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PROJECTION MODELS FOR HEALTH EFFECTS ASSESSMENT IN POPULATIONS EXPOSED TO RADIOACTIVE AND NONRADIOACTIVE POLLUTANTS

Volume III

SPAHR Interactive Package Guide

by

James J. Collins

ARGONNE NATIONAL LABORATORY

ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

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Division of Biological and Medical Research

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This is Volume III of a five volume series entitled Projection Models for Health Effects Assessment in Populations Exposed to Radioactive and Nonradioactive Pollutants, NUREG/CR-2364, ANL-81-59. The series presents version 4.1 of the Simulation Package for the Analysis of Health Risk (SPAHR) computer package and model. The complete series of SPAHR documentation is contained in the following five volumes:

Volume I	Introduction to the SPAHR Demographic Model for Health Risk J. J. Collins, R. T. Lundy, D. Grahn, and M. E. Ginevan
Volume II	SPAHR Introductory Guide J. J. Collins and R. T. Lundy
Volume III	SPAHR Interactive Package Guide J. J. Collins
Volume IV	SPAHR User's Guide J. J. Collins and R. T. Lundy
Volume V	SPAHR Programmer's Guide J. J. Collins and R. T. Lundy

PROJECTION MODELS FOR HEALTH EFFECTS ASSESSMENT IN POPULATIONS EXPOSED TO RADIOACTIVE AND NONRADIOACTIVE POLLUTANTS

ABSTRACT

The Simulation Package for the Analysis of Health Risk (SPAHR) is a computer software package based upon a demographic model for health risk projections. The model extends several health risk projection models by making realistic assumptions about the population at risk, and thus represents a distinct improvement over previous models. Complete documentation for use of SPAHR is contained in this five-volume publication. The demographic model in SPAHR estimates population response to environmental toxic exposures. Latency of response, changing dose level over time, competing risks from other causes of death, and population structure can be incorporated into SPAHR to project health risks. Risks are measured by morbid years, number of deaths, and loss of life expectancy. Comparisons of estimates of excess deaths demonstrate that previous health risk projection models may have underestimated excess deaths by a factor of from 2 to 10, depending on the pollutant and the exposure scenario. The software supporting the use of the demographic model is designed to be user oriented. Complex risk projections are made by responding to a series of prompts generated by the package. The flexibility and ease of use of SPAHR make it an important contribution to existing models and software packages.

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EXECUTIVE SUMMARY

Prediction of the health consequences to the general population of exposure to airborne and waterborne pollutants is becoming an important feature of environmental impact analyses. Such prediction requires not only knowledge of the dose term and the dose-response function, but also a model for projecting the health risk to some future population. Health risk projections entail considerable uncertainty about the measurement of the dosage that individuals receive and about the magnitude and nature of the biological response at a given population exposure. The uncertainties regarding the individual dose and the dose-response function have received much attention, but the uncertainty associated with the health risk projection model itself has not been fully addressed.

The purpose of this publication is threefold. First, the uncertainties in various health risk projection models will be addressed, and the assumptions inherent in each model will be stated explicitly. Second, a new model that is an extension of earlier models will be introduced. It is argued that this new model, referred to as the demographic model, is superior to previous models because it makes fewer assumptions about the population at risk and the potential of the population to change over time. Third, a computer package referred to as the Simulation Package for Analysis of Health Risk (SPAHR) is presented which facilitates the application of this model for various pollutants and populations at risk.

The core of any risk assessment scheme is the exposure-response model. This is the quantitative relationship between the level of exposure to the hazard of interest and the deleterious effects resulting from that hazard. If the population exposed to the hazard is homogeneous with respect to its likelihood of suffering ill effects from the exposure, estimation of effects is straightforward; we need know only the total number of persons exposed to estimate the effects. However, if the population is heterogeneous (i.e., different persons have differing risks of suffering health effects from exposure to the hazard), then a reasonable assessment of population risk depends upon the distribution of persons by level of risk.

Research indicates that risk levels are often related to the age and sex characteristics of the exposed population. This is true for both radiation and air pollution exposures. When the risk level is a predictable function of age and sex or some other traceable component of the demographic structure of the population, the estimation of projected health effects becomes less straightforward. If one adds to this complexity the long latency periods between exposure and response, the competing risks from other causes of mortality, and the changing demographic structure of the population over time, the projection of health effects becomes even more complex.

Evaluation of the health consequences for populations exposed to pollutants has become an important issue because of the increasing number of known

or suspected carcinogens in the environment. To date, three projection methods have been used in health risk assessments: the single coefficient model, the multi-coefficient model, and the life table model. Each has its own shortcomings, as discussed in Volume I, Chapter 2. This document presents a fourth model that is more useful and realistic than the previous models because it incorporates age, fertility, and mortality structure, and can follow populations through time under changing levels of mortality, fertility, and pollution exposure. This model is referred to as the demographic model.

A sensitivity analysis of the demographic model indicates that population structure alone for a 100-year exposure to 1 rem may introduce more than a factor of 10 variation in the number of excess deaths. This finding substantiates the premise that the population structure may be more important in a health risk projection than the uncertainty inherent in the dose-response functions.

A comparison of the demographic model with the single coefficient model, the most widely used in health risk projections, is presented in Volume I, Chapter 7. It is concluded that the single coefficient model, even in a short-term projection, may seriously underestimate excess deaths since it is unable to accumulate exposure. For instance, comparison of the single coefficient model with the demographic model for continuous exposure to 0.87 ppb of benzene for 50 years yields widely different estimates of excess mortality. The single coefficient model estimates 2,250 deaths, while the demographic model estimates values from 6,386 to 17,568. In the years 2015-2020, the excess leukemia deaths projected by the demographic model are ten times as large as those of the single coefficient model.

The demographic model is also compared with the life table model used in the 1980 BEIR report to estimate excess cancer deaths from exposure to ionizing radiation. The life table model correctly estimates the increased individual probability of death associated with a given radiation scenario. However, the life table model yields misleading results in the estimation of excess deaths for a specific population. The results presented in the 1980 BEIR report underestimate excess deaths by 50% in some instances. For example, using the linear-quadratic, absolute risk model for a continuous exposure of 1 rad per year for 70 years, the life table model estimates 2459 excess male deaths per million while the demographic model estimates 3769 excess male deaths per million.

This document is divided into five volumes:

I. Introduction to the SPAHR Demographic Model for Health Risk

II. SPAHR Introductory Guide

III. SPAHR Interactive Package Guide

IV. SPAHR User's Guide

V. SPAHR Programmer's Guide

The first volume presents the theory behind the SPAHR health risk projection model and several applications of the model to actual pollution episodes. The elements required for an effective health risk projection model are specified, and the models that have been used to date in health risk projections are outlined. These are compared with the demographic model, whose formulation is described in detail. Examples of the application of air pollution and radiation dose-response functions are included in order to demonstrate the estimation of future mortality and morbidity levels and the range of variation in excess deaths that occurs when population structure is changed. Volumes II through V provide the potential user with detailed guidance and appropriate examples to aid in the interpretation of numerical demographic output from the application of the model to realistic circumstances.

