORVs, continued

Documentation

C. Paik, R. Hammersley, and J. Scobel, "MAAP4 Benchmarking of AP600 OSU Experiments," *2004 Pacific Basin Nuclear Conference.* Honolulu, Hawaii (March 21–25, 2004), ANS paper 93495.
Presentation to the MAAP Users Group by FAI, November 2003.

Comparison to Integral Experiments:
IE5. Waltz Mill Ice Condenser SLOCA, MLOCA, and LLOCAs

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Versions	Scale/Scope of Experiment	Number of Sequences	Principal Sources of Documentation
FAI	PWR, WICE	1	No time scale	4.0.4, 4.0.6, 4.0.7	Ice condenser containment	4 LOCAs	MAAP4 User's Manual (1999); also code transmittal documents (2005, 2007)

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Containment	Pressure	Fair agreement; difficult to determine the extent and implications of the pressure differences because there are no scales on the plots (they are proprietary)	This benchmark applies to the generic containment model; the heat transfer to the ice is the driving force.

Validation of Code Capabilities

Heat transfer to ice	Validated based on containment pressure response and ice mass

Conclusions from the Authors of the Benchmark

"Comparing the MAAP4 ice condenser containment model with a spectrum of LOCA experiments shows that the MAAP4 characterization provides good agreement with the behavior for the various size LOCA conditions investigated, including long term decay heat added to the containment atmosphere. Furthermore, it shows that the MAAP4 mechanistic ice melt model provides a good characterization of the ice melt for a wide spectrum of accident conditions, including long term decay heat steam release. The model also provides a good representation of the ice melt drain temperature and lower compartment water temperature."

Comparison to Integral Experiments:
IE5. Waltz Mill Ice Condenser SLOCA, MLOCA, and LLOCAs, continued

Documentation

MAAP4 User's Manual [1]: Volume III-C, Rev. 0.2, September 1999. (using Rev. 4.0.4)
MAAP4 transmittal documents for Rev. 4.0.6 and Rev. 4.0.7 [12, 13]. (plotted results only, 2005 and 2007)

Comparison to Integral Experiments:
IE6. PNL Ice Condenser Heat Transfer

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Versions	Scale/Scope of Experiment	Number of Sequences	Principal Sources of Documentation
FAI	PWR, WICE	1	1 hr	4.0.4, 4.0.6, 4.0.7	Ice condenser containment: heat transfer to the ice	3 heat transfer experiments	MAAP4 User's Manual (1999); also code transmittal documents (2005, 2007)

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
None	—	—	Benchmark applies only to the ice condenser portion of the containment model, not to the generic containment model.

Notes and Recommendations for Users

The values of the heat transfer coefficient for natural convection and radiation in the ice condenser, input parameter HTADDI, that yield a good match between the calculated and experimental gas exit temperatures are relatively small (on the order of 1 W/m^2-K [0.176 Btu/ft^2-hr-F]). It is unknown why differences in the values of a factor of four influence the predicted gas temperatures to the large extent seen in the benchmark results.

The review team recommends that users with ice condenser plants evaluate the sensitivity of their sequence results to the ice condenser input parameters. Of particular importance for ice condensers is the time at which the ice melts and the properties of the gas and condensate exiting the ice condenser compartment because of their impact on the overall energy balance and on the hydrogen concentration in the containment.

Comparison to Integral Experiments:
IE6. PNL Ice Condenser Heat Transfer, continued

Issue for Code Development and User Support

The review team recommends that investigations be done to determine which parameters have the most influence on the heat transfer in the ice condenser and how sensitive the results are to the parameter values. The important output variables, particularly those that define the energy balance around the condenser (for example, temperatures and steam partial pressures), should be communicated to the users. These investigations should tie in to the existing benchmarks as well as any potentially new benchmarks. A particular item of interest is how the condensate temperature, which is an input to the benchmarks, affects the results. The large sensitivity of the input heat transfer coefficient HTADDI on the gas exit temperatures, as seen in this benchmark, is also of interest.

Validation of Code Capabilities

Heat transfer to ice	Validated based on the gas (steam and air) exit temperatures

Comparison to Integral Experiments:
IE6. PNL Ice Condenser Heat Transfer, continued

Conclusions from the Authors of the Benchmark

"Comparison of the MAAP ice condenser containment model with a spectrum of inlet conditions to the ice condenser shows good agreement for the thermal-hydraulic response of the test performed. This is true for those experiments utilizing high steam partial pressures as well as those with a low steam partial pressure. Furthermore, the imposed gas flow rate is equivalent to the velocity through the ice bed that would be promoted by a single train of ice condenser recirculation air fans. Therefore, the behavior observed in these experiments and the good agreement observed between the experimental measurements and the MAAP model develop a level of confidence that the MAAP calculation is a good representation of the containment response for a spectrum of accident sequences."

Documentation

MAAP4 User's Manual [1]: Volume III-C, Rev. 0, June 1999. (using Rev. 4.0.4)
MAAP4 transmittal documents for Rev. 4.0.6 and Rev. 4.0.7 [12, 13]. (plotted results only, 2005 and 2007)

Comparison to Integral Experiments:
IE7. CSTF Containment Heat Transfer

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Versions	Scale/Scope of Experiment	Number of Sequences	Principal Sources of Documentation
FAI	PWR, WICE	1 and 2	1 hr	4.0.4, 4.0.7	Forced and counter-current (natural) convection in containment	7 gas circulation experiments	MAAP4 User's Manual (1999); also, code transmittal documents (2005, 2007)

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Containment	Pressure	Very good agreement	Applies to the generic containment model (not to heat transfer to ice)

Conclusions from the Authors of the Benchmark

"These comparisons of the MAAP Generalized Containment Model with the spectrum of test conditions considered for the simulated ice condenser containment in the CSTF vessel show that the MAAP model provides an effective representation of the containment response under both natural circulation and forced flow conditions. Good agreement between the calculated and measured behaviors is obtained for all of the test conditions examined in the CSTF test program and therefore the user has the confidence that the MAAP model can follow the influences of light gas, such as hydrogen, being released to the containment as a consequence of postulated accident sequences. Furthermore, the sensitivity studies performed illustrate the importance of including representations for both forced and natural circulation flows between the containment compartments, including natural circulation counter-current flows through the partially opened doors in the CSTF simulation. Since the expected ice condenser response to small break LOCA conditions is to have lower inlet doors only partially opened, this potential for examining both the forced flow and natural circulation flow is important. Furthermore, it is particularly important to assess the potential for experiencing "flooding" of the gas flow in the partially opened doors as a result of the imposed recirculation flow by the air return fans."

Comparison to Integral Experiments:
IE7. CSTF Containment Heat Transfer, continued

Documentation

MAAP4 User's Manual [1]: Volume III-C, Rev. 0, June 1999. (using Rev. 4.0.4)
MAAP4 transmittal documents for Rev. 4.0.7 [12, 13]. (plotted results only, 2007)

Comparison to Integral Experiments:
IE8. HDR Containment Mixing: E11.2 for SLOCA, T31.5 for LLOCA

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Versions	Scale/Scope of Experiment	Number of Sequences	Principal Sources of Documentation
FAI	Generic	1 and 2	1–22 hr	4.0.0, 4.0.2, 4.0.6, 4.0.7	Large-scale containment mixing	1 SLOCA, 1 LLOCA	Journal paper (1999), MAAP4 User's Manual (1994), conference proceedings (1991)

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Containment	Pressure	Very good agreement	The benchmark uses the subnodal physics option in the containment model.

Note

The HDR containment is more highly nodalized and is more vertically oriented than the containments for commercial reactors. The subnodal physics model in MAAP4 is particularly appropriate for this type of configuration, and it contributed to the very good agreement between the code predictions and the data. The subnodal physics model will have a smaller impact for less nodalized containments. MAAP4 is known to slightly over-predict the pressure in the containment. The subnodal physics model will slightly over-predict the pressure even more (essentially another "adder"), which is conservative.

Comparison to Integral Experiments:
IE8. HDR Containment Mixing: E11.2 for SLOCA, T31.5 for LLOCA, continued

Conclusions from the Authors of the Benchmark

E11.2 paper: "The MAAP4 code over-predicted the peak pressure by 0.25 bar. On the other hand, the MAAP4 code correctly predicted the thermal and hydrogen stratification observed in the E11.2 test. In addition, the intricate gas turnover phenomena in the dome region during the external spray time period was also correctly predicted by the code. Subnodal physics implemented in the MAAP4 containment model are responsible for the capability to predict the hydrogen and thermal stratification that were observed in the HDR E11.2 test."

T31.5 conference proceedings: "1) MAAP predicted the pressure accurately. 2) MAAP substantially over-predicted the temperature in the source room, indicating a non-homogeneous condition in the source room. MAAP uses lumped parameter models in each node. 3) In general, MAAP did well in predicting temperatures above the break location. However, for lower nodes where natural circulation plays an important role in distributing hot gas into the lower part of the containment, MAAP predicted much steeper temperature gradients. 4) MAAP predicted better mixing than indicated by data. As a consequence, the hydrogen concentration in the lower node rose more rapidly than indicated by data. Also, MAAP predicted complete homogenization after about 18000 sec. Data indicates stratification of hydrogen persisting up to the end of the transient."

Documentation

S. Lee, C. Paik, R. Henry, M. Epstein, and M. Plys, "Benchmark of the Heiss Dampf Reaktor E11.2 Containment Hydrogen-Mixing Experiment Using the MAAP4 Code," *Nuclear Technology.* Vol. 125, p. 182–196 (1999). (presumed to be Rev. 4.0.2)
MAAP4 User's Manual [1]: Volume III, Section 2, Rev. 0, May 1994. (using Rev. 4.0.0)
C. Paik, S. Lee, and M. Plys, "MAAP Prediction of the HDR T31.5 Containment Experiment," *National Heat Transfer Conference.* AIChE, Minneapolis, Minnesota (1991). (presumed to be Rev. 4.0.0)
MAAP4 transmittal documents for Rev. 4.0.6 and Rev. 4.0.7 [12, 13]. (plotted results only, 2005 and 2007)

Comparison to Integral Experiments:
IE9. ISP-35 Containment Mixing

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Scale/Scope of Experiment	Number of Sequences	Principal Source of Documentation
Japanese consortium	Generic	1 and 2	30 min	Not specified (estimated to be 4.0.0)	Containment mixing	1 contain-ment experiment	Conference proceedings (1995)

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Containment	Pressure	Very good agreement	The authors identified that the modeling of counter-current flow through junctions in MAAP4 is a primary reason why the code successfully simulates the gas distribution in the containment.

Conclusions from the Authors of the Benchmark

"The international standard problem ISP-35 for hydrogen mixing in a containment vessel has been analyzed using the MAAP4 code. The MAAP4 code has obtained good results for simulating the helium gas concentration in each compartment, even in a dead-end compartment such as the pressurizer compartment. In general, the analytical results for the pressure in the containment vessel, the gas temperature, and the helium concentrations in each compartment agree very well with the test results. Therefore, it has been verified that the MAAP4 code provides a good simulation of the hydrogen mixing problem."

Comparison to Integral Experiments:
IE9. ISP-35 Containment Mixing, continued

Documentation

H. Iizuka, Y. Furukawa, O. Kawabata, J. Uchida, Y. Narumiya, N. Hayashi, T. Sakai, and T. Yamauchi, "An Analysis of Hydrogen Mixing and Distribution Problem ISP–35 Using the MAAP4 Code," *International Conference on Probabilistic Safety Assessment Methodology and Applications.* KAERI, Seoul, Korea (1995). (presumed to be Rev. 4.0.0)

Comparison to Integral Experiments:
IE10. Semiscale in 1992 MAAP3B Qualification Studies–Various PWR Sequences

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Scale/Scope of Experiments	Number of Sequences	Principal Source of Documentation
GKA	PWR WLD	1	5 min–5 hr	MAAP3B Rev. 16	Primary system with 1 loop and steam generator, full height, 1/1705 volume scale	4 LOCAs, 2 LOOPs, 3 SGTRs	EPRI technical report (1992)

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Good agreement with MAAP3B	The benchmark is generally but not specifically applicable to MAAP4 because it was done with MAAP3B, and it is not feasible to extract details from the existing information.

Documentation

1992 MAAP Thermal-Hydraulic Qualification Studies [2, 5].

Comparison to Integral Experiments:
IE11. FIST in 1992 MAAP3B Qualification Studies–Various BWR Sequences

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Versions	Scale/Scope of Experiments	Number of Sequences	Principal Source of Documentation
GKA	BWR	1	8 min–50 min	MAAP3B Rev. 6	Primary system, full height, 1/624 volume scale	1 MLOCA, 2 LOFWs	EPRI technical report (1992)

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Good agreement with MAAP3B	The benchmark is generally but not specifically applicable to MAAP4 because it was done with MAAP3B, and it is not feasible to extract details from the existing information.

Documentation

1992 MAAP Thermal-Hydraulic Qualification Studies [2, 5].

Comparison to Integral Experiments:
IE12. MIST in 1992 MAAP3B Qualification Studies–PWR SLOCA Sequences

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Scale/Scope of Experiments	Number of Sequences	Principal Source of Documentation
GKA	PWR B&W	1	1 hr, 12 hr	MAAP3B Rev. 16	Primary system with 2 loops and steam generators, full height, 1/817 volume scale	2 SLOCAs	EPRI technical report (1992)

Major Code Models Compared and Review of Agreement

Model	Indicator	Agreement Based on Expert Review	Notes
Overall code	—	Good agreement with MAAP3B	The benchmark is generally but not specifically applicable to MAAP4 because it was done with MAAP3B, and it is not feasible to extract details from the existing information.

Documentation

1992 MAAP Thermal-Hydraulic Qualification Studies [2, 5].

Comparison to Separate Effects Experiments:
SE1. MAAP4 Function VFVOL–Void fraction and boiled-up level in the core compared to THTF experiments (with minor comparisons to FLHT4 and IIST)

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Principal Source of Documentation
FAI	Generic	1 and 2	Not applicable	All (no change with version)	MAAP4 User's Manual (2007)

Code Model Compared and Validation

Model	Indicator	Validation
Voiding in the core	Void fraction	Subroutine VFVOL is validated based on good agreement of the calculated average void fraction as a function of steam superficial velocity with values generated from the THTF experiments, using the value of 2 for the drift flux proportionality constant (input parameter FVOL).

Conclusions from the Authors of the Benchmark

Presentation: "Benchmarking of the MAAP subroutine VFVOL with the information from all three of these experiments demonstrates good agreement with the data reported from these facilities."

Documentation

MAAP4 User's Manual [1]: Volume III-D, Rev. 0, April 2007.
Presentation to the MAAP Users Group by FAI, December 2005.

Comparison to Separate Effects Experiments:
SE2. MAAP4 Subroutine HLNC–Hot leg circulation flow and heat transfer to the steam generator compared to Westinghouse 1/7th scale experiments (also referred to as SF_6 and Stewart experiments)

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Principal Source of Documentation
FAI (manual), EPRI (report)	PWR Westinghouse	1 and 2	Not applicable	4.0.5 (4.0.2 in report)	MAAP4 User's Manual (2003), EPRI technical report (1997)

Code Model Compared and Validation

Model	Indicators	Validation
HLNC	Combined counter-current and unidirectional flow in the hot leg and heat transfer to the steam generator tubes	Subroutine HLNC is validated based on good agreement of the flow rates, fluid temperatures, and heat transfer to the tubes for various experimental configurations, using the value of 0.115 for the flow correlation coefficient (input parameter FWHL) and values in the range of 0.2 to 0.45 for the fraction of tubes carrying flow from the inlet plenum to the outlet plenum of the steam generator (input parameter FAOUT).

Note

Improvements to the model identified in the Rev. 4.0.2 work were incorporated into Rev. 4.0.3.

Comparison to Separate Effects Experiments:
SE2. MAAP4 Subroutine HLNC–Hot leg circulation flow and heat transfer to the steam generator compared to Westinghouse 1/7th scale experiments (also referred to as SF_c and Stewart experiments), continued

Conclusions from the Authors of the Benchmark

Paraphrased from manual: The model and data agree for specific values of FA_{out}, the fraction of tubes carrying the out-flow from the U-tube steam generators.

Report: "Representative comparisons of the predictions of this model to measured flow rates in some of the experiments are given ...[including] results as a function of the fraction of tubes which bear flow in the "out" direction from the inlet plenum to the outlet plenum. The rather good performance of the model, and the relative insensitivity of the flow rates to changes in input parameters such as this fraction, afford confidence in the code's predictions."

Documentation

MAAP4 User's Manual [1]: Volume II, HLNC description, Rev. 0.2, January 2003.

Steam Generator Management Project, Risks from Severe Accidents Involving Steam Generator Tube Leaks or Ruptures, Volume 1: Risk Assessment. EPRI, Palo Alto, CA: 1997. TR-106194-V1. (prepared by Polestar, Dames & Moore, FAI, and Structural Integrity Associates)

Comparison to Separate Effects Experiments:
SE3. MAAP4 Subroutine FLOEXP–Pressurizer model compared to Marviken, FAI and GE vessel blowdown experiments

Author	Plant Type	PRA Level	Time Frame	MAAP4 Code Version	Principal Source of Documentation
FAI	PWR	1	Not applicable	4.0.0 with Marviken and FAI experiments; 4.0.7 with GE experiments	MAAP4 User's Manual (2003 and anticipated 2010)

Code Model Compared and Validation

Model	Indicators	Validation
Pressurizer control volume, including boiled-up level and critical flow	Pressure, level, gas volume, break flow	Subroutine FLOEXP is validated based on good agreement of the calculated quantities with the experimental data. The validation applies to all of the critical flow calculations because the same model is used.

Note

The discharged water is steam in the Marviken experiment, two-phase in the FAI experiments, and liquid and two-phase in the GE large vessel experiments.

Conclusions from the Authors of the Benchmark

Regarding the Marviken experiments: "shows the actual and predicted vessel pressure in the Marviken vessel as a function of time. The FLOEXP prediction agrees well with the experimental data."

Regarding the FAI experiments: "the predicted pressure closely matches the actual pressure, and the gas volume is slightly over-predicted."

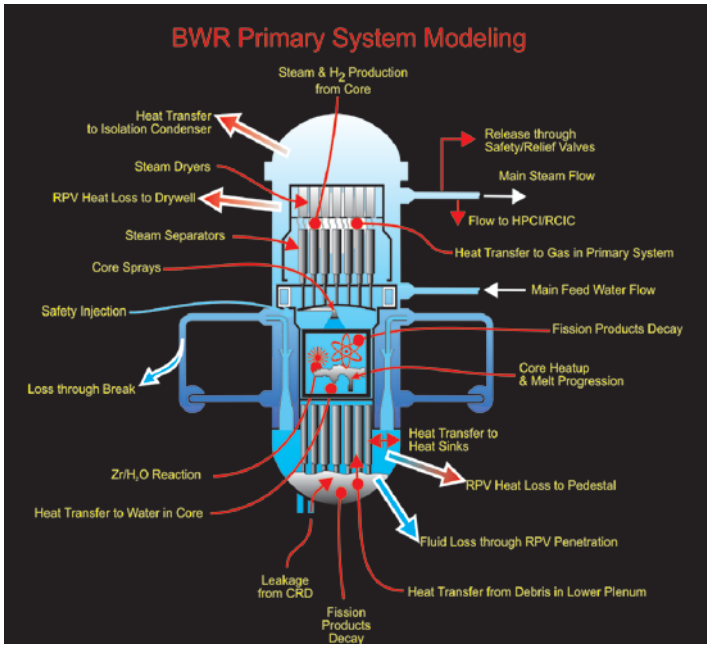
Regarding the GE experiments: "the calculated pressure and the level swell were well compared against the data."

ATTACHMENT 21

Fauske & Associates, LLC, *MAAP (Modular Accident Analysis Program)*, http://www.fauske.com/pdf/MAAP.pdf

MAAP
(Modular Accident Accident Analysis Program)

The new MAAP4 computer code (including the MAAP4-GRAAPH graphical interface) provides a flexible, efficient, integrated tool for evaluating the in-plant effects of a wide range of postulated accidents and for examining the impact of operator actions on accident progressions.



Background

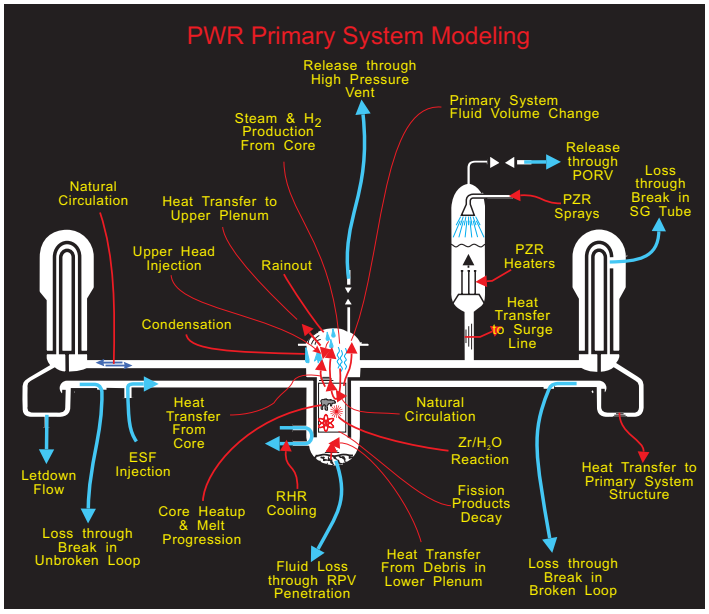
Following the accident at Three Mile Island, the nuclear power industry developed the MAAP computer code as part of the industry degraded core rulemaking (IDCOR) program. Upon dissolution of IDCOR, ownership of the modular code, which features one version for PWRs and one for BWRs, transferred to EPRI, and a period of enhancements began. MAAP has been developed and maintained by Fauske & Associates since the beginning of the code in 1981.

Objective

To provide a useful methodology for analyzing the in-plant effects of a wide range of postulated accidents and possible accident management actions for current design and ALWRs.

Approach

The project team revised the MAAP-3B code to include major model improvements in areas of core heat-up, lower plenum phenomenology, corium-concrete interactions, containment and auxiliary-building thermal hydraulics, and hydrogen combustion. Furthermore, models were added to characterize actions that could stop the accident, i.e., in-vessel cooling, external cooling of the reactor vessel, and ex-vessel cooling. Moreover, the team implemented mathematical solution techniques to maintain a quick-running code suitable for extensive accident screening and parameter sensitivity analysis applications. As part of the development, the code underwent a complete design review.



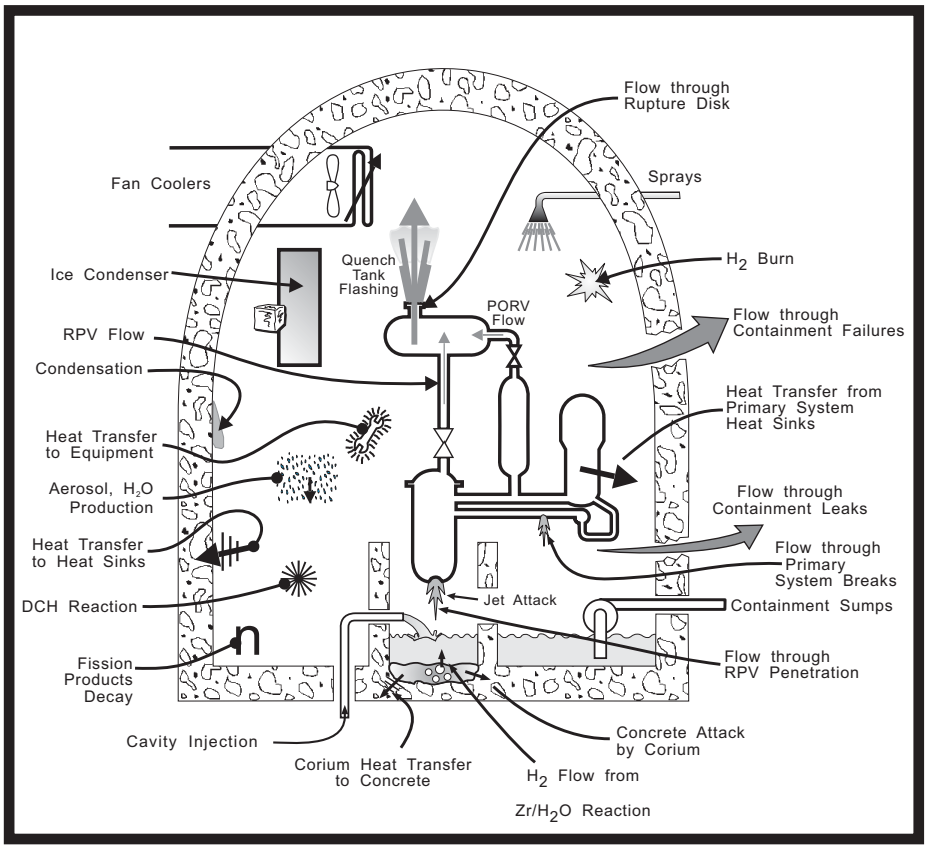
FAUSKE & ASSOCIATES, LLC

World Leader in Nuclear and Chemical Process Safety

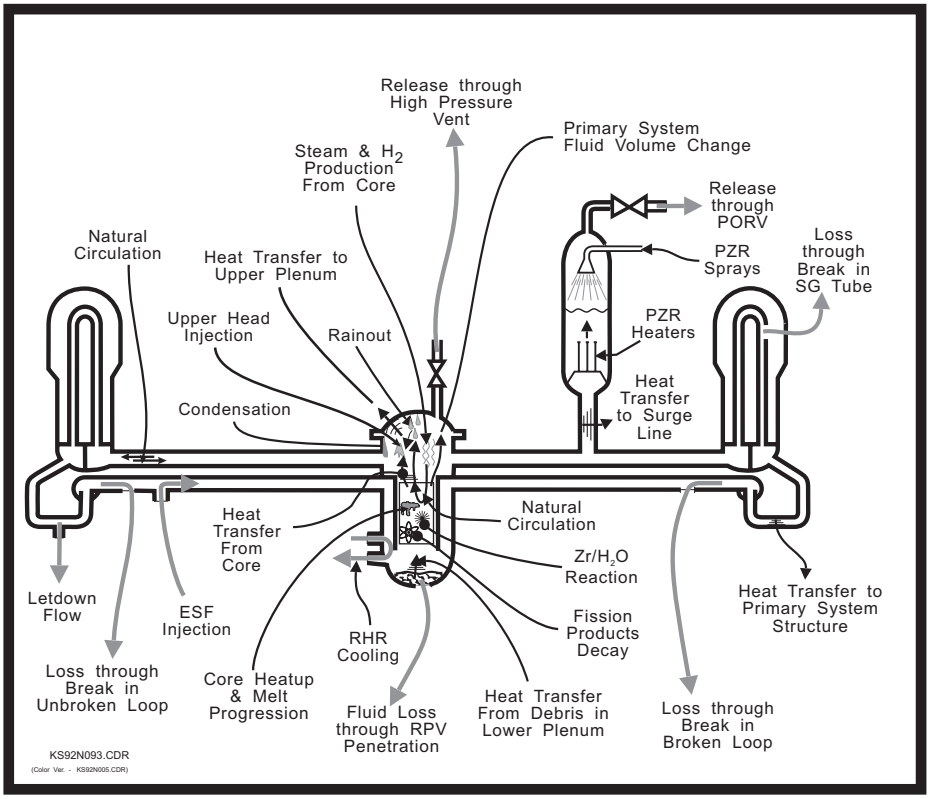
16W070 83rd Street • Burr Ridge, Illinois 60527

(877) Fauske1 or (630) 323-8750 • Fax: (630) 986-5481 • E-Mail: Info@Fauske.com • Fauske.com

BWR Primary System Modeling



PWR Primary System Modeling



Results

Both PWR and BWR versions of the code can predict the progression of hypothetical accident sequences from a set of initiating events to either a safe, stable, coolable state or to an impaired containment and depressurization. The code, which features restart capability as well as the MAAP4-GRAAPH graphical interface to maximize input and output flexibility, evaluates a wide spectrum of phenomena including steam formation; core heat-up; cladding oxidation and hydrogen evolution; vessel failure; corium-concrete interactions; ignition of combustible gases; fluid entrainment by high-velocity gases; and fission-product release, transport, and deposition. The code also addresses important engineered safety systems and allows a user to model operator interventions. Code documentation consists of four volumes: volume 1 provides general user guidance; volume 2 treats in detail the code's structure, phenomenological modeling, and numerical algorithms, volume 3 documents the integral benchmarks, and volume 4 includes the user's manuals for MAAP4-GRAAPH and MAAP4-DOSE (where applicable).

For more information on the MAAP Code, please contact us:

Info@Fauske.com
877-Fauske1 US Toll Free
(630 323-8750
Fauske.com

ATTACHMENT 22

Letter from Gary M. Holahan, NRC, to Theodore U. Marston, EPRI
(Dec. 4, 2001)

December 4, 2001

Theodore U. Marston
Vice President & Chief Nuclear Officer
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94304-1395

Dear Mr. Marston:

I am writing regarding the use of the Modular Accident Analysis Program (MAAP) computer code in the reactor licensing process, and the associated NRC staff reviews.

NRC and EPRI met on December 15, 2000, to discuss the MAAP code. EPRI and the Nuclear Energy Institute agreed to consider a future review of MAAP by the staff. EPRI also agreed to provide the staff with the MAAP user guidance to help the staff understand the code. EPRI provided a list of MAAP guidance documents (April 7, 2001, e-mail from G. Vine), but we are still awaiting a decision by EPRI regarding the review of MAAP.

Until the MAAP code is submitted to the NRC for review and accepted for specific applications, please be advised that we intend to take the following approach in reviewing licensee submittals that rely on MAAP.

- For each plant-specific submittal that relies on MAAP for a design-basis application, we will review those portions of the code relevant to the application, as we would any other licensing basis code. The review will generally be limited to identifying the critical MAAP models, assumptions, and code input used in the application, verifying the validity of the models by benchmarking the code with experiments and other codes, and assessing the integration of the MAAP results (e.g., containment pressure and temperature history) into the analysis package. We may supplement this review by performing audit calculations (using staff codes) to confirm the results. The approval of the analysis will be limited to that specific licensing action (i.e., the approval will not be an approval of MAAP.) The review costs will be billable to the licensee making the application.

  This approach will also be used for plant-specific submittals that rely on MAAP for severe accident applications, when we consider a technical review appropriate.

- For MAAP applications submitted via topical reports, a similar review approach will be taken. The scope and depth of the review will depend on the particular application, and could be based on a phenomena identification and ranking (PIRT) evaluation for each application. Due to the broad scope of the MAAP code, any code review and acceptance will be limited to that specific type of application and be conditioned upon use of the code in a prescribed manner. The product of the review would be a safety evaluation report on the acceptability of the specific code version for the subject application. The review costs will be billable to the organization submitting the topical report.

Two particular types of MAAP applications deserve specific mention: (1) the use of MAAP to support the development of PRA success criteria, and (2) the use of MAAP to support urgent license amendment requests, e.g., when a quick approval is needed for a plant to restart. With regard to the first application, we stated in a July 6, 1993, letter to NUMARC, that the results of a contractor review of the MAAP3.0B did not call into question the overall adequacy of the code for use in individual plant examinations (which typically included development of Level 1 PRA success criteria), and that licensees bear the burden of proof that they have applied the code properly. While we do not intend to routinely evaluate PRA success criteria methodology as part of risk-informed license amendment reviews, we expect that in some situations a limited assessment of the use of MAAP for success criteria will be warranted. Regarding the second application, in the absence of a generic review and approval of the MAAP code as a topical report, the staff will not generally accept MAAP analyses without additional technical justification and confirmatory calculations (including licensee-supplied confirmatory calculations using other codes), because the staff will not be in a position to perform the necessary review on short notice.

The NRC staff is willing to meet with EPRI to discuss possible MAAP applications for which a detailed code review and staff acceptance may be useful. If you have any questions, please feel free to call me at 301-415-2884.

Sincerely,

Gary M. Holahan, Director
Division of Systems Safety and Analysis
Office of Nuclear Reactor Regulation

cc: Gary Vine

DISTRIBUTION: JWermiel JHannon SCollins AThadani LOlshan PBoehnert Dmodeen,NEI

SEE PREVIOUS CONCURRENCE*

SPSB:DSSA	SPSB:DSSA	SPSB:DSSA	D/DAF/OCFO	NRR:DSSA
RPalla	MRubin	RBarret	CTurner	GHolahan
10/24/01	10/31/01	11/01/01	11/15/01	11/27/01

NRR:ADPT	Tech Ed	D/DSSA-SIGNED
BSheron	PKleene	GMHolahan
11/29/01	10/22/01	12/04/01

ATTACHMENT 23

Excerpt from EPRI Report 1013492, "Probabilistic Risk Assessment Compendium of Candidate Consensus Models" at 2-3 (2006)

ELECTRIC POWER
RESEARCH INSTITUTE

Probabilistic Risk Assessment Compendium of Candidate Consensus Models

Technical Report

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

ERIN Engineering and Research, Inc.

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

Probabilistic Risk Assessment Compendium of Candidate Consensus Models

1013492

Final Report, August 2006

EPRI Project Manager
K. Canavan

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1395 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

CITATIONS

This report was prepared by

ERIN Engineering and Research, Inc.
2105 S. Bascom Ave., Suite 350
Campbell, CA 95008

Principal Investigators
E. T. Burns
D. E. True

This report describes research sponsored by the Electric Power Research Institute (EPRI).

The report is a corporate document that should be cited in the literature in the following manner:

Probabilistic Risk Assessment Compendium of Candidate Consensus Models. EPRI, Palo Alto, CA: 2006. 1013492.

2.2 Consensus Model

A definition of a consensus model is not presented in the ASME PRA Standard or in RG 1.200. In order to facilitate communication and consistency in the application of the definition for key source of uncertainty, *consensus approach or model* is defined as:

- An available, published model or approach that has been used or accepted by the regulator in previous risk-informed applications
  or
- An industry best practice that has been peer reviewed by an appropriate stakeholder group, and its implementation in the subject PRA has been subject to peer review

Consensus models and approaches may both prove useful in PRA development and implementation.

Consensus models can span a wide spectrum as shown in the following:

- Well-defined data to be used in a single model characterization (for example, reactor protection system [RPS] black box reliability from NUREG/CR-5500)
- A methodology such as the technique for human error rate prediction (THERP) that can be applied with substantial judgment in its method of application
- The use of a computer code such as Modular Accident Analysis Program (MAAP) for success criteria
- The use of Idaho National Engineering and Environmental Laboratory (INEEL) common-cause data to characterize intrasystem common-cause effects

Each of these candidate consensus models can have varying degrees of flexibility in its application and yet retain the characteristic of being a consensus model.

The PRA peer review is tasked with the job of ensuring that the application of the consensus model is done within the constraints and technical underpinnings that support the consensus model. This peer review is considered a necessary part of the process of ensuring that key modeling uncertainties are minimized.

2.3 Output

The project provides a compendium of both the consensus models that are agreed will address individual ASME PRA supporting requirements and useful models or approaches that are documented and have proven to be generally acceptable for current generation PRAs but may not have the complete pedigree that is expected of the consensus models.

ATTACHMENT 24

Excerpt from NEA Committee on the Safety of Nuclear Installations, NEA/CSNI/R(2007)16, *Recent Developments in Level 2 PSA and Severe Accident Management* (Nov. 2007)

Unclassified **NEA/CSNI/R(2007)16**

Organisation de Coopération et de Développement Economiques
Organisation for Economic Co-operation and Development **15-Nov-2007**

English text only

NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

NEA/CSNI/R(2007)16
Unclassified

RECENT DEVELOPMENTS IN LEVEL 2 PSA AND SEVERE ACCIDENT MANAGEMENT

NOVEMBER 2007

English text only

JT03236099

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 30 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The Commission of the European Communities takes part in the work of the OECD.

OECD Publishing disseminates widely the results of the Organisation's statistics gathering and research on economic, social and environmental issues, as well as the conventions, guidelines and standards agreed by its members.

* * *

This work is published on the responsibility of the Secretary-General of the OECD. The opinions expressed and arguments employed herein do not necessarily reflect the official views of the Organisation or of the governments of its member countries.

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full member. NEA membership today consists of 28 OECD member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Portugal, Republic of Korea, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The Commission of the European Communities also takes part in the work of the Agency.

The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made of senior scientists and engineers, with broad responsibilities for safety technology and research programmes, and representatives from regulatory authorities. It was set up in 1973 to develop and co-ordinate the activities of the NEA concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations.

The committee's purpose is to foster international co-operation in nuclear safety amongst the OECD member countries. The CSNI's main tasks are to exchange technical information and to promote collaboration between research, development, engineering and regulatory organisations; to review operating experience and the state of knowledge on selected topics of nuclear safety technology and safety assessment; to initiate and conduct programmes to overcome discrepancies, develop improvements and research consensus on technical issues; to promote the co-ordination of work that serve maintaining competence in the nuclear safety matters, including the establishment of joint undertakings.

The committee shall focus primarily on existing power reactors and other nuclear installations; it shall also consider the safety implications of scientific and technical developments of new reactor designs.

In implementing its programme, the CSNI establishes co-operate mechanisms with NEA's Committee on Nuclear Regulatory Activities (CNRA) responsible for the programme of the Agency concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with NEA's Committee on Radiation Protection and Public Health (CRPPH), NEA's Radioactive Waste Management Committee (RWMC) and the NEA's Nuclear Science Committee (NSC) on matters of common interest.

Many of the computer codes adopted for severe accident analysis in member states were identified and described in the original report, together with a summary of the status of validation and benchmarking activities these codes have undergone. Changes in national requirements and emphasis also resulted in the discontinuation of the support for some of these codes. As is reflected in the original report, many of the key physical processes modelled in the separate phenomena codes are similarly adopted in the integrated PSA codes. This has led to a scaling down or termination of development effort in these codes. More recently, driven by the demand from the many Level 2 PSAs performed worldwide, for applications to both existing plants and future designs, the integrated codes in particular have undergone further model improvement and validation/ benchmarking activities. A recent notable code initiative is the development of the Franco-German integrated code ASTEC which is based on some of the separate phenomena codes (e.g. ESCADRE, RALOC, FIPLOC, ICARE2 and IODE) listed in the original report.

Current application in Level 2 PSAs has tended to make use of the integral codes for providing the baseline analysis of accident sequences with additional supplementary analysis provided by other standalone codes for the detailed evaluation of certain phenomena, if required. Analysis involving standalone codes is also performed to support uncertainty analysis. The update in this document is restricted to recent development in integral codes and includes: MAAP, MELCOR, ASTEC and THALES. The general model description for these codes is updated in Appendix A. The assessment status for these codes is updated and summarised in Section 3.3.1. A summary is also provided in Section 3.3.2 on some recent and ongoing international validation effort involving some of the separate phenomena code.

3.3.1 Assessment status of integral codes

Assessment status of MAAP: Many comparisons between the MAAP code and separate effects tests, integral experiments, actual plant transients, and accidents have been performed to illustrate the performance of individual models and to provide confidence in the MAAP integral results. The assessment matrix listed in Table 3.2 shows the experimental benchmarking status of the MAAP computer code [3.14]. It is seen that the various code versions (entries in the matrix refer to MAAP version number) have been compared to several separate effects and integral experiments. These include: CORA and PHEBUS (core damage); LOFT FP-2 (integral severe accident test); ABCOVE (aerosol behaviour); CSE (containment spray); COPO (molten pool heat transfer); FARO (debris quenching); Surtsey IET (DCH); SWISS, SURC-4, ACE, KfK BETA (core-concrete interaction); NUPEC mixing tests; Marviken, FAI, and GE vessel blowdown tests; and HDR containment experiment, among many others. The current version of the code, MAAP 4 [3.15], has also been benchmarked against the TMI-2 accident. This comparison study shows that MAAP4 provides a reasonable simulation of the TMI-2 accident in terms of the system response prior to core uncovery, during core degradation, following core reflood, and the lower head behaviour after 224 minutes. These are all severe accident processes that are essential for application of computer codes for decisions related to design, operations, emergency operating procedures, and accident management.

The comparison of MAAP4 calculations with the HDR T31.5 experimental data showed that the pressure was predicted accurately, but the local prediction of the temperature was not as good since the code uses lumped parameter models [3.16]. The MAAP4 code predictions of the NUPEC mixing tests showed good agreement with the experimental data, and specifically, the gas concentration comparisons were encouraging [3.17]. In general, the PHEBUS FPT0 test results were in good

ATTACHMENT 25

Excerpt from Kenneth D. Kok, Ed., *Nuclear Engineering Handbook* (2009)

Nuclear Engineering Handbook

Edited by

Kenneth D. Kok

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Printed in the United States of America on acid-free paper
10 9 8 7 6 5 4 3 2 1

International Standard Book Number: 978-1-4200-5390-6 (Hardback)

Library of Congress Cataloging-in-Publication Data

Nuclear engineering handbook / editor, Kenneth D. Kok.
p. cm. -- (Mechanical engineering series)
Includes bibliographical references and index.
ISBN 978-1-4200-5390-6 (hard back : alk. paper)
1. Nuclear engineering--Handbooks, manuals, etc. I. Kok, Kenneth D. II. Title. III. Series.

TK9151.N834 2009
621.48--dc22 2009014909

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

- Severe accident phenomenology such as high-pressure melt ejection (HPME) leading to direct containment heating (DCH), in-vessel steam explosion (IVSE) leading to alpha-mode containment failure, ex-vessel steam explosion (EVSE) potentially leading to vessel relocation, hydrogen burn, liner melt-though, and basemat melt-through
- Source term evaluation and categorization, e.g., LERF
- Containment thermal hydraulic (T/H) response during severe accident progression
- Examples include containment failure modes (early versus late), fragility curves, and failure mechanisms

The most commonly used Level-II PRA tools include CAFTA for fault tree analysis, ETA-II code for containment analysis, and the modular accident analysis program (MAAP) for severe accident simulation. The MAAP code is also used for equipment success criteria development, although some PRA practitioners use the RELAP code for this purpose.

16.3.5 Level-III PRA

The intent of Level-III PRA is to assess:

- Radionuclide releases to the environment (radiological dose assessment)
- Nuclear aerosol plume dispersion models
- Risk to the public health including early and late fatalities

The most commonly known Level-III PRA tools include the CRAC code and the MACCS code.

The plant-specific PRA model contains key elements such as:

(1) Accident initiators based on plant's specific design. These are called special initiators such as loss of offsite power (LOOP) and loss of service water.
(2) Accident sequences based upon expected system responses and operator actions following plant procedures (e.g., EOPs, AOPs, and plant-specific severe accidents guidelines).
(3) System models (such as MFW, AFW, HPSI, LPSI, and SW) that represent installed system designs, and their support systems.
(4) Equipment failure rates based upon plant failure data, generic historical data, or a combination of both.
(5) Maintenance unavailabilities based on plant maintenance procedures, frequencies, and practices.
(6) Human error rates calculated using plant-specific procedures and simulator results.

16.3.6 Uses of PRA

Nuclear power plants risk practitioners use PRA methods and tools for:

- Identifying plant risks and vulnerabilities
- Identifying risk-significant SSCs and, hence, help focusing the plant limited resources on what is critical to plant safety

ATTACHMENT 26

Excerpts from NUREG-1437, Supp. 47, "Generic Environmental Impact Statement for License Renewal of Nuclear Plants: Columbia Generating Station – Final Report, Vol. 2, App. F (Apr. 2012)

F U.S. NUCLEAR REGULATORY COMMISSION STAFF EVALUATION OF SEVERE ACCIDENT MITIGATION ALTERNATIVES FOR COLUMBIA GENERATING STATION IN SUPPORT OF LICENSE RENEWAL APPLICATION REVIEW

F.1 Introduction

Energy Northwest, formerly known as Washington Public Power Supply System (WPPSS), submitted an assessment of severe accident mitigation alternatives (SAMAs) for the Columbia Generating Station (CGS), formerly known as Washington Nuclear Plant 2 (WNP-2), as part of the Environmental Report (ER) (EN, 2010). This assessment was based on the most recent CGS probabilistic safety assessment (PSA) available at that time, a plant-specific offsite consequence analysis performed using the MELCOR Accident Consequence Code System 2 (MACCS2) computer code (NRC, 1998), and insights from the CGS individual plant examination (IPE) (Parrish, 1994) and individual plant examination of external events (IPEEE) (Parrish, 1995). In identifying and evaluating potential SAMAs, Energy Northwest considered SAMA candidates that addressed the major contributors to core damage frequency (CDF) and population dose at CGS, as well as SAMA candidates for other operating plants that have submitted license renewal applications (LRAs). Energy Northwest identified 150 potential SAMA candidates. This list was reduced to 28 SAMA candidates by eliminating the following SAMAs that are not applicable to CGS:

- SAMAs with design differences
- SAMAs that have already been implemented at CGS
- SAMAs whose estimated implementation costs would exceed the dollar value associated with eliminating all severe accident risk at CGS
- SAMAs that are related to a non-risk significant system and, therefore, have a very low benefit
- SAMAs that are similar in nature and can be combined with another SAMA candidate

Energy Northwest assessed the costs and benefits associated with each of the remaining SAMA candidates and concluded in the ER that three of the candidate SAMAs evaluated are potentially cost-beneficial.

Based on a review of the SAMA assessment, the U.S. Nuclear Regulatory Commission (NRC) issued a request for additional information (RAI) to Energy Northwest by letters dated July 1, 2010 (Doyle, 2010a), November 10, 2010 (Doyle, 2010b), December 2, 2010 (Doyle, 2010c), and March 10, 2011 (Doyle, 2011a). Key questions concerned the following:

- changes to the internal, fire, and seismic events PSA models since the SAMA analysis was performed
- internal and external reviews of the PSA models since the IPE
- the relationship between the containment event trees (CETs) used for the internal, fire, and seismic events Level 2 analyses
- the process for selecting the representative Modular Accident Analysis Program (MAAP) case for each release category

- population, meteorological, and economic assumptions used in the Level 3 analysis
- the use of internal, fire, and seismic events importance analysis in identifying plant-specific SAMAs
- the use of industry SAMA analyses in identifying SAMAs applicable to CGS
- the potential impact of internal, fire, and seismic events PSA model uncertainty on the SAMA analysis results
- further information on the cost-benefit analysis of several specific SAMA candidates and low-cost alternatives

Energy Northwest submitted additional information by letters dated September 17, 2010 (Gambhir, 2010), January 28, 2011 (Gambhir, 2011), and May 6, 2011 (Swank, 2011). In response to the RAIs, Energy Northwest provided the following:

- a description of the major changes to the PSA models since those used in the ER SAMA analysis
- a detailed sensitivity analysis of the impact on the SAMA analysis from the revised models and internal and external review comments on the PSA models
- a description of the CETs used for the internal, fire, and seismic PSA models and the relationship between each
- the process for selecting representative MAAP cases for each release category
- further details on the population, meteorological, and economic assumptions used in the Level 3 analysis
- basic events importance lists for the internal, fire, and seismic PSA models and the SAMA candidates that mitigate each basic event
- a review of the applicability of industry cost-effective SAMA candidates to CGS
- results of a revised screening and cost-benefit analysis based on consideration of PSA model uncertainties
- additional information regarding several specific SAMAs

Energy Northwest's responses addressed the NRC staff's concerns and resulted in the identification of additional potentially cost-beneficial SAMAs.

An assessment of SAMAs for CGS is presented below.

F.2 Estimate of Risk for CGS

Energy Northwest's estimates of offsite risk at CGS are summarized in Section F.2.1. The summary is followed by the NRC staff's review of CGS's risk estimates in Section F.2.2.

F.2.1 CGS's Risk Estimates

Two distinct analyses are combined to form the basis for the risk estimates used in the SAMA analysis—the CGS Level 1 and 2 PSA models, which is an updated version of the IPE (Parrish, 1994) and a supplemental analysis of offsite consequences and economic impacts (essentially a Level 3 PSA model) developed specifically for the SAMA analysis. The SAMA

analysis is based on the most recent CGS Level 1 and Level 2 PSA models available at the time of the ER, referred to as CGS PSA Revision 6.2. The scope of the CGS PSA includes Level 1 and Level 2 internal, fire, and seismic events risk models. CGS PSA Revision 6.2 is composed of the following:

- CGS internal events PSA Revision 6.2 model
- CGS fire PSA Revision 2 model
- CGS seismic PSA Revision 1 model

The fire PSA and seismic PSA are based on the internal events Level 1 and Level 2 PSA Revision 6.2 model. The ER included a SAMA analysis based on CGS PSA Revision 6.2 (EN, 2010). Subsequently, in response to NRC staff RAIs, a sensitivity analysis of the SAMA results was provided based on the updated CGS PSA Revision 7.1 (Gambhir, 2011), (Swank, 2011).

The baseline CDF for the purposes of the SAMA evaluation, based on CGS PSA Revision 6.2, is approximately 4.8×10^{-6} per year for internal events (which includes internal flooding), 7.4×10^{-6} per year for fire events, and 5.2×10^{-6} per year for seismic events, as determined from quantification of the Level 1 PSA models. The sensitivity analysis CDF, based on CGS PSA Revision 7.1, is approximately 7.4×10^{-6} per year for internal events, 1.4×10^{-5} per year for fire events, and 4.9×10^{-6} per year for seismic events (Gambhir, 2011). For the baseline and sensitivity analysis, the risk reduction benefits associated with internal, fire, and seismic events were separately estimated based on the internal events, fire, and seismic Level 1 and Level 2 PSAs. Energy Northwest accounted for the potential risk reduction benefits associated with non-fire and non-seismic external events (e.g., high wind, external flood, and other (HFO) events) by multiplying the estimated benefits for internal events by a factor of 2 (i.e., the contribution from HFO events was assumed to be the same as that from internal events). The estimated SAMA benefits for internal events, fire events, seismic events, and non-fire and non-seismic external events were then summed to provide an overall benefit. This is discussed further in Sections F.2.2 and F.6.2.

The breakdown of CDF by initiating event is provided in Tables F-1, F-2, and F-3 for internal events, fire compartments, and seismic damage sequences (SDSs), respectively. The results from both the baseline PSA model (Revision 6.2) and the sensitivity analysis PSA model (Revision 7.1) are provided. As shown in Table F-1, events initiated by station blackout (SBO), internal flooding, and special initiators—such as loss direct current (DC) and alternating current (AC) buses, loss of heating, ventilation and air conditioning (HVAC), and loss of service water and air systems—are the dominant contributors to the internal event CDF for CGS PSA Revision 6.2. The dominant contributors to internal event CDF for CGS PSA Revision 7.1 are internal flooding, anticipated transients without scram (ATWS), loss of feedwater (FW), and manual shutdown. In response to an NRC staff RAI (Gambhir, 2010), Energy Northwest explained that SBO and loss-of-offsite power (LOOP) sequences include plant centered, grid-related, and severe weather related contributions and are dominated by the plant centered contribution. As shown in Table F-2, the dominant contributors to fire CDF are fires in the radwaste building for CGS PSA Revisions 6.2 and 7.1. As shown in Table F-3, the dominant contributors to seismic CDF are structural failures of the reactor pressure vessel (RPV) or Category 1 buildings or both and wide-spread failure of safe shutdown equipment list (SSEL) equipment for CGS PSA Revisions 6.2 and 7.1.

Table F-1. CGS CDF for internal events

Initiating event	PSA Model Revision 6.2		PSA Model Revision 7.1	
	CDF (per year)	% contribution to CDF[(a)]	CDF (per year)	% contribution to CDF[(b)]
SBO	$1.6x10^{-6}$	33	$1.3x10^{-7}$	2
Internal flooding	$7.4x10^{-7}$	15	$2.3x10^{-6}$	31
Special initiators	$7.2x10^{-7}$	15	$3.0x10^{-7}$	4
LOOP	$3.0x10^{-7}$	6	$9.3x10^{-8}$	1
RPV rupture	$3.0x10^{-7}$	6	$1.0x10^{-8}$	<1
Loss of condenser	$2.2x10^{-7}$	5	$3.7x10^{-7}$	5
Inadvertent stuck open main steam safety relief valve (SRV)	$2.1x10^{-7}$	4	$8.3x10^{-8}$	1
Loss of FW	$1.9x10^{-7}$	4	$7.2x10^{-7}$	10
Steam line break outside containment	$1.5x10^{-7}$	3	$5.8x10^{-7}$	8
Manual shutdown	$1.3x10^{-7}$	3	$7.9x10^{-7}$	10
Turbine trip	$1.2x10^{-7}$	2	$1.5x10^{-7}$	2
ATWS	$8.4x10^{-8}$	2	$1.4x10^{-6}$	19
Main steam isolation valve (MSIV) closure	$4.6x10^{-8}$	1	$3.6x10^{-7}$	5
Loss of coolant accidents (LOCAs)	$4.8x10^{-9}$	<1	$2.0x10^{-7}$	3
Total CDF (internal events) [(c)]	**$4.8x10^{-6}$**	**100**	**$7.4x10^{-6}$**	**100**

[(a)] Percentage is based on internal event CDF contribution in ER Table E.3-3 (EN, 2010) and total internal event CDF.

[(b)] Percentage is based on internal event CDF contribution in Table A-1 (internal events) of the responses to NRC staff RAIs (Gambhir, 2011) and total internal event CDF.

[(c)] Columns may not sum to reported totals due to round off.

Table F-2. Important CGS fire compartments and their contribution to fire CDF

Fire compartment	PSA Model Revision 6.2		PSA Model Revision 7.1	
	CDF (per year)	% contribution to CDF[(a)]	CDF (per year)	% contribution to CDF[(a)]
R1J: Reactor Building 522'[3]	$1.2x10^{-6}$	16	$\leq 1.2x10^{-6}$	≤9
W14: Radwaste 467' Switchgear Room 1	$1.0x10^{-6}$	14	$1.4x10^{-6}$	10
W04: Radwaste 467' electrical equipment room	$8.4x10^{-7}$	11	$1.7x10^{-6}$	12
R1D: Northwest Reactor Building 471'[3]	$7.4x10^{-7}$	10	$\leq 7.4x10^{-7}$	≤5
W11: Radwaste A/C room[3]	$7.3x10^{-7}$	10	$\leq 7.3x10^{-7}$	≤5
W03: Radwaste 467' cable chase	$4.5x10^{-7}$	6	$9.4x10^{-7}$	7
W08: Radwaste 467' Switchgear Room 2	$3.6x10^{-7}$	5	$9.7x10^{-7}$	7

Fire compartment	PSA Model Revision 6.2		PSA Model Revision 7.1	
	CDF (per year)	% contribution to CDF[(a)]	CDF (per year)	% contribution to CDF[(a)]
Y01: Transformer yard[3]	$3.2x10^{-7}$	4	$\leq 3.2x10^{-7}$	≤2
W10: Radwaste main control room[3]	$3.0x10^{-7}$	4	$\leq 3.0x10^{-7}$	≤2
W05: Radwaste 467' Battery Room 1	$2.5x10^{-7}$	3	$3.2x10^{-7}$	2
W02: Radwaste cable spreading room	$2.2x10^{-7}$	3	$4.4x10^{-7}$	3
W13: Radwaste 525' emergency chiller	$2.0x10^{-7}$	3	$4.9x10^{-7}$	4
T1A: Turbine Generator West 441'	$1.6x10^{-7}$	2	$2.9x10^{-7}$	2
T12: Turbine generator south corridors[3]	$1.3x10^{-7}$	2	$\leq 1.3x10^{-7}$	≤1
W1A: Radwaste Building 437'	$1.2x10^{-7}$	2	$4.4x10^{-7}$	3
W07: Radwaste 467' Division 2 electrical equipment	$9.0x10^{-8}$	1	$1.7x10^{-6}$	12
R1B: Northeast Reactor Building 471'	$5.8x10^{-8}$	<1	$1.6x10^{-7}$	1
T1C: Turbine Generator East 441'	$5.2x10^{-8}$	<1	$1.3x10^{-6}$	9
T1D: Turbine Generator West 471'	$4.9x10^{-8}$	<1	$1.6x10^{-7}$	1
R1C: Southeast Reactor Building 471'	$2.0x10^{-8}$	<1	$3.9x10^{-7}$	3
R1L: Reactor Building 572'	$3.3x10^{-9}$	<1	$2.4x10^{-7}$	2
Total fire CDF[(b)]	**$7.4x10^{-6}$**	**100**	**$1.4x10^{-5}$**	**100**

[(a)] Percentage is based on fire CDF contribution in Table A-1 (fire) of the responses to NRC staff RAIs (Gambhir, 2011), (Swank, 2011) and total fire CDF.

