JAERI-M
89-112

DEVELOPMENT OF A COMPUTER CODE SYSTEM FOR SELECTING OFF-SITE PROTECTIVE ACTION IN RADIOLOGICAL ACCIDENTS BASED ON THE MULTIOBJECTIVE OPTIMIZATION METHOD

September 1989

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編集兼発行　日本原子力研究所
印　　　刷　日立高速印刷株式会社

Development of a Computer Code System for Selecting Off-site Protective Action in Radiological Accidents Based on the Multiobjective Optimization Method

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(Received August 3, 1989)

This report presents a new method to support selection of off-site protective action in nuclear reactor accidents, and provides a user's manual of a computer code system, PRASMA, developed using the method. The PRASMA code system gives several candidates of protective action zones of evacuation, sheltering and no action based on the multiobjective optimization method, which requires objective functions and decision variables. We have assigned population risks of fatality, injury and cost as the objective functions, and distances from a nuclear power plant characterizing the above three protective action zones as the decision variables.

Keywords : Protective Action, Reactor Accident, Evacuation, Sheltering,
Multiobjective Optimization Method, Risk, Consequence,
Objective Function, Decision Variable, PRASMA

JAERI－M　89－112

原子力発電プラント緊急時の防護対策に係わる意思決定を支援するための計算コードシステムの開発

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（1989年8月3日受理）

原子力発電プラント緊急時の防護対策に係わる意思決定を支援するための評価手法を開発した。本報は，同手法とそれに基づいた計算コードシステムＰＲＡＳＭＡの使用手引について述べたものである。本コードシステムは，多目的変数最適化法に基づき，緊急時に周辺住民に対してとられる防護対策（屋内退避と避難）の実施範囲の選定を支援するためのものである。最適化の対象となる目的変数として，死亡，傷害および費用についての集団リスクを考慮した。また，これらの目的変数を最適化，すなわちリスクを最小化する上での防護対策範囲を定めるパラメータ（決定変数）としてプラントからの距離を考慮した。

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Contents

目　次

1. Introduction

Two major reactor accidents in commercial nuclear power plants, i.e. Three Mile Island 2 (TMI-2) and Chernobyl 4, have raised our attention for importance to not only the nuclear safety problem relating to severe accidents research, accident management and operator actions, but also issues relating to emergency preparedness and response such as the most appropriate protective action to be taken, its timing, emergency level, a reasonable emergency planning zone and so on.

Weerakkody and Witzig (1),(2) (hereafter called WW) proposed the model to select an appropriate off-site protective action of the choices of evacuation, sheltering, and no action in a nuclear reactor accident emergency. The model is based on the statistical decision theory, where the minimax principle and the Bayes action principle are taken alternatively using a concept of entropy for selection between these principles. Although the model proposed by WW takes account of three kinds of consequences (individual fatality, injury and cost) associated with reactor accidents, the consequences are eventually reduced to one-dimensional measure, i.e. individual fatality, using conversion factors between the fatality and the other consequences (injury and cost). Since fatality, injury and cost have different units of consequences, it is questionable to reduce these consequences to one-dimensional measure of consequence. This would bring uncertainty in the reduced one-dimensional consequence due to uncertainty involved in conversion factors.

In order to overcome the above problem, we have developed a new method to select an appropriate off-site protective action during reactor accidents. The method is based upon the multiobjective optimization method, where different kinds of consequences are treated as they are without introducing one-dimensional reduced measure of consequence. We introduce population risks of fatality, injury and cost, because population effects would be important in emergency preparedness from a point of view of overall risks around the site of concern. In this report, the population risk is defined as integrated individual risk over the population around the affected nuclear power plant, and individual risk is defined as the product of individual consequence and occurrence probability of the event corresponding to the consequence. The fatality and injury considered are (a) early and continuing effects and late somatic effects due to radiation exposure, and (b) travel consequence and non-radiological consequence of sheltering. The cost considered is cost of evacuation and sheltering. The population risks are calculated based on the individual risks provided by the SOPA (Selects Off-site Protective Action) model developed by WW, taking account of population density around the nuclear power plant. Given calculated population risks, the new method provides some candidates of protective action zones of evacuation, sheltering and no action. To make numerical calculations with the method possible, we have developed a computer code system PRASMA (Protective Action Selection based on Multiobjective Optimization Approach) as the first version which will be revised when more sophisticated individual model included in PRASMA be developed and more reliable data be prepared in future.

Chapter 2 describes the methodology for selecting off-site protective action based on multiobjective optimization approach. Chapter 3 outlines the composition and functions of the PRASMA code system. Chapter 4 gives an explanation of input and output variables. A sample run with PRASMA is given in chapter 5.

2. Multiobjective Optimization Approach

The off-site protective action selection is closely related to several consequences caused by reactor accidents, such as fatality, injury and cost. In order to treat these consequences as they are, we have developed a model, PRASMA, by applying the multiobjective optimization method to the problem of the off-site protective action selection.

Since the PRASMA model uses the data of consequences and risks given by the WW's SOPA model, we first recapitulate the WW's model based on the statistical decision theory in section 2.1. The PRASMA model based on the multiobjective optimization method are developed and described in the following sections, where the multiobjective variables and decision variables are introduced.

2.1 Recapitulation of Statistical Decision Theory

For the convenience of the discussions developed in the following sections, we will now recapitulate the statistical decision theory for application to selecting off-site protective action proposed by WW.(1),(2) The loss function, the uncertainty states, and Bayes action principle will be briefly described which are essential to model the off-site protective action selection problem. A detailed description of the model developed by WW is provided in Ref. 1.

2.1.1 The Loss Function and the Radioactivity Release State

The loss functions, a set of consequences associated with a nuclear reactor accident, selected by WW are radiation fatalities, radiation injuries, evacuation fatalities, evacuation injuries, cost of evacuation, consequences at shelters of relocation and consequences of sheltering. The CRAC2 model(3) was used as the major guide for radiation dose calculations. It should be noted that these seven components are measured in different units (fatalities per person, injuries per person, and dollars per person) and that to solve the statistical decision problem WW have reduced these seven components to the one-dimensional loss function, fatalities per person, using appropriate conversion factors.

As the radioactivity release states, a set of parameters that contains uncertainty and that influences the loss functions is selected. The parameters are release duration, warning time, noble gas release, particulate release, height of release, and energy of release.

2.1.2 The Spectrum of Potential Release State

Although the release state space consists of an infinite members, they are practically divided into a manageably finite number of members of release states, $\mathbf{S}_j$, where "j" denotes the j-th member. To identify the finite number of members of potential release states, the model developed uses the functional event tree of safety systems associated with the initiating event and containment event tree. The complete description of the spectrum of release states requires not only identification of each member but also the occurrence probability $g(\mathbf{S}_j)$ of each member.

2.1.3 The Bayes Action Principle

The Bayes action principle suggests that the appropriate action a_k would minimize the individual risk at distance x from the plant, $Z(a_k,x)$, defined as

$$Z(a_k,x) = \sum_j g(\mathbf{S}_j)\ L(a_k,\mathbf{S}_j,x). \tag{2.1}$$

$L(a_k,\mathbf{S}_j,x)$ is a loss function value at distance x if action a_k is taken when release state is $\mathbf{S}_j$. Here, $Z(a_k,x)$ is nothing more than the linear or actuarial conditional risk.

2.2 Multiobjective Optimization Method

2.2.1 General Theory(4),(5)

Multiobjective programming deals with optimization problems with two or more objective functions. The multiobjective optimization problem is written generally as

$$\text{minimize} \quad \mathbf{Z}(\mathbf{X}) = [Z_1(\mathbf{X}),\ Z_2(\mathbf{X}),\ \ldots,\ Z_p(\mathbf{X})] \qquad (2.2)$$
$$\text{subject to} \quad \mathbf{X} \in F$$

in which $\mathbf{Z}(\mathbf{X})$ is a p-dimensional vector composed of the objective functions, F is the feasible region in a decision space and **X** called decision variable denotes a set of variables in the decision space.

A solution **X** is noninferior if there exists no feasible **X'** such that

$$Z_i(\mathbf{X}') \leq Z_i(\mathbf{X}), \quad i = 1, 2, \ldots, p \qquad (2.3)$$

where the strict inequality holds at least one i. Here, $\mathbf{Z}(\mathbf{X})$ corresponding to a noninferior solution **X** is called the noninferior function. In other words, the noninferior $\mathbf{Z}(\mathbf{X})$ is a vector that is not dominated by other $\mathbf{Z}(\mathbf{X}')$ in all of its objective functions. Solving inequality (2.3) is to find all such noninferior solutions.

Figure 2.1 represents for the two-dimensional case a mapping of the feasible decision space F to the outcome R.(4) The noninferior solutions are shown crosshatched along the "southwest" boundary in the outcome space. It should be noted that the multiobjective optimization method generally gives several solutions instead of one definite solution.

There exist several solution techniques(5) for multiobjective optimization problems including weighting method,(4) constraint method(4) and direct method.(6) These techniques would be applicable to a specific or a simple problem where relationship between objective function and decision variables is expressed in a analytic form. The direct usage of these methods does not seem to practical to the present problem, we, therefore, have developed a technique to numerically solve the inequality (2.3) (see section 3.2.2).

2.2.2 Population Risks, Objective Functions and Decision Variables

The WW model for the off-site protective action selection is based on the individual loss function or risk and does not consider the effect of the population around the nuclear power plant. We introduce here a concept of population risk, which is closely related to decision variables and multiobjective functions required in the multiobjective optimization approach.

In order to determine decision variables, we divide off-site area of concern into three zones of evacuation, sheltering and no action. Then, as decision variables, we assign distances from the affected plant which characterize these three zones. As objective functions, we assign three kinds of population risks relating to fatality, injury and cost. A more detailed description is provided below.

We start with the objective function, that is population risk, given by

$$Z_i = \iint_{A_E} f(\mathbf{r}) z_i(E,\mathbf{r}) d\mathbf{r} + \iint_{A_S} f(\mathbf{r}) z_i(S,\mathbf{r}) d\mathbf{r} + \iint_{A_N} f(\mathbf{r}) z_i(N,\mathbf{r}) d\mathbf{r}. \qquad (2.4)$$

Here Z_i is the i-th objective function relating to population fatality, injury or cost as denoted by subscript i. The variables $z_i(E,\mathbf{r})$, $z_i(S,\mathbf{r})$ and $z_i(N,\mathbf{r})$ are individual i-th risk at the location specified by $\mathbf{r}$ under protective actions of evacuation, sheltering and no action, respectively, defined as

$$z_i(a_k,\mathbf{r}) = \sum_j g(\mathbf{S}_j) L_i(a_k,\mathbf{S}_j,\mathbf{r}), \qquad (2.5)$$

$$a_k = E,\ S \text{ or } N.$$

Here, $L_i(a_k,\mathbf{S}_j,\mathbf{r})$ is a loss function value of i-th consequence. The protective action zones of evacuation, sheltering and no action are denoted by A_E, A_S and A_N, respectively, and $f(\mathbf{r})$ means a population density function. The individual risk $z_i(a_k,\mathbf{r})$ is calculated using the SOPA model. In the SOPA model, the loss function caused by radiation dose is essentially based upon the CRAC2 model, where the direction of radiation plume is assumed to be unchanged and the spread of plume perpendicular to wind direction is considered in a term of the top hat function. In order to make calculation of the population risks in Eq. (2.4) easy and practical, we limit the area of concern to an area shown in Figure 2.2. The lateral dispersion parameter, $\sigma_y(x)$, at distance x from the plant to the downwind location is given by

$$\sigma_y(x) = a \cdot x^b \tag{2.6}$$

with two parameters a and b, which depend upon atmosphere conditions and their values are given in Table 2.1.

Since Eq. (2.4) takes a general form with respect to integral region of protective action zone, some insight would be needed to make the integral calculation in Eq. (2.4) practically possible. It is generally probable that for a large amount of radioactive release to the environment the protective action will be varied from evacuation to sheltering, and sheltering to no action as the distance from the plant is larger. We therefore consider three protective actions of evacuation, sheltering and no action, and assume that these zones are characterized by two parameters, X_E and X_S, presenting distances from the plant. In other words, X_E and X_S denote the boundary between the zones of evacuation and sheltering, and the boundary between the zones of sheltering and no action, respectively, as illustrated in Figure 2.2. Assuming that an inequality $X_E \leq X_S$ is satisfied and that the population density in the area concerned depends on only the distance from the plant to the downwind location, the objective function Z_i in Eq. (2.4) is rewritten as

$$\begin{aligned} Z_i &= 3\int_{X_{min}}^{X_E} dx\, \sigma_y(x) f(x) z_i(E,x) \\ &+ 3\int_{X_E}^{X_S} dx\, \sigma_y(x) f(x) z_i(S,x) \\ &+ 3\int_{X_S}^{X_{max}} dx\, \sigma_y(x) f(x) z_i(N,x), \end{aligned} \tag{2.7}$$

with

$$X_{min} \leq X_E \leq X_S \leq X_{max}. \tag{2.8}$$

Here X_{min} is the boundary between on-site and off-site, and X_{max} is the maximum distance considered where radiation effects to the public are expected to be negligibly small. Now the objective function includes two parameters, X_E and X_S, relating to protective action zone. In applying the multiobjective optimization method to off-site protective action selection, we take the variable set $\mathbf{X} = (X_E, X_S)$ as decision variables. In other words, the objective functions Z_i are optimized by solving the inequality relation (2.3) so as to determine values of the variable $\mathbf{X}$.

2.3 Summary of Method

In order to select an appropriate off-site protective action in a nuclear reactor accident, the multiobjective optimization method has been introduced. We have assigned population risks of fatality, injury and cost as objective functions, and distances from a plant as decision variables. The population risks are calculated based on the individual risk given by the SOPA model with taking account of population statistics. The procedure to select the off-site protective action in the multiobjective optimization method is summarized as follows:

(1) Determine the set of potential release states $\mathbf{S}_j$ and the occurrence probability, $g(\mathbf{S}_j)$, of each state.

(2) For each potential release state, calculate individual consequences (or loss functions), $L_i(a_k,\mathbf{S}_j,x)$, of fatality, injury and cost at distance x from the plant under actions a_k of evacuation, sheltering and no action.

(3) Calculate individual risk $z_i(a_k,x)$ of fatality, injury and cost at distance x as given by

$$z_i(a_k,x) = \sum_j g(\mathbf{S}_j)\, L_i(a_k,\mathbf{S}_j,x). \tag{2.9}$$

(4) Calculate population risk Z_i as a function of the set of variables $\mathbf{X}=(X_E,X_S)$ (X_E: distance denoting boundary between zones of evacuation and sheltering, X_S: distance denoting boundary between

zones of sheltering and no action) using a population density around the plant.

(5) Solve the inequality relations in the multiobjective optimization method by assigning Z_i and $\mathbf{X}$ as objective functions and a set of decision variables, respectively.

Table 2.1 Dispersion parameter values.

Stability class	Description	a	b
A	extremely unstable	0.3658	0.9031
B	moderately unstable	0.2751	0.9031
C	slightly unstable	0.2089	0.9031
D	neutral	0.1471	0.9031
E	slightly stable	0.1046	0.9031
F	very stable	0.0722	0.9031

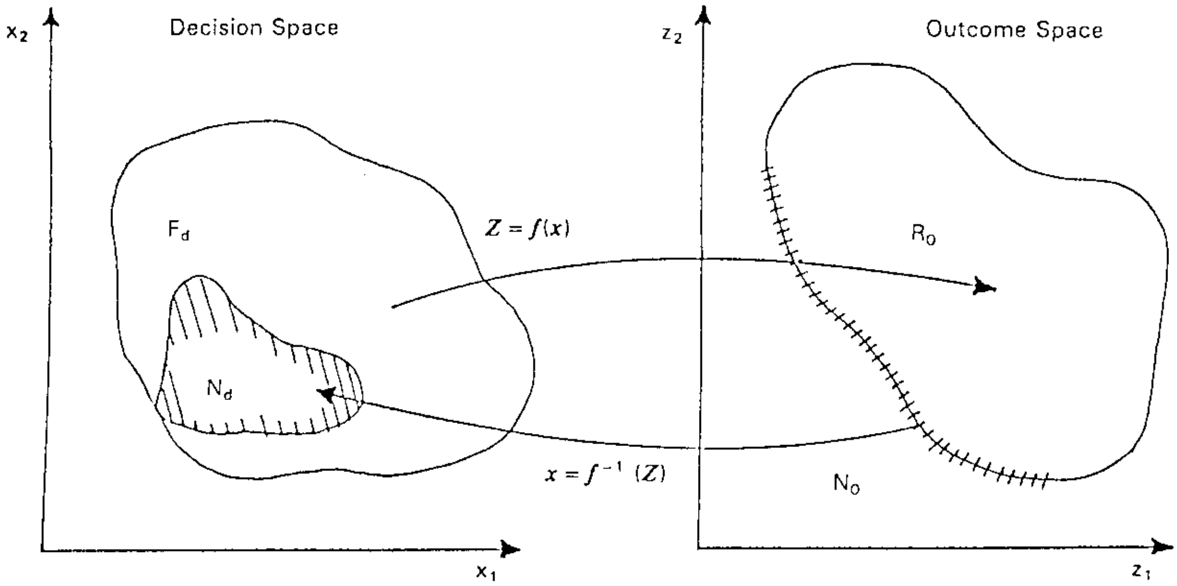

Fig. 2.1 Mapping of decision space into outcome space; crosshatched subspace N_d and N_o are noninferior solutions$^{(4)}$.

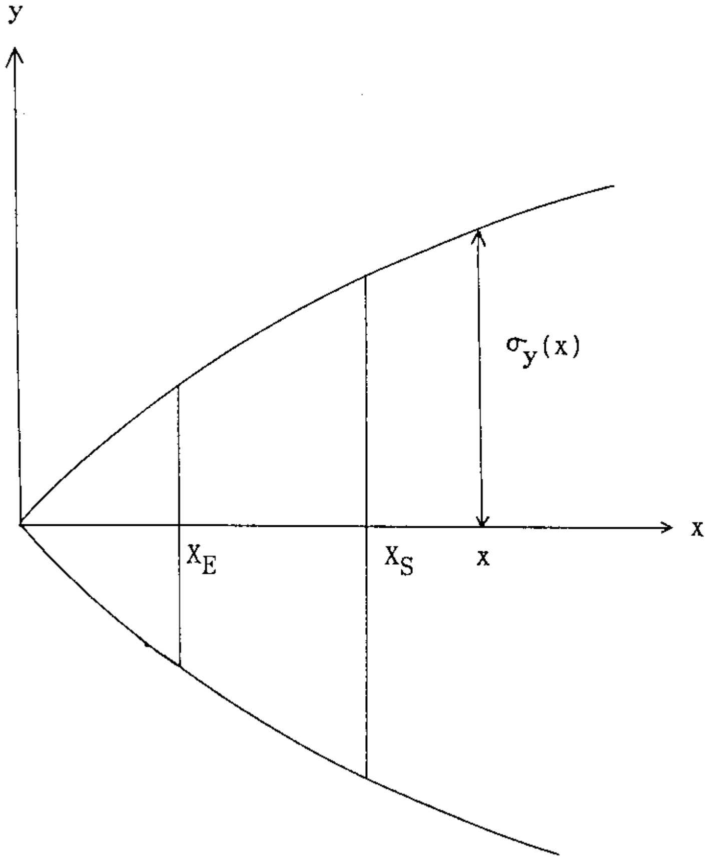

Fig. 2.2 Conceptual diagram illustrating area considered in the PRASMA model for off-site protective action.