1.0 INTRODUCTION

This manual outlines the use of the interactive capabilities of the Simulation Package for Analysis of Health Risk (SPAHR). SPAHR is an integrated system of computer programs designed for simulating numerous health risk scenarios using the techniques of demographic modeling. This system of computer programs has been designed to be very flexible so as to allow the user to simulate a l[illegible] variety of scenarios. It provides the user with an integrated packa[illegible] or projecting the impacts on human health of exposure to various hazards, particularly those resulting from the effluents related to energy production. For a full description of the capabilities of the SPAHR program the user should refer to Volume IV, SPAHR User's Guide.

Because SPAHR is so versatile, it may be difficult for the occasional user to construct programs for sophisticated analyses. In order to remedy this situation, an "interactive" question and answer capability has been added to SPAHR. This procedure is self-documenting, so that the user needs little or no familiarity with SPAHR. This interactive capability also provides the user with virtually immediate results for various health risk scenarios. Of course, a general understanding of the demographic model employed in SPAHR is absolutely necessary for an interpretation of the results. Volume I, Introduction to the SPAHR Demographic Model for Health Risk, provides an overview of this model. Nevertheless, the interactive package provides the user with a valuable tool for employing the SPAHR model. This interactive capability makes SPAHR perhaps the most user-oriented computer program for making health risk assessments.

1.1 Overview of the Interactive Modules Available

Three interactive modules are currently available in SPAHR. These modules focus on health effects arising from radiation exposure. Later modules will also include other sources of pollution. The three modules now available in SPAHR are PRIMER, SITE, and WORKER.

PRIMER is an interactive module that utilizes many of the unique features of SPAHR. It can perform health risk projections for several populations exposed to various levels of radiation. It was developed to serve as a general introduction to the use of SPAHR, and thus was named PRIMER. A much more versatile module that extends the capabilities of PRIMER is WORKER.

WORKER is an interactive module that, like PRIMER, performs health risk projections for several populations exposed to radiation. However, WORKER also allows the user to specify radiation doses to individual organs and the size, age, and sex structure of the population at risk. This module was developed to perform analyses on specific worker populations, and thus was named WORKER. The use of this module, however, is not limited to worker populations; WORKER is so versatile that it can be used for most applications.

SITE is the third interactive module available in SPAHR. This module was written for use in connection with the Final Environment Statement for various nuclear plant sites (e.g., USAEC, 1972). This module allows the user to specify the total population and the average individual exposure in rems per year for persons at several distances from the nuclear power plant.

1.2 Using the Argonne Computer

SPAHR has been written to provide a significant amount of output at the terminal, and the user may not need to examine the extended output. If needed, the extended output can be mailed to the user, or the user can examine it during the session by entering TYPE SPAHR3 LISTING E. To halt the typing the user enters a break and then HT.

The interactive version of SPAHR is best suited for a 132-character hard-copy terminal, but any terminal can be used. The extended output is 132 characters wide, so output will wrap around on a 72-character terminal.

1.3 The FTS Number

The interactive version of SPAHR is currently accessible on the main computer at Argonne National Laboratory. Of the two ways to use this computer, the use of the FTS number is easier, although it requires an FTS phone line. The user simply dials (312) 972-7603, and when the computer tone is heard, the phone is connected to the coupler. When the connection is complete, the user enters a return and the computer will respond with

ARGONNE NATIONAL LABORATORY--PLEASE TYPE C FOR CMS, W FOR WYLBUR, OR TT FOR TSO.

C	*(The user should respond with C because the interactive version of SPAHR is located on CMS.)*

VM/370 ONLINE

(return)	*(The user should respond first with a carriage return. The computer will then respond with a period.)*
LOGON BXXXXXX	*(The user should then enter the computer user number provided and press return. The computer will respond with a request for a password.)*

ENTER PASSWORD:

XXX	*(The user then will supply the password and press return.)*

At this point the computer will respond with a series of messages concerning the present status of your computer space. When the typing has stopped, the computer responds with a period; the user should again press return. This return sets up the user's file space for SPAHR. The user may now enter PRIMER, SITE, or WORKER depending upon the type of analysis desired.

LOGOFF *(The user enters LOGOFF to terminate the session.)*

1.4 The TYMNET Number

The user may also use SPAHR through the TYMNET system. This procedure is somewhat more complex than the use of the FTS number, but it is more reliable because the TYMNET number is designed for computer use only. The user accesses the TYMNET system by first dialing the local TYMNET number. Each city has a different number. Dial your local TYMNET telephone access number and wait for ringing, an answer, and a high pitched tone. Couple your terminal to the telephone line. The user should then hit the return key until the terminal responds

PLEASE TYPE YOUR TERMINAL IDENTIFIER

E *(The user enters E using a TI silent 700; the terminal should be set at half duplex with capital letters.)*

TYMNET will then display:

-XXXX-444--

PLEASE LOG IN: Respond by typing your TYMNET user name, followed by a carriage return. TYMNET will then prompt for your password:

PASSWORD: Respond by typing your TYMNET password, followed by a carriage return. Wait until you receive either a ; or the message

HOST IS ONLINE either of which indicates a complete connection to the host computer. The user should now follow the same CMS logon instructions as those provided for use of the FTS number.

2.0 THE USE OF PRIMER

PRIMER is an interactive package that performs a health risk assessment for a number of energy-related effluents where the exposure level is constant over the duration of the exposure. This package allows the user many options. First, the duration of exposure can be specified along with the length of the projection. For example, the user can specify a single year's exposure to an effluent and follow its effects in a population for 100 years. Second, a number of models simulating the effects of various effluents are also available. These include several air pollution models as well as the radiation models presented in the BEIR (Biological Effects of Ionizing Radiation) Committee reports of 1972 and 1980 (NAS, 1972 and 1980). The NAS 1972 report is referred to as BEIR I, while NAS 1980 is referred to as BEIR III. Third, these models can be applied to one of several available populations, including the "standard" populations used by the BEIR Committee and also several populations that have unique exposure levels to various effluents.

2.1 The Florida Phosphate Lands: An Example

An example of the use of the PRIMER package is instructive. The example to follow is a replication of a health assessment for persons living in the Bone Valley Region of Florida. This population is exposed to radon-222 and its radioactive daughters because houses are built on land containing phosphate rock. These phosphate deposits contain naturally elevated levels of radium-226, which decays to radon-222. Therefore, a large number of persons in this region are exposed to continuous, low-level ionizing radiation. An extensive analysis of the potential health effects on this population is provided in a report by Dreyer et al., 1980. Subsequently, this report will be referred to by its series number, NUREG/CR-1728.