[(b)] Columns may not sum to reported totals due to round off or assumptions about bounding values for selected compartments in PSA Revision 7.1 (see footnote 3).

[(c)] Only fire CDF contributions for compartments that increased by at least 1 percent from PSA Revision 6.2 were provided for Revision 7.1. Contributions for these others remaining from Revision 6.2 are shown as bounding values, based on their previous contributions in Revision 6.2, since it was reported that non increased by more than 1 percent.

Table F-3. Important SDSs and their contribution to seismic CDF

SDS sequence	Description of seismic-induced failures	PSA Model Revision 6.2		PSA Model Revision 7.1	
		CDF (per year)	% contribution to CDF[(a)]	CDF (per year)	% contribution to CDF[(a)]
SDS42	Failure of RPV or Category I buildings or both	$2.4x10^{-6}$	46	$2.4x10^{-6}$	49
SDS41	Wide-spread failure of safety SSEL equipment	$1.6x10^{-6}$	31	$1.6x10^{-6}$	33
SDS2	Balance of plant (BOP), CST, LOOP, small-small LOCA	$1.8x10^{-7}$	3	0	0
S624	LOOP, small-small LOCA, and Division 1 & 2 AC distribution, BOP, and CST failure	$2.2x10^{-7}$	4	$9.0x10^{-8}$	2

SDS sequence	Description of seismic-induced failures	PSA Model Revision 6.2		PSA Model Revision 7.1	
		CDF (per year)	% contribution to CDF[(a)]	CDF (per year)	% contribution to CDF[(a)]
SDS4	BOP, condensate storage tank (CST), LOOP, small-small LOCA, Diesel Generators (DGs) 1 & 2	$1.8x10^{-7}$	3	$8.2x10^{-8}$	2
S523	BOP, CST, LOOP, nitrogen (N_2) tank, small-small LOCA, DGs 1 & 2, Division III	$1.3x10^{-7}$	2	$1.4x10^{-7}$	3
SLAC	BOP, CST, LOOP, N_2 tank, medium LOCA, Division I & II, Division III, offsite AC not recoverable	$1.1x10^{-7}$	2	$1.1x10^{-7}$	2
S725	BOP, CST, LOOP, N_2 tank, small-small LOCA, Division I & II, Division III, offsite AC not recoverable	$1.0x10^{-7}$	2	$1.0x10^{-7}$	2
SDS22	BOP, CST, LOOP, N_2 tank, small-small LOCA, DGs 1 & 2	$6.2x10^{-8}$	1	$2.8x10^{-8}$	1
SDS38	BOP, CST, LOOP, N_2 tank, DGs stalled and not restarted	$5.8x10^{-8}$	1	$9.5x10^{-8}$	2
Other		$1.6x10^{-7}$	3	$1.4x10^{-7}$	3
Total Seismic CDF[(b)]		**$5.2x10^{-6}$**	**100**	**$4.9x10^{-6}$**	**100**

[(a)] Percentage is based on seismic CDF contribution in Table A-1 (Seismic) of the responses to NRC staff RAIs (Gambhir, 2011) and total seismic CDF.

[(b)] Columns may not total to reported totals due to round off.

The Level 2 CGS PSA models that form the basis for the SAMA evaluation are updated versions of the Level 2 IPE (Parrish, 1994) and IPEEE (Parrish, 1995) models. The Level 2 analysis is linked to the Level 1 model by assigning each Level 1 core damage sequence to a plant damage state (PDS). The Level 1 core damage sequences are binned into 21 PDSs for internal and fire events and 12 PDSs for seismic events. The Level 2 model uses a set of CETs, one for each PDS, containing both phenomenological and systemic events. The CET probabilistically evaluates the progression of the damaged core with respect to release to the environment. CET nodes are evaluated using supporting fault trees and logic rules. In the baseline analysis, the CET end states are examined for considerations of timing of release, magnitude of release, and whether the fission products were scrubbed and subsequently assigned to release categories. In the sensitivity analysis, the CET endstates are examined for considerations of timing and magnitude of release and are subsequently assigned to release categories.

The result of the Level 2 PSA is a set of four release categories in the baseline analysis and nine release categories in the sensitivity analysis, with their respective frequency and release characteristics. The frequency of each release category was obtained by summing the frequency of the individual accident progression CET endpoints binned into the release category. Source terms were developed for each of the release categories using the results of MAAP computer code calculations. In response to NRC staff RAIs, Energy Northwest stated that MAAP Version 4.0.4 was used in both the CGS baseline and sensitivity analyses to develop

the source terms for input to the Level 3 consequence analyses (Gambhir, 2010). The source terms for each release category are provided in Table E.6-6 of ER Appendix E (EN, 2010) for the baseline analysis and Table 2-4 of the RAI responses (Gambhir, 2011) for the sensitivity analysis. The frequency of each release category is provided in ER Appendix E Tables E.4-3, E.4-5, and E.4-6 for internal, fire, and seismic events, respectively, for the baseline analysis, and in corresponding Tables A-3, A-4, and A-5 of the RAI responses for the sensitivity analysis.

The offsite consequences and economic impact analyses use the MACCS2 code to determine the offsite risk impacts on the surrounding environment and public. Inputs for these analyses include plant-specific and site-specific input values for core radionuclide inventory, source term and release characteristics, site meteorological data, projected population distribution (within an 80-kilometer (km) (50-mile (mi)) radius) for the year 2045, emergency response evacuation modeling, and economic data. The core radionuclide inventory is based on plant-specific evaluation and corresponds to end-of-cycle values for the CGS operating at the current licensed power of 3,486 megawatt-thermal (MWt). The magnitude of the onsite impacts (in terms of clean-up and decontamination costs and occupational dose) is based on information provided in NUREG/BR-0184 (NRC, 1997a).

In the ER, Energy Northwest estimated the dose to the population within 80 km (50 mi) of the CGS site to be approximately 0.037 person-Sievert (Sv) (3.7 person-roentgen equivalent man (rem)) per year for internal events, 0.086 person-Sv (8.6 person-rem) per year for fire events, and 0.067 person-Sv (6.7 person-rem) per year for seismic events. These numbers equal a total population dose from internal and external events of 0.190 person-Sv (19.0 person-rem) per year for the baseline analysis using CGS PSA Revision 6.2. The breakdown of the total population dose by containment release mode for internal, fire, and seismic events is summarized in Table F-4. Large, late, not-scrubbed (LLN) release is the dominant contributor to the population dose risk at CGS for all three hazard types.

In response to NRC staff RAIs, Energy Northwest estimated the dose to the population within 80 km (50 mi) of the CGS site to be approximately 0.055 person-Sv (5.5 person-rem) per year for internal events, 0.090 person-Sv (9.0 person-rem) per year for fire events, and 0.059 person-Sv (5.9 person-rem) per year for seismic events. These numbers equal a total population dose from internal and external events of 0.204 person-Sv (20.4 person-rem) per year for the sensitivity analysis using CGS PSA Revision 7.1. The breakdown of the total population dose by containment release mode for internal, fire, and seismic events is summarized in Table F-5. Moderate and intermediate release is the dominant contributor to the population dose risk at CGS for internal and fire events while high and early release is the dominant contributor to population dose risk for seismic events.

Table F-4. Breakdown of population dose by containment release mode for PSA Revision 6.2

	Internal events		Fire events		Seismic events	
Containment release mode	**Population dose (person-rem[a] per year)**	**% contribution[b]**	**Population dose (person-rem[a] per year)**	**% contribution[b]**	**Population dose (person-rem[a] per year)**	**% contribution[b]**
Large, Late, Not-Scrubbed (LLN)	2.1	57	7.6	88	3.9	58
Large, early, not-	0.9	23	0.3	4	2.8	42

Containment release mode	Internal events		Fire events		Seismic events	
	Population dose (person-rem[a] per year)	% contribution[b]	Population dose (person-rem[a] per year)	% contribution[b]	Population dose (person-rem[a] per year)	% contribution[b]
scrubbed (LEN)						
Large, late scrubbed (LLS)	0.7	20	0.7	8	negligible	negligible
Large, early scrubbed (LES)	0.0	0	0.0	0	0.0	0
Containment intact (COK)	negligible	negligible	negligible	negligible	negligible	negligible
Total	**3.7**	**100**	**8.6**	**100**	**6.7**	**100**

[a] One person-rem = 0.01 person-Sv

[b] Percentage is based on population dose contribution in Tables E.7-1, E.7-2, and E.7-3 of the ER (EN, 2010) for internal events, fire events, and seismic events, respectively, and total population dose for each hazard.

Table F-5. Breakdown of population dose by containment release mode for PSA Revision 7.1

Containment release mode	Internal events		Fire events		Seismic events	
	Population dose (person-rem[a] per year)	% contribution[b]	Population dose (person-rem[a] per year)	% contribution[b]	Population dose (person-rem[a] per year)	% contribution[b]
High/early release (H/E)	0.7	13	0.1	1	3.8	64
High/intermediate release (H/I)	0.3	6	0.1	1	0.9	15
Moderate/early release (M/E)	0.2	4	<0.1	<1	negligible	negligible
Moderate/ intermediate release (M/I)	4.0	74	8.5	94	1.1	19
Low/early release (L/E)	<0.1	1	<0.1	<1	<0.1	<1
Low/intermediate release (L/I)	negligible	negligible	<0.1	<1	negligible	negligible
Low-low/early release (LL/E)	<0.1	<1	0.1	1	<0.1	<1
Low-low/ intermediate release (LL/I)	0.1	2	0.1	1	0.1	2
Containment intact (COK)	negligible	0	negligible	0	negligible	0

Containment release mode	Internal events		Fire events		Seismic events	
	Population dose (person-rem[a] per year)	% contribution[b]	Population dose (person-rem[a] per year)	% contribution[b]	Population dose (person-rem[a] per year)	% contribution[b]
Total[c]	**5.5**	**100**	**9.0**	**100**	**5.9**	**100**

[a] One person-rem = 0.01 person-Sv

[b] Percentage is based on population dose contribution in Tables A-6, A-7, and A-8 of the RAI responses (Gambhir, 2011) for internal events, fire events, and seismic events, respectively, and total population dose for each hazard.

[c] Column may not total to reported totals due to round off.

F.2.2 Review of CGS's Risk Estimates

Energy Northwest's determination of offsite risk at CGS is based on the following major elements of analysis:

- Level 1 and 2 risk models that form the bases for the original 1992 IPE submittal (Sorensen, 1992) and subsequent Revision 1 IPE submittal (Parrish, 1994), the external event analyses of the 1995 IPEEE submittal (Parrish, 1995), and the major modifications to the IPE model that have been incorporated in the CGS internal events, fire, and seismic PSAs
- MACCS2 analyses performed to translate fission product source terms and release frequencies from the Level 2 PSA model into offsite consequence measures (essentially equates to a Level 3 PSA)

Each of these analyses was reviewed to determine the acceptability of the CGS risk estimates for the SAMA analysis, as summarized below.

The NRC staff's review of the Energy Northwest IPE is described in an NRC report dated April 8, 1997 (NRC, 1997b), which is based on Revision 1 of the IPE. Energy Northwest requested that NRC discontinue its review of the original IPE after Revision 1 of the IPE was submitted. Based on a review of the Revision 1 IPE submittal and responses to RAIs, the NRC staff concluded that the IPE submittal met the intent of GL 88-20 (NRC, 1988); that is, the applicant's IPE process is capable of identifying the most likely severe accidents and severe accident vulnerabilities. Although no vulnerabilities were identified in the IPE, several improvements to the plant or procedures were identified. These improvements have been either implemented at the site or addressed in the SAMA evaluation process, and they are discussed in Section F.3.2.

There have been 13 revisions to the internal events PSA model since the 1992 IPE submittal, or 12 revisions since the 1994 IPE submittal reviewed by the NRC. CGS PSA Revision 6.2 was used as the baseline PSA for the SAMA analysis while the updated CGS PSA Revision 7.1 was used in a sensitivity analysis. A listing of the major changes in each revision of the internal events PSA was provided by Energy Northwest in the ER (EN, 2010) and in response to an NRC staff RAI (Gambhir, 2011) and is summarized in Table F-6. A comparison of the internal events CDF between the 1994 IPE and Revision 6.2 of the CGS PSA model used for the baseline analysis indicates a decrease of approximately 73 percent (from 1.8×10^{-5} per year to

$4.8x10^{-6}$ per year). A subsequent revision, Revision 7.1, used for the sensitivity analysis, resulted in an increase in the internal events CDF to $7.4x10^{-6}$ per year compared to the Revision 6.2 CDF.

The internal events CDF value from the 1994 Energy Northwest IPE ($1.8x10^{-5}$ per year) is in the middle of the range of the CDF values reported in the IPEs for BWR 5/6 plants. Figure 11.2 of NUREG-1560 shows that the IPE based internal events CDFs for these plants range from about $1x10^{-5}$ per year to $4x10^{-5}$ per year, with an average CDF for the group of about $2x10^{-5}$ per year (NRC, 1997c). It is recognized that other plants have updated the values for CDF subsequent to the IPE submittals to reflect modeling and hardware changes. Based on CDF values reported in the SAMA analyses for LRAs, the internal events CDF result for CGS used for the SAMA analysis ($4.8x10^{-6}$ per year used for the baseline analysis and $7.4x10^{-6}$ per year used for the sensitivity analysis) is less than the internal event CDF for other plants of similar vintage and characteristics.

The truncation limits for the Revision 6.2 PSA internal events, fire, and seismic models used in the quantification of Level 1 and Level 2 CDFs range from $5x10^{-14}$ to $1x10^{-8}$ per year. The NRC staff asked Energy Northwest to explain the basis for the different truncation limits used in the CDF quantification (Doyle, 2010a). In response to the RAI, Energy Northwest explained that in general a four-order difference between the calculated total and truncation limit was maintained, except in a few cases where a lesser difference was appropriate, such as the case where the calculated CDF appeared to converge at a higher truncation limit (Gambhir, 2010). Thus, the truncation limit varied for each hazard model depending upon the level at which convergence occurred. In a followup RAI response, Energy Northwest further explained that at least a four-order difference between the calculated total and truncation limit was maintained in all cases for the Revision 7.1 PSA model (Swank, 2011).

There have been three revisions to the fire PSA model and two revisions to the seismic PSA model since the 1995 IPEEE submittal, as summarized in Tables F-7 and F-8, respectively. A comparison of the fire events CDF between the 1995 IPEEE and Revision 2 of the CGS fire events PSA model used for the baseline SAMA evaluation indicates a decrease of approximately 58 percent (from $1.8x10^{-5}$ per year to $7.4x10^{-6}$ per year). A comparison of the seismic events CDF between the 1995 IPEEE and Revision 1 of the CGS seismic events PSA model used for the baseline SAMA evaluation indicates a decrease of approximately 75 percent (from $2.1x10^{-5}$ per year to $5.2x10^{-6}$ per year). Subsequently, as a result of integrating Revision 2 of the fire PSA model and Revision 1 of the seismic PSA model with internal events PSA Revision 7.1 (no upgrades to the fire or seismic models were performed), the fire CDF increased to $1.4x10^{-5}$ per year, and the seismic CDF decreased to $4.9x10^{-6}$ per year (Gambhir, 2011). The integrated PSA Revision 7.1 model was then used for the sensitivity analysis.

Table F-6. CGS internal events PSA historical summary

PSA version	Summary of changes from prior model	CDF (per year)
Revision 0 08/1992	Original IPE submittal	$5.4x10^{-5}$

PSA version	Summary of changes from prior model	CDF (per year)
Revision 1 07/1994	Revision 1 IPE submittal • revised common cause failure (CCF) for SRVs, MSIVs, & circuit breakers • revised LOOP initiating frequency, event tree structure, & power recovery factors • revised human reliability analysis (HRA) methodology • enhanced MAAP calculations	1.8×10^{-5}
Revision 2 08/1996	• updated initiating frequencies • developed a failure modes effects analysis • added event trees for loss of Division 2 DC, loss of AC Bus, loss of control room HVAC, & loss of HVAC to switchgear buses SM-7 and SM-8 • deleted event trees for loss of service water, loss of CN • added reactor core isolation cooling (RCIC) as success path in the stuck open relief valve event tree	1.4×10^{-5}
Revision 3 09/1997	• updated “test & maintenance” unavailability data • updated random failure data • updated CCF data • revised the LOCA (large, medium, small) initiating event frequency • recalculated interfacing system LOCA (ISLOCA) initiating event frequency	1.7×10^{-5}
Revision 4 09/1999	• modified the LOOP initiating event frequency • added emergency diesel generator (EDG) recovery • implemented decay heat removal (DHR) success after AC recovery during LOOP • added load shed & offsite recovery during LOOP • deleted the success path using water make-up from the diesel fire pump during LOOP • updated EDG failure rate data using plant-specific data	2.1×10^{-5}
Revision 4.1 09/2001	• updated equipment failure rate & unavailability data	2.2×10^{-5}
Revision 4.2 06/2002	• added mechanism operated cell switch model • added firewater for post containment failure injection	1.8×10^{-5}

PSA version	Summary of changes from prior model	CDF (per year)
Revision 5 01/2004	• added the RPV rupture as an initiating event • revised the LOOP & SBO event tree sequences • updated the transient & LOCA initiating event frequencies • revised the AC fault tree to include a second battery charger • applied the emergency core cooling system (ECCS) pump room HVAC engineering calculations • added reactor building HVAC fault tree • revised non-recovery probabilities for offsite power (Gambhir, 2010) • revised calculation for battery life (Gambhir, 2010) • added success criteria for some systems • updated failure rate data • revised the Level 2 analysis focusing on large early-release frequency (LERF)	7.3×10^{-6}
Revision 5.1 04/2005	• revised the HRA • revised the flooding analysis • updated the equipment test & maintenance data	5.6×10^{-6}
Revision 5.2 04/2005	• corrected an error in the residual heat removal (RHR) fault tree	5.7×10^{-6}
Revision 6 01/2006	• incorporated numerous modeling changes to address the requirements of mitigating system performance indicator (MSPI) implementation, including ATWS, ISLOCA, steam generator HVAC, & LOOP	4.7×10^{-6}
Revision 6.1 05/2006	• removed “Failure to Remain Closed” event for valve RHR-V-48A	4.7×10^{-6}
Revision 6.2 08/2006	• revised the power sources for air handling units WMA-AH-53A/B	4.8×10^{-6}
Revision 7.1 2010	• enhanced CET to enable reflection of plant & procedure changes • expanded CET to address broader spectrum of release end states • added success paths for degraded core conditions • incorporated updated CGS-specific emergency procedures • incorporated results of latest containment safety study • performed additional plant-specific MAAP calculations to support improved system success criteria • explicitly linked the Level 1 & 2 accident sequences	7.4×10^{-6}

(a) CGS internal event PSA version was used as the basis for the SAMA baseline analysis.

(b) CGS internal event PSA version was used as the basis for the SAMA sensitivity analysis.

Table F-7. CGS fire events PSA historical summary

PSA version	Summary of changes from prior model	CDF (per year)
IPEEE 06/1994	IPEEE submittal	$1.8x10^{-5}$
Revision 0 04/2002	• Upgraded to incorporate NRC comments on IPEEE	$1.2x10^{-5}$
Revision 1 06/2004	• Incorporated latest Electric Power Research Institute (EPRI) fire events database • Incorporated internal events PSA Revision 5.0 Level 1 model • Re-evaluated cable spreading rooms (RC 2A, 2B, and 2C) as one area • Included Level 2 PSA	$1.4x10^{-5}$
Revision 2[(a)] 11/2006	• Incorporated internal events PSA Revision 6.2 Level 1 model • Incorporated the updated compartment fire loss data obtained from the revised cable database • Refined compartment fires scenarios to use the internal events PSA LOOP & SBO event trees	$7.4x10^{-6}$
Revision 2[(b)] 2010	• Incorporated internal events PSA Revision 7.1 model	$1.4x10^{-5}$

(a) CGS fire event PSA version was used as the basis for the SAMA baseline analysis.

(b) CGS fire event PSA version was used as the basis for the SAMA sensitivity analysis.

Table F-8. CGS seismic events PSA historical summary

PSA version	Summary of changes from prior model	CDF (per year)
IPEEE 06/1995	IPEEE submittal	$2.1x10^{-5}$
Revision 0 12/2004	• upgraded seismic IPEEE to Level 1 and 2 PSA consistent with the ANSI/ANS-58.21-2003 standard (ANS, 2003) & the EPRI Seismic Probabilistic Risk Assessment Implementation Guide	$6.7x10^{-6}$
Revision 1[(a)] 02/2007	• incorporated internal events PSA Revision 6.2 Level 1 model • deleted LERF multipliers & incorporated new model based on the internal events PSA Level 2 Revision 6.2 model • re-quantified & revised importance, sensitivity, & uncertainty analysis • updated EDG-3 mission time • revised & added HEPs • added new seismic event trees	$5.2x10^{-6}$
Revision 1[(b)] 2010	• incorporated internal events PSA Revision 7.1 model	$4.9x10^{-6}$

[(a)] CGS seismic event PSA version was used as the basis for the SAMA baseline analyses.

[(b)] CGS seismic event PSA version was used as the basis for the SAMA sensitivity analysis.

The NRC staff considered the peer reviews performed for the CGS PSA and the potential impact of the review findings on the SAMA evaluation. In the ER, and in response to an NRC staff RAI (Gambhir, 2010), Energy Northwest identified and described the scope of four external reviews and seven technical reviews. The first external review, conducted by the BWR Owners' Group (BWROG) in 1997 and referred to as the BWROG Certification Peer Review, reviewed PSA model, Revision 3, Level 1 and 2 internal events (including internal flooding). Energy Northwest stated that all comments produced by this review were resolved.

Two external reviews, an industry peer review, and an NRC inspection of the CGS PSA were conducted in 2004 in support of Energy Northwest's participation in the NRC's Regulatory Guide (RG) 1.200 pilot program. Within this pilot program, the CGS internal and fire events PSAs were upgraded and peer reviewed to the American Society of Mechanical Engineering (ASME) Standard RA-Sa-2003 (ASME, 2003) as modified by the trial use version of NRC RG 1.200 (NRC, 2004b). The industry peer review, conducted by ERIN Engineering (Webring, 2004) in 2004, reviewed PSA model, Revision 5.0, Level 1 and 2 internal and fire events PSA. Energy Northwest stated that there were no Level A (extremely important) facts and observations (F&Os) from this review. In response to an NRC staff RAI, Energy Northwest listed and described all unresolved Level B (important) F&Os, with the exception of F&Os categorized as having only documentation impacts, which are not resolved in the Revision 6.2 PSA model (Gambhir, 2010). Energy Northwest explained that all but two of these F&Os address ASME PSA supporting requirements (SRs) that were determined by the peer review team to meet at least capability Category I (CC-I) requirements. Energy Northwest's assessment of the two F&Os against SRs that were determined to not meet at least CC-I determined that one is primarily a documentation issue that limits the ability to identify basic event LERF contributors. The other recommends completing switchgear room heat-up calculations that, after completion, confirmed that the PSA Revision 6.2 modeling used for the SAMA baseline evaluation is conservative. Furthermore, Energy Northwest stated that all of the identified Level B F&Os have been resolved in the PSA Revision 7.1 model used for the SAMA sensitivity analysis.

Subsequent to the industry peer review, the NRC performed an inspection of the CGS PSA documentation, the industry peer review results, and the applicant's self-assessment report in 2004 to determine if RG 1.200 and the ASME standard provide adequate guidance to demonstrate the technical adequacy of a PSA (Benney, 2006). The NRC review was conducted like a typical peer review except that the review also addressed the usability of the ASME standard. The ER provides a list of specific unresolved issues as in-progress at the time of the ER for the next revision of the PSA model based on this review (EN, 2010). These findings include recommendations to credit mitigation systems that are not currently modeled, refinement of initiator frequencies and failure probabilities, and recommendations to refine assessment and modeling of equipment performance related to flooding events and Level 2 phenomena. In response to an NRC staff RAI, Energy Northwest stated that all significant unresolved F&Os or issues that would impact the PSA quantitative results are addressed by the unresolved Level B F&Os discussed above for the 2004 industry peer review, which have been resolved in the PSA Revision 7.1 model used for the SAMA sensitivity analysis.

The last of the four external peer reviews is an NRC inspection of the CGS PSA, performed in 2006, to verify that CGS correctly implemented the MSPI guidance. This included review of the data CGS used to generate the MSPI basis document and actual unavailability and unreliability values. There were no unresolved issues from this NRC inspection (Gambhir, 2010).

The technical reviews of the CGS PSA identified and described by Energy Northwest are as follows:

- A 1994 independent technical review of the Revision 0 and Revision 1 IPE by Scientech (previously NUS)—All review comments were resolved.
- A 2002 internal review of the systems analysis (SY) and initiating events (IE) elements of PSA Revision 4.2—Changes to the SY and IE elements were subsequently evaluated by the 2004 industry peer review and NRC inspection.
- A 2002–2003 technical review by Scientech to upgrade the internal events PSA Revision 4.2 model to support a license amendment request to change the DG completion time technical specification—This request was subsequently evaluated by the 2004 industry peer review and NRC inspection.
- A 2004 technical review by independent consultants to assess a common cause condition associated with the mechanism operated cell switch for the 4160 V switchgear—All identified issues were resolved.
- A 2004 technical review by ERIN Engineering of the PSA Revision 5.0 model HRA related to SBO IEs—The review identified many additional human failures, some of which were resolved in PSA Revision 5.1. Unresolved issues, characterized as an area of model incompleteness, were identified in the ER and subsequently resolved in the PSA Revision 7.1 model used for the SAMA sensitivity analysis.
- A 2006 self-assessment of the Revision 6.0 PSA model to assure it would meet the implementation requirements for MSPI—Unresolved issues, characterized as an area of model incompleteness, were identified in the ER and subsequently resolved in the PSA Revision 7.1 model used for the SAMA sensitivity analysis.
- A 2008 self-assessment of CGS PSA adequacy to support extension of completion time for low-pressure coolant injection (LPCI) and low-pressure core spray (LPCS) systems—Unresolved issues, characterized as an area of model incompleteness, were identified in the ER and subsequently resolved in the PSA Revision 7.1 model used for the SAMA sensitivity analysis.

The NRC staff asked Energy Northwest to identify any changes to the plant, including physical and procedural modifications, since Revision 6.2 of the CGS internal events PSA, Revision 2 of the CGS fire PSA, and Revision 1 of the seismic PSA that could have a significant impact on the results of the SAMA analysis (Doyle, 2010a). In response to the RAI, Energy Northwest identified three physical plant changes since PSA model Revision 6.2 that could potentially impact the SAMA evaluation (Gambhir, 2010). The first change provides for the ability to cross-connect a DG to either the Division 1 or 2 emergency buses during extended SBO and included changes to LOOP and SBO procedures. Implementation of this change reduces CDF and, therefore, the benefits associated with SAMAs identified to improve plant response to LOOP or SBO; Energy Northwest concluded that the SAMA analysis is conservative relative to this modification. The second change added a portable 480 V DG (DG-4) and included associated procedure changes for its use to provide an alternate source of AC power. Implementation of this change improves the ability of CGS to cope with an SBO when one DG is inoperable and, therefore, reduces CDF. The third change was an upgrade of the FW and turbine control systems. The anticipated higher reliability from these improved systems has not been credited in the PSA because of insufficient operational history to support a Bayesian update; therefore, Energy Northwest considers this improvement to be risk neutral for the purposes of the SAMA evaluation. Since each of the three changes either reduces or maintains (i.e., does not increase) plant risk, Energy Northwest concluded that implementation of these changes either reduces or maintains (i.e., does not increase) the benefits calculated for the evaluated SAMA candidates (Gambhir, 2010).

In response to this same RAI, Energy Northwest explained that the CGS internal events PSA model had been updated to Revision 7.1 since the SAMA evaluation reported in the ER, which resulted in a higher CDF and a lower LERF (Gambhir, 2010). Energy Northwest further explained, in a followup response to the NRC staff RAIs, that the PSA Revision 7.1 model incorporated the following:

- resolution of F&Os from the 2004 peer review
- resolution of areas of model incompleteness identified by CGS internal technical reviews
- upgrades to meet NRC RG 1.200 Revision 2 (NRC, 2009a) and the associated ASME standard RA-S-2008 (ASME, 2008) for Level 1, LERF, and flooding modeling
- plant and procedure changes, such as the DG cross-connect discussed previously (Gambhir, 2011)

These changes were first incorporated in the PSA Revision 7.0 model. A peer review of the Revision 7.0 PSA model was performed on Level 1 and 2 internal events (with internal flooding) in 2009, and a report was issued in January 2010. Energy Northwest explains that F&Os from this peer review that could significantly impact the model quantification were incorporated into the Revision 7.1 model, and a review of the remaining F&Os associated with SRs that were graded as CC-I or "not met" identified none that would significantly impact the results of the SAMA analysis (Gambhir, 2011). Energy Northwest performed a sensitivity study using the Revision 7.1 PSA model (which integrates internal, fire, and seismic events) to assess the impact of these modeling updates on the results of the SAMA evaluation. The results of this sensitivity study are discussed throughout this appendix.

In another RAI, the NRC staff noted that several of the peer review and self-identified findings that were characterized as not expected to significantly alter the SAMA results appear to address potential non-conservatisms in the Level 1 and 2 PSA model. The staff asked Energy Northwest to justify its conclusion that resolution of these issues will not impact the SAMA analysis (Doyle, 2010a). In response to the RAI, Energy Northwest concurred that the list of findings identified in the RAI address areas of non-conservatism and explained that each of these findings has since been resolved in PSA Revision 7.1 (Gambhir, 2010). As discussed previously, in response to this and other RAIs, Energy Northwest provided a sensitivity analysis of the SAMA analysis results using PSA Revision 7.1.

The NRC staff asked Energy Northwest to describe the PSA quality control process used at CGS (Doyle, 2010a). In response to the RAI, Energy Northwest explained that the process for controlling the technical adequacy of the PSA is contained in a CGS engineering procedure that is consistent with guidance in NRC RG 1.174 (NRC, 2002). This PSA configuration procedure covers the following:

- monitoring PSA input and collecting new information for incorporation
- updating the PSA to be consistent with the as-built and as-operated plant
- assessing cumulative impact of pending PSA changes
- controlling computer codes supporting the PSA
- preparing documentation
- qualifying PSA reviewers

The CGS internal events PSA model has been peer-reviewed, the peer review findings were all resolved and their impacts assessed in a sensitivity analysis using the updated PSA model. Additionally, Energy Northwest satisfactorily addressed NRC staff questions regarding the PSA.

Based on this information, the NRC staff concludes that the internal events Level 1 PSA model is of sufficient quality to support the SAMA evaluation.

As indicated above, the CGS PSA includes explicit fire and seismic event PSA models, in addition to the internal events PSA model. Both the fire and seismic PSA models have been significantly updated since the IPEEE. The updated fire and seismic CDF results are described in the ER and are included in Tables F-7 and F-8.

The CGS IPEEE was submitted in June 1995 (Parrish, 1995) in response to Supplement 4 of GL 88-20 (NRC, 1991a). This submittal included an internal fire PSA, a seismic PSA, and a screening analysis for other external events. While no fundamental weaknesses or vulnerabilities to severe accident risk in regard to the external events were identified, many opportunities for risk reduction were identified as discussed below. In a letter dated February 26, 2001, the NRC staff concluded that the submittal met the intent of Supplement 4 to GL 88-20, and the applicant's IPEEE process is capable of identifying the most likely severe accidents and severe accident vulnerabilities (NRC, 2001).

The seismic portion of the IPEEE consisted of a seismic PSA completed in accordance with NRC guidance for IPEEE submittals (NRC, 1991a) and the NRC PSA procedures guide (NRC, 1983). Plant models were primarily based on the IPE (Parrish, 1994). Major inputs to the seismic PSA were from the following:

- plant walkdowns in which components and structures were screened against the review level earthquake of 0.5g conducted in accordance with the EPRI methodology for Seismic Margins Assessment (EPRI, 1991)
- relay chatter evaluation conducted in accordance with NRC guidance for IPEEE submittals
- seismic fragility evaluation conducted per the EPRI methodology for developing seismic fragilities (EPRI, 1994)

A site-specific seismic hazard estimate was developed for CGS by Geomatrix and documented in a hazard report (Geomatrix, 1994a) which is stored as a permanent record by Energy Northwest. Key elements of the seismic PSA included a seismic hazard analysis, a seismic fragility evaluation, system and accident sequence analysis, and evaluation of seismic CDF and public risk.

The seismic CDF resulting from the CGS IPEEE was calculated to be 2.1×10^{-5} per year using a site-specific seismic hazard curve. The CGS IPEEE did not identify any vulnerabilities due to seismic events but did identify several improvements to the plant or procedures to reduce seismic risk. These improvements have been either implemented at the site or addressed in the SAMA evaluation process, and they are discussed in Section F.3.2.

Subsequent to the IPEEE, Energy Northwest upgraded the seismic PSA to be consistent with the American Nuclear Society (ANS) standard for external events PSAs, ANSI/ANS-58.21-2003 (ANS, 2003), and with EPRI seismic PSA implementation guidance (EPRI, 2003). Major inputs to the seismic events PSA include the following:

- a plant-specific hazard curve
- results and insights obtained from seismic plant walkdowns conducted in support of the IPEEE (Parrish, 1995)

- plant-specific structural and component seismic fragility analyses
- relay chatter evaluation
- the Level 1 and 2 Revision 6.2 PSA models

These upgrades to the seismic PSA resulted in a seismic CDF of 5.2×10^{-6} per year, using a site-specific seismic hazard curve, which was used for the SAMA evaluation. In response to NRC staff RAIs, Energy Northwest reported the seismic CDF for PSA Revision 7.1 used in the SAMA sensitivity analysis to be 4.9×10^{-6} per year (Gambhir, 2011). In the RAI responses, Energy Northwest explained that the seismic PSA was not updated for the Revision 7.1 model and that the decrease in seismic CDF from Revision 6.2 to Revision 7.1 is due to integration of the seismic PSA model with the updated internal events model. Energy Northwest identified an increase in seismic CDF, due to the suppression pool no longer being assumed to be available as a source of makeup inventory for RCIC. This increase is more than offset by a decrease in the seismic CDF due to a reduction in CCF probabilities for the DGs and refinement of the likelihood of failure of high-pressure core spray (HPCS) injection given containment failure to remove conservatism.

The NRC staff noted that the seismic CDF contribution was zero for two seismic damage states (i.e., S2P2 and S20P2) reported in Table A-1 of the RAI responses (Gambhir, 2011). The staff asked Energy Northwest to explain the reason for this since the seismic CDF was not zero for the two seismic damage states using the CGS PSA Revision 6.2 model (Doyle, 2011a). In response to the followup RAI, Energy Northwest explained that S2P2 and S20P2 are seismic SBO event trees with RCIC successful; however, the RCIC success criteria for PSA Revision 7.1 requires the CST to be available but that the CST is assumed to fail in seismic events (Swank, 2011). Therefore, all of the S2P2 and S20P2 cutsets transferred to the seismic SBO event trees with RCIC unavailable (i.e., S2P3 and S20P3) (Swank, 2011).

The NRC staff asked Energy Northwest to address if seismic hazard analysis information, developed later for the nearby U.S. Department of Energy (DOE) Hanford Site and by the U.S. Geological Survey (USGS), could impact the results of the SAMA analysis (Doyle, 2010a). In response to the RAI, Energy Northwest emphasizes that the 1994 seismic hazard analysis used in the CGS IPEEE was specifically developed for the CGS site. The seismic hazard analyses developed by Geomatrix Consultants for the DOE Hanford Site in 1994 (Geomatrix, 1994b), and updated in 1996 (Geomatrix, 2006), developed site-specific seismic hazard curves for each location evaluated on the Hanford Site (Gambhir, 2010). Energy Northwest also discussed the results of a 2005 study that develops a site-specific seismic response model for the DOE Hanford Site Waste Treatment Plant (WTP) that better characterizes the effect from deep layers of sediments “interbedded” with basalt (PNNL, 2005). Energy Northwest explains that each of these studies evaluates locations that are at least 10 mi distant from the CGS site, that the soil structure at the CGS site is thicker than at the WTP site, and that the site-specific hazard curves developed for the Hanford Site locations are, therefore, less applicable to the CGS site. Energy Northwest notes that after years of study of the seismic hazard at WTP, it eventually concluded (PNNL, 2007) that the hazard results obtained for WTP using the newest ground motion models at the WTP were similar to the 1996 model results. Energy Northwest also notes that the recently updated USGS assessment of seismic hazards in the U.S. offers an opportunity for an independent verification of the seismic results developed for the CGS site by Geomatrix consultants. In the RAI response, Energy Northwest compares the peak ground acceleration (PGA) at times 500 and 2,500 years calculated using the 2008 USGS data (USGS, 2008) for the coordinates corresponding to the CGS site, which are lower than the PGAs predicted by the Geomatrix CGS model, as shown in Table F-9. Based on these results, Energy Northwest

concludes that the CGS seismic model is conservative relative to the latest USGS seismic hazard data in predicting an appropriate ground motion for the CGS site. Accordingly, Energy Northwest concludes that the 1994 seismic hazard study used in the CGS seismic PSA model used in the SAMA evaluation still provides an adequate seismic input to the PSA models to effectively identify relevant SAMA candidates (Gambhir, 2010).

Table F-9. Comparison of USGS and Geomatrix data

Study	PGA for time = 500 years (10% in 50 years)	PGA for time = 2,500 years (2% in 50 years)
USGS, 2008	0.072 g	0.169 g
Geomatrix, 1994	0.081 g	0.178 g

The NRC staff noted that no reviews of the seismic PSA were identified in the ER and asked Energy Northwest to describe any such reviews and to assess the impact of any unresolved findings on the SAMA evaluation (Doyle, 2010a). In response to the RAI, Energy Northwest stated that no external peer reviews have been performed on the seismic PSA while one internal self-assessment has been performed (Gambhir, 2010). The self-assessment was performed on Revision 0 of the seismic PSA against the ANSI/ANS 58.21-2003 (ANS, 2003) standard, and it identified four SRs that were not met (excluding findings that were judged to be documentation only). The assessment also noted that no peer review had been performed. Two of the findings had to do with the adequacy of the ground motion study and soil-structure interaction analysis performed by Geomatrix consultants. Energy Northwest's assessment of these findings is that, based on the evaluation of the more recent seismic hazard analysis information discussed previously, these studies confirm that the CGS site seismic characterization is adequate. Two of the findings questioned the adequacy of existing seismic PSA sensitivity studies. Energy Northwest concluded that the impact of these findings on the SAMA evaluation is addressed by the 95th percentile seismic CDF uncertainty analysis discussed in Section F.6.2. Regarding the lack of a seismic PSA peer review, Energy Northwest noted that the impact on the SAMA evaluation of this finding cannot be determined but that future enhancements to the seismic PSA are planned to make it consistent with the seismic PSA standard (ASME, 2009).

The CGS internal events modeling is an input to the seismic PSA model, the seismic PSA has been updated to a more recent external events PSA standard, the SAMA evaluation included a sensitivity analysis of the seismic CDF, and Energy Northwest has satisfactorily addressed NRC staff RAIs regarding the seismic PSA. Based on this information, the NRC staff concludes that the seismic PSA model, in combination with the sensitivity analysis of the seismic CDF, provides an acceptable basis for identifying and evaluating the benefits of SAMAs.

The IPEEE fire analysis was performed with PSA technology but employed elements of EPRI's fire-induced vulnerability evaluation (FIVE) methodology (EPRI, 1992) for systemic screening and ignition source frequency determination. The IPEEE fire areas were based on definitions of Appendix R fire areas for CGS. A plant walkdown and verification process was employed to verify that all assumptions and calculations were supported by the physical condition of the plant. Fire areas were qualitatively screened if the area did not contain safety equipment, including cabling, or components and cables whose failure would result in a reactor scram. Of the 93 fire areas, 36 were qualitatively screened. Fire initiating event frequencies were estimated for each of the remaining 57 unscreened fire areas using the FIVE methodology. It was assumed that a fire would destroy all equipment and cables in a fire area and that a fire

would not propagate to more than one fire area. Computerized fire simulations were performed with COMPBRN III (NRC, 1986) to determine fire growth and spread characteristics in critical fire areas. The likelihood for fire suppression was determined based on the availability of automatic fire suppression as well as the likelihood that fires from specific combustion sources would not significantly affect the PSA-related components and cables located in the fire area. Fire-initiating events in each fire area and fire-induced failures were combined with random equipment failure modes using the internal events PSA to determine the fire CDF for each unscreened fire area. A fire area was quantitatively screened from further analysis if the fire-induced core damage was less than $1x10^{-6}$ per year. All but 16 fire areas were quantitatively screened. The remaining 16 important fire areas were further evaluated for consideration of crediting recovery actions or analysis refinements or both.

As reported in Table 1.4-2 of the IPEEE, the fire CDF for the 16 important fire areas is $9.2x10^{-6}$ per year. A separate control room fire evaluation estimated the fire CDF for the control room to be $8.4x10^{-6}$ per year. The total fire CDF resulting from the CGS IPEEE was calculated to be 1.8×10^{-5} per year. The CGS IPEEE did not identify any vulnerabilities due to fire events but did identify several improvements to plant procedures to reduce fire risk. These improvements have been either implemented at the site or addressed in the SAMA evaluation process, and they are discussed in Section F.3.2.

Subsequent to the IPEEE, Energy Northwest created a fire PSA. Energy Northwest describes the fire PSA model in the ER as being based on the internal events PSA model but developed using elements of NUREG/CR-6850 (NRC, 2005). Energy Northwest explains that, in general, the CGS fire PSA approach was to develop fire event trees for each fire area incorporating extinguishment and propagation split fractions from the EPRI fire events database (EPRI, 1993), automatic suppression when applicable, and likelihood of plant trip for different compartment and loss scenarios. For screening fire event trees, the loss scenarios were simplified into loss of the single worst equipment or cable (for example, as indicated by a calculated importance measure) or loss of all equipment and cables in the compartment. Each compartment has a fire-initiating event tree and two conditional fire event trees for single equipment or cable or compartment losses. The conditional fire event trees are either turbine trip or loss of FW event trees, as appropriate for the compartment losses. In performing the fire analysis, consideration was given to all fire damage mechanisms, including smoke, loss of lighting and indication, and fire suppression system impacts on equipment. The fire PSA explicitly examined the HEPs used for the fire scenarios to ensure that equipment and indication losses, fire-induced stress, communications difficulties, and potential impacts from smoke and heat were included.

The CGS IPEEE demonstrated that only a few fire compartments had the potential for fire propagation from one compartment to another. Based on this finding, a detailed evaluation of potential fire propagation between compartments has not been performed for the fire PSA. However, a set of qualitative assessments was performed to confirm that such scenarios would likely be insignificant contributors. For the fire-initiating event tree, split fractions were developed for each group of fixed ignition sources that defined a scenario. The split fractions are single basic events added to the fault tree. As with the screening event trees, early extinguishment (i.e., de-energization, self-extinguishment, or manual suppression not by the fire brigade) and automatic extinguishment were not credited. For transient fire ignition sources, the locations that could impact overhead or nearby combustibles were determined. Hot gas layer formation was considered qualitatively as either not credible (due to room size or ceiling height above critical cable runs) or included in scenarios involving loss of all equipment and cables in applicable compartments.

For each scenario, fire-induced equipment failures were determined, including hot short events that could spuriously actuate components and result in undesired configurations. To identify the potential hot shorts that should be included in the fire PSA, the internal events basic events were reviewed. Those basic events that represented failure of a valve (or damper) to remain open or closed, depending on which position was desirable, were considered susceptible to hot shorts. Hot short failures (more than 120 locations) were identified and explicitly included in this fire evaluation. The hot short impact included failure of minimum-flow valves in flow paths needed for the emergency core cooling injection and valves and dampers needed for containment isolation. Detailed analysis of the main control room was performed, and the potential for control room evacuation was considered.

These upgrades to the fire PSA resulted in a fire CDF of 7.4×10^{-6} per year for CGS PSA Revision 6.2, which was used for the baseline SAMA evaluation. In response to NRC staff RAIs, Energy Northwest reported the fire CDF for PSA Revision 7.1 used in the SAMA sensitivity analysis to be 1.4×10^{-5} per year (Gambhir, 2011). In the RAI responses, Energy Northwest explained that the fire PSA was not updated for the Revision 7.1 model and that the change in fire CDF from Revision 6.2 to Revision 7.1 is due to integration of the fire PSA model with the updated internal events model. Energy Northwest identified that the predominant reasons for the increase in fire CDF were as follows:

- The reactor coolant system is no longer assumed to be available as a backup source of makeup inventory in the event RCIC fails.
- Reactor feedwater (RFW) is now assumed to fail if a full compartment burnout occurs.
- Some Division 2 equipment is conservatively assumed to fail due to a fire in the Division 1 electrical equipment room.
- One train of RHR is no longer assumed to be available and not failed for a fire in the cable chase.
- Fire-induced loss of offsite power is no longer assumed to be recovered through repair activities.

The NRC staff asked Energy Northwest to clarify the extent to which NUREG/CR-6850 was used to update the fire PSA, to describe the conservatisms in the fire PSA, and to describe how conservatisms in the fire PSA have been reduced since the IPEEE (Doyle, 2010a). In response to the RAI, Energy Northwest clarified that the use of NUREG/CR-6850 was limited to only the refinement of electrical hot short probabilities and that use of the EPRI fire events database does not follow the NUREG/CR-6850 guidance (Gambhir, 2010). Energy Northwest further explained that updates to the fire PSA since the IPEEE reduced conservatisms in the IPEEE analysis by refining the cables selected that impact the fire PSA and by performing plant-specific fire modeling, and no attempt was made to reduce conservatisms in the PSA Revision 6.2 model when performing the SAMA evaluation. In response to a followup NRC staff RAI asking Energy Northwest to describe the remaining conservatisms in the fire PSA (Doyle, 2010c), Energy Northwest summarized the areas of conservatisms in the fire PSA as the assumption that a fire would destroy all equipment and cables in some risk-significant fire areas and in the assumed fire ignition frequencies that newer industry data indicate are lower (Gambhir, 2011).

In a separate RAI, the NRC staff asked Energy Northwest to explain how potentially screening out sequences in the simplified loss scenarios that might have contained risk significant hot short events affects the results of the fire PSA and the SAMA evaluation since hot shorts were

only considered for unscreened sequences (Doyle, 2010a). Energy Northwest responded that no sequences were screened out of the analysis but that the purpose of using screening fire event trees was to determine those sequences that required further development before quantification (Gambhir, 2010). After initial quantification, those fire compartments found to have an initial CDF greater than 5.0×10^{-7} per year were analyzed in more detail to be more realistic, which typically involved identifying additional scenarios for each compartment and modeling each scenario with its own fire event tree. Those fire compartments having an initial CDF less than 5.0×10^{-7} per year were not refined further, but the associated cutsets were retained in the fire PSA.

As noted earlier, the fire PSA was included in the industry peer review conducted by ERIN Engineering in 2004. Energy Northwest states in the ER that the review produced 33 findings, that all Level A and B F&Os were addressed and resolved in the Revision 6.2 PSA model used in the SAMA evaluation, and that the remaining unresolved findings are not expected to significantly alter the results of the SAMA analysis. In response to an NRC staff RAI, Energy Northwest clarified that, since the fire PSA standard was not available at the time of the review, the peer review was performed on the fire PSA to the high-level requirements identified in the 2003 ASME standard (Gambhir, 2010). Energy Northwest also identified one unresolved finding that resulted in the grading of the high-level requirement as not met. Energy Northwest's assessment of this finding, which was that the fire PSA does not credit fire brigade response, is that the PSA Revision 6.2 modeling is conservative relative to the SAMA evaluation.

In a separate RAI, the NRC staff noted that many of the unresolved findings identified in the ER appear to be non-conservative and asked Energy Northwest to ensure that resolution of these findings would not significantly alter the results of the SAMA analysis (Doyle, 2010a). Energy Northwest responded that all significant findings from the 2004 peer review, with the exception of the finding discussed above that would reduce model conservatism, have been resolved and that the unresolved findings identified in the ER are from the 2008 self-assessment discussed previously for internal events PSA (Gambhir, 2010). Energy Northwest also discussed each of the areas of potential non-conservatism identified in the RAI and provided the basis for concluding that resolution of these issues will not impact the results of the SAMA evaluation, as follows:

- The electronic database used to select and locate cables does not include all conduit locations. Energy Northwest judged that the 95th percentile CDF uncertainty analysis discussed in Section F.6.2 is sufficient to account for this area of model incompleteness.
- The assumed hot short probability of 0.3 implicitly assumes all circuit failures are intra-cable for multi-conductor cables protected by controlled power transformers. Energy Northwest judged that the 95th percentile CDF uncertainty analysis discussed in Section F.6.2 is sufficient to account for this modeling uncertainty.
- A transformer fire scenario must be re-evaluated for Division 2 switchgear room to remove non-conservatism from current modeling. Energy Northwest stated that, based on a re-evaluation of the transformer fire scenario for the Division 1 switchgear room, which decreased the fire CDF, enhancements to the Division 2 fire PSA modeling are not anticipated to significantly alter the results of the SAMA analysis.
- The fire PSA credits systems or trains that fire-related plant procedures instruct operators to defeat. Energy Northwest stated that since operators have discretion to continue using a system in service during a fire until the fire causes safe shutdown

parameter degradation or visible fire damage to vital plant equipment or cabling, the current PSA modeling is compatible with this acceptable practice.

- The PSA modeling of hot shorts events corresponding to single spurious actuations captures most but not all multiple spurious operations (MSOs). Energy Northwest judged that the 95th percentile CDF uncertainty analysis discussed in Section F.6.2 is sufficient to account for this area of model incompleteness.

Energy Northwest concluded that a future upgrade of the fire PSA will address these issues, that the eventual net risk impact of these refinements cannot be estimated at this time, and that any impacts are judged to be encompassed by the 95th percentile CDF uncertainty analysis discussed in Section F.6.2.

In a followup RAI, the NRC staff asked Energy Northwest to describe any modeling enhancements that have been made to compensate for the incompleteness in the cable location database and in the modeling of MSOs (Doyle, 2010b). Energy Northwest responded by re-emphasizing that conservatisms in the PSA include the use of hot short probabilities of 0.3 unless hot short durations were specifically evaluated and modeled, in lieu of potentially non-conservative lower values, and that loss of all equipment and cables in the compartment was assumed for lower risk fire compartments, in lieu of more realistic modeling of fire scenarios (Gambhir, 2011). Relative to the MSO modeling incompleteness, Energy Northwest stated that conservative treatment of hot short modeling was used in part to respond to this incompleteness, that plant modifications are in progress to address MSOs in safe shutdown circuits in response to Enforcement Guidance Memorandum 09-02 (NRC, 2009b), and that the PSA will be updated once these modifications are implemented in the plant. Relative to the cable database incompleteness, Energy Northwest stated that the cable and raceway database has been updated and now identifies the cables in conduit that were not included in PSA Revision 6.2. The update provided building and, in most cases, fire zone locations of the conduits. Using this updated information, Energy Northwest performed a sensitivity analysis using PSA Revision 7.1 that assumed that conduits whose location was known only at the fire zone level were failed for all fire scenarios within that zone. The sensitivity analysis compared the risk reduction worth (RRW) for six existing fire-related SAMA candidates, representative of important systems and fire compartments at CGS, before and after the model changes were made. The results show that for those SAMA candidates in which the RRW increased, the increase was less than the uncertainty factor applied in the 95th percentile CDF uncertainty analysis discussed in Section F.6.2. Energy Northwest concludes that this sensitivity analysis result supports the conclusion that modeling incompleteness in the fire PSA does not impact the SAMA results.

The NRC staff considers Energy Northwest's explanation and assessment of the areas of incompleteness in the fire PSA reasonable and determines that, in light of the known conservatisms in the PSA model, resolution of these incompleteness issues is not likely to impact the results of the SAMA analysis.

In other followup RAIs, the NRC staff noted that NUREG/CR-6850 guidance indicates that hot short probabilities may be double the 0.3 value (i.e., 0.6) for circuits not protected by control power transformers. The staff asked Energy Northwest to provide the basis for the 0.3 hot short probability assumption and the basis for the conclusion that the 95th percentile CDF uncertainty analysis discussed in Section F.6.2 accounts for this modeling uncertainty (Doyle, 2010c), (Doyle, 2011a). In response to the RAIs, Energy Northwest provided the results of a sensitivity analysis of selected SAMA candidates that were re-evaluated using a hot short probability of 0.6

for circuits that were not confirmed to have a control power transformer present. The results of the sensitivity analysis are discussed in Section F.4.

The CGS internal events modeling is an input to the fire PSA model, the fire PSA has been updated to incorporate industry fire data and NRC guidance, the fire PSA model has been peer reviewed and the peer review findings were all addressed, and Energy Northwest has satisfactorily addressed NRC staff RAIs regarding the fire PSA. Based on this information, the NRC staff concludes that the fire PSA model provides an acceptable basis for identifying and evaluating the benefits of SAMAs.

The Energy Northwest IPEEE analysis of high winds, tornadoes, external floods, and other external events (HFO) followed the screening and evaluation approaches specified in Supplement 4 to GL 88-20 (NRC, 1991a) and in associated guidance in NUREG-1307 (1991b). For high winds, external floods, volcanic activity, and accidents at nearby facilities, the IPEEE concluded that Energy Northwest meets the 1975 Standard Review Plan criteria (NRC, 1975) and, therefore, the contribution from these hazards to CDF is less than the 1.0×10^{-6} per year criterion (EN, 1995). Although the CGS IPEEE did not identify any vulnerabilities due to HFO events, one improvement to reduce risk was identified. This improvement has been implemented, as further discussed in Section F.3.2.

