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Code Manual for MACCS2

User's Guide

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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.

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

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.

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 ≤ 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 ≤ 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: $0.0 \leq$ 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: $0.0 \leq$ value $\leq$ 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 ≤ 2 m/s
15	F	2 m/s < u ≤ 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 ≤ 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 ≤ 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 ≤ value ≤ 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 ≤ value ≤ 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
```

6.2.2 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: $0 \leq$ value ≤ 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.

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

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:	$0 \leq$ value ≤ 10
Purpose:	Specifies the number of long-term population dose result blocks to be printed.

Variable Name:	ORGNAM
Variable Type:	Character, Scalar
Allowed Range:	$2 \leq$ length ≤ 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:	$1 \leq$ value $\leq$ 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:	IX1DS9 $\leq$ value $\leq$ 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.