Four Florida counties are located in the Bone Valley Region: Hillsborough, Polk, Hardee, and Manatee. These four counties are of special interest to the SPAHR user because of their diverse age structures. Manatee County, for instance, has a relatively old population with 32% of its persons over age 65, while Hillsborough County has only 10.5% of its population in this age group and a more typical age structure. Figure 2.1 presents the population pyramids

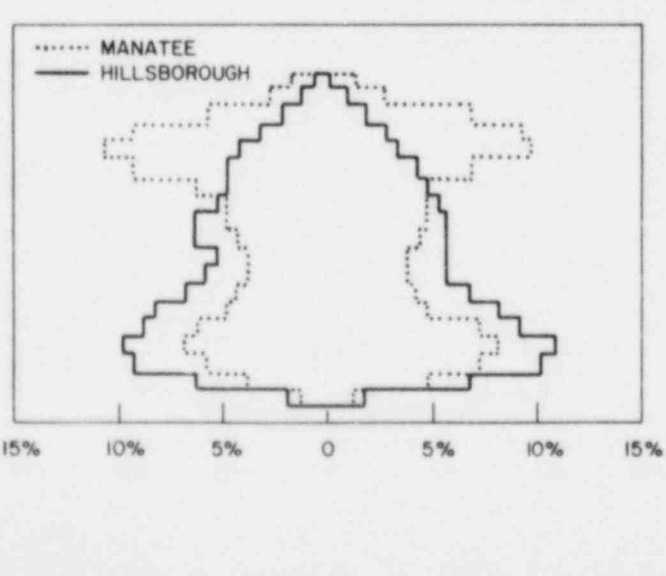

Fig. 2.1

Population pyramids of Manatee and Hillsborough Counties, Florida, 1970.

for these two counties. Because of this diversity in age structures, we will limit our analysis to these two counties. Because they have similar fertility and mortality levels, any differences in the health assessments can be attributed to the age structure.

To provide an instructive example, we will use an annual whole body dose of 0.225 rem, although we do not infer an equivalence to the lung dose from radon. The SPAHR program will also use the same total population size (14,000) and the same duration of exposure (70 years) as referenced by Dreyer et al. (1980) in a discussion of the estimated excess lung cancer deaths that might occur among the residents of the reclaimed phosphate lands. The BEIR I relative risk model (NAS, 1972) with a lifetime plateau is used because it yields the highest estimates of excess death of all the BEIR I models.

2.2 The PRIMER Session

The following is a description of the PRIMER interactive routine that will perform the analysis described above. The computer prompts are in capital letters, and the user responses are in italics. Comments on this routine are in parentheses and are indented to the right. The user initiates the routine by issuing the command

PRIMER

THIS IS AN INTERACTIVE PROGRAM TO ASSIST YOU IN PRODUCING AN INPUT COMMAND FILE FOR THE SPAHR PACKAGE. USER RESPONSES DURING EXECUTION MAY BE:

1. BYPASS OPTIONAL INPUT BY ENTERING A CARRIAGE RETURN.

2. ENTER REQUESTED INPUT. TERMINATE WITH A CARRIAGE RETURN.

WHAT WAS THE BEGINNING YEAR OF EXPOSURE?

1970 *(This is the initial year.)*

WHAT WAS THE LAST YEAR OF EXPOSURE?

2040 *(The report cited above used a 70 year exposure, or 1970 plus 70 equals 2040.)*

WHAT WAS THE LEVEL (IN REMS PER YEAR)?

0.225 *(This is the annual dose in rems calculated earlier)*

DO YOU WISH TO ASSUME A LIFETIME RISK PERIOD?

Yes *(The life long plateau is used if yes is entered.)*

DO YOU WISH TO USE THE "RELATIVE RISK" VERSION OF THE MODEL?

Yes *(If the user responded no, an absolute risk model would be used.)*

WHAT IS THE FINAL YEAR OF THE PROJECTION? (NOTE: TO ESTIMATE ALL POSSIBLE EXCESS DEATHS, THE PROJECTION SHOULD EXCEED THE FINAL YEAR OF EXPOSURE BY 100 YEARS.)

2140 *(The projection exceeds the final year of exposure by 100 years.)*

END INPUT FOR PRIMER COMMAND FILE.

DO YOU WISH TO RUN THIS PROBLEM?

Yes *(The user could specify no at this point. The file would then be saved as TEMP COMMAND A, and the user could run it later.)*

THE FOLLOWING POPULATIONS ARE AVAILABLE

1 DATA1 UNITED STATES WHITE POPULATION 1970 (BEIR I)

2 DATA2 UNITED STATES BLACK POPULATION 1970 (BEIR I)

3 DATA3 UNITED STATES WHITE POPULATION 1969-71 (BEIR III)

4 MANATEE MANATEE COUNTY, FLORIDA 1969-71 (BEIR I)

5 HILLSBR HILLSBOROUGH COUNTY FLORIDA 1969-71 (BEIR I)

4 *(Select Manatee County)*

DO YOU WANT EXTENDED OUTPUT MAILED TO YOU?

Yes *(If no is specified, the user will receive output only from his terminal.)*

ENTER ADDRESS FOR MAILING. (HIT RETURN TWICE TO END ENTRY.)

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At this point the SPAHR main program takes over and starts to process the information you have entered. In the present example, we replicate health projections reported in NUREG/CR-1728.

2.3 The Results from PRIMER

Some highlights of the preceding analysis are presented in Table 2.1. The analysis was performed separately for Manatee and Hillsborough Counties. The total mortality levels indicate that Hillsborough County is expected to have about 25% more excess deaths than Manatee County. This is due to the younger age structure of Hillsborough County, and thus the greater number of person-years spent in the exposure interval. Many of the older persons in Manatee County die before the long latency period associated with most cancers ends, so there are fewer excess deaths. The pattern of excess deaths can be followed over time. Prior to the year 2000 there are no significant differences in excess deaths between the two populations. After the year 2000 Hillsborough County shows substantially larger numbers of excess deaths. The exposure to the excess radiation ceases in the year 2040, but the excess deaths continue to rise because of the long latency period of the cancers. After the year 2060, twenty years after the exposure ends, the excess deaths in both populations begin to fall, virtually disappearing by 2135.

Table 2.1. Year-by-Year Estimates of Excess Mortality for Manatee and Hillsborough Counties in Florida for 14,000 Persons Exposed to 0.225 rem Annually for 70 Years.