In the SAMA analysis submitted in the ER, the benefit from HFO events was assumed to be equivalent to the benefit that was derived from the internal events model. In response to an NRC staff RAI, Energy Northwest explained that the bases for this assumption are as follows:

- Some of the HFO events are captured in the LOOP contributor.
- The IPEEE analysis found that all of the HFO events contributed less than 1.0×10^{-6} per year to the CDF.
- The internal events CDF for is more than a factor of four greater than the HFO screening CDF of 1.0×10^{-6} per year.

Based on the low contribution to CDF from HFO events, and the internal events CDF of 4.8×10^{-6} per year for CGS PSA Revision 6.2, the NRC staff agrees that assuming the benefits from HFO events is equivalent to the benefits from internal events is reasonable and conservative (Gambhir, 2011). This same assumption, albeit at the higher internal events CDF of 7.4×10^{-6} per year, was also used for CGS PSA Revision 7.1 in the sensitivity analysis.

The NRC staff reviewed the general process used by Energy Northwest to translate the results of the Level 1 PSA into containment releases, as well as the results of the Level 2 analysis, as described in the ER and in response to NRC staff RAIs (Gambhir, 2010), (Gambhir, 2011). The CGS PSA Revision 6.2 Level 2 model used in the baseline analysis is completely revised from the model used in the IPE, including being updated as a result of the peer reviews performed in 1997 and 2004, and it reflects the CGS plant as designed and operated in 2006. The Level 2 model was further updated to support the CGS PSA Revision 7.1 model used in the sensitivity analysis.

The Level 2 analysis is linked to the Level 1 model by assigning each Level 1 core damage sequence to a PDS. Sequences are assigned to one of 21 PDSs based on the functional characteristics of the sequence (e.g., necessary systems are recoverable or not recoverable) and the status of systems that were important to containment performance (e.g., necessary systems are available or not available). Each PDS is described in Table E.4-1 of Appendix E of the ER (EN, 2010).

A CET was developed for each PDS, and quantification of the CETs was facilitated by fault tree analysis and use of split fractions. In response to a NRC staff RAI, Energy Northwest explains that PDSs were organized by accident type (e.g., loss of containment heat removal, loss of coolant injection, and ATWS), initiator type, systems available to mitigate the accident, and power and system recoverability and that the CETs contain both phenomenological and system failure events (Gambhir, 2010). The CETs are constructed with events in the order that they were expected to occur with the exception that events on which other events are dependent were generally placed at the beginning of the CET. Energy Northwest lists fault tree modeled branch points as including the following:

- containment intact after vessel failure
- high-pressure injection
- LPCI and LPCS recovered before containment failure
- debris cooled after vessel failure
- RHR recovered
- containment vent recovered
- power conversion system recovered for containment heat sink
- reactor vessel depressurized prior to containment failure

Energy Northwest further lists phenomenological branch points as including the following:

- containment isolated at time of core damage
- power recovered prior to vessel failure (based on timing)
- power recovered between vessel failure and containment failure (based on timing)
- shell failure due to high pressure melt ejection
- large containment failure mode
- failure in drywell

Containment failure modes identified were in-vessel steam explosion, vessel blow-down, ex-vessel steam explosion, direct heating, and hydrogen explosion.

Each PDS is analyzed through the Level 2 CETs to evaluate the phenomenological progression of the sequence. In the baseline analysis, five release categories were defined based on characteristics that determine the timing (i.e., early and late, for time of initial release less/greater than four hours after general emergency declaration) and magnitude (i.e., large, small, and none, for Cesium Iodide (CsI) inventory release greater than 0.1 percent, less than one percent, and no release) of the release. They were also defined based on whether the fission products were or were not scrubbed prior to release. One release category, large early scrubbed release, was not used; however, Energy Northwest carried this release category in the analysis because its consequences offer insight into the sensitivities of the site-specific data. The CET end states are assigned to one of the five release categories. The frequency of each release category was obtained by summing the frequency of the individual accident progression CET endpoints binned into the release category. The release category frequencies are provided in ER Appendix E Tables E.4-3, E.4-5, and E.4-6 for internal, fire, and seismic events, respectively (EN, 2010).

Source term release fractions were developed for each of the five release categories based on the results of plant-specific calculations using the MAAP Version 4.0.4 (Gambhir, 2010). A single MAAP case was chosen to represent each of the five release categories based primarily on three criteria:

- It represents a CGS accident class that would be expected to be included in the release category.
- It represents the appropriate timing characteristic of the release category.
- The CsI release fraction is representative of the release category.

In response to an NRC staff RAI, Energy Northwest stated that, for release categories in which multiple MAAP cases were available to select from, the representative MAAP case was selected to include reasonable conservatism based on qualitative weighting factors such as the timing and magnitude of the initial and total releases (Gambhir, 2010). The RAI response describes the specific logic used in the selection of the representative MAAP case for each release category. The resulting release characteristics for each release category are provided in Table E.6-6 of Appendix E to the ER (EN, 2010).

The NRC staff noted that approximately 88 percent of the fire release frequency is associated with “late” releases. It asked Energy Northwest to explain the phenomenology that causes this “late” contribution to be much higher than the “late” contribution for internal events, which is approximately 47 percent, and to explain why LERF is less for fire events than for internal events (Doyle, 2010a). In response to the RAI, Energy Northwest provided two tables that compare the internal events and fire events CDF and LERF for each PDS. Energy Northwest also explained that the higher “late” contribution from fires is because the Level 1 fire PSA has a significantly higher contribution from long term loss of DHR scenarios (non-LERF contributors) than the Level 1 internal events PSA results (Gambhir, 2010). The higher contribution to loss of DHR scenarios is due to fire-initiating events that may fail or impact use of the main condenser and containment venting for heat removal and fire-initiating events that may fail a single division of suppression pool cooling. Energy Northwest further clarified that fire-induced LERF is less than internal event LERF primarily because the CDF contribution from SBO sequences with early failure of HPCS and RCIC is less for fire events than for internal events. Additionally, the fire PSA does not include failure scenarios that contribute to LERF that are included in the internal events PSA. For example, there are no fire-induced flooding scenarios, no fire-induced ATWS events, and no fire-induced containment bypass events.

In a followup RAI, the NRC staff noted that fire events, but not internal events, contribute to PDS 2C, transient with stuck-open SRV, or LOCA with loss of containment heat removal and containment failure occurs prior to core damage with the reactor vessel at low pressure. However, internal events, but not fire events, contribute to PDS 2D, transient with loss of containment heat removal, and containment fails prior to core damage with reactor vessel at high pressure. The staff asked Energy Northwest to clarify this discrepancy and to explain why there are no fire-induced containment bypass events (Doyle, 2010c). In response to the RAI, Energy Northwest clarified that the reference to PDS 2C was an error and that the CDF and LERF values reported for PDS 2C should have been reported for PDS 2D. Energy Northwest provided revised tables comparing the internal events and fire events CDF and LERF for each PDS (Gambhir, 2011). Energy Northwest further clarified that fire-induced containment bypass events are addressed in the fire PSA but that PDS 5, LOCA outside containment with failure to isolate the break, is not used in the fire PSA. Rather, Energy Northwest assumes that the dominant impact of a fire to containment isolation is for a fire to cause a major containment isolation pathway to not close or to inadvertently open, and so the fire Level 2 CETs contain a first branch node that asks if the containment is isolated. The split fraction used for this branch node is consistent with that used for the internal events node for loss of containment. The LERF for fire-induced loss of containment isolation is, therefore, reflected in several PDSs, which generally contribute to the LEN release category. Energy Northwest also explained that

the likelihood of a fire-induced ISLOCA at CGS is significantly less than that for failure of containment isolation. This is based on the highest potential ISLOCA pathway from the containment at CGS being the RHR shutdown cooling line that contains two motor-operated valves in series. Since one of these motor-operated valves is maintained in the closed position during normal plant operation with power removed from the motor via a protected isolation switch, a spurious signal from a hot short cannot cause the valve motor to energize. Furthermore, the isolated, de-energized power feeder is routed in a grounded steel conduit to protect it against external three-phase hot shorts. A fire-induced three-phase hot short impacting the power feeder is significantly less than the probability for failure of containment isolation assumed in the fire PSA (Gambhir, 2011).

As discussed previously for the Level 1 PSA, the Level 2 model was included in the 1997 BWROG and 2004 ERIN Engineering peer reviews. Energy Northwest stated that all comments produced by the BWROG review were resolved. Of the 11 unresolved Level B F&Os identified in the 2004 ERIN Engineering peer review in response to an NRC staff RAI, 9 of the F&Os had to do with the Level 2 (LERF) analysis (Gambhir, 2010). As discussed previously, Energy Northwest determined that resolution of these F&Os will not impact the SAMA analysis. Furthermore, Energy Northwest stated that all of the identified Level B F&Os have been resolved in the PSA Revision 7.1 model used for the SAMA sensitivity analysis.

In the PSA Revision 7.1 sensitivity analysis, 13 release categories were defined based on characteristics that determine the timing (i.e., early, intermediate, and late, for time of initial release less than 3 hours, between 3 and 24 hours, and greater than 24 hours after general emergency declaration, respectively) and magnitude (i.e., high, medium, low, low-low, and none, for CsI inventory release greater than 10 percent, between 1 and 10 percent, between 0.1 and 1 percent, less than 0.1 percent, and no release, respectively) of release. The “late” time category was not used, leaving nine release categories to which CET end-states were assigned (Swank, 2011). The definition for the “early” time category was changed from “less than 4 hours” assumed in the baseline analysis to “less than 3 hours” based on the latest CGS emergency action levels for declaring a general emergency and the latest evacuation time estimates. The CET end-states are assigned to one of the nine release categories. The frequency of each release category was obtained by summing the frequency of the individual accident progression CET endpoints binned into the release category. The characteristics of each release category are provided in Table 2-4 of the RAI responses, while the release category frequencies are provided in Tables A-3, A-4, and A-5 of the RAI responses for internal, fire, and seismic events, respectively (Gambhir, 2011).

Source-term release fractions were also developed for each of the nine release categories based on the results of plant-specific calculations using MAAP Version 4.0.4 (Gambhir, 2011). In response to an NRC staff RAI, Energy Northwest stated the CGS plant-specific MAAP calculations were revised to represent the current CGS configuration, and additional MAAP calculations were performed to support the development of CGS PSA Revision 7.1 (Gambhir, 2011). Energy Northwest also stated that the representative MAAP cases selected for the nine release categories are updated from those used in the baseline analysis, and a quantitative weighting evaluation was performed based on the dominant cutset contributors to, and the associated MAAP cases available for, each release category. Energy Northwest’s RAI response provides an example of how the quantitative weighting evaluation was performed for the H/E category and the logic for selecting the representative MAAP case for this release category. The resulting release characteristics are presented in Table 2.4 of the RAI response (Gambhir, 2011).

The NRC staff noted that the total release frequency determined from the individual release category frequencies provided in Tables A-3, A-4, and A-5 of the RAI responses (Gambhir, 2011) for internal, fire, and seismic events, respectively, are different than the corresponding CDFs reported in Table A-1 of the RAI responses. The staff asked Energy Northwest to clarify the reason for these differences (Doyle, 2011a). In response to the RAI, Energy Northwest explained that the CDF contribution from the "Containment Intact" (COK) release category was incorrect in these table and provided revised Tables A-3, A-4, and A-5 that corrected the errors (Swank, 2011). Energy Northwest also explained that the total release frequency for internal events from revised Table A-3 (i.e., 7.50E-6 per year) is slightly different from the internal events CDF of 7.4E-06 per year reported in Table F-1. This is because the CDF is determined from the sum of the minimal cutsets while the release frequency is determined from the sum of the release category frequencies.

As discussed previously for the PSA Revision 7.1 Level 1 PSA, the Level 2 model was included in the 2009 peer review of PSA Revision 7.0. Energy Northwest stated that F&Os from this peer review that could significantly impact the model quantification were incorporated into the Revision 7.1 model and concluded that resolution of the remaining unresolved F&Os from this review would not impact the SAMA analysis. Energy Northwest performed a sensitivity study using the Revision 7.1 PSA model (which integrates internal, fire, and seismic events) to assess the impact of these modeling updates on the results of the SAMA evaluation. The results of this sensitivity study are discussed throughout this appendix.

Based on the NRC staff's review of the Level 2 methodology, that Energy Northwest has adequately addressed NRC staff RAIs, that the Level 2 PSA model was reviewed in more detail as part of the 1997 BWR owners group peer review and a 2004 peer review, and that the findings from these peer reviews have been resolved and their impact assessed in a sensitivity analysis using the updated PSA model, the NRC staff concludes that the Level 2 PSA provides an acceptable basis for evaluating the benefits associated with various SAMAs.

As indicated in the ER, the reactor core radionuclide inventory used in the consequence analysis was based on the licensed thermal power of 3,486 MWt, the maximum rated power level limit for CGS for the extended period of operations.

The NRC staff reviewed the process used by Energy Northwest to extend the containment performance (Level 2) portion of the PSA to an assessment of offsite consequences (essentially a Level 3 PSA). This included consideration of the source terms used to characterize fission product releases for the applicable containment release categories and the major input assumptions used in the offsite consequence analyses. The MACCS2 code was used to estimate offsite consequences. Plant-specific input to the code includes the source terms for each release category and the reactor core radionuclide inventory (both discussed above), site-specific meteorological data, projected population distribution within an 80-km (50-mile) radius for the year 2045, emergency evacuation modeling, and economic data. This information is provided in Section E.6 of Attachment E to the ER (EN, 2010) and in response to NRC staff RAIs (Gambhir, 2010).

Releases were modeled as occurring at 13 meters (m) above ground level. The thermal content of each of the releases is assumed to be buoyant plume rise, except for intact containment which used an ambient release. Wake affects for the 70-m (246-ft) high and 45-m (148-ft) roughly square containment building were included in the model. Sensitivity analyses were performed for the elevation and release duration. Increasing the release height from 13–44 m for the large early and large late scrubbed releases increased the population dose risk and

offsite economic cost risk by less than 1 percent. Increasing the release duration to a maximum value of 24 hr (86,400 seconds) decreased the population dose risk by less than 1 percent and increased the offsite economic cost risk by less than 1 percent. Based on the information provided, the NRC staff concludes that the release parameters used are acceptable for the purposes of the SAMA evaluation.

Energy Northwest used site-specific meteorological data for the 2006 calendar year as input to the MACCS2 code. The development of the meteorological data is discussed in Section E.6.3 of Attachment E to the ER. The data were collected from the onsite meteorological tower located approximately 2,500 feet (ft) west of the reactor building. Data from 2003–2006 were considered, but the 2006 data were chosen because it was found to have the most complete set of data. A sensitivity analysis was performed using the year 2003 meteorological data. The results showed an increase in the population dose risk and offsite economic cost risk of less than 6.1 and 6.6 percent, respectively. In response to an NRC staff RAI, Energy Northwest explained that missing data were filled in depending on the span of unusable data (Gambhir, 2010). If the data gap was less than 10 hours, then the average value of the data on either side was used (for all data points). If the data gap was greater than 10 hours, then data from the previous and subsequent hours were used (one-half filled from the previous data and one-half filled from the subsequent data). The base case analysis assumed no perpetual rainfall in the last spatial segment of the model (40–50 mi). A sensitivity analysis performed using the maximum hourly rainfall from year 2006, 0.14 in. in one hour, showed that neither population dose risk nor offsite economic cost risk was affected. A second sensitivity case was performed using watershed indices of one (maximum runoff). The results showed no impact on the consequence metrics. The NRC staff notes that previous SAMA analysis results have shown little sensitivity to year-to-year differences in meteorological data and concludes that the approach taken for collecting and applying the meteorological data in the SAMA analysis is reasonable.

The population distribution the applicant used as input to the MACCS2 analysis was estimated for the year 2045 using year 2000 U.S. Census Bureau data, as presented in the CGS final safety analysis report (FSAR), and the expected annual population growth rate. This bounds the license renewal extension to year 2043. The population distribution was determined for each of 16 directions and each of 10 concentric rings based on the year 2000 census block data. The population estimate for the year 2045 was projected using a growth rate calculated based on county population projections (WOFM, 2007) and the 2000 U.S Census Bureau data (USCB, 2000a). The NRC staff noted that the population projections provided in Tables E.6-2 and E.6-3 of Appendix E of the ER are inconsistent and asked Energy Northwest to explain the reason for the differences between the two tables (Doyle, 2010a). In response to the RAI, Energy Northwest explained that Table E.6-2 is a population estimate based on Table 2.1-1 of the CGS FSAR, which shows a decreasing trend in population growth rate. Additionally, the population estimate in Table E.6-3, which was used for the SAMA evaluation, assumes a 14.2 percent per decade growth rate based on the State-wide Washington State census data (Gambhir, 2010). Energy Northwest further explained that Table E.6-2 was included in the ER to demonstrate the conservatism of the population projection in Table E.6-3, and the 14.2 percent per decade rate was used to estimate population growth for all sectors for Table E.6-3. Transient population was included within the 10-mi emergency planning zone (EPZ) of CGS. Sensitivity analyses were performed using the estimated year 2060 population assuming 14.2 percent per decade and 20 percent per decade population growth rates. This resulted in an increase in the population dose risk and offsite economic cost risk of approximately 19 percent and 15 percent, respectively, for the 14.2 percent per decade case and an increase of approximately 57 percent and 46 percent, respectively, for the 20 percent

per decade case. A sensitivity analysis was also performed assuming an increase of 16 persons in the base 0–1 mi EPZ zone population. This resulted in no change in the population dose risk and less than 1 percent increase in the offsite economic cost risk. The NRC staff considers the methods and assumptions for estimating population reasonable and acceptable for purposes of the SAMA evaluation.

Emergency evacuation was modeled as a single evacuation zone extending out 16 km (10 mi) from the plant. Energy Northwest assumed that 95 percent of the population would evacuate. This assumption is conservative relative to the NUREG-1150 study (NRC, 1990a), which assumed evacuation of 99.5 percent of the population within the EPZ. The evacuated population was assumed to move at an average speed of approximately 2.4 meters per second (m/s) (5.4 mi per hour (mph)) with a delayed start time of 50 minutes after declaration of a general emergency. In response to an NRC staff RAI, Energy Northwest performed a sensitivity study assuming a 15 minute notification delay and an evacuation delay time of 60 minutes (Gambhir, 2010). The results showed no impact on the population dose risk or offsite economic cost risk. Two additional sensitivity analyses were performed in which the evacuation speed was decreased to 2.1 m/s (4.7 mph) and reduced by a factor of 2 to 1.2 m/s (2.7 mph). The results showed no change in the population dose risk or offsite economic cost risk. This was attributed to the low EPZ population. The NRC staff concludes that the evacuation assumptions and analysis are reasonable and acceptable for the purposes of the SAMA evaluation.

Site-specific economic data were provided from the 2002 Census of Agriculture (USDA, 2004a), (USDA, 2004b) for each of the five counties surrounding the plant to a distance of 50 mi. These included the fraction of land devoted to farming, annual farm sales, fraction of farm sales resulting from dairy production, value of farm and non-farm land, and information on regional crops. In addition, generic economic data that apply to the region as a whole were taken from the MACCS2 sample problem input. The daily cost of compensating people for evacuating and relocating was developed from cost data for Washington and Oregon (Oregon, 2002), (USCB, 2000a), (USCB, 2000b), (USGSA, 2008), (Washington, 2002). In response to an NRC staff RAI, Energy Northwest clarified that no escalation was applied to the MACCS2 sample problem input, and a sensitivity study was performed using an escalation factor of 4.1 percent from 1993–2008 (Gambhir, 2010). Applying this escalation factor to the MACCS2 economic data resulted in less than a 1 percent increase in the total benefit for each SAMA analysis case. The NRC staff noted that the default MACCS2 growing season was assumed and asked Energy Northwest to assess the impact of this assumption on the SAMA evaluation (Doyle, 2010a). In response to the RAI, Energy Northwest confirmed that the growing season within the EPZ is longer than the assumed default growing season and performed a sensitivity analysis assuming a longer regional growing season of 302 days (Gambhir, 2010). The results showed no change in population dose risk or offsite economic cost risk. The ER provides the results of a sensitivity analysis of the sheltering shielding factors assumed in the MACCS2 analyses. For this analysis, the sheltering shielding factors were changed from the MACCS2 default assumptions to the minimum values suggested by NUREG/CR-4551 (NRC, 1990b). The results showed no change in the population dose risk and offsite economic cost risk.

The NRC staff concludes that the methodology used by Energy Northwest to estimate the offsite consequences for CGS provides an acceptable basis from which to proceed with an assessment of risk reduction potential for candidate SAMAs. Accordingly, the NRC staff based its assessment of offsite risk on the CDF and offsite doses reported by Energy Northwest.

F.3 Potential Plant Improvements

The process for identifying potential plant improvements, an evaluation of that process, and the improvements evaluated in detail by CGS are discussed in this section.

F.3.1 Process for Identifying Potential Plant Improvements

Energy Northwest's process for identifying potential plant improvements (SAMAs) consisted of the following elements:

- review of the dominant cutsets and most significant plant systems from the current, plant-specific Level 1 internal events PSA
- review of the most significant IEs and sequences from the current, plant-specific Level 2 internal events PSA contributing to each release category
- review of potential plant improvements and PSA insights identified in the CGS IPE and IPEEE
- review of SAMA candidates identified for LRAs for selected BWR plants
- review of other industry documentation discussing potential plant improvements

Based on this process, an initial set of 150 candidate SAMAs, referred to as Phase I SAMAs, was identified. Subsequently, after further review of the IPEEE, one of these SAMA candidates was further divided into two SAMA candidates, resulting in a total of 151 Phase I SAMAs. In Phase I of the evaluation, Energy Northwest performed a qualitative screening of the initial list of SAMAs and eliminated SAMAs from further consideration using the following criteria:

- The SAMA is not applicable to CGS due to design differences or it has already been implemented at CGS (66 SAMAs screened).
- The SAMA was determined to provide very little benefit (36 SAMAs screened).
- The SAMA is similar to another SAMA under consideration and was subsumed into the similar SAMA (7 SAMAs screened).
- The SAMA has estimated implementation costs that would exceed the dollar value associated with eliminating all severe accident risk at CGS (15 SAMAs screened).

Based on this screening, 123 SAMAs were eliminated, leaving 28 for further evaluation. The remaining SAMAs, referred to as Phase II SAMAs, are listed in Table E.11-7 of Attachment E to the ER (EN, 2010). In Phase II, a detailed evaluation was performed for each of the 28 remaining SAMA candidates, as discussed in Sections F.4 and F.6 below.

As previously discussed in Section F.2.2, the risk reduction benefits associated with internal, fire, and seismic events were separately estimated by Energy Northwest using the internal events, fire events, and seismic events PSA models, respectively. Energy Northwest accounted for the potential risk reduction benefits associated with HFO events by assuming that the contribution from HFO events was the same as that from internal events. The estimated SAMA benefits for internal events, fire events, seismic events, and HFO events were then summed to provide an overall benefit.

F.3.2 Review of CGS's Process

Energy Northwest's efforts to identify potential SAMAs focused primarily on areas associated with internal IEs but also included explicit consideration of potential SAMAs for fire and seismic events. The initial list of SAMAs generally addressed the accident sequences considered to be important to CDF from functional, initiating event, and RRW perspectives at CGS.

Energy Northwest's SAMA identification process began with a review of the list of potential BWR enhancements in Table 13 of NEI 05-01 (NEI, 2005). Review of this generic SAMA list resulted in 144 SAMAs being identified. The one SAMA from the generic SAMA list not included as a CGS SAMA was for an ice condenser plant, which is not applicable to CGS.

For the Level 1 internal events PSA, Energy Northwest provided tabular listings of the top 100 cutsets sorted according to their contribution to CDF, representing over 56 percent of the Level 1 CDF, and the CGS plant systems having an RRW of 1.0 or greater, sorted according to their RRW (EN, 2010). From the cutsets, Energy Northwest identified the significant contributors and the SAMA candidates that address each of these contributors. Energy Northwest also identified SAMA candidates addressing the CGS systems having the highest RRW values. In response to an NRC staff RAI, Energy Northwest stated that one SAMA candidate, SAMA AC/DC-29, "replace EDG-3 with a diesel diverse from EDG-1 and EDG-2," was identified as a result of a review of the top 100 cutsets (Gambhir, 2010).

The NRC staff noted that the list of top 100 cutsets from the Level 1 PSA identified many operator errors and non-recovery actions and asked Energy Northwest to explain why no plant-specific SAMAs, such as procedure improvements, were identified to address these human failure events (Doyle, 2010a). In response to the RAI, Energy Northwest explained that significant HRA model improvements and procedure enhancements were made to the PSA to incorporate F&Os from the 2004 PSA peer review. Additionally, a review of the important HEPs determined that the Phase I SAMAs identified from the generic industry SAMA list addressed these important human errors, most of which were already implemented at CGS (Gambhir, 2010). Energy Northwest also noted that considerable emphasis has been placed on improving procedures in order to improve operator response at CGS and that its review of CGS procedures did not identify additional inherent weaknesses that could be removed by enhancements to improve operator actions. To support this assessment, Energy Northwest provided a list of important HEPs that have had either risk modeling improvements or procedural enhancements and showed that, in PSA model Revision 7.1, the risk of the most risk-important operator errors based on RRW have significantly decreased. While no new SAMAs were identified to address specific risk-important HEP basic events, Energy Northwest noted that new SAMA OT-07R, "increase operator training on systems and operator actions determined to be important from the PSA," was identified in a separate NRC staff RAI (see below) to assess if a general training and procedural update associated with time critical and high risk important operator actions would be cost-beneficial. Energy Northwest provided a Phase II evaluation of this SAMA using PSA model Revision 7.1, the results of which are provided in Table F-11 and further discussed in Section F.6.2 (Gambhir, 2011).

For the Level 2 PSA model, Energy Northwest identified the major contributors to each of the dominant release categories, representing approximately 100 percent of the population dose-risk (EN, 2010). Energy Northwest also identified the SAMA candidates that address the major contributors to release category LEN. The NRC staff asked Energy Northwest to review each of the major contributors to each of the dominant release categories and identify the SAMA candidates that address each of the contributors (Doyle, 2010a). Energy Northwest

responded to the RAI by identifying the SAMA candidates that address the major contributors to release categories LLN and LLS (Gambhir, 2010). No new SAMA candidates were identified from this review.

The NRC staff noted that, although the ER discusses a Level 1 basic events importance analysis and presents high-level insights, it does not provide a basic events importance listing or discuss a Level 2 importance analysis. As a result, the staff asked Energy Northwest to provide Level 1 and 2 importance lists and assess each important basic event for potential SAMAs (Doyle, 2010a). Energy Northwest responded by providing tabular listings of the PSA model Revision 7.1 Level 1 and LERF internal events basic events sorted according to their RRW (Gambhir, 2011). SAMAs impacting these basic events would have the greatest potential for reducing risk. Energy Northwest used an RRW cutoff of 1.025, which corresponds to about a 2.5 percent change in internal events CDF given 100-percent reliability of the equipment or human actions affected by the SAMA. This equates to an internal events benefit of approximately $12,000, the minimum cost of a procedure change at CGS (Gambhir, 2011). Energy Northwest correlated the CDF and LERF events with the SAMAs identified in the ER and in response to other NRC staff RAIs, and it showed that, with some exceptions, all of the significant basic events are addressed by one or more SAMAs. The additional SAMAs identified from this review are as follows:

- SAMA AT-15R, “install modifications to make use of high pressure core spray (HPCS) more likely for ATWS”
- SAMA FL-07R, “protect the HPCS from flooding resulting from ISLOCA events”
- SAMA OT-09R, “for the non-LOCA initiating events, credit the Z (Power Coversion System recovery) function”
- SAMA CB-10R, “provide additional non-destructive evaluation (NDE) and inspections of main steam (MS) piping in Turbine Building”

These SAMAs are included in Table F-11 and are discussed further in Section F.6.2. If a basic event of high risk importance is not addressed by a SAMA, that is because one of the following is true regarding the basic event (Gambhir, 2011):

- It has an RRW value that is too low or the potential enhancement has an implementation cost that is too high to result in a cost-beneficial SAMA.
- It was determined to have no feasible SAMA that would further reduce risk.
- It requires a hardware modification but has an RRW benefit value that is well below the $100,000 minimum implementation cost for a hardware modification.
- It is a LERF-based success event

Based on this additional information, the NRC staff agrees that cost-beneficial improvements for these basic events are unlikely.

Although the IPE did not identify any fundamental vulnerabilities or weaknesses related to internal events, Energy Northwest considered the potential plant improvements described in the IPE in the identification of plant-specific candidate SAMAs for internal events. The CGS IPE identified nine improvements associated with core damage as follows (Parrish, 1994):

(1) modify the isolated phase buses to allow expeditious alignment of the 500 kilovolt (kV) highline to the plant AC distribution system via the main step-up transformer

(2) increase the capacity of the 230 kV/115kV plant bus transfer

(3) install an additional battery charger

(4) evaluate potential improvements to procedures and training for the recognition and isolation of floods identified to cause multiple system failures

(5) evaluate potential improvements to maintenance practices to ameliorate CCFs

(6) modify emergency procedures to allow use of the automatic depressurization system inhibit switch in non-ATWS scenarios

(7) evaluate potential improvements in the SBO emergency procedure to prevent unwanted depressurization

(8) evaluate performing periodic inspection and maintenance of the Omega seal separating the drywell and wetwell air spaces

(9) modify the air supply to the inboard MSIVs and the containment vent valves for backup from the containment N_2 system

Energy Northwest stated in the ER that Improvements 4, 6, and 7 have been implemented at CGS. Additionally, SAMA candidates AC/DC-27, “install permanent hardware changes that make it possible to establish 500 kV backfeed through the main step-up transformer,” and AC/DC-28, “reduce common cause failures (CCFs) between EDGs EDG-3 and EDG-1/2,” were identified to address Improvements 1 and 5, respectively (EN, 2010). Energy Northwest further stated that Improvement 3 has been partially implemented, but, since battery chargers are not significant contributors to risk, no SAMA is considered for this improvement. The NRC staff agrees that since battery chargers were not identified as risk significant in the importance analysis described previously, a SAMA to address IPE Improvement 3 is unlikely to be cost-beneficial.

Energy Northwest reported that a cost-benefit analysis had previously been performed for Improvement 2 and determined the modification to not be cost-effective. The NRC staff asked Energy Northwest to provide a summary and scope of this cost-benefit analysis (Doyle, 2010a). In response to the RAI, Energy Northwest explained that the cost-benefit analysis focused on increasing the capacity of the 230 kV startup transformer since it is the primary offsite power source, and its loading has less margin than the 115 kV transformer. The decrease in CDF from the modification was estimated to be 7.0E-07 per year in Revision 1 of the IPE. The analysis assumed a benefit of $250,000 for each decrease of 1.0E-06 per year in CDF. The implementation cost of the modification was estimated to be $2 million. Since the implementation cost was greater than the estimated benefit, the modification was determined not to be cost effective (Gambhir, 2010). Energy Northwest also noted that SAMA AC/DC-27 represents a similar SAMA in terms of cost and benefit. The NRC staff considers Energy Northwest’s clarification reasonable and agrees that, based on Energy Northwest’s evaluation of AC/DC-27, a SAMA to address IPE Improvement 2 is unlikely to be cost-beneficial.

The ER did not address IPE Improvement 8. Since failure of the drywell-to-wetwell Omega seal is not identified as a risk-important system on the RRW listings discussed previously, the NRC staff concludes that a SAMA to address IPE Improvement 8 is unlikely to be cost-beneficial.

The ER did not address IPE Improvement 9. The NRC staff noted that Revision 1 of the IPE identifies this improvement as being marginally cost effective and that the improvement could increase in importance if the other IPE-identified improvements were implemented. Considering that many of the improvements were indeed implemented, the NRC staff asked Energy Northwest to provide an assessment of a SAMA to address IPE Improvement 9 (Doyle, 2010a). In response to the RAI, Energy Northwest explained that the change in CDF by making gas supply to the MSIVs perfect is negligible (RRW = 1.000) and, therefore, a SAMA to do this was screened from further consideration (Gambhir, 2010). Energy Northwest also explained that a procedure to use portable N_2 bottle(s) to manually open the containment vent valves was developed, the RRW for the air supply to the containment vent valves is 1.0002, and the PSA was not updated to incorporate the procedure because of its low risk significance. Therefore, because of the low-risk benefit, a SAMA to provide another air or N_2 supply to the containment vent valves was screened from further consideration. Based on the low risk significance of the air supply to the MSIVs and containment vent valves, the NRC staff agrees that a SAMA to address IPE Improvement 9 is unlikely to be cost-beneficial.

Energy Northwest reviewed the Phase II SAMAs from prior SAMA analyses for 12 General Electric BWR sites and stated in the ER that no additional SAMAs were identified from this review (EN, 2010). The NRC staff noted that Table E.9-3 of the ER identifies two SAMAs that appear to have been identified from the review of prior SAMA analyses and asked Energy Northwest to clarify this discrepancy (Doyle, 2010a). In response to an NRC staff RAI, Energy Northwest stated that two of the SAMAs identified in the ER were identified from this review (Gambhir, 2010). The NRC staff also asked Energy Northwest to provide an assessment of the applicability of each of the cost-beneficial SAMAs from the 12 BWR sites to CGS (Doyle, 2010a). In response to the RAI, Energy Northwest provided the results of the review of the 72 cost-beneficial SAMAs from the prior SAMA analyses. Energy Northwest concluded that 21 are not applicable to CGS, 26 are already implemented at CGS or were screened on very low benefit, 10 had already been identified and evaluated in the ER, 1 was identified and evaluated in response to a separate NRC staff RAI (SAMA FR-08 discussed below), 10 were evaluated further in the Phase II evaluation, and the remaining were duplicate SAMAs identified in more than one of the prior SAMA analyses (Gambhir, 2010), (Gambhir, 2011). The 10 SAMAs identified and evaluated further are as follows:

- SAMA FW-05R, “examine the potential for operators to control reactor feedwater (RFW) and avoid a reactor trip”
- SAMA FL-04R, “install one isolation valve in each of standby service water (SW), plant service water (TSW), and fire protection (FP) lines in the Control Building area of the Radwaste Building to facilitate rapid isolation by the operators upon receipt of a high flow alarm”
- SAMA FL-05R, “install three clamp-on flow instruments to certain drain lines in the Control Building area of the Radwaste Building and alarm in the Control Room”
- SAMA FL-06R, “perform additional NDE inspections to the three lines identified in SAMA FL-04R to verify that degradation is not occurring in these lines”
- SAMA CC-24R, “backfeed the HPCS system with [emergency bus] SM-8 to provide a third power source for HPCS”
- SAMA CC-25R, “enhance alternate injection reliability by including residual heat removal service water and fire water crosstie in maintenance program”
- SAMA CC-26R, “install hard pipe from diesel fire pump to vessel”

- SAMA OT-07R, “increase operator training on systems and operator actions determined to be important from the PSA”
- SAMA OT-08R, “install explosion protection around CGS transformers”
- SAMA OT-10R, “increase fire pump house building integrity to withstand higher winds so the fire system will be capable of withstanding a severe weather event”

These SAMAs are included in Table F-11 and are discussed further in Section F.6.2.

Based on this information, the NRC staff concludes that the set of SAMAs evaluated in the ER, together with those identified in response to NRC staff RAIs, addresses the major contributors to internal event CDF.

Energy Northwest also provided a tabular listing of the Level 1 fire PSA basic events sorted according to their RRW (EN, 2010). Energy Northwest used an RRW cutoff of 1.000, which corresponds to less than a 0.1 percent change in CDF given 100-percent reliability of the SAMA. Energy Northwest also provided a listing of the fire compartments representing over 98 percent of the fire CDF. No additional SAMAs were identified from this review.

The NRC staff asked Energy Northwest to identify and evaluate SAMAs to address each of the risk significant Level 1 fire basic events. In a separate RAI, the NRC staff asked Energy Northwest to provide a listing of the risk significant Level 2 fire basic events and assess each important basic event for potential SAMAs (Doyle, 2010a). In response to the RAIs, Energy Northwest provided the following using PSA model Revision 7.1 (Gambhir, 2010), (Gambhir, 2011):

- a tabular listing of Level 1 fire PSA basic events sorted first according to RAW and then according to their RRW
- a second tabular list of Level 1 fire PSA basic events sorted according to their RRW
- a tabular list of LERF fire basic events

In these listings, Energy Northwest used an RRW cutoff of 1.015, which corresponds to about a 1.5 percent decrease in fire CDF given 100-percent reliability of the equipment or human actions affected by the SAMA. This equates to a fire events benefit of approximately $12,000, the minimum cost of a procedure change at CGS. For each basic event listed, Energy Northwest correlated the CDF and LERF events with the SAMAs identified in the ER and with several newly identified SAMAs and showed that, with some exceptions, all of the significant basic events are addressed by one or more SAMAs. The additional SAMAs identified from this review are as follows:

- SAMA FR-09R, “install early detection for FR1J (physical analysis unit R-1J) and FR1D (physical analysis unit R-1D)”
- SAMA FR-10R, “install early detection in the Control Room (RC-10)”
- SAMA FR-11R, “install early detection for FW14 (analysis unit RC-14), FW04 (analysis unit RC-04), FW11 (analysis unit RC-11), FW03 (analysis unit RC-03), FW08 (analysis unit RC-08), FW05 (analysis unit RC-05), FW02 (analysis unit RC-02), FW13 (analysis unit RC-13), and FW1A (analysis unit RC-1A)”
- SAMA FR-12R, “install early detection for FT1A (physical analysis unit T-1A) and FT12 (physical analysis unit T-12)”

- SAMA AC/DC-30R, “provide an additional diesel generator (DG) diverse from DG-1 and DG-2”

These SAMAs are included in Table F-11 and are discussed further in Section F.6.2. If a basic event of high risk importance is not addressed by a SAMA, that is because one of the following is true in regard to the basic event:

(1) It requires a hardware modification, but it has an RRW benefit value that is well below the $100,000 minimum implementation cost for a hardware modification.

(2) It was determined to have no feasible or viable SAMA that would further reduce risk.

(3) It has no physical meaning or is a parameter required for modeling purposes (such as split fractions, fire source partitioning factors, ratios of fixed source to total source in fire zone, phenomenological values, and success terms).

(4) It is an event for which a plant modification is already being implemented to improve equipment reliability.

(5) It is a LERF-based success event.

(6) It was judged to not be a realistic contribution to risk because the fire PSA conservatively does not credit the air accumulators installed at each of the SRVs.

Regarding Item 6, the NRC asked that Energy Northwest provide an assessment of what the RRW values would be for the associated basic events if the air accumulators were credited (Doyle, 2010c). In response to the RAI and the sensitivity study of PSA Revision 7.1, Energy Northwest showed that each of the fire basic events in question is, in fact, addressed by an existing SAMA (Gambhir, 2010), (Gambhir, 2011). Based on this additional information, the NRC staff agrees that cost-beneficial improvements are unlikely for those basic events for which no SAMA was identified.

The NRC staff also asked Energy Northwest to identify and evaluate SAMAs to address each of the risk significant Level 1 and 2 seismic basic events (Doyle, 2010a). In response to the RAI, Energy Northwest provided tabular listings of the PSA model Revision 7.1 Level 1 and LERF seismic basic events sorted according to their RRW (Gambhir, 2011). SAMAs impacting these basic events would have the greatest potential for reducing risk. Energy Northwest used an RRW cutoff of 1.03, which corresponds to about a 3 percent reduction in seismic CDF given 100-percent reliability of the SAMA. This equates to a seismic events benefit of approximately $12,000, the minimum cost of a procedure change at CGS (Gambhir, 2011). Energy Northwest correlated the CDF and LERF events with the SAMAs identified in the ER and in response to RAIs and showed that, with a few exceptions, all of the significant basic events are addressed by one or more SAMAs. No additional SAMA candidates were identified from this review. For the exceptions in which a basic event of risk importance is not addressed by a SAMA, Energy Northwest explained that this is because the basic event requires hardware modifications for multiple components but has an RRW benefit value that is well below the implementation cost for multiple hardware modifications or has no physical meaning or is a parameter required for modeling purposes (such as split fractions and success terms). Based on this additional information, the NRC staff agrees that cost-beneficial improvements for these basic events are unlikely.

In a followup RAI, the NRC staff noted that the Level 1 and Level 2 seismic basic events importance lists identify only a few basic events and asked Energy Northwest to explain why this is the case (Doyle, 2011a). In response to the RAI, Energy Northwest explained that the

seismic PSA model includes random failures but that none of these events showed up in the lists because the random failure events had RRW values less than the 1.03 value used as a cutoff for identifying important basic events (Swank, 2011).

In another followup RAI, the NRC staff noted that the importance analyses reviews performed for internal, fire, and seismic events only addressed CDF and LERF and asked Energy Northwest to provide a review of risk-important basic events for release categories H/I and M/I, which are also significant contributors to the CGS dose-risk (Doyle, 2011a). In response to the RAI, Energy Northwest provided a tabular listing of PSA model Revision 7.1 internal, fire, and seismic basic events contributing to the H/I and M/I release categories that were either not included in the Level 1 and LERF importance analyses discussed previously or whose resolution for the basic event changed (Swank, 2011). Basic events that were found to be events that had no physical meaning (such as flag events and phenomenological events) were not included in the listing. Energy Northwest developed separate basic event listings for internal, fire, and seismic basic events contributing to the H/I and M/I release categories and used RRW cutoffs for each corresponding to a basic event benefit of approximately $12,000, the minimum cost of a procedure change at CGS. Energy Northwest correlated the H/I and M/I basic events with the SAMAs identified in the ER and in response to RAIs and showed that, with a few exceptions, all of the basic events are addressed by one or more SAMAs. No additional SAMA candidates were identified from this review. For the exceptions in which a basic event of risk importance is not addressed by a SAMA, Energy Northwest explained that the reasons for this are as follows:

- No feasible SAMA was identified to address the basic event.
- The only feasible SAMA candidate for the basic event had essentially already been implemented.
- The basic event is a basic PSA model assumption that is not a candidate for a SAMA.

Based on this additional information, the NRC staff agrees that cost-beneficial improvements for these basic events are unlikely.

Although the IPEEE did not identify any fundamental vulnerabilities or weaknesses related to external events, four improvements related to internal fire events, six improvements related to seismic events, and one improvement related to high winds, floods, and other (HFO) external events were identified. All of these improvements have been resolved as either having been implemented (seven improvements) or determined to not be necessary based on an engineering evaluation that determined the existing design or procedure or both was adequate (three improvements), or determined to not be necessary based on a cost-benefit evaluation (one improvement) (NRC, 2001).

Regarding the last improvement, which is to strengthen the motor control center (MCC) base connections, the NRC staff asked Energy Northwest to justify not including it as a SAMA, especially considering that the seismic hazard curve has changed since the IPEEE (Doyle, 2010a). Energy Northwest responded that the newer seismic hazard curves, as discussed in Section F.2.2, have been shown to be consistent with the CGS seismic hazard curves used for the seismic PSA and that the fragility of the MCCs has, therefore, not changed (Gambhir, 2010). Nevertheless, Energy Northwest identified SAMA SR-05R, “improve seismic ruggedness of MCC-7F and MCC-8F,” to address this issue. This SAMA is included in Table F-11 and is discussed further in Section F.6.2.

Energy Northwest also reviewed the PSA insights from the CGS IPEEE for fire events, seismic events, and other external events. The review of the fire PSA insights indicated that the dominant fire sequences render containment venting, the power conversion system, and one train of RHR or service water unavailable. Based on the review of these insights, Energy Northwest identified one additional SAMA candidate to improve the fire resistance of critical cables (SAMA FR-07). This SAMA candidate was subsequently divided into two SAMA candidates, one to protect the containment vent valve cables from fires (SAMA FR-07a) and the second to protect the transformer E-TR-S cables from fires (SAMA FR-07b).

The NRC staff noted that both SAMAs FR-07a and FR-07b were determined to be cost-beneficial in the Phase II evaluation and asked Energy Northwest to provide an evaluation of a SAMA to protect RHR and service water cables from fires (Doyle, 2010a), (Doyle, 2010c). In response to the RAI, Energy Northwest stated that since CGS electrical cabling is currently protected from fire to manually shutdown in the RHR alternate shutdown mode (Appendix R), a SAMA was identified and evaluated to provide additional protection from MSOs in auto initiation circuits of RHR and service water (Gambhir, 2010), (Gambhir, 2011). This SAMA, SAMA FR-08, “improve the fire resistance of cables to RHR and SW,” is included in Tables F-10 and F-11 and is discussed further in Section F.6.2.

Based on the applicant’s IPEEE, the review of the results of the CGS PSA, which includes seismic and fire events, and the expected cost associated with further risk analysis and potential plant modifications, the NRC staff concludes that the opportunity for seismic and fire-related SAMAs has been adequately explored. The staff finds that it is unlikely that there are any additional cost-beneficial seismic or fire-related SAMA candidates.

As stated earlier, other external hazards (high winds, external floods, volcanic activity, transportation and nearby facility accidents, and other external events) are below the IPEEE threshold screening frequency, or met the 1975 SRP design criteria, and are not expected to represent opportunities for cost-beneficial SAMA candidates.

For many of the Phase II SAMAs listed in the ER, the information provided did not sufficiently describe the proposed modification. Therefore, the NRC staff asked the applicant to provide more detailed descriptions of the modifications and cost estimates for several of the Phase II SAMA candidates (Doyle, 2010a). In response to the RAI, Energy Northwest provided the requested information (Gambhir, 2010). This is discussed further in Section F.5.

The NRC staff questioned Energy Northwest about lower cost alternatives to some of the SAMAs evaluated (Doyle, 2010a), including the following:

- establishing procedures for opening doors or using portable fans for sequences involving room cooling failures, such as the EDG room
- using a portable independently powered pump to inject into containment
- using the security diesel generator or EDG-4 to extend the life of the 125-V DC batteries
- using a portable generator to provide power to individual 125-V DC MCCs upon loss of a DC bus to improve availability of HPCS

In response to the RAI, Energy Northwest addressed the suggested lower cost alternatives (Gambhir, 2010). This is discussed further in Section F.6.2.

Energy Northwest's Phase I SAMA screening process initially eliminated 124 SAMAs using the criteria discussed in Section F.3.1, leaving 27 for further evaluation. Phase I SAMA SR-01, "increase seismic ruggedness of standby service water (SSW) pumps and RHR heat exchangers," while originally retained for further evaluation was subsequently screened after further consideration and the determination that it would provide very little benefit, thus reducing to 26 the number of SAMAs retained for further evaluation. Three SAMAs—SAMA CB-03, "increase leak testing of valves in ISLOCA paths," SAMA CB-08, "revise emergency operating procedures (EOPs) to improve ISLOCA identification," and SAMA CB-09, "improve operator training on ISLOCA coping"—were originally screened because they were similar to another SAMA but were subsequently included for further evaluation, raising the total to 29 SAMAs retained for further evaluation.

The NRC staff noted that Phase I SAMA CC-21, "revise procedure to align LPCI or core spray to CST on loss of suppression pool cooling," was not eliminated in the Phase I screening evaluation but was not included in the Phase II detailed evaluation and asked Energy Northwest to clarify the screening of this SAMA (Doyle, 2011a). In response to the RAI, Energy Northwest explained that CGS has the following existing water sources from which to provide injection (Swank, 2011):

- service water cross-connect to the RHR system
- fire water through a cross-connect to a condensate booster pump and through a fire hose connection to LPCI piping
- condensate from the hotwell with makeup from the CST via multiple pathways

Energy Northwest further explained that CGS has a direct gravity drain from the CST to both the HPCS and RCIC pumps and that, therefore, CST inventory would only be available for low pressure injection on loss of these systems prior to CST inventory depletion. Based on the ability to provide injection from alternative sources through multiple pathways that are proceduralized, Energy Northwest screened SAMA CC-21, leaving 28 for further evaluation. Based on this information, the NRC staff agrees that SAMA CC-21 is unlikely to be cost-beneficial.

The NRC staff noted that many Phase I SAMAs were screened on very low benefit without an assessment of the RRW for the systems being addressed and asked that Energy Northwest provide the RRW for each of these SAMAs (Doyle, 2010a). Energy Northwest responded by providing an assessment of the RRW, risk significance, or reliability of the systems addressed by each Phase I SAMA screened on very low benefit and concluded that all of these SAMAs were appropriately screened on very low benefit (Gambhir, 2010). Based on this additional information, the NRC staff agrees that the Phase I SAMAs screened on very low benefit are unlikely to be cost-beneficial improvements.

The NRC staff observed that the screening of SAMA FW-04, "add a motor-driven feedwater (FW) pump," in the Phase I evaluation on very low benefit appeared to be based on FW unavailability being more sensitive to loss of flow from the condensate booster pumps and FW pumps than from independent or CCFs of the FW pumps. The staff asked that Energy Northwest justify the screening of the SAMA (Doyle, 2010a). In response to the RAI, Energy Northwest clarified that the top 79 percent of contributors to RFW unavailability are factors other than the RFW pumps and that, as a result, it was concluded that adding an additional motor-driven RFW pump would add little benefit relative to the cost incurred (Gambhir, 2010). Nevertheless, Energy Northwest observed that the importance of RFW has increased in PSA

model Revision 7.1 and provided a Phase II evaluation of SAMA FW-04. This SAMA is included in Table F-11 and is discussed further in Section F.6.2.

The NRC staff noted that Section 9.2 of the ER indicates two seismic SAMA candidates were evaluated, yet only one seismic SAMA was included in the Phase II evaluation. The staff asked that Energy Northwest clarify this discrepancy (Doyle, 2010a). Energy Northwest responded that SAMA SR-01, "increase seismic ruggedness of SSW pumps and RHR heat exchangers," was originally assessed during the Phase I screening evaluation to be included in the Phase II evaluation, but it was subsequently screened after a more detailed evaluation determined that strengthening the RHR heat exchangers and SSW pumps would provide very little benefit (Gambhir, 2010). The NRC staff considers Energy Northwest's clarification reasonable.

The NRC staff notes that the set of SAMAs submitted is not all-inclusive, since additional, possibly even less expensive, design alternatives can always be postulated. However, the NRC staff concludes that the benefits of any additional modifications are unlikely to exceed the benefits of the modifications evaluated, and the alternative improvements would not likely cost less than the least expensive alternatives evaluated when the subsidiary costs associated with maintenance, procedures, and training are considered.

The NRC staff concludes that Energy Northwest used a systematic and comprehensive process for identifying potential plant improvements for CGS, and the set of SAMAs evaluated in the ER, together with those evaluated in response to NRC staff inquiries, is reasonably comprehensive and, therefore, acceptable. This search included reviewing insights from the plant-specific risk studies, including internal initiated events as well as fire and seismic initiated events, and reviewing plant improvements considered in previous SAMA analyses.

F.4 Risk Reduction Potential of Plant Improvements

Energy Northwest evaluated the risk-reduction potential of the 28 remaining SAMAs that were applicable to CGS. The majority of the SAMA evaluations were performed in a bounding fashion in that the SAMA was assumed to eliminate the risk associated with the proposed enhancement. Such bounding calculations overestimate the benefit and are conservative.

Energy Northwest used model re-quantification to determine the potential benefits. The CDF and population dose reductions were estimated using the CGS internal events PSA Revision 6.2 model for internal events, the CGS fire PSA Revision 2 model for fire events, and the CGS seismic PSA Revision 1 model for seismic events. The changes made to the models to quantify the impact of SAMAs are detailed in Table E.11-1 of Attachment E to the ER (EN, 2010). Table F-10 lists the assumptions considered in the ER to estimate the risk reduction for each of the evaluated SAMAs, the estimated risk reduction in terms of percent reduction in CDF and population dose, and the estimated total benefit (present value) of the averted risk. The estimated benefits reported in Table F-10 reflect the combined benefit in both internal and external events. The determination of the benefits for the various SAMAs is further discussed in Section F.6.

The NRC staff noted that the risk reduction for many SAMAs was reported to be 0.00E+00 and asked Energy Northwest to clarify if the results for these SAMAs were actually zero or if the results are negligible and, if actually zero, to specifically justify the zero risk reduction reported for four of the SAMAs (Doyle, 2010a). In response to the RAI, Energy Northwest clarified that the reduction in CDF was calculated for CDF results reported to four significant digits and that, therefore, the 0.00E+00 values reported in Table E.11-1 of the ER are known to be zero in

almost every instance (Gambhir, 2010). Energy Northwest further identified two specific SAMAs where the change in CDF was judged to be negligible but reported to be 0.00E+00 in Table E.11-1 of the ER. The two SAMAs—SAMA CB-01, "install additional pressure or leak monitoring instruments for detection of ISLOCAs," and SAMA SR-03, "modify safety related CST"—were reported to have a 0.00E+00 reduction in internal events and seismic events CDF, respectively, when the reduction in each of these CDFs was actually calculated to be 1.0E-09 per year. Energy Northwest also justified the reported 0.00E+00 risk reduction reported for the following SAMAs, as requested by NRC staff in the RAI:

- SAMA AC/DC-01, "provide additional DC battery capacity," with a reported reduction in fire CDF of 0.00E+00—Energy Northwest explained that this SAMA would increase the time for recovery of offsite power during an SBO and that the fire PSA assumes that recovery of fire-induced offsite power is not feasible in the near term. Therefore, there is no risk reduction from providing additional DC power capacity for fire events (Gambhir, 2010).
- SAMA CC-20, "improve ECCS suction strainers," with a reported reduction in internal events, fire, and seismic CDFs of 0.00E+00—Energy Northwest explained that modeling of the suction strainers was incomplete in PSA model Revision 6.2 because each of the redundant suction strainers was modeled as independent from one another. Therefore, no reduction in CDF was calculated (Gambhir, 2010). Energy Northwest noted that modeling of the suction strainers was improved in PSA model Revision 7.1 to include CCFs in response to a Level C F&O from the 2004 peer review. The sensitivity study using PSA model Revision 7.1 does report a non-zero reduction in internal event CDF for this SAMA, as provided in Table F-11 (Gambhir, 2011).
- SAMA CB-01, "install additional pressure or leak monitoring instruments for detection of ISLOCAs," with a reported reduction in internal events, fire, and seismic CDFs of 0.00E+00—Energy Northwest clarified that the risk reduction in internal events CDF was actually calculated to be 1.0E-09 per year as a result of eliminating the ISLOCA contribution but was reported to be 0.00E+00 in Table E.11-1 of the ER (Gambhir, 2010). Energy Northwest further explained that the fire PSA does not currently model the potential for fire-induced ISLOCA but that this area of model incompleteness is judged to be a negligible contributor to fire CDF. The reason for this is that an ISLOCA in the shutdown cooling line composed of two valves in series has a low likelihood because one of the valves (RHR-V-9) is maintained in a closed position during normal plant operation with power removed (via a protected isolation switch) so that hot shorts cannot cause the valve motor to energize and open the valve (and the de-energized power feeder is protected against external three-phase hot shorts). Additionally, a hot short plus random failure of a check valve is required to produce an ISLOCA for other pathways. Regarding the seismic PSA, Energy Northwest explained that both seismic damage states SDS41 and SDS42 include potential ISLOCAs but that ISLOCAs cannot be differentiated from other contributors to core damage.
- SAMA AT-14, "diversify standby liquid control (SLC) explosive valve operation," with a reported reduction in fire and seismic CDFs of 0.00E+00—Energy Northwest explained that fire-induced ATWS is not modeled in the fire PSA based on its low risk-significance per NUREG/CR-6850 (NRC, 2005) and, thus, has very little risk reduction potential for fire (Gambhir, 2010). Regarding the seismic PSA, Energy Northwest explained that seismic damage state SDS40, an unmitigated seismic-induced ATWS scenario having a seismic CDF contribution of 7.3E-09 per year, is the dominant contributor to seismic-ATWS sequences and that diversification of the SLC explosive valves would not

mitigate this sequence. Energy Northwest further considered that only a significant increase in seismic ruggedness in the SLC explosive valves and its piping would provide significant mitigation, but a significant improvement in seismic ruggedness is not practical due to its connectivity to other systems that would also require a corresponding improvement in seismic ruggedness to be effective.