3. Description of the PRASMA code system

This chapter describes composition and functions of the PRASMA code system.

3.1 Composition

The PRASMA code system is composed of three computer codes, IND, POP and GRAPH, and two interface files, IRISK and PRISK, as is shown in Figure 3.1. The IND code calculates individual risks of fatality, injury, and cost at a distance from a reference nuclear power plant under protective actions of evacuation, sheltering, and no action. The models embedded in IND are essentially the same as those in SOPA, although a slight modification of SOPA has been made to incorporate SOPA into the PRASMA code system. The POP code calculates population risks using individual risk values of the IND output through the interface file IRISK and taking account of population density, and then provides several candidates of appropriate off-site protective action zones based on the multiobjective optimization method. The GRAPH code graphically draws the output of IND and POP with the data being delivered through the interface files, IRISK and PRISK.

3.2 Functions

This section describes the functions of three member codes, IND, POP, and GRAPH of the PRASMA code system.

3.2.1 IND

The IND code for calculating individual risks of fatality, injury, and cost consists of several subroutines. Figure 3.2 illustrates the flow diagram of the IND code. Function of each subroutine in IND and modified parts from SOPA are outlined below. A more detailed description of these subroutines(1) is provided in Appendix A.

(1) Subroutine SPECT

The purpose of this subroutine is to find potential release states for the accident and to estimate their occurrence probabilities using a functional event tree of safety systems and a containment event tree. The model embedded in this subroutine is currently limited to pressurized water reactors.

(2) Subroutine RAD

This subroutine calculates the loss function values associated with health effect to an average person and a pregnant woman from radiation exposure. The exposure pathways considered are cloudshine, groundshine, and inhalation under evacuation, sheltering, and no action. The subroutine RAD is composed of five lower subroutines, XANDG, DOSE, RISK, SHEL, and EVAC. The brief description of these subroutines is as follows:

1) Subroutine XANDG

This subroutine calculates the value of σ_y, σ_z and χ/Q. Here σ_y and σ_z are the lateral dispersion parameter and the vertical dispersion parameter associated with the standard Gaussian-plume formation model, respectively. χ/Q is time integrated concentration of the airborne nuclide per amount of radioactivity released to the atmosphere.

2) Subroutine DOSE

This subroutine calculates the dose received from three early exposure pathways, cloudshine, short-term groundshine, and inhalation.

3) Subroutine RISK

This subroutine calculates two kinds of health effects, early and continuing effects and late somatic effects, due to radiation exposure based on the models presented in NUREG/CR-4214.(7) Early and continuing effects considered are mortality and morbidity due to the incidence of any of the hematopoietic syndrome, pulmonary syndrome, gastrointestinal syndrome, and pre- and neo-natal death. Late somatic effects considered are mortality and morbidity due to the incidence of thirteen kinds of cancers.

4) Subroutine SHEL

This subroutine calculates the dose reduction factor for sheltering, which is a ratio of dose received while sheltering to dose received while not taking any action.

5) Subroutine EVAC

This subroutine calculates the dose reduction factor for evacuation, which is a ratio of dose received while evacuation to dose received while not taking any action.

(3) Subroutine NONRAD

This subroutine calculates those components of the loss function whose cause is not radiation, including the travel consequences of fatality and injury associated with evacuation, cost of evacuation, and non-radiological consequences of sheltering.

(4) Subroutine BAYES

This subroutine calculates individual risks of fatality, injury, and cost under evacuation, sheltering, and no action at a distance from an affected nuclear power plant.

(5) Modification from SOPA

The models embedded in the IND code are identical to those in the SOPA code. However some modification of SOPA has been made in incorporating it into the PRASMA code system. Modified features from

SOPA to IND are as follows:

1) The IND code has a capability of calculating individual risks at sequential distances from an affected nuclear power plant with one computer run. This function is very useful to calculate population risks in Eq.(2.7), where a numerical integration of individual risks over distance x is required.

2) In order to make an application of PRASMA to the off-site protective action problem more general, some parameters in the SOPA source program relating to plant and/or site are extracted and reduced to IND input variables. The extracted parameters are shown in Table 3.1.

3) Since the minimax principle and selection between the minimax and the Bayes action principles are irrelevant to PRASMA, a part of program relating to them has been omitted in IND.

4) Since the PRASMA model does not require conversion factors between fatality and injury or cost, the conversion factors have been omitted in IND.

3.2.2 POP

The POP code calculates population risks of fatality, injury and cost, and provides several candidates of appropriate off-site protective action zones based on the multiobjective optimization method. The current POP code has an option to select two or three objective functions. Two objective functions included in POP are population risks of fatality and injury (called two-dimensional model hereafter), and three objective functions are population risks of fatality, injury, and cost (called three-dimensional model hereafter).

Figure 3.3 illustrates the flow diagram of POP. Functions of subroutines NC81, SOL2, and SOL3 included in POP are as follows:

(1) Subroutine NC81

This subroutine calculates the population risks Z_i of fatality, injury, and cost given by the Eq.(2.7):

$$
\begin{aligned}
Z_i = {} & 3\int_{X_{min}}^{X_E} dx\,\sigma_y(x)f(x)z_i(E,x) \\
& + 3\int_{X_E}^{X_S} dx\,\sigma_y(x)f(x)z_i(E,x) \\
& + 3\int_{X_S}^{X_{max}} dx\,\sigma_y(x)f(x)z_i(E,x)
\end{aligned}
$$

where, $z_i(E,x)$, $z_i(S,x)$, and $z_i(N,x)$ obtained from the IND output are the individual risks under evacuation, sheltering, and no action, respectively. The off-site population density distribution function f(x) is given by a user as input. The distribution functions currently embedded in this subroutine are :

$$f(x) = c_0, \tag{3.1}$$

$$f(x) = c_1 + c_2 \exp\{-(x-X_C)^2/(2\sigma^2)\}/(\sqrt{2\pi}\,\sigma), \tag{3.2}$$

$$f(x) = \text{histogram}, \tag{3.3}$$

where c_0, c_1, c_2, σ, and X_C are parameters characterizing the distribution and given by input. Data for histogram are given by a user with three input variables of RDXA (equal distance width), RXMAXA (maximum distance considered from the plant), and RDATAA (frequency of each class).

For the numerical integral calculation, the Simpson's formula is used in this subroutine.

(2) Subroutine SOL2

The purpose of this subroutine is to find appropriate off-site protective action zones by solving the inequality relation (2.3) in the multiobjective optimization method for the two-dimensional model.

To solve the inequality (2.3), we have developed a method which solves the inequality directly in a numerical way. A set of decision variable (X_E, X_S) is discretized under the assumption of inequality relation, $X_E \leq X_S$. Figure 3.4 shows an example of calculational points of (X_E, X_S) as denoted by *. The population risks, Z_i, calculated at each point are applied to the inequality relation (2.3). A part of program list of this subroutine presenting a logic to solve inequality (2.3) is shown in Figure 3.5.

(3) Subroutine SOL3

The purpose of this subroutine is to find off-site protective action zones by solving inequality relation (2.3) in the multiobjective optimization method for the three-dimensional model. The solution technique developed for the two-dimensional model has been extended to the three-dimensional model.

3.2.3 GRAPH

The function of the GRAPH code is to print out the output from IND and POP to NLP (Nihongo Line Printer) in a graphic form using a graphic package, DISSPLA.(8) The GRAPH code makes automatic axis scaling with linear X- and Y-axes.

The GRAPH code consists of two subroutines, GRAPH1 and GRAPH2, functions of which are described below:

(1) Subroutine GRAPH1

This subroutine graphically prints out the following quantities given as the IND output through the interface file IRISK:

(a) Individual risks of fatality, injury, and cost at the distance from a nuclear power plant under evacuation, sheltering, and no action.

(2) Subroutine GRAPH2

This subroutine consists of three lower subroutines, PLOT1, PLOT2 and PLOT3, and graphically prints out the following quantities given as the POP output through the interface file PRISK:

(a) Population risks of fatality and injury at the calculational points of decision variable (X_E, X_S) in the two-dimensional model (subroutine PLOT1).

(b) Two-dimensional presentation of a pair of population risks of fatality and injury, in the two-dimensional model (subroutine PLOT2).

(c) Population risks of fatality, injury, and cost at the calculational points of decision variable (X_E, X_S) in the three-dimensional model (subroutine PLOT3).

3.3 Limitation

Limitation of the current PRASMA code system is summarized as follows:

(1) PRASMA deals with only a PWR plant, although it could be extended to accommodate a BWR plant by incorporating the BWR source term spectrum and appropriate event trees.

(2) In the two-dimensional model, the multiobjective functions are limited to population risks of fatality and injury.

(3) Protective action zones are limited to the downwind direction and hence the distribution function for the off-site population density is given as a function of one-dimensional parameter, x, representing distance from the plant to the downwind location.

Other miscellaneous limitations associated with each member code will be described in section 4.1.

Table 3.1 Parameters extracted from the SOPA source program as the IND input variables.

- Occurrence probabilities of steam explosion, inadequate isolation, and hydrogen combustion.
- Volume of containment.
- Constant of proportionality relating to design leakage
- Heat released.
- Release height.
- Release duration.
- Period between the instant of recognizing potential emergency and the instant of radionuclide release start.
- Fraction of core inventory released to the environment.
- Breathing rate.
- Grass length indicating surface roughness.
- Time step width for dose reduction factor calculations.
- Non-radioactive consequences of fatality and injury.

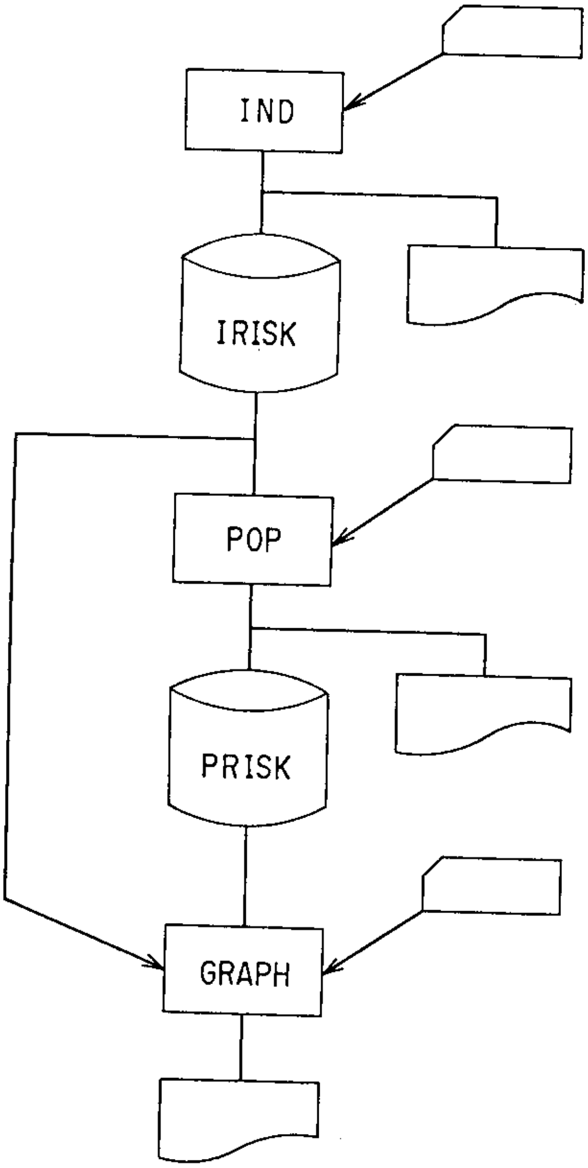

Fig. 3.1 Composition of the PRASMA code system.

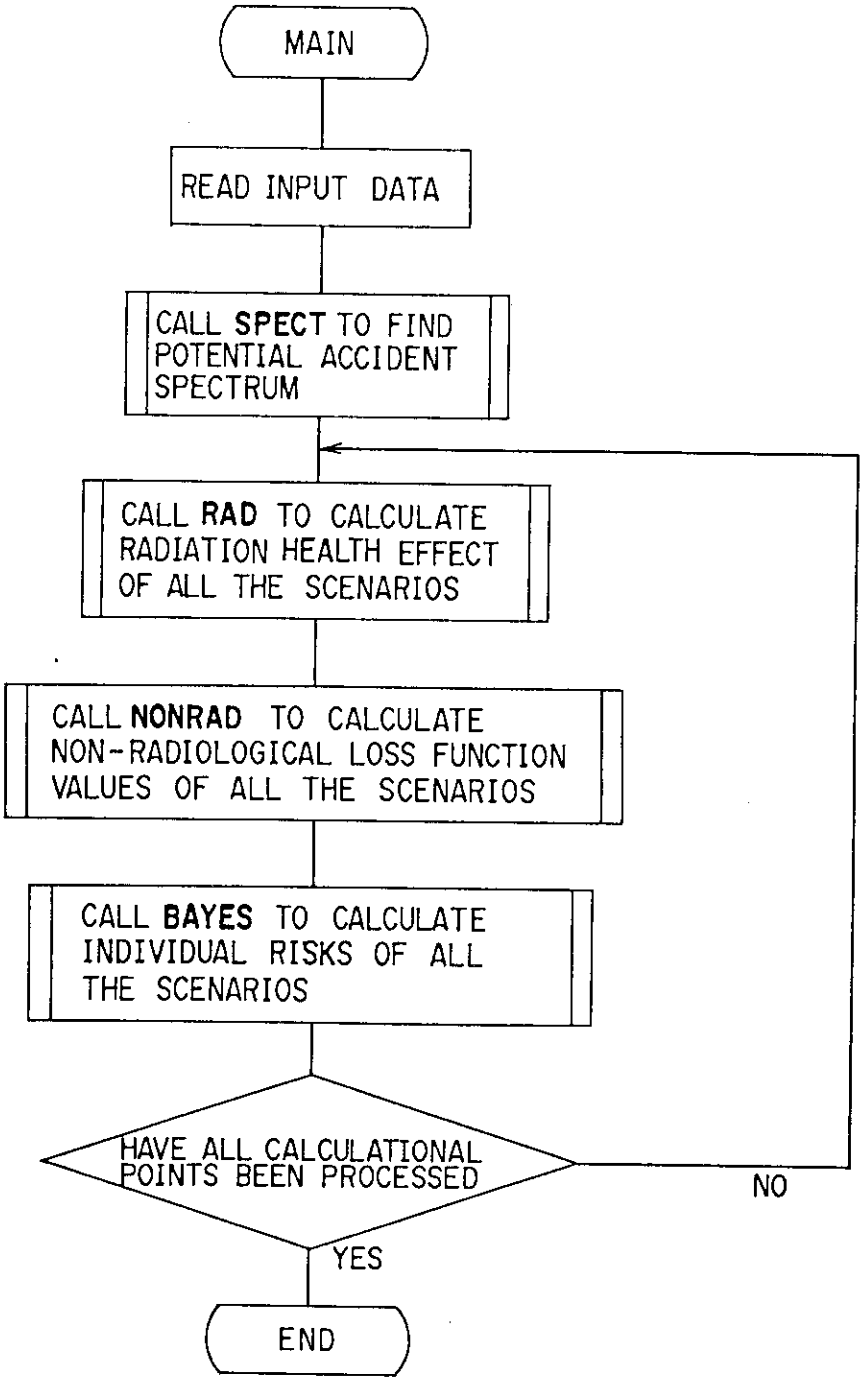

Fig. 3.2 The flow diagram of IND.

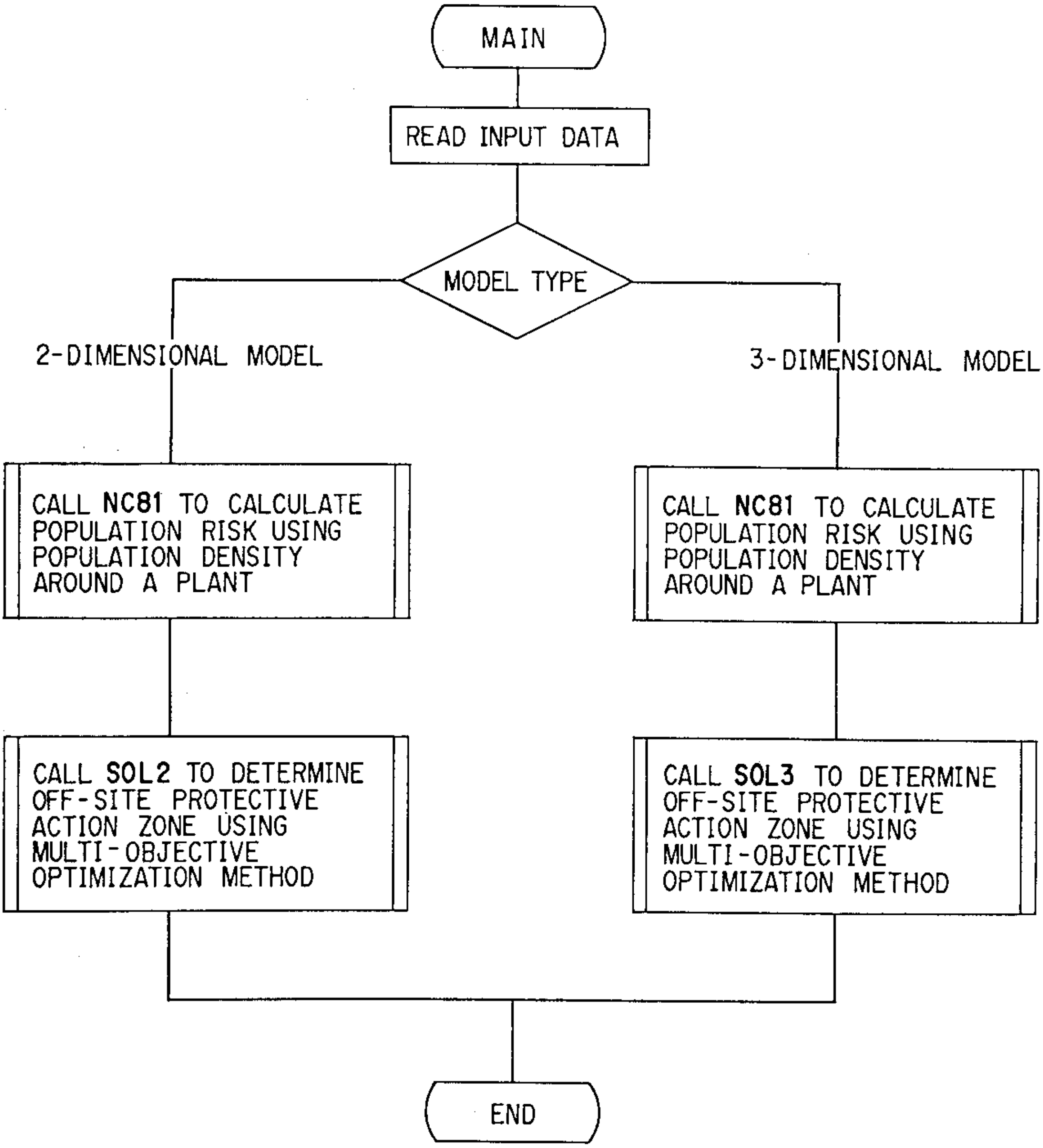

Fig. 3.3 The flow diagram of POP.