	Manatee		Hillsborough	
	Female	Male	Female	Male
1970-1975	0.0	0.0	0.0	0.0
1975-1980	0.1	0.1	0.1	0.1
1980-1985	0.2	0.2	0.2	0.2
1985-1990	0.3	0.3	0.3	0.3
1990-1995	0.4	0.4	0.3	0.4
1995-2000	1.1	0.9	1.0	1.1
2000-2005	1.3	1.1	1.4	1.5
2005-2010	1.5	1.3	1.8	1.8
2010-2015	1.7	1.6	2.2	2.3
2015-2020	2.0	2.0	2.6	2.9
2020-2025	2.4	2.4	3.2	3.5
2025-2030	2.8	2.9	3.8	4.2
2030-2035	3.3	3.5	4.4	4.8
2035-2040	3.7	4.0	5.0	5.4
2040-2045	4.2	4.5	5.5	6.0
2045-2050	4.6	4.9	5.9	6.4
2050-2055	4.9	5.2	6.2	6.6
2055-2060	5.1	5.3	6.4	6.7
2060-2065	4.9	5.0	6.1	6.2
2065-2070	5.6	4.7	5.7	5.7
2070-2075	4.4	4.4	5.3	5.3
2075-2080	4.1	4.1	5.0	4.9
2080-2085	3.8	3.8	4.6	4.5
2085-2090	3.5	3.5	4.2	4.0
2090-2095	3.1	3.1	3.7	3.5
2095-2100	2.7	2.6	3.1	2.8
2100-2105	2.3	2.1	2.6	2.2
2105-2110	1.8	1.6	2.0	1.6
2110-2115	1.3	1.0	1.4	1.0
2115-2120	0.9	0.5	0.9	0.5
2120-2125	0.5	0.2	0.4	0.2
2125-2130	0.3	0.1	0.2	0.1
2130-2135	0.1	0.0	0.1	0.0
2135-2140	0.0	0.0	0.0	0.0
Total	78.4	77.7	95.9	97.0

This health risk projection demonstrates the importance of incorporating age structure into the analysis. Because these two counties border one another, they share many demographic characteristics such as fertility levels and mortality structure. More diverse assessments can be obtained by changing fertility and mortality levels (c.f. Volume I). In fact, the user may wish to try the above example with another population to see how much the results change.

Table 2.1 represents a small portion of the information available in the SPAHR output. Morbidity and mortality by cause of death are also available, along with person-years lost, decreases in life expectancies, and changes in age-, sex-, and cause-specific death rates. In short, the SPAHR output provides the user with a variety of information suitable for a wide range of applications.

3.0 THE USE OF WORKER

An extension of the PRIMER interactive module is available in the module WORKER. WORKER gives the added capability of specifying population structures (e.g., age structure of a working population) and allowing doses for individual organs. This module was developed to perform analyses on specific worker populations, such as employees in nuclear power plants. The use of this module need not, however, be limited to worker populations, as the following example will demonstrate.

3.1 Risk of Breast Cancer from Low-Dose Radiation: An Example

The female risk of developing breast cancer has been demonstrated to increase with exposure to moderate levels of radiation (i.e., over 50 rad; NAS, 1980). The risk is greatest for persons exposed as adolescents, although exposure at any age appears to imply some risk. The dose response relationship has been described as linear, nonthreshold (Boice et al., 1979). While age-specific absolute risk estimates from several studies are similar, a relative risk model may be most appropriate for breast cancer (Boice et al., 1979).

Boice et al. (1979) estimated radiation risks for American women based upon the combined data from two American studies, with the Massachusetts patients frequently examined fluoroscopically and the Rochester women irradiated for postpartum mastitis. Because breast cancer rates are so much higher for American women than for Japanese women, Boice et al. excluded the Japanese survivors of atomic bomb detonations in the estimation of risk coefficients. The difference in underlying rates of breast cancer for American and Japanese women is very important for estimation of the relative risk coefficient, because this coefficient represents a percentage increase in the baseline cancer rate. The BEIR 1980 estimates developed for SPAHR, however, are based solely on the atomic bomb survivors. It would be of interest, therefore, to compare the risk estimates of Boice et al. (1979) with those generated in SPAHR and evaluate the effects of different baseline rates on the estimation and subsequent application of the relative risk coefficients.

3.2 The WORKER Session

The WORKER interactive module will perform the above analysis. In the example session to follow, a series of cohorts are followed by specifying 1,000,000 females in the age groups of interest. For instance, specifying 1,000,000 females in the age group 30-34 under a particular exposure scenario will essentially generate a lifetime excess risk of developing breast cancer per 1,000,000 women for those who are exposed at ages 30 to 34. The computer prompts are in capital letters, and the user responses are in italics. Comments are in parentheses and are indented to the right. The user initiates the session by issuing the command

WORKER

THIS IS AN INTERACTIVE PROGRAM TO ASSIST YOU IN PRODUCING AN INPUT COMMAND FILE FOR THE SPAHR PACKAGE. USER RESPONSES DURING EXECUTION MAY BE:

1. TYPE "HELP" FOR ADDITIONAL INFORMATION.
2. BYPASS OPTIONAL INPUT BY ENTERING A CARRIAGE RETURN.
3. ENTER REQUESTED INPUT. TERMINATE WITH A CARRIAGE RETURN.

ENTER THE INITIAL YEAR TO BE ASSOCIATED WITH THE DATA.

1970 *(This is the initial year.)*

DO YOU WISH TO SPECIFY THE TOTAL POPULATION SIZE?

YES *(You want to override the program's default population size, which is derived from the data used.)*

WHAT IS THE TOTAL POPULATION SIZE?

1,000,000 *(We want the estimate in excess deaths per 1,000,000 women at risk.)*

WHAT IS THE FINAL YEAR OF THE PROJECTION?
(NOTE: TO ESTIMATE ALL POSSIBLE EXCESS DEATHS, THE PROJECTION SHOULD EXCEED THE FINAL YEAR OF EXPOSURE BY 100 YEARS.)

2035 *(Like the Boice et al. study, we have chosen age 30 as our first year of exposure, so we wish to follow these women for 65 years to age 95 in 2035.)*

DO YOU WANT TO SPECIFY PERSONS BY AGE?

YES *(We want 1,000,000 females in age group 30-34.)*

HOW MANY MALES ARE THERE AGE 0-1?

0

HOW MANY FEMALES ARE THERE AGE 0-1?

0

HOW MANY MALES ARE THERE AGE 1-4?

0

HOW MANY FEMALES ARE THERE AGE 1-4?

0 *(We continue to enter 0 for each age group up to 30-34.)*

HOW MANY MALES ARE THERE AGE 30-34?

0

HOW MANY FEMALES ARE THERE AGE 30-34?

1,000,000 *(We want 1,000,000 females in age group 30-34.)*

HOW MANY MALES ARE THERE AGE 35-39?

0

HOW MANY FEMALES ARE THERE AGE 35-39?

0 *(We continue to enter 0 persons in each subsequent age group.)*

DO YOU WANT THE EFFECT OF THE EXPOSURE TO BE LIFELONG?

YES *(Assume no plateau for excess risk.)*

DO YOU WISH TO USE THE "RELATIVE RISK" VERSION OF THE MODEL?

YES *(If you respond no, an absolute risk model is used.)*

WHAT WAS THE FIRST YEAR OF EXPOSURE TO THIS LEVEL OF RADIATION?