As indicated in Section F.2.1, in response to an NRC staff RAI, Energy Northwest provided the results of a sensitivity study using PSA model Revision 7.1 (Gambhir, 2011). Table F-11 lists the assumptions considered in the sensitivity analysis to estimate the risk reduction for each of the evaluated SAMAs, the estimated risk reduction in terms of percent reduction in CDF and population dose, and the estimated total benefit (present value) of the averted risk. As with Table F-10, the estimated benefits reported in Table F-11 reflect the combined benefit in both internal and external events. Energy Northwest stated in the sensitivity study that the modeling approach used for SAMAs evaluated in the ER was the same as that used in the sensitivity study.

The NRC staff noted that implementation of SAMA CW-02, “add redundant DC control power for pumps,” SAMA CW-03, “replace ECCS pump motors with air-cooled motors,” and SAMA CW-04, “provide self-cooled ECCS seals,” results in an increase in the fire population dose risk. Additionally, implementation of SAMA AC/DC-30R, “provide an additional diesel generator diverse from DG-1 and DG-2,” results in an increase in the internal events CDF and population dose risk. The staff asked that Energy Northwest explain these apparent anomalies (Doyle, 2011a). In response to the RAI, Energy Northwest clarified that the increase in population dose for SAMAs CW-02, CW-03, and CW-04 is due to the modeling assumption that the associated hardware failures were eliminated, which resulted in the redistribution of CDF between PDSs in the CET quantifications (Swank, 2011). The PDSs associated with the modeled success branches are binned to release categories that have higher dose consequences than the modeled failure branches, thus increasing the dose risk for these SAMAs. For SAMA AC/DC-30R, Energy Northwest replied that this SAMA was incorrectly modeled and provided revised results, which are reported in Table F-11. The NRC staff considers Energy Northwest’s clarifications reasonable.

The modeling approaches for SAMA CC-01, “install an independent active or passive high pressure injection system,” and SAMA CC-02, “provide an additional high pressure injection pump with independent diesel,” were reported to be different in the ER yet the estimated benefits for the two SAMAs were identical. In the sensitivity study, Energy Northwest clarified that the same modeling approach was used for both of these SAMAs (Gambhir, 2011).

As mentioned in Section F.2.2, the NRC staff noted that the hot short probability of 0.3 assumption used in the fire PSA is not necessarily consistent with the guidance in NUREG/CR-6850 (NRC, 2005), which recommends doubling the 0.3 value to 0.6 for circuits where control power transformers are not present. The staff asked Energy Northwest to provide an assessment of this potential non-conservatism on the SAMA analysis (Doyle, 2010c), (Doyle, 2011a). In the RAI, the NRC staff asked Energy Northwest to specifically re-evaluate 7 Phase II SAMAs identified to address fire risk and 10 Phase II SAMAs identified to address internal events risk, representing the Phase II SAMAs that have a high baseline benefit relative to the estimated implementation cost. In response to the RAIs, Energy Northwest provided the results of a sensitivity analysis using PSA model Revision 7.1 wherein each of the SAMA was re-evaluated assuming a hot short probability of 0.6 for those circuits that were not confirmed to have a control power transformer present (Gambhir, 2011), (Swank, 2011). Energy Northwest re-quantified the base PSA model using the revised hot short probability assumptions, which

increased the fire CDF to 1.43×10^{-5} per year from 1.37×10^{-5} per year, and then re-quantified the PSA model again for each of the SAMAs by making the associated model changes described in Table F-11. Energy Northwest's analysis showed that the reduction in fire CDF increased by a factor of 1.0 to 2 for the SAMA identified to address fire events and by a factor of 1.0 to 1.38 for all but one of the SAMAs identified to address internal events. The re-evaluation of one SAMA resulted in the reduction in fire CDF decreasing by about 8 percent, the reason for which is provided in the RAI response. Based on these results, Energy Northwest concluded that the potential non-conservatism in the SAMA analysis is bounded by the uncertainty analysis using the 95th percentile CDF discussed in Section F.6.2. Based on the results of the sensitivity analysis being bounded by the 95th percentile CDF uncertainty analysis, and that the sensitivity analysis was performed for those SAMAs most likely to be impacted by the hot short probability assumption, the NRC staff concludes that using a hot short probability of 0.3 will not impact the results of the SAMA analysis.

The NRC staff has reviewed Energy Northwest's bases for calculating the risk reduction for the various plant improvements and concludes that the rationale and assumptions for estimating risk reduction are reasonable and generally conservative (i.e., the estimated risk reduction is higher than what would actually be realized). Accordingly, the NRC staff based its estimates of averted risk for the various SAMAs on Energy Northwest's risk reduction estimates.

Table F-10. SAMA cost and benefit screening analysis for CGS[a]

SAMA	Assumptions	% Risk Reduction[b,d]		Total Benefit ($)[h]		Cost ($)
		CDF	Population dose	Baseline (internal + external)	Baseline with uncertainty[c]	
Increase availability of DC power	In response to an NRC staff RAI, increase time available to recover offsite and onsite power before RCIC is lost to 10 hours during SBO scenarios from 7 hours with DC power load-shedding and from 5 hours without load-shedding (Gambhir, 2011).	IE—5 F—0 S—1	IE—4 F—0 S—1	37K	100K	
AC/DC-01—Provide additional DC battery capacity						1.8M
AC/DC-02—Replace lead-acid batteries with fuel cells						1.0M
AC/DC-03—Add a portable, diesel-driven battery charger to existing DC system						500K
Increase Availability of Onsite AC Power	In response to an NRC staff RAI, eliminate failure of EDG-1 (Gambhir, 2010).	IE—32 F—11 S—4	IE—15 F—9 S—4	250K	720K	
AC/DC-10—Provide an additional DG						11M
AC/DC-15—Install a gas turbine generator						2.1M
AC/DC-16—Install tornado protection of gas turbine generator						2.1M
AC/DC-23—Develop procedures to repair or replace failed 4 kV breakers	Eliminate failures of the 4 kV breakers.	IE—1 F—2 S—<1	IE—<1 F—2 S—<1	20K	61K	375K

SAMA	Assumptions	% Risk Reduction[b,d]		Total Benefit ($)[h]		Cost ($)
		CDF	Population dose	Baseline (internal + external)	Baseline with uncertainty[c]	
AC/DC-27—Install permanent hardware changes that make it possible to establish 500 kV backfeed through the main step-up transformer	In response to an NRC staff RAI, for internal and fire events, modify fault tree to include a new basic event, having a failure probability of 1.0E-02, representing the unavailability of the 500 kV power source (Gambhir, 2010). The 500 kV power source is not available in seismic events.	IE—24 F—28 S—0	IE—9 F—26 S—0	300K	870K	1.7M
AC/DC-28(g)—Reduce CCFs between EDG-3 and EDG-1/2	**CCFs between EDG-1 and EDG-3, between EDG-2 and EDG-3, and among all three EDGs are reduced by a factor of 2.**	**IE—12 F—2 S—<1**	**IE—6 F—1 S—<1**	**73K**	**200K**	**100K**
AC/DC-29—Replace EDG-3 with a diesel diverse from EDG-1 and EDG-2	Eliminate all CCFs between EDG-3 and EDGs-1/2.	IE—26 F—4 S—<1	IE—12 F—2 S—<1	150K	420K	4.2M
AT-05—Add an independent boron injection system	In response to an NRC staff RAI, eliminate failure of the SLC system and all risk from seismic damage state (SDS) 40 (Gambhir, 2010).	IE—<1 F—0 S—<1	IE—<1 F—0 S—<1	5.6K	16K	800K
AT-07—Add a system of relief valves to prevent equipment damage from pressure spikes during an ATWS	Eliminate all CCFs of SRVs.	IE—0 F—0 S—0	IE—0 F—0 S—0	0K	0K	1.1M
AT-13—Automate SLC injection in response to ATWS event	Eliminate failures of operators to initiate SLC.	IE—≈0 F—0 S—0	IE—≈0 F—0 S—0	0.2K	0.5K	660K
AT-14—Diversify SLC explosive valve operation	Eliminate CCFs between the SLC valves.	IE—≈0 F—0 S—0	IE—≈0 F—0 S—0	0.4K	1.0K	370K
Reduce Probability of an Interfacing Systems Loss of Coolant Accident (ISLOCA)	Eliminate ISLOCA events.	IE—≈0 F—0 S—0	IE—≈0 F—0 S—0	0K	0K	

SAMA	Assumptions	% Risk Reduction[b,d]		Total Benefit ($)[h]		Cost ($)
		CDF	Population dose	Baseline (internal + external)	Baseline with uncertainty[c]	
CB-01—Install additional pressure or leak monitoring instruments for detection of ISLOCAs						5.6M
CB-03—Increase leak testing of valves in ISLOCA paths						400K
CB-08—Revise EOPs to improve ISLOCA identification						5.6M[f]
CB-09—Improve operator training on ISLOCA coping						5.6M[f]
CC-01—Install an independent active or passive high pressure injection system	Reduce probability of failure of the HPCS system to 1.0E-09 (Gambhir, 2011).	IE—63 F—74 S—4	IE—41 F—71 S—4	875K	2.6M	29M
CC-02—Provide an additional high pressure injection pump with independent diesel	Reduce probability of failure of the HPCS system to 1.0E-09 (Gambhir, 2011).	IE—63 F—74 S—4	IE—41 F—71 S—4	875K	2.6M	5.2M
CC-03b—Raise RCIC backpressure trip set points	**Unavailability of RCIC for failure to run events are reduced by a factor of 3.**	**IE—9 F—1 S—<1**	**IE—5 F—1 S—<1**	**54K**	**150K**	**82K**
CC-20—Improve ECCS suction strainers	Eliminate failures of the ECCS suction strainer due to plugging.	IE—≈0 F—≈0 S—≈0	IE—≈0 F—≈0 S—≈0	0K	0K	10M
CP-01—Install an independent method of suppression pool cooling	Eliminate failures of suppression pool cooling.	IE—17 F—52 S—1	IE—28 F—56 S—1	540K	1.6M	6.0M
CW-02—Add redundant DC control power for pumps	In response to an NRC staff RAI, eliminate failure of control power for the ECCS pumps (Gambhir, 2010).	IE—<1 F—3 S—<1	IE—<1 F—3 S—<1	25K	75K	650K

SAMA	Assumptions	% Risk Reduction[b,d]		Total Benefit ($)[h]		Cost ($)
		CDF	Population dose	Baseline (internal + external)	Baseline with uncertainty[c]	
Improve Reliability of ECCS Pumps	In response to an NRC staff RAI, essentially eliminate failure of the low-pressure ECCS pumps due to pump motor cooling dependencies on service water (Gambhir, 2011).	IE—4 F—10 S—<1	IE—6 F—10 S—<1	110K	310K	
CW-03—Replace ECCS pump motors with air-cooled motors						1.1M
CW-04—Provide self-cooled ECCS seals						675K
CW-07—Add a service water pump	In response to an NRC staff RAI, eliminate failure of one train of service water (Gambhir, 2010).	IE—6 F—17 S—<1	IE—8 F—19 S—<1	180K	530K	6.1M
FR-03—Install additional transfer and isolation switches	Reduce the probability of the most risk significant hot shorts to zero.	IE—0 F—30 S—0	IE—0 F—31 S—0	210K	650K	2.0M
FR-07a—Improve the fire resistance of critical cables for containment venting	**In response to an NRC staff RAI, eliminate fire-related failures of the containment vent (Gambhir, 2010).**	**IE—0 F—46 S—0**	**IE—0 F—50 S—0**	**330K**	**1.0M**	**400K**
FR-07b—Improve the fire resistance of critical cables for transformer E-TR-S	**In response to an NRC staff RAI, eliminate hot shorts for transformer E-TR-S (Gambhir, 2010).**	**IE—0 F—11 S—0**	**IE—0 F—11 S—0**	**75K**	**230K**	**100K**
FR-08(e)—Improve the fire resistance of cables to RHR and SW	**Eliminate failure of RHR trains A and B due to a fire.**	**IE—0 F—72 S—0**	**IE—0 F—78 S—0**	**520K**	**1.6M**	**1.25M**
HV-02—Provide a redundant train or means of ventilation [for the critical switchgear room]	**In response to an NRC staff RAI, completely remove switchgear dependencies on HVAC and eliminate the loss of HVAC IEs (Gambhir, 2010).**	**IE—11 F—16 S—<1**	**IE—17 F—16 S—<1**	**210K**	**620K**	**480K**
SR-03—Modify safety-related CST	In response to an NRC staff RAI, availability of the CST is credited during seismic events (Gambhir, 2010).	IE—0 F—0 S—≈0	IE—0 F—0 S—≈0	0K	0K	980K

SAMA	Assumptions	% Risk Reduction[b,d]		Total Benefit ($)[h]		Cost ($)
		CDF	Population dose	Baseline (internal + external)	Baseline with uncertainty[c]	

[a] SAMAs in **bold** are potentially cost-beneficial.

[b] Percent risk reduction values between 0.1 and 1 are shown as "<1," those having a value less than 0.1 are shown as "≈0," and those shown as "0" were reported to be 0 in the ER and in response to NRC staff RAI 5.n (Gambhir, 2010).

[c] Estimated uncertainty benefits are provided in response to NRC staff RAIs 6.j (Gambhir, 2010) and 6.j-1ii (Gambhir, 2011).

[d] IE = internal events; F = fire events; S = seismic events.

[e] SAMA identified and evaluated in response to NRC staff RAIs 5.l (Gambhir, 2010) and 5.l-1 and 6.j-1ii (Gambhir, 2011).

[f] The implementation cost estimate was revised in the PSA Revision 7.1 sensitivity study (Gambhir, 2011).

[g] SAMA AC/DC-28 reduces CCFs among the EDGs by such actions as providing separate fuel supplies, separate maintenance crews, diverse instrumentation, etc., as compared to SAMA AC/DC-29, which replaces EDG-3 with an EDG from a different manufacturer from EDG-1 and EDG-2 (EN, 2010).

[h] The total benefit is the sum of the benefits for internal events, fire events, seismic events, and HFO events.

Table F-11. SAMA cost and benefit screening analysis for CGS sensitivity analysis [a,b]

SAMA	Assumptions	% Risk Reduction[c]		Total Benefit ($)[f]		Cost ($)
		CDF	Population Dose	Baseline (Internal + External)	Baseline With Uncertainty	
Increase Availability of DC Power	Increase time available to recover offsite/onsite power before RCIC is lost to 10 hours during SBO scenarios from 7 hours with DC power load-shedding and from 5 hours without load-shedding (Gambhir, 2011).	IE—1 F—0 S—0	IE—0 F—0 S—<1	3.3K	8.1K	
AC/DC-01—Provide additional DC battery capacity						1.8M
AC/DC-02—Replace lead-acid batteries with fuel cells						1.0M
AC/DC-03—Add a portable, diesel-driven battery charger to existing DC system						500K
Increase Availability of Onsite AC Power	In response to an NRC staff RAI, eliminate failure of EDG-1 (Gambhir, 2010).	IE—2 F—9 S—1	IE—<1 F—7 S—2	88K	230K	
AC/DC-10—Provide an additional DG						11M
AC/DC-15—Install a gas turbine generator						2.1M
AC/DC-16—Install tornado protection of gas turbine generator						2.1M
AC/DC-23—Develop procedures to repair or replace failed 4 kV breakers	Eliminate failures of the 4 kV breakers.	IE—5 F—1 S—0	IE—6 F—2 S—0	71K	170K	375K

SAMA	Assumptions	% Risk Reduction[c]		Total Benefit ($)[f]		Cost ($)
		CDF	Population Dose	Baseline (Internal + External)	Baseline With Uncertainty	
AC/DC-27—Install permanent hardware changes that make it possible to establish 500 kV backfeed through the main step-up transformer	In response to an NRC staff RAI, for internal and fire events, modify fault tree to include a new basic event, having a failure probability of 1.0E-02, representing the unavailability of the 500 kV power source (Gambhir, 2010). The 500 kV power source is not available in seismic events.	IE—10 F—38 S—0	IE—9 F—37 S—0	420K	1.1M	1.7M
AC/DC-28[e]—Reduce CCFs between EDG-3 and EDG 1/2	CCFs between EDG-1 and EDG-3, between EDG-2 and EDG-3 and between all three EDGs are reduced by a factor of 2.	IE—<1 F—1 S—0	IE—0 F—<1 S—<1	6.8K	17K	100K
AC/DC-29—Replace EDG-3 with a diesel diverse from EDG-1 and EDG-2	Eliminate all CCFs between EDG-3 and EDGs-1/2.	IE—1 F—2 S—0	IE—<1 F—1 S—<1	18K	46K	4.2M
AT-05—Add an independent boron injection system	In response to an NRC staff RAI, eliminate failure of the SLC system and all risk from seismic damage state (SDS) 40 (Gambhir, 2010).	IE—2 F—0 S—0	IE—7 F—0 S—<1	41K	100K	800K
AT-07—Add a system of relief valves to prevent equipment damage from pressure spikes during an ATWS	Eliminate all CCFs of SRVs.	IE—0 F—0 S—0	IE—0 F—0 S—0	0	0	1.1M
AT-13—Automate SLC injection in response to ATWS event	Eliminate failures of operators to initiate SLC.	IE—<1 F—0 S—0	IE—1 F—0 S—0	9.7K	23K	660K
AT-14—Diversify SLC explosive valve operation	Eliminate CCFs between the SLC valves.	IE—0 F—0 S—0	IE—0 F—0 S—0	0	0	370K
Reduce Probability of an ISLOCA	Eliminate ISLOCA events.	IE—1 F—0 S—0	IE—3 F—0 S—0	20K	49K	
CB-01—Install additional pressure or leak monitoring instruments for detection of ISLOCAs						5.6M

SAMA	Assumptions	% Risk Reduction[c]		Total Benefit ($)[f]		Cost ($)
		CDF	Population Dose	Baseline (Internal + External)	Baseline With Uncertainty	
CB-03—Increase leak testing of valves in ISLOCA paths CB-08—Revise EOPs to improve ISLOCA identification CB-09—Improve operator training on ISLOCA coping						400K 5.6M 5.6M
CC-01—Install an independent active or passive high pressure injection system	Reduce probability of failure of the HPCS system to 1.0E-09 (Gambhir, 2011).	IE—60 F—74 S—2	IE—56 F—66 S—2	1.2M	3.0M	29M
CC-02—Provide an additional high pressure injection pump with independent diesel	Reduce probability of failure of the HPCS system to 1.0E-09 (Gambhir, 2011).	IE—60 F—74 S—2	IE—56 F—66 S—2	1.2M	3.0M	5.2M
CC-03b—Raise RCIC backpressure trip set points	Unavailability of RCIC for failure to run events is reduced by a factor of 3.	IE—<1 F—0 S—0	IE—0 F—0 S—0	<1K	1.4K	82K
CC-20—Improve ECCS suction strainers	Eliminate failures of the ECCS suction strainer due to plugging.	IE—1 F—0 S—0	IE—1 F—<1 S—0	7.4K	18K	10M
CP-01—Install an independent method of suppression pool cooling	eliminate failures of suppression pool cooling.	IE—33 F—54 S—1	IE—56 F—83 S—1	1.0M	2.6M	6.0M
CW-02—Add redundant DC control power for pumps	In response to an NRC staff RAI, eliminate failure of control power for the ECCS pumps (Gambhir, 2010).	IE—10 F—5 S—0	IE—13 F—(-)9 S—0	100K	240K	650K
Improve reliability of ECCS pumps CW-03—Replace ECCS pump motors with air-cooled motors	In response to an NRC staff RAI, essentially eliminate failure of the low-pressure ECCS pumps due to pump motor cooling dependencies on service water (Gambhir, 2011).	IE—3 F—3 S—0	IE—1 F—(-)9 S—0	-5.8K	-18K	1.1M

SAMA	Assumptions	% Risk Reduction[c]		Total Benefit ($)[f]		Cost ($)
		CDF	Population Dose	Baseline (Internal + External)	Baseline With Uncertainty	
CW-04—Provide self-cooled ECCS seals						675K
CW-07—Add a service water pump	In response to an NRC staff RAI, eliminate failure of one train of service water (Gambhir, 2010).	IE—11 F—12 S—0	IE—12 F—6 S—<1	190K	480K	6.1M
FR-03—Install additional transfer and isolation switches	Reduce the probability of the most risk significant hot shorts to 0.	IE—0 F—6 S—0	IE—0 F—2 S—0	36K	93K	2.0M
FR-07a—Improve the fire resistance of critical cables	**In response to an NRC staff RAI, eliminate fire-related failures of the containment vent (Gambhir, 2010).**	**IE—0 F—30 S—0**	**IE—0 F—47 S—0**	**320K**	**840K**	**400K**
FR-07b—Improve the fire resistance of critical cables	In response to an NRC staff RAI, eliminate hot shorts for transformer E-TR-S (Gambhir, 2010).	IE—0 F—3 S—0	IE—0 F—4 S—0	31K	81K	100K
FR-08—Improve the fire resistance of cables to RHR and SW	**Eliminate failure of RHR trains A and B due to a fire.**	**IE—0 F—56 S—0**	**IE—0 F—64 S—0**	**510K**	**1.3M**	**1.25M**
HV-02—Provide a redundant train or means of ventilation	In response to an NRC staff RAI, completely removed switchgear dependencies on HVAC and eliminated the loss of HVAC IEs (Gambhir, 2010).	IE—<1 F—0 S—0	IE—<1 F—0 S—0	2.2K	5.3K	480K
SR-03—Modify safety-related CST	In response to an NRC staff RAI, availability of the CST is credited during seismic events (Gambhir, 2010).	IE—0 F—0 S—1	IE—0 F—0 S—1	3.1K	9.3K	980K
SR-05R—Improve seismic ruggedness of MCC-7F and MCC-8F	**Eliminate loss of room cooling for Division 1 and 2 switchgear rooms in a seismic event.**	**IE—0 F—0 S—19**	**IE—0 F—0 S—0**	**57K**	**170K**	**150K**
OT-08R—Install explosion protection around CGS transformers	Eliminate plant-centered LOOP and switchyard-centered LOOP.	IE—1 F—0 S—0	IE—<1 F—0 S—0	9.4K	23K	700K

SAMA	Assumptions	% Risk Reduction[c]		Total Benefit ($)[f]		Cost ($)
		CDF	Population Dose	Baseline (Internal + External)	Baseline With Uncertainty	
FL-05R—Clamp on flow instruments to certain drain lines in the control building of the radwaste building and alarm in the control room	**Control building flood isolation HEPs are reduced to 1.0E-02.**	**IE—16 F—0 S—0**	**IE—35 F—0 S—0**	**250K**	**610K**	**250K**
FL-04R—Add one isolation valve in the service water, turbine SW, and FP lines in the control building area of the radwaste building	**Control building flood isolation HEPs are reduced to 0.0.**	**IE—17 F—0 S—0**	**IE—35 F—0 S—0**	**260K**	**620K**	**380K**
FL-06R—Additional NDE and inspections [in the control building]	**Control building flood isolation HEPs are reduced by a factor of 2.**	**IE—8 F—0 S—0**	**IE—18 F—0 S—0**	**130K**	**310K**	**14K**
CC-24R—Backfeed the HPCS system with SM-8 to provide a third power source for HPCS	**Eliminate loss of HPCS due to loss of AC power (both offsite and onsite).**	**IE—7 F—9 S—0**	**IE—7 F—13 S—0**	**170K**	**420K**	**105K**
CC-25R—Enhance alternate injection reliability by including RHR, SW and fire water cross-tie in the maintenance program	**Reduce the probability of failure of the subject valves to 0.0 from a probability based on a 10-year mean time between surveillance tests.**	**IE—1 F—1 S—0**	**IE—1 F—<1 S—<1**	**12K**	**29K**	**13K**
OT-07R—Increase operator training on systems and operator actions determined to be important from the PSA	**Top 10 most risk-significant HEPs are reduced by a factor of 10.**	**IE—25 F—5 S—0**	**IE—8 F—<1 S—0**	**200K**	**480K**	**40K**
FW-05R—Examine the potential for operators to control RFW and avoid a reactor trip	**Eliminate loss of RFW due to loss of DC power from DC Bus E-DP-S1/7 and reduce unavailability of DC Bus E-DP-S1/7 to 1.0E-09.**	**IE—3 F—7 S—0**	**IE—2 F—4 S—0**	**72K**	**180K**	**29K**
FR-09R—Install early fire detection in the following physical analysis units: R-1B, R-1D, and R-1J	Fire ignition frequencies in the most important fire areas of the reactor building are reduced by a factor of 10.	IE—0 F—15 S—0	IE—0 F—7 S—0	100K	260K	680K

SAMA	Assumptions	% Risk Reduction[c]		Total Benefit ($)[f]		Cost ($)
		CDF	Population Dose	Baseline (Internal + External)	Baseline With Uncertainty	
AT-15R—Modifications to make use of HPCS more likely for ATWS (use of auto bypass, installing throttle valve)	Reduce the HEP of failure to use HPCS during ATWS conditions to 1.0E-03.	IE—15 F—0 S—0	IE—1 F—0 S—0	80K	190K	2.8M
OT-09R—For the non-LOCA IEs, credit the Z (power conversion system recovery) function	**For transient initiators, eliminate tripping of MSIVs on high steam tunnel temperature.**	**IE—4 F—8 S—0**	**IE—5 F—13 S—0**	**130K**	**330K**	**130K**
FR-12R—Install early fire detection in the following physical analysis units: T-1A, T-12, T-1C, and T-1D	Fire ignition frequencies in the most important fire areas of the turbine building are reduced by a factor of 10.	IE—0 F—12 S—0	IE—0 F—12 S—0	110K	270K	725K
FR-11R—Install early fire detection in the following analysis units: RC-02, RC-03, RC-04, RC-05, RC-07, RC-08, RC-11, RC-13, RC-14, and RC-1A	**Fire ignition frequencies in the most important fire areas of the control building are reduced by a factor of 10.**	**IE—0 F—56 S—0**	**IE—0 F—63 S—0**	**510K**	**1.3M**	**1.0M**
FR-10R—Install early fire detection in the main control room: RC-10	Fire ignition frequencies in the main control room are reduced by a factor of 10.	IE—0 F—1 S—0	IE—0 F—2 S—0	14K	36K	535K
FL-07R—Protect the HPCS from flooding that results from ISLOCA events	Reduce the probability of failure of HPCS caused by flooding due to ISLOCA to 0.0.	IE—0 F—0 S—0	IE—2 F—0 S—0	11K	26K	1.05M
AC/DC-30R[d]—Provide an additional DG diverse from DG-1 and DG-2	Eliminate failure of EDG-2.	IE—<1 F—15 S—2	IE—<1 F—12 S—2	130K	350K	10M
CC-26R—Install hard pipe from diesel fire pump to vessel	Reduce HEPs for failure to align the diesel fire pump to the RPV to 0.0.	IE—<1 F—0 S—0	IE—<1 F—1 S—0	5.7K	14K	710K

SAMA	Assumptions	% Risk Reduction[c]		Total Benefit ($)[f]		Cost ($)
		CDF	Population Dose	Baseline (Internal + External)	Baseline With Uncertainty	
OT-10R—Increase fire pump house building integrity to withstand higher winds so the fire system will be capable of withstanding a severe weather event	Reduce the probability of failure of the pump house to 0.0 from a probability of 1.37E-04 for a high wind during a plant-initiating event and reduce the probability of a high wind given LOOP from a probability of 1.0.	IE—<1 F—0 S—0	IE—<1 F—0 S—0	1.5K	3.5K	735K
FW-04—Add a motor-driven FW pump	Reduce the probability of failure of RFW by a factor of 1,000 and eliminate dependencies between FW trains. Reduce the loss of FW initiating event frequency by a factor of 1,000.	IE—40 F—25 S—0	IE—42 F—26 S—0	620K	1.5M	10M
CB-10R—Provide additional NDE and inspections of MS pipe in turbine building	Reduce MS pipe break outside containment initiating event frequencies by a factor of 2.0.	IE—2 F—0 S—0	IE—2 F—0 S—0	20K	48K	125K

[a] SAMAs in **bold** are potentially cost-beneficial.

[b] Screening analysis assumptions and results, unless otherwise noted, are provided in the PSA Revision 7.1 sensitivity study (Gambhir, 2011).

[c] IE = internal events; F = fire events; S = seismic events

[d] Revised risk reduction and benefit results for this SAMA are provided in response to followup NRC staff RAI 8 (Swank, 2011).

[e] SAMA AC/DC-28 reduces CCFs among the EDGs by such actions as: providing separate fuel supplies, separate maintenance crews, diverse instrumentation, etc., as compared to SAMA AC/DC-29, which replaces EDG-3 with an EDG from a different manufacturer from EDG-1 and EDG-2 (EN, 2010).

[f] The total benefit is the sum of the benefits for internal events, fire events, seismic events, and HFO events.

F.5 Cost Impacts of Candidate Plant Improvements

Energy Northwest estimated the costs of implementing the candidate SAMAs through the development of site-specific cost estimates and use of other licensees' estimates for similar improvements. The cost estimates used from other SAMA analyses were adjusted for inflation. In response to an NRC staff RAI, Energy Northwest clarified that the site-specific cost estimates conservatively did not include contingency costs for unforeseen implementation obstacles, the cost of replacement power during extended outages required to implement the modifications, or the costs associated with recurring training, maintenance, and surveillance (Gambhir, 2010).

The NRC staff requested more information on the process Energy Northwest used to develop the site-specific cost estimates and the level of detail used to develop these estimates (Doyle, 2010a). Energy Northwest responded to the RAI by explaining that the cost estimates were developed by a team of three Energy Northwest and consultant personnel having over 50 years of cumulative experience at CGS and over 90 years of collective experience in the nuclear industry in areas of electrical and mechanical engineering, field engineering, design engineering, construction management, operations and maintenance support, licensing, and PSA (Gambhir, 2010). The team consulted with relevant plant experts in the conceptual development of each SAMA and used an interview process to develop the implementation costs. The experts interviewed had expertise in areas such as FP, operations and maintenance procedures, operations, training, design engineering, and system engineering. Cost elements considered in the development of the cost estimates generally included material, labor, engineering, licensing, training, procedures, and surveillance testing. The team also reviewed the cost estimates from published documents such as other SAMA analyses. Energy Northwest noted that if the estimated implementation cost was sufficiently greater than the maximum estimated benefit, a more detailed cost estimate was not developed. Energy Northwest emphasized that team focused on underestimating the actual cost of implementation in order to ensure that the estimates used in the cost-benefit evaluation were conservative. Based on the use of personnel having significant nuclear plant engineering and operating experience, the NRC staff considers the process Energy Northwest used to develop the site-specific cost estimates reasonable.

The NRC staff reviewed the bases for the applicant's cost estimates (presented in Table E.11-6 of Attachment E to the ER). For certain improvements, the NRC staff also compared the cost estimates to estimates developed elsewhere for similar improvements, including estimates developed as part of other applicants' analyses of SAMAs for operating reactors. The NRC staff noted that the estimated cost of $375,000 for SAMA AC/DC-23, "develop procedures to repair or replace failed 4 kV breakers," is high for what is described as procedure development (Doyle, 2010a). In response to the RAI, Energy Northwest clarified that this SAMA assumes that a 4,160 V breaker failure could be repaired within the necessary repair time if roll-in spares were staged and ready for replacing the failed breaker. Therefore, the estimated implementation cost includes the cost of eight spare breakers identified in the RAI response, procedure development, engineering evaluation, and staging restraints (Gambhir, 2010). Energy Northwest further noted that each breaker is estimated to cost $35,000 based on the current manufacturer's cost for a typical Class 1E 4,160 V, 1,200 amp breaker, for a total of $280,000 for procurement of the eight breakers. Installation of staging restraints and setup of the breakers is estimated to cost $45,000 for three different locations where the breakers are located, engineering evaluation and documentation is estimated to cost $30,000, and procedure development is estimated to cost $20,000. The NRC staff considers the estimated cost for CGS to be reasonable and acceptable for purposes of the SAMA evaluation.

The NRC staff noted that the implementation cost for SAMA CC-03b, “raise RCIC backpressure trip set points,” was estimated to be $82,000 and $160,000 in different sections of the ER and that both estimates seem high for what appears to be a minor software change (Doyle, 2010a). In response to the RAI, Energy Northwest clarified that the estimated implementation cost for this SAMA is $82,000, that implementing the SAMA requires an amendment to the CGS technical specifications, and that the cost estimate includes costs for licensing and NRC review in addition to engineering, maintenance, training, and procedures. Based on this additional information, the NRC staff considers the estimated cost to be reasonable and acceptable for purposes of the SAMA evaluation.

As indicated in Section F.3.2., NRC staff asked the applicant to provide more detailed descriptions of the modifications and cost estimates for several of the Phase II SAMA candidates (Doyle, 2010a). In response to the RAI, Energy Northwest provided more detail on both the modification and the estimated implementation costs for the following SAMAs (Gambhir, 2010):

- SAMA AC/DC-27, “install permanent hardware changes that make it possible to establish 500 kV backfeed through the main step-up transformer”
- SAMA CW-04, “provide self-cooled ECCS seals”
- SAMA FR-07a, “improve the fire resistance of cables to the containment vent valve”\
- SAMA FR-07b, “improve the fire resistance of cables to transformer E-TR-S”
- SAMA HV-02, “provide a redundant train or means of ventilation”

The NRC staff reviewed the cost estimates for SAMAs AC/DC-27, CW-04, and HV-02 and considers them to be reasonable and acceptable for purposes of the SAMA evaluation.

Relative to SAMAs FR-07a and FR-07b, the NRC staff noted that the cost estimates were based on replacing the existing cables with metal-sheathed cables and asked Energy Northwest to justify the use of metal-sheathed cables for electrical failure modes that may not be prevented by metal-sheathed cables (Doyle, 2010c). In response to the RAI, Energy Northwest clarified that basing the cost estimate for these SAMAs on metal-jacketed (armored) cable was not intended to imply that armored cable could be used to mitigate all spurious operations. The cost of armored cabling was used because it is among the least costly of a variety of options available to mitigate fire-induced spurious operations. Therefore, using it is conservative for purposes of the SAMA cost-benefit evaluation, and Energy Northwest has actual cost information from installation of armored cable from which to base the cost estimate (Gambhir, 2011). Energy Northwest further explained that during implementation of these SAMAs, specific protective schemes applicable to the circuit failure mode(s) of concern will be selected. Since the cost of armored cabling is a least cost option for protecting against fire-induced spurious operations, the NRC staff considers the cost estimates for these SAMAs reasonable and acceptable for purposes of the SAMA evaluation.

As indicated in Section F.2.1, in response to an NRC staff RAI, Energy Northwest provided the results of a sensitivity study using PSA model Revision 7.1 (Gambhir, 2011). In the sensitivity study, Energy Northwest noted that the estimated implementation costs for the following Phase I SAMAs that were based on industry estimates in the ER were revised in the sensitivity study to reflect site-specific cost estimates:

- SAMA AT-10, “install an ATWS sized filtered containment vent to remove decay heat”

- SAMA CP-12, “install a filtered containment vent to remove decay heat”
- SAMA CP-22, “increase depth of the concrete basemat or use an alternate concrete material to ensure melt-through does not occur”
- SAMA CP-24, “construct a building to be connected to primary/secondary containment and maintained at a vacuum”

Energy Northwest also noted that a cost estimate was developed for Phase I SAMA CC-12, “add a diverse low pressure injection system,” screened in the ER on very low benefit, using a cost estimate developed by another applicant for a similar improvement. The bases for the revised and new cost estimates are provided in Section 4.3 of the sensitivity study (Gambhir, 2011). The NRC staff reviewed the cost estimates for these SAMAs and considers them to be reasonable and acceptable for purposes of the SAMA evaluation.

The estimated costs for SAMA CB-08, “revise EOPs to improve ISLOCA identification,” and SAMA CB-09, “improve operator training on ISLOCA coping,” were reported in the ER to be $20,000 and $30,000, respectively. In the sensitivity study, Energy Northwest clarified that these cost estimates are in addition to the estimated implementation cost for the ISLOCA detection instrumentation provided for in SAMA CB-01, “install additional pressure or leak monitoring instruments for detection of ISLOCA paths” (Gambhir, 2011).

The NRC staff concludes that the cost estimates provided by Energy Northwest are sufficient and appropriate for use in the SAMA evaluation.

F.6 Cost-Benefit Comparison

CGS cost-benefit analysis and the NRC staff’s review are described in the following sections.

F.6.1 CGS’s Evaluation

The methodology used by Energy Northwest was based primarily on NRC’s guidance for performing cost-benefit analysis (i.e., NUREG/BR-0184, “Regulatory Analysis Technical Evaluation Handbook” (NRC, 1997a)). The guidance involves determining the net value for each SAMA according to the following formula:

Net Value = (APE + AOC + AOE + AOSC) - COE where:

APE = present value of averted public exposure ($)

AOC = present value of averted offsite property damage costs ($)

AOE = present value of averted occupational exposure costs ($)

AOSC = present value of averted onsite costs ($)

COE = cost of enhancement ($)

If the net value of a SAMA is negative, the cost of implementing the SAMA is larger than the benefit associated with the SAMA, and it is not considered cost-beneficial. Energy Northwest’s derivation of each of the associated costs is summarized below.

NUREG/BR-0058 has recently been revised to reflect the NRC’s policy on discount rates. Revision 4 of NUREG/BR-0058 states that two sets of estimates should be developed—one at 3 percent and one at 7 percent (NRC, 2004a). Energy Northwest provided a base set of results

using the 7 percent discount rate and a sensitivity study using the 3 percent discount rate (EN, 2010). Energy Northwest also provided similar results for the sensitivity study discussed in Section F.2.1 (Gambhir, 2011).

Averted Public Exposure (APE) Costs

The APE costs were calculated using the following formula:

APE = Annual reduction in public exposure (Δ person-rem per year)
x monetary equivalent of unit dose ($2,000 per person-rem)
x present value conversion factor (13.05 based on a 35-year period with a 7-percent discount rate)

As stated in NUREG/BR-0184 (NRC, 1997a), it is important to note that the monetary value of the public health risk after discounting does not represent the expected reduction in public health risk due to a single accident. Rather, it is the present value of a stream of potential losses extending over the remaining lifetime (in this case, the renewal period) of the facility. Thus, it reflects the expected annual loss due to a single accident, the possibility that such an accident could occur at any time over the renewal period, and the effect of discounting these potential future losses to present value. For the purposes of initial screening, which assumes elimination of all severe accidents due to internal, fire, and seismic events, Energy Northwest calculated an APE of approximately $96,000, $224,000, and $176,000, respectively, for the 35-year time period to expiration of the renewed CGS license (EN, 2010). For the sensitivity analysis using PSA model Revision 7.1, Energy Northwest calculated an APE of approximately $143,000, $234,000, and $154,000 due to internal, fire, and seismic events, respectively (Gambhir, 2011). The NRC staff notes that the benefit evaluation need only to be estimated for the 20-year license renewal period and therefore Energy Northwest's evaluation for CGS is conservative.

Averted Offsite Property Damage Costs (AOC)

The AOCs were calculated using the following formula:

AOC = Annual CDF reduction
x offsite economic costs associated with a severe accident (on a per-event basis)
x present value conversion factor

For the purposes of initial screening, which assumes all severe accidents due to internal, fire, and seismic events are eliminated, Energy Northwest calculated an annual offsite economic risk of about $6,100, $15,500, and $11,100, respectively, based on the Level 3 risk analysis. This results in a discounted value of approximately $80,000, $203,000, and $145,000 for internal, fire, and seismic events, respectively, for the 35-year time period to expiration of the renewed CGS license (EN, 2010). For the sensitivity analysis using PSA model Revision 7.1, Energy Northwest calculated an annual offsite economic risk of about $7,100, $11,200, and $8,400 and an AOC of approximately $92,000, $146,000, and $110,000 due to internal, fire, and seismic events, respectively (Gambhir, 2011).

Averted Occupational Exposure (AOE) Costs

The AOE costs were calculated using the following formula:

AOE = Annual CDF reduction

x occupational exposure per core damage event

x monetary equivalent of unit dose

x present value conversion factor

Energy Northwest derived the values for averted occupational exposure from information provided in Section 5.7.3 of the Regulatory Analysis Handbook (NRC, 1997a). Best estimate values provided for immediate occupational dose (3,300 person-rem) and long-term occupational dose (20,000 person-rem over a 10-year cleanup period) were used. The present value of these doses was calculated using the equations provided in the handbook in conjunction with a monetary equivalent of unit dose of $2,000 per person-rem, a real discount rate of 7 percent, and a time period of 35 years to represent the period to expiration of the renewed CGS license. For the purposes of initial screening, which assumes all severe accidents due to internal, fire, and seismic events are eliminated, Energy Northwest calculated an AOE of approximately $2,200, $3,400, and $2,400, respectively, for the 35-year time period to expiration of the renewed CGS license (EN, 2010). For the sensitivity analysis using PSA model Revision 7.1, Energy Northwest calculated an AOE of approximately $3,500, $6,300, and $2,200 due to internal, fire, and seismic events, respectively (Gambhir, 2011).

Averted Onsite Costs (AOSC)

AOSCs include averted cleanup and decontamination costs and averted power replacement costs. Repair and refurbishment costs are considered for recoverable accidents only and not for severe accidents. Energy Northwest derived the values for AOSC based on information provided in Section 5.7.6 of NUREG/BR-0184, the Regulatory Analysis Handbook (NRC, 1997a).

Energy Northwest divided this cost element into two parts—the onsite cleanup and decontamination cost, also commonly referred to as averted cleanup and decontamination costs, and the replacement power cost (RPC).

Averted cleanup and decontamination costs (ACC) were calculated using the following formula:

ACC = Annual CDF reduction

x present value of cleanup costs per core damage event

x present value conversion factor

The total cost of cleanup and decontamination subsequent to a severe accident is estimated in the regulatory analysis handbook to be $1.5x109 (undiscounted). This value was converted to present costs over a 10-year cleanup period and integrated over the term of the proposed expiration of the renewed CGS license. For the purposes of initial screening, which assumes all severe accidents due to internal, fire, and seismic events are eliminated, Energy Northwest calculated an ACC of approximately $67,500, $104,000, and $73,900, respectively, for the 35-year time period to expiration of the renewed CGS license. For the sensitivity analysis using PSA model Revision 7.1, Energy Northwest calculated an ACC of approximately $105,600, $193,000, and $68,400 due to internal, fire, and seismic events, respectively (Gambhir, 2011).

Long-term RPCs were calculated using the following formula:

RPC = Annual CDF reduction

x present value of replacement power for a single event

x factor to account for remaining service years for which replacement power is required

x reactor power scaling factor

Energy Northwest based its calculations on the rated CGS net electric output of 1,107 megawatt-electric (MWe) per unit and scaled up from the 910 MWe reference plant in NUREG/BR-0184 (NRC, 1997). Therefore, Energy Northwest applied a power scaling factor of 1,107/910 to determine the RPCs. For the purposes of initial screening, which assumes all severe accidents due to internal, fire, and seismic events are eliminated, Energy Northwest calculated an RPC of approximately $99,600, $154,000, and 109,000, respectively, for the 35-year time period to expiration of the renewed CGS license. For the sensitivity analysis using PSA model Revision 7.1, Energy Northwest calculated an RPC of approximately $155,700, $284,000, and $101,000 due to internal, fire, and seismic events, respectively (Gambhir, 2011).

Using the results for ACC and RPC, Energy Northwest calculated an AOSC of approximately $167,000, $258,000, and $183,000 for internal, fire, and seismic events, respectively, for the 35-year time period to expiration of the renewed CGS license (EN, 2010). For the sensitivity analysis using PSA model Revision 7.1, Energy Northwest calculated an AOSC of approximately $261,000, $477,000, and $169,000 due to internal, fire, and seismic events, respectively (Gambhir, 2011).

Using the above equations, Energy Northwest estimated the total present dollar value equivalent associated with eliminating severe accidents from internal, fire, and seismic events at CGS to be about $346,000, $689,000, and $506,000, respectively, for a total of $1,541,000. Use of an internal events multiplier of 2.0 to account for other external events (i.e., high winds, external floods, etc.) increases the value to $1,887,000. This represents the dollar value associated with eliminating all internal and external event severe accident risk at CGS, and is also referred to as the modified maximum averted cost risk.

For the sensitivity analysis using PSA model Revision 7.1, Energy Northwest estimated the total present dollar value equivalent associated with eliminating severe accidents from internal, fire, and seismic events at CGS to be about $500,000, $863,000, and $436,000, respectively, for a total of $1.8 million (Gambhir, 2011). Use of an internal events multiplier of 2.0 to account for other external events (i.e., high winds, external floods, etc.) increases the value to $2.3 million.

Energy Northwest's Results

If the implementation costs for a candidate SAMA exceeded the calculated benefit, the SAMA was considered not to be cost-beneficial. In the baseline analysis contained in the ER (using a 7 percent discount rate), Energy Northwest identified no potentially cost-beneficial SAMAs. Based on a sensitivity analysis using a 3 percent discount rate, three SAMA candidates were determined to be potentially cost-beneficial. The potentially cost-beneficial SAMAs are as follows:

- SAMA AC/DC-28, "reduce CCFs between EDG-3 and EDG 1/2"
- SAMA FR-07a, "improve the fire resistance of cables to the containment vent valve"
- SAMA FR-07b, "improve the fire resistance of cables to transformer E-TR-S"

The potentially cost-beneficial SAMAs, and Energy Northwest's plans for further evaluation of these SAMAs are discussed in more detail in Section F.6.2.

F.6.2 Review of CGS's Cost-Benefit Evaluation

The cost-benefit analysis performed by Energy Northwest was based primarily on NUREG/BR-0184 (NRC, 1997a) and discount rate guidelines in NUREG/BR-0058 (NRC, 2004), and it was executed consistent with this guidance.

The risk reduction benefits associated with internal, fire, and seismic events were separately estimated by Energy Northwest using the internal events, fire events, and seismic events PSA models, respectively. Energy Northwest accounted for the potential risk reduction benefits associated with HFO events by assuming that the contribution from HFO events was the same as that from internal events. The estimated SAMA benefits for internal events, fire events, seismic events, and HFO events were then summed to provide an overall benefit. No SAMAs were determined to be potentially cost-beneficial from this evaluation.

Energy Northwest provided the assumptions and results of sensitivity analyses, including the following:

- RPC is 20 percent of the baseline RPC (Gambhir, 2010)
- use of 3 percent and 10 percent discount rates
- use of 14,000 person-rem for short term dose and 30,000 person-rem for long term doses
- use of an onsite cleanup and decontamination cost of $2 billion
- escalating the annual RPC to 2008 dollars by an average annual inflation rate of 4.1 percent (Gambhir, 2010)
- variations in MACCS2 input parameters (as discussed in Section F.2.2)

The results of the sensitivity case using a 3 percent discount rate resulted in three SAMAs (SAMAs AC/DC-28, FR-07a, and FR-07b, as described above) becoming potentially cost-beneficial (EN, 2010). Although not cost-beneficial in the baseline analysis, Energy Northwest committed to consider implementation of these three SAMAs through normal CGS processes for evaluating possible changes to the plant (EN, 2010).

The NRC staff noted that the ER states that the net and gross electrical power outputs for CGS are 1,190 MWe and 1,230 MWe, respectively, while Energy Northwest used a rated electrical power of 1,107 MWe in estimating RPCs. The staff requested that Energy Northwest provide the rationale for using 1,107 MWe in the SAMA analysis and to assess the sensitivity of the SAMA analysis results to this assumption (Doyle, 2010a). In response to the RAI, Energy Northwest clarified that 1,107 MWe represents a capacity factor of 93 percent of the net electrical output of 1,190 MWe (Gambhir, 2010).[1] Energy Northwest also provided the results of a sensitivity analysis using 1,190 MWe in estimating RPCs and determined that this change in assumption does not impact the conclusions of the SAMA analysis (i.e., none of the SAMAs previously determined to not be cost-beneficial became cost-beneficial).

As indicated in Section F.3.2, in response to an NRC staff RAI, Energy Northwest identified SAMA FR-08, "improve the fire resistance of cables to RHR and SW," to provide additional protection from MSOs in auto initiation circuits of RHR and service water (Gambhir, 2010).

[1] Crediting the reduction in electrical power level due to capacity factor, i.e., 1,190 MWe x 0.93=1,107 MWe, is atypical for SAMA analyses. However, Energy Northwest provided the sensitivity analysis using 1,190 MWe to indicate the reduction does not impact conclusions.

Energy Northwest provided a Phase II evaluation of this SAMA (Gambhir, 2010). Energy Northwest's analysis (using a 7 percent discount rate) determined that this SAMA candidate was not cost-beneficial in the baseline analysis.

As indicated in Section F.2.1, in response to an NRC staff RAI, Energy Northwest provided the results of a sensitivity study using PSA model Revision 7.1 (Gambhir, 2011). Energy Northwest provided a Phase II evaluation of the Phase II SAMAs using PSA model Revision 7.1. Also included in this sensitivity study was SAMA FR-08. Energy Northwest's analysis (using a 7 percent discount rate) determined that none of the SAMAs were cost-beneficial in the baseline sensitivity analysis.

As indicated in Section F.3.2, in response to NRC staff RAIs, Energy Northwest's review of the internal and fire basic events importance lists for PSA model Revision 7.1 resulted in the identification of the following additional SAMAs candidates (Gambhir, 2010), (Gambhir, 2011):

- SAMA AT-15R, "install modifications to make use of HPCS more likely for ATWS"
- SAMA FL-07R, "protect the HPCS from flooding resulting from ISLOCA events"
- SAMA OT-09R, "for the non-LOCA initiating events, credit the Z (power conversion system recovery) function"
- SAMA CB-10R, "provide additional NDE and inspections of MS piping in Turbine Building"
- SAMA FR-09R, "install early detection for FR1J (physical analysis unit R-1J) and FR1D (physical analysis unit R-1D"
- SAMA FR-10R, "install early detection in the Control Room (RC-10)"
- SAMA FR-11R, "install early detection for FW14 (analysis unit RC-14), FW04 (analysis unit RC-04), FW11 (analysis unit RC-11), FW03 (analysis unit RC-03), FW08 (analysis unit RC-08), FW05 (analysis unit RC-05), FW02 (analysis unit RC-02), FW13 (analysis unit RC-13), and FW1A (analysis unit RC-1A)"
- SAMA FR-12R, "install early detection for FT1A (physical analysis unit T-1A) and FT12 (physical analysis unit T-12)"
- SAMA AC/DC-30R, "provide an additional diesel generator (DG) diverse from DG-1 and DG-2"

Energy Northwest provided a Phase II evaluation of these SAMAs in the PSA model Revision 7.1 sensitivity study (Gambhir, 2011). Energy Northwest's analysis (using a 7 percent discount rate) determined that SAMA OT-09R was potentially cost-beneficial in the baseline sensitivity analysis.

As indicated in Section F.3.2, in response to an NRC staff RAI, Energy Northwest's review of the Phase II SAMAs from prior SAMA analyses for 12 General Electric BWR sites resulted in the identification of the following additional SAMA candidates (Gambhir, 2010), (Gambhir, 2011):

- SAMA FW-05R, "examine the potential for operators to control RFW and avoid a reactor trip"

- SAMA FL-04R, “install one isolation valve in each of standby SW, TSW, and FP lines in the Control Building area of the Radwaste Building to facilitate rapid isolation by the operators upon receipt of a high flow alarm”
- SAMA FL-05R, “install three clamp-on flow instruments to certain drain lines in the Control Building area of the Radwaste Building and alarm in the Control Room”
- SAMA FL-06R, “perform additional NDE inspections to the three lines identified in SAMA FL-04R to verify that degradation is not occurring in these lines”
- SAMA CC-24R, “backfeed the HPCS system with [emergency bus] SM-8 to provide a third power source for HPCS”
- SAMA CC-25R, “enhance alternate injection reliability by including residual heat removal service water and fire water crosstie in maintenance program”
- SAMA CC-26R, “install hard pipe from diesel fire pump to vessel”
- SAMA OT-07R, “increase operator training on systems and operator actions determined to be important from the PSA”
- SAMA OT-08R, “install explosion protection around CGS transformers”
- SAMA OT-10R, “increase fire pump house building integrity to withstand higher winds so the fire system will be capable of withstanding a severe weather event”

Energy Northwest provided a Phase II evaluation of each of these SAMAs in the PSA model Revision 7.1 sensitivity study (Gambhir, 2011). Energy Northwest’s analysis (using a 7 percent discount rate) determined that SAMAs FW-05R, FL-05R, FL-06R, CC-24R, and OT-07R were potentially cost-beneficial in the baseline sensitivity analysis.

As indicated in Section F.3.2, in response to an NRC staff RAI, Energy Northwest identified SAMA SR-05R, “improve seismic ruggedness of MCC-7F and MCC-8F,” to address a seismic improvement identified in the IPEEE (Gambhir, 2010). Energy Northwest provided a Phase II evaluation of this SAMA in the PSA model Revision 7.1 sensitivity study (Gambhir, 2011). Energy Northwest’s analysis (using a 7 percent discount rate) determined that this SAMA candidate was not cost-beneficial in the baseline sensitivity analysis.

Energy Northwest did not provide in the ER an assessment of the impact on the SAMA evaluation of CDF uncertainties based on their assumption that there were already a large number of conservative assumptions and inputs included in the baseline evaluation, which are delineated in Section E.12 of the ER. The NRC staff noted that this is not consistent with the guidance in NEI 05-01 and requested Energy Northwest provide an assessment of the impact of CDF uncertainties on the SAMA analysis (Doyle, 2010a), (Doyle, 2010c). In response to the RAI, Energy Northwest presents the results of an uncertainty analysis of the internal, fire, and seismic event CDFs for PSA model Revision 6.2, which indicates that the 95th percentile value is a factor of 2.7, 3.1, and 3.2, respectively, times the corresponding point estimate CDFs for CGS (Gambhir, 2010). Energy Northwest considered whether any additional Phase II SAMAs might be cost-beneficial if the benefits from internal events and other external events were increased by a factor of 2.7, if the benefits from fire events were increased by a factor of 3.1, and if the benefits from seismic events were increased by a factor of 3.2. SAMA FR-08 identified in response to an NRC staff RAI and described above was included in this uncertainty analysis. Energy Northwest ’s analysis (using a 7 percent discount rate) determined that SAMAs CC-03b, HV-02, and FR-08 are potentially cost-beneficial (Gambhir, 2011). SAMAs

AC/DC-28, FR-07a, and FR-07b, which were previously determined to be cost-beneficial in the 3 percent sensitivity case, were also determined to be cost-beneficial in the uncertainty analysis.