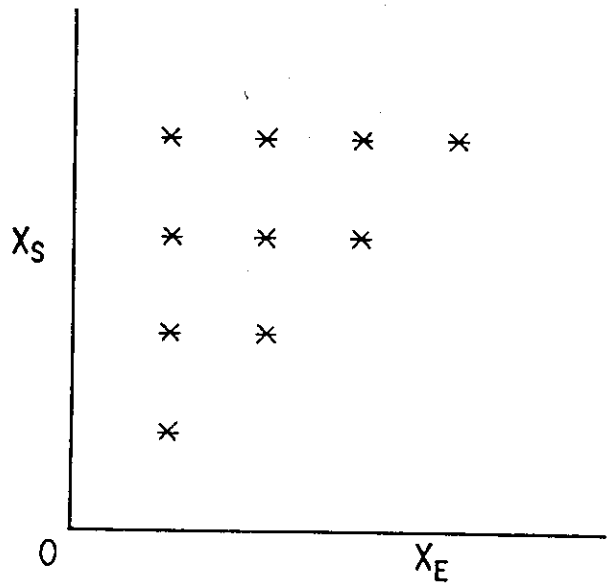

Fig. 3.4 An example of discretization of decision variable (X_E, X_S).

```
      DO 520 I=1,NDATA
       DO 530 J=1,NDATA
         IF(J .EQ. I) GOTO 530
           IF((ZWF1(J) .LT. ZWF1(I)) .AND.
     1        (ZWI1(J) .LE. ZWI1(I))) THEN
           ELSE
            IDEC1(I,J)=1
           ENDIF
  530    CONTINUE
  520  CONTINUE
      DO 540 I=1,NDATA
       DO 550 J=1,NDATA
         IF(J .EQ. I) GOTO 550
           IF((ZWF1(J) .LE. ZWF1(I)) .AND.
     1        (ZWI1(J) .LT. ZWI1(I))) THEN
           ELSE
            IDEC2(I,J)=1
           ENDIF
  550    CONTINUE
  540  CONTINUE
       DO 580 I=1,NDATA
        DO 590 J=1,NDATA
          IDECI(I,J)=IDEC1(I,J)*IDEC2(I,J)
  590   CONTINUE
  580   CONTINUE
       K=0
       DO 600 I=1,NDATA
      DF=1.0
        DO 610 J=1,NDATA
         IF(J .EQ. I) GOTO 610
          DF=DF*IDECI(I,J)
  610   CONTINUE
        IF(DF .EQ. 1.0) THEN
          K=K+1
          ISOLT1(K)=I
        ENDIF
  600  CONTINUE
```

Fig. 3.5 A program list presenting a logic for solving inequality relation (2.3) in the two-demensional model.

4. Input/Output Variables

4.1 Input Variables

Table 4.1 shows input variables to the IND code. Those parameters extracted from the SOPA source program as the IND input variables and those newly added as the IND input variables are marked with * and +, respectively. All the input variables other than NAME, PARENT, QIN, HALF, DEPV, DCCS, GCCS, and BCCS are free format. Table 4.3 shows the input variables to the POP code, where all the input variables are free format. Input variables to the GRAPH code are shown in Table 4.4.

4.2 Output Variables

4.2.1 Interface File

The PRASMA code system includes two interface files, IRISK and PRISK, as has been shown in Figure 3.1. The interface file IRISK stores the individual risks of fatality, injury, and cost under off-site protective actions of evacuation, sheltering, and no action which are calculated from the IND code. The interface file PRISK stores the population risks of fatality, injury, and cost which are calculated from the POP code. Table 4.5 summarizes the individual radiological and non-radiological risks under each protective action calculated by IND.

The interface file IRISK whose logical record length is 48 byte with fixed block plays a role of delivering the IND output data to the input data of POP and GRAPH. The interface file PRISK whose logical record length is 96 byte with fixed block plays a role of delivering the POP output data to the GRAPH input data. The contents of the interface files, IRISK and PRISK, are shown in Tables 4.6 and 4.7, respectively.

4.2.2 Output items

Table 4.8 shows the output items of each member code in the PRASMA code system. An example of output list of each code will be given in chapter 5.

Table 4.1 Input variables to IND (1/10).

Card No.	Variable	Description
1	INIT	initiating event 1 : large break loss of coolant accidents 2 : small break loss of coolant accidents 3 : loss of off-site power 4 : loss of feed water
2	ICPRES	availability of containment pressure (option for presenting design leakage) 0 : unavailable 1 : available
	ICFRN	availability of containment noble gas concentration (option for presenting design leakage) 0 : unavailable 1 : available
	ICFRI	availability of containment iodine fraction (option for presenting design leakage) 0 : unavailable 1 : available

Table 4.1 Input variables to IND (2/10).

Card No.	Variable	Description
3	DFRN(I)	fraction of core inventory in containment atmosphere for I-th nuclide group I=1 : noble gas =2 : iodine
4	DELP	pressure difference of inside and outside of containment [psi]
	DELT	expected leak duration [min]
5	IDEM(I)	flag presenting demand for I-th safety system in an accident sequence ($1 \leq I \leq 15$) 0 : undemaded 1 : demanded for the accident sequence initiated by a LOFW, for instance (see Figure A.1 and Table A.1 in Appendix A) I=1 : reactor trip 2 : auxiliary feed water and secondary heat removal 3 : pilot-operated relief valve demanded ? 4 : pilot-operated relief valve closed ? 5 : high pressure injection 6 : long term core cooling 7 : containment spray injection system

Table 4.1 Input variables to IND (3/10).

Card No.	Variable	Description
		8 : containment heat removal system 9 : containment spray recirculation system
6	IFUN(I)	flag presenting I-th safety system function in an accident sequence ($1 \leq I \leq 15$) 0 : unfunctional 1 : functional
7	FAV(I)	failure probability of I-th safety system function in an accident sequence ($1 \leq I \leq 15$)
8	INPRI(I)	print out option for input data ($1 \leq I \leq 4$) 0 : no print 1 : print
9	IOUT(I)	print out option for output data ($1 \leq I \leq 10$) 0 : no print 1 : print
10	WIND	wind speed [m/s]
	FMIX	mixing height of the atmosphere [m]
	ISTA	atmosphere stability category

Table 4.1 Input variables to IND (4/10).

Card No.	Variable	Description
		1 = extremely unstable (A) 2 = moderately unstable (B) 3 = slightly unstable (C) 4 = neutral (D) 5 = slightly stable (E) 6 = very stable (F)
	$XMIN^+$	minimum distance considered from a nuclear power plant in calculation of individual risks [m]
	$DISTM^+$	maximum distance considered from a nuclear power plant in calculation of individual risks [m]
	DX^+	distance width for calculation of individual risks [m] ($DX \leq DISTM$)
	ZLOC	vertical height of the location of concern [m]
11	NAME(I)	isotope name of I-th nuclide (A8), ($1 \leq I \leq 54$) (see Table 4.2)
	PARENT(I)	fertile nuclide of I-th nuclide (A8), ($1 \leq I \leq 54$)
	QIN(I)	core inventory of I-th nuclide [Ci], (E10.3), ($1 \leq I \leq 54$)

Table 4.1 Input variables to IND (5/10).

Card No.	Variable	Description
	HALF(I)	half life of I-th nuclide [day], (E10.3), $(1 \leq I \leq 54)$
	DEPV(I)	deposition velocity to the ground of I-th nuclide [m/s], (E10.3), $(1 \leq I \leq 54)$
12	DCCS(I,J)	cloudshine dose commitment factor for I-th nuclide and J-th organ [rem/(Ci s/m^3)], (E10.3), $(1 \leq I \leq 54)$ J = 1 : whole body = 2 : total bone marrow = 3 : lung = 4 : testes
13	GSCCS(I,J)	groundshine dose commitment factor for I-th nuclide and J-th organ [rem/(Ci/m^2)], (E10.2), $(1 \leq I \leq 54)$ J = 1 : whole body = 2 : total bone marrow = 3 : lung = 4 : testes
14	BCCS(I,J)	dose factor for inhaled I-th nuclide and J-th organ [rem/C_i], (E10.1), $(1 \leq I \leq 54)$ J = 1 : thyroid = 2 : skeleton = 3 : lower large intestinal wall

Table 4.1 Input variables to IND (6/10).

Card No.	Variable	Description
		= 4 : lung = 5 : total bone marrow
15	FNUM(I)	air ventilation rate of shelter [1/min] I = 1 : noble gas = 2 : iodine
	IBTYPE	building type 1 : wood 2 : basement wood house 3 : brick 4 : basement of brick 5 : large office building
16	SPEEDS	speed of evacuation [m/min]
	IDAYS	time of accident 1 = day time 2 = night time
	TPS	time spent on preparation to evacuate [min]
	TDMS	time spent on recommending off-site protective strategy after realizing the emergency [min]

Table 4.1 Input variables to IND (7/10).

Card No.	Variable	Description
17	EVDIST	evacuation distance [km]
	EVCOST	evacuation cost [$/person]
	RSHEL	non-radioactive consequence of sheltering [$/person]
18	PALP*	occurrence probability of steam explosion
	PBETA*	occurrence probability of inadequate isolation
	PGAM*	occurrence probability of hydrogen combustion
19	VCON*	volume of containment [m^3]
	CCON*	constant of proportionality relating to design leakage
20	QH(I)*	heat released in I-th accident scenario [cal/s], ($1 \leq I \leq 10$) I=1 : large LOCA 2 : Small LOCA 3 : loss of feed water 4 : loss of off-site power 5-10 : not used

Table 4.1 Input variables to IND (8/10).

Card No.	Variable	Description
21	QH(I)*	heat released in I-th accident scenario [cal/s], $(11 \leq I \leq 20)$
22	HEIG(I)*	release height in I-th accident scenario [m], $(1 \leq I \leq 10)$
23	HEIG(I)*	release height in I-th accident scenario [m], $(11 \leq I \leq 20)$
24	RD(I)*	release duration in I-th accident scenario [min] $(1 \leq I \leq 11)$
25	TW(I)*	period between the instant of recognizing potential emergency and the instant of radionuclide release start in I-th accident scenario [min], $(1 \leq I \leq 11)$
26	FRN(I,J)*	fraction of core inventory released to the environment for I-th nuclide group and J-th accident scenario $(1 \leq I \leq 7)$, $(1 \leq J \leq 9)$
27	FRN(I,11)*	fraction of core inventory released to the environment for I-th nuclide group and the 11-th accident scenario $(1 \leq I \leq 7)$

Table 4.1 Input variables to IND (9/10).

Card No.	Variable	Description
28	BRA(I)*	breathing rate [m/s] I = 1 : day time = 2 : night time
29	LENG*	grass length indicating surface roughness [cm]
30	DELTIG*	time step width in integral calculation for reduction factor [min]
31	F1MLF*	non-radioactive consequence of fatality resulting from collision of evacuation vehicle [fatality/(person mile)]
	F2MLF*	non-radioactive consequence of fatality resulting from evacuating in the direction of the radioactive plume [fatality/(person mile)]
	F3MLF*	non-radioactive consequence of fatality caused by a shelter of relocation [fatality/(person mile)]
	F1MLJ*	non-radioactive consequence of injury resulting from collision of evacuation vehicle [injury/(person mile)]

Table 4.1 Input variables to IND (10/10).

Card No.	Variable	Description
	F2MLJ*	non-radioactive consequence of injury resulting from evacuating in the direction of the radioactive plume [injury/(person mile)]
	F3MLJ*	non-radioactive consequence of injury caused by a shelter of relocation [injury/(person mile)]

Table 4.2 Isotope name of I-th nuclide.

I	Isotope	I	Isotope	I	Isotope	I	Isotope
1	Kr-85	16	Te-127	31	Tc-99m	46	Nd-147
2	Kr-85m	17	Te-127m	32	Ru-103	47	Np-239
3	Kr-87	18	Te-129	33	Ru-105	48	Pu-238
4	Kr-88	19	Te-129m	34	Ru-106	49	Pu-239
5	Xe-133	20	Te-131m	35	Rh-105	50	Pu-240
6	Xe-135	21	Te-132	36	Y-90	51	Pu-241
7	I-131	22	Sb-127	37	Y-91	52	Am-241
8	I-132	23	Sb-129	38	Zr-95	53	Cu-242
9	I-133	24	Ba-140	39	Zr-97	54	Cu-244
10	I-134	25	Sr-89	40	Nb-95		
11	I-135	26	Sr-90	41	La-140		
12	Cs-134	27	Sr-91	42	Ce-141		
13	Cs-136	28	Co-58	43	Ce-143		
14	Cs-137	29	Co-60	44	Ce-144		
15	Rb-86	30	Mo-99	45	Pr-143		

Table 4.3 Input variables to POP (1/4).

Card No.	Variable	Description
1	TITLE	title (A70)
2	IDIM	option for model selection 2 : two-dimensional model 3 : three-dimensional model
	ISTA	atmosphere stability category (see Card No. 10 in Table 4.1)
3	XMN	minimum distance considered from a nuclear power plant in calculation of population risks [km]
	DELX	distance width in integral calculation of population risks [km], (DELX $\leq$ XLIM)
	XLIM	maximum distance considered from a nuclear power plant in calculation of population risks [km]
4	IOPT	option for selecting population density distribution functions for average person and pregnant woman (see Figure 4.1 and Eqs. (3.1) through (3.3)) 1 = uniform distribution function 2 = Gaussian type distribution function 3 = histogram

Table 4.3 Input variables to POP (2/4).

Card No.	Variable	Description
5-A	ROHOA	parameter c_0 for average person in case of IOPT=1 [person/km^2]
	ROHOP	parameter c_0 for pregnant woman in case of IOPT=1 [person/km^2]
5-B	ROHOA	parameter c_1 in the Gaussian distribution function for average person in case of IOPT=2 [person/km^2]
	ROH1A	parameter c_2 in the Gaussian distribution function for average person in case of IOPT=2 [person/km]
	SIGA	parameter σ in the Gaussian distribution function for average person in case of IOPT=2 [km]
	XCA	parameter X_C in the Gaussian distribution function for average person in case of IOPT=2 [km]
	ROHOP	parameter c_1 in the Gaussian distribution function for pregnant woman in case of IOPT=2 [person/km^2]
	ROH1P	parameter c_2 in the Gaussian distribution function for pregnant woman in case of IOPT=2 [person/km]

Table 4.3 Input variables to POP (3/4).

Card No.	Variable	Description
	SIGP	parameter σ in the Gaussian distribution function for pregnant woman in case of IOPT=2 [km]
	XCP	parameter X_C in the Gaussian distribution function for pregnant woman in case of IOPT=2 [km]
5-C	RDXA	equal distance width of population distribution histogram for average person in case of IOPT=3 [km]
	RXMAXA	maximum distance of population distribution histogram for average person in case of IOPT=3 [km]
	RDXP	equal distance width of population distribution histogram for pregnant woman in case of IOPT=3 [km]
	RXMAXP	maximum distance of population distribution histogram for pregnant woman in case of IOPT=3 [km]
6	RDATAA(I)	frequency of I-th class of population distribution histogram for average person in case of IOPT=3 [person/km^2], ($1 \leq I \leq 5$)

Table 4.3 Input variables to POP (4/4).

Card No.	Variable	Description
7	RDATAA(I)	frequency of I-th class of population distribution histogram for average person in case of IOPT=3 [person/km^2], $(6 \leq I \leq 10)$
8	RDATAA(I)	frequency of I-th class of population distribution histogram for average person in case of IOPT=3 [person/km^2], $(11 \leq I \leq 15)$
9	RDATAP(I)	frequency of I-th class of population distribution histogram for pregnant woman in case of IOPT=3 [person/km^2], $(1 \leq I \leq 5)$
10	RDATAP(I)	frequency of I-th class of population distribution histogram for pregnant woman in case of IOPT=3 [person/km^2], $(6 \leq I \leq 10)$
11	RDATAP(I)	frequency of I-th class of population distribution histogram for pregnant woman in case of IOPT=3 [person/km^2], $(11 \leq I \leq 15)$

Table 4.4 Input variables to GRAPH (1/2).

Card No.	Variable	Description
1	KDIM	output option for two- or three-dimensional model (see Figure 4.2) 2: two-dimensional model 3: three-dimensional model
2	LH1AF	title for GRAPH1 output relating to average person fatality (to be ended with the mark ¥, A60)
3	LH1PF	title for GRAPH1 output relating to pregnant woman fatality (to be ended with the mark ¥, A60)
4	LH1AI	title for GRAPH1 output relating to average person injury (to be ended with the mark ¥, A60)
5	LH1PI	title for GRAPH1 output relating to pregnant woman injury (to be ended with the mark ¥, A60)
6	LH1AC	title for GRAPH1 output relating to average person cost (to be ended with the mark ¥, A60)
7	LH1PC	title for GRAPH1 output relating to pregnant woman cost (to be ended with the mark ¥, A60)

Table 4.4 Input variables to GRAPH (2/2).

Card No.	Variable	Description
8	LHP1A	title for PLOT1 output relating to average person fatality and injury (to be ended with the mark ¥, A60)
9	LHP1P	title for PLOT1 output relating to pregnant woman fatality and injury (to be ended with the mark ¥, A60)
10	LHP2A	title for PLOT2 output relating to average person fatality and injury (to be ended with the mark ¥, A60)
11	LHP2P	title for PLOT2 output relating to pregnant woman fatality and injury (to be ended with the mark ¥, A60)
12	LHP3A	title for PLOT3 output relating to average person fatality, injury and cost (to be ended with the mark ¥, A60)
13	LHP3P	title for PLOT3 output relating to pregnant woman fatality, injury and cost (to be ended with the mark ¥, A60)

Table 4.5 IND output.