1970 *(This is the model year.)*

WHAT WAS THE FINAL YEAR OF EXPOSURE TO THIS LEVEL OF RADIATION?

1971 *(Assume a one-year exposure.)*

WHICH OF THE FOLLOWING RADIATION MODELS DO YOU WISH TO USE?

6 MODEL6 1972 BEIR REPORT LINEAR MODEL
7 MODEL7 1980 BEIR REPORT LINEAR MODEL
8 MODEL8 1980 BEIR REPORT LINEAR-QUADRATIC MODEL
9 MODEL9 1980 BEIR REPORT QUADRATIC MODEL

7 *(Use the linear model from 1980 BEIR Committee Report.)*

DO YOU WANT THE DOSE TO BE ORGAN SPECIFIC?

YES

IS THERE A DOSE FOR THE CANCER SITE OF THYROID?

NO *(No dose for the thyroid.)*

IS THERE A DOSE FOR THE CANCER SITE OF BREAST?

YES *(The dose is for the breast.)*

WHAT IS THIS DOSE LEVEL IN REMS?

1.0 *(The dose level is one rem per year.)*

WHAT IS THE DURATION (IN YEARS) OF THE DOSE FOR THIS ORGAN?

1.0 *(The duration of the dose is one year.)*

IS THERE A DOSE FOR THE CANCER SITE OF LUNG?

NO *(Continue to enter no dose for the other cancer sites: ESOPH, STOMACH, INTEST, LIVER, PANCREAS, URINARY, LYMPHOMA, LEUKEMIA, BONE, OTHER.)*

ENTER ANY NUMBER OF COMMENT LINES AND/OR RETURN ADDRESS. TERMINATE WITH A BLANK LINE

END INPUT FOR PRIMER COMMAND FILE
DO YOU WISH TO RUN THIS PROBLEM?

YES

THE FOLLOWING POPULATIONS ARE AVAILABLE

1	DATA1	U.S. WHITE POPULATION 1970 (BEIR I)
2	DATA2	U.S. BLACK POPULATION 1970 (BEIR I)
3	MANATEE	MANATEE COUNTY, FLORIDA (BEIR I)
4	HILLSBR	HILLSBOURGH COUNTY, FLORIDA (BEIR I)
5	DENVER	DENVER, COLORADO (BEIR I)
6	DATA6	U.S. WHITE POPULATION 1969-71 (BEIR III)
7	DATA7	U.S. WHITE POPULATION 1970 (BEIR III)
8	DATA8	U.S. TOTAL POPULATION 1970 (BEIR III)
9	DATA9	U.S. TOTAL POPULATION 1969-71 FERTILITY=0 (BEIR III)
10	DATA10	U.S. TOTAL POPULATION 1969-71 (BEIR III)

ENTER LINE NUMBER OF DESIRED POPULATION

9 *(We choose the U.S. 1969-71 total U.S. population with fertility set to zero.)*

DO YOU WANT EXTENDED OUTPUT MAILED TO YOU?

NO

---> INPUT COMMAND FILE SAVED AS : TEMP COMMAND A

SPAHR now begins to process the information provided and begins printing output. The excess breast cancer deaths from the exposure scenario for one million women aged 30-34 are provided at the user's terminal in the following form:

	MORBID YEARS LOST		DEATHS	
CAUSE	FEMALE	MALE	FEMALE	MALE
THYROID	.0	.0	7739.	.0
BREAST	3.388E+06	.0	2.983E+05	.0
LUNG	.0	.0	1.271E+05	.0
ESOPH	.0	.0	1.685E+04	.0
STOMACH	.0	.0	7.551E+04	.0
INTEST	.0	.0	2.299E+05	.0
LIVER	.0	.0	8263.	.0
PANCREAS	.0	.0	9.125E+04	.0
URINARY	.0	.0	5.957E+04	.0
LYMPHOMA	.0	.0	5.489E+04	.0
LEUKEMIA	.0	.0	5.908E+04	.0
BONE	.0	.0	6561.	.0
OTHER	.0	.0	5.708E+05	.0
BASELN	.0	.0	9.746E+06	.0
BREAST_1	9153.	.0	805.8	.0
EXCESS	.0	.0	805.8	.0

A baseline value of 298,300 breast cancer deaths is projected for females in this birth cohort. In addition, 806 excess breast cancer deaths are expected to occur if these women are exposed to 1 rad for one year between the ages of 30 and 34. Much more detail is provided in the extended output, but the terminal output will be sufficient for the present analysis.

3.3 The Results of WORKER

Table 3.1 compares the estimates of excess breast cancer deaths derived by Boice et al. (1979) with those of SPAHR. Boice et al. used a lifetable technique similar to SPAHR to estimate excess deaths. They presented the results of two linear models, one with cell killing and one without. Their estimates of excess death diminished with age largely because of competing risks from other causes of death. Persons exposed at age 70 are less likely to die from the radiation-induced breast cancer than are younger persons because mortality levels in general are much higher after age 70. Boice et al. noted a general similarity in the number of excess deaths estimated by the absolute and relative risk models. If the baseline, age-specific breast cancer rates and total mortality rates were the same for the Massachusetts and

Table 3.1. Number of Radiation-Induced Breast Cancers among 1,000,000 Women Exposed to 1 Rad for 1 Year for Two Estimation Techniques

Age at Exposure	Boice et al. Estimates*				Estimates from SPAHR Using the BEIR 1980 Models					
	Linear Dose Response		Linear Dose Response with Cell Killing at High Doses		Linear		Linear-quadratic		Pure quadratic	
	Absolute	Relative	Absolute	Relative	Absolute	Relative	Absolute	Relative	Absolute	Relative
35-39	234	312	307	425	262	806	109	330	1	2
40-44	202	288	266	391	224	559	94	233	1	1
45-49	172	257	226	350	196	447	80	184	0	1
50-54	143	226	187	307	171	314	67	124	0	0
55-59	115	191	151	259	142	240	54	92	0	0
60-64	88	154	116	208	113	200	43	77	0	0
65-69	64	117	84	158	87	164	33	63	0	0
70-74	42	79	55	108	64	130	24	50	0	0

*Taken from Table V, Boice et al., 1979.

Rochester samples and for the female population used to construct the life-table, then the absolute and relative risk models would yield exactly the same number of excess deaths. Any lack of similarity in the absolute and relative risk estimates, therefore, reflects differences in the baseline mortality patterns of the two groups.

The SPAHR estimates use the model coefficients from the BEIR 1980 committee report (NAS, 1980). The committee defined three models, linear, linear-quadratic, and pure quadratic. These models and their operationalization are outlined in Volume I. The three model types present very diverse estimates of excess mortality. The pure quadratic model, both relative and absolute, projects almost no effect from an exposure at any age. The linear model with relative risk (NAS, 1980) estimates almost twice as many excess deaths as the highest estimates of Boice et al. (1979). Results of the linear model with absolute risk, however, are well within the range of the excess deaths estimated by Boice et al. Estimates of the linear-quadratic model fall between those of the linear and the pure quadratic models. The relative risk estimates of the BEIR linear-quadratic model are much larger than the absolute risk estimates, as is the case for the BEIR linear model.