The NRC staff noted that Energy Northwest's CDF uncertainty analysis did not reconsider Phase I SAMAs that were screened on very low benefit or excessive implementation cost and asked Energy Northwest to reconsider these screened Phase I SAMAs based on their potential benefit from using the 95th percentile CDF factors (Doyle, 2010b). In response to this RAI, Energy Northwest reconsidered the Phase I SAMAs screened on very low benefit or excessive implementation cost as part of the PSA model Revision 7.1 sensitivity study discussed in Section F.2.2 (Gambhir, 2011). In this sensitivity study, Energy Northwest presents the results of an uncertainty analysis of the PSA model Revision 7.1 internal, fire, and seismic event CDFs, which indicates that the 95th percentile value is a factor of 2.4, 2.6, and 3.0, respectively, times the corresponding point estimate CDFs for CGS. Energy Northwest considered whether any additional Phase I SAMAs might be retained for further analysis based on the RRW benefit of each screened SAMA and the 95th percentile CDF factors. The RRW benefit for each SAMA was calculated as follows:

RRW Benefit = total present dollar value equivalent associated with completely eliminating severe accidents from internal, fire, or seismic events at CGS

x (1 – 1/RRW)

For each SAMA, a CDF and LERF RRW was determined based on its improvement of the specific hazard or hazards that are affected. The CDF and LERF RRW benefit for each hazard was calculated using the above equation. The RRW benefits from internal events were increased by a factor of 2.4, the RRW benefits from fire events were increased by a factor of 2.6, the RRW benefits from seismic events were increased by a factor of 3.0, and the RRW benefits from other external events were assumed to be equal to the RRW benefits from internal events after being increased by the factor of 2.4. The total of the CDF and LERF RRW benefits with uncertainty factors applied (using a 7 percent discount rate) were summed and, if the result was greater than the estimated implementation cost of the SAMA, it was retained for further analysis. One such Phase I SAMA, as indicated in Section F.3.2, was identified—SAMA FW-04, "add a motor-driven feedwater pump." The specific rationale for screening the other Phase I SAMA candidates is provided in Tables A-15 and A-16 of the sensitivity study (Gambhir, 2011). Several of the Phase I SAMA candidates originally screened in the ER on very low benefit or excessive implementation cost were screened by Energy Northwest in the sensitivity study as not applicable to CGS or already implemented at CGS after further consideration of the SAMA. The NRC staff noted that several of the Phase I SAMAs were screened based on dividing the total estimated benefit by the number of trains or components and asked Energy Northwest to re-assess the screening of these SAMAs by considering the entire risk reduction (Doyle, 2011a). Energy Northwest responded to the RAI by providing an estimated implementation cost to address the entire risk reduction potential for each of these SAMAs and determined that in each of these cases these SAMAs would continue to be screened on excessive implementation cost (Swank, 2011). Based on this additional information, the NRC staff considers the applicant's rationale for screening the other Phase I SAMAs from further consideration in the Phase II evaluation to be reasonable.

In the sensitivity study, Energy Northwest also presents the results of an uncertainty analysis in which the estimated benefits from internal events and other external events, fire events, and seismic events were increased by a factor of 2.4, 2.6, and 3.0, respectively. The additional Phase I SAMA, SAMA FW-04, as described above, was included in this sensitivity analysis.

Also included in this sensitivity analysis were the additional SAMAs identified in response to NRC staff RAIs, as described above. Four SAMAs became cost-beneficial in Energy Northwest's analysis (SAMAs SR-05R, FL-04R, CC-25R, and FR-11R, as described above). SAMAs FR-07a and FR-08, which were previously determined to be cost-beneficial, were also determined to be cost-beneficial in the uncertainty analysis.

In the sensitivity study, Energy Northwest provided the assumptions and results of sensitivity analysis assuming use of 3 percent (Gambhir, 2011). This analysis did not identify any additional potentially cost-beneficial SAMAs.

The NRC staff observed that the SAMA candidates that were screened in the Phase I evaluation by being subsumed could potentially have a lower implementation cost than the SAMA candidate in which it was subsumed. The staff requested that Energy Northwest provide a Phase II evaluation of these SAMAs (Doyle, 2010a), (Doyle, 2010c). In response to the RAI, Energy Northwest provided the estimated benefits and implementation costs for SAMA AC/DC-02, "replace lead-acid batteries with fuel cells," SAMA AC/DC-03, "add a portable diesel-driven battery charger to existing DC system," SAMA AC/DC-15, "install a gas turbine generator," and SAMA AC/DC-16, "install tornado protection on gas turbine generator," using both PSA model Revision 6.2 and Revision 7.1 (Gambhir, 2010), (Gambhir, 2011). Energy Northwest's analysis (using a 7 percent discount rate) determined that none of these SAMA candidates were cost-beneficial in either the baseline or the uncertainty analysis for either PSA model Revision 6.2 or Revision 7.1.

Energy Northwest also noted that the ER provided a cost-benefit evaluation of SAMA CB-03, "increase leak testing of valves in ISLOCA paths," SAMA CB-08, "revise EOPs to improve ISLOCA identification," and SAMA CB-09, "improve operator training on ISLOCA coping," even though these SAMAs were stated to have been screened in the Phase I evaluation by being subsumed. As discussed in Section F.3.1, a Phase II evaluation of these three SAMAs was provided in the ER, the results for which are included in Table F-10 (EN, 2010). Energy Northwest also provided a Phase II evaluation of these SAMAs in the sensitivity study using PSA model Revision 7.1, the results for which are included in Table F-11 (Gambhir, 2011). Energy Northwest's analysis (using a 7 percent discount rate) determined that none of these SAMA candidates was cost-beneficial in either the baseline or the uncertainty analysis for either PSA model Revision 6.2 or Revision 7.1.

As indicated in Section F.3.2, the NRC staff noted that for certain SAMAs considered in the ER, there may be alternatives that could achieve much of the risk reduction at a lower cost (Doyle, 2010a). The NRC staff asked the applicant to evaluate additional lower cost alternatives to the SAMAs considered in the ER, as summarized below:

- Establishing procedures for opening doors or using portable fans or both for sequences involving room cooling failures, such as the EDG room—In response to the NRC staff RAI, Energy Northwest noted that Phase I SAMA HV-03, "enhance procedures for actions on loss of HVAC," considered the opening of doors and use of portable fans as potential improvements at CGS, and existing CGS procedures already included these operator actions if conditions were favorable (Gambhir, 2010). Specific areas where this alternate means of room cooling was found to be effective and proceduralized were the critical switchgear rooms, the ECCS pump rooms, and the MCC rooms in the reactor building. Thermal dynamic analyses were performed where needed to determine that the alternative method of room cooling would be effective and to ensure adequate response time to implement the procedures. Energy Northwest further explained that

the proposed alternate means of room cooling is of limited benefit for the DG room areas because of the need to avoid drawing the heat from these areas into the adjacent electrical equipment panel room, in which the electronics have a lower temperature limit than in the DG room areas. Based on this logic, Energy Northwest screened SAMA HV-03 in the Phase I evaluation. The NRC staff concludes that this alternative has been adequately addressed.

- Using a portable independently powered pump to inject into containment—In response to the NRC staff RAI, Energy Northwest clarified that CGS already has the capability and procedures to connect fire water to the condensate system so as to inject fire water into the RPV to flood containment via a breach in the RPV and connect fire water to the containment spray system via a pumper truck so as to inject fire water into containment via containment spray (Gambhir, 2010). Given these existing capabilities, Energy Northwest concluded that the intent of the proposed alternative has already been met at CGS. The NRC staff agrees with this conclusion.
- Using the security DG or EDG-4 or both to extend the life of the 125-V DC batteries—In response to the NRC staff RAI, Energy Northwest stated that Phase I SAMA AC/DC-03, "add a portable, diesel-driven battery charger to existing DC system," consists of constructing a permanent location for the portable EDG-4, which can be aligned to two different MCCs (MC-7A or MC-8A) that provide both AC power and DC power (through the battery charger) to the aligned train (Gambhir, 2010). Energy Northwest further noted that SAMA AC/DC-03, while originally screened in the Phase I evaluation, was evaluated in response to a separate NRC staff RAI (discussed above), the results of which are provided in Tables F-10 and F-11, and determined to not be cost-beneficial. Energy Northwest also explained that SAMA AC/DC-03 is a lower cost alternative to using the CGS security DG because its use would result in multiple use issues and require additional distribution equipment and cabling. The NRC staff concludes that this alternative has been adequately addressed.
- Using a portable generator to provide power to individual 125-V DC MCCs upon loss of a DC bus to improve availability of HPCS—In response to the NRC staff RAI, Energy Northwest stated that this SAMA would only be beneficial for scenarios in which HPCS is operating on its DG (EDF-3) power so that AC power is available and the HPCS DC charger or battery is lost (Gambhir, 2010). Energy Northwest determined that the RRW for the HPCS DC system is less than 1.005 and concluded that this SAMA would be of very little benefit and not be cost-beneficial. Since the RRW of 1.005 corresponds to a benefit of approximately $12,000, which is less than the minimum cost of $100,000 for a hardware change, the NRC staff agrees with Energy Northwest's conclusion that the proposed alternative is unlikely to be cost-beneficial.

Energy Northwest stated that the six potentially cost-beneficial SAMAs (SAMAs AC/DC-28, CC-03b, FR-07a, FR-07b, FR-08, and HV-02), identified in the ER and in response to NRC staff RAIs using PSA model Revision 6.2, will be further evaluated through the normal processes for evaluating possible plant changes at CGS (EN, 2010), (Gambhir, 2011). Energy Northwest also stated that the 10 additional potentially cost-beneficial SAMAs (SAMAs SR-05R, FL-05R, FL-04R, FL-06R, CC-24R, CC-25R, OT-07R, FW-05R, OT-09R, and FR-11R), identified in response to NRC staff RAIs using PSA model Revision 7.1, will be further evaluated through the normal processes for evaluating possible plant changes at CGS (Gambhir, 2011). In response to an NRC staff RAI, Energy Northwest clarified that the normal process for evaluating possible plant changes at CGS involves first entering the cost-beneficial SAMA candidate into the action request system for SAMAs that require plant modifications or procedure changes and submitting

a training request for SAMAs that require training (Gambhir, 2011). After the requests are submitted, formal processes are followed for each SAMA type (i.e., hardware modification, procedure change, training) to determine if the SAMA is ultimately implemented.

The NRC staff concludes that, with the exception of the potentially cost-beneficial SAMAs discussed above, the costs of the other SAMAs evaluated would be higher than the associated benefits.

F.7 Conclusions

Energy Northwest compiled a list of 151 SAMAs based on a review of the dominant cutsets and most significant plant systems from the plant-specific internal events PRA, insights from the plant-specific IPE and IPEEE, Phase II SAMAs from LRAs for other plants, and review of other industry documentation. A qualitative screening removed SAMA candidates that modified features not applicable to Energy Northwest due to design differences or have already been implemented at CGS, were determined to provide very little benefit, were similar to another SAMA under consideration and was subsumed into the similar SAMA, and have implementation costs that exceed that maximum benefit. Based on this screening, 123 SAMAs were eliminated, leaving 28 candidate SAMAs for evaluation.

For the remaining SAMA candidates, more detailed design and cost estimates were developed as shown in Table F-10. The cost-benefit analyses showed that none of the SAMA candidates were potentially cost-beneficial in the baseline analysis. Energy Northwest performed additional analyses to evaluate the impact of parameter choices on the results of the SAMA assessment. As a result, three SAMAs were identified as potentially cost-beneficial in the ER (SAMAs AC/DC-28, FR-07a, and FR-07b). In response to an NRC staff RAI, Energy Northwest evaluated the same SAMA candidates, and additional SAMA candidates identified in response to NRC staff RAIs, using the 95 percentile internal, fire, and seismic event CDFs to account for uncertainties in the PSA models. This analysis identified three additional SAMAs (SAMA CC-03b, FR-08, and HV-02) as being potentially cost-beneficial. In response to another NRC staff RAI, Energy Northwest performed a sensitivity study to address concerns regarding a significant update to the CGS PSA model since the SAMA analysis was developed. In this sensitivity analysis, Energy Northwest re-evaluated, using the updated CGS PSA model, each of the initial 28 candidate SAMAs and several additional SAMA candidates identified in response to NRC staff RAIs. The SAMA candidates evaluated in the sensitivity study are shown in Table F-11. This study showed that 10 additional SAMAs (SAMA SR-05R, FL-05R, FL-04R, FL-06R, CC-24R, CC-25R, OT-07R, FW-05R, OT-09R, and FR-11R) were potentially cost-beneficial. Energy Northwest has indicated that all 16 potentially cost-beneficial SAMAs will be further evaluated through the normal processes for evaluating possible plant changes at CGS.

The NRC staff reviewed the Energy Northwest analysis and concludes that the methods used, and the implementation of those methods, were acceptable. The treatment of SAMA benefits and costs support the general conclusion that the SAMA evaluations performed by Energy Northwest are reasonable and sufficient for the license renewal submittal. The level of treatment of SAMAs for external events was deemed sufficient to support the conclusion that the likelihood of there being cost-beneficial enhancements in this area was minimized by improvements that have been realized as a result of the IPEEE process, separate analysis of fire and seismic events, and inclusion of a multiplier to account for other external events. Therefore, the NRC staff concurs with Energy Northwest's identification of 16 potentially cost-beneficial SAMAs.

One of these 16 SAMAs—SAMA FL-06R—entails additional NDE and inspection of certain water pipes to lower the risk of flooding due to a pipe break. The NRC noted that SAMA FL-06R appears to relate to managing the effects of aging and may be mandated by the NRC as part of license renewal pursuant to 10 CFR Part 54. The NRC asked for more information about the relationship to the aging management programs proposed in the safety portion of the LRA (Doyle, 2011b), (Cunanan, 2011). Energy Northwest responded by stating that the piping is within the scope of aging management programs (Swank, 2011) but that corrective actions to adjust preventative maintenance activities have already been completed such that SAMA FL-06R would now screen out in Phase 1 as already implemented (Javorik, 2011). Because SAMA FL-06R has already been implemented at CGS, which would have constituted its being screened out during Phase 1 of the SAMA evaluation, the NRC concludes that no further actions are necessary.

Given the potential for cost-beneficial risk reduction, the NRC staff agrees that further evaluation of the remaining 15 SAMAs by Energy Northwest through its long-range planning process is appropriate. The staff concludes that the mitigative alternatives for these 15 do not involve aging management of passive, long-lived systems, structures, and components during the period of extended operation. Therefore, they need not be implemented as part of license renewal pursuant to 10 CFR Part 54.

F.8 References

American Nuclear Society (ANS), “Standard for External Events PRA Methodology,” ANSI/ANS 58.21-2003, La Grange Park, IL, December 2003.

American Society of Mechanical Engineers (ASME), “Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications,” ASME RA-Sa-2003, New York, NY, December 2003.

ASME, “Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications,” ASME/ANS RA-S-2008, New York, NY, 2008.

ASME, “Addenda to ASME RA-S-2008, Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications,” ASME RA-Sa-2009, February 2, 2009.

Benney, Brian J., NRC, letter to J. V. Parrish, Energy Northwest, “Columbia Generating Station—Issuance of Amendment Re: Extension of Diesel Generator Completion Time (TAC No. MC3203),” April 14, 2006, ADAMS Accession No. ML061000672.

Cunanan, Arthur, NRC, letter to B. J. Sawatzke, Energy Northwest, “Request for Additional Information for the Review of the Columbia Generating Station License Renewal Application Regarding Fire Water and Open Cycle Cooling Aging Management Programs (TAC No. ME3058),” November 8, 2011, ADAMS Accession No. ML11305A157.

Doyle, Daniel, NRC, letter to W. S. Oxenford, Energy Northwest, “Request for Additional Information for the Review of the Columbia Generating Station License Renewal Application—SAMA Review (TAC No. ME3121),” July 1, 2010 (2010a), ADAMS Accession No. ML101760421.

Doyle, Daniel, NRC, letter to S. K. Gambhir, Energy Northwest, “Request for Additional Information for the Review of the Columbia Generating Station License Renewal Application—

SAMA Review (TAC No. ME3121)," November 10, 2010 (2010b), ADAMS Accession No. ML102870984.

Doyle, Daniel, NRC, letter to S. K. Gambhir, Energy Northwest, "Request for Additional Information for the Review of the Columbia Generating Station License Renewal Application—SAMA Review (TAC No. ME3121)," December 2, 2010 (2010c), ADAMS Accession No. ML103330246.

Doyle, Daniel, NRC, letter to S. K. Gambhir, Energy Northwest, "Request for Additional Information for the Review of the Columbia Generating Station License Renewal Application—Severe Accident Mitigation Alternative Review (TAC No. ME3121)," March 10, 2011 (2011a), ADAMS Accession No. ML110670379.

Doyle, Daniel, NRC, letter to D. A. Swank, Energy Northwest, "Request for Additional Information for the Review of the Columbia Generating Station License Renewal Application—Severe Accident Mitigation Alternative Review (TAC No. ME3121)," August 30, 2011 (2011b), ADAMS Accession No. ML11214A237.

Energy Northwest (EN), "Columbia Generating Station—License Renewal Application, Appendix E: Applicant's Environmental Report; Operating License Renewal Stage," Richland, WA, January 20, 2010, ADAMS Accession No. ML100250666.

Electric Power Research Institute (EPRI), "A Methodology for Assessment of Nuclear Power Plant Seismic Margin," EPRI NP-6041-SL, Revision 1, Palo Alto, CA, August 1991.

EPRI, "Fire-Induced Vulnerability Evaluation (FIVE)," EPRI TR-100370, Revision 0, Palo Alto, CA, April 1992.

EPRI, "Fire Events Data Base for U.S. Nuclear Power Plants," NSAC/178L, Palo Alto, CA, January 1993.

EPRI, "Methodology for Developing Seismic Fragilities," EPRI NP-103059, Palo Alto, CA, April 1994.

EPRI, "Seismic Probabilistic Risk Assessment Implementation Guide," EPRI TR-1002989, Palo Alto, CA, December 2003.

Gambhir, Sudesh K., Energy Northwest, letter to NRC Document Control Desk, "Columbia Generating Station, Docket No. 50-397, Response to Request for Additional Information, License Renewal Application," Richland, WA, September 17, 2010, ADAMS Accession No. ML102660151.

Gambhir, Sudesh K., Energy Northwest, letter to NRC Document Control Desk, "Columbia Generating Station, Docket No. 50-397, Response to Request for Additional Information for the Review of the Columbia Generating Station, License Renewal Application," Richland, WA, January 28, 2011, ADAMS Accession No. ML110330395.

Geomatrix Consultants Inc. (Geomatrix), "Probabilistic Seismic Hazard Analysis WNP-2 Nuclear Power Plant Hanford Washington," Project No. 1846, December 1994 (1994a).

Geomatrix, "Probabilistic Seismic Hazard Analysis, DOE Hanford Site, Washington," WHC-SD-W236-TI-002, Westinghouse Hanford Company, Richland, WA, 1994 (1994b).

Geomatrix, "Probabilistic Seismic Hazard Analysis, DOE Hanford Site, Washington," WHC-SD-W236-TI-002 Rev 1a, Westinghouse Hanford Company, Richland, WA, 1996.

Javorik, A., Energy Northwest, letter to NRC Document Control Desk, "Columbia Generating Station, Docket No. 50-397, Response to Request for Additional Information, License Renewal Application," Richland, WA, November 17, 2011, ADAMS Accession No. ML11325A067.

Nuclear Energy Institute (NEI), "Severe Accident Mitigation Alternative (SAMA) Analysis Guidance Document," NEI 05-01, Revision A, Washington, D.C., November 2005.

Oregon, "Department of Revenue: Research and Statistical Reports, Property Tax Statistics Fiscal Year 2002-03," 2003–2003, Available URL: http://www.oregon.gov/DOR/STATS/303-405-03-toc.shtml (accessed February 2008).

Pacific Northwest National Laboratory (PNNL), "Site-Specific Seismic Response Model for the Waste Treatment Plant, Hanford Washington," PNNL-15089, Richland, WA, 2005.

PNNL, "Updated Site Response Analyses for the Waste Treatment Plant, DOE Hanford Site, Washington," PNNL-16653, Richland, WA, 2007.

Parrish, J.V., WPPSS, letter to NRC Document Control Desk, "WNP-2, Operating License NPF-21, Revision 1 to Response to Generic Letter 88-20, 'Individual Plant Examination for Severe Accident Vulnerabilities 10CFR 50.54 (F),'" Richland, WA, July 27, 1994, ADAMS Accession No. ML0800904931.

Parrish, J.V., WPPSS, letter to NRC Document Control Desk, "WNP-2, Operating License NPF-21, Initial Submittal of Individual Plant Examination for External Events (IPEEE) (TAC No. 74489)," Richland, WA, June 26, 1995, ADAMS Accession No. ML0800903630.

Sorensen, G.C., WPPSS, letter to NRC Document Control Desk, "WNP-2, Operating License NPF-21, Revision 1 to Response to Generic Letter 88-20, 'Individual Plant Examination for Severe Accident Vulnerabilities 10CFR 50.54 (f),'" Richland, WA, August 28, 1992, ADAMS Accession No. ML0800904991.

Swank, David A., Energy Northwest, letter to NRC Document Control Desk, "Columbia Generating Station, Docket No. 50-397, Response to Request for Additional Information Related to the Review of the Severe Accident Mitigation Alternative Analysis," Richland, WA, May 6, 2011, ADAMS Accession No. ML11129A186.

U.S. Census Bureau (USCB), "United States Census 2000, State and County QuickFacts," 2000 (2000a), Available URL: http://www.census.gov/main/www/cen2000.html (accessed July 2008).

USCB, "Population Estimates Program," 2000 (2000b), Available URL: www.factfinder.census.gov (accessed February 2008).

U.S. Department of Agriculture (USDA), "2002 Census of Agriculture: Washington State and County data," Volume 1, Geographic Area Series, Part 47, AC-02-A-37, June 2004 (2004a).

USDA, "2002 Census of Agriculture: Oregon State and County data," Volume 1, Geographic Area Series, Part 47, AC-02-A-37, June 2004 (2004b).

U.S. General Services Administration (USGSA), "Per Diem Rates," 2008, Available URL: http://www.gsa.gov (accessed April 23, 2008).

U.S. Geological Survey (USGS), "2008 NSHM Gridded Data, Peak Ground Acceleration," 2008, Available URL: http://earthquake.usgs.gov/hazards/products/conterminous/2008/data/.

U.S. Nuclear Regulatory Commission (NRC), "Standard Review Plan for the Review of Safety Analysis Report for Nuclear Power Plants," NUREG-0800, Washington, D.C., November 1975.

NRC, "PRA Procedures Guide: A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants," NUREG/CR-2300, Washington, D.C., January 1983.

NRC, "COMPBRN III—A Computer Code for Modeling Compartment Fires," NUREG/CR-4566, July 1986.

NRC, "Individual Plant Examination for Severe Accident Vulnerabilities," Generic Letter 88-20, November 23, 1988.

NRC, "Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants," NUREG-1150, Washington, D.C., 1990 (1990a).

NRC, "Evaluation of Severe Accident Risks: Quantification of Major Input Parameters," NUREG/CR-4551, Volume 2, Revision 1, Part 7, Washington, D.C., December 1990 (1990b).

NRC, "Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE)," Generic Letter No. 88-20, Supplement 4, NUREG-1407, Washington, D.C., June 1991 (1991a).

NRC, "Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities," NUREG-1407, Washington, D.C., June 1991 (1991b).

NRC, *Regulatory Analysis Technical Evaluation Handbook*, NUREG/BR-0184, Washington, D.C., 1997 (1997a).

NRC, "Safety Evaluation by the Office of Nuclear Reactor Regulation Related to Individual Plant Examination Washington Public Power Supply System Nuclear Project No. 2, Docket No. 50-397," Washington, D.C., April 8, 1997 (1997b).

NRC, "Individual Plant Examination Program: Perspectives on Reactor Safety and Plant Performance," NUREG-1560, Washington, D.C., 1997 (1997c).

NRC, *Code Manual for MACCS2: Volume 1, User's Guide,* NUREG/CR-6613, Washington, D.C., May 1998.

NRC, "Review of Columbia Generating Station Individual Plant of Examination of External Events Submittal (TAC Nos. M83695)," Washington, D.C., February 26, 2001.

NRC, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis," RG 1.174, Revision 1, Washington, D.C., November 2002.

NRC, "Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission," NUREG/BR-0058, Revision 4, Washington, D.C., 2004 (2004a).

NRC, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities," RG 1.200 for Trial Use, Washington, D.C., February 2004 (2004b).

NRC, "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities," NUREG/CR-6850, Volume 2, Washington, D.C., September 2005.

NRC, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed activities Basis," RG 1.200, Revision 2, Washington, D.C., March 2009 (2009a).

NRC, "Enforcement Guidance Memorandum, Enforcement Discretion for Fire Induced Circuit Faults," EGM 09-02, Washington, D.C., May 14, 2009 (2009b), ADAMS Accession No. ML090300446.

Swank, D., Energy Northwest, letter to NRC Document Control Desk, "Columbia Generating Station, Docket No. 50-397, Response to Request for Additional Information, License Renewal Application," Richland, WA, September 29, 2011, ADAMS Accession No. ML11278A187.

Washington, "Department of Revenue Washington State, Property Tax Statistics 2002," 2002, Available URL: http://dor.wa.gov/Content/AboutUs/StatisticsAndReports/2002/Property_Tax_Statistics_2002/default.aspx (accessed February 2008).

Washington Office of Financial Management (WOFM), "Provisional Projections of the Total Resident Population for Growth Management," 2007, Available URL: http://www.ofm.wa.gov/pop/gma/projections07.asp (accessed November 6, 2008).

Webring, R.L., Energy Northwest, letter to NRC Document Control Desk, "Columbia Generating Station, Docket No. 50-397, Application for Amendment of Facility Operating License No. NPF-21 for Extension of Diesel Generator Completion Time," Richland, WA. May 19, 2004, ADAMS Accession No. ML102660151.

ATTACHMENT 27

NUREG-1437, Supp. 45, "Generic Environmental Impact Statement for License Renewal of Nuclear Plants: Regarding Hope Creek Generating Station and Salem Nuclear Generating Station, Units 1 and 2, Vol. 2, App. G (Mar. 2011)

G. U.S. Nuclear Regulatory Commission staff Evaluation of Severe Accident Mitigation Alternatives for Hope Creek Generating Station in Support of License Renewal Application Review

G.1 Introduction

PSEG Nuclear, LLC, (PSEG or the applicant) submitted an assessment of severe accident mitigation alternatives (SAMAs) for the Hope Creek Generating Station (HCGS) as part of the environmental report (ER) (PSEG 2009). This assessment was based on the most recent HCGS probabilistic risk assessment (PRA) available at that time; a plant-specific offsite consequence analysis performed using the MELCOR Accident Consequence Code System, Version 2 (MACCS2) computer code, and insights from the HCGS individual plant examination (IPE) (PSEG 1994) and individual plant examination of external events (IPEEE) (PSEG 1997). In identifying and evaluating potential SAMAs, PSEG considered SAMAs that addressed the major contributors to core damage frequency (CDF) and release frequency at HCGS, as well as SAMA candidates for other operating plants that have submitted license renewal applications. PSEG initially identified 23 potential SAMAs. This list was reduced to 21 unique SAMA candidates by eliminating SAMAs that: (1) are not applicable to HCGS due to design differences, (2) have already been implemented at HCGS, (3) would achieve the same risk reduction results that had already been achieved at HCGS by other means, (4) have excessive implementation cost, or (5) could be combined with another SAMA candidate. PSEG assessed the costs and benefits associated with each of the potential SAMAs, and concluded in the ER that several of the candidate SAMAs evaluated are potentially cost-beneficial.

Based on a review of the SAMA assessment, the staff of the U.S. Nuclear Regulatory Commission (NRC) issued a request for additional information (RAI) to PSEG by letter dated May 20, 2010 (NRC 2010a) and, based on a review of the RAI responses, the staff requested clarification for RAI response by teleconference dated July 29, 2010 (NRC 2010b). The staff's requests concerned the following:

- Discussion of internal and external review comments on the PRA model, including the impact of the 2008 PRA peer review comments on the SAMA analysis results
- the process and criteria used to assign containment event tree (CET) end states to release categories
- additional details on the seismic analysis
- the SAMA screening process and additional potential SAMAs not previously considered
- further information on the costs and benefits of several specific candidate SAMAs and low cost alternatives

PSEG submitted additional information in response to the staff requests by letters dated June 1, 2010 (PSEG 2010a) and August 18, 2010 (PSEG 2010b). In these response letters, PSEG provided the following:

- a listing of open gaps and findings from the 2008 PRA peer review and an assessment of their impact on the SAMA analysis
- additional description of how CET end states were assigned to release categories and how representative sequences were selected for each release category;
- clarification of certain elements of the seismic analysis and an assessment of the impact of seismic assumptions on the external events multiplier
- analyses of additional SAMAs
- additional information regarding several specific SAMAs

PSEG's responses addressed the staff's concerns, and resulted in the identification of additional potentially cost-beneficial SAMAs.

An assessment of SAMAs for HCGS is presented below.

G.2 Estimate of Risk for Hope Creek Generating Station

PSEG's estimates of offsite risk at HCGS are summarized in Section G.2.1. The summary is followed by the NRC staff's review of PSEG's risk estimates in Section G.2.2.

G.2.1 PSEG's Risk Estimates

Two distinct analyses are combined to form the basis for the risk estimates used in the SAMA analysis: (1) the HCGS Level 1 and Level 2 PRA model, which is an updated version of the IPE (PSEG 1994), and (2) a supplemental analysis of offsite consequences and economic impacts (essentially a Level 3 PRA model) developed specifically for the SAMA analysis. The SAMA analysis is based on the most recent HCGS Level 1 and Level 2 PRA model available at the time of the ER, referred to as the HC108B update. The scope of this HCGS PRA does not include external events.

The HCGS CDF is approximately 5.1×10^{-6} per year as determined from quantification of the Level 1 PRA model at a truncation of 1×10^{-12} per year. When determining the frequency of the source term categories from the sum of the CET sequences, or Level 2 PRA model, a higher truncation of 5×10^{-11} per year was used and the resulting release frequency (from all release categories, which consist of intact containment, late release, and early release) is approximately 4.4×10^{-6} per year. The latter value was used as the baseline CDF in the SAMA evaluations (PSEG 2009). The CDF is based on the risk assessment for internally-initiated events, which includes internal flooding. PSEG did not explicitly include the contribution from external events within the HCGS risk estimates; however, it did account for the potential risk reduction benefits associated with external events by multiplying the estimated benefits for internal events by a factor of 6.3. This is discussed further in Sections G.2.2 and G.6.2.

The breakdown of CDF by initiating event is provided in Table G-1 (PSEG 2009). As shown in this table, events initiated by loss of offsite power, loss of service water and other transients (manual shutdown and turbine trip with bypass) are the dominant contributors to the CDF. Anticipated transient without scram (ATWS) sequences account for 3 percent of the CDF, station blackout (SBO) accounts for 12 percent of the CDF (PSEG 2010a).

Table G-1. Hope Creek Generating Station Core Damage Frequency for Internal Events

Initiating Event	CDF (per year)	% Contribution to CDF[1]
Loss of Offsite Power	9.3×10^{-7}	18
Loss of Service Water (SW)	8.1×10^{-7}	15
Manual Shutdown	7.7×10^{-7}	15
Turbine Trip with Bypass	6.2×10^{-7}	12
Small Loss of Coolant Accident (LOCA) – Water (Below Top of Active Fuel)	2.8×10^{-7}	5
Small LOCA – Steam (Above Top of Active Fuel)	2.3×10^{-7}	4
Loss of Condenser Vacuum	2.0×10^{-7}	4
Fire Protection System Rupture Outside Control Room	1.9×10^{-7}	4
Isolation LOCA in Emergency Core Cooling System (ECCS) Discharge Paths	1.1×10^{-7}	2
Main Steam Isolation Valve (MSIV) Closure	1.1×10^{-7}	2
Internal Flood Outside Lower Relay Room	9.7×10^{-8}	2
Loss of Feedwater	8.8×10^{-8}	2
Loss of Safety Auxiliaries Cooling System	7.9×10^{-8}	2
Reactor Auxiliaries Cooling System (RACS) Common Header Unisolable Rupture	7.6×10^{-8}	1
Unisolable SW A Pipe Rupture in RACS Room	5.7×10^{-8}	1
Unisolable SW B Pipe Rupture in RACS Room	5.7×10^{-8}	1
Others (less than 1% each)	4.1×10^{-7}	8
Total CDF (internal events)	**5.1×10^{-6}**	**100**

[1]Column totals may be different due to round off.

Source: PSEG, 2009

The Level 2 HCGS PRA model that forms the basis for the SAMA evaluation is essentially a complete revision to the IPE model. The Level 2 model uses three CETs containing both phenomenological and systemic events. The Level 1 core damage sequences are binned into accident classes that provide the interface between the Level 1 and Level 2 CET analysis. The CETs are linked directly to the Level 1 event trees and CET nodes are evaluated using supporting fault trees.

The result of the Level 2 PRA is a set of 11 release or source term categories, with their respective frequency and release characteristics. The results of this analysis for HCGS are provided in Table E.3-6 of the ER Appendix E (PSEG 2009). The categories were defined based on the timing of the release, the magnitude of the release, and whether or not the

containment remains intact or fails. The frequency of each release category was obtained by summing the frequency of the individual accident progression CET endpoints binned into the release category. Source terms were developed for each of the 11 release categories using the results of Modular Accident Analysis Program (MAAP) Version 4.0.6 computer code calculations.

The offsite consequences and economic impact analyses use the MACCS2 code to determine the offsite risk impacts on the surrounding environment and public. Inputs for these analyses include plant-specific and site-specific input values for core radionuclide inventory, source term and release characteristics, site meteorological data, projected population distribution (within a 50-mile [mi] radius) for the year 2046, emergency response evacuation modeling, and economic data. The core radionuclide inventory corresponds to the end-of-cycle values for HCGS operating at 3917 megawatt-thermal (MW[t]), which is two percent above the current extended power uprate (EPU) licensed power level of 3,840 MWt. The magnitude of the onsite impacts (in terms of clean-up and decontamination costs and occupational dose) is based on information provided in NUREG/BR-0184 (NRC 1997a).

In the ER, PSEG estimated the dose to the population within 50-mi (80-kilometers [km]) of the HCGS site to be approximately 0.23 person-Sievert (person-Sv) (22.9 person-roentgen equivalent man [rem]) per year. The breakdown of the total population dose by containment release mode is summarized in Table G-2. Releases from the containment within the early time frame (0 to less than 4 hours following event initiation) and intermediate time frame (4 to less than 24 hours following event initiation) dominate the population dose risk at HCGS.

Table G-2. Breakdown of Population Dose by Containment Release Mode

Containment Release Mode	Population Dose (Person-Rem[1] Per Year)	Percent Contribution [2]
Early Releases (< 4hrs)	11.9	52
Intermediate Releases (4 to <24 hrs)	9.9	43
Late Releases (≥24 hrs)	1.1	5
Intact Containment	<0.1	negligible
Total	**22.9**	**100**

[1]One person-rem = 0.01 person-Sv

[2]Derived from Table E.3-7 of the ER (PSEG 2009)

G.2.2 Review of PSEG's Risk Estimates

PSEG's determination of offsite risk at HCGS is based on the following three major elements of analysis:

- the Level 1 and 2 risk models that form the bases for the 1994 IPE submittal (PSEG1994), and the external event analyses of the 1997 IPEEE submittal (PSEG 1997),
- the major modifications to the IPE model that have been incorporated in the HCGS PRA, and
- the MACCS2 analyses performed to translate fission product source terms and release frequencies from the Level 2 PRA model into offsite consequence measures (essentially this equates to a Level 3 PRA).

Each of these analyses was reviewed to determine the acceptability of PSEG's risk estimates for the SAMA analysis, as summarized below.

The staff review of the HCGS IPE is described in an NRC report dated April 23, 1996 (NRC 1996). Based on a review of the IPE submittal and responses to RAIs, the staff concluded that the IPE process is capable of identifying the most likely severe accidents and severe accident vulnerabilities, and therefore, that the HCGS IPE has met the intent of Generic Letter (GL) 88-20 (NRC 1988).

During the performance of the IPE, transients involving heating, ventilation, and air conditioning (HVAC) failure were determined to contribute inordinately to the CDF. This was labeled a vulnerability and a procedure to provide alternate ventilation was developed. The implementation of this procedure removed this vulnerability. Credit for this procedure was taken in the HCGS IPE submittal. No other vulnerabilities were identified. In the ER, PSEG indicated that there were three improvements identified in the process of performing the IPE. Two of the improvements were performing refined calculations to allow increased credit for existing plant design features. The third was developing a procedure for operation of the Safety Auxiliaries Cooling System in severe accident conditions. All of these improvements are stated to have been implemented (PSEG 2009).

There have been twelve revisions to the IPE model since the 1994 IPE submittal. A listing of the changes made to the HCGS PRA since the original IPE submittal was provided in the ER (PSEG 2009) and in response to an RAI (PSEG 2010a) and is summarized in Table G-3. A comparison of internal events CDF between the 1994 IPE and the current PRA model indicates a decrease of about a factor of ten in the total CDF (from 4.7×10^{-5} per year to 5.1×10^{-6} per year). This reduction can be attributed to significant changes in success criteria, modeling details and removal of conservatism.

Table G-3. Hope Creek Generating Station PRA Historical Summary

PRA Version	Summary of Changes from Prior Model	Total CDF[1] (per year)
1994	IPE Submittal	4.7×10^{-5}
Model 0 9/1994	- Credit taken for beyond design basis performance of Safety Auxiliaries Cooling System (SACS) and Station Service Water System (SSWS) based on updated success criteria calculations.	1.3×10^{-5}
Model 1.0 7/1999	- Integrated the Level I and II models - Updated the database - Further developed sequence end states - Developed fault trees for special initiators - Reviewed dependent operator actions	1.9×10^{-5}
Model 1.3[2] 10/2000	- Requantified two important human error probabilities - Revised treatment of disallowed maintenance to credit plant procedures and operating practices. - Revised common cause failure assessment - Eliminated core spray room cooling dependency on SACS based on review of room heat up calculations - Added models for breaks outside containment and manual shutdown - Updated ATWS analysis	9.3×10^{-6}
Model 2003A 8/2003	- Incorporated resolution of 1999 BWROG peer review Facts and Observations (Attachment 14 to PSEG 2005) - Converted from NUPRA to CAFTA software - Performed completely new human reliability assessment - Revised accident sequence definitions - Performed new MAAP calculations for extended power uprate (EPU) conditions - Updated data - Modified system models - Updated common cause failure analysis - Added internal flood accident sequences	3.1×10^{-5}
Rev. 2.0 10/2004	- Modified 480 VAC dependencies - Modified SACS success criteria - Modified SACS-SW Human Error Probabilities	1.7×10^{-5}
Model 2005C[3] 2/2006	- Removed conservatism in the SACS-SW success criteria - Included more detailed logic for AC power supplies - Removed conservatism in operator action human error probabilities (HEPs) - Reduced turbine trip initiating event frequency	9.8×10^{-6}

PRA Version	Summary of Changes from Prior Model	Total CDF[1] (per year)
HC108A 8/2008	BWROG Peer Reviewed - Incorporated seasonal success criteria for SACS and SSWS - Updated internal flooding scenarios and initiating event frequencies to be consistent with ASME PRA standard - Credited use of portable battery charger for Station Blackout scenarios - Reassessed human error probabilities using Electric Power Research Institute (EPRI) human reliability analysis (HRA) calculator - Updated evaluation of dependent operator actions	7.6×10^{-6}
HC108B 12/2008	- Credited procedure changes for local manual manipulation of SSWS valves under LOOP conditions - Removed conservatism in modeling of 120 VAC inverter room cooling logic - Updated SACS pump failure probabilities to be consistent with Bayesian update values	5.1×10^{-6} (4.4×10^{-6})[4]

[1]Total CDF includes internal floods. Prior to Model 2003A, IPE internal flood analysis was retained.

[2]Changes for Model 1.3 includes those for prior intermediate Models 1.1 and 1.2. All changes were considered minor.

[3]Changes for Model 2005C includes those for prior intermediate Models 2005A and 2005B. All changes to Models 2005A and 2005B were considered minor.

[4]Model HC108B truncation limit was decreased to 1×10^{-12} per year from 5×10^{-11} per year utilized for the HC108A and 2005 models. The CDF in parentheses is the result based on the higher truncation limit.

Source: PSEG, 2009

The CDF value from the 1994 IPE (4.7×10^{-5} per year) is in the upper third of the values reported for other boiling water reactor (BWR) 3/4 plants. Figure 11.2 of NUREG-1560 shows that the IPE-based total internal events CDF for BWR 3/4 plants ranges from 9×10^{-8} per year to 8×10^{-5} per year, with an average CDF for the group of 2×10^{-5} per year (NRC 1997b). It is recognized that other plants have updated the values for CDF subsequent to the IPE submittals to reflect modeling and hardware changes. The current internal events CDF results for HCGS (5.1×10^{-6} per year) are comparable to that for other plants of similar vintage and characteristics.

The staff considered the peer reviews performed for the HCGS PRA, and the potential impact of the review findings on the SAMA evaluation. In the ER (PSEG 2009) and in response to a staff RAI (PSEG 2010a) and in other unrelated submittals (PSEG 2005), PSEG described three BWROG peer reviews for the HCGS PRA. The first was a pilot of the BWROG peer review process conducted in 1996 of PRA Model 0. The second, conducted in 1999, reviewed PRA Model 1.0. The third, conducted in 2008, reviewed the HC108A Model.

The 1999 peer review identified no Level A (extremely important) and 80 Level B (important) facts and observations (F&Os). It was stated that these F&Os were resolved and incorporated in the 2003A PRA Model (PSEG 2005).

The 2008 peer review of the HC108A model was requested by PSEG because of the significant changes in PRA methods since the prior peer review. This peer review was performed using

the Nuclear Energy Institute (NEI) peer review process (NEI 2007) and the ASME PRA Standard (ASME 2005) as endorsed by the NRC in Regulatory Guide (RG)1.200, Revision. 1 (NRC 2007). In the ER PSEG summarizes the results of the peer review by reporting the number of ASME Standard's supporting requirements (SRs) that were assessed to meet each of the standard's capability categories. Of the 301 SRs applicable to HCGS, 286 were found to meet the requirements for Capability Category II or higher, seven met Capability Category I and eight did not meet any Capability Category. The 2005 ASME PRA standard describes Capability Category II as follows: (1) the scope and level of detail has resolution and specificity sufficient to identify the relative importance of significant contributors at the *component* level including human actions, as necessary; (2) *plant-specific* data/models are used for significant contributors; and (3) departures from realism will have *small* impact on the conclusions and risk insights as supported by good practices. Similarly, it describes Capability Category I as follows: (1) the scope and level of detail has resolution and specificity sufficient to identify the relative importance of significant contributors at the *system or train* level including human actions, (2) *generic* data/models are acceptable except for the need to account for the unique design and operational features of the plant, and (3) departures from realism will have *moderate* impact on the conclusions and risk insights as supported by good practices (ASME 2005)

In the ER, PSEG indicated that the SRs identified as "not met" were addressed in the HC108B model. In response to a staff RAI, PSEG provided a listing and discussion of the resolution of the SRs that only met Capability Category I and of other Peer Review Finding-level F&Os (PSEG 2010a). It should be noted that a Finding-level F&O is essentially equivalent to and replaces the previously used Level A and B F&Os[1] and is defined as an observation that is necessary to address to ensure: (1) the technical adequacy of the PRA; (2) the capability/robustness of the PRA update process; and (3) the process for evaluating the necessary capability of the PRA technical elements (NEI 2007).

Of the seventeen identified SRs and findings, thirteen were stated to have been resolved as part of the HC108B PRA update and re-assessed as meeting Capability Category II at a minimum as a result of additional investigation, analysis and/or documentation. Four of the SRs and findings remain open. In the discussion of the status and impact of these open items, PSEG concluded that the resolution of each would not impact the conclusions of the SAMA risk assessment. Two of the open items were documentation issues. One issue was related to the need for additional plant-specific data for important events. PSEG indicated that a review of HCGS recent experience indicates "no anomalous behavior" and that minor changes to component unavailability and unreliability values would not change the conclusions of the SAMA risk evaluation. The fourth issue was related to the identification, characterization and documentation of model uncertainties. PSEG indicated that a number of sensitivity evaluations were performed and that other areas of the HCGS PRA were investigated for potential impact on the PRA results but none were found to rise to the level of being candidates for modeling uncertainty. PSEG concluded that the resolution of this open item would not impact the conclusions of the SAMA evaluation (PSEG 2010a). PSEG further stated that the HCGS PRA

[1] Earlier in the history of the PRA Peer Review process, F&Os were divided into four categories, from most (A) to least significant (D). "Findings" have taken the place of the former A and B level F&Os, while "Suggestions" are now used when citing what formerly would have been F&Os at the C and D level.

treatment of model uncertainty is considered to meet the requirements of the latest NRC guidance on model uncertainty, NUREG-1855 (NRC 2009).

In the initial response to the staff's RAIs (PSEG 2010a) PSEG's discussion of the resolution of the supporting requirements that were not met addressed only six items whereas the initial listing in the ER indicated that there were eight SRs that were not met. In response to the request for clarification PSEG stated that the final review report identified six SRs as not being met, but that the draft had cited eight (PSEG 2010b).

Based on review with respect to the requirements of the ASME PRA Standard, the NRC staff considers PSEG's disposition of the peer review findings to be reasonable and that final resolution of the findings is not likely to impact the results of the SAMA analysis.

The Revision HC108B model reflects the current (as of the date of the ER submittal) HCGS configuration and design. The applicant states that HCGS risk management personnel have reviewed plant modifications and procedure changes since the HC108B model freeze date. No changes were identified that required PRA model updates and therefore the licensee concluded that none of the plant modifications and procedure changes since the HC108B PRA update would impact the conclusions of the SAMA analysis. (PSEG 2010a, PSEG 2010b)

In response to an RAI, PSEG described the overall quality assurance program applicable to the HCGS PRA and its updates by providing descriptions of significant governing PSEG procedures. These procedures address the overall risk management program, risk management documentation including quality requirements for preparation, review and approval, configuration control and PRA model updates. Based on PSEG's procedures, the HCGS PRA is controlled with the appropriate requirements.

Given that the HCGS internal events PRA model has been peer-reviewed and the peer review findings with potential to impact SAMA evaluations were all dispositioned, and that PSEG has satisfactorily addressed NRC staff questions regarding the PRA, the NRC staff concludes that the internal events Level 1 PRA model is of sufficient quality to support the SAMA evaluation.

As indicated above, PSEG does not maintain a current HCGS external events PRA that explicitly models seismic and fire initiated core damage accidents that can be linked with the current Level 2 and 3 PRA. However, the models developed for seismic and fire events in the IPEEE were partially updated in 2003 to use revised initiating event frequencies and conditional core damage probabilities based on the 2003A internal events PRA Model. These results were used to identify SAMAs that address important fire and seismic risk contributors, as discussed below in Section G.3.2. The updated seismic and fire core damage results are described in ER Section E.5.1.7

The HCGS IPEEE was submitted in July 1997 (PSEG 1997), in response to Supplement 4 of Generic Letter 88-20 (NRC 1991a). The submittal included a seismic PRA, an internal fire PRA, and an evaluation of high winds, external flooding, and other hazards. While no fundamental weaknesses or vulnerabilities to severe accident risk in regard to the external events were identified, two potential enhancements were identified as discussed below. In a letter dated July 26, 1999 (NRC 1999), the NRC staff concluded that PSEGs IPEEE process is capable of identifying the most likely severe accidents and severe accident vulnerabilities, and therefore, that the HCGS IPEEE has met the intent of Supplement 4 to Generic Letter 88-20.

The HCGS IPEEE seismic analysis used a seismic PRA following NRC guidance (NRC 1991a). The seismic PRA included: a seismic hazard analysis, a seismic fragility assessment, a seismic systems analysis, and quantification of seismic CDF.

The seismic hazard analysis estimated the annual frequency of exceeding different levels of ground motion. Seismic CDFs were determined for both the EPRI (EPRI 1989) and the Laurence Livermore National Laboratory (LLNL) (NRC 1994) hazard assessments. The seismic fragility assessment utilized the walkdown procedures and screening caveats in EPRI's seismic margin assessment methodology (EPRI 1991). Fragility calculations were made for about 90 components and, using a screening criterion of median peak ground acceleration (pga) of 1.5 g which corresponds to a 0.5 pga high confidence low probability of failure (HCLPF) capacity, a total of 17 components were screened in. The seismic systems analysis defined the potential seismic induced structure and equipment failure scenarios that could occur after a seismic event and lead to core damage. The HCGS IPE event tree and fault tree models were used as the starting point for the seismic analysis. Quantification of the seismic models consisted of convoluting the seismic hazard curve with the appropriate structural and equipment seismic fragility curves to obtain the frequency of the seismic damage state. The conditional probability of core damage given each seismic damage state was then obtained from the IPE models with appropriate changes to reflect the seismic damage state. The CDF was then given by the product of the seismic damage state probability and the conditional core damage probability.

The seismic CDF resulting from the HCGS IPEEE was calculated to be 3.6×10^{-6} per year using the LLNL seismic hazard curve and 1.0×10^{-6} per year using the EPRI seismic hazard curve. Both utilized the HCGS Model 0 internal events PRA, with a CDF of 1.3×10^{-5} per year for quantification of non-seismic failures.

The HCGS IPEEE did not identify any vulnerability due to seismic events or any potential improvements to reduce seismic risk. The IPEEE noted, however, that fire water tanks are not seismically robust and hence no credit was taken for the fire protection system in the seismic PRA. This is discussed further in Section G.3.2.

Subsequent to the IPEEE, PSEG updated the seismic PRA utilizing conditional core damage probabilities from the 2003A PRA model modified to reflect the seismic human reliability assessment that was performed to support the IPEEE, referred to as the HCGS 2003 External Events Update (PSEG 2009). The resulting seismic CDF using the EPRI seismic hazard curves is 1.1×10^{-6} per year. In the ER, PSEG provided a listing and description of the top ten seismic core damage contributors. The dominant seismic core damage contributors with a CDF of 1×10^{-8} per year or more are listed in Table G-4. In response to a staff RAI, PSEG also determined the updated seismic CDF using the LLNL seismic hazard curve and the total seismic CDF was determined to be 3.6×10^{-6} per year. The seismic CDF utilizing the LLNL hazard curves for dominant seismic core damage contributors are also listed in Table G-4.

Table G-4. Dominant Contributors to the Seismic Core Damage Frequency

		Based on EPRI Seismic Hazard Curves		Based on LLNL Seismic Hazard Curves	
Basic Event ID	**Seismic Sequence Description**	**CDF (per year)**	**% Contribution to Seismic CDF**	**CDF (per year)**	**% Contribution to Seismic CDF**
%IE-SET36	Seismic-Induced Equipment Damage State SET-36 (Impacts – 120V PNL481)	6.7×10^{-7}	60	2.5×10^{-6}	70
%IE-SET18	Seismic-Induced Equipment Damage State SET-18 (Impacts – LOOP)	3.1×10^{-7}	27	3.3×10^{-7}	9
%IE-SET37	Seismic-Induced Equipment Damage State SET-37 (Impacts – 125V)	6.8×10^{-8}*	6	4.4×10^{-7}	12
%IE-SET35	Seismic-Induced Equipment Damage State SET-35 (Impacts – 120V PNL482, RSP)	4.6×10^{-8}	4	1.6×10^{-7}	5
%IE-SET38	Seismic-Induced Equipment Damage State SET-38 (Impacts – 1E panel room ventilation.)	2.1×10^{-8}	2	5.4×10^{-8}	2

* In response to an RAI, PSEG indicated that the value reported in the ER page E-99 for this contributor was in error and should be that given in the IPEEE - 6.8×10^{-8} per year (PSEG 2010a).

Source: PSEG, 2009

For both hazard curves, the largest contributor to seismic CDF is a seismic-induced loss of all four divisions of 1E 120 VAC instrumentation distribution panels that leads directly to core damage. Other significant contributors are: for the EPRI hazard curves, a seismic-induced loss of offsite power which together with non-seismic random failures leads to core damage and, for the LLNL hazard curves, a seismic induced failure of all 125 VDC 1E power to loads that lead directly to core damage. The failure of all four 1E 120 VAC divisions and failure of all 125 VDC occur at a relatively high ground acceleration (a median failure at 1.08g and 1.47g, respectively) while the loss of offsite power occurs at a relatively low ground acceleration (a median failure of 0.31g) (PSEG 1997).

The NRC staff requested the applicant assess the impact the higher seismic CDF resulting from the use of the LLNL hazard curves would have on the external events multiplier and the results of the SAMA analysis as well as the impact of the increased CDF for important seismic sequences on the identification and evaluation of SAMAs for these sequences. This is discussed further below and in Sections G.3.2 and G.6.2.

The HCGS IPEEE fire analysis employed EPRI's fire-induced vulnerability evaluation (FIVE) methodology (EPRI 1993) to perform a fire compartment interaction analysis (FCIA) and a

quantitative screening analysis. This was then followed by a PRA quantification of the unscreened compartments.

The FCIA identified 209 fire compartments meeting the FIVE criteria for the entire plant. The quantitative screening utilized a threshold fire ignition frequency obtained using the FIVE methodology and the assumptions that all fires resulted in a reactor trip or more severe transient and that any fire in a compartment damaged all the equipment and cables in the compartment. Using the assessed screening fire frequency and conservatively determined screening conditional core damage probabilities (CCDPs) from the Model 0 internal events PRA resulted in screening out (at a CDF of less than 1×10^{-6} per year) of all but 38 fire compartments.

The analysis for the unscreened areas employed a detailed probabilistic assessment of each possible fire initiator/target combination including intermediate fire growth stages. Fire damage calculations used a modified version of the FIVE fire propagation methodology. No explicit credit was taken for manual or automatic fire suppression. Final quantification utilized FIVE fire data and refined CCDPs from the Model 0 internal events PRA. The resulting fire induced CDF was calculated to be 8.1×10^{-5} per year. A walkdown and verification process was employed to verify that the assumptions and calculations were supported by the physical condition of the plant.

The HCGS IPEEE did not identify any vulnerabilities due to internal fires or any potential improvements to reduce internal fire risk.

Subsequent to the IPEEE, PSEG updated the fire PRA to incorporate more recent fire initiating event frequencies based on information in the 2002 NRC fire database and conditional core damage probabilities from the 2003A PRA model, referred to as the 2003 HCGS External Events Update. The resulting fire CDF is 1.7×10^{-5} per year.