Action	Individual risk					
	Fatality		Injury		Cost	
	R	N	R	N	R	N
Evacuation	○	○	○	○	–	○
Sheltering	○	–	○	–	–	○
No action	○	–	○	–	–	–

○ : IND output
– : not applicable
R : radiological risk
N : non-radiological risk

Table 4.6 The structure of the interface file IRISK (1/3).

Record No.	Variable	Description
1	NPOINT	total number of calculational points (I4)
	DX	distance width for sequential calculations [km] (F5.2)
2	BAYSF1(I,1)	individual risk value of fatality under no action for average person at I-th calculational point (E16.8)
	BAYSF1(I,2)	individual risk value of fatality under sheltering for average person at I-th calculational point (E16.8)
	BAYSF1(I,3)	individual risk value of fatality under evacuation for average person at I-th calculational point (E16.8)
NPOINT+2	BAYSF2(I,1)	individual risk value of fatality under no action for pregnant woman at I-th calculational point (E16.8)
	BAYSF2(I,2)	individual risk value of fatality under sheltering for pregnant woman at I-th calculational point (E16.8)
	BAYSF2(I,3)	individual risk value of fatality under evacuation for pregnant woman at I-th calculational point (E16.8)

Table 4.6 The structure of the interface file IRISK (2/3).

Record No.	Variable	Description
2xNPOINT+2	BAYSI1(I,1)	individual risk value of injury under no action for average person at I-th calculational point (E16.8)
	BAYSI1(I,2)	individual risk value of injury under sheltering for average person at I-th calculational point (E16.8)
	BAYSI1(I,3)	individual risk value of injury under evacuation for average person at I-th calculational point (E16.8)
3xNPOINT+2	BAYSI2(I,1)	individual risk value of injury under no action for pregnant woman at I-th calculational point (E16.8)
	BAYSI2(I,2)	individual risk value of injury under sheltering for pregnant woman at I-th calculational point (E16.8)
	BAYSI2(I,3)	individual risk value of injury under evacuation for pregnant woman at I-th calculational point (E16.8)
4xNPOINT+2	BAYSC1(I,1)	individual risk value of cost under no action for average person at I-th calculational point (E16.8)

Table 4.6 The structure of the interface file IRISK (3/3).

Record No.	Variable	Description
	BAYSC1(I,2)	individual risk value of cost under sheltering for average person at I-th calculational point (E16.8)
	BAYSC1(I,3)	individual risk value of cost under evacuation for average person at I-th calculational point (E16.8)
5xNPOINT+2	BAYSC2(I,1)	individual risk value of cost under no action for pregnant woman at I-th calculational point (E16.8)
	BAYSC2(I,2)	individual risk value of cost under sheltering for pregnant woman at I-th calculational point (E16.8)
	BAYSC2(I,3)	individual risk value of cost under evacuation for pregnant woman at I-th calculational point (E16.8)

Table 4.7 The structure of the interface file PRISK (1/2).

Record No.	Variable	Description
1	IDIM	option for model selection (I2) 2 : two-dimensional model 3 : three-dimensional model
	NDATA	total number of calculational points (I5)
2	ZWF1(I)	population risk of fatality for average person at I-th calculational point (E16.8), $(1 \leq I \leq NDATA)$
	ZWI1(I)	population risk of injury for average person at I-th calculational point (E16.8), $(1 \leq I \leq NDATA)$
	ZWC1(I)	population risk of cost for average person at I-th calculational point (E16.8), $(1 \leq I \leq NDATA)$, (used for only three-dimensional model)
	ZWF2(I)	population risk of fatality for pregnant woman at I-th calculational point (E16.8), $(1 \leq I \leq NDATA)$
	ZWI2(I)	population risk of injury for pregnant woman at I-th calculational point (E16.8), $(1 \leq I \leq NDATA)$

Table 4.7 The structure of the interface file PRISK (2/2).

Record No.	Variable	Description
	ZWC2(I)	population risk of cost for pregnant woman at I-th calculational point (E16.8), $(1 \leq I \leq NDATA)$ (used for only three-dimensional model)
NDATA+1	ICNT1	total number of solutions of inequality relation for average person (I5)
	ICNT2	total number of solutions of inequality relation for pregnant woman (I5)
NDATA+2	KAI1(I)	address of solutions of inequality relation for average person (I5), $(1 \leq I \leq ICNT1)$
NDATA+ICNT1+3	KAI2(I)	address of solution of inequality relation for pregnant woman (I5), $(1 \leq I \leq ICNT2)$

Table 4.8 Output items of the PRASMA code system.

Code	Output Item
IND	• Individual risks of fatality, injury, and cost under off-site protective actions of evacuation, sheltering, and no action at calculational points. • The occurrence probabilities of accident spectra and loss function values under off-site protective actions of evacuation, sheltering, and no action.
POP	• Population risks of fatality, injury, and cost at calculational points. • Off-site protective action zones.
GRAPH	• Graphical representation of individual risks of fatality, injury, and cost at the distance from a nuclear power plant under off-site protective actions of evacuation, sheltering, and no action. • Graphical representation of population risks of fatality and injury at calculational points of decision variable (X_E, X_S) in the two-dimensional model. • Two-dimensional graphical representation of a pair of population risks of fatality and injury. • Graphical representation of population risks of fatality, injury and cost at calculational points of decision variable (X_E, X_S) in the three-dimensional model.

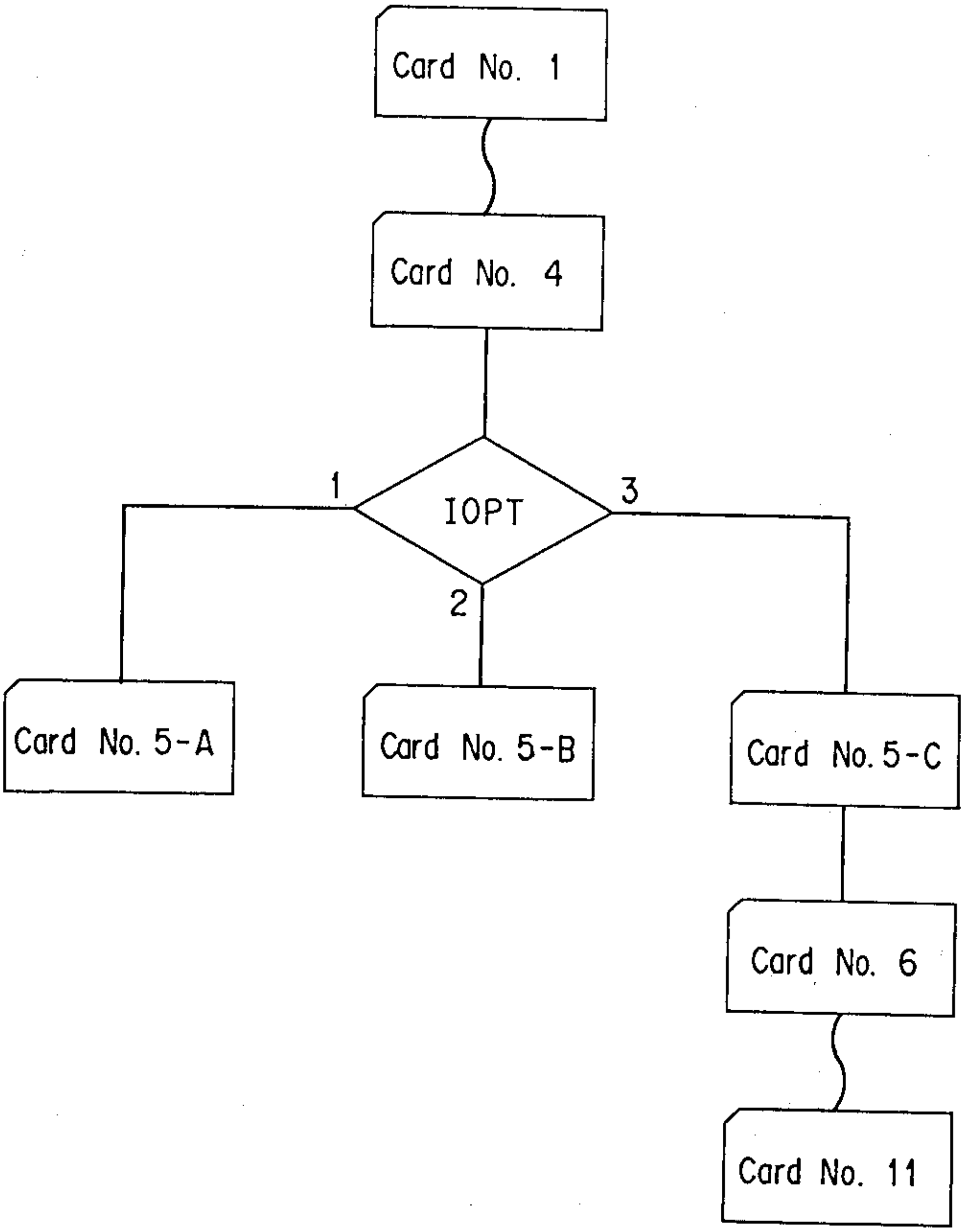

Fig. 4.1 Selection of a population density distribution function.

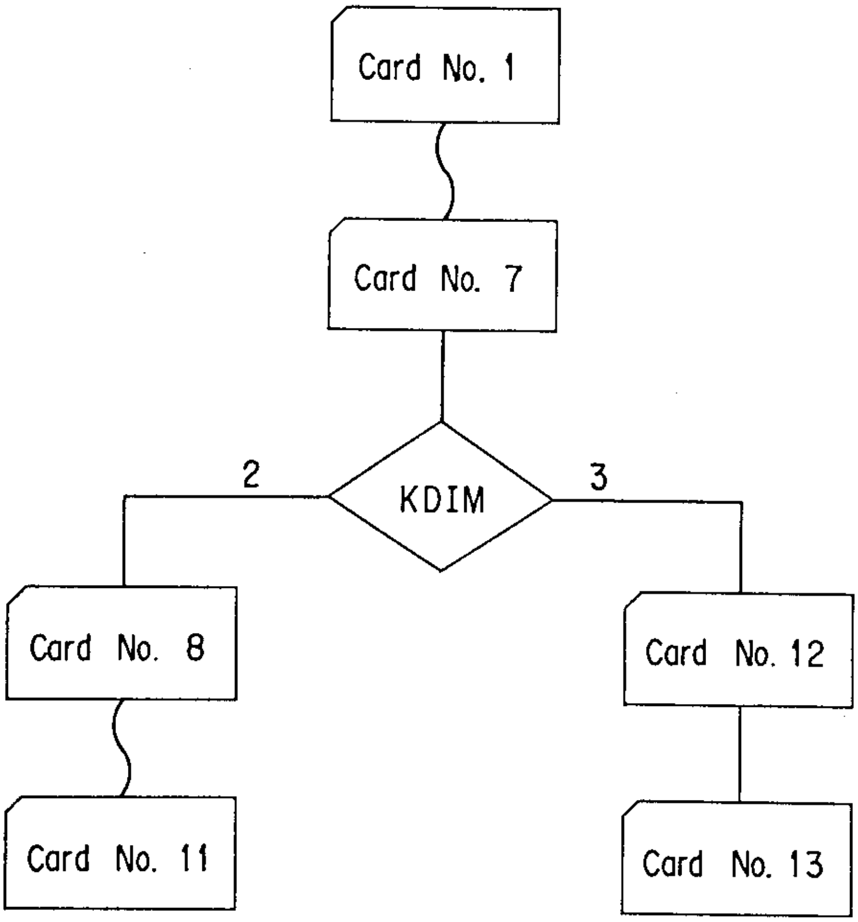

Fig. 4.2 Selection of output option for GRAPH.

5. Sample Run

This chapter provides a sample run of the PRASMA code system by applying it to the TMI-2 accident scenario. Input data to IND characterizing the accident scenario were taken from those to SOPA given in Ref. 1. The modeling of plant status is limited to the response of the following functions:

RT- reactor trip
AFW- auxiliary feed water and secondary heat removal
PORV- demand for the pilot operated relief valve
PORC- closure of PORV subsequent to a demand
HPI- high pressure injection
HPR- high pressure recirculation
CSI- containment spray injection
CHR- containment heat removal
CSR- containment spray recirculation

Some of these systems were at different status during different periods of the accident. Table 5.1 summarizes the sample inputs of the plant status at 3 hours 23 min after the initiation of the accident. A population density around the TMI-2 site was assumed to be the uniform distribution. The sample input data list to PRASMA is shown in Tables 5.2(a) through 5.2(c).

Tables 5.3(a) and 5.3(b) show sample output data list of PRASMA including individual risks and population risks of fatality, injury and cost of average person for protective actions of no action, sheltering and evacuation, and solutions that minimize the population risks using the multiobjective optimization method in the three-dimensional model. Here decision variables (X_E = distance denoting the boundary between zones of evacuation and sheltering, X_S = distance denoting the boundary between zones of sheltering and no action) were varied from 1 km to 29 km, the boundary between on-site and off-site was assumed to be 1 km, and the maximum distance considered in the present sample run was assumed to be 30 km.

Solutions for the inequality in the multiobjective optimization method reveal that the choice of evacuation is not desirable, but that of sheltering is favorable. Figure 5.1 illustrates the results of population risks for three protective actions which have shown in Table 5.3(b). Here the calculational points on X-axis correspond to the set of decision variables (X_E, X_S) as denoted "NO." in the first column of Table 5.3(b). Solutions are indicated by the mark "■" in Figure 5.1. Of many solutions, it is revealed that the solution corresponding to the fifteenth calculational point with decision variable values of X_E = 1 km and X_S = 29 km may be the most favorable, since the population risks of fatality and injury are the smallest of all while corresponding cost is not so larger than that for the other solutions.

Table 5.1 Description of plant status(1).

Function	Status
RT	Successful
AFW	Failed(a)
PORV	Demanded
PORC	Successful
HPI	Failed(b)
HPR	Not Demanded
CSI	Not Demanded
CSR	Not Demanded
CHR	Not Demanded
Potential for Hydrogen Explosion	Probability = 0.05
Actual Release	Yes

(a) While the system was available at this instant, it had been locked out during testing and not put back to service.

(b) While the HPI was operable, it had been bypassed by the operators.

Table 5.2(a) Input data list of IND (1/5).

```
3
1 1 1
.46,0.0,0.0,0.0,0.0,0.0,0.0
10 1440
1 1 1 1 1 0 0 0 0 0 0 0 0 0
1 0 1 1 0 0 0 0 0 0 0 0 0 0
.000036  .0011   .1 .013  .012  .0009  .0003  .0009
.0009 .00001 .00001 .00001 .00001 .00001 .00001
0,0,0,0
0,0,0,0,0,0,0,0,0,0,0
2,1000,1,1000,30000,2000,1.
 KR-85                6.639E+05 3.999E+03      0.00
 KR-85M               3.126E+07 1.867E-01      0.00
 KR-87                5.696E+07 5.278E-02      0.00
 KR-88                7.691E+07 1.167E-01      0.00
 XE-133   I-133       1.841E+08 5.290E+00      0.00
 XE-135   I-135       3.800E+07 3.821E-01      0.00
 I-131    TE-131M     8.737E+07 8.040E+00   1.00E-04
 I-132    TE-132      1.286E+08 9.521E-02   1.00E-04
 I-133                1.840E+08 8.667E-01   1.00E-04
 I-134                2.017E+08 3.653E-02   1.00E-04
 I-135                1.734E+08 2.744E-01   1.00E-04
 CS-134               0.075E+08 7.500E+02   1.00E-04
 CS-136               0.030E+08 1.300E+01   1.00E-04
 CS-137               0.047E+08 1.100E+04   1.00E-04
 RB-86                0.260E+05 1.870E+01   1.00E-04
 TE-127   SB-127      0.059E+08 0.391E+00   1.00E-04
 TE127M               0.011E+08 1.090E+02   1.00E-04
 TE-129   SB-129      0.310E+08 0.480E-01   1.00E-04
 TE129M               0.053E+08 0.340E+00   1.00E-04
 TE-131M              0.130E+08 1.250E-00   1.00E-04
 TE-132               1.200E+08 3.250E-00   1.00E-04
 SB-127               0.061E+08 3.880E-00   1.00E-04
 SB-129               0.330E+08 8.050E-00   1.00E-04
 BA-140               1.600E+08 1.280E+01   1.00E-04
 SR-89                0.940E+08 5.210E+01   1.00E-04
 SR-90                0.037E+08 1.103E+04   1.00E-04
 SR-91                1.100E+08 0.403E-00   1.00E-04
 CO-58                0.780E+06 7.100E+01   1.00E-04
 CO-60                0.290E+06 1.920E+03   1.00E-04
 MO-99                1.600E+08 2.800E-00   1.00E-04
 TC-99M               1.400E+08 0.250E-00   1.00E-04
 RU-103               1.100E+08 3.950E+01   1.00E-04
 RU-105               0.720E+08 0.185E-00   1.00E-04
 RU-106               0.250E+08 3.660E-00   1.00E-04
 RH-105   RU-105      0.490E+08 1.500E-00   1.00E-04
 Y-90     SR-90       0.039E+08 2.670E-00   1.00E-04
 Y-91     SR-91       1.200E+08 5.900E+01   1.00E-04
 ZR-95                1.500E+08 6.520E+01   1.00E-04
 ZR-97                1.500E+08 0.710E+00   1.00E-04
 NB-95    ZR-95       1.500E+08 3.500E+01   1.00E-04
 LA-140   BA-140      1.600E+08 1.670E-00   1.00E-04
 CE-141               1.500E+08 3.230E+01   1.00E-04
 CE-143               1.300E+08 1.380E+00   1.00E-04
 CE-144               0.850E+08 2.840E+02   1.00E-04
 PR-143   CE-143      1.300E+08 1.370E+01   1.00E-04
 ND-147               0.600E+08 1.110E+01   1.00E-04
 NP-239               1.640E+09 2.350E-00   1.00E-04
```