The differences between the relative and absolute risk estimates in the BEIR models point out the problem that Boice et al. sought to avoid by using study samples from the United States to estimate United States population risk. Because Japanese women have much lower breast cancer levels than do American women, a relative risk model derived from Japanese data would estimate more excess deaths than would an absolute risk model derived from the same data.

Which model type, relative or absolute, better represents the phenomenon of excess breast cancer from radiation? If a linear relative risk formulation is a more accurate representation, the Japanese data may be better suited for modeling excess mortality because there are more observations. Then the excess deaths estimated for the American female population by the BEIR linear relative risk formulation will be more accurate than those provided by Boice et al. Boice et al. do point out that the relative risk formulation appears to fit the data better. However, if the phenomenon is best described by the linear absolute formulation, the estimates of excess deaths from the BEIR linear relative risk formulation may be overestimates.

4.0 THE USE OF SITE

SITE is an interactive routine that performs individual assessments for a series of populations. SITE was designed especially for performing health risk assessments around nuclear power plants. It allows the user to specify the total population and the average individual exposure in rems per year for persons at various distances from the plant, corresponding to information provided in the Final Environment Statement for various nuclear plant sites (e.g. USAEC, 1972). While the program prompts for population and dose levels for persons living in mile-based radii from the plant, the user can enter any population and dose data in this program. SITE was specifically developed to assess the health impact of the Three Mile Island accident. However, this does not preclude its use in general assessments around other nuclear plants.

The following example demonstrates how the SPAHR model is used to replicate the analysis of the health impact due to the accident at the Three Mile Island Nuclear Station. The original assessment of this accident performed by the Nuclear Regulatory Commission estimated 0.7 fatal cancers (USNRC, 1979). This assessment, however, used the total mortality levels of the 1972 BEIR committee report and assumed that the population around Three Mile Island has the age, fertility, and mortality structures of the 1967 population of the United States.

A more reasonable approach, is to use the actual population around the Three Mile Island Nuclear Power Station. In our example the age and sex structures of the 1978 population within a 50-mile radius of the plant were first constructed from county estimates made by the U.S. Census (Bureau of the Census, 1980). The fertility and mortality structures of this population in 1979 were not available; instead, the 1970 U.S. population values were used.[1] The assignment of persons to different distances from the plant assumes that the age, sex, mortality, and fertility structures are uniform in each area, with the only differences being in the total population. The total population estimate in each area is taken from Table A-6 of the U.S. Nuclear Regulatory Commission report mentioned earlier. In summary, the age, sex, fertility, and mortality structures of the area within 50 miles of the Three Mile Island Nuclear Power Station during the accident of early 1979 were constructed as accurately as possible from the existing data.

4.1 The SITE Session

The following is a description of the SITE interactive routine that performs the above analysis. The user responses are in italics, while the computer prompts are in capital letters. Comments on this routine are indented to the right. The user first calls the SITE routine.

---

[1]When the appropriate data become available they will be added to SPAHR.

SITE

THIS IS AN INTERACTIVE PROGRAM TO ASSIST YOU IN PRODUCING AN INPUT COMMAND FILE FOR THE SPAHR PACKAGE. USER RESPONSES DURING EXECUTION MAY BE:

1. TYPE "HELP" FOR ADDITIONAL INFORMATION.
2. BYPASS OPTIONAL INPUT BY ENTERING A CARRIAGE RETURN.
3. ENTER REQUESTED INPUT. TERMINATE WITH A CARRIAGE RETURN.

WHAT WAS THE BEGINNING YEAR OF EXPOSURE?

1979 *(This is the initial year of exposure to the excess radiation at Three Mile Island, TMI.)*

WHAT WAS THE ENDING YEAR OF EXPOSURE?

1980 *(The actual exposure at TMI lasted only 10 days, but SPAHR uses an annual dose, so 1980 is used as the final year of exposure.)*

WHAT WAS THE DOSE LEVEL (IN REMS) OF THE ENTIRE U.S.?

0.0 *(Zero is entered in this case since there was no significant excess exposure beyond 50 miles from TMI.)*

WHAT IS THE FINAL YEAR OF PROJECTION?

2079 *(The year 2079 is entered to allow the one-year dose to cause all possible excess deaths.)*

DO YOU WANT TO USE THE "RELATIVE RISK" VERSION OF THE MODEL?

Yes *(If the user entered no, the absolute model would be used.)*

DO YOU WANT TO USE THE LIFELONG PLATEAU? (I.E., IS THE EFFECT OF THE EXPOSURE LIFELONG?)

No *(The lifelong plateau is used if yes is entered.)*

INPUT FOR DISTANCE RANGE 0-1 MILES. POPULATION = ?

658 *(The input for the rest of the program is taken from Table A-1 of USNRC, 1979.)*

DOSE RATE = ?

0.0778 *(The routine then prompts the user for each of the distance radii. Finally, when data for each radius have been entered, the routine responds.)*

DO YOU WISH TO REVIEW THE POPULATION AND DOSAGE?

Yes *(If no is entered here the information entered by the user is not reviewed.)*

INDEX	RANGE	POPULATION	DOSAGE
1	0- 1	658	0.0778
2	1- 2	2017	0.0331
3	2- 3	7579	0.0633
4	3- 4	9676	0.0364
5	4- 5	8891	0.0086
6	5-10	137474	0.0059
7	10-20	577288	0.00024
8	20-30	433001	0.000063
9	30-40	273857	0.000069
10	40-50	713210	0.00000048

(From comparison with the table cited above, the data on index 9 are incorrect.)

DO YOU WISH TO MAKE ANY CORRECTIONS?

Yes

NOTE: A "CARRIAGE RETURN" WILL CAUSE A CONTINUATION TO THE NEXT STEP.

INDEX = ?

9 *(Index 9 contains the error.)*

POP-SIZE (9) = ?

273857

DOSE (9) = ?

0.0000069 *(Enter the data correctly.)*

DO YOU WISH TO REVIEW THE POPULATION AND DOSAGE?

No

END INPUT FOR SITE COMMAND FILE.

DO YOU WISH TO RUN THIS PROBLEM?

Yes (*The user could specify no at this point. The file then would be saved, and the user could run it later.*)

THE FOLLOWING POPULATIONS ARE AVAILABLE

1	TMI	THREE MILE ISLAND NUCLEAR STATION (1979)
2	OCONEE	OCONEE NUCLEAR STATION (1970)
3	TROJAN	TROJAN NUCLEAR PLANT (1980)
4	LIMERK	LIMERICK GENERATING STATION (1980)
5	SKAGIT	SKAGIT NUCLEAR POWER PROJECT (1980)
6	VRAIN	FORT ST. VRAIN NUCLEAR GENERATING STATION (1970)

ENTER LINE NUMBER OF DESIRED POPULATION?