In the ER, PSEG provided a listing and description of the top ten fire core damage contributors. The important fire core damage contributors with a CDF of 1×10^{-7} per year or more are listed in Table G-5. As can be seen from these results the fire risk at HCGS is dominated by panel fires in the control room.

Table G-5. Important Contributors to Fire Core Damage Frequency

Basic Event ID	Fire Area Description	CDF per year	% Contribution to Fire CDF
%IE-FIRE03	Control Room Fire Scenario Small Cab_3 (Loss of Emer. Bat.)	5.3×10^{-6}	31
%IE-FIRE02	Control Room Fire Scenario Small Cab_2 (Loss of SSWS)	4.4×10^{-6}	25
%IE-FIRE01	Control Room Fire Scenario Small Cab_1 (Loss of SACS)	3.8×10^{-6}	22
%IE-FIRE28	Compartment 5339 Fire Scenario 5339_2	7.5×10^{-7}	4
%IE-FIRE37	Diesel Generator Room (D) Fire Scenario 5304_2	7.0×10^{-7}	4
%IE-FIRE20	Diesel Generator Room (C) Fire Scenario 5306_2	6.7×10^{-7}	4

Basic Event ID	Fire Area Description	CDF per year	% Contribution to Fire CDF
%IE-FIRE38	Compartment 3425/5401 Fire Scenario 5401_1	5.9×10^{-7}	3
%IE-FIRE06	Control Room Fire Scenario Large Cab_1 (MSIV Closure)	5.1×10^{-7}	3

Source: PSEG, 2009

In the ER, PSEG states that an effective comparison between the internal events PRA results and the fire analysis results is not possible because neither the plant response model nor the fire modeling methodology used in the updated fire model is current. PSEG identified in the ER areas where fire CDF quantification may introduce levels of uncertainty different from those expected in the internal events PRA, including a number of conservatisms in the fire modeling, as follows:

- Several system models assume the systems are unavailable or are unrecoverable in a fire. For example, any fire is assumed to result in a plant trip, even if it is not severe. Bounding fire modeling assumptions are used for many fire scenarios. For example, all cables are damaged in a fire even if they are enclosed in cable trays or conduit. Because of a lack of industry experience with regard to crew performance during the types of fires modeled in the fire PRA, the characterization of crew actions in the fire PRA is generally considered to be conservative.

PSEG's conclusion is that while some of the conservatisms have been addressed in the updated fire model, the result is still believed to be conservative.

Considering the above discussion, the conservatisms in the updated fire PRA model as currently understood, and the response to the staff RAIs, the staff concludes that the fire CDF of 1.7×10^{-5} per year is reasonable for the SAMA analysis.

The IPEEE analysis of high winds, floods and other (HFO) external events indicated that each of the events identified in NUREG-1407 (NRC 1991b) had a core damage contribution of less than the screening criterion of 1×10^{-6} per year. This was done by either showing compliance with the 1975 Standard Review Plan criteria or by a bounding analysis that demonstrated that the CDF contribution was less than the screening criterion. For the SAMA analysis, PSEG assumed a CDF contribution of 1×10^{-6} per year for each of high winds, external floods, transportation and nearby facilities, detritus, and chemical releases, for a total HFO CDF contribution of 5×10^{-6} per year (PSEG 2009).

Although the HCGS IPEEE did not identify any vulnerabilities due to HFO events, two improvements to reduce risk were identified as described below.

For high winds, the HCGS design was compared to the SRP criteria and found to have a CDF contribution less than the screening criterion. A walkdown was performed to evaluate high wind hazards and as a result work was initiated to install a missile shield in front of a door into the Technical Support Center. This improvement has been implemented.

For external floods the HCGS was found to be adequately protected from the postulated occurrence of the probable maximum hurricane surge with wave run-up coincident with the high tide at the 10% exceedance level. HCGS was also found to comply with the latest probable maximum precipitation criteria. A walkdown confirmed that there were no severe accident vulnerabilities due to external floods.

A review of transportation and nearby facility accidents confirmed that there were no severe accident vulnerabilities from these accidents. During the review it was discovered that in a single year there had been some unauthorized shipments of explosives on the Delaware River in the vicinity of the HCGS. The U.S. Coast Guard (USCG), which controls such shipments, was contacted and procedures were put in place to prevent such shipments in the future. This improvement has been implemented.

The staff asked about the status and potential impact on the SAMA analysis of a liquefied natural gas (LNG) terminal planned for Logan Township, New Jersey, upstream on the Delaware River from the HCGS site (NRC 2010a). In response to the RAI, PSEG discussed the current status of the LNG terminal as well as the regulatory controls for LNG marine traffic and LNG ship design and the safety record for LNG shipping (PSEG 2010a). The LNG terminal remains in the planning stage and no construction has begun. Further, the state of Delaware has denied applications for several required environmental permits and approvals. PSEG concluded that based on the regulatory process and controls for assuring the safety and security of LNG ships, the safety record of LNG ships and the uncertainty of the planned terminal, consideration of potential SAMAs associated with the possible future terminal is not warranted. The staff agrees with this conclusion.

As indicated in the ER (PSEG 2009), a multiplier of 6.3 was used to adjust the internal event risk benefit associated with a SAMA to account for external events. This multiplier was based on a total external event CDF of 2.3×10^{-5} per year. This CDF is the sum of the updated fire CDF of 1.7×10^{-5} per year, the updated seismic CDF of 1.1×10^{-6} per year, and the HFO CDF of 5×10^{-6} per year. The external event CDF is thus approximately 5.3 times the internal events CDF of 4.4×10^{-6} per year used in the SAMA analysis at a truncation of 5×10^{-11} per year. The higher truncation used for determining the multiplier is to be consistent with that used to determine the release category frequencies and that used to evaluate the fire and seismic CDFs. The total CDF is thus 6.3 times the internal events CDF (PSEG 2009).

As indicated above, in response to an staff RAI, PSEG determined the seismic CDF based on the LLNL hazard curve to be 3.6×10^{-6} per year (PSEG 2010a). If this is utilized instead of the value using the EPRI hazard curve, the total external events CDF is 2.6×10^{-5} per year and the external events multiplier is 6.8. The impact of this revised multiplier on the SAMA assessment is discussed further in Section G.3.2 and Section G.6.2.

The staff reviewed the general process used by PSEG to translate the results of the Level 1 PRA into containment releases, as well as the results of the Level 2 analysis, as described in the ER and in response to staff requests for additional information (PSEG 2010a, PSEG 2010b). The HCGS Level 2 PRA model is essentially a complete revision of the IPE Level 2 model, including completely revised containment event trees and system fault trees and completely updated thermal hydraulic analyses, incorporating the latest emergency operating procedures (EOPs), severe accident guidelines (SAGs), and emergency action level (EAL) and implementation using the Computer-Aided Fault Tree Analysis (CAFTA) software.

The current Level 2 model utilizes a set of three containment event trees (CETs) containing both phenomenological and systemic events. The Level 1 core damage sequences are grouped into core damage accident classes with similar characteristics. All the sequences in an accident class are then input to one of the three CETs by linking the level 1 event tree sequences with the level 2 CET. The CETs are analyzed by the linking of fault trees that represent each CET node. These fault trees are based on the Level 1 models for the system or function as modified for Level 2 considerations of timing, procedures, access or dependencies including recovery actions as documented in the HCGS emergency Operating Procedures and Severe Accident Management Guidelines.

Each CET end state represents a radionuclide release to the environment and is characterized by one of thirteen release bins based on magnitude and timing of release. Magnitude is given by cesium iodide (CsI) release fraction: High (H) > 10%, Moderate (M) 1% to 10%, Low (L) 0.1% to 1%, Low-Low (LL) <0.1% and negligible or no release<< 0.1%. Timing is given by time of initial release from the time of declaration of a General Emergency: Early (E) < 4 hours, Intermediate (I), 4 to 24 hours and Late (L) > 24 hours. The assignment of each end state to a given release bin is made on the basis of a MAAP calculation for the accident sequence or a similar MAAP calculated sequence. The thirteen release bins were subsequently refined into eleven release categories for input to the MELCOR Accident Consequence Code Systems (MACCS) consequence calculations by dividing the high early release bin into three release categories (high pressure, low pressure and breaks outside containment) and combining several of the end states with Low and Low-Low release magnitudes.

The frequency of each release category was obtained by summing the frequency of the contributing CET end states. The release characteristics for each release category were developed by using the results of Modular Accident Analysis Program (MAAP 4.0.6) computer code calculations. A representative MAAP case for each of the release categories was chosen based on a review of the Level 2 cutsets and the dominant types of scenarios that contribute to the results. The MAAP case chosen for each release category was generally the case with the highest consequence (PSEG 2010a). A description of the representative MAAP case for each release or source term category is provided in Table E.3-5 of the ER. The release categories, their frequencies, and release characteristics are presented in Table E.3-6 of the ER (PSEG 2009).

It is noted for the SAMA analysis the CET end state and release category frequencies were determined using a truncation value of 5×10^{-11} per year. This results in a total CDF of approximately 4.4×10^{-6} per year, which is about 16 percent less that the internal events CDF of 5.1×10^{-6} per year obtained when a truncation of 1×10^{-12} per year. The staff considers that use of the release frequency rather than the Level 1 CDF will have a negligible impact on the results of the SAMA evaluation because the external event multiplier and uncertainty multiplier used in the SAMA analysis (discussed in Section G.6.2) have a much greater impact on the SAMA evaluation results than the small error arising from the model quantification approach.

The staff review of release category information noted an apparent discrepancy in the release magnitude and release timing assigned for ST5 and ST7 and requested the applicant to clarify the reasons for these discrepancies (NRC 2010a). Both these release categories involve loss of containment heat removal with subsequent containment failure, core damage and fission product release. For ST5 the containment failure is in the wet well while for ST7 the

containment failure is in the drywell. While the drywell failure would be expected to result in a higher release than a wet well failure, the reverse is true for the results provided in the ER. Further, the release timings were found to be slightly different even though the core damage times were the same. In response to the RAI, PSEG pointed out that the wet well failure for ST5 occurred below the water level and, due to the loss of suppression pool water inventory, resulted in significantly less cesium iodide removal from the safety relief valve (SRV) flow to the suppression pool for ST5 than for the drywell failure case ST7 (PSEG 2010a). The differing release pathways resulted in the slightly different times for the initiation of release to the environment.

Based on the staff's review of the Level 2 methodology, the applicant's responses to RAIs and the fact that the Level 2 model was reviewed in more detail as part of the 2008 BWROG peer review and found to be acceptable (except for two documentation related findings which would not impact the SAMA analysis), the staff concludes that the Level 2 PRA provides an acceptable basis for evaluating the benefits associated with various SAMAs.

The staff reviewed the process used by PSEG to extend the containment performance (Level 2) portion of the PRA to an assessment of offsite consequences (essentially a Level 3 PRA). This included consideration of the source terms used to characterize fission product releases for the applicable containment release categories and the major input assumptions used in the offsite consequence analyses. The MACCS2 code was utilized to estimate offsite consequences. Plant-specific input to the code includes the source terms for each category and the reactor core radionuclide inventory (both discussed above), site-specific meteorological data, projected population distribution within an 80-kilometer (50-mile) radius for the year 2046, emergency evacuation modeling, and economic data. This information is provided in Section E.3 of Appendix E to the ER (PSEG, 2009).

PSEG used the MACCS2 code and a core inventory from a plant specific calculation at end of cycle to determine the offsite consequences of activity release. In response to an staff RAI, PSEG stated that the MACCS2 analysis was based on the core inventory used in the NRC-approved Alternate Source Term for HCGS (PSEG, 2010a).

All releases were modeled as being from the top of the reactor containment building and at low thermal content (ambient). Sensitivity studies were performed on these assumptions and indicated little or no change in population dose or offsite economic cost. Assuming a ground level release decreased dose risk and cost risk by 6 percent and 7 percent, respectively. Assuming a buoyant plume decreased dose risk and cost risk by 1 percent. Based on the information provided, the staff concludes that the release parameters utilized are acceptable for the purposes of the SAMA evaluation.

PSEG used site-specific meteorological data for the 2004 calendar year as input to the MACCS2 code. The development of the meteorological data is discussed in Section E.3.7 of Appendix E to the ER. The data were collected from onsite and local meteorological monitoring systems. Sensitivity analyses using MACCS2 and the meteorological data for the years 2005 through 2007 show that use of data for the year 2004 results in the largest dose and economic cost risk. Missing meteorological data was filled by (in order of preference): using data from the backup met pole instruments (10-meter), using corresponding data from another level of the main met tower, interpolation (if the data gap was less than 6 hours), or using data from the same hour and a nearby day (substitution technique). The 10-meter wind speed and direction

were combined with precipitation and atmospheric stability (derived from the vertical temperature gradient) to create the hourly data file for use by MACCS2. The staff notes that previous SAMA analyses results have shown little sensitivity to year-to-year differences in meteorological data and concludes that the use of the 2004 meteorological data in the SAMA analysis is reasonable.

The population distribution the licensee used as input to the MACCS2 analysis was estimated for the year 2046 using year 1990 and year 2000 census data as accessed by SECPOP2000 (NRC, 2003) as a starting point. In response to a staff RAI, PSEG stated that the transient population was included in the 10-mile EPZ, and included prior to the population projection (PSEG, 2010a). A ten year population growth rate was estimated using the year 1990 to year 2000 SECPOP2000 data and applied to obtain the distribution in 2046. The baseline population was determined for each of 160 sectors, consisting of sixteen directions for each of ten concentric distance rings to a radius of 50 miles surrounding the site. The SECPOP2000 census data from 1990 and 2000 were used to determine a ten year population growth factor for each of the concentric rings. The population growth was averaged over each ring and applied uniformly to all sectors within each ring. The staff requested PSEG provide an assessment of the impact on the SAMA analysis if a wind-direction weighted population estimate for each sector were used (NRC, 2010a). In response to the RAI, PSEG stated that the impacts associated with angular population growth rates on PDR and OECR are minimal and bounded by the 30% population sensitivity case (PSEG, 2010a). This is based on the relatively even wind distribution profile surrounding the site, the tendency for lateral dispersion between sectors, and the use of mean values in the analysis. A sensitivity study was performed for the population growth at year 2040. A 30 percent increase in population resulted in a 29 percent increase in dose risk and a 30 percent increase in cost risk. In response to a staff RAI, PSEG stated that the radial growth rates used in the MACCS2 analysis provides a more conservative population growth estimate than using 'whole county' data for averaging (PSEG, 2010a). PSEG also identified that the population sensitivity case of 30 percent growth was approximately equivalent to adding 5.9 percent to the 10-year growth rate. The staff considers the methods and assumptions for estimating population reasonable and acceptable for purposes of the SAMA evaluation.

The emergency evacuation model was modeled as a single evacuation zone extending out 10 mi (16 km) from the plant (the emergency planning zone – EPZ). PSEG assumed that 95 percent of the population would evacuate. This assumption is conservative relative to the NUREG-1150 study (NRC 1990), which assumed evacuation of 99.5 percent of the population within the emergency planning zone. The evacuated population was assumed to move at an average radial speed of approximately 6.3 mi per hour (2.8 meters per second [m/s]) with a delayed start time of 65 minutes after declaration of a general emergency (KLD, 2004). A general emergency declaration was assumed to occur at the onset of core damage. The evacuation speed is a time-weighted average value accounting for season, day of week, time of day, and weather conditions. It is noted that the longest evacuation time presented in the study (i.e., full 10 mile EPZ, winter snow conditions, 99th percentile evacuation) is 4 hours (from the issuance of the advisory to evacuate). Sensitivity studies on these assumptions indicate that there is minor impact to the population dose or offsite economic cost by the assumed variations. The sensitivity study reduced the evacuation speed by 50 percent to 1.4 m/s. This change resulted in a 2 percent increase in population dose risk and no change in offsite economic cost

risk. The staff concludes that the evacuation assumptions and analysis are reasonable and acceptable for the purposes of the SAMA evaluation.

Site specific agriculture and economic parameters were developed manually using data in the 2002 National Census of Agriculture (USDA, 2004) and from the Bureau of Economic Analysis (BEA ,2008) for each of the 23 counties surrounding HCGS, to a distance of 50 miles. Therefore, recently discovered problems in SECPOP2000 do not impact the HCGS analysis. The values used for each of the 160 sectors were the data from each of the surrounding counties multiplied by the fraction of that county's area that lies within that sector. Region-wide wealth data (i.e., farm wealth and non-farm wealth) were based on county-weighted averages for the region within 50-miles of the site using data in the 2002 National Census of Agriculture (USDA ,2004) and the Bureau of Economic Analysis (BEA, 2008). Food ingestion was modeled using the new MACCS2 ingestion pathway model COMIDA2 (NRC, 1998a). For HCGS, less than one percent of the total population dose risk is due to food ingestion.

In addition, generic economic data that is applied to the region as a whole were revised from the MACCS2 sample problem input in order to account for cost escalation since 1986, the year that input was first specified. A factor of 1.96, representing cost escalation from 1986 to April 2008 was applied to parameters describing cost of evacuating and relocating people, land decontamination, and property condemnation.

The staff concludes that the methodology used by PSEG to estimate the offsite consequences for HCGS provides an acceptable basis from which to proceed with an assessment of risk reduction potential for candidate SAMAs. Accordingly, the staff based its assessment of offsite risk on the CDF and offsite doses reported by PSEG.

G.3 Potential Plant Improvements

The process for identifying potential plant improvements, an evaluation of that process, and the improvements evaluated in detail by PSEG are discussed in this section.

G.3.1 Process for Identifying Potential Plant Improvements

PSEG's process for identifying potential plant improvements (SAMAs) consisted of the following elements:

- review of the most significant basic events from the current, plant-specific PRA and insights from the HCGS PRA Group
- review of potential plant improvements identified in, and original results of, the HCGS IPE and IPEEE
- review of SAMA candidates identified for license renewal applications for six other U.S. nuclear sites
- review of generic SAMA candidates from NEI 05-01 (NEI, 2005) to identify SAMAs that might address areas of concern identified in the HCGS PRA

Based on this process, an initial set of 23 candidate SAMAs, referred to as Phase I SAMAs, was identified. In this Phase I evaluation, PSEG performed a qualitative screening of the initial list of SAMAs and eliminated SAMAs from further consideration using the following criteria:

- The SAMA is not applicable at HCGS due to design differences.
- The SAMA has already been implemented at HCGS.
- The SAMA would achieve results that have already been achieved at HCGS by other means.
- The SAMA has estimated implementation costs that would exceed the dollar value associated with completely eliminating all severe accident risk at HCGS.

Based on this screening, one SAMA was eliminated, and one additional SAMA was eliminated by subsuming it into another SAMA. Therefore, 21 SAMAs required further evaluation. The results of the Phase I screening analysis is given in Table E.5-3 of Appendix E to the ER. The remaining SAMAs, referred to as Phase II SAMAs, are listed in Table E.6-1 of Appendix E to the ER. In Phase II a detailed evaluation was performed for each of the 21 remaining SAMA candidates, as discussed in Sections G.4 and G.6 below. To account for the potential impact of external events, the estimated benefits based on internal events were multiplied by a factor of 6.3, as previously discussed.

G.3.2 Review of PSEG's Process

PSEG's efforts to identify potential SAMAs focused primarily on areas associated with internal initiating events, but also included explicit consideration of potential SAMAs for important fire and seismic initiated core damage sequences. The initial list of SAMAs generally addressed the accident sequences considered to be important to CDF from risk reduction worth (RRW) perspectives at HCGS, and included selected SAMAs from prior SAMA analyses for other plants.

PSEG provided a tabular listing of the Level 1 PRA basic events sorted according to their RRW (PSEG, 2009). SAMAs impacting these basic events would have the greatest potential for reducing risk. PSEG used a RRW cutoff of 1.006, which corresponds to about a 0.6 percent change in CDF given 100-percent reliability of the SAMA.[2] This equates to a benefit of approximately $100,000 (after the benefits have been multiplied by a factor of 6.3 to account for external events), which is the minimum implementation cost associated with a procedure change.[3] As a result of this review, 11 SAMAs were identified.

---

[2] Subsequently, PSEG extended the review down to a RRW of 1.005 to account for a revised external events multiplier of 6.8, as discussed in Section G.2.2.

[3] NUREG/BR-0184 provides calculational techniques by which reductions in risk can be equated to monetary values. The reverse calculation can convert monetary values, such as the cost of a procedure, to a risk reduction for the specific plant under consideration. In this way, the $100,000 cost of a site-wide procedure change equates to a RRW of 1.006, representing the potential to reduce risk by 0.6%. The subsequent use of a RRW of 1.005 represents the potential to reduce risk by 0.5% (NRC 1997a).

In the Level 1 importance review, PSEG stated for the important initiating events that "this initiator event is a compilation of industry and plant specific data. (No specific SAMA identified)." The staff requested that PSEG provide assurance that for each of these initiating events there is not a dominant contributor for which a potential SAMA to reduce the initiating event frequency or mitigate the impact of the initiator would be viable. In response to this RAI, PSEG discussed each of the initiators and the previously identified SAMAs that would reduce the importance of the initiator by mitigating other failures in the core damage sequences associated with these initiators (PSEG, 2010a). In response to a request for clarification PSEG indicated that HCGS specific failures that are contributors to the initiating event frequencies that pose a unique vulnerability are typically captured and corrected within existing procedures, e.g., the corrective action program, and can result in procedure changes, plant modifications and training enhancements aimed at reducing further recurrence (PSEG, 2010b). Based on this discussion and a review of the latest ten years of HCGS Licensee Event Reports, the staff concludes that it is unlikely that further HCGS data review will identify any additional cost beneficial SAMAs beyond those already identified.

The PSEG response to the staff request for clarification provided additional information on initiators modeled utilizing a fault tree approach rather then being based on initiating event data. For the loss of station auxiliaries cooling system initiating event (%IE-SACS), PSEG identified and evaluated SAMA 42, "Installation of SACS Standby Diesel-Powered Pump" (PSEG 2010b).

For an event involving the station service water system (NR-IE-SWS, "Nonrecovery of %IE-SWS"), the importance review identified two SAMAs as potentially mitigating this event: (1) SAMA 3, "Install Back-up Air Compressor to Supply Air-Operated Valves (AOVs)," and (2) SAMA 4, "Provide Procedural Guidance to Cross-Tie Residual Heat Removal (RHR) Trains." In response to a staff RAI to clarify the source and applicability of these SAMAs to this event, PSEG discussed the modeling involving the NR-IE-SWS event and the applicability of the SAMAs in terms of the more general loss of decay heat removal function of which the event is associated and other SAMAs that would mitigate this event (PSEG, 2010a). Based on this discussion, the staff concludes that this event is adequately addressed in the SAMA analysis.

For a significant number of the Level 1 events reviewed no SAMAs were identified with the reason stated to be that "…based on low contribution to L[evel] 1 risk and engineering judgment, the anticipated implementation costs of hardware mods associated with mitigating this event would likely exceed the expected cost-risk benefit" (PSEG, 2009). In response to a staff RAI, PSEG provided a revised assessment of each of these events that showed that each was either already addressed by an existing SAMA or that no effective SAMAs could be identified (PSEG 2010a).

The staff also requested PSEG to specifically consider the following proposed SAMAs to address basic events on the Level 1 importance list for which no SAMA was identified (NRC, 2010a):

- Install a diverse redundant temperature controller to address basic event SAC-XHE-MC-DF01, "dependent failure of miscalibration of temperature controller HV-2457S." In response to the RAI, PSEG explained that this SAMA is not warranted since 1) procedures are already in place to manually control the affected system which, if credited using a failure probability of 0.1, would reduce the RRW for this basic event to

1.005, the revised review threshold (discussed below), and 2) controller miscalibration would be observed during normal operation (PSEG, 2010a).

- Install flood barriers to address basic event %FL-FPS-5302, "internal flood outside lower relay room." In response to the RAI, PSEG clarified that the ER incorrectly did not identify SAMA 8, "Convert Selected Fire Protection Piping from Wet Pipe to Dry Pipe System," to address this event and further explained that the proposed SAMA is not necessary because the conversion to a dry pipe system was considered preferable to developing flood barriers considering the multiple doors that exist in the corridor outside the relay room (PSEG, 2010a).

- Install a spray shield to address basic event SWS-MOV-VF-SPRAY, "flood – spray causes motor-operated valve (MOV) failure in reactor auxiliaries cooling system (RACS) compartment." In response to the RAI, PSEG explained that the proposed SAMA is not required because the PRA conservatively assumes that all relevant spray events cause failure of the MOVs and that an assumption of 1 in 10 events causing failure would reduce the RRW for this basic event to below the 1.005 revised review threshold (PSEG, 2010a).

- Installation of a passive containment vent to address basic event NR-RHRVENT-INT, "fail to initiate vent given failure to initiate residual heat removal (RHR) in suppression pool cooling (SPC)." This proposed SAMA would also be an alternative to SAMA 4, "Provide Procedural Guidance to Cross-tie RHR Trains." In response to the RAI, PSEG indicated that changing the existing hard pipe venting system to a passive vent design is not considered feasible due to the loss in response flexibility provided by the existing hard pipe venting system and the potential for premature opening of the rupture disks in the passive design (PSEG 2010a). In response to a request for clarification PSEG identified and evaluated SAMA 41, "Installation of Passive Hardened Containment Ventilation Pathway" (PSEG, 2010b).

In summary, as a result of PSEG's reconsideration of basic events for which no SAMA had been identified in the ER, two new SAMAs were identified: (1) SAMA 41, "Installation of Passive Hardened Containment Ventilation Pathway," and (2) SAMA 42, "Installation of SACS Standby Diesel-Powered Pump." A Phase II cost-benefit evaluation was performed for each of these additional SAMAs, which is discussed in Section G.6.2.

In response to a staff RAI, PSEG extended the review down to a RRW of 1.005 to account for a revised external events multiplier of 6.8, which was discussed in Section G.2.2. This extended review identified one additional SAMA as follows: SAMA RAI 5.j-IE1, "Install a Key Lock Switch for Bypass of the MSIV Low Level Isolation Logic" (PSEG, 2010a; PSEG, 2010b). The Phase II cost-benefit evaluation of this SAMA is discussed in Section G.6.2.

PSEG also provided and reviewed the Level 2 PRA basic events, down to a RRW of 1.006, for cutsets stated to contribute to large early release. This review did not identify any additional SAMAs. In response to a staff RAI, PSEG revisited this review using only the cutsets from the

high and moderate release categories, which contribute over 99 percent of the population dose-risk and offsite economic cost risk (PSEG, 2010a). The Level 2 basic events for the remainder of the release categories were not included in the review so as to prevent high frequency-low consequence events from biasing the importance listing. In addition the review was extended down to a RRW of 1.005 to account for a revised external events multiplier of 6.8. The revisited review identified one additional SAMA, not identified in the extended Level 1 review discussed above, as follows: SAMA RAI 5p-1, “Install an Independent Boron Injection System." The Phase II cost-benefit evaluation of this SAMA is discussed in Section G.6.2.

The staff also requested PSEG to specifically consider the following proposed SAMAs (NRC, 2010a):

1. Installation of a curb or barrier inside the drywell to prevent early failure of the drywell shell due to shell melt-through. This proposed SAMA addresses basic event CNT-DWV-FF-MLTFL, “drywell (DW) shell melt-through failure due to containment failure,” for which no SAMA was identified. In response to the RAI, PSEG explained that this proposed SAMA would not be effective in reducing risk because 1) injection is not available and, without cooling, the core debris would degrade the barrier to the point of failure, and 2) an early unscrubbed release pathway is already available as a result of pre-existing containment failures resulting from loss of decay heat removal (PSEG, 2010a).

2. Replacement of the normally open floor and equipment drain MOVs with fail-closed air-operated valves (AOVs). While this proposed SAMA is stated in the ER to be a more costly alternative to SAMA 5, “restore AC power with onsite gas turbine generator,” the staff noted in the RAI that it might also be more effective and therefore have a larger benefit. In response to the RAI, PSEG provided a Phase II cost-benefit evaluation of this proposed SAMA, which is discussed in Section G.6.2.

One additional SAMA, SAMA 18, “replace a return fan with a different design in service water pump room,” was identified in the ER based on a review of PRA insights from the HCGS PRA Group and was identified to address two basic events on the Level 1 basic events importance list.

PSEG reviewed the cost-beneficial Phase II SAMAs from prior SAMA analyses for five General Electric BWR and one Westinghouse PWR sites. PSEG’s review determined that all but two of the Phase II SAMAs reviewed were either already represented by an existing SAMA, are already implemented at HCGS, have low potential for risk reduction at HCGS, or were not applicable to the HCGS design. This review resulted in two SAMAs being identified by PSEG for HCGS.

PSEG’s disposition of industry SAMA “auto align 480V AC portable station generator” is stated to be addressed by SAMA 5, “restore AC power with onsite gas turbine generator.” The staff noted that the industry SAMA could mitigate events other than those addressed by SAMA 5 and requested PSEG to evaluate the industry SAMA (NRC, 2010a). In response to a staff RAI PSEG identified and evaluated an additional SAMA to automate the alignment of the portable 480V AC generator (PSEG, 2010a; PSEG, 2010b). The cost-benefit evaluation of this additional SAMA is discussed in Section G.6.2.

The ER states that an industry SAMA to "develop a procedure to open the door of the EDG buildings upon the higher temperature alarm" was included in the HCGS SAMA analysis. The staff noted that no such SAMA was evaluated and asked PSEG to clarify this discrepancy (NRC 2010a). In response to the RAI, PSEG explained that this SAMA would not reduce HCGS risk since EDG room cooling issues are small contributors to risk at HCGS and that the statement in the ER is incorrect (PSEG, 2010a).

The NRC asked PSEG to address a SAMA to "increase boron concentration or enrichment in the SLC system," which was determined to be potentially cost-beneficial in the Duane Arnold SAMA analysis (NRC 2010a). In response to the RAI, PSEG explained that this SAMA would have a negligible benefit at HCGS because Standby Liquid Control (SLC) is automatically initiated at HCGS and the basic events the SAMA addresses (related to manual SLC initiation) are not on the importance lists (PSEG, 2010a).

PSEG considered the potential plant improvements described in the IPE in the identification of plant-specific candidate SAMAs for internal events. Review of the IPE led to no additional SAMA candidates since the three improvements identified in the IPE have already been implemented at HCGS. (PSEG, 2009)

Based on this information, the staff concludes that the set of SAMAs evaluated in the ER, together with those identified in response to staff RAIs, addresses the major contributors to internal event CDF.

Although the IPEEE did not identify any fundamental vulnerabilities or weaknesses related to external events, two improvements related to HFO events were identified. The two improvements have been implemented at HCGS (PSEG, 2009). In the ER PSEG also identified three post IPEEE site changes to determine if they could impact the IPEEE results and possibly lead to a SAMA. From this review no additional SAMAs were identified.

In a further effort to identify external event SAMAs, PSEG identified the top 10 fire scenarios contributing to fire CDF based on the results of the updated HCGS fire PRA model and reviewed the top 8 fire scenarios for potential SAMAs. These 8 scenarios are the only HCGS fire scenarios having a benefit equal to or greater than approximately $100,000, which is the approximate value of implementing a procedure change at a single unit at HCGS.[4] The maximum benefit for a fire area is the dollar value associated with completely eliminating the fire risk in that fire area. SAMAs having an implementation cost of less than that of a procedure change, or $100,000, are unlikely. As a result of this review, PSEG identified six Phase I SAMAs to reduce fire risk. The SAMAs identified included both procedural and hardware alternatives (PSEG, 2009). The staff concludes that the opportunity for fire-related SAMAs has been adequately explored and that it is unlikely that there are additional potentially cost-beneficial, fire-related SAMA candidates.

[4] Salem, which is a dual-unit site, also assumes this $100,000 cost for a procedure change, but this is halved to $50,000 for each unit.

For seismic events, PSEG reviewed the top 10 seismic sequences contributing to seismic CDF based on the results of the 2003 HCGS seismic analysis and initially reviewed the top 2 seismic sequences for potential SAMAs. These two sequences are the only HCGS seismic sequences having a benefit equal to or greater than approximately $100,000, which is the approximate value of implementing a procedure change at a single unit at HCGS. The maximum benefit for a seismic sequence is the dollar value associated with completely eliminating the seismic risk for that sequence. SAMAs having an implementation cost of less than that of a procedure change, or $100,000, are unlikely. As a result of this review, PSEG identified three Phase I SAMAs to reduce seismic risk (PSEG, 2009).

In response to a staff RAI, PSEG revised the review of seismic sequences to account for the increased maximum benefit of each sequence resulting from the use of the LLNL seismic hazard curve instead of the EPRI curve used initially, as discussed in Section G.2.2. This resulted in two additional seismic sequences having a benefit equal to or greater than the $100,000 threshold. As a result of the review of these sequences three additional SAMAs were identified: (1) reinforce 1E 125V DC distribution panels 1A/B/C/D-D-417, (2) reinforce 1E 120V AC distribution panels 1A/B/C/DJ482, and (3) reinforce the 1E 120V AC 481 distribution panels to 1.0g Seismic Rating (PSEG, 2010a; PSEG, 2010b). The cost-benefit evaluation of these additional SAMAs is discussed in Section G.6.2.

The staff concludes that the opportunity for seismic-related SAMAs has been adequately explored and that it is unlikely that there are additional potentially cost-beneficial, seismic-related SAMA candidates.

As stated earlier, other external hazards (high winds, external floods, transportation and nearby facility accidents, release of on-site chemicals, and detritus) are below the IPEEE threshold screening frequency, or met the 1975 SRP design criteria, and are not expected to represent vulnerabilities. Nevertheless, PSEG reviewed the IPEEE results and subsequent plant changes for each of these external hazards and determined that either: (1) the maximum benefit from eliminating all associated risk was less than approximately $100,000, which is the approximate value of implementing a procedure change at a single unit at HCGS, or (2) only hardware enhancements that would significantly exceed the maximum value of any potential risk reduction were available. As a result of this review, PSEG identified no additional Phase I SAMAs to reduce HFO risk (PSEG, 2009). Based on it being extremely unlikely that any hardware enhancement could be implemented for less than the cost of a procedural change ($100,000), the staff concludes that the licensee's rationale for eliminating other external hazards enhancements from further consideration is reasonable.

The staff noted that, while the generic SAMA list from NEI 05-01 (NEI, 2005) was stated to have been used in the identification of SAMAs for HCGS, it was not specifically reviewed to identify SAMAs that might be applicable to HCGS but rather was used to identify SAMAs that might address areas of concern identified in the HCGS PRA (NRC, 2010a). The staff asked PSEG to provide further information to justify that this approach produced a comprehensive set of SAMAs for consideration. In response to the RAI, PSEG explained that, based on the early SAMA reviews, both the industry and NRC came to realize that a review of the generic SAMA list was of limited benefit because they were consistently found to not be cost-beneficial and that the

real benefit was considered to be in the development of SAMAs generated based on plant specific risk insights from the PRA models (PSEG, 2010a).

Furthermore, while the generic list does include potential plant improvements for plants having a similar design to HCGS, plant designs are sufficiently different that the specific plant improvements identified in the generic list are generally not directly applicable to HCGS, and require alteration to specifically address the HCGS design and risk contributors or otherwise would be screened as not applicable to the HCGS design. The staff considers PSEG's limited use of the NEI 05-01 generic SAMA list as only an idea source to generate SAMAs that address important contributors to Salem risk reasonable for this particular HCGS application. .

The staff noted that the 23 Phase I SAMA numbers were not consecutive from 1 to 23, but rather were intermittently numbered between 1 and 40 and requested clarification on the process used to develop the Phase I SAMA list (NRC, 2010a). In response to the RAI, PSEG clarified that the original SAMA list was generated from an importance list using the HC108A PRA model, and that review of the subsequent importance list developed using the HC108B PRA model determined that certain SAMAs were either no longer applicable or were subsumed into other existing SAMAs (PSEG, 2010a). PSEG further clarified that the resulting set of Phase I SAMAs was not renumbered to be consecutive so as to avoid configuration management errors that could occur when working with other documentation and supplemental files. Also, SAMAs identified from the review of external events were given a starting number of 30 so as to avoid overlap with SAMAs developed for internal events.

As indicated above two Phase 1 SAMAs were screened out. SAMA 38, "Enhance Fire Water System (FWS) and Automatic Depressurization System (ADS) for Long-term Injection," was screened out on the basis that a procedure has been implemented to address the actions associated with this SAMA. However, as discussed in ER Section E.5.1.7.2.2, this SAMA requires enhancement to the FWS, including strengthening the fire water tanks. In response to an staff RAI, PSEG provided an additional discussion regarding this SAMA and how enhancements to the FWS have been addressed as part of the implementation of the current procedure (PSEG, 2010a). The additional discussion indicated that the seismic sequence from which this SAMA originated was a low magnitude earthquake for which there would be a relatively small chance for failure of the FWS. Consequently, strengthening the FWS would have little impact on the sequence and, upon reevaluation, is not needed as part of SAMA 38. PSEG therefore concluded that the procedure implements the remaining requirements of this SAMA.

SAMA 14, "Alternate Room Cooling for Service Water (SW) Rooms," was screened out on the basis that it was subsumed into SAMA 4, "cross-tie RHR pump trains." It is described as providing an alternate means of opening Torus Vent Valves, but no basic event in the importance lists is identified as being addressed by this SAMA. In response to an staff RAI, PSEG provided a further discussion of this SAMA and its disposition (PSEG, 2010a). SAMA 14 was originally developed to address important containment venting failure events. The importance of these events would be reduced if the need to vent containment is reduced by addressing failure of SW room cooling which leads to loss of containment heat removal. It was

subsequently determined that SAMA 4 was the most viable SAMA to address the loss of containment heat removal and SAMA 14 was subsumed into SAMA 4. PSEG also indicated that a loss of SW room cooling could also be addressed by a new SAMA that provides an alternate room cooling strategy for the SW room using procedures and portable fans. A Phase II detailed evaluation was performed for this new SAMA, referred to as SAMA RAI 7.a-1, "enhance procedures and provide additional equipment to respond to loss of all service water pump room supply or return fans" (PSEG, 2010a).

The staff questioned PSEG about lower cost alternatives to some of the SAMAs evaluated (NRC, 2010a), including:

- Establishing procedures for opening doors and/or using portable fans for sequences involving room cooling failures.
- Extending the procedure for using the B.5.b low pressure pump for non-security events to include all applicable scenarios, not just SBOs.
- Utilizing a portable independently powered pump to inject into containment.

In response to the RAIs, PSEG addressed the suggested lower cost alternatives (PSEG, 2010a). A new SAMA, SAMA RAI 7.a-1 discussed above, was assessed in a Phase II detailed evaluation for the first item while the other two items are effectively covered by existing procedures. This is discussed further in Section G.6.2.

The staff notes that the set of SAMAs submitted is not all-inclusive, since additional, possibly even less expensive, design alternatives can always be postulated. However, the staff concludes that the benefits of any additional modifications are unlikely to exceed the benefits of the modifications evaluated and that the alternative improvements would not likely cost less than the least expensive alternatives evaluated, when the subsidiary costs associated with maintenance, procedures, and training are considered.

The staff concludes that PSEG used a systematic and comprehensive process for identifying potential plant improvements for HCGS, and that the set of potential plant improvements identified by PSEG is reasonably comprehensive and, therefore, acceptable. This search included reviewing insights from the plant-specific risk studies, and reviewing plant improvements considered in previous SAMA analyses. While explicit treatment of external events in the SAMA identification process was limited, it is recognized that the prior implementation of plant modifications for fire and seismic risks and the absence of external event vulnerabilities reasonably justifies examining primarily the internal events risk results for this purpose.

G.4 Risk Reduction Potential of Plant Improvements

PSEG evaluated the risk-reduction potential of the 21 remaining SAMAs that were applicable to HCGS, and additional SAMAs identified in response to staff RAIs. The SAMA evaluations were performed using realistic assumptions with some conservatism. On balance, such calculations overestimate the benefit and are, therefore, conservative.

PSEG used model re-quantification to determine the potential benefits. The CDF, population dose reductions, and offsite economic cost reductions were estimated using the HCGS PRA model. The changes made to the model to quantify the impact of SAMAs are detailed in Section E.6 of Appendix E to the ER (PSEG, 2009). Table G-6 lists the assumptions considered to estimate the risk reduction for each of the evaluated SAMAs, the estimated risk reduction in terms of percent reduction in CDF and population dose, and the estimated total benefit (present value) of the averted risk. The estimated benefits reported in Table G-6 reflect the combined benefit in both internal and external events. The determination of the benefits for the various SAMAs is further discussed in Section G.6.

The staff questioned the assumptions used in evaluating the benefit or risk reduction estimate of SAMA 5, "Restore AC Power with Onsite Gas Turbine Generator." The assessment of this SAMA assumed this was equivalent to reducing the probability of failure to cross tie the HCGS emergency diesel generators. This assumption does not provide credit for the gas turbine generator (GTG) in the situation where all the emergency generators are unavailable (NRC, 20010a). In response to the RAIs, PSEG provided the results of a sensitivity study which the staff subsequently noted did not appear to include credit for the hardware changes included in the cost estimate (NRC, 2010b). In response to the request for clarification, PSEG provided the results of a re-evaluation of SAMA 5 that incorporated the additional capability for mitigating a more complete set of loss of offsite power initiators consistent with the hardware changes proposed (PSEG, 2010b). The revised results are provided in Table G-6.

For SAMAs that specifically addressed fire events (i.e., SAMA 30, "Provide Procedural Guidance for Partial Transfer of Control Functions from Control Room to the Remote Shutdown Panel," SAMA 31, "Install Improved Fire Barriers in the Main Control Room (MCR) Control Cabinets Containing the Primary Main Steam Isolation Valve (MSIV) Control Circuits," SAMA 32, "Install Additional Physical Barriers to Limit Dispersion of Fuel Oil from Diesel Generator (DG) Rooms," SAMA 33, "Install Division II 480V AC Bus Cross-ties," SAMA 34, "Install Division I 480V AC Bus Cross-ties," and SAMA 35, "Relocate, Minimize and/or Eliminate Electrical Heaters in Electrical Access Room"), the reduction in fire CDF and population dose was not directly calculated (in Table G-6 this is noted as "Not Estimated"). For these SAMAs, an estimate of the impact was made based on general assumptions regarding: the approximate contribution to total risk from external events relative to that from internal events; the fraction of the external event risk attributable to fire events; the fraction of the fire risk affected by the SAMA (based on information from the 2003 HCGS External Events Update); and the assumption that the SAMA eliminates 90 percent (SAMAs 30, 32, 33, and 34), 99 percent (SAMA 35), or all (SAMA 31) of the fire risk affected by the SAMA. Specifically, it is assumed that the contribution to risk from external events is approximately 5.3 times that from internal events, and that internal fires contribute 74 percent of this external events risk. The fire basic events impacted by the SAMA are identified and the portion of the total fire risk contributed by each of these fire basic events determined. For SAMA 31, the benefit or averted cost risk from reducing the fire risk affected by the SAMA is then calculated by multiplying the ratio of the fire risk affected by the SAMA to the internal events CDF by the total present dollar value equivalent associated with completely eliminating severe accidents from internal events at HCGS. For the other fire SAMAs, the benefit or averted cost risk from reducing the fire risk affected by the

SAMA is then calculated by multiplying the ratio of 90 percent, or 99 percent (SAMA 35), of the fire risk affected by the SAMA to the internal events CDF by the total present dollar value equivalent associated with completely eliminating severe accidents from internal events at HCGS. These SAMAs were assumed to have no additional benefits in internal events.

The staff questioned the calculated impact for SAMA 35 which assumed that 90 percent of the fire risk affected by the SAMA was eliminated rather than the 99 percent stated in the ER (NRC, 2010a). In response to the RAI, PSEG provided a revised evaluation using 99 percent (PSEG, 2010a). The revised results are provided in Table G-6.

For SAMAs that specifically addressed seismic events (i.e., SAMA 36, "Provide Procedural Guidance for Loss of All 1E 120V AC Power," and SAMA 37, "Reinforce 1E 120V AC Distribution Panels") the reduction in seismic CDF and population dose also was not directly calculated. As was done for fire SAMAs, an estimate of the impact of seismic SAMAs was made based on general assumptions regarding: the approximate contribution to total risk from external events relative to that from internal events; the fraction of the external event risk attributable to seismic events; the fraction of the seismic risk affected by the SAMA (based on information from the 2003 HCGS External Events Update); and the assumption that the SAMA eliminates 50 percent (SAMA 36) or 90 percent (SAMA 37) of the seismic risk affected by the SAMA. Specifically, it is assumed that the contribution to risk from external events is approximately 5.3 times that from internal events, and that seismic events contribute 5 percent of this external events risk. The seismic basic events impacted by the SAMA are identified and the portion of the total seismic risk contributed by each of these seismic basic events determined. The benefit or averted cost risk from reducing the seismic risk affected by the SAMA is then calculated by multiplying the ratio of 50 percent (SAMA 36), or 90 percent (SAMA 37), of the seismic risk affected by the SAMA to the internal events CDF by the total present dollar value equivalent associated with completely eliminating severe accidents from internal events at HCGS. These SAMAs were assumed to have no additional benefits in internal events.

The staff has reviewed PSEG's bases for calculating the risk reduction for the various plant improvements and concludes, with the above clarifications, that the rationale and assumptions for estimating risk reduction are reasonable and generally conservative (i.e., the estimated risk reduction is higher than what would actually be realized). Accordingly, the staff based its estimates of averted risk for the various SAMAs on PSEG's risk reduction estimates.

Table G-6. SAMA Cost/Benefit Screening Analysis for Hope Creek Generating Station[a]

SAMA	Assumptions	% Risk Reduction		Total Benefit ($)		Cost ($)
		CDF	Population Dose	Baseline (Internal + External)	Baseline With Uncertainty[e]	
1 – Remove Automatic Depressurization System (ADS) Inhibit from Non-ATWS Emergency Operating Procedures	**The probability that operators fail to inhibit ADS was reduced to 0.1 from 1.0.**	**26**	**29**	**5.3M**	**14.9M**	**200K**
3 – Install Back-up Air Compressor to Supply AOVs	**The probability that operators fail to restore service water was reduced to 0.5 from 1.0.**	**16**	**16**	**3.3M**	**9.4M**	**700K**
4 – Provide Procedural Guidance to Cross-Tie RHR Trains	**The probability that operators fail to recover RHR was reduced to 0.1 from 0.35.**	**12**	**21**	**4.4M**	**12.4M**	**100K**
5[b] – Restore AC Power with Onsite Gas Turbine Generator	**The probability that operators fail to cross-tie the emergency diesel generators (EDGs) was reduced to 0.1 from 1.0. In response to a staff RAI, the GTG failure probability, maintenance unavailability, and human error probability were set to 0.**	**9**	**11**	**2.2M**	**6.3M**	**2.05M**
7 – Install Better Flood Protection Instrumentation for Reactor Auxiliaries Cooling System (RACS) Compartment	The probability that operators fail to isolate locally a service water rupture in the RACS compartment was reduced to 0.1 from 1.0.	4	2	330K	930K	3.07M
8 – Convert Selected Fire Protection Piping from Wet to Dry Pipe System	**The probability that operators fail to isolate a fire protection header leak was reduced to 0.1 from 1.0.**	**4**	**1**	**300K**	**860K**	**600K**
10 – Provide Procedural Guidance to use B.5.b Low Pressure Pump for Non-Security Events	**The probability that operators fail to align residual heat removal service water (RHRSW) for injection into the reactor pressure vessel (RPV) was reduced to 1.0E-02 from 1.0E-01.**	**1**	**1**	**200K**	**570K**	**100K**

Table G-6. SAMA Cost/Benefit Screening Analysis for Hope Creek Generating Station[a]

SAMA	Assumptions	% Risk Reduction		Total Benefit ($)		Cost ($)
		CDF	Population Dose	Baseline (Internal + External)	Baseline With Uncertainty[e]	
15 – Alternate Design of Core Spray System (CSS) Suction Strainer to Mitigate Plugging	The probability that operators fail to locally open each of the service water valves was reduced to 8.36E-04 from 8.36E-03.	2	1	130K	360K	1.0M
16 – Use of Different Designs for Switchgear Room Cooling Fans	The probability that FANS AVH401 through DVH400 fail-to-start and fail-to-run was set to 0.	2	1	130K	370K	400K
17 – Replace a Supply Fan with a Different Design in Service Water Pump Room	**The probability that FANS AV503 through DV503 fail-to-start and fail-to-run was set to 0.**	**5**	**5**	**960K**	**2.7M**	**600K**
18 – Replace a Return Fan with a Different Design in Service Water Pump Room	**The probability that FANS AV504 through DV504 fail-to-start and fail-to-run was set to 0.**	**5**	**5**	**960K**	**2.7M**	**600K**
30 – Provide Procedural Guidance for Partial Transfer of Control Functions from Control Room to the Remote Shutdown Panel	**Reduce the fire CDF contribution from Fire Basic Events %IE-FIRE03, %IE-FIRE02, and %IE-FIRE01 by 90 percent.**	**NOT ESTIMATED**		**8.6M**	**24M**	**100K**
31 – Install Improved Fire Barriers in the Main Control Room (MCR) Control Cabinets Containing the Primary Main Steam Isolation Valve (MSIV) Control Circuits	Eliminate the fire CDF contribution from Fire Basic Event %IE-FIRE06.	NOT ESTIMATED		360K	1.0M	1.2M
32 – Install Additional Physical Barriers to Limit Dispersion of Fuel Oil from Diesel Generator (DG) Rooms	**Reduce the fire CDF contribution from Fire Basic Event %IE-FIRE28 by 90 percent.**	**NOT ESTIMATED**		**480K**	**1.4M**	**800K**
33 – Install Division II 480V AC Bus Cross-ties	Reduce the fire CDF contribution from Fire Basic Event %IE-FIRE37 by 90 percent.	NOT ESTIMATED		450K	1.3M	1.32M

Table G-6. SAMA Cost/Benefit Screening Analysis for Hope Creek Generating Station[a]

SAMA	Assumptions	% Risk Reduction		Total Benefit ($)		Cost ($)
		CDF	Population Dose	Baseline (Internal + External)	Baseline With Uncertainty[e]	
34 – Install Division I 480V AC Bus Cross-ties	Reduce the fire CDF contribution from Fire Basic Event %IE-FIRE20 by 90 percent.	NOT ESTIMATED		430K	1.2M	1.32M
35 – Relocate, Minimize and/or Eliminate Electrical Heaters in Electrical Access Room	**Reduce the fire CDF contribution from Fire Basic Event %IE-FIRE38 by 99 percent.**	**NOT ESTIMATED**		**410K[c]**	**1.2M[c]**	**270K**
36 – Provide Procedural Guidance for Loss of All 1E 120V AC Power	**Reduce the seismic CDF contribution from Seismic Basic Event %IE-SET36 by 50 percent.**	**NOT ESTIMATED**		**240K**	**680K**	**270K**
37 – Reinforce 1E 120V AC Distribution Panels	**Reduce the seismic CDF contribution from Seismic Basic Event %IE-SET36 by 90 percent.**	**NOT ESTIMATED**		**430K**	**1.2M**	**500K**
39 – Provide Procedural Guidance to Bypass Reactor Core Isolation Cooling (RCIC) Turbine Exhaust Pressure Trip	**As provided in response to a staff RAI, modify fault tree to include a new operator action, having a failure probability of 1.0E-02, representing failure of the operator to defeat the HPCI/RCIC back pressure permissive .**	**10**	**<1**	**130K**	**380K**	**120K**
40 – Increase Reliability/Install Manual Bypass of Low Pressure (LP) Permissive	As provided in response to a staff RAI, the probability of common cause mis-calibration of all ECCS pressure transmitters was reduced to 8.0E-06 from 8.0E-05.	1	1	210K	610K	620K
41[d] – Installation of Passive Hardened Containment Ventilation Pathway	A completely passive containment vent system requiring no operator actions is assumed.	15	30	6.2M	18M	>25M

Table G-6. SAMA Cost/Benefit Screening Analysis for Hope Creek Generating Station[a]

SAMA	Assumptions	% Risk Reduction		Total Benefit ($)		Cost ($)
		CDF	Population Dose	Baseline (Internal + External)	Baseline With Uncertainty[e]	
42[d] – Installation of SACS Standby Diesel-Powered Pump	Reduce the probability of initiating event %IE-SACS to 1.16E-05 per year from 1.16E-04 per year.	2	1	270K	760K	6.2M

(a) SAMAs in bold are potentially cost-beneficial.

(b) SAMA 5A added as a sensitivity case to SAMA 5 to provide a comprehensive, long term mitigation strategy for SBO scenarios.

(c) SAMAs 30, 31, and 32 were identified and evaluated in response to a staff RAI (PSEG 2010a). The RAI response stated that the percent risk reduction was developed using Salem PRA Model Version 4.3 and that the implementation costs for SAMAs 30 and 31 are expected to be significantly greater than the $100K assumed in the SAMA evaluation.

(d) Value estimated by staff using information provided in the ER.

(e) Using a factor of 2.5.

Source: PSEG, 2009

G.5 Cost Impacts of Candidate Plant Improvements

PSEG estimated the costs of implementing the 21 candidate SAMAs through the development of site-specific cost estimates. The cost estimates conservatively did not include the cost of replacement power during extended outages required to implement the modifications, nor did they include contingency costs for unforeseen difficulties (PSEG, 2010a). The cost estimates provided in the ER did not account for inflation, which is considered another conservatism.

The staff reviewed the bases for the applicant's cost estimates (presented in Table E.5-3 of Attachment E to the ER). For certain improvements, the staff also compared the cost estimates to estimates developed elsewhere for similar improvements, including estimates developed as part of other licensees' analyses of SAMAs for operating reactors.

The ER stated that plant personnel developed HCGS-specific costs to implement each of the SAMAs. The staff requested more information on the process PSEG used to develop the SAMA cost estimates (NRC, 2010a). PSEG responded to the RAI by explaining that the cost estimates were developed in a series of meetings involving personnel responsible for development of the SAMA analysis and the two PSEG license renewal site leads who are engineering managers each having over 25 years of plant experience, including project management, operations, plant engineering, design engineering, procedure support, simulators, and training (PSEG, 2010a). During these meetings, each SAMA was validated against the plant configuration, a budget-level estimate of its implementation cost was developed, and, in some instances, lower cost approaches that would achieve the same objective were developed. The SAMA implementation costs were then reviewed by the Design Engineering Manager for both technical and cost perspectives and revised accordingly. PSEG further explained that seven general cost categories were used in development of the budget-level cost estimates: engineering, material, installation, licensing, critical path impact, simulator modification, and procedures and training. Based on the use of personnel having significant nuclear plant engineering and operating experience, the staff considers the process PSEG used to develop budget-level cost estimates reasonable.