Table 5.2(a) Input data list of IND (2/5).

```
 PU-238  CM-242   0.570E+05 3.250E+04  1.00E-04
 PU-239  NP-239   0.210E+05 8.900E+06  1.00E-04
 PU-240  CM-244   0.215E+05 2.400E+06  1.00E-04
 PU-241           0.034E+08 5.350E+03  1.00E-04
 AM-241  PU-241   0.170E+04 1.500E+05  1.00E-04
 CU-242           0.005E+08 1.630E+02  1.00E-04
 CU-244           0.230E+05 6.630E+03  1.00E-04
KR-85     4.75E-04 5.78E-04 4.47E-04 5.88E-04
KR-85M    3.64E-02 5.50E-02 3.22E-02 4.78E-02
KR-87     1.81E-01 1.02E-01 1.72E-01 1.32E-01
KR-88     4.07E-01 4.83E-01 4.47E-01 2.03E-01
XE-133    9.06E-03 1.59E-02 8.97E-03 9.28E-03
XE-135    5.07E-02 8.47E-02 5.06E-02 7.36E-02
I-131     8.72E-02 1.08E-01 8.22E-02 9.75E-02
I-132     5.11E-01 5.89E-01 4.83E-01 5.03E-01
I-133     1.54E-01 1.83E-01 1.46E-01 1.62E-01
I-134     5.33E-01 5.80E-01 5.00E-01 4.83E-01
I-135     4.19E-01 4.42E-01 4.00E-01 3.39E-01
CS-134    3.50E-01 4.03E-01 3.28E-01 3.50E-01
CS-136    4.78E-01 5.42E-01 4.44E-01 4.44E-01
CS-137    1.22E-01 1.49E-01 1.15E-01 1.35E-01
RB-86     2.07E-02 2.27E-02 1.94E-02 1.97E-02
TE-127    9.36E-04 1.16E-03 8.78E-04 1.05E-03
TE127M    1.10E-03 1.79E-03 5.61E-04 1.50E-03
TE-129    1.47E-02 1.81E-02 1.35E-02 1.61E-02
TE129M    7.83E-03 9.92E-03 6.97E-03 8.86E-03
TE-131M   3.14E-01 3.56E-01 2.94E-01 2.35E-01
TE-132    4.75E-02 7.31E-02 4.19E-02 6.14E-02
SB-127    1.51E-01 1.84E-01 1.43E-01 1.63E-01
SB-129    2.68E-01 2.97E-01 2.53E-01 2.47E-01
BA-140    4.44E-02 5.61E-02 4.14E-02 5.06E-02
SR-89          0.0      0.0      0.0      0.0
SR-90          0.0      0.0      0.0      0.0
SR-91     1.69E-01 1.93E-01 1.60E-01 1.64E-01
CO-58     2.16E-01 2.40E-01 2.01E-01 2.01E-01
CO-60     6.00E-01 6.31E-01 5.67E-01 4.89E-01
MO-99     3.64E-02 4.44E-02 3.42E-02 3.92E-02
TC-99M    3.06E-02 5.42E-02 2.54E-02 2.84E-02
RU-103    1.11E-01 1.36E-01 1.05E-01 1.24E-01
RU-105    1.79E-01 2.21E-01 1.67E-01 1.97E-01
RU-106    4.31E-02 5.22E-02 4.06E-02 4.69E-02
RH-105    1.82E-02 2.74E-02 1.61E-02 2.36E-02
Y-90           0.0      0.0      0.0      0.0
Y-91      6.25E-04 6.39E-04 5.94E-04 4.67E-04
ZR-95     1.62E-01 1.87E-01 1.52E-01 1.61E-01
ZR-97     4.22E-02 4.72E-02 4.00E-02 3.86E-02
NB-95     1.66E-01 1.83E-01 1.56E-01 1.52E-01
LA-140    5.67E-01 6.06E-01 5.39E-01 4.58E-01
CE-141    1.83E-02 3.22E-02 1.50E-02 1.74E-02
CE-143    6.81E-02 9.36E-02 6.08E-02 7.89E-02
CE-144    4.31E-03 7.61E-03 3.44E-03 4.17E-03
PR-143          0.0     0.0      0.0      0.0
ND-147    3.14E-02 4.39E-02 2.78E-02 3.42E-02
NP-239    3.08E-02 4.07E-02 2.65E-02 3.58E-02
PU-238    5.25E-05 4.25E-05 9.38E-06 4.19E-05
PU-239    2.30E-05 2.17E-05 5.42E-06 1.94E-05
PU-240    4.64E-05 3.89E-05 9.17E-06 3.70E-05
PU-241    4.17E-10 8.53E-10 2.94E-10 3.65E-10
```

Table 5.2(a) Input data list of IND (3/5).

AM-241	4.56E-03	9.33E-03	3.22E-03	3.08E-03	
CU-242	5.00E-05	3.89E-05	8.31E-06	3.09E-05	
CU-244	1.42E-03	2.81E-03	1.07E-03	1.27E-03	
KR-85	0.0	0.0	0.0	0.0	
KR-85M	0.0	0.0	0.0	0.0	
KR-87	0.0	0.0	0.0	0.0	
KR-88	0.0	0.0	0.0	0.0	
XE-133	0.0	0.0	0.0	0.0	
XE-135	0.0	0.0	0.0	0.0	
I-131	7.08E+02	8.73E+02	6.63E+02	7.85E+02	
I-132	1.07E+02	1.23E+02	1.01E+02	1.05E+02	
I-133	3.11E+02	3.75E+02	2.01E+02	3.22E+02	
I-134	4.14E+01	4.56E+01	3.88E+01	3.76E+01	
I-135	2.85E+02	3.18E+02	2.69E+02	2.52E+02	
CS-134	3.60E+03	4.26E+03	3.47E+03	3.67E+03	
CS-136	4.10E+03	4.68E+03	3.32E+03	3.82E+03	
CS-137	1.31E+03	1.69E+03	1.24E+03	1.46E+03	
RB-86	1.85E+02	2.02E+02	1.73E+02	1.66E+02	
TE-127	8.13E-01	1.01E+00	7.67E-01	9.14E-01	
TE127M	5.84E+01	9.20E+01	3.37E+01	7.77E+01	
TE-129	1.98E+00	2.44E+00	1.83E+00	2.17E+00	
TE129M	2.46E+02	3.07E+02	2.22E+02	2.74E+02	
TE-131M	9.60E+02	1.10E+02	8.90E+02	8.86E+02	
TE-132	3.08E+03	3.63E+03	2.88E+03	3.08E+03	
SB-127	9.20E+02	1.11E+03	8.65E+02	9.95E+02	
SB-129	1.04E+02	1.16E+02	9.78E+01	9.57E+01	
BA-140	3.65E+03	3.98E+03	3.46E+03	3.11E+03	
SR-89	0.0	0.0	0.0	0.0	
SR-90	0.0	0.0	0.0	0.0	
SR-91	2.05E+02	2.39E+02	1.93E+02	2.07E+02	
CO-58	2.24E+03	2.50E+03	2.10E+03	2.09E+03	
CO-60	5.88E+03	6.22E+03	5.58E+03	4.80E+03	
MO-99	3.25E+02	4.65E+02	2.91E+02	3.32E+02	
TC-99M	1.62E+01	2.88E+01	1.35E+01	1.51E+01	
RU-103	1.16E+03	1.42E+03	1.09E+03	1.30E+03	
RU-105	7.94E+01	9.98E+01	7.37E+01	8.91E+01	
RU-106	4.56E+02	5.54E+02	4.30E+02	4.97E+02	
RH-105	5.67E+01	8.55E+01	5.01E+01	7.37E+01	
Y-90	0.0	0.0	0.0	0.0	
Y-91	5.91E+00	6.06E+00	5.66E+00	4.44E+00	
ZR-95	1.77E+03	2.04E+03	1.67E+03	1.76E+03	
ZR-97	5.38E+02	6.52E+02	5.10E+02	5.89E+02	
NB-95	1.64E+03	1.80E+03	1.54E+03	1.49E+03	
LA-140	1.80E+03	1.92E+03	1.71E+03	1.46E+03	
CE-141	1.82E+02	3.24E+02	1.50E+02	1.73E+02	
CE-143	2.24E+02	3.08E+02	2.00E+02	2.59E+02	
CE-144	1.20E+02	1.67E+02	1.07E+02	1.03E+02	
PR-143	0.0	0.0	0.0	0.0	
ND-147	3.05E+02	4.26E+02	2.70E+02	3.34E+02	
NP-239	2.02E+02	3.26E+02	1.74E+02	2.35E+02	
PU-238	6.20E+00	5.02E+00	1.14E+00	4.97E+00	
PU-239	2.63E+00	2.40E+00	6.22E-01	2.23E+00	
PU-240	5.47E+00	4.57E+00	1.08E+00	4.38E+00	
PU-241	2.21E-03	4.52E-03	1.56E-03	1.94E-03	
AM-241	1.43E+02	2.05E+02	1.02E+02	1.26E+02	
CU-242	5.46E+00	4.25E+00	9.05E-01	4.35E+00	
CU-244	3.46E+01	6.81E+01	2.61E+01	3.08E+01	
KR-85	1.8E-01	1.5E-01	1.8E-01	1.8E-01	6.1E-01

Table 5.2(a) Input data list of IND (4/5).

```
KR-85M      2.0E-01   1.9E-01   2.2E-01   2.1E-01   3.9E-01
KR-87       9.7E-01   8.3E-01   1.0E+00   9.6E-01   1.3E+00
KR-88       2.0E+00   1.8E+00   2.3E+00   2.0E+00   3.1E+00
XE-133      4.0E-01   3.6E-01   4.2E-01   4.1E-01   1.6E+00
XE-135      9.1E-01   7.2E-01   9.9E-01   9.4E-01   2.1E+00
 I-131      1.1E+06   2.1E+02   3.6E+02   2.4E+03   1.9E+02
 I-132      6.6E+03   4.7E+01   6.0E+01   1.0E+03   5.0E+01
 I-133      1.8E+05   9.2E+01   3.3E+02   3.1E+03   9.4E+01
 I-134      1.1E+03   1.9E+01   2.0E+01   5.6E+02   2.0E+01
 I-135      4.4E+04   8.7E+01   2.2E+02   2.5E+03   9.1E+01
CS-134      1.4E+04   4.7E+04   1.8E+04   5.1E+04   4.8E+04
CS-136      5.9E+03   5.9E+03   7.5E+03   8.2E+03   6.0E+03
CS-137      9.5E+03   3.6E+04   1.1E+04   4.0E+04   3.7E+04
RB-86       6.1E+03   6.5E+03   7.1E+03   1.4E+04   6.5E+03
TE-127      3.0E+00   5.2E+00   7.8E+02   1.6E+03   3.9E+00
TE127M      1.9E+02   2.0E+03   2.1E+04   1.2E+05   8.0E+02
TE-129      8.1E-01   1.2E+00   5.7E+00   5.6E+02   1.1E+00
TE129M      3.7E+02   1.4E-03   3.7E+04   1.5E+05   8.4E+02
TE-131M     9.5E+04   2.5E+02   8.5E+03   1.1E+04   3.1E+02
TE-132      9.7E+04   9.1E+02   6.1E+03   3.0E+04   1.0E+03
SB-127      2.2E+02   2.6E+02   2.6E+04   2.5E+04   3.3E+02
SB-129      3.8E+01   3.9E+01   8.1E+02   3.2E+03   4.6E+01
BA-140      1.2E+03   5.2E+03   1.6E+04   6.3E+03   3.4E+03
SR-89       1.2E+03   3.0E+04   1.4E+04   7.8E+03   1.3E+04
SR-90       2.8E+03   2.4E+06   1.6E+04   1.8E+04   6.9E+05
SR-91       1.7E+02   3.4E+02   2.6E+03   4.3E+03   3.2E+02
CO-58       1.6E+03   2.6E+03   7.2E+03   6.1E+04   3.1E+03
CO-60       4.4E+03   5.0E+04   1.9E+04   1.3E+06   5.8E+08
MO-99       1.5E+02   1.1E+02   2.1E+04   1.6E+04   1.3E+02
TC-99M      4.6E+01   1.0E+01   1.1E+01   8.9E+01   1.1E+01
RU-103      6.6E+02   8.8E+02   1.1E+04   5.4E+04   1.1E+03
RU-105      1.5E+01   1.7E+01   1.2E+03   2.2E+03   2.4E+01
RU-106      1.0E+03   5.9E+03   1.3E+05   3.9E+06   6.2E+03
RH-105      9.9E+00   1.6E+01   5.1E+03   3.6E+03   2.3E+01
Y-90        2.1E+01   1.0E+03   4.0E+04   3.3E+04   5.1E+02
Y-91        1.8E+02   1.9E+04   5.0E+04   2.0E+05   9.3E+03
ZR-95       1.5E+03   3.4E+03   1.5E+04   1.3E+05   3.6E+03
ZR-97       8.6E+01   1.4E+02   1.9E+04   1.5E+04   1.0E+02
NB-95       9.5E+02   1.2E+03   7.1E+03   3.1E+04   1.4E+03
LA-140      2.3E+02   7.0E+02   2.1E+04   1.6E+04   6.8E+02
CE-141      6.0E+01   3.2E+02   1.5E+04   6.2E+04   2.7E+02
CE-143      2.5E+01   1.1E+02   1.6E+04   1.3E+04   1.1E+02
CE-144      8.4E+01   1.9E+04   1.2E+05   2.9E+06   9.2E+03
PR-143      9.9E-01   8.6E+01   2.5E+04   4.9E+04   3.4E+01
ND-147      6.8E+01   2.4E+02   2.2E+04   3.8E+04   2.0E+02
NP-239      1.5E+01   1.6E+02   1.3E+04   9.3E+03   6.4E+01
PU-238      6.0E+02   4.9E+08   5.2E+04   3.1E+08   8.7E+05
PU-239      5.6E+02   5.2E+08   4.8E+04   2.9E+08   9.2E+05
PU-240      5.6E+02   5.2E+08   4.9E+04   2.9E+08   9.2E+05
PU-241      1.4E-01   8.3E+06   4.8E+02   5.7E+05   1.5E+04
AM-241      6.9E+02   5.5E+08   5.5E+04   3.1E+08   9.9E+05
CU-242      6.5E+02   4.8E+06   5.7E+04   8.7E+07   8.5E+03
CU-244      7.0E+02   3.3E+08   5.5E+04   3.1E+08   5.8E+05
.001,.0001,4
1000,2,100.0,20.
200. 250.0 1.3E-5
0.0001 0.0013  0.05
56634.0 0.02588
```

Table 5.2(a) Input data list of IND (5/5).

```
0.3658 0.2751 0.2089 0.1471 0.1046 0.0722
0.0003 0.070 0.144 1.60 8.55 22.92
2.094 1.098 0.911 0.516 0.395 0.18
-12.2 2.54 0.0 -16.5 -43.2 -61.7
0.000037
0.020 0.018 0.011 0.007 0.005 0.004
0.074 0.060 0.036 0.020 0.015 0.011
0.150 0.120 0.065 0.035 0.024 0.016
0.220 0.170 0.088 0.046 0.029 0.017
0.350 0.250 0.130 0.054 0.028 0.013
0.560 0.380 0.150 0.045 0.016 0.004
0.760 0.511 0.150 0.024 0.004 0.001
0.899 0.600 0.140 0.014 0.001 0.001
0.951 0.600 0.130 0.011 0.001 0.001
1.0E+6 1.0E+6 1.0E+6 1.0E+6 1.0E+6 1.0E+6 1.0E+6 1.0E+6 1.0E+6 1.0E+6
1.0E+6 1.0E+6 1.0E+6 1.0E+6 1.0E+6 1.0E+6 1.0E+6 1.0E+6 1.0E+6 1.0E+6
20. 20. 20. 20. 20. 20. 20. 20. 20. 20.
20. 20. 20. 20. 20. 20. 20. 20. 20. 20.
30. 30. 90. 180. 240. 600. 600. 30. 30. 1440. 1440.
60. 60. 120. 120. 60. 60. 60. 6000. 6000. 0. 0.
0.9 0.9 0.8 0.6 0.3 0.3 0.006 0.002 0.003
0.7 0.7 0.2 0.09 0.03 0.0008 0.00005 0.0001 0.0000007
0.4 0.5 0.2 0.04 0.009 0.0008 0.00001 0.0005 0.0000006
0.4 0.3 0.3 0.03 0.005 0.001 0.00002 0.000001 0.000000009
0.05 0.06 0.02 0.005 0.001 0.00009 0.000001 0.000000001 1.0E-11
0.4 0.02 0.03 0.003 0.0006 0.00007 1.0E-6 0.0 0.0
0.003 0.004 0.003 0.0004 0.00007 0.00001 0.0000002 0.0 0.0
0.0 3.0E-8 0.0 0.0 0.0 0.0 0.0
0.000218 0.000113 0.000325
10
5.0
0.0 2.5E-7 3.9E-6 1.5E-7 1.0E-7 2.6E-4
```

Table 5.2(b) Input data list of POP.

```
 @@@@ INPUT DATA LIST OF POP @@@@
BASE CASE IN 3-DIMENSIONAL MODEL
3 1
1.00000000 2.00000000 30.0000000
1
400.000000 400.000000
```

Table 5.2(c) Input data list of GRAPH.

```
 @@@@@ INPUT DATA LIST OF GRAPH @@@@@
   3
INDIVIDUAL RISK OF FATALITY (AVERAGE PERSON)¥
INDIVIDUAL RISK OF FATALITY (PREGNANT WOMAN)¥
INDIVIDUAL RISK OF INJURY (AVERAGE PERSON)¥
INDIVIDUAL RISK OF INJURY (PREGNANT WOMAN)¥
INDIVIDUAL RISK OF COST (AVERAGE PERSON)¥
INDIVIDUAL RISK OF COST (PREGNANT WOMAN)¥
POP RISK OF FATALITY, INJURY AND COST (AVERAGE PERSON)¥
POP RISK OF FATALITY, INJURY AND COST (PREGNANT WOMAN)¥
```