1 (*Select TMI.*)

DO YOU WANT EXTENDED OUTPUT MAILED TO YOU?

Yes (*If no is specified you will only receive output from your terminal.*)

ENTER ADRESS FOR MAILING. (HIT RETURN TWICE TO END ENTRY.)

James J. Collins (*Simply enter your mailing address.*)
BIM/202
Division of Biological and Medical Research
Argonne National Laboratory
Argonne, IL 60439

At this point the SPAHR main program takes over and begins to process the information you have entered. In this case we have replicated the analysis performed by NRC concerning the health impacts of the accident at the Three Mile Island Nuclear Station.

4.2 The Accident at Three Mile Island: An Example

The results of the SPAHR replication of the Three Mile Island Health Assessment are presented in Table 4.1. The dose levels labeled "best estimate," "lower bound," and "upper bound" are presented in Table 4.2 and were taken directly from the report of the Nuclear Regulatory Commission, as was the total population in each radius (USNRC, 1979). Four model types for each of the three dose levels were estimated by employing the SPAHR routine SITE. These four model types were adapted from the 1972 BEIR Committee report (NAS, 1972). For a complete explanation of these model types the user should refer to Volume I.

TABLE 4.1. Projected Potential Excess Deaths Due to the Three Mile Island Accident in the Offsite Population within 50 Miles Using the 1972 BEIR Committee Dose Response Functions in the SPAHR Model

Model Type	Dose Levels*		
	Best Estimate	Lower Bound	Upper Bound
Absolute (30-year plateau)	0.37	0.33	1.09
Absolute (no plateau)	0.54	0.43	1.43
Relative (30-year plateau)	0.80	0.64	2.13
Relative (no plateau)	1.81	1.45	4.83
Geometric Mean of the Four Model Types	0.73	0.57	2.00

*Taken from Table 4.2.

Table 4.2. Average Individual Exposure to Population 0 to 50 Miles from Three Mile Island Nuclear Station March 28 through April 3, 1979

Radius (Mile)	Total Population*	Average Individual Exposure (mR)		
		Best Estimate*	Lower Range**	Upper Range**
0-1	658	77.8	62.1	205.6
1-2	2017	33.1	26.4	87.5
2-3	7579	63.3	50.5	167.3
3-4	9676	36.4	29.0	96.2
4-5	8891	8.6	6.9	22.7
5-10	137474	5.9	4.7	15.6
10-20	577288	0.24	0.19	0.63
20-30	433001	0.063	0.050	0.166
30-40	273857	0.0069	0.0055	0.0182
40-50	713210	0.00048	0.00038	0.00127
Collective Dose (Person-Rem)		2005.7	1600	5300

*Taken from Table A-1 (USNRC, 1979).

**Estimated from footnote e, Table 4-6 (USNRC, 1979) and distributed by area in the same proportion as in Table A-1 of same report.

Each of the four model types and dose levels provides a different estimate of the total excess deaths. The estimates range from 0.33 for the lower bound of the absolute risk model with a 30-year plateau to 4.83 for the upper bound of the relative risk model with no plateau. The absolute risk models yield lower numbers of excess deaths than do the relative risk models, in keeping with an observation by the 1972 BEIR committee (NAS, 1972). However, this difference in the estimates of excess deaths from these model types is a result of the age and mortality structures of the population and not of the model types themselves. Nevertheless, in the present example the absolute risk models do produce lower estimates of excess deaths. In each of the dose levels the relative risk model with no plateau yields excess death estimates four to five times as high as does the absolute risk model with a 30-year plateau.

The different dose levels also produce varying estimates of excess deaths. The upper-bound estimates are more than three times as large as the lower-bound estimates. For the sake of parsimony, the geometric mean of the estimates of the four model types for each dose level was computed. This summary measure can be loosely interpreted as the best estimate for a particular dose level. Therefore, the best estimate of the potential excess deaths around Three Mile Island is 0.73. This figure is remarkably consistent with the estimate of 0.7 of the Nuclear Regulatory Commission (USNRC, 1979). The geometric means of the lower and upper bound dose levels can also be loosely interpreted as the lower and upper bounds of the best estimate. Therefore, the best estimate of 0.73 excess deaths is bounded by 0.57 and 2.0. This estimate of the range again comes very close to the Nuclear Regulatory Commission estimates of the range. In general, therefore, the results of the SPAHR analysis and the report of Nuclear Regulatory Commission are remarkably similar.

This similarity of results appears to be due to two major factors. First, the duration of exposure (10 days) was very short. In the case of a single exposure of short duration, a demographic model such as that employed in SPAHR has little advantage over a single coefficient model such as the one used by the Nuclear Regulatory Commission. The strength of SPAHR is its ability to model health effects resulting from exposures of long duration (i.e., longer than one year). In the case of short exposures these two models should yield similar results if the assumptions concerning the underlying population are similar. In the present analysis the only major differences in assumptions between the two approaches are in the age structure of the population. Figure 4.1 presents population pyramids for the U.S. white population in 1970 and the population within 50 miles of Three Mile Island in 1978. The Nuclear Regulatory Commission used for its assessment the 1967 U.S. population, which is not very different from the 1970 population. Comparison of the TMI population

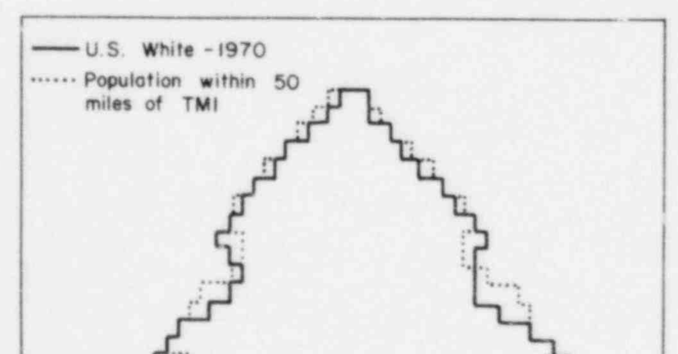

Figure 4.1.

Population pyramids of the U. S. White population in 1970 and the population within 50 miles of Three Mile Island.

age structure with that of the United States in 1970 reveals substantial similarity. The major differences between the two appear in the very young ages, where the 1970 population has a somewhat wider base, reflecting the larger percentage under 15 years. Nonetheless, the age structures are similar. In summary, the NRC approach and the SPAHR model yield similar results because of the similarity in the age structures and the short duration of exposure.

In addition to the above results, the SPAHR routine SITE also provides extended detail to the user. The excess deaths for each of the ten radii under study are provided in the output. In addition, SITE was used to solve four models at three different dose levels. For the sake of brevity, only the highest and lowest estimate of these models is presented.