The staff requested additional clarification on the estimated cost of $2.05 million for implementation of SAMA 5, "Restore AC Power with Onsite Gas Turbine Generator," and on the implementation cost of $270,000 for implementation of SAMA 36, "Provide Procedural Guidance for Loss of All 1E 120 V AC Power," which are high for what are described as procedure changes and operator training (NRC, 2010a). In response to an RAI, PSEG further described the SAMA 5 modification as providing the necessary equipment to connect a dedicated transformer at Salem Unit 3 to HCGS, which is significantly more costly than, and is in addition to, the procedure changes (PSE,G 2010a). It was also explained that the SAMA 5 modification assumes that Salem Generating Station (Salem) SAMA 2 to install the dedicated transformer is already implemented and that SAMA 5 is a safety-related permanent plant modification. In response to a different RAI, PSEG explained that the SAMA 36 modification involves the development of a group of procedures, not just the revision of existing procedures or the

development of a single procedure. In addition, there is a significant effort involved with determining a success path to achieve safe shutdown, to update the simulator to include all necessary components to implement the success path, to test the success path, and to implement the new procedures. Based on this additional information, the staff considers the estimated cost to be reasonable and acceptable for purposes of the SAMA evaluation.

The staff asked PSEG to justify the estimated cost of $100,000 for SAMA 10, "Provide Procedural Guidance to use B.5.b Low Pressure Pump for Non-Security Events," for what is described as including a new pump when $100K is the estimated cost of a procedure change used in the SAMA analysis (NRC, 2010a). PSEG responded that the cost estimate for SAMA 10 assumes that an existing pump already installed at HCGS will be made available to implement this SAMA (PSEG, 2010a). Based on this additional information, the staff considers the estimated cost to be reasonable and acceptable for purposes of the SAMA evaluation.

In response to an RAI requesting a more detailed description of the changes associated with SAMA 16, "Use of Different Designs for Switchgear Room Cooling Fans," PSEG provided additional information detailing the cost estimate of this improvement (PSEG, 2010a). The staff reviewed the cost estimate and found it to be reasonable, and generally consistent with estimates provided in support of other plants' analyses.

The staff noted that SAMA 31, "Install Improved Fire Barriers in the Main Control Room (MCR) Control Cabinets Containing the Primary Main Steam Isolation Valve (MSIV) Control Circuits," is similar to Salem SAMAs 21 and 22 in that each involves installing fire barriers to prevent the propagation of a fire between cabinets and requested an explanation for why the estimated cost of $1.2 million for SAMA 31 to modify one cabinet is similar to the estimated cost of $1.6 million for Salem SAMA 22 to modify three Control Room consoles and is more than one-third of the $3.23 million cost for Salem SAMA 21 to modify 48 Relay Room cabinets (NRC, 2010a). PSEG responded that making the modifications to the SAMA 31 Control Room console, which is estimated to be $400,000for materials and installation, is more complicated than making modifications to the Salem SAMA 21 Relay Room cabinets, which is estimated to be $35,000 to $70,000 for materials and maintenance (PSEG, 2010a). Specifically, SAMA 31 requires making ventilation modifications due to the significant heat loads in addition to adding fire barrier materials. PSEG also explained that both SAMA 31 and Salem SAMA 22 assumed the same material and installation cost per console ($400,000) and the same engineering cost ($800,000) but that the engineering cost was evenly divided between the two units at Salem to arrive at a cost per unit. The staff considers the basis for the differences in cost estimates reasonable.

The staff noted that the estimated cost of $620K for SAMA 40, "Increase Reliability/Install Manual Bypass of Low Pressure (LP) Permissive," is significantly higher than the estimated cost of $250,000 for a similar improvement evaluated for the Duane Arnold nuclear power plant license renewal application (NRC, 2010a). In response to the RAI, PSEG clarified that SAMA 40 involves the installation of six key-lock switches to bypass various low pressure submissives

(PSEG, 2010a). Key-lock switches are used rather than jumpers, as was assumed in the Duane Arnold application, because the benefit of this SAMA cannot be obtained otherwise due to the effort required to install six jumpers, which is a more time intensive action than the time required to operate key-lock switches. Based on this additional information, the staff considers the estimated cost for HCGS to be reasonable and acceptable for purposes of the SAMA evaluation.

The staff also noted that the estimated cost of $1.32 million each for SAMA 33, "Install Division II 480 V AC Bus Cross-ties," and SAMA 34, "Install Division I 480 V AC Bus Cross-ties," is significantly higher than the estimated cost of $328,000 to $656,000 for a similar improvement evaluated for other nuclear power plant license renewal applications, i.e., Wolf Creek and Susquehanna (NRC, 2010a). In response to the RAI, PSEG described these modifications as involving the installation of new tie-breakers and cables for the 480 V AC bus cross-ties, having a material and installation cost of $400,000 (PSEG, 2010a). The most significant cost was for engineering, which was estimated to be $800,000 due to the electrical load analysis required to support the cross-ties. Based on this additional information, the staff considers the basis for the estimated cost to be reasonable.

The staff concludes that the cost estimates provided by PSEG are sufficient and appropriate for use in the SAMA evaluation.

G.6 Cost-Benefit Comparison

PSEG's cost-benefit analysis and the staff's review are described in the following sections.

G.6.1 PSEG's Evaluation

The methodology used by PSEG was based primarily on NRC's guidance for performing cost-benefit analysis, (i.e., NUREG/BR-0184, *Regulatory Analysis Technical Evaluation Handbook* [NRC 1997a]). The guidance involves determining the net value for each SAMA according to the following formula:

Net Value = (APE + AOC + AOE + AOSC) – COE
where
APE = present value of averted public exposure ($)
AOC = present value of averted offsite property damage costs ($)
AOE = present value of averted occupational exposure costs ($)
AOSC = present value of averted onsite costs ($)
COE = cost of enhancement ($)

If the net value of a SAMA is negative, the cost of implementing the SAMA is larger than the benefit associated with the SAMA and it is not considered cost-beneficial. PSEG's derivation of each of the associated costs is summarized below.

NUREG/BR-0058 has recently been revised to reflect the NRC's policy on discount rates. Revision 4 of NUREG/BR-0058 states that two sets of estimates should be developed, one at 3 percent and one at 7 percent (NRC, 2004). PSEG performed the SAMA analysis using the 3 percent discount rate and a sensitivity study using the 7 percent discount rate (PSEG, 2009).

Averted Public Exposure (APE) Costs

The APE costs were calculated using the following formula:

APE = Annual reduction in public exposure (Δperson-rem/year)
× monetary equivalent of unit dose ($2,000 per person-rem)
× present value conversion factor (15.04 based on a 20-year period with a 3-percent discount rate)

As stated in NUREG/BR-0184 (NRC, 1997a), it is important to note that the monetary value of the public health risk after discounting does not represent the expected reduction in public health risk due to a single accident. Rather, it is the present value of a stream of potential losses extending over the remaining lifetime (in this case, the renewal period) of the facility. Thus, it reflects the expected annual loss due to a single accident, the possibility that such an accident could occur at any time over the renewal period, and the effect of discounting these potential future losses to present value. For the purposes of initial screening, which assumes elimination of all severe accidents, PSEG calculated an APE of approximately $688,000 for the 20-year license renewal period.

Averted Offsite Property Damage Costs (AOC)

The AOCs were calculated using the following formula:

AOC = Annual CDF reduction
x offsite economic costs associated with a severe accident (on a per-event basis)
x present value conversion factor.

This term represents the sum of the frequency-weighted offsite economic costs for each release category, as obtained for the Level 3 risk analysis. For the purposes of initial screening, which assumes elimination of all severe accidents caused by internal events, PSEG calculated an AOC of about $155,000 based on the Level 3 risk analysis. This results in a discounted value of approximately $2,332,000 for the 20-year license renewal period.

Averted Occupational Exposure (AOE) Costs

The AOE costs were calculated using the following formula:

AOE = Annual CDF reduction
× occupational exposure per core damage event
× monetary equivalent of unit dose
× present value conversion factor

PSEG derived the values for averted occupational exposure from information provided in Section 5.7.3 of the regulatory analysis handbook (NRC, 1997a). Best estimate values provided for immediate occupational dose (3,300 person-rem) and long-term occupational dose (20,000 person-rem over a 10-year cleanup period) were used. The present value of these doses was calculated using the equations provided in the handbook in conjunction with a monetary equivalent of unit dose of $2,000 per person-rem, a real discount rate of 3 percent, and a time period of 20 years to represent the license renewal period. For the purposes of initial screening, which assumes elimination of all severe accidents caused by internal events, PSEG calculated an AOE of approximately $2,700 for the 20-year license renewal period (PSEG, 2009).

Averted Onsite Costs (AOSC)

AOSC include averted cleanup and decontamination costs and averted power replacement costs. Repair and refurbishment costs are considered for recoverable accidents only and not for severe accidents. PSEG derived the values for AOSC based on information provided in Section 5.7.6 of NUREG/BR-0184, the regulatory analysis handbook (NRC, 1997a).

PSEG divided this cost element into two parts – the onsite cleanup and decontamination cost, also commonly referred to as averted cleanup and decontamination costs (ACC), and the replacement power cost (RPC).

ACCs were calculated using the following formula:

ACC = Annual CDF reduction
x present value of cleanup costs per core damage event
× present value conversion factor

The total cost of cleanup and decontamination subsequent to a severe accident is estimated in NUREG/BR-0184 to be $1.5 x 10^9 (undiscounted). This value was converted to present costs over a 10-year cleanup period and integrated over the term of the proposed license extension. For the purposes of initial screening, which assumes elimination of all severe accidents caused by internal events, PSEG calculated an ACC of approximately $87,000 for the 20-year license renewal period.

Long-term RPCs were calculated using the following formula:

RPC = Annual CDF reduction
x present value of replacement power for a single event
× factor to account for remaining service years for which replacement power is required
× reactor power scaling factor

PSEG based its calculations on a HCGS net output of 1287 megawatt electric (MWe) and scaled up from the 910 MWe reference plant in NUREG/BR-0184 (NRC, 1997a). Therefore PSEG applied a power scaling factor of 1287/910 to determine the replacement power costs. For the purposes of initial screening, which assumes elimination of all severe accidents caused by internal events, PSEG calculated an RPC of approximately $35,000 and an AOSC of approximately $122,000 for the 20-year license renewal period.

Using the above equations, PSEG estimated the total present dollar value equivalent associated with completely eliminating severe accidents from internal events at HCGS to be about $3.14 million. Use of a multiplier of 6.3 to account for external events increases the value to $19.8 million and represents the dollar value associated with completely eliminating all internal and external event severe accident risk for a single unit at HCGS, also referred to as the Maximum Averted Cost Risk (MACR).

PSEG's Results

If the implementation costs for a candidate SAMA exceeded the calculated benefit, the SAMA was considered not to be cost-beneficial. In the baseline analysis contained in the ER (using a 3 percent discount rate, and considering the impact of external events), PSEG identified nine potentially cost-beneficial SAMAs. PSEG performed additional analyses to evaluate the impact of parameter choices (alternative discount rates and variations in MACCS2 input parameters) and uncertainties on the results of the SAMA assessment and, as a result of this analysis, identified four additional potentially cost-beneficial SAMAs.

The potentially cost-beneficial SAMAs are:

- SAMA 1 – remove ADS Inhibit from Non-ATWS Emergency Operating Procedures
- SAMA 3 – Install Back-Up Air Compressor to Supply AOVs
- SAMA 4 – Provide Procedural Guidance to Cross-Tie RHR Trains
- SAMA 8 – Convert Selected Fire Protection Piping from Wet to Dry Pipe System
- SAMA 10 – Provide Procedural Guidance to Use B.5.b Low Pressure Pump for Non-Security Events
- SAMA 17 – Replace a Supply Fan with a Different Design in Service Water Pump Room
- SAMA 18 – Replace a Return Fan with a Different Design in Service Water Pump Room
- SAMA 30 – Provide Procedural Guidance for Partial Transfer of Control Functions from the Control Room to the Remote Shutdown Panel
- SAMA 32 – Install Additional Physical Barriers to Limit Dispersion of Fuel Oil from DG Rooms
- SAMA 35 – Relocate, Minimize, and/or Eliminate Electrical Heaters in Electrical Access Room

- SAMA 36 – Provide Procedural Guidance for Loss of All 1E 120V AC Power
- SAMA 37 – Reinforce 1E 120V AC Distribution Panels
- SAMA 39 – Provide Procedural Guidance to Bypass RCIC Turbine Exhaust Pressure Trip

PSEG indicated that they plan to further evaluate these SAMAs for possible implementation using existing HCGS Plant Heal Committee processes (PSEG, 2009).

The potentially cost-beneficial SAMAs, and PSEG's plans for further evaluation of these SAMAs, are discussed in detail in Section G.6.2.

G.6.2 Review of PSEG's Cost-Benefit Evaluation

The cost-benefit analysis performed by PSEG was based primarily on NUREG/BR-0184 (NRC, 1997a) and discount rate guidelines in NUREG/BR-0058 (NRC, 2004) and was executed consistent with this guidance.

SAMAs identified primarily on the basis of the internal events analysis could provide benefits in certain external events, in addition to their benefits in internal events. To account for the additional benefits in external events, PSEG multiplied the internal event benefits for each internal event SAMA by a factor of 6.3, which is the ratio of the total CDF from internal and external events to the internal event CDF. As discussed in Section G.2.2, this factor was based on a seismic CDF of 1.1×10^{-6} per year, plus a fire CDF of 1.7×10^{-5} per year, plus the screening values for high winds, external flooding, transportation, detritus, and chemical release events (1×10^{-6} per year for each). The external event CDF of 2.3×10^{-5} per year is thus 5.3 times the internal events release frequency CDF of 4.4×10^{-6} per year. The total CDF is thus 6.3 [$(2.3 \times 10^{-5} + 4.4 \times 10^{-6}) / 4.4 \times 10^{-6}$] times the internal events release frequency CDF (PSEG 2009). Seven SAMAs were determined to be cost-beneficial in PSEG's analysis (SAMAs 1, 3, 4, 10, 17, 18, and 39 as described above).

PSEG did not multiply the internal event benefits by the factor of 6.3 for eight SAMAs that specifically address fire and seismic risk (SAMAs 30, 31, 32, 33, 34, 35, 36, and 37). Multiplying the internal event benefits by 6.3 for these SAMAs would not be appropriate because these SAMAs are specific to fire or seismic risks and would not have a corresponding benefit on the risk from internal events. Two of these SAMAs were found to be cost-beneficial in PSEG's analysis (SAMAs 30 and 35, as described above).

PSEG considered the impact that possible increases in benefits from analysis uncertainties would have on the results of the SAMA assessment. In the ER, PSEG presents the results of an uncertainty analysis of the internal events CDF which indicates that the 95th percentile value is a factor of 2.84 times the point estimate CDF for HCGS. Since the two Phase I SAMAs that were screened based on qualitative criteria were screened due to one being subsumed into

another SAMA or one having already been implemented at HCGS, a re-examination of the Phase I SAMAs based on the upper bound benefits was not necessary. PSEG considered the impact on the Phase II analysis if the estimated benefits were increased by a factor of 2.84 (in addition to the multiplier of 6.3 for external events). Four additional SAMAs became cost-beneficial in PSEG's analysis (SAMAs 8, 32, 36, and 37 as described above).

PSEG provided the results of additional sensitivity analyses in the ER, including use of a 7 percent discount rate and variations in MACCS2 input parameters. These analyses did not identify any additional potentially cost-beneficial SAMAs (PSEG, 2009).

PSEG indicated that the 13 potentially cost-beneficial SAMAs (SAMAs 1, 3, 4, 8, 10, 17, 18, 30, 32, 35, 36, 37, and 39) will be considered for implementation through the established HCGS Plant Health Committee process (PSEG, 2009).

As indicated in Section G.3.2, in response to staff RAIs, PSEG considered additional plant improvements to address basic events for which no SAMAs had been identified in the ER. PSEG determined that of the plant improvements considered, two additional SAMAs warrant further consideration: (1) SAMA 41, "Installation of Passive Hardened Containment Ventilation Pathway," and (2) SAMA 42, "Installation of SACS Standby Diesel-Powered Pump." Each of these new SAMAs is included in Table G-6 and were evaluated as described above. PSEG's analysis determined that neither of these SAMA candidates was cost-beneficial in either the baseline analysis or the uncertainty analysis.

As indicated in Section G.2.2, PSEG determined that the external events multiplier would be 6.8 if the higher seismic CDF obtained using the LLNL hazard curves were used rather than the EPRI hazard curves. As discussed in Section G.3.2, PSEG then reviewed the Level 1 and Level 2 basic events down to an RRW of 1.005 to account for the revised external events multiplier of 6.8. In addition, since the maximum benefit of each seismic sequence increased as a result of using the LLNL hazard curves, PSEG reviewed two additional seismic sequences having a benefit equal to or greater than $100,000, the minimum expected SAMA implementation cost at HCGS. These reviews resulted in the identification and evaluation of five additional SAMAs, as summarized below:

- SAMA RAI 5.j-IE1, "Install a Key Lock Switch for Bypass of the Main Steam Isolation Valve (MSIV) Low Level Isolation Logic." PSEG estimated the implementation cost for this SAMA to be the same as SAMA 40, "Increase Reliability/Install Manual Bypass of Low Pressure (LP) Permissive," or $620,000, which also involved installation of key lock bypass switches (PSEG, 2010a). The maximum benefit was estimated to be $110,000 in the baseline analysis, and $300,000 after accounting for uncertainties, which assumed that the risk of the basic event addressed by this SAMA was completely eliminated. Since the implementation cost was greater than the estimated benefit accounting for uncertainties, PSEG concluded that SAMA RAI 5.j-IE1 was not cost-beneficial.

- SAMA RAI 5p-1, "Install an Independent Boron Injection System." PSEG estimated the implementation cost of this SAMA to be $1.5 million based on the estimate for a similar SAMA to install a redundant system evaluated in the Browns Ferry nuclear power plant license renewal application and the estimated cost to install an additional tank (PSEG 2010a). To estimate the risk reduction, PSEG modified the HCGS PRA model fault tree to include a new basic event, having a failure probability of 1.0×10^{-03}, representing failure of the redundant system. The benefit was estimated to be $390,000 in the baseline analysis, and $1.1 million after accounting for uncertainties. Since the implementation cost was greater than the estimated benefit accounting for uncertainties, PSEG concluded that SAMA RAI 5p-1 was not cost-beneficial.

- Reinforce 1E 125V DC distribution panels 1A/B/C/D-D-417. PSEG estimated the minimum implementation cost for this SAMA to be the same as SAMA 37, "Reinforce 1E 120V AC Distribution Panels," or $500K, but expects the cost to be higher because these panels have a much higher HCLPF value than the SAMA 37 120V AC panels (PSEG, 2010a). To estimate the risk reduction, PSEG assumed that the contribution to risk from external events is approximately 5.8 times that from internal events (based on a revised seismic CDF of 3.58×10^{-6} per year using the LLNL hazard curves), that seismic events contribute 14 percent of this external events risk, and that 50 percent of the fire risk affected by the SAMA is eliminated. The benefit was estimated to be $155,000 in the baseline analysis, and $440,000 after accounting for uncertainties. Since the implementation cost was greater than the estimated benefit accounting for uncertainties, PSEG concluded that this SAMA was not cost-beneficial.

- Reinforce 1E 120V AC distribution panels 1A/B/C/DJ482. PSEG estimated the implementation cost for this SAMA to be the same as SAMA 37, or $500,000, which also addresses 120V AC panels (PSEG, 2010a). To estimate the risk reduction, PSEG assumed that the contribution to risk from external events is approximately 5.8 times that from internal events (based on a revised seismic CDF of 3.58×10^{-6} per year using the LLNL hazard curves), that seismic events contribute 14 percent of this external events risk, and that all of the seismic risk affected by the SAMA is eliminated. The benefit was estimated to be $110,000 in the baseline analysis, and $320,000 after accounting for uncertainties. Since the implementation cost was greater than the estimated benefit accounting for uncertainties, PSEG concluded that this SAMA was not cost-beneficial.

- Reinforce 1E 120V AC distribution panels to 1.0g Seismic Rating. This SAMA assumes that 1) SAMA 37 is implemented, 2) the HCLPF values for the 120V AC panels are further increased to 1 g as a result of the implementation, 3) the above SAMA to reinforce the 125V DC panels is implemented, and 4) the HCLPF values for the panels are increased from the current 0.57g to 1.0g as a result of the implementation (PSEG 2010b). SAMA 37 originally was assumed to reduce the risk of seismic basic event %IE-SET36, "seismic-induced equipment damage state SET-36 (impacts – 120V PNL481," by 90 percent while the proposed SAMA to reinforce the 125V DC panels, by itself was

originally assumed to reduce the risk of seismic basic event %IE-SET37, seismic-induced equipment damage state (impacts – 125V)," by 50 percent. The synergistic benefit of this new proposed SAMA to reinforce the 120V AC panels to a HCLPF value of 1.0g is assumed to be the sum of the benefit to eliminate the remaining 10 percent of the risk of event %IE-SET36 ($176,000) and the remaining 50 percent of the risk of event %IE-SET37 ($155,000), for a total benefit of $330,000 in the baseline analysis, and $940,000 after accounting for uncertainties. PSEG estimated the implementation cost for this SAMA to be $900,000, which assumes the panels can be modified and not have to be replaced. Since the estimated benefit is greater than the implementation cost, PSEG determined that this proposed SAMA was potentially cost-beneficial. PSEG stated that this proposed SAMA will be considered for implementation through the established HCGS Plant Health Committee process.

The staff notes that SAMA 37 was determined to be cost-beneficial and will be considered by PSEG for implementation through the established HCGS Plant Health Committee process. PSEG concluded, however, that the above originally proposed SAMA to reinforce the 125V DC panels was, by itself, not cost-beneficial, yet it was assumed to be implemented in the evaluation of this new proposed combined SAMA. Because the risk reduction from this new proposed SAMA to reinforce the 120V AC panels to a HCLPF value of 1.0g cannot be obtained without implementation of the proposed SAMA to reinforce the 125V DC panels, the staff concludes that both SAMAs (SAMA 37 and the combined SAMA of reinforcing both the 120 VAC and 125 VDC panels) should be considered for implementation.

As indicated in Section G.3.2, two plant improvements were identified in the ER but not included in the SAMA evaluation because they were higher cost than the SAMA selected for evaluation. The staff noted however that the two improvements could have larger benefits than the SAMAs evaluated because they could be more effective or could mitigate additional events (PSEG, 2010a). In response to the RAIs, PSEG evaluated the two improvements, as summarized below:

- Replace the normally open floor and equipment drain MOVs with fail-closed AOVs. PSEG estimated the implementation cost of this SAMA to be $2.05 million, which is half the estimate for a similar SAMA to replace cooling water system MOVs, which are larger than drain MOVs, with fail-closed AOVs evaluated in the TMI-1 nuclear power plant license renewal application (PSEG, 2010a). To estimate the risk reduction, PSEG assumed that the entire release frequency associated with basic event CIS-DRAN-L2-OPEN, "valves open automatically for drainage normally open," after adjustment to account for existing procedures that are not credited, was eliminated. The benefit, assuming an external multiplier of 6.8, was estimated to be $710,000 in the baseline analysis, and $2.0 millionafter accounting for uncertainties. Since the implementation cost was greater than the estimated benefit accounting for uncertainties, PSEG concluded the proposed improvement was not cost-beneficial.

- Auto align 480V AC portable station generator. For HCGS, this improvement is described as requiring permanent installation of an existing portable generator and adding the logic to perform the auto start and load function. PSEG estimated the implementation cost of this SAMA to be at least $1.0 million based on an estimate of $1.0 million from the Shearon Harris nuclear power plant license renewal application to permanently install a 480V AC generator and pump and an estimate of $3.1 million from the TMI-1 nuclear power plant license renewal application to automate the start and load of an existing, permanently installed 4KV AC generator (PSEG, 2010a; PSEG, 2010b). To estimate the risk reduction, PSEG set the failure probabilities of existing operator actions to align the portable generator, and associated joint human error probabilities, to zero. The benefit, assuming an external multiplier of 6.8, was estimated to be $210,000 in the baseline analysis, and $600,000 after accounting for uncertainties. Since the implementation cost was greater than the estimated benefit accounting for uncertainties, PSEG concluded the proposed improvement was not cost-beneficial.

As indicated in Section G.3.2, for certain SAMAs considered in the ER, there may be alternatives that could achieve much of the risk reduction at a lower cost. The staff asked the applicant to evaluate additional lower cost alternatives to the SAMAs considered in the ER, as summarized below (NRC, 2010a):

- Establishing procedures for opening doors and/or using portable fans for sequences involving room cooling failures. In response to the staff RAI, PSEG stated that HCGS already has procedures to implement the suggested alternative on loss of normal Switchgear Room HVAC and that this event is credited in the PRA model (PSEG, 2010a). However, PSEG did provide an evaluation to implement the suggested alternative in the Service Water Pump Room, which is considered a more practical and cost effective change than SAMA 17, “Replace a Supply Fan with a Different Design in Service Water Pump Room,” and SAMA 18, “Replace a Return Fan with a Different Design in Service Water Pump Room,” which involve permanent hardware modifications. The cost of implementing an alternate room cooling strategy for this room, identified as SAMA RAI 7.a-1, was estimated to be $150,000. The baseline benefit was assumed to be the sum of the estimated benefits for SAMAs 17 and 18, or $1.9 million. Accounting for the revised multiplier of 6.8 and uncertainties increases the benefit to $5.9 million. Since the estimated benefit is greater than the implementation cost, PSEG determined that SAMA RAI 7.a-1 was potentially cost-beneficial. PSEG also stated that this SAMA will be further evaluated in parallel with cost-beneficial SAMAs 17 and 18 since there may be some benefit associated with the permanent hardware modifications considered in these SAMAs.

- Extending the procedure for using the B.5.b low pressure pump for non-security events to include all applicable scenarios, not just SBOs. In response to the staff RAI, PSEG stated that the estimated benefit for SAMA 10, “Provide Procedural Guidance to use B.5.b Low Pressure Pump for Non-Security Events,” already includes the risk reduction

for all applicable scenarios (PSEG, 2010a). The staff concludes that the suggested alternative has already been addressed.

- Utilizing a portable independently powered pump to inject into containment. In response to the staff RAI, PSEG explained that the HCGS PRA model already credits use of the diesel fire pump to inject into the RPV and containment and that the addition of another independently powered pump to provide injection would have limited benefit (PSEG, 2010a). PSEG further noted that SAMA 10 already evaluated aligning the B.5.b low pressure pump with RHRSW to provide al alternate source of injection. The staff concludes that the suggested alternative has already been addressed.

As indicated in Section G.4, the staff questioned PSEG on the risk reduction potential for certain SAMAs (NRC, 2010a; NRC, 2010b), as summarized below.

- For SAMA 5, "Restore AC Power with Onsite Gas Turbine Generator," PSEG provided a revised estimate of the benefit that included credit for the additional capability for mitigating a more complete set of loss of offsite power initiators that is consistent with the hardware changes proposed (PSEG, 2010a; PSEG, 2010b). This SAMA was determined to be potentially cost-beneficial in PSEG's revised analysis. PSEG stated that SAMA 5 will be considered for implementation through the established HCGS Plant Health Committee process.

- For SAMA 35, "Relocate, Minimize and/or Eliminate Electrical Heaters in Electrical Access Room", PSEG provided a revised estimate of the benefit assuming 99 percent of the fire risk affected by the SAMA was eliminated (PSEG, 2010a). This SAMA was determined to remain cost-beneficial in PSEG's revised analysis.

The staff notes that the 13 cost-beneficial SAMAs (SAMAs 1, 3, 4, 8, 10, 17, 18, 30, 32, 35, 36, 37, and 39) identified in PSEG's original baseline and uncertainty analysis, and the three SAMAs and plant improvements determined to be cost-beneficial in response to staff RAIs ("establishing procedures for opening doors and/or using portable fans for sequences involving Service Water Pump Room cooling failures," SAMA 5, and "reinforce 1E 120V AC distribution panels to 1.0g Seismic Rating"), are included within the set of SAMAs that PSEG plans to further consider for implementation through the established Plant Health Committee (PHC) process. The staff suggests that the proposed SAMA to "reinforce the 120V DC panels" also be considered for implementation since it must be implemented to obtain the risk reduction benefits of the SAMA to "reinforce 1E 120V AC distribution panels to 1.0g Seismic Rating."

In response to an staff RAI, PSEG described the PHC as being chaired by the Plant Manager and includes as members the Plant Engineering Manager and the Directors of Operations, Engineering, Maintenance, and Work Management (PSEG, 2010a). The PHC is chartered with reviewing issues that require special plant management attention to ensure effective resolution and, with respect to each of the potentially cost-beneficial SAMAs, will decide on one of the

following courses of actions: (1) approve for implementation, (2) conditionally approved for implementation pending the results of requested evaluations, (3) not approved for implementation, or (4) table until additional information needed to make a final decision is provided to the PHC. Additional information requested may include (1) making corrections to the original SAMA analysis, (2) examining an alternate solution, (3) performing sensitivity studies to determine the effect of implementing a sub-set of SAMAs, already approved SAMAs, or already approved non-SAMA design changes on the SAMA, or (4) coordinating the SAMA with related Mitigating System Performance Index (MSPI) margin recovery activities. If approved or conditionally approved for implementation, the SAMA will be ranked with respect to priority and assigned target years for implementation.

The concludes that, with the exception of the potentially cost-beneficial SAMAs discussed above, the costs of the other SAMAs evaluated would be higher than the associated benefits.

G.7 Conclusions

PSEG compiled a list of 23 SAMAs based on a review of: the most significant basic events from the plant-specific PRA and insights from the HCGS PRA group, insights from the plant-specific IPE and IPEEE, Phase II SAMAs from license renewal applications for other plants, and the generic SAMA candidates from NEI 05-01. A qualitative screening removed SAMA candidates that: (1) are not applicable to HCGS due to design differences, (2) have already been implemented at HCGS, (3) would achieve results that have already been achieved at HCGS by other means, and (4) have estimated implementation costs that would exceed the dollar value associated with completely eliminating all severe accident risk at HCGS. Based on this screening, 2 SAMAs were eliminated leaving 21 candidate SAMAs for evaluation. Nine additional SAMA candidates or plant improvements were identified and evaluated in response to staff RAIs.

For the remaining 21 SAMA candidates, a more detailed design and cost estimate were developed as shown in Table G-6. The cost-benefit analyses in the ER and RAI response showed that 9 of the SAMA candidates were potentially cost-beneficial in the baseline analysis (Phase II SAMAs 1, 3, 4, 10, 17, 18, 30, 35, and 39). PSEG performed additional analyses to evaluate the impact of parameter choices and uncertainties on the results of the SAMA assessment. Four additional SAMA candidates (SAMAs 8, 32, 36, and 37) were identified as potentially cost-beneficial in the ER. In response to a staff RAI regarding the assumptions used to estimate the risk reduction potential of certain SAMAs, PSEG identified one additional potentially cost-beneficial SAMA (SAMA 5). In response to staff RAIs regarding the seismic CDF and potential lower cost alternatives, PSEG further identified “establishing procedures for opening doors and/or using portable fans for sequences involving Service Water Pump Room cooling failures” and “reinforce 1E 120V AC distribution panels to 1.0g Seismic Rating” as being potentially cost-beneficial enhancements. PSEG has indicated that all 14 potentially cost-beneficial SAMAs, as well as the enhancements “establishing procedures for opening doors and/or using portable fans for sequences involving Service Water Pump Room cooling failures” and “reinforce 1E 120V AC distribution panels to 1.0g Seismic Rating,” will be considered for implementation through the established HCGS Plant Health Committee process. In addition, it is suggested that the plant improvement to “reinforce the 120V DC panels” be included in the

set of SAMAs to be considered for implementation since it must be implemented to obtain the risk reduction benefits of the plant improvement to "reinforce 1E 120V AC distribution panels to 1.0g Seismic Rating."

The staff reviewed the PSEG analysis and concludes that the methods used and the implementation of those methods was sound. The treatment of SAMA benefits and costs support the general conclusion that the SAMA evaluations performed by PSEG are reasonable and sufficient for the license renewal submittal. Although the treatment of SAMAs for external events was somewhat limited, the likelihood of there being cost-beneficial enhancements in this area was minimized by improvements that have been realized as a result of the IPEEE process, and inclusion of a multiplier to account for external events.

The staff concurs with PSEG's identification of areas in which risk can be further reduced in a cost-beneficial manner through the implementation of the identified, potentially cost-beneficial SAMAs. Given the potential for cost-beneficial risk reduction, the staff agrees that further evaluation of these SAMAs by PSEG is warranted. However, these SAMAs do not relate to adequately managing the effects of aging during the period of extended operation. Therefore, they need not be implemented as part of license renewal pursuant to Title 10 of the *Code of Federal Regulations*, Part 54.

G.8 References

American Society of Mechanical Engineers (ASME). 2005. "Addenda to ASME RA-S-2002, Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications." ASME RA-Sb-2005, December 2005.

BEA (Bureau of Economic Analysis). 2008. Regional Economic Accounts, accessed June 20 at http://www.bea.gov/regional/reis/.

Electric Power Research Institute (EPRI). 1989. "Probabilistic Seismic Hazard Evaluations at Nuclear Plant Sites in the Central and Eastern United States; Resolution of the Charleston Earthquake Issues." EPRI NP-6395-D, EPRI Project P101-53. Palo Alto, CA. April 1989.

Electric Power Research Institute (EPRI). 1991. "A Methodology for Assessment of Nuclear Power Plant Seismic Margin," EPRI NP-6041. Palo Alto, CA. August 1991.

Electric Power Research Institute (EPRI). 1993. "Fire Induced Vulnerability Evaluation (FIVE) Methodology." TR-100370, Revision 1, Palo Alto, CA. September 19, 1993.

KLD Associates, Inc. (KLD). 2004. *Salem / Hope Creek Nuclear Generating Stations Development of Evacuation Time Estimates*. KLD TR-356. February 2004.
Nuclear Energy Institute (NEI). 2005. "Severe Accident Mitigation Alternative (SAMA) Analysis Guidance Document." NEI 05-01 (Rev. A), Washington, D.C. November 2005.

Nuclear Energy Institute (NEI). 2007. "Process for Performing Follow-on PRA Peer Reviews using the ASME PRA Standard (Internal Events)." NEI 05-04, Rev. 1, Washington, D.C. December 2007.

Public Service Electric and Gas Company (PSEG). 1994. "Hope Creek Generating Station. Individual Plant Examination." April 1994. Accessible at ML080160331.

Public Service Electric and Gas Company. (PSEG). 1997. "Hope Creek Generating Station Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities." July 1997. Accessible at ML080160320.

Public Service Electric and Gas Company (PSEG). 2005. Letter from George P. Barnes, PSEG, to NRC Document Control Desk. Subject: "Request for License Amendment Extended Power Uprate Hope Creek Generating Station Facility Operating License NPF-57 Docket No: 50-354," Hancocks Bridge, New Jersey. Nov. 7, 2005. Accessible at ML053200202.

PSEG Nuclear, LLC (PSEG). 2009. *Hope Creek Generating Station - License Renewal Application, Applicant's Environmental Report, Operating License Renewal Stage,* August 2009. Accessible at ML092430484.

PSEG Nuclear, LLC (PSEG). 2010a. Letter from Paul J. Davison, PSEG, to NRC Document Control Desk. Subject: "Response to NRC Request for Additional Information dated April 20, 2010, related to the Severe Accident Mitigation Alternatives (SAMA) review associated with the Hope Creek Generating Station License Renewal Application," Hancocks Bridge, New Jersey. June 1, 2010. Accessible at ML101550149.

PSEG Nuclear, LLC (PSEG). 2010b. Letter from Christine T. Neely, PSEG, to NRC Document Control Desk. Subject: "Supplement to RAI responses submitted in PSEG Letter LR-N10-0181 dated June 1, 2010, related to the Severe Accident Mitigation Alternatives (SAMA) review of the Hope Creek Generating Station," Hancocks Bridge, New Jersey. August 18, 2010. Accessible at ML102320212.

U.S. Department of Agriculture (USDA). 2002. "2002 Census of Agriculture - Volume 1, Geographic Area Series, Part 8 (Delaware), Part 20 (Maryland), Part 30.

U.S. Nuclear Regulatory Commission (NRC). 1988. Generic Letter 88-20, "Individual Plant Examination for Severe Accident Vulnerabilities." November 23, 1988.

U.S. Nuclear Regulatory Commission (NRC). 1990. *Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants*. NUREG-1150. Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1991b. "Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities." NUREG-1407. Washington, D.C. May 1991.

U.S. Nuclear Regulatory Commission (NRC). 1991a. "Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities." Generic Letter No. 88-20, Supplement 4. Washington, D.C. June 28, 1991.

U.S. Nuclear Regulatory Commission (NRC). 1994. *Revised Livermore Seismic Hazard Estimates for Sixty-Nine Nuclear Plant Sites East of the Rocky Mountains.* NUREG-1488, April 1994. Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1996. Letter from David H. Jaffe, U.S. NRC, to Leon R. Eliason, PSEG. Subject: "NRC staff's Evaluation of the Individual Plant Examination (IPE) Submittal (NLR-N94070) Hope Creek Generating Station (TAC No. M74421)." April 23, 1996.

U.S. Nuclear Regulatory Commission (NRC). 1997a. *Regulatory Analysis Technical Evaluation Handbook*. NUREG/BR-0184. Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1997b. *Individual Plant Examination Program: Perspectives on Reactor Safety and Plant Performance*. NUREG-1560. Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1998. *Code Manual for MACCS2: User's-Guide.* NUREG/CR-6613, Volume 1, May 1998. Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1999. Letter from Richard B. Ennis, U.S. NRC, to Harold W. Keiser, PSEG. Subject: "Review of Individual Plant Examination of External Events (IPEEE) Submittal for Hope Creek Generating Station (TAC No. M83630)". April 26, 1999.

U.S. Nuclear Regulatory Commission (NRC). 2003. *SECPOP2000: Sector Population, Land Fraction, and Economic Estimation Program*. NUREG/CR-6525, Rev. 1. Sandia National Laboratories. August 2003

U.S. Nuclear Regulatory Commission (NRC). 2004. *Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission*. NUREG/BR-0058, Rev. 4. Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 2007. "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities." Regulatory Guide 1.200, Revision 1. January 2007.

U.S. Nuclear Regulatory Commission (NRC). 2009. *Guidance on the Treatment of Uncertainties Associated with PRAs in Risk-Informed Decision Making*. NUREG-1855, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 2010a. Letter from Charles Eccleston, U.S. NRC, to Thomas Joyce, PSEG. Subject: Revised Request for Additional Information Regarding Severe Accident Mitigation Alternatives for Hope Creek Generating Station. May 20, 2010. Accessible at ML101310058.

U.S. Nuclear Regulatory Commission (NRC). 2010b. Subject: Summary of Telephone Conference Held on July 29, 2010 between the U.S. Nuclear Regulatory Commission and PSEG Nuclear LLC, Concerning Follow-up Questions Pertaining to the Salem Nuclear Generating Station, Units 1 and 2, and Hope Creek Generating Stations License Renewal Environmental Review. August 13, 3010. Accessible at ML102220012.

ATTACHMENT 28

F. Eltawila, U.S. NRC, "NRC Source Term Research – Outstanding Issues and Future Directions," European Review Meeting on Severe Accident Research, Karlsruhe, Germany, June 12-14, 2007, Slide

NRC Source Term Research
Outstanding Issues and Future Directions

Farouk Eltawila, Director
Division of Risk Assessment & Special Projects
Office Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission

Accident Source Terms in the US regulatory process

- **Releases of fission products to the containment:**
  - **Defense in depth**
  - **Regulatory evaluation of engineered safety features (ESFs)**
- **Releases of fission products to the environment:**
  - **Consequences of reactor accidents**
  - **Accident management and emergency response**

ATTACHMENT 29

TID-14844, "Calculation of Distance Factors for Power and Test Reactors" (Mar. 1962)

TID-14844
REACTOR TECHNOLOGY

CALCULATION OF DISTANCE FACTORS FOR POWER AND TEST REACTOR SITES*

Technical Information Document

By

J. J. DiNunno
F. D. Anderson
R. E. Baker
R. L. Waterfield

March 23, 1962

Division of Licensing and Regulation
U. S. Atomic Energy Commission

*Second printing--minor editorial changes made from the first printing.

TABLE OF CONTENTS

I. PURPOSE

It is the intent that this document to provide reference information and guidance on procedures and basic assumptions whereby certain factors pertinent to reactor siting as set forth in Title 10 Code of Federal Regulations Part 100 (10 CFR 100)[1] can be used to calculate distance requirements for reactor sites which are generally consistent with current siting practices.

For any proposed reactor: the performance experience accumulated elsewhere; the engineering safeguards; the inherent stability and safety features; and the quality of design, materials, construction, management and operation are all important factors that must be included in the evaluation of the suitability of a site.

For a particular site; size, topography, meteorology, hydrology, ease of warning and removing people in times of emergency, and thoroughness of plans and arrangements for minimizing injuries and interference with offsite activities, all enter an evaluation.

Consideration of these as well as other aspects of hazards evaluation involves so many different situations and such complex technological problems that it would be quite impossible to anticipate and answer all questions that will arise.

This technical document sets forth one method of computing distances and exposures, for one general class of reactors. In developing this example conservative assumptions have been intentionally selected.

Designers of reactors are expected to examine all significant aspects of the hazards and safety problem they believe are appropriate to the particular

situation with which they are dealing. In any case, the designer and/or applicant bears the responsibility for justifying all the assumptions and methods of calculation used in a hazards evaluation. The fact that aspects of the problem are not considered in the example set forth here, does not in any way relieve the designer and/or applicant of the responsibility for carefully examining, in his particular case, every significant facet of the hazards and safety problem.

II. INTRODUCTION

An applicant for a license to construct a power or test reactor is required by Atomic Energy Commission (AEC) regulations, Title 10 Code of Federal Regulations Part 50 (10 CFR Part 50), to submit in support of his application a hazards summary report that includes details pertinent to the site proposed for the reactor. Approval or disapproval is given by the Commission after review and evaluation of the reactor design and the proposed location by the Division of Licensing and Regulation and the Advisory Committee on Reactor Safeguards (ACRS). Such review and evaluation includes an analysis of the consequences of potential accidents.

The probability and consequences of major reactor accidents have been the subject of widespread interest and study since the earliest days of reactor development. To date, however, the technology has not progressed to the point where it is possible to assign quantitative numbers to all the significant factors relative to safety or to predict with surety the probabilities of malfunctioning of engineering features of plant design under all operating conditions that might exist. There is rather general agreement, however, as expressed in the Brookhaven report, "Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Power Plants",[2] that the probability of a major accident in reactor plants constructed and operated in accordance with general practices now observed is exceedingly small. The following is quoted from the report:

> "As to the probabilities of major reactor accidents, some experts believe that numerical estimates of a quantity

so vague and uncertain as the likelihood of occurrence of major reactor accidents has no meaning. They decline to express their feeling about this probability in numbers. Others, though admitting similar uncertainty, nevertheless, ventured to express their opinions in numerical terms.... However, whether numerically expressed or not, there was no disagreement in the opinion that the probability of major reactor accidents is exceedingly low."

This low probability of occurrence is due to both the inherently safe features of reactors and the safeguards that have been engineered into the plants as a part of deliberate and planned effort to insure safety. The question of suitability of a site for a reactor, however, requires consideration not only of the factors influencing the probability of occurrence of an accident, but also the risk in terms of possible exposure of people to the hazardous consequences of such an accident. Although the probability of a serious accident may be primarily a function of facility design and the risk in terms of exposure may be primarily a function of location, the two are not independent. Site characteristics may dictate the inclusion of specific engineered safeguard features and a proposed facility design in turn may have marked influence on the acceptability of the site for location of the reactor.

Values of radiation exposure dose that can be used as reference values in the evaluation of reactor sites have been set forth in 10 CFR 100. Considerations that led to the establishment of these reference values and the site criteria in which they are embodied are discussed in the sections that follow. In addition, a hypothetical case is analyzed to illustrate the calculation of distance factors as required by 10 CFR 100.

III. BASIC CRITERIA

The AEC has set forth in 10 CFR 100 a number of the factors considered by the Commission in the evaluation of reactor sites and the general criteria used at this time as guides in approving or disapproving proposed sites. One of the factors identified is the following:

> "Population density and use characteristics of the site environs, including, among other things, the exclusion area, low population zone, and population center distance."

The guides (10 CFR 100.11) also set forth pertinent factors to be considered in estimating the exclusion area, low population zone and population center distance.

Specifically, 10 CFR 100 requires an applicant for a construction permit to determine the following:[1]

> "(1) <u>An exclusion area</u> of such size that an individual located at any point on its boundary for two hours immediately following onset of the postulated fission product release would not receive a total radiation dose to the whole body in excess of 25 rem or a total radiation dose in excess of 300 rem to the thyroid from iodine exposure.
>
> (2) <u>A low population zone</u> of such size that an individual located at any point on its outer boundary who is exposed to the radioactive cloud resulting from the postulated fission product release (during the entire period of its passage) would not receive a total radiation dose to the

whole body in excess of 25 rem or a total radiation dose in excess of 300 rem to the thyroid from iodine exposure.

(3) A population center distance of at least 1 1/3 times the distance from the reactor to the outer boundary of the low population zone. In applying this guide due consideration should be given to the population distribution within the population center. Where very large cities are involved, a greater distance may be necessary because of total integrated population dose considerations."

In these criteria, two concepts are worthy of particular comment:

Note 1: Exposure Limits

The whole body dose of 25 rem referred to in the above excerpts from 10 CFR 100 corresponds numerically to the once in a lifetime accidental or emergency dose for radiation workers, which, according to NCRP recommendations[3], may be disregarded in the determination of their radiation exposure status. However, neither its use in the context of this regulation nor that of a correspondingly low internal organ dose (such as, for example, the 300 rem to the thyroid might be considered in this application) is intended to imply that these numbers constitute acceptable emergency doses to the public under accident conditions. Rather, this 25 rem value and the 300 rem thyroid value have been set forth in these guides as reference values which can be used in the evaluation of reactor sites for reactors that reflect through their design, construction and operation an exceedingly low probability for a major accident, and through location and other safeguards against the hazardous consequences of an accident, should one occur, a low probability of public damage from such accidents. These exposure values cannot be considered as being independent from the likelihood of serious accidents nor from considerations of the total number of persons that might be exposed. They have been set forth as reasonable bases for reactor site evaluations in the context of considerations such as those indicated in Section V. of this document.

Note 2: Population Center Distance

One basic objective of the criteria is to assure that the cumulative exposure dose to large numbers of people as a consequence of any nuclear accident should be low in comparison with what might be considered reasonable for total population dose. Further, since accidents of greater potential hazard than those commonly postulated as representing an upper limit are conceivable, although highly improbable, it was considered desirable to provide for protection against excessive exposure doses of people in large centers, where effective protective measures might not be feasible. Neither of these objectives were readily achievable by a single criterion. Hence, the population center distance was added as a site requirement when it was found for several projects evaluated that the specifications thereof would approximately fulfill the desired objectives and reflect a more accurate guide to current siting practices. In an effort to develop more specific guidance on the total man-dose concept, the Commission intends to give further study to the subject. Meanwhile, in recognition of the problem, the population center distance to very large cities may have to be greater than those suggested by these guides.

IV. POSTULATION OF A MAJOR REACTOR ACCIDENT

In evaluating proposed reactor sites, the basic safety questions involve the possibility of accidents which might cause radioactivity release to areas beyond the site, the possible magnitudes of such releases and the consequences these might have. Practically, there are two difficult aspects to the estimation of potential accidents in a proposed reactor which affect the problem of site evaluation.

1. The necessity for site appraisal arises early in the life of a project when many of the detailed features of design which might affect the accident potential of a reactor are not settled.
2. The inherent difficulty of postulating an accident representing a reasonable upper limit of potential hazard.

In practice, after systematic identification and evaluation of foreseeable types of accidents in a given facility, a nuclear accident is then postulated which would result in a potential hazard that would not be exceeded by any other accident considered credible during the lifetime of the facility. Such an accident has come to be known as the "maximum credible accident".

For pressurized and boiling water reactors, for example, the "maximum credible accident" has frequently been postulated as the complete loss of coolant upon complete rupture of a major pipe, with consequent expansion of the coolant as flashing steam, meltdown of the fuel and partial release of the fission product inventory to the atmosphere of the reactor building. There may be other combinations of events which could also release significant

amounts of fission products to the environment, but in every case, for the events described above to remain the maximum credible accident the probability of their occurrence should be exceedingly small, and their consequences should be less than those of the maximum credible accident. In the analysis of any particular site-reactor combination, a realistic appraisal of the consequences of all significant and credible fission release possibilities is usually made to provide an estimate in each case of what actually constitutes the "maximum credible" accident. This estimated or postulated accident can then be evaluated to determine whether or not the criteria set out in 10 CFR 100 are met. As a further important benefit, such systematic analyses of potential accidents often lead to discovery of ways in which safeguards against particular accidents can be provided.

Since a number of analyses have indicated that the pipe rupture-meltdown sequence in certain types of water cooled reactors would result in the release of fission products not likely to be exceeded by any other "credible" accident, this accident was designated the "maximum credible accident" (MCA) for these reactors. The remainder of this discussion will refer chiefly to this type of reactor and this type of accident. Corresponding maximum credible accidents can by similar analyses be postulated for gas-cooled, liquid metal cooled, and other types of reactors.

Power and test reactors presently being operated or constructed near inhabited areas, pursuant to licenses issued by the Commission, are enclosed within external containment vessels of some type. This outer barrier to fission product release to the atmosphere has within its enclosure all or a substantial part of the primary plant coolant piping systems representing an inner barrier. Cladding on the fuel provides an additional barrier that acts as a retaining "can" for the fissionable material and the fission products formed. Thus, gross release of fission products to the atmosphere would only occur after the breaching of the two inner barriers, the fuel cladding and the primary system, and then the external barrier, the containment building.

A gross release of fission products into the reactor building might be initiated by: (1) a nuclear power excursion which would cause pressures in the primary cooling system sufficient to rupture the coolant piping or some part of the system; or (2) a failure of the piping or other parts of the system due to some defect in the materials. In either case, loss of the coolant would set the stage for possible fuel meltdown from the heat of fission product decay.

The rupture of the coolant system from high internal pressures due to uncontrolled internal heat generation would only occur after such failures as the following:

1) reactivity control mechanisms fail to function;
2) high-pressure relief systems fail to perform;
3) pressures exceed rupture limits of the piping material.

These prior failures need not occur for the case of a spontaneous pipe rupture. However, for such a case, the assumption of a complete shear of a pipe represents an extremely unlikely event. Nevertheless, assuming that such a break occurs and coolant is lost, fuel melting would require that:

1) decay heat is sufficient to increase fuel element temperature to the melting point, and
2) safeguard systems usually provided to flood or spray the core with water are either inoperative or insufficient to keep fuel elements from melting.

From such considerations, and from detailed analysis of the inherent self-stabilizing characteristics and engineered "accident prevention" safeguards, assurance is obtained that the likelihood of a major reactor accident is extremely small. Yet such a possibility for a serious accident cannot be completely discounted and the consequences, therefore, must be considered.

If a major release of fission products to the environment should occur, the potential exposure doses to persons off-site are extremely difficult to determine with exactness because of the complex and interwoven technical

parameters involved. The amount of each kind of radioactive material present in a reactor system can be estimated fairly closely, as a function of the power level history, but the quantity of this material that would be released as a result of an accident is unpredictable. Quantities in the order of 10 per cent of the gross activity have been assumed in the past. Experimental data would indicate these values to be conservative for accidents of the type usually visualized. The exact release can vary so much with the reactor system and with the detailed nature of an accident that the degree of conservatism in the assumptions made in any given case, is not known. Further, there is a multiplicity of possible combinations of the physical and chemical form of the radioactive materials released into the containment vessel and of the ways that atmospheric conditions might cause these radioactive materials to be transported to regions beyond the site boundary.

In accidents of the "maximum credible" type, it is usually assumed that the radioactive materials, along with erosion and corrosion products, would be dispersed in the coolant through melting or rupture of fuel elements, and then find passage to the outer containment barrier through breaches in the coolant system. On breaching, the expansion to a larger volume and a lower pressure in the containment vessel would result in steam, in addition to the gaseous fission products, and production of vapors as well as liquid and solid aerosols of a wide range of sizes. Some ejected materials may conceivably burn on contact with air, and thus increase the volatiles and fractions of fine particles. At the same time, a certain amount of the airborne fission products would be removed by such phenomena as adsorption, deposition, plate-out and steam condensation within the reactor building or containment structure. The removal process would be complicated by conversion of normally gaseous fission products into solids by decay, and condensation of volatiles. Removal by adsorption and settling processes would be affected by turbulence. Superimposed upon these factors is the radioactive decay resulting in reduction of source strength with time by

conversion to more stable isotopes. All of these factors make it difficult to determine with any exactness the radioactive content of the air which might leak out of the containment vessel.

The objective of estimating the radioactive inventory within the outer containment barrier is to attain a starting point for calculating the potential radiological hazard in the surrounding environs. For people in the proximity of the reactor building, the confined radioactive inventory represents a decaying source of direct gamma radiation which is attenuated by such factors as the structural shielding, distance, and shielding by the topography. For those at more distant points, the transport by air of the radioactive materials which might leak from the containment vessel is the major radiological consideration. For air transport, factors such as the physical nature of the material leaking from the containment vessel, release height, particle deposition with distance, wind direction, speed and variability, and air temperature gradients become important in determining the extent of these potential hazards. The meteorological factors will be a function of the region in which the reactor is located as well as the time of the day and season. Finally, when estimates have been made of the potential concentration of radioactivity likely to result at any distant point from the "maximum credible accident", there still remains a difficult problem of translating atmospheric concentrations into whole body or thyroid exposure doses to people at these points. For internal doses, the controlling ones, there are assumptions to be made about rates of breathing, percentage retention in the body, and cumulative doses to internal organs resulting from retained materials. As the last exercise, there is the problem of establishing some acceptable exposure dose criteria, within the context of this procedural operation, for a comparative measure of the acceptability or unacceptability of the estimated exposures resulting from the hypothetical accident. It is from a study of these complex interwoven technical parameters that the values for the exclusion area, low population zone and population center distance must be determined.

V. ANALYTICAL METHOD

In the procedural method described herein for calculating reactor distances for power and test reactors, the highly complex phenomena involving parameters which may vary over wide ranges of values have been made manageable by simplifying assumptions, specifying that certain secondary factors are to be ignored, and fixing the values of certain key parameters. In utilizing this method, it is recognized that:

1) there is a substantial degree of judgment involved in establishing the basic assumptions and assigning definitive values to variable parameters;
2) the results obtained are approximations, sometimes relatively poor ones, to the result which would be obtained if the effects of the full play of all the variables and influencing factors could be recognized and fixed with certainty--an impossibility in the present state of the art;
3) the net effect of the assumptions and approximations is believed to give more conservative results (greater distances) than would be the case if more accurate calculations could be made.

While this approach represents a considerable simplification in the handling of the many complex phenomena involved, it represents the same very conservative approach to site selection that has characterized such evaluations in the past.

A. Fundamental Assumptions

The fundamental assumptions upon which the distances are calculated with estimates of the degree of conservatism represented in each case are as follows.