Table 5.3(a) Output data list of IND (1/5).

```
 @@@@ INPUT DATA LIST OF IND @@@@
3
1 1 1
0.459999979 0.0 0.0 0.0 0.0 0.0 0.0
10.0000000 1440.00000
1 1 1 1 1 0 0 0 0 0 0 0 0 0
1 0 1 1 0 0 0 0 0 0 0 0 0 0
0.359999976E-04 0.109999999E-02 0.100000024 0.130000003E-01 0.119999982E-01 0.900000101E-03 0.299999956E-03 0.900000101E-03
0.900000101E-03 0.999999975E-05 0.999999975E-05 0.999999975E-05 0.999999975E-05 0.999999975E-05 0.999999975E-05
0 0 1 1
0 0 0 0 0 0 0 0 1 1
2.00000000 1000.00000 1 1000.00000 10000.0000 10000.0000 1.00000000
0.999999931E-03 0.100000005E-03 4
1000.00000 2 100.000000 20.0000000
200.000000 250.000000 0.129999999E-04
0.100000005E-03 0.129999989E-02 0.500000007E-01
56634.0000 0.258800015E-01
1000000.00 1000000.00 1000000.00 1000000.00 1000000.00 1000000.00 1000000.00 1000000.00 1000000.00 1000000.00
1000000.00 1000000.00 1000000.00 1000000.00 1000000.00 1000000.00 1000000.00 1000000.00 1000000.00 1000000.00
20.0000000 20.0000000 20.0000000 20.0000000 20.0000000 20.0000000 20.0000000 20.0000000 20.0000000 20.0000000
20.0000000 20.0000000 20.0000000 20.0000000 20.0000000 20.0000000 20.0000000 20.0000000 20.0000000 20.0000000
30.0000000 30.0000000 90.0000000 180.000000 240.000000 600.000000 600.000000 30.0000000 30.0000000 20.0000000
60.0000000 60.0000000 120.000000 120.000000 60.0000000 60.0000000 60.0000000 6000.00000 6000.00000 0.0 0.0
0.899999976 0.899999976 0.800000012 0.600000024 0.300000012 0.300000012 0.600000098E-02 0.200000009E-02 0.300000003E-02
0.699999988 0.699999988 0.199999988 0.899999738E-01 0.300000012E-01 0.800000038E-03 0.500000024E-04 0.100000005E-03 0.699999987E-06
0.399999976 0.500000000 0.199999988 0.399999991E-01 0.899999961E-02 0.800000038E-03 0.999999975E-05 0.500000082E-03 0.600000021E-06
0.399999976 0.300000012 0.300000012 0.300000012E-01 0.499999896E-02 0.999999931E-03 0.200000068E-04 0.100000034E-05 0.900000074E-08
0.500000007E-01 0.599999987E-01 0.199999996E-01 0.499999896E-02 0.999999931E-03 0.900000014E-04 0.100000034E-05 0.100000008E-08
0.999999996E-11
0.399999976 0.199999996E-01 0.300000012E-01 0.300000003E-02 0.599999912E-03 0.699999946E-04 0.100000034E-05 0.0 0.0
0.300000003E-02 0.400000066E-02 0.300000003E-02 0.400000019E-03 0.699999946E-04 0.999999975E-05 0.199999988E-06 0.0 0.0
0.0 0.299999989E-07 0.0 0.0 0.0 0.0 0.0
0.218000001E-03 0.113000002E-03 0.324999914E-03
10
5.00000000
0.0 0.250000028E-06 0.389999968E-05 0.150000005E-06 0.100000022E-06 0.259999884E-03
********* INITIATING EVENT ***************************
LOSS OF FEED WATER
 SEQUENCE           PROBABILITY
  1                     0.0
  2                     0.0
  3                     0.0
  4                     0.0
  5                     0.0
  6                     0.0
  7                     0.0
  8                     0.100000E+01
  9                     0.0
 10                     0.0
 11                     0.0
 12                     0.0
 13                     0.0
 RPS FAILURE PROBABILITY                        0.0
 AFW FAILURE PROBABILITY                        0.100000E+01
 HPIS FAILURE PROBABILITY                       0.100000E+01
 HPRS FAILURE PROBABILITY                       0.900000E-03
 PORC FAILURE PROBABILITY                       0.0
PWR CATEGORY         PROBABILITY
1                     0.24299983E-13
2                     0.49940061E-01
3                     0.10064937E-03
```

Table 5.3(a) Output data list of IND (2/5).

```
4                   0.0
5                   0.12984413E-02
6                   0.25626900E-06
7                   0.85397414E-03
8                   0.0
9                   0.0
**********RADIATION RISK-SHELTERING****************
  DOSE REDUCTION FACTOR-NG                        =0.056
  DOSE REDUCTION FACTOR I.& P.                    =0.006
  RESIDENCE TIME FOR REDUCTION FACTOR             =  86.56
  DOSE REDUCTION FACTOR CLOUDSHINE                =0.400
  DOSE REDUCTION FACTOR GROUNDSHINE               =0.050
NIGHT TIME EVACUATION
SPEED OF EVACUATION (M/MIN)           1000.0
RELEASE DURATION(MIN)                   30.0
TIME FOR PREPARATION                   100.0
TIME FOR DECISION MAKING                20.0
WARNING TIME                            60.0
DOSE REDUCTION FACTOR -NG=1.76
DOSE REDUCTION FACTOR -I. INH.=5.41
DOSE REDUCTION FACTOR -I. CLO.=1.87
DOSE REDUCTION FACTOR -I. GRO.=1.87
                TIMELY EVACUTION POSSIBLE IF
                EVACUATION STARTS WITHIN   43.  MINUTES
**********RADIATION RISK-SHELTERING****************
  DOSE REDUCTION FACTOR-NG                        =0.056
  DOSE REDUCTION FACTOR I.& P.                    =0.006
  RESIDENCE TIME FOR REDUCTION FACTOR             =  86.56
  DOSE REDUCTION FACTOR CLOUDSHINE                =0.400
  DOSE REDUCTION FACTOR GROUNDSHINE               =0.050
NIGHT TIME EVACUATION
SPEED OF EVACUATION (M/MIN)           1000.0
RELEASE DURATION(MIN)                   30.0
TIME FOR PREPARATION                   100.0
TIME FOR DECISION MAKING                20.0
WARNING TIME                            60.0
DOSE REDUCTION FACTOR -NG=1.76
DOSE REDUCTION FACTOR -I. INH.=5.41
DOSE REDUCTION FACTOR -I. CLO.=1.87
DOSE REDUCTION FACTOR -I. GRO.=1.87
                TIMELY EVACUTION POSSIBLE IF
                EVACUATION STARTS WITHIN   43.  MINUTES
**********RADIATION RISK-SHELTERING****************
  DOSE REDUCTION FACTOR-NG                        =0.119
  DOSE REDUCTION FACTOR I.& P.                    =0.015
  RESIDENCE TIME FOR REDUCTION FACTOR             = 211.28
  DOSE REDUCTION FACTOR CLOUDSHINE                =0.400
  DOSE REDUCTION FACTOR GROUNDSHINE               =0.050
NIGHT TIME EVACUATION
SPEED OF EVACUATION (M/MIN)           1000.0
RELEASE DURATION(MIN)                   90.0
TIME FOR PREPARATION                   100.0
TIME FOR DECISION MAKING                20.0
WARNING TIME                           120.0
DOSE REDUCTION FACTOR -NG=0.0
DOSE REDUCTION FACTOR -I. INH.=0.0
DOSE REDUCTION FACTOR -I. CLO.=0.0
DOSE REDUCTION FACTOR -I. GRO.=0.0
                TIMELY EVACUTION POSSIBLE IF
                EVACUATION STARTS WITHIN  101.  MINUTES
**********RADIATION RISK-SHELTERING****************
  DOSE REDUCTION FACTOR-NG                        =0.185
```

Table 5.3(a) Output data list of IND (3/5).

```
  DOSE REDUCTION FACTOR I.& P.                  =0.026
  RESIDENCE TIME FOR REDUCTION FACTOR           = 394.04
  DOSE REDUCTION FACTOR CLOUDSHINE              =0.400
  DOSE REDUCTION FACTOR GROUNDSHINE             =0.050
NIGHT TIME EVACUATION
SPEED OF EVACUATION (M/MIN)           1000.0
RELEASE DURATION(MIN)                  180.0
TIME FOR PREPARATION                   100.0
TIME FOR DECISION MAKING                20.0
WARNING TIME                           120.0
DOSE REDUCTION FACTOR -NG=0.0
DOSE REDUCTION FACTOR -I. INH.=0.0
DOSE REDUCTION FACTOR -I. CLO.=0.0
DOSE REDUCTION FACTOR -I. GRO.=0.0
                TIMELY EVACUTION POSSIBLE IF
                EVACUATION STARTS WITHIN   100.  MINUTES
**********RADIATION RISK-SHELTERING****************
  DOSE REDUCTION FACTOR-NG                      =0.224
  DOSE REDUCTION FACTOR I.& P.                  =0.034
  RESIDENCE TIME FOR REDUCTION FACTOR           = 515.34
  DOSE REDUCTION FACTOR CLOUDSHINE              =0.400
  DOSE REDUCTION FACTOR GROUNDSHINE             =0.050
NIGHT TIME EVACUATION
SPEED OF EVACUATION (M/MIN)           1000.0
RELEASE DURATION(MIN)                  240.0
TIME FOR PREPARATION                   100.0
TIME FOR DECISION MAKING                20.0
WARNING TIME                            60.0
DOSE REDUCTION FACTOR -NG=0.19
DOSE REDUCTION FACTOR -I. INH.=0.41
DOSE REDUCTION FACTOR -I. CLO.=0.21
DOSE REDUCTION FACTOR -I. GRO.=0.21
                TIMELY EVACUTION POSSIBLE IF
                EVACUATION STARTS WITHIN    39.  MINUTES
**********RADIATION RISK-SHELTERING****************
  DOSE REDUCTION FACTOR-NG                      =0.390
  DOSE REDUCTION FACTOR I.& P.                  =0.070
  RESIDENCE TIME FOR REDUCTION FACTOR           =1240.15
  DOSE REDUCTION FACTOR CLOUDSHINE              =0.400
  DOSE REDUCTION FACTOR GROUNDSHINE             =0.050
NIGHT TIME EVACUATION
SPEED OF EVACUATION (M/MIN)           1000.0
RELEASE DURATION(MIN)                  600.0
TIME FOR PREPARATION                   100.0
TIME FOR DECISION MAKING                20.0
WARNING TIME                            60.0
DOSE REDUCTION FACTOR -NG=0.10
DOSE REDUCTION FACTOR -I. INH.=0.15
DOSE REDUCTION FACTOR -I. CLO.=0.10
DOSE REDUCTION FACTOR -I. GRO.=0.10
                TIMELY EVACUTION POSSIBLE IF
                EVACUATION STARTS WITHIN    37.  MINUTES
**********RADIATION RISK-SHELTERING****************
  DOSE REDUCTION FACTOR-NG                      =0.390
  DOSE REDUCTION FACTOR I.& P.                  =0.070
  RESIDENCE TIME FOR REDUCTION FACTOR           =1240.15
  DOSE REDUCTION FACTOR CLOUDSHINE              =0.400
  DOSE REDUCTION FACTOR GROUNDSHINE             =0.050
NIGHT TIME EVACUATION
SPEED OF EVACUATION (M/MIN)           1000.0
RELEASE DURATION(MIN)                  600.0
TIME FOR PREPARATION                   100.0
```

Table 5.3(a) Output data list of IND (4/5).

```
TIME FOR DECISION MAKING                 20.0
WARNING TIME                             60.0
DOSE REDUCTION FACTOR -NG=0.10
DOSE REDUCTION FACTOR -I. INH.=0.15
DOSE REDUCTION FACTOR -I. CLO.=0.10
DOSE REDUCTION FACTOR -I. GRO.=0.10
                TIMELY EVACUTION POSSIBLE IF
                EVACUATION STARTS WITHIN    37.  MINUTES
**********RADIATION RISK-SHELTERING***************
  DOSE REDUCTION FACTOR-NG                        =0.056
  DOSE REDUCTION FACTOR I.& P.                    =0.006
  RESIDENCE TIME FOR REDUCTION FACTOR             =  86.56
  DOSE REDUCTION FACTOR CLOUDSHINE                =0.400
  DOSE REDUCTION FACTOR GROUNDSHINE               =0.050
NIGHT TIME EVACUATION
SPEED OF EVACUATION (M/MIN)            1000.0
RELEASE DURATION(MIN)                    30.0
TIME FOR PREPARATION                    100.0
TIME FOR DECISION MAKING                 20.0
WARNING TIME                           6000.0
DOSE REDUCTION FACTOR -NG=0.0
DOSE REDUCTION FACTOR -I. INH.=0.0
DOSE REDUCTION FACTOR -I. CLO.=0.0
DOSE REDUCTION FACTOR -I. GRO.=0.0
                TIMELY EVACUTION POSSIBLE IF
                EVACUATION STARTS WITHIN  5983.  MINUTES
**********RADIATION RISK-SHELTERING***************
  DOSE REDUCTION FACTOR-NG                        =0.056
  DOSE REDUCTION FACTOR I.& P.                    =0.006
  RESIDENCE TIME FOR REDUCTION FACTOR             =  86.56
  DOSE REDUCTION FACTOR CLOUDSHINE                =0.400
  DOSE REDUCTION FACTOR GROUNDSHINE               =0.050
NIGHT TIME EVACUATION
SPEED OF EVACUATION (M/MIN)            1000.0
RELEASE DURATION(MIN)                    30.0
TIME FOR PREPARATION                    100.0
TIME FOR DECISION MAKING                 20.0
WARNING TIME                           6000.0
DOSE REDUCTION FACTOR -NG=0.0
DOSE REDUCTION FACTOR -I. INH.=0.0
DOSE REDUCTION FACTOR -I. CLO.=0.0
DOSE REDUCTION FACTOR -I. GRO.=0.0
                TIMELY EVACUTION POSSIBLE IF
                EVACUATION STARTS WITHIN  5983.  MINUTES
**********RADIATION RISK-SHELTERING***************
  DOSE REDUCTION FACTOR-NG                        =0.605
  DOSE REDUCTION FACTOR I.& P.                    =0.126
  RESIDENCE TIME FOR REDUCTION FACTOR             =2920.15
  DOSE REDUCTION FACTOR CLOUDSHINE                =0.400
  DOSE REDUCTION FACTOR GROUNDSHINE               =0.050
NIGHT TIME EVACUATION
SPEED OF EVACUATION (M/MIN)            1000.0
RELEASE DURATION(MIN)                  1440.0
TIME FOR PREPARATION                    100.0
TIME FOR DECISION MAKING                 20.0
WARNING TIME                              0.0
DOSE REDUCTION FACTOR -NG=0.08
DOSE REDUCTION FACTOR -I. INH.=0.08
DOSE REDUCTION FACTOR -I. CLO.=0.07
DOSE REDUCTION FACTOR -I. GRO.=0.07
                TIMELY EVACUTION POSSIBLE IF
                EVACUATION STARTS WITHIN   -23.  MINUTES
```

Table 5.3(a) Output data list of IND (5/5).

```
**********RADIATION RISK-SHELTERING****************
  DOSE REDUCTION FACTOR-NG                                    =0.605
  DOSE REDUCTION FACTOR I.& P.                                =0.126
  RESIDENCE TIME FOR REDUCTION FACTOR                         =2920.15
  DOSE REDUCTION FACTOR CLOUDSHINE                            =0.400
  DOSE REDUCTION FACTOR GROUNDSHINE                           =0.050
NIGHT TIME EVACUATION
SPEED OF EVACUATION (M/MIN)                   1000.0
RELEASE DURATION(MIN)                         1440.0
TIME FOR PREPARATION                           100.0
TIME FOR DECISION MAKING                        20.0
WARNING TIME                                     0.0
DOSE REDUCTION FACTOR -NG=0.08
DOSE REDUCTION FACTOR -I. INH.=0.08
DOSE REDUCTION FACTOR -I. CLO.=0.07
DOSE REDUCTION FACTOR -I. GRO.=0.07
                TIMELY EVACUTION POSSIBLE IF
                EVACUATION STARTS WITHIN   -23.  MINUTES
```

Table 5.3(b) Output data list of POP (1/4).

NO.	AVERAGE PERSON EVACUATION ZONE(KM)	SHELTERING ZONE(KM)	POPULATION RISK OF FATALITY(PERSON)			
			NO ACTION	SHELTERING	EVACUATION	TOTAL
1	1.00	1.00	0.65705276E+02	0.0	0.0	0.65705276E+02
2	1.00	3.00	0.45333359E+02	0.29268026E+00	0.0	0.45626038E+02
3	1.00	5.00	0.40021637E+02	0.44325209E+00	0.0	0.40464874E+02
4	1.00	7.00	0.35739319E+02	0.57620662E+00	0.0	0.36315521E+02
5	1.00	9.00	0.31989029E+02	0.70252371E+00	0.0	0.32691544E+02
6	1.00	11.00	0.28494095E+02	0.82276970E+00	0.0	0.29316864E+02
7	1.00	13.00	0.25059021E+02	0.93857008E+00	0.0	0.25997589E+02
8	1.00	15.00	0.21707962E+02	0.10503492E+01	0.0	0.22758301E+02
9	1.00	17.00	0.18447220E+02	0.11587772E+01	0.0	0.19605988E+02
10	1.00	19.00	0.15301437E+02	0.12621098E+01	0.0	0.16563538E+02
11	1.00	21.00	0.12057037E+02	0.13660326E+01	0.0	0.13423065E+02
12	1.00	23.00	0.89802399E+01	0.14654112E+01	0.0	0.10445648E+02
13	1.00	25.00	0.59705200E+01	0.15616503E+01	0.0	0.75321655E+01
14	1.00	27.00	0.29208527E+01	0.16575928E+01	0.0	0.45784454E+01
15	1.00	29.00	0.0	0.17495613E+01	0.0	0.17495575E+01
16	3.00	3.00	0.45333359E+02	0.0	0.51953918E+02	0.97287262E+02
17	3.00	5.00	0.40021637E+02	0.15057182E+00	0.51953918E+02	0.92126099E+02
18	3.00	7.00	0.35739319E+02	0.28352636E+00	0.51953918E+02	0.87976746E+02
19	3.00	9.00	0.31989029E+02	0.40984344E+00	0.51953918E+02	0.84352768E+02
20	3.00	11.00	0.28494095E+02	0.53008944E+00	0.51953918E+02	0.80978088E+02
21	3.00	13.00	0.25059021E+02	0.64588982E+00	0.51953918E+02	0.77658813E+02
22	3.00	15.00	0.21707962E+02	0.75766897E+00	0.51953918E+02	0.74419525E+02
23	3.00	17.00	0.18447220E+02	0.86609697E+00	0.51953918E+02	0.71267212E+02
24	3.00	19.00	0.15301437E+02	0.96942949E+00	0.51953918E+02	0.68224762E+02
25	3.00	21.00	0.12057037E+02	0.10733519E+01	0.51953918E+02	0.65084290E+02
26	3.00	23.00	0.89802399E+01	0.11727304E+01	0.51953918E+02	0.62106873E+02
27	3.00	25.00	0.59705200E+01	0.12689695E+01	0.51953918E+02	0.59193390E+02
28	3.00	27.00	0.29208527E+01	0.13649120E+01	0.51953918E+02	0.56239670E+02
29	3.00	29.00	0.0	0.14568806E+01	0.51953918E+02	0.53410782E+02
30	5.00	5.00	0.40021637E+02	0.0	0.71005798E+02	0.11102742E+03
31	5.00	7.00	0.35739319E+02	0.13295454E+00	0.71005798E+02	0.10687807E+03
32	5.00	9.00	0.31989029E+02	0.25927162E+00	0.71005798E+02	0.10325409E+03
33	5.00	11.00	0.28494095E+02	0.37951761E+00	0.71005798E+02	0.99879410E+02
34	5.00	13.00	0.25059021E+02	0.49531800E+00	0.71005798E+02	0.96560135E+02
35	5.00	15.00	0.21707962E+02	0.60709715E+00	0.71005798E+02	0.93320847E+02
36	5.00	17.00	0.18447220E+02	0.71552515E+00	0.71005798E+02	0.90168533E+02
37	5.00	19.00	0.15301437E+02	0.81885767E+00	0.71005798E+02	0.87126083E+02
38	5.00	21.00	0.12057037E+02	0.92278051E+00	0.71005798E+02	0.83985611E+02
39	5.00	23.00	0.89802399E+01	0.10221586E+01	0.71005798E+02	0.81008194E+02
40	5.00	25.00	0.59705200E+01	0.11183977E+01	0.71005798E+02	0.78094711E+02
41	5.00	27.00	0.29208527E+01	0.12143402E+01	0.71005798E+02	0.75140991E+02
42	5.00	29.00	0.0	0.13063087E+01	0.71005798E+02	0.72312103E+02
43	7.00	7.00	0.35739319E+02	0.0	0.74362350E+02	0.11010165E+03
44	7.00	9.00	0.31989029E+02	0.12631708E+00	0.74362350E+02	0.10647768E+03
45	7.00	11.00	0.28494095E+02	0.24656308E+00	0.74362350E+02	0.10310300E+03
46	7.00	13.00	0.25059021E+02	0.36236346E+00	0.74362350E+02	0.99783722E+02
47	7.00	15.00	0.21707962E+02	0.47414261E+00	0.74362350E+02	0.96544434E+02
48	7.00	17.00	0.18447220E+02	0.58257061E+00	0.74362350E+02	0.93392120E+02
49	7.00	19.00	0.15301437E+02	0.68590313E+00	0.74362350E+02	0.90349670E+02
50	7.00	21.00	0.12057037E+02	0.78982598E+00	0.74362350E+02	0.87209198E+02
51	7.00	23.00	0.89802399E+01	0.88920456E+00	0.74362350E+02	0.84231781E+02
52	7.00	25.00	0.59705200E+01	0.98544365E+00	0.74362350E+02	0.81318298E+02
53	7.00	27.00	0.29208527E+01	0.10813856E+01	0.74362350E+02	0.78364578E+02
54	7.00	29.00	0.0	0.11733541E+01	0.74362350E+02	0.75535690E+02
55	9.00	9.00	0.31989029E+02	0.0	0.76425476E+02	0.10841449E+03
56	9.00	11.00	0.28494095E+02	0.12024599E+00	0.76425476E+02	0.10503981E+03
57	9.00	13.00	0.25059021E+02	0.23604637E+00	0.76425476E+02	0.10172054E+03
58	9.00	15.00	0.21707962E+02	0.34782553E+00	0.76425476E+02	0.98481247E+02
59	9.00	17.00	0.18447220E+02	0.45625353E+00	0.76425476E+02	0.95328934E+02