Table 4.3 presents the estimated excess deaths from the absolute risk model with a 30-year plateau in the lower dose range and from the relative risk model with no plateau in the upper dose range. Both models break down the excess deaths by sex for each of the 10 radii. Both model types show that the population in the 5- to 10-mile radius experiences the largest number of excess deaths, while the population in the 40- to 50-mile radius experiences the smallest number. In no case do the estimates of excess deaths (male or female) in any radius exceed 1, again demonstrating the small health impact of the Three Mile Island accident. The absolute model predicts more deaths for females, while the relative risk model predicts more deaths for males.

A second example of the use of the SPAHR routine SITE is presented in Table 4.4. The breakdown in mortality by cause of death is shown for the 5- to 10-mile radius using the relative risk model with a 30-year plateau and the best-estimate dose level. Table 4.4 is taken directly from the SITE output. As Table 4.3 shows, this 5- to 10-mile radius represents the area where the largest number of predicted excess deaths will occur. Ten causes of cancer death are listed, and the list is repeated. The first set of deaths represents the baseline mortality level in the projection interval, while the second set of deaths, or those deaths followed by a 1, represents the excess deaths due to the effluent. The word _BASELN_ represents the total number of spontaneous or baseline deaths in the population during the projection interval. Total excess deaths are listed under EXCESS1. In the 100-year projection interval, 103,900 deaths are estimated to occur among women. Of these, 17,600 are from cancer, and 0.1558 of the deaths due to cancer are estimated to result from the accident at Three Mile Island. This table presents both baseline and excess morbid years lost. Of the 26,902 morbid years lost to female breast cancer in this radius, less than one-half a year (0.3953) is estimated to be lost because of the accident at Three Mile Island.

A final measure of the impact of the accident to persons living at various distances from the plant can be obtained from examining the change in life expectancies over time. Table 4.5 presents these estimates for persons in three different radii using the relative risk model with no plateau. The only

Table 4.3. Estimated Excess Deaths Due to the Three Mile Island Accident in the Offsite Population in Each of 10 Radii Using Two Model Types in the SPAHR Formulation.

Radius (Miles)	Total Population*	Average Individual Exposure (mR)		Excess Deaths Predicted by Models: Absolute (30-yr plateau) Lower Bound		Excess Deaths Predicted by Models: Relative (no plateau) Upper Bound	
		Lower Bound	Upper Bound	Females	Males	Females	Males
0-1	658	62.1	205.6	0.005	0.003	0.060	0.062
1-2	2017	26.4	87.5	0.007	0.004	0.078	0.082
2-3	7579	50.5	167.3	0.049	0.030	0.561	0.588
3-4	9676	29.0	96.2	0.036	0.022	0.412	0.431
4-5	8891	6.9	22.7	0.008	0.005	0.089	0.094
5-10	137474	4.7	15.6	0.082	0.051	0.949	0.994
10-20	577288	0.19	0.63	0.014	0.009	0.161	0.167
20-30	433001	0.050	0.166	0.003	0.002	0.032	0.033
30-40	273857	0.0055	0.0182	0.000	0.000	0.022	0.023
40-50	713210	0.00038	0.00127	0.000	0.000	0.000	0.000
Sum	2165651			0.204	0.126	2.364	2.474

*Taken from Table A-1 (USNRC, 1979)

Table 4.4. Output from SPAHR

Cause	Morbid Years Lost		Deaths	
	Female	Male	Female	Male
Leukemia	1359.	1576.	742.4	861.0
Lung	6548.	1.413E+04	1376.	5586.
Stomach	1120.	1376.	751.6	997.0
Alimenry	1.959E+04	1.514E+04	3717.	3298.
Pancreas	520.6	401.5	1157.	854.2
Breast	2.692E+04	222.5	3365.	27.81
Bone	207.4	361.2	89.87	105.6
Thyroid	473.0	218.2	87.59	40.41
Other	2.865E+04	2.924E+04	6310.	6441.
Cancer	.0	.0	1.760E+04	1.821E+04
BASELN	.0	.0	1.039E+05	1.123E+05
Leukemi1*	4.710E-02	5.416E-02	2.574E-02	2.960E-02
Lung___1	8.931E-02	.1914	1.876E-02	7.566E-02
Stomach1	1.219E-02	1.473E-02	8.179E-03	1.067E-02
Alimenr1	1.724E-02	1.323E-02	3.306E-03	2.882E-03
Pancrea1	1.724E-03	1.295E-03	3.831E-03	2.756E-03
Breast_1	.3953	3.279E-03	4.942E-02	4.099E-04
Bone___1	2.390E-02	3.287E-02	6.989E-03	9.611E-03
Thyroid1	2.310E-03	1.223E-03	4.277E-04	2.266E-04
Other__1	.1780	.1760	3.920E-02	3.876E-02
_EXCESS1	.0	.0	.1558	.1706
EXCESS	.0	.0	.1558	.1706

*Denotes excess deaths due to effluent.

perceivable change in life expectancy over time occurs among women in the 0- to 1-mile radius, which received the highest average individual dose. Only after 1994 is there any perceivable decrease in life expectancy resulting from the accident, and this decrease is in the range of only 1/1000 of a year, from 75.628 to 75.627 years. After 2024 the life expectancy is equal to that in 1979. In other words, the effect of the accident will be spread out over a long period of time, roughly 50 years. The accident has no perceivable effect on the life expectancy in the other two radii because the individual dose is so small. The small decrease in life expectancies across time for all radii should be compared to the increasing life expectancy in this country since at least 1880, which indicates that life expectancy in the United States should continue to increase, more than making up for this small decrease.

In summary, the SPAHR routine SITE can perform health risk assessments based upon data tables found in Final Environmental Statements provided by the

Nuclear Regulatory Commission. The accident at Three Mile Island has been reanalyzed using this routine. In general, the health impacts estimated by the NRC (USNRC, 1979) are remarkably consistent with the results of SPAHR. However, the SPAHR approach provides added detail that can be useful in examining the effects through time, over space, between sexes, and across diseases.

Table 4.5. Estimated Life Expectancies at Birth for Females at Various Distances from TMI Assuming a Relative Risk Model (No Plateau), Best Estimate Dose Level

	Life Expectancies at Birth		
	0-1 Miles	3-4 Miles	5-10 Miles
1978-84	75.628	75.628	75.628
1984-89	75.628	75.628	75.628
1989-94	75.628	75.628	75.628
1994-99	75.627	75.628	75.628
1999-2004	75.627	75.628	75.628
2004-09	75.627	75.628	75.628
2009-14	75.627	75.628	75.628
2014-19	75.627	75.628	75.628
2019-24	75.627	75.628	75.628
2024-29	75.628	75.628	75.628
2029-2079	75.628	75.628	75.628

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