1. Experts agree and experience to date, though limited, confirms that there is only an exceedingly small probability of a serious accident in reactors approved or likely to be approved for construction.[2] The probability is still lower for an accident in which significant amounts of fission products are released into the confined primary coolant system and a great deal lower for accidents which would release significant quantities of radioactivity from the primary system into the reactor building.
2. It is assumed that the reactor is a pressurized water type for which the maximum credible accident will release into the reactor building 100 percent of the noble gases, 50 percent of the halogens and 1 percent of the solids in the fission product inventory. Such a release represents approximately 15 percent of the gross fission product activity.[11]
3. Fifty percent of the iodines in the containment vessel is assumed to remain available for release to the atmosphere. The remaining fifty percent of the iodines is assumed to absorb onto internal surfaces of the reactor building or adhere to internal components. Rather than the assumed reduction factor of two, it is estimated that removal of airborne iodines by various physical phenomena such as adsorption, adherence and settling could give an effect of 3-10 reduction in the final result. Credit has not been taken for the effects of washdown or filtering from

protective safeguards such as cooling sprays and internal air recirculating systems. Washdown features and filtering networks could provide additional reduction factors of 10-1000.

4. The release of available (airborne) radioactivity from the reactor building to the environment is assumed to occur at a constant leakage rate of 0.1 per cent per day. The leakage and pressure conditions are assumed to persist throughout the effective course of the accident, which for practical purposes, would be until the iodine activity becomes insignificant. The maximum pressure within the reactor building and the leakage rate would actually decrease with time as the steam condenses from contact with cooling surfaces. By assuming no change in leak rate as a function of pressure drop, it is estimated that the final off-site doses calculated may be too high by factors of 5-10.

5. Atmospheric dispersion of material from the reactor building is assumed to occur according to the well-known relationship developed by O. G. Sutton[4] involving meteorological factors of wind velocity, atmospheric stability, and diffusion parameters. Application of this treatment to reactor hazards analysis was discussed in WASH-740,[2] and AECU-3066.[5] Recently a simplified method of dispersion calculation has been proposed, by Pasquill[6] and Meade,[7] which reflects recent dispersion field trails, as well as current dispersion theories. In the hypothetical situation examined here the latter method gives the same numerical results as the Sutton method for distances out to about seven miles. Beyond this distance, the new method predicts somewhat greater concentrations.

6. The assumption is made that a shift in wind direction does not occur for the duration of the leakage of the fission products from the containment barrier. If leakage from the containment barrier is assumed to occur over a significant time period, (in the order of days) a reduction factor of 2-50 could result from

shifts in wind directions. Wind meandering from any one centerline direction might also result in a reduction factor of approximately 3.

7. Atmospheric dispersion is assumed to occur under inversion type weather conditions. For weather conditions which exist for 75 percent or so of the time at most sites, the atmospheric dispersion conditions could be more favorable, by factors of 5-1000.[8]

8. Cloud depletion as ground deposition (particulate fallout) is not assumed during cloud travel. Such deposition during cloud travel could reduce the low population zone distance by factors of 2-5.

9. In calculating the direct gamma dose, credit is not taken for shielding by the containment structure and applicable reactor shielding or topography. In some cases it is recognized that such shielding could reduce the direct gamma dose by a factor of 2-1000.

10. Decay of fission products is assumed while they are confined to the containment building but is not assumed during their transit to the receptor point. The decay enroute is not significant for the conditions of release considered here but would lower the calculated doses slightly if included.

11. In determining the whole body direct gamma dose, only the external gamma dose due to the fission products contained in the reactor building was considered significant for the assumed conditions. The whole body direct gamma dose due to the cloud passage for the assumed conditions would contribute only on the order of 1 to 10 percent of the total whole body direct gamma dose at the exclusion and low population zone distances.[5]

Thus, even if the postulated maximum credible accident should occur, the resulting exposure doses would probably be many times lower than those calculated by the indicated method.

On the other hand, there are potential, conceivable conditions which would result in larger fission product releases than those assumed to be released in the maximum credible accident, and the consequences could be more hazardous. Other potentially more hazardous factors than those represented by the example calculation include the following conditions.

1. Total radioactivity release to the containment vessel could theoretically be up to six times as large as those assumed. Release of long-lived fission products to the containment vessel could theoretically be up to 99 times as large as that assumed. Such releases would increase doses to the lung, bone, and total body.

2. For some sites, the atmospheric diffusion conditions for a small proportion of time could be worse than those assumed in these calculations. Such diffusion conditions could result in an increase in the inhalation doses.

3. If the external containment structure should be rendered completely ineffective at the outset of the accident, the consequences of the "maximum credible" accident would be increased many orders of magnitude. In such a case, the dose from the cloud and ground contamination could become significant in determining the external dose.

Although the analytical approach presented herein does not take into account the effects of the full play of all the variables and influencing factors, it is considered to be a reasonable procedure that results in distances roughly reflecting current siting practices for water-cooled reactors. The assumptions made can be used as a point of departure for consideration of particular site requirements resulting from evaluation of the characteristics of a particular reactor, its purpose, and the proposed plan of operation.

B. Inhalation Dose Calculations

The potential doses to the critical organs as a consequence of inhalation of a portion of the passing cloud were determined in the manner indicated below. For the specific conditions of this example, the thyroid dose is controlling and although the method is quite general, the results of the calculation are specific for the iodine release. If the type and conditions of release were different, the controlling dose could be that to the lung, bone, gut, or other critical organ.

The amount of radioactive material inhaled by a person standing a distance, d (meters), downwind for time, τ (seconds), on the centerline of a cloud of radioactive material being continuously emitted from a ground level source is given by equation (1).

$$A_\tau = \frac{R\, Q_\tau P_o}{\pi\, \bar{u}\, \sigma_y \sigma_z} \text{ curies} \quad \ldots\ldots\ldots\ldots (1)$$

Where:

A_τ is the amount of radioactive material inhaled from the cloud, (curies), during exposure for τ seconds.

R is the breathing rate, (meter^3.second^{-1}).

Q_τ is the amount of radioactive material in the total cloud, per megawatt reactor power, as it passes the receiver point d meters downwind, (curies.Mw^{-1}), during the time interval τ.

P_o is the rated reactor power level, (Megawatts).

$\bar{u}$ is the average wind speed, (meters.second^{-1}).

σ_y, σ_z are standard deviations of the cloud centerline concentrations in the vertical and horizontal directions, respectively.*

$$\sigma_y = \frac{1}{\sqrt{2}} C_y d^{1-n/2}, \quad \sigma_z = \frac{1}{\sqrt{2}} C_z d^{1-n/2}$$

C_y, C_z are the virtual diffusion coefficients in the vertical and horizontal planes, respectively, (meters$^{n/2}$).

*See Appendix A for further discussion.

n is the stability parameter, (dimensionless).

d is the distance downwind, (meters).

Equation (1) is the time integrated expression resulting from the O. G. Sutton model of atmospheric diffusion, neglecting depletion of the cloud either by radioactive decay or scavenging during transit, multiplied by the breathing rate.

Meteorological parameters were selected to be indicative of slow dispersion at a rate estimated to occur at a reasonable frequency. Such conditions could be expected to apply between 15 percent and 25 percent of the time in most areas of the United States. They would correspond closely to Pasquill's type F, stable dispersion regime, which has a frequency of occurrence (in England) in this range, according to Beattie.[9] parameter values used were:

$$\bar{u} = 1 \text{ meter.sec}^{-1}$$

$$C_y = 0.40 \text{ meters}^{\,n/2}$$

$$C_z = 0.07 \text{ meters}^{\,n/2}$$

$$n = 0.5$$

$$\sigma_y = \left[1/2\ C_y^{\ 2} d^{\ 2-n}\right]^{1/2} = \frac{0.40}{\sqrt{2}}\ d^{0.75}$$

$$\sigma_z = \left[1/2\ C_z^{\ 2}\ d^{2-n}\right]^{1/2} = \frac{0.07}{\sqrt{2}}\ d^{0.75}$$

The "source term", Q_τ, in equation (1) will be dependent upon the amount of radioactive material which has accumulated in the reactor during operation. A simplified formula for the reactor inventory, q_t, for a specific isotope is given by equation (2).

$$q_t = \frac{P_o \times 3.2 \times 10^{16} \times \gamma_i\ (1-e^{-\lambda_r T_o})}{3.7 \times 10^{10}}$$

$$q_t = 0.865 \times 10^6\ P_o \gamma_i (1-e^{-\lambda_r T_o}) \text{(curies)} \quad \ldots\ldots\ldots\ldots (2)$$

Where:

q_t is the amount of isotope type i contained by the reactor at shutdown, (curies).

P_o is the rated reactor power level, (Megawatts).

3.2×10^{16} is the number of fissions.second^{-1}.megawatt^{-1}.

γ_i is the fission yield, (atoms$_i$.fission^{-1}).

λ_r is the radiological decay constant for the isotope, equal to $\frac{0.693}{T_r}$, (seconds^{-1}).

T_r is the radiological half-life for the isotope, (seconds^{-1}).

T_o is the time interval during which the reactor has operated, (seconds).

3.7×10^{10} is the number of disintegrations·sec^{-1}·curie^{-1}.

When the reactor has been operated for a time interval such that $T_o \gg T_r$, the term $e^{-\lambda_r T_o}$ becomes insignificant and the resulting formula for the "saturation" inventory, q_s, is given by equation (3).

$$q_s = 0.865 \times 10^6 \, P_o \, \gamma_i \text{ (curies)} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

Note that this is only true when $T_o \gg T_r$, and therefore does not hold for very long-lived isotopes. The approximation is adequate for iodines but inadequate for Sr-90. Saturation values for the several iodine isotopes per Megawatt are given in Table I.

Table I. Saturation Inventory of Iodine Isotopes

Isotope	λ_r(10) (sec^{-1})	Yield(11) (%)	$[q_s/P]$ (curies/Mw)
131	9.96×10^{-7}	2.9	2.51×10^4
132	8.26×10^{-5}	4.4	3.81×10^4
133	9.20×10^{-6}	6.5	5.63×10^4
134	2.20×10^{-4}	7.6	6.58×10^4
135	2.86×10^{-5}	5.9	5.10×10^4

The amount of a specific isotope, Q_τ, per Megawatt power, which is released from the reactor building to the atmosphere during the time interval, τ, assuming constant leak rate and radioactive decay only until release, is given by equation (4).

$$Q_\tau = F_p F_b \left[\frac{q_t}{P}\right] \int_0^\tau \lambda_1 e^{-(\lambda_1+\lambda_r)t}\, dt \left(\text{curies}\cdot\text{Mw}^{-1}\right)$$

$$Q_\tau = F_p F_b \left[\frac{q_t}{P}\right] \frac{\lambda_1}{\lambda_1+\lambda_r} \left[1-e^{-(\lambda_1+\lambda_r)\tau}\right] \left(\text{curies}\cdot\text{Mw}^{-1}\right) \quad . \; . \; . (4)$$

Where:

P is unit reactor power (one megawatt).

F_p is the fraction of the isotope released from the primary containment system to the building.

F_b is the fraction of the isotope which remains airborne and available to be released from the building to the atmosphere.

q_t is given by equation (2).

λ_1 is the rate of leakage from the reactor building to the atmosphere, (seconds^{-1}).

λ_r is the radiological decay constant, (seconds^{-1}).

τ is the time interval since the start of release during which exposure is assumed to take place, (seconds).

Consideration is given to a reactor which has been operated for a sufficiently long time period that saturation values, q_s, for the iodine isotopes may be assumed in equation (4). Furthermore, because the radii for establishing the limit of the exclusion area and the low population zone are determined by the doses resulting from two hour and infinite exposure, respectively, τ may be assumed to be 7200 seconds and infinity.

Two forms of the equation are therefore necessary for the evaluation.

For exclusion distance:

$$Q_\tau = F_p \times F_b \times \left[\frac{q_s}{P}\right] \frac{\lambda_1}{\lambda_1+\lambda_r} \left[1-e^{-(\lambda_1+\lambda_r)7200}\right] \left(\text{curies.Mw}^{-1}\right) \; . \; (5)$$

For low population zone distance:

$$Q_\tau = F_p \times F_b \times \left[\frac{q_s}{P}\right] \frac{\lambda_1}{\lambda_1+\lambda_r} \left(\text{curies.Mw}^{-1}\right) . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . (6)$$

The model assumed in developing equation (4) is somewhat oversimplified because it assumes that the fission product is formed directly by fission

process rather than through decay. Actually, most of the iodine isotopes are formed from the decay of tellurium or, as is generally the case, from the decay of antimony and tellurium. The actual formation is of the type $A \rightarrow B \rightarrow C$ rather than formation of C directly. When the half lives of the precursors are short compared to that of the iodine considered, the effect of the precursors may be ignored and the model is adequate, but when the half life of one or more of the precursors is long compared to the iodine isotope considered, that half life will be the controlling factor in the decay chain after shutdown and the source determination must consider this factor. In the case of I^{132}, the complete decay chain and half lives involved are:

$$Sb^{132}(1.9 \text{ minute}) \rightarrow Te^{132}(77 \text{ hour}) \rightarrow I^{132}(2.4 \text{ hour}).$$

If the reactor has been in operation sufficiently long to establish radiological equilibrium, the activity of the Te^{132} and the I^{132} are equal. Since the activity of I^{132} after reactor shutdown will be determined by the decay rate of the Te^{132}, equations (4), (5), and (6) may be used to determine the I^{132} source terms if the decay constant of the Te^{132} is used in place of the decay constant of I^{132}. A more exact determination of the source term for I^{131} would also consider that amount which would be produced from the $Sb^{131} \rightarrow Te^{131}$ chain subsequent to shutdown. The amount is relatively insignificant and the calculation would needlessly complicate the example.

Values for Q_τ for the exclusion and low population distance can be readily determined because values for all the factors have been given or calculated. Table II contains a listing for each of the iodine isotopes and the two time periods involved using the values:

$$F_p = 0.5,$$

$$F_b = 0.5,$$

$$\lambda_1 = 0.1\% \text{ day}^{-1}.$$

$$= 0.001 \text{ day}^{-1},$$

$$\lambda_1 = 1.16 \times 10^{-8} \text{ sec}^{-1}.$$

The breathing rate, R, in equation (1) is also a variable. The "standard man"[10] is considered to breathe 20 meters^3.day^{-1}; half during the active 8 hours and the remaining half during his relatively inactive or resting

Table II Amount of Iodine Released in Time τ

Iodine Isotope	Q_τ (curies.Mw^{-1}) τ = 2 hours (Exclusion area)	$\tau = \infty$ (Low population zone)
131	5.20×10^{-1}	7.20×10^{1}
132*	5.95×10^{-1}	4.42×10^{1}
133	1.15×10^{0}	1.75×10^{1}
134	6.80×10^{-1}	8.70×10^{-1}
135	9.65×10^{-1}	5.15×10^{0}

*includes Te^{132} contribution following shutdown for $\tau = \infty$. These values of Q_τ will be used directly in evaluating equation (1).

hours. Since concern for personnel in the exclusion zone is based on two hours of inhalation, consider the breathing rate to be characteristic of the active portion of the normal work day,

$$R = 10 \text{ meters}^3/8 \text{ hours} = 3.47 \times 10^{-4} (m^3.sec^{-1}).$$

For the low population zone, the average breathing rate is assumed,

$$R = 20 \text{ meters}^3/24 \text{ hrs} = 2.32 \times 10^{-4} (m^3.sec^{-1}).$$

Since values have been given or calculated for all factors in equation (1), the amount inhaled, A_τ, can be determined for various distances, d, downwind. When the amount inhaled of a specific isotope is determined, the dose to the critical organ which will be delivered by this amount can be calculated. The dose rate, D', to the critical organ such as the thyroid at any time subsequent to the inhalation is given by equation (7).

$$D' \text{ (rads.sec}^{-1}) = A_\gamma(\text{curies}) \times 3.7 \times 10^{10}(\text{dis.sec}^{-1}.\text{curie}^{-1})$$

$$\times f_a \times \bar{E}(\text{Mev.dis}^{-1})\ 1.6 \times 10^{-6}(\text{ergs}\cdot\text{Mev}^{-1})e^{-\lambda_e t}$$

$$\div m(\text{grams})\ 100\ (\text{ergs}\cdot\text{gm}^{-1}.\text{rad}^{-1})$$

$$= \frac{5.92 \times 10^2\ A_\gamma\ f_a \bar{E} e^{-\lambda_e t}}{m}\ (\text{rads.sec}^{-1}) \ldots\ldots (7)$$

Where:

A_γ is given by equation (1).

f_a is the fraction of the amount inhaled which is deposited in the critical organ.

$\bar{E}$ is the effective energy absorbed by the critical organ per disintegration, (Mev).

$\lambda_e = \lambda_r + \lambda_b = \frac{0.693}{T_e}$, (sec^{-1}).

λ_b is the biological elimination rate for the isotope, (sec^{-1}).

T_e is the effective half life for the isotope in the body, (sec).

m is the mass of the critical organ, (grams).

And the dose to the critical organ, delivered in time, T is given by equation (8).

$$D_T = \int_0^T D'\ dt$$

$$= \frac{5.92 \times 10^2\ A_\gamma\ f_a \bar{E} \left[1 - e^{-\lambda_e T}\right]}{m\ \lambda_e}\ (\text{rads})$$

$$D_T = \frac{8.54 \times 10^2}{m}\ A_\gamma\ f_a\ \bar{E}\ T_e \left[1 - e^{-\frac{0.693\ T}{T_e}}\right] (\text{rads}) \ldots\ldots\ldots (8)$$

When the time, T, (over which the dose is determined) is much greater than the effective half life of the isotopes, the quantity, $e^{-\frac{0.693\ T}{T_e}}$, becomes insignificant and the dose to the critical organ is given by equation (9).

$$D_\infty = 8.54 \times 10^2\ \frac{A_\gamma\ f_a\ \bar{E}\ T_e}{m}\ (\text{rads}) \ldots\ldots\ldots\ldots\ldots (9)$$

Using equation (9), $\frac{D_\infty}{A_\gamma}$ has been evaluated for the iodine isotopes and the values are presented in Table III.

Table III Dose to Critical Organ Per Iodine Curie Inhaled

Iodine Isotope	T_e(sec)	D_∞/A_η(rads.curie^{-1})
131	6.57×10^5	1.48×10^6
132	8.39×10^3	5.35×10^4
133	7.52×10^4	4.0×10^5
134	3.11×10^3	2.5×10^4
135	2.42×10^4	1.24×10^5

C. External Gamma Dose Calculations

The external gamma radiation dose at the exclusion and low population zone distances due to fission products contained in the reactor building were determined in the following manner. The source of radiation was considered to be those fission products released from the primary system to the containment building--krypton, xenon, iodines, and a mixture of the remaining "solid" mixed fission products.

From a point source of radiation-given off by a specific gamma emitting isotope, the dose rate at a distance, d (meters), away in air is given by equation (10).

$$\text{Dose rate, } D'(\text{rads.sec}^{-1}) = F_p x P_o(\text{Mw}) \times \left[\frac{q_s}{P}\right](\text{curies.Mw}^{-1})$$
$$\times 3.7 \times 10^{10}\ (\text{dis.sec}^{-1}\text{.curie}^{-1}) \times E_\gamma(\text{Mev.dis}^{-1})$$
$$\times 1.6 \times 10^{-6}(\text{ergs.Mev}^{-1}) \times \mu_a(\text{meter}^{-1})\ B\ e^{-\mu d_e - \lambda_r t}$$
$$\div 1.293 \times 10^3(\text{grams.meter}^{-3}_{air}) \times 10^2\ (\text{ergs.gram}^{-1}\text{.rad}^{-1})$$
$$\times 4\pi d^2\ (\text{meter}^2) \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

In equation (10), the dose buildup factor, B, is expressed by equation (10a).[12]

$$B = 1 + k\mu d \quad \ldots\ldots\ldots\ldots\ldots\ldots (10a)$$

After combining terms, equation (10) can be expressed as

$$D' = 0.985\ S_o x\ F_p x\ P_o\ \mu_a\ d^{-2}\ [1 + k\mu d]\ e^{-\mu d} \times e^{-\lambda_r t}\ (\text{rads.sec}^{-1}) \ldots (11)$$
$$D' = C\ e^{-\lambda_r t}$$

Where:

S_o is the initial gamma source strength for the specific isotope at shutdown, $(Mev.sec^{-1}.Mw^{-1})$.

F_p is the fraction of the isotope released to the reactor building.

P_o is the rated reactor power level, (Mw).

μ_a is the energy absorption coefficient, $(meter^{-1})$.

k is the linear absorption constant, $(\frac{\mu-\mu_a}{\mu_a})$.

μ is the linear absorption coefficient, $(meter^{-1})$.

d is the distance to receptor, (meters).

λ_r is the radiological decay constant, (sec^{-1}).

t is the time after shutdown, (sec).

C is a constant defined by the equation.

The term, S_o, combines three terms in equation (11):

$$S_o = \left[\frac{q_s}{P}\right] x\ 3.7 \times 10^{10} \times E_\gamma\ (Mev.sec^{-1}.\ Mw^{-1}).$$

Where:

$\left[\frac{q_s}{P}\right]$ is the saturation inventory, $(curies.Mw^{-1})$.

E_γ is the total gamma energy per disintegration, $(Mev.dis^{-1})$.

3.7×10^{10} is the number of disintegrations.sec^{-1}.$curie^{-1}$.

Table IV contains values of S_o, F_p, S_R, T_r, μ, μ_a, k, and E_{avg} for the isotopes, the "solid" mixed fission products and the gross fission products assumed to be released to the reactor building. The values of μ, μ_a, and k are energy dependent. Hence, "average" energies, E_{avg}, were selected after reviewing the weighted spectrum for each isotope and mixtures.[11] The term S_R is the product of S_o and F_p for the assumed release conditions.

Integrating the direct gamma dose rate, D', over a specific exposure time yields the direct gamma dose.

$$D_\gamma = \int_o^\tau D'_r\ dt(rads)$$

$$= C\int_o^\tau e^{-\lambda_r t}\ dt$$

$$D_\gamma = \frac{C}{\lambda_r}\left[1-e^{-\lambda_r \tau}\right](rads). \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ (12)$$

Table IV. External Gamma I Data

Gamma Source	Half Life[11] T_r	"Average" Energy E(Mev)	Initial[11] Source Strength S_o(Mev/sec-Mw)	Release Fraction F_p	Released Source Strength S_R(Mev/sec-Mw)	Linear[13] Absorption Coefficient μ (meter^{-1})	Linear[13] Absorption Constant k	Energy[13] Absorption Coefficient μ_a(meter^{-1})
I. Iodine								
131	8.05 days	0.4	3.63×10^{14}	0.5	1.81×10^{14}	1.23×10^{-2}	2.22	3.8×10^{-3}
132	2.4 hrs.	0.8	2.82×10^{15}	0.5	1.41×10^{15}	9.1×10^{-3}	1.45	3.7×10^{-3}
133	20.8 hrs.	0.55	1.15×10^{15}	0.5	0.57×10^{15}	1.08×10^{-2}	1.85	3.9×10^{-3}
134	52.5 mins.	1.3	3.10×10^{15}	0.5	1.55×10^{15}	7.2×10^{-3}	1.10	3.4×10^{-3}
135	6.68 hrs	1.5	2.90×10^{15}	0.5	1.45×10^{15}	6.7×10^{-3}	1.02	3.3×10^{-3}
Total Iodine	- -	-	1.03×10^{16}	0.5	5.16×10^{15}	- -	-	- -
II. Xenon								
131m	12.0 days	0.163	1.50×10^{12}	1.0	1.50×10^{12}	1.7×10^{-2}	4.0	3.3×10^{-3}
133m	2.3 days	0.233	1.16×10^{13}	1.0	1.16×10^{13}	1.5×10^{-2}	3.2	3.6×10^{-3}
133	5.27 days	0.081	1.67×10^{14}	1.0	1.67×10^{14}	2.2×10^{-2}	7.0	2.7×10^{-3}
135m	15.6 mins.	0.520	2.94×10^{14}	1.0	2.94×10^{14}	1.1×10^{-2}	1.9	3.9×10^{-3}
135	9.13 hrs.	0.250	4.65×10^{14}	1.0	4.65×10^{14}	1.5×10^{-2}	3.0	3.6×10^{-3}
Total Xenon	- -	- -	9.40×10^{14}	1.0	9.40×10^{14}	- -	-	- -
III. Krypton								
83m	114 mins.	0.02	6.35×10^{12}	1.0	6.35×10^{12}	(dose considered negligible)		
85m	4.36 hrs.	0.20	8.65×10^{13}	1.0	8.65×10^{13}	1.6×10^{-2}	3.5	3.5×10^{-3}
87	78 mins.	2.00	4.84×10^{14}	1.0	4.84×10^{14}	5.8×10^{-3}	0.9	3.0×10^{-3}
88	2.77 hrs.	2.00	2.44×10^{15}	1.0	2.44×10^{15}	5.8×10^{-3}	0.9	3.0×10^{-3}
Total Krypton	- -	- -	3.02×10^{15}	1.0	3.02×10^{15}	- -	-	- -
IV. Mixed Fission Products "Solids"	(Varied)*	0.7	3.72×10^{16}	0.01	3.72×10^{14}	1.0×10^{-2}	1.6	3.8×10^{-3}
V. Gross Fission Products Total of I,II,III,IV	- -	- -	5.15×10^{16}	- -	9.49×10^{15}	- -	-	- -

*"Solid" Fission Products have an effective half-life of 2.72 hours during the first 2 hours of decay after long-time operation and have an effective decay rate which follows $t^{-0.21}$ after the first 2 hours.[11]

Considering the exclusion distance, the expose time is 2 hours and equation (12) becomes:

$$D_\gamma = \frac{C}{\lambda_r}\left[1-e^{-7200\lambda_r}\right] \text{(rads)} \quad \ldots\ldots\ldots (13)$$

and for the low population zone, the exposure time is 30 days, which is several half-lives for the isotopes of the noble gases and iodine. Equation (13) for these isotopes, may be written as:

$$D_\gamma = \frac{C}{\lambda_r} \text{(rads)} \quad \ldots\ldots\ldots\ldots\ldots (14)$$

In the case of the "solid" mixed fission products the dose for the first two hours was considered to be decaying exponentially with a half-life of 2.72 hours ($\lambda_r = 7.05 \times 10^{-5}$ sec^{-1}) and subsequently as $t^{-0.21}$ based on interpretations of data from Blomeke and Todd.[11]

For the first two hours, the dose was:

$$D_\gamma = \frac{C}{\lambda_r}\left[1-e^{-\lambda_r \tau_1}\right] \text{(rads)} \quad \ldots\ldots\ldots\ldots\ldots (15)$$

and for the 30 days, the dose was:

$$D_\gamma = \frac{C}{\lambda_r}\left[1-e^{-\lambda_r \tau_1}\right] + C\, e^{-\lambda_r \tau_1} \int_{\tau_1}^{\tau_2} t^{-0.21}\, dt$$

$$D_\gamma = \frac{C}{\lambda_r}\left[1-e^{-\lambda_r \tau_1}\right] + \frac{C\, e^{-\lambda_r \tau_1}}{0.79}\left[\tau_2^{\,0.79} - \tau_1^{\,0.79}\right] \text{(rads)} \quad \ldots\ldots (16)$$

and since $\tau_2 \gg \tau_1$, equation (16) can be written:

$$D_\gamma = \frac{C}{\lambda_r}\left[1-e^{-\lambda_r \tau_1}\right] + \frac{C\, e^{-\lambda_r \tau_1}}{0.79}\, \tau_2^{\,0.79} \text{(rads)} \quad \ldots\ldots (17)$$

The total direct gamma dose is the sum of the doses from each of the source terms as determined by equations (13) and (15) for the exclusion area and equations (14) and (17) for the low population zone.

D. Results

The results of the calculations performed for the inhalation (iodine) dose and the external gamma dose for the exclusion area (τ= 2 hours) and the low population zone ($\tau=\infty$ and 30 days, respectively) are presented in

Table V. External Gamma Dos sults

Direct Gamma Dose (rads/Mw)

Gamma Source	Exclusion Radius (τ = 2 hours) 100 m	300 m	600 m	1000 m	Low Population zone (τ = 30 days) 100 m	300 m	600 m	1000 m
I. Iodine								
131	5.3×10^{-1}	1.24×10^{-2}	1.49×10^{-4}	-------	7.4×10^{1}	1.72×10^{0}	2.06×10^{-2}	9.15×10^{-5}
132	2.66×10^{0}	1.02×10^{-1}	3.01×10^{-3}	4.9×10^{-5}	5.95×10^{0}	2.26×10^{-1}	6.75×10^{-3}	1.08×10^{-4}
133	1.62×10^{0}	4.82×10^{-2}	9.25×10^{-4}	-------	2.44×10^{1}	7.25×10^{-1}	1.39×10^{-3}	1.05×10^{-4}
134	1.61×10^{0}	8.05×10^{-2}	3.85×10^{-3}	1.24×10^{-4}	2.02×10^{0}	1.02×10^{-1}	4.84×10^{-3}	1.55×10^{-4}
135	2.62×10^{0}	1.39×10^{-1}	7.75×10^{-3}	2.86×10^{-4}	1.40×10^{1}	7.40×10^{-1}	4.11×10^{-2}	1.52×10^{-3}
Total Iodine	9.04×10^{0}	3.82×10^{-1}	1.57×10^{-2}	4.79×10^{-4}	1.2×10^{2}	3.51×10^{0}	7.47×10^{-2}	1.98×10^{-3}
II. Xenon								
131m	5.16×10^{-3}	5.16×10^{-5}	-------	-------	1.09×10^{0}	1.09×10^{-2}	3.24×10^{-4}	-------
133m	3.86×10^{-2}	5.71×10^{-4}	3.0×10^{-6}	-------	1.54×10^{0}	2.27×10^{-2}	1.18×10^{-4}	-------
133	6.73×10^{-1}	2.73×10^{-3}	1.83×10^{-6}	-------	6.1×10^{1}	2.5×10^{-2}	1.68×10^{-4}	-------
135m	1.55×10^{-1}	4.62×10^{-3}	8.25×10^{-5}	-------	1.55×10^{-1}	4.6×10^{-3}	8.25×10^{-5}	-------
135	1.41×10^{0}	2.02×10^{-2}	1.06×10^{-4}	-------	9.7×10^{0}	1.4×10^{-1}	7.3×10^{-4}	-------
Total Xenon	2.28×10^{0}	2.82×10^{-2}	1.93×10^{-4}	-------	7.35×10^{1}	2.03×10^{-1}	1.42×10^{-3}	-------
III. Krypton								
83m	(negligible contribution)				(negligible contribution)			
85m	2.40×10^{-1}	2.98×10^{-3}	1.14×10^{-5}	-------	8.8×10^{-1}	1.09×10^{-2}	4.2×10^{-5}	-------
87	5.4×10^{-1}	3.2×10^{-2}	2.27×10^{-3}	1.19×10^{-4}	8.25×10^{-1}	4.86×10^{-2}	3.44×10^{-3}	1.81×10^{-4}
88	3.52×10^{0}	2.1×10^{-1}	1.48×10^{-2}	7.75×10^{-4}	1.03×10^{1}	6.15×10^{-1}	4.32×10^{-2}	2.28×10^{-3}
Total Krypton	4.3×10^{0}	2.45×10^{-1}	1.71×10^{-2}	8.94×10^{-4}	1.2×10^{1}	6.75×10^{-1}	4.67×10^{-2}	2.46×10^{-3}
IV. Fission Products "Solids"	7.55×10^{-1}	2.52×10^{-2}	5.8×10^{-4}	6.0×10^{-6}	1.21×10^{1}	4.05×10^{-1}	9.25×10^{-3}	9.0×10^{-5}
V. Released Fission Products Total Dose	1.64×10^{1}	6.8×10^{-1}	3.29×10^{-2}	1.38×10^{-3}	2.18×10^{2}	4.79×10^{0}	1.32×10^{-1}	4.53×10^{-3}

Table VI. Inhalation Dose Results

Inhalation Source	Inhalation Iodine Dose (rads/MW)							
	Exclusion Radius (τ = 2 hours)				Low Population Zone ($\tau = \infty$)			
Iodine	10^2m	10^3m	10^4m	10^5m	10^2m	10^3m	10^4m	10^5m
131	6.02×10^{0}	1.94×10^{-1}	6.02×10^{-3}	1.94×10^{-4}	5.6×10^{2}	1.79×10^{1}	5.6×10^{-1}	1.79×10^{-2}
132	3.36×10^{-1}	1.08×10^{-2}	3.36×10^{-4}	1.08×10^{-5}	1.24×10^{1}	3.98×10^{-1}	1.24×10^{-2}	3.98×10^{-4}
133	3.61×10^{0}	1.16×10^{-1}	3.61×10^{-3}	1.16×10^{-4}	3.66×10^{1}	1.18×10^{0}	3.66×10^{-2}	1.18×10^{-3}
134	1.33×10^{-1}	4.28×10^{-3}	1.33×10^{-4}	4.28×10^{-6}	1.14×10^{-1}	3.66×10^{-3}	1.14×10^{-4}	3.66×10^{-6}
135	9.4×10^{-1}	3.01×10^{-2}	9.4×10^{-4}	3.01×10^{-5}	3.35×10^{0}	1.07×10^{-1}	3.35×10^{-3}	1.07×10^{-4}
Total Iodine	1.10×10^{1}	3.55×10^{-1}	1.10×10^{-2}	3.55×10^{-4}	6.12×10^{2}	1.96×10^{1}	6.12×10^{-1}	1.96×10^{-2}

Values Assumed for Results:

$F_b = 0.5$

$F_p = 0.5$

$\bar{u} = 1$ meter.sec^{-1}

$C_y = 0.40$ meters$^{n/2}$

$C_z = 0.07$ meters$^{n/2}$

$n = 0.5$

$\lambda_1 = 0.1$ percent.day^{-1}

Tables V and VI. Based upon these results, initial estimates of distances for reactors of various power levels have been developed and are listed in Table VII.

Table VII. Calculated Radii for Water Cooled Reactors of Various Power Levels

Power Level (Mw_t)	Exclusion area distance (miles)	Low population zone distance (miles)	Population center distance (miles)
1500	0.88	13.3	17.7
1200	0.77	11.5	15.3
1000	0.67	10.3	13.7
900	0.63	9.4	12.5
800	0.58	8.6	11.5
700	0.53	8.2	10.9
600	0.48	7.2	9.6
500	0.43	6.5	8.7
400	0.37	5.4	7.2
300	0.31	4.5	6.0
200	0.29	3.4	4.5
100	0.25	2.2	2.9
50	0.21	1.4	1.9
10	0.13	0.5	0.7

The estimated radii for power reactors are graphically represented in Figures 1 and 2. For the exclusion distance, doses from both direct gamma radiation from the reactor building and from iodine in the cloud escaping from the reactor building were calculated, and the distance established on the basis of the effect requiring the greater isolation. Figure 1 shows the thyroid and whole body doses for various power levels.

Under the conditions assumed, the doses resulting from the inhalation of the isotopes of iodine are controlling for the low population zone distance and population center distance. However, it is possible that such may not always be the case and this should be checked for each case under consideration. The low population zone distance results from

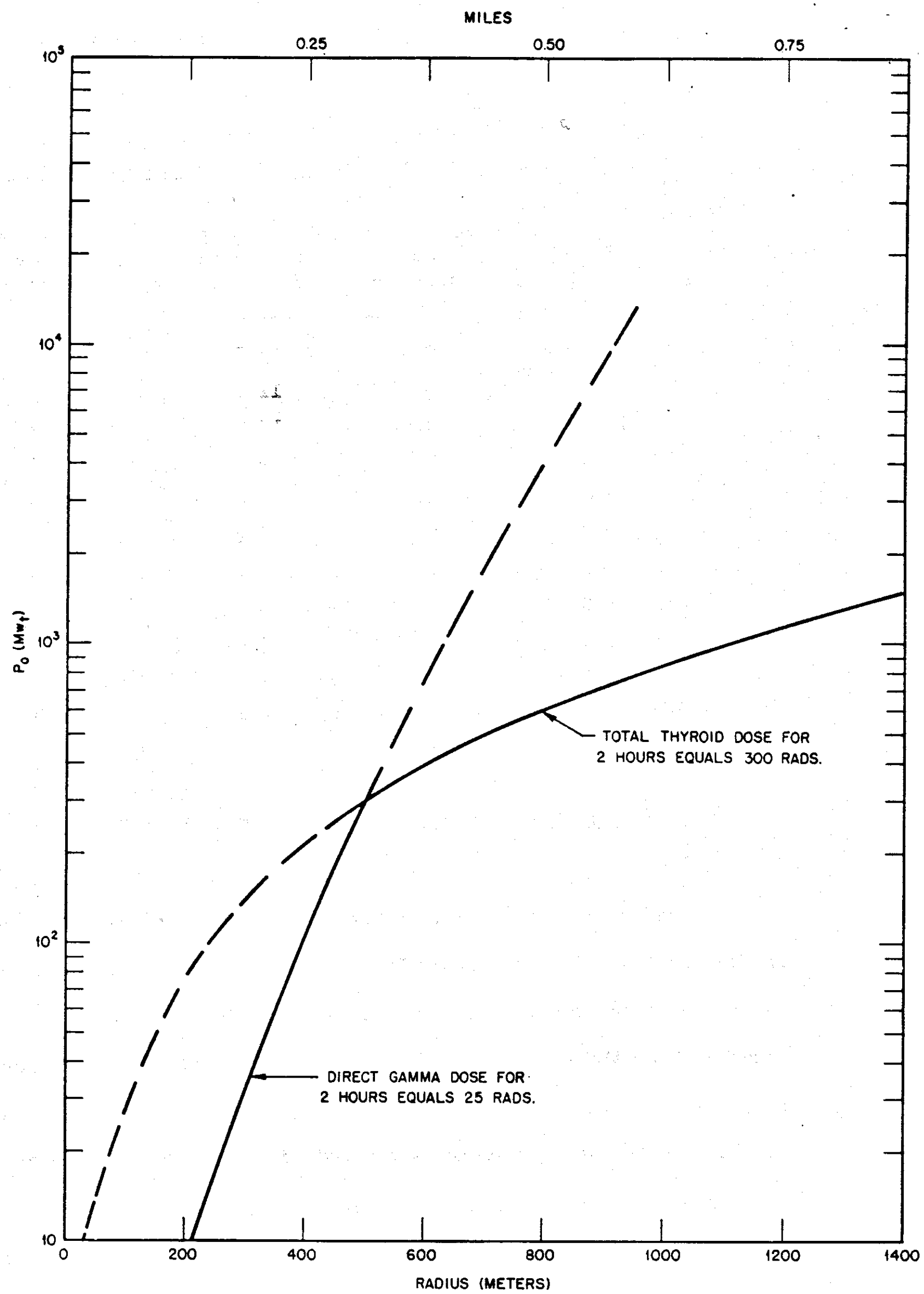


Figure 1. Exclusion Radius Determination.

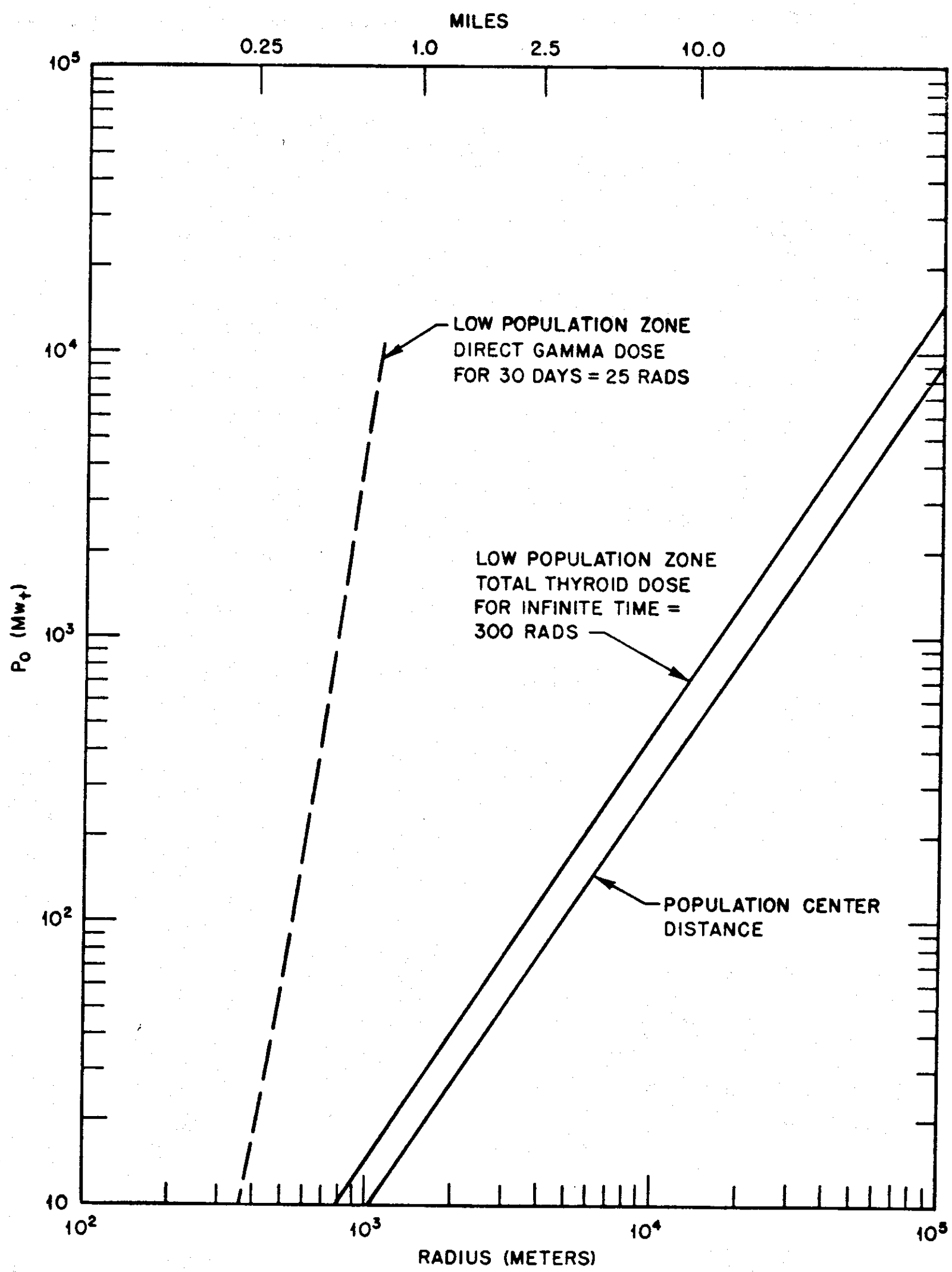


Figure 2. Population Radius Determination.

integrating the effects of iodine 131 through 135. The population center distance equals the low population zone distance increased by a factor of one-third. Figure 2 shows the relationship between the inhalation and direct dose for various power levels.

VI. COMPARISON OF ANALYTICAL METHOD TO EXISTING REACTOR SITES

As an indication of how the use of the above analytical method results in distances reflecting current siting practices, the method was

Table VIII. Calculated Distances for Selected Reactors

		Exclusion Area		Low Population Area	Population Center Distance	
ctor	Power Level (Mw_t)	Calculated Distance (miles)	Actual Distance (miles)	Calculated Distance (miles)	Calculated Distance (miles)	Actual Distance (miles)
Dresden	630	0.50	0.50	7.4	9.9	14.0
Con. Ed.	585	0.48	0.30	7.0	9.4	17.0
Yankee	485	0.42	0.50	6.3	8.4	21.0
*PRDC	300	0.31	0.75	4.5	6.1	7.5
PWR	270	0.31	0.40	4.1	5.6	7.5
Consumers	240	0.30	0.50	3.9	5.2	135.0
*Hallam	240	0.30	0.25	3.9	5.2	17.0
Pathfinder	203	0.29	0.50	3.4	4.6	3.5
PG&E	202	0.29	0.25	3.4	4.6	3.0
*Phila.Elec.	115	0.26	0.57	2.4	3.2	21.0
NASA	60	0.22	0.50	1.6	2.1	3.0
[illegible]	60	0.22	0.50	1.6	2.1	25.0
[illegible] River	58	0.22	0.23	1.5	2.0	20.0
VBWR	50	0.21	0.40	1.4	1.9	15.0
*Piqua	48	0.21	0.14	1.4	1.8	27.0

*NOTE: These reactors are not water moderated and are included in the table for illustrative purposes only. The distances for all reactors were based on the same assumption with respect to fission product release from the fuel and containment vessel and the subsequent dispersal events. There can be considerable differences between reactor types in the events that could result in a major accident and the releases that might be experienced. This must be examined on an individual basis for each reactor and the distances determined accordingly.

applied to a number of reactor projects that have been proposed or are currently authorized for construction. These results are given in Table VIII.

VII. APPENDIX

A. Relationship of the Sutton Diffusion Parameter and the Generalized Gaussian Parameter

The traditional form of the O. G. Sutton atmospheric diffusion equation describing the centerline concentration downwind of a continuous point source is generally written:

$$\frac{\chi}{Q'} = \frac{1}{\pi \, \bar{u} \, C_y \, C_z \, d^{2-n}}$$

This equation was based on an extension of diffusion theory, an assumed homogeneous isotropic source, and an assumed three dimensional Gaussian distribution model.

When the receptor and cloud centerline are coincident with the ground level, the concentration is assumed to be doubled as a consequence of "ground reflection":

$$\frac{\chi}{Q'} = \frac{2}{\pi \, \bar{u} \, C_y \, C_z \, d^{2-n}}$$

The diffusion coefficients, C_y and C_z are mathematical quantities which represent the diffusion capability of the atmosphere. However, Sutton and others found it necessary to determine values of C_y and C_z indirectly from data obtained through experimental field measurement. By expressing the diffusion coefficients in terms of standard deviations of the Gaussian distribution model which is assumed to describe the spacial relationship of cloud

concentration, the resulting equation may be written in the more useful form:

$$\frac{\chi}{Q'} = \frac{1}{\pi \ \bar{u} \ \sigma_y \ \sigma_z}$$

Where:

σ_y and σ_z are the standard deviations of the cloud concentration in the vertical and horizontal directions, respectively.

The factor of two which was introduced for "ground reflection" has been included in this equation. The equation in this form, with the Gaussian parameters, permit direct interpretation of experimental data obtained from field measurements.

The relationship between the generalized diffusion parameters [14] and the more familiar Sutton parameters [4] are expressed as:

$$\sigma_y = \frac{1}{\sqrt{2}} \ C_y \ d^{1-n/2}$$

$$\sigma_z = \frac{1}{\sqrt{2}} \ C_z \ d^{1-n/2}$$

In the generalized form, the parameters σ_y and σ_z are functions of distance and can be approximated directly from anemoneter records if appropriate averaging techniques are supplied [7].

B. Bibliography

The following reference documents contain information pertaining to data obtained from various reactor projects and from associated analytical programs. The following list constitutes a brief summary of the information available on certain factors pertinent to reactor siting.

1. McCullough, C. R., Safety Aspects of Nuclear Reactors, D. Van Nostrand Company, Inc., Princeton, New Jersey, 1957.

2. Rockwell, T., "Reactor Shielding Design Manual", TID-7004, March 1956.

3. Ritchie, P. H., "Dosimetry Aspects of Nuclear Accidents", Nuclear Safety, 2(1) pp 71-75, September 1960.

4. Culver, H. N., "Maximum Credible Accident Exposures at Reactor Site Boundaries", Nuclear Safety, 2(1) pp 83-96, September 1960.

5. Progress in Nuclear Safety - Series 4, "Technology, Engineering and Safety", Hurst, R., Lyon, R. N., and Nicholls, C. M. - Editors, Pergamon Press, New York, New York, 1960.

6. Brittan, R. O., "Reactor Containment", ANL-5948, May 1959.

C. List of Symbols and Definitions

Symbol	Represents	Dimensions
$A_{\tilde{c}}$	Amount of radioactive material inhaled by an individual during a specific time period.	curies
B	Build up factor.	-
C_y, C_z	Meteorological virtual diffusion coefficients in the vertical and horizontal planes, respectively.	$meters^{n/2}$
d	Distance from the source of radiation or release point.	meters
D'	Dose rate delivered by an exposure to radiation.	$rads \cdot sec^{-1}$
D_T, D_∞	Dose delivered during time interval "T" or infinite time.	rads
D_γ	Dose delivered by direct exposure to gamma radiation.	rads
$\bar{E}$	Effective energy absorbed by the critical organ per disintegration.	$Mev \cdot dis^{-1}$
E_{avg}	Average energy assumed for selecting values of μ.	$Mev \cdot dis^{-1}$
E_γ	Total gamma energy emitted per disintegration.	$Mev \cdot dis^{-1}$
f_a	Fraction of inhaled material which is subsequently deposited in the critical organ.	-
F_b	Fraction of material released to the reactor building and available to be released to the atmosphere.	-
F_p	Fraction of inventory released from the primary system to the reactor building.	-

List of Symbols and Definitions (Cont'd.)

Symbol	Represents	Dimensions
k	Linear absorption constant, $\left(\frac{\mu-\mu_a}{\mu_a}\right)$.	-
m	Mass of the critical organ.	grams
n	Meteorological stability parameter.	-
P	Rated reactor power level.	Mw_t
P_o	Unit reactor power (1 megawatt).	
q_s	Saturated reactor inventory for a specific isotope.	curies
q_t	Reactor inventory for a specific isotope after a finite operating time.	curies
Q_τ	Amount of a specific isotope released to the atmosphere during a finite time interval per megawatt reactor power.	$curies \cdot Mw^{-1}$
R	Breathing rate.	$meters^3 \cdot sec^{-1}$
S_o, S_r	Source terms at shutdown - total and released to reactor building.	$Mev \cdot sec^{-1} \cdot Mw^{-1}$
t, T	Time variables.	seconds
T_o	Reactor operating time.	seconds
T_b, T_e, T_r	Biological, effective, and radiological half-lives.	seconds
$\bar{u}$	Average wind speed.	$meters \cdot sec^{-1}$
τ, τ_1, τ_2	Exposure time intervals.	seconds
σ_y, σ_z	Standard deviations of cloud concentration.	-
γ_i	Fission yield.	$nuclei \cdot fission^{-1}$
$\lambda_b, \lambda_e, \lambda_r$	Biological, effective, and radiological elimination and decay constants.	$second^{-1}$
λ_1	Leak rate from the containments shell (reactor building)	$second^{-1}$
μ, μ_a	Linear and energy absorption coefficients	$meter^{-1}$

REFERENCES

1. "Reactor Site Criteria", Title 10, Code of Federal Regulations, Part 100 (10 CFR 100), February 11, 1961.

2. "Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Power Plants, " WASH-740, March 1957.

3. "Permissible Dose From External Sources of Ionizing Radiation", NBS Handbook No. 59, w/addendum of April 1958, September 24, 1954.

4. Sutton, O. G., "A Theory of Eddy Diffusion in the Atmosphere", Proceedings of the Royal Society (London), 135A:143, 1932.

5. "Meteorology and Atomic Energy", AECU-3066, July 1955.

6. Gifford, F. A. Jr., "Use of Routine Meteorological Observations for Estimating Atmospheric Dispersion", Nuclear Safety, 2(4) pp 47-51, June 1961.

7. Meade, P. J., "Meteorological Aspects of the Safety and Location of Reactor Plants", World Meteorological Organization, Technical Note No. 33, pp 13-22, 1960.

8. Hosler, C. R., "Low-Level Inversion Frequency in the Contiguous United States", Monthly Weather Review, 89 pp 319-339, September 1961.

9. Beattie, J. R., "An Assessment of Environmental Hazards from Fission Product Releases", AHSB(S)R9, May 1961.

10. "Report of ICRP Committee II on Permissible Dose for Internal Radiation (1959)", Health Physics (Journal), Volume 3, June 1960.

11. Blomeke, J. O. and Todd, M. F., "Uranium-235 Fission Product Production as a Function of Thermal Neutron Flux, Irradiation Time, and Decay Time", ORNL-2127, Part 1, Volume 1 and 2, November 1958.

12. Goldstein, H., The Attentuation of Gamma Rays and Neutrons in Reactor Shields, May 1957.

13. The Reactor Handbook, AECD-3645, Volume 1, "Physics", February 1955.

14. Gifford, F. A. Jr., "Atmospheric Dispersion Calculations Using the Generalized Gaussian Plume Model", Nuclear Safety, 2(2) pp 56-59, December 1960.

ATTACHMENT 30

Regulatory Guide 1.183, "Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors"
(Jan. 2000)

U.S. NUCLEAR REGULATORY COMMISSION July 2000

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 1.183

(Draft was issued as DG-1081)

ALTERNATIVE RADIOLOGICAL SOURCE TERMS FOR EVALUATING DESIGN BASIS ACCIDENTS AT NUCLEAR POWER REACTORS

10, 1997, is allowed by 10 CFR 50.67, "Accident Source Term," to voluntarily revise the accident source term used in design basis radiological consequence analyses.

In general, information provided by regulatory guides is reflected in NUREG-0800, the Standard Review Plan (SRP) (Ref 3). The NRC staff uses the SRP to review applications to construct and operate nuclear power plants. This regulatory guide applies to Chapter 15.0.1 of the SRP.

The information collections contained in this regulatory guide are covered by the requirements of 10 CFR Part 50, which were approved by the Office of Management and Budget (OMB), approval number 3150-0011. The NRC may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a currently valid OMB control number.

B. DISCUSSION

An accident source term is intended to be representative of a major accident involving significant core damage and is typically postulated to occur in conjunction with a large loss-of-coolant accident (LOCA). Although the LOCA is typically the maximum credible accident, NRC staff experience in reviewing license applications has indicated the need to consider other accident sequences of lesser consequence but higher probability of occurrence. The design basis accidents (DBAs) were not intended to be actual event sequences, but rather, were intended to be surrogates to enable deterministic evaluation of the response of a facility's engineered safety features. These accident analyses are intentionally conservative in order to compensate for known uncertainties in accident progression, fission product transport, and atmospheric dispersion. Although probabilistic risk assessments (PRAs) can provide useful insights into system performance and suggest changes in how the desired depth is achieved, defense in depth continues to be an effective way to account for uncertainties in equipment and human performance. The NRC's policy statement on the use of PRA methods (Ref. 4) calls for the use of PRA technology in all regulatory matters in a manner that complements the NRC's deterministic approach and supports the traditional defense-in-depth philosophy.

Since the publication of TID-14844 (Ref. 1), significant advances have been made in understanding the timing, magnitude, and chemical form of fission product releases from severe nuclear power plant accidents. In 1995, the NRC published NUREG-1465, "Accident Source Terms for Light-Water Nuclear Power Plants" (Ref. 5). NUREG-1465 used this research to provide estimates of the accident source term that were more physically based and that could be applied to the design of future light-water power reactors. NUREG-1465 presents a representative accident source term for a boiling-water reactor (BWR) and for a pressurized-water reactor (PWR). These source terms are characterized by the composition and magnitude of the radioactive material, the chemical and physical properties of the material, and the timing of the release to the containment. The NRC staff considered the applicability of the revised source terms to operating reactors and determined that the current analytical approach based on the TID-14844 source term would continue to be adequate to protect public health and safety. Operating reactors licensed under that approach would not be required to re-analyze accidents using the revised source terms. The NRC staff also determined that some licensees might wish to use an AST in analyses to support cost-beneficial licensing actions.