Table 5.3(b) Output data list of POP (2/4).

```
AVERAGE PERSON
   EVACUATION ZONE(KM)       SHELTERING ZONE(KM)          POPULATION RISK OF INJURY(PERSON)
NO.                                   NO ACTION        SHELTERING       EVACUATION        TOTAL
  1        1.00                1.00   0.44744238E+03   0.0              0.0               0.44744238E+03
  2        1.00                3.00   0.42740527E+03   0.99239844E+00   0.0               0.42839746E+03
  3        1.00                5.00   0.39069019E+03   0.15436878E+01   0.0               0.39223364E+03
  4        1.00                7.00   0.35409448E+03   0.20690794E+01   0.0               0.35616333E+03
  5        1.00                9.00   0.31788623E+03   0.25572271E+01   0.0               0.32044336E+03
  6        1.00               11.00   0.28200098E+03   0.30114040E+01   0.0               0.28501221E+03
  7        1.00               13.00   0.24630934E+03   0.34561758E+01   0.0               0.24976540E+03
  8        1.00               15.00   0.21122223E+03   0.38898754E+01   0.0               0.21511188E+03
  9        1.00               17.00   0.17635571E+03   0.43143015E+01   0.0               0.18066992E+03
 10        1.00               19.00   0.14157666E+03   0.47251692E+01   0.0               0.14630176E+03
 11        1.00               21.00   0.10956616E+03   0.51412611E+01   0.0               0.11470728E+03
 12        1.00               23.00   0.79318359E+02   0.55450048E+01   0.0               0.84863281E+02
 13        1.00               25.00   0.51123291E+02   0.59403172E+01   0.0               0.57063477E+02
 14        1.00               27.00   0.25434814E+02   0.63384171E+01   0.0               0.31773193E+02
 15        1.00               29.00   0.0              0.67215567E+01   0.0               0.67214355E+01
 16        3.00                3.00   0.42740527E+03   0.0              0.32661026E+02    0.46006616E+03
 17        3.00                5.00   0.39069019E+03   0.55128938E+00   0.32661026E+02    0.42390234E+03
 18        3.00                7.00   0.35409448E+03   0.10766802E+01   0.32661026E+02    0.38783203E+03
 19        3.00                9.00   0.31788623E+03   0.15648279E+01   0.32661026E+02    0.35211206E+03
 20        3.00               11.00   0.28200098E+03   0.20190048E+01   0.32661026E+02    0.31668091E+03
 21        3.00               13.00   0.24630934E+03   0.24637766E+01   0.32661026E+02    0.28143408E+03
 22        3.00               15.00   0.21122223E+03   0.28974762E+01   0.32661026E+02    0.24678058E+03
 23        3.00               17.00   0.17635571E+03   0.33219023E+01   0.32661026E+02    0.21233862E+03
 24        3.00               19.00   0.14157666E+03   0.37327700E+01   0.32661026E+02    0.17797021E+03
 25        3.00               21.00   0.10956616E+03   0.41488619E+01   0.32661026E+02    0.14637598E+03
 26        3.00               23.00   0.79318359E+02   0.45526056E+01   0.32661026E+02    0.11653198E+03
 27        3.00               25.00   0.51123291E+02   0.49479179E+01   0.32661026E+02    0.88732178E+02
 28        3.00               27.00   0.25434814E+02   0.53460178E+01   0.32661026E+02    0.63441650E+02
 29        3.00               29.00   0.0              0.57291574E+01   0.32661026E+02    0.38390137E+02
 30        5.00                5.00   0.39069019E+03   0.0              0.76905136E+02    0.46759521E+03
 31        5.00                7.00   0.35409448E+03   0.52539158E+00   0.76905136E+02    0.43152490E+03
 32        5.00                9.00   0.31788623E+03   0.10135393E+01   0.76905136E+02    0.39580469E+03
 33        5.00               11.00   0.28200098E+03   0.14677162E+01   0.76905136E+02    0.36037378E+03
 34        5.00               13.00   0.24630934E+03   0.19124880E+01   0.76905136E+02    0.32512671E+03
 35        5.00               15.00   0.21122223E+03   0.23461876E+01   0.76905136E+02    0.29047339E+03
 36        5.00               17.00   0.17635571E+03   0.27706137E+01   0.76905136E+02    0.25603125E+03
 37        5.00               19.00   0.14157666E+03   0.31814814E+01   0.76905136E+02    0.22166309E+03
 38        5.00               21.00   0.10956616E+03   0.35975733E+01   0.76905136E+02    0.19006885E+03
 39        5.00               23.00   0.79318359E+02   0.40013170E+01   0.76905136E+02    0.16022461E+03
 40        5.00               25.00   0.51123291E+02   0.43966293E+01   0.76905136E+02    0.13242480E+03
 41        5.00               27.00   0.25434814E+02   0.47947292E+01   0.76905136E+02    0.10713452E+03
 42        5.00               29.00   0.0              0.51778688E+01   0.76905136E+02    0.82082764E+02
 43        7.00                7.00   0.35409448E+03   0.0              0.10234998E+03    0.45644434E+03
 44        7.00                9.00   0.31788623E+03   0.48814774E+00   0.10234998E+03    0.42072412E+03
 45        7.00               11.00   0.28200098E+03   0.94232464E+00   0.10234998E+03    0.38529321E+03
 46        7.00               13.00   0.24630934E+03   0.13870964E+01   0.10234998E+03    0.35004614E+03
 47        7.00               15.00   0.21122223E+03   0.18207960E+01   0.10234998E+03    0.31539282E+03
 48        7.00               17.00   0.17635571E+03   0.22452221E+01   0.10234998E+03    0.28095068E+03
 49        7.00               19.00   0.14157666E+03   0.26560898E+01   0.10234998E+03    0.24658252E+03
 50        7.00               21.00   0.10956616E+03   0.30721817E+01   0.10234998E+03    0.21498828E+03
 51        7.00               23.00   0.79318359E+02   0.34759254E+01   0.10234998E+03    0.18514404E+03
 52        7.00               25.00   0.51123291E+02   0.38712378E+01   0.10234998E+03    0.15734448E+03
 53        7.00               27.00   0.25434814E+02   0.42693377E+01   0.10234998E+03    0.13205396E+03
 54        7.00               29.00   0.0              0.46524773E+01   0.10234998E+03    0.10700220E+03
 55        9.00                9.00   0.31788623E+03   0.0              0.11130563E+03    0.42919165E+03
 56        9.00               11.00   0.28200098E+03   0.45417690E+00   0.11130563E+03    0.39376074E+03
 57        9.00               13.00   0.24630934E+03   0.89894867E+00   0.11130563E+03    0.35851367E+03
 58        9.00               15.00   0.21122223E+03   0.13326483E+01   0.11130563E+03    0.32386035E+03
 59        9.00               17.00   0.17635571E+03   0.17570744E+01   0.11130563E+03    0.28941821E+03
```

Table 5.3(b) Output data list of POP (3/4).

```
AVERAGE PERSON
   EVACUATION ZONE(KM)         SHELTERING ZONE(KM)         POPULATION RISK OF COST(DOLLAR)
NO.                                          NO ACTION        SHELTERING       EVACUATION       TOTAL
  1           1.00                  1.00    0.14005292E-06   0.0              0.0              0.14005292E-06
  2           1.00                  3.00    0.13839241E-06   0.44298895E-01   0.0              0.44299029E-01
  3           1.00                  5.00    0.13530058E-06   0.12678546E+00   0.0              0.12678552E+00
  4           1.00                  7.00    0.13085042E-06   0.24550897E+00   0.0              0.24550903E+00
  5           1.00                  9.00    0.12508661E-06   0.39928102E+00   0.0              0.39928108E+00
  6           1.00                 11.00    0.11804104E-06   0.58724803E+00   0.0              0.58724809E+00
  7           1.00                 13.00    0.10973855E-06   0.80874628E+00   0.0              0.80874634E+00
  8           1.00                 15.00    0.10019954E-06   0.10632334E+01   0.0              0.10632334E+01
  9           1.00                 17.00    0.89441073E-07   0.13502550E+01   0.0              0.13502550E+01
 10           1.00                 19.00    0.77477978E-07   0.16694164E+01   0.0              0.16694155E+01
 11           1.00                 21.00    0.64322990E-07   0.20203724E+01   0.0              0.20203714E+01
 12           1.00                 23.00    0.49987818E-07   0.24028177E+01   0.0              0.24028168E+01
 13           1.00                 25.00    0.34482753E-07   0.28164711E+01   0.0              0.28164701E+01
 14           1.00                 27.00    0.17817342E-07   0.32610855E+01   0.0              0.32610846E+01
 15           1.00                 29.00    0.0              0.37364264E+01   0.0              0.37364254E+01
 16           3.00                  3.00    0.13839241E-06   0.0              0.85190181E+06   0.85190175E+06
 17           3.00                  5.00    0.13530058E-06   0.82486510E-01   0.85190181E+06   0.85190187E+06
 18           3.00                  7.00    0.13085042E-06   0.20121002E+00   0.85190181E+06   0.85190194E+06
 19           3.00                  9.00    0.12508661E-06   0.35498208E+00   0.85190181E+06   0.85190212E+06
 20           3.00                 11.00    0.11804104E-06   0.54294908E+00   0.85190181E+06   0.85190231E+06
 21           3.00                 13.00    0.10973855E-06   0.76444733E+00   0.85190181E+06   0.85190250E+06
 22           3.00                 15.00    0.10019954E-06   0.10189342E+01   0.85190181E+06   0.85190281E+06
 23           3.00                 17.00    0.89441073E-07   0.13059559E+01   0.85190181E+06   0.85190306E+06
 24           3.00                 19.00    0.77477978E-07   0.16251173E+01   0.85190181E+06   0.85190337E+06
 25           3.00                 21.00    0.64322990E-07   0.19760733E+01   0.85190181E+06   0.85190375E+06
 26           3.00                 23.00    0.49987818E-07   0.23585186E+01   0.85190181E+06   0.85190412E+06
 27           3.00                 25.00    0.34482753E-07   0.27721720E+01   0.85190181E+06   0.85190456E+06
 28           3.00                 27.00    0.17817342E-07   0.32167864E+01   0.85190181E+06   0.85190500E+06
 29           3.00                 29.00    0.0              0.36921272E+01   0.85190181E+06   0.85190544E+06
 30           5.00                  5.00    0.13530058E-06   0.0              0.24381810E+07   0.24381800E+07
 31           5.00                  7.00    0.13085042E-06   0.11872351E+00   0.24381810E+07   0.24381800E+07
 32           5.00                  9.00    0.12508661E-06   0.27249557E+00   0.24381810E+07   0.24381800E+07
 33           5.00                 11.00    0.11804104E-06   0.46046257E+00   0.24381810E+07   0.24381800E+07
 34           5.00                 13.00    0.10973855E-06   0.68196082E+00   0.24381810E+07   0.24381800E+07
 35           5.00                 15.00    0.10019954E-06   0.93644792E+00   0.24381810E+07   0.24381810E+07
 36           5.00                 17.00    0.89441073E-07   0.12234688E+01   0.24381810E+07   0.24381810E+07
 37           5.00                 19.00    0.77477978E-07   0.15426302E+01   0.24381810E+07   0.24381810E+07
 38           5.00                 21.00    0.64322990E-07   0.18935862E+01   0.24381810E+07   0.24381810E+07
 39           5.00                 23.00    0.49987818E-07   0.22760315E+01   0.24381810E+07   0.24381820E+07
 40           5.00                 25.00    0.34482753E-07   0.26896849E+01   0.24381810E+07   0.24381820E+07
 41           5.00                 27.00    0.17817342E-07   0.31342993E+01   0.24381810E+07   0.24381830E+07
 42           5.00                 29.00    0.0              0.36096401E+01   0.24381810E+07   0.24381830E+07
 43           7.00                  7.00    0.13085042E-06   0.0              0.47213260E+07   0.47213250E+07
 44           7.00                  9.00    0.12508661E-06   0.15377206E+00   0.47213260E+07   0.47213250E+07
 45           7.00                 11.00    0.11804104E-06   0.34173906E+00   0.47213260E+07   0.47213250E+07
 46           7.00                 13.00    0.10973855E-06   0.56323731E+00   0.47213260E+07   0.47213250E+07
 47           7.00                 15.00    0.10019954E-06   0.81772441E+00   0.47213260E+07   0.47213260E+07
 48           7.00                 17.00    0.89441073E-07   0.11047459E+01   0.47213260E+07   0.47213260E+07
 49           7.00                 19.00    0.77477978E-07   0.14239073E+01   0.47213260E+07   0.47213260E+07
 50           7.00                 21.00    0.64322990E-07   0.17748632E+01   0.47213260E+07   0.47213260E+07
 51           7.00                 23.00    0.49987818E-07   0.21573086E+01   0.47213260E+07   0.47213270E+07
 52           7.00                 25.00    0.34482753E-07   0.25709620E+01   0.47213260E+07   0.47213270E+07
 53           7.00                 27.00    0.17817342E-07   0.30155764E+01   0.47213260E+07   0.47213280E+07
 54           7.00                 29.00    0.0              0.34909172E+01   0.47213260E+07   0.47213280E+07
 55           9.00                  9.00    0.12508661E-06   0.0              0.76784800E+07   0.76784790E+07
 56           9.00                 11.00    0.11804104E-06   0.18796700E+00   0.76784800E+07   0.76784790E+07
 57           9.00                 13.00    0.10973855E-06   0.40946525E+00   0.76784800E+07   0.76784790E+07
 58           9.00                 15.00    0.10019954E-06   0.66395235E+00   0.76784800E+07   0.76784800E+07
 59           9.00                 17.00    0.89441073E-07   0.95097399E+00   0.76784800E+07   0.76784800E+07
```

Table 5.3(b) Output data list of POP (4/4).

```
OFF-SITE PROTECTIVE ACTION ZONES BY 3-DIMESIONAL MODEL

AVERAGE PERSON

EVACUATION ZONE(KM)     SHELTERING ZONE(KM)      FATALITY RISK      INJURY RISK      COST RISK
              1.00                   1.00      0.65705276E+02   0.44744238E+03   0.14005292E-06
              1.00                   3.00      0.45626038E+02   0.42839746E+03   0.44299029E-01
              1.00                   5.00      0.40464874E+02   0.39223364E+03   0.12678552E+00
              1.00                   7.00      0.36315521E+02   0.35616333E+03   0.24550903E+00
              1.00                   9.00      0.32691544E+02   0.32044336E+03   0.39928108E+00
              1.00                  11.00      0.29316864E+02   0.28501221E+03   0.58724809E+00
              1.00                  13.00      0.25997589E+02   0.24976540E+03   0.80874634E+00
              1.00                  15.00      0.22758301E+02   0.21511188E+03   0.10632334E+01
              1.00                  17.00      0.19605988E+02   0.18066992E+03   0.13502550E+01
              1.00                  19.00      0.16563538E+02   0.14630176E+03   0.16694155E+01
              1.00                  21.00      0.13423065E+02   0.11470728E+03   0.20203714E+01
              1.00                  23.00      0.10445648E+02   0.84863281E+02   0.24028168E+01
              1.00                  25.00      0.75321655E+01   0.57063477E+02   0.28164701E+01
              1.00                  27.00      0.45784454E+01   0.31773193E+02   0.32610846E+01
              1.00                  29.00      0.17495575E+01   0.67214355E+01   0.37364254E+01
PREGNANT WOMAN

EVACUATION ZONE(KM)     SHELTERING ZONE(KM)      FATALITY RISK      INJURY RISK      COST RISK
              1.00                   1.00      0.82454803E+02   0.45150781E+03   0.14005292E-06
              1.00                   3.00      0.60212662E+02   0.43125391E+03   0.44299029E-01
              1.00                   5.00      0.52748489E+02   0.39514990E+03   0.12678552E+00
              1.00                   7.00      0.47449448E+02   0.35902905E+03   0.24550903E+00
              1.00                   9.00      0.43045944E+02   0.32320459E+03   0.39928108E+00
              1.00                  11.00      0.39137909E+02   0.28766577E+03   0.58724809E+00
              1.00                  13.00      0.35442017E+02   0.25232127E+03   0.80874634E+00
              1.00                  15.00      0.31897232E+02   0.21753293E+03   0.10632334E+01
              1.00                  17.00      0.28475372E+02   0.18295972E+03   0.13502550E+01
              1.00                  19.00      0.25230621E+02   0.14851587E+03   0.16694155E+01
              1.00                  21.00      0.21883347E+02   0.11673169E+03   0.20203714E+01
              1.00                  23.00      0.18747345E+02   0.86745850E+02   0.24028168E+01
              1.00                  25.00      0.15707458E+02   0.58817871E+02   0.28164701E+01
              1.00                  27.00      0.12627579E+02   0.33357666E+02   0.32610846E+01
              1.00                  29.00      0.97138367E+01   0.81665039E+01   0.37364254E+01
```

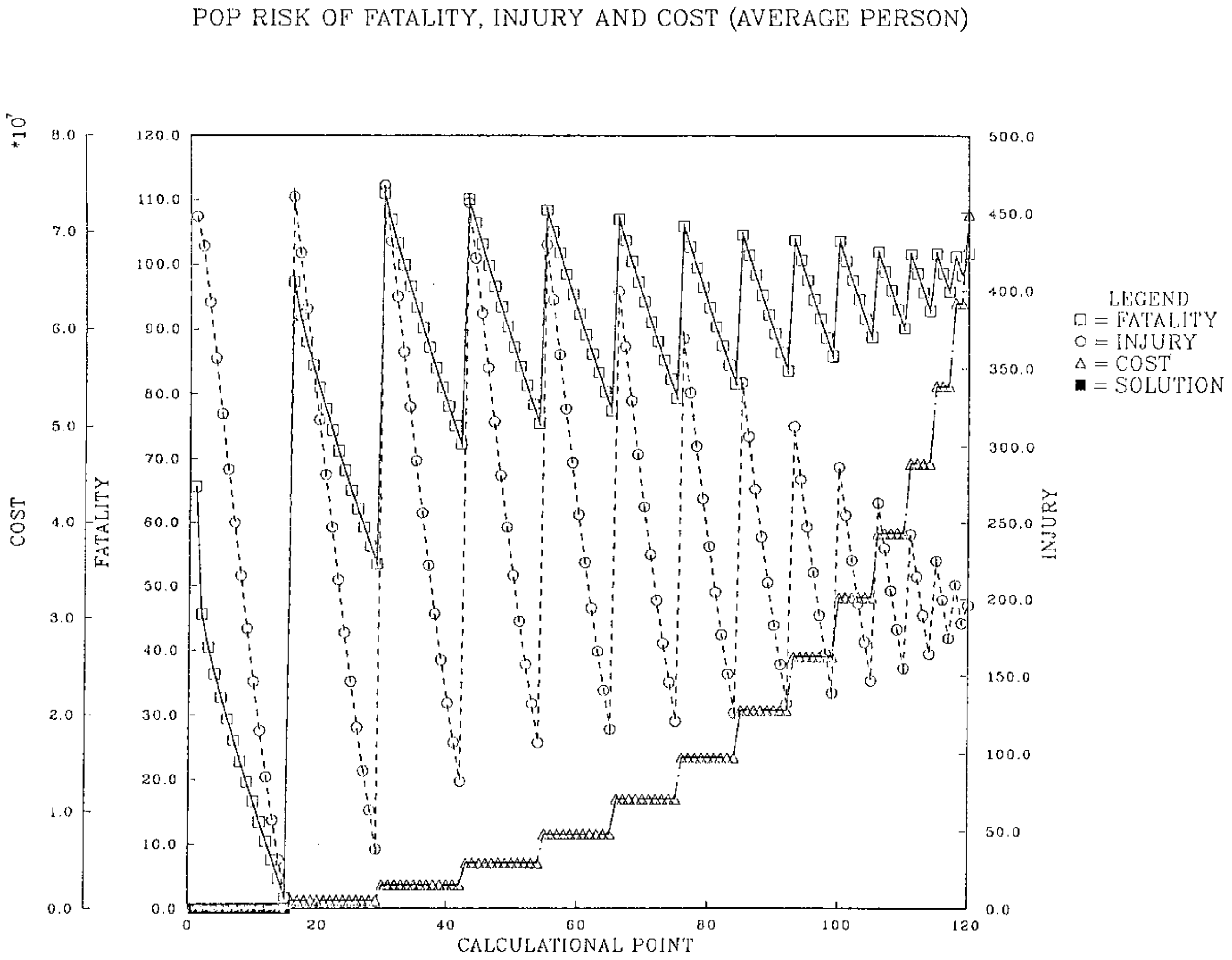

Fig. 5.1 Population risks of fatality, injury and cost under protective actions of evacuation, sheltering and no action (PLOT3 output).

6. Concluding Remarks

The first version of the PRASMA code system has been developed which supports selection of off-site protective action in nuclear reactor accidents. The methodology adopted for decision making is the multiobjective optimization method, where we have assigned population risks of fatality, injury and cost as objective functions, and distances from an affected nuclear power plant as decision variables determining the protective action zones of evacuation, sheltering and no action.

Major difference between the SOPA and the PRASMA models exists in treatment of loss or objective functions: In the SOPA model several loss functions with different units are reduced to one loss function using the conversion factors. Although such treatment gives definite choice of protective action dependent upon the distance from the affected nuclear power plant, the results include uncertainty caused by uncertainties in the conversion factors. On the other hand, the PRASMA model treats several objective functions as they are, and provides several candidates of choice of protective action. The PRASMA model, therefor, has function of screening for selecting reasonable protective action. Among the selected candidates, a decision maker might select the most favorable one based on his subjective judgment by comparing objective function values in the candidates.

The present PRASMA model owes individual risk estimation to the SOPA model that uses simplified models for evaluating several elements such as identification of potential accident sequences, their occurrence probability, source terms, environmental radiological consequences, non-radiological consequences due to sheltering and evacuation, and so on. Since the SOPA model was developed at radiological accident in the United States, it is necessary to modify and revise the SOPA model to be available in Japan. Hence, in order to make the PRASMA model more efficient and applicable as a supporting tool for decision making at radiological accidents in Japan, future work will be devoted to (a) developing a more sophisticated model for each element, (b) collecting extensive data including plant information, probabilistic risk assessment results for Japanese nuclear power plants, natural/social environmental data around nuclear power plants, and (c) making feasibility study with those revised models and collected data.

In addition, although the present PRASMA model uses the population risks as objective functions, a multiobjective optimization approach using individual risks as objective functions will be developed in the next step. Then a comparative study on the method based on the individual and population risks would give us deeper insight on selection of off-site protective action during radiological accidents.

Acknowledgment

The authors are grateful to K. Namatame, K. Kobayashi and H. Matsuzuru of Japan Atomic Energy Research Institute for reviewing and making many helpful remarks on the manuscript.

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Acknowledgment

The authors are grateful to K. Namatame, K. Kobayashi and H. Matsuzuru of Japan Atomic Energy Research Institute for reviewing and making many helpful remarks on the manuscript.

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4. N.Z. Cho, I.A. Papazoglou and R.A. Bari, "Multiobjective Programming Approach to Reliability Allocation for Nuclear Power Plants," Nuclear Science and Engineering, **95**, 165 (1987).

5. J.L. Cohon, Multiobjective Programming and Planning, Academic Press, New York (1978).

6. C.K. Park, R.A. Bari and W. Kerr, "Multiobjective Optimization Approach to Containment Performance Criteria," BNL Technical Report, A-3705 (1986).

7. J.S. Evans, D.W. Moeller and D.W. Cooper, "Health Effect Model for Nuclear Power Plant Accident Consequence Analysis," NUREG/CR-4214, SAND85-7185 (1985).

8. "Display Integrated Software System and Plotting Language, User's Manual, Version 10.0," Integrated Software System Corporation, (1984).

Appendix A Description of the IND model

This appendix provides a more detailed description of models(1) used in the IND code. The IND code for calculating individual risks includes major subroutines of SPECT, RAD and NONRAD, which will be described below.

A.1 Subroutine SPECT

The purpose of this subroutine is to find potential release states for the accident using the information related to plant status defined by safety systems demanded, response of the safety systems demanded, and status of the containment. When actual releases exist, they will be added to the potential release states with an associated likelihood of unity.

Subroutine SPECT can handle accident sequences initiated by large break loss of coolant accident (large break LOCA), small break LOCA, transients initiated by loss of off-site power (LOOP), and transient initiated by loss of feed water (LOFW). Figure A.1 shows an event tree illustrating potential sequences initiated by a LOFW for pressurized water reactor (PWR). In addition to the event tree shown in Figure A.1, SPECT considers combinations of containment safety function response shown in Table A.1. Hence, potential sequences leading to core-melt are specified by two-dimensional array (J, K), the J-th sequence on Figure A.1 and the K-th case on Table A.1.

The potential containment failure modes considered in SPECT are α-steam explosions, β-inadequate isolation, γ-hydrogen burning, δ-over pressure failure, and ε-base-mat melt-through. These containment failure modes and their dependence upon each other are illustrated in Figure A.2, where it is assumed that there may exist situations where a core-melt takes place without necessarily containment failure.

In selecting the release state category of a given accident sequence, WASH-1400 was used as the major guide. All potential accident sequences are classified into 9 classes and allocated source term characteristics.

A.2 Subroutine RAD

This subroutine calculates the consequences to the general public from radiation exposure (cloudshine, groundshine, inhalation) under a) no action, b) evacuation, and c) sheltering. Radiation effects are calculated for an average person and a pregnant woman. This subroutine RAD calls subroutines XANDG, DOSE, RISK, SHEL, and EVAC. For the most part the subroutines XANDG, DOSE, and RISK uses models adopted in the CRAC2 code as a guidance.

A.2.1 XAND

Subroutine XANDG calculates the lateral dispersion parameter σ_y [m], the vertical dispersion parameter σ_z [m], and the value of χ/Q [s/m^3] (χ : time integrated concentration of the airborne nuclide, Q : amount of radioactivity released to the atmosphere). The parameter σ_y using the empirical best-fit functions for the Pasquill-Gifford curves is given by the equation:

$$\sigma_y = ax^b$$

for duration time less than or equal to three min. Here, a is a constant that depends on the stability of the atmosphere, b is 0.9031, and x is distance from the nuclear power plant to downwind. To account for the meander of the plume for releases of large durations, σ_y is adjusted as follows:

$$\sigma_y(T) = \sigma_y(3\ \text{min})(T/3)^Q,$$

where,

$Q = 0.2$ for $3 < T < 60$ minutes,

$Q = 0.25$ for $60 < T < 600$ minutes,

T = release duration [min].

For releases greater than 600 minutes durations, the release duration is assumed to be 600 minutes.

The parameter σ_z is calculated using the equation:

$$\sigma_z = 0.8L \qquad \text{for } x > 2x_o$$

$$\sigma_z = 0.465L + 0.335L(x - x_o)/x_o \qquad \text{for } x_o < x < 2x_o$$

$$\sigma_z = (cx^d + e)(10/3)^{1/5} \qquad \text{for } x < x_o$$

where,

x_o = $[(0.465L - e)/c]^{1/d}$,
L = mixing height,
c,d,e = constants depending on the stability of the atmosphere.

The value of χ/Q is calculated using the equation:

$$\chi/Q = [3(2\pi)^{1/2}\,\sigma_y\,\sigma_z\,u]^{-1}\,[\exp\{-(z - h_{eff})^2/(2\sigma_z^2)\} + \exp\{(z + h_{eff})^2/(2\sigma_z^2)\}]$$

where,

$h_{eff} = h + 2.6\{0.000037Q_H/(u - s)\}^{1/3}$ for stable atmosphere condition

$h_{eff} = h + 1.6[0.000037Q_H(x^*)^2]^{1/3}/u$ for neutral or unstable atmosphere condition

z = vertical height of the location of interest [m]
h = height of release point [m]
u = wind speed [m/s]
Q_H = heat release rate [cal/s]
s = 0.00087 for slightly stable atmosphere
s = 0.00175 for very stable atmosphere
$x^* = 2.08(0.000037Q_H)^{2/5}(h)^{3/5}$

A.2.2 DOSE

Subroutine DOSE calculates only the doses received from the three early exposure pathways: the early exposure pathways are cloudshine (doses received from gamma rays when immersed in the radioactive cloud), short-term groundshine (doses received from exposure to radiation from nuclides deposited on the ground), and inhalation (doses received from radionuclides inhaled). The following equations are used for calculations of cloudshine doses, groundshine doses, and inhaled doses. For cloudshine doses,

$$TC(j,k) = \sum_{i=1,n(j)} DCCS(i,k)\ \chi_i\ CFAC$$

where,

$TC(j,k)$ = total cloudshine dose to the k-th organ from the j-th nuclide group [rem]

$n(j)$ = number of nuclides in the j-th nuclide group

$DCCS(i,k)$ = dose factor for the i-th nuclide and the k-th organ [rem/(Ci s/m^3)]

CFAC = semi-infinite cloud correction factor

χ_i = time integrated concentration of the airborne i-th nuclide [Ci s/m^3]

For groundshine doses,

$$TG(j,k) = \sum_{i=1,n(j)} GCCS(i,k)\ G_i$$

where,

$TG(j,k)$ = total groundshine dose to the k-th organ from the i-th nuclide group [rem]

$GCCS(i,k)$ = dose factor for the i-th nuclide and the k-th organ [rem/(Ci/m^2)]

G_i = ground concentration of the i-th nuclide [Ci/m^2]

For inhaled doses,

$$TB(j,k) = \sum_{i=1,n(j)} BCCS(i,k)\ \chi_i\ BR$$

where,

TB(j,k) = total inhaled dose to the k-th organ from the i-th nuclide group [rem]

BCCS(i,k) = dose factor inhaled for the i-th nuclide and the k-th organ [rem/Ci]

BR = breathing rate [m^3/s]

A.2.3 RISK

Subroutine RISK calculates health effects due to radiation exposure using the models presented in NUREG/CR-4214. The models used in subroutine RISK are as follows.

(1) early and continuing effects

If r is the probability of radiation fatality/injury incidence of interest, then,

$$r = 1 - e^{-H},$$

$$H = 0.693(d/\alpha)^b$$

where,

H = cumulative hazard

d = dose to the organ of interest [rem]

α, b = model parameters

The cumulative probability of mortality due to the incidence of early effect is calculated using the equation:

$$r_{cum,early} = 1 - \exp[-(H_1 + H_2 + H_3 + H_4)]$$

where, H_1, H_2, H_3 and H_4 are the cumulative hazards for the hematopoietic syndrome, pulmonary syndrome, gastrointestinal syndrome, and prenatal/neonatal death, respectively.

(2) late somatic effects

Mortality from the incidence of seven types of cancers including leukemia, two types of in-utero cancers resulting in mortality, and morbidity from the incidence of six cancer types are included in the late somatic effect calculations. The general form of the equation used to calculate the late somatic is given by

$$r = R(1)\ g(d)$$

where, R(1) is the upperbound of the probability of incidence of the somatic effect for a dose of one gray (100 rads) for a complete life time. g(d) is the conversion factor that converts the upperbound to the central estimate, and is calculated using the equation:

$$g(d) = 0.3 + 0.0047d,$$

where d is the dose in rems. The cumulative effect from the probability of incidence of late somatic mortalities and morbidities is calculated using the equations:

$$r_{cum,late} = T_1 + T_2 + \dots + T_p$$

where, T_k is the risk of the k-th somatic effect, and

$$\begin{aligned} T_1 &= r_1, \\ T_2 &= r_2(1 - T_1), \dots , \\ T_p &= r_p(1 - T_1 - T_2 - \dots - T_{p-1}) \end{aligned}$$

A.2.4 SHEL

Subroutine SHEL calculates the magnitude of dose reductions achieved through sheltering. A ratio is introduced, called the doses reduction factor (DRF), which is the ratio of doses received while sheltering to doses received while not taking any action. The subroutine SHEL uses a model developed by Weerakkody that takes into account temporal variation of concentration of nuclides outside the shelter, isotopic mix, air ventilation rate of the shelter, decay of nuclides, and the dose factor (Ci/rem inhaled) of the nuclides. The mathematical model used can be summarized by the following equation:

$$\mathrm{DRFS}(j,p) = \frac{\int^{\mathrm{TUL}} G(t) \sum_{i=1,n(j)} [f_i \exp(-\lambda_i t) \mathrm{DF}_i]dt}{\int^{\mathrm{TUL}} F(t) \sum_{i=1,n(j)} [f_i \exp(-\lambda_i t) \mathrm{DF}_i]dt}$$

where,

$\mathrm{DRFS}(j,p)$ = dose reduction factor for sheltering for doses received from the j-th nuclide group through the p-th exposure pathway

$n(j)$ = number of nuclides in the j-th nuclide group

f_i = fraction of the i-the nuclide in the j-th group of nuclides

$G(t)$ = term proportional to the nuclide concentration inside the shelter

$F(t)$ = term proportional to the nuclide concentration outside the shelter that takes into account temporal variation of nuclide concentration

DF_i = dose factor for the i-th nuclide of the j-th group [rem/Ci inhaled]

λ_i = decay constant of the i-th nuclide [1/s]

TUL = $2[\mathrm{RD} + (x + 2\sigma_y)/u]$ [s]

RD = release duration [s]

u = wind speed [m/s]

x = distance from the reactor to the downwind location of interest [m]

σ_y = lateral dispersion parameter

The major contribution to the total doses comes from noble gases and iodines. Therefore, in SHEL, isotopic mix, decay constants of iodines and noble gases are used to calculate the dose reduction factor for inhalation from these two nuclide groups. The inhalation dose reduction factor for doses received from other nuclides are assumed to be equal to those of the iodines.

A.2.5 EVAC

Subroutine EVAC calculates the dose reduction factors for evacuation. Unlike sheltering, the dose reduction factor for evacuations are largely scenario dependent. Further, the dose reduction factors for evacuations may range from essentially zero for a timely evacuation to values greater than one, implying increased radiation doses attributes to evacuations. The model used in the subroutine EVAC is illustrated by the following major equations:

$$\mathrm{DRFE}(j,p) = \frac{\int^{\mathrm{TUL}} \sum_{i=1,n(j)} F(t,x)\ f_i\ CF(x)\ DF_{ip}\ \exp(-\lambda_i t)\ dt}{\int^{\mathrm{TUL}} \sum_{i=1,n(j)} F(t,x_o)\ f_i\ CF(x_o)\ DF_{ip}\ \exp(-\lambda_i t)\ dt}$$

where,

DRFE(j,p) = dose reduction factor for evacuation for doses received from the j-th nuclide group through the p-th exposure pathway

F(t,x) = the term that takes into consideration the temporal (except decay) and the spatial variations of the nuclide concentration

n(j) = number of nuclides in the j-th nuclide group

f_i = fraction of the i-the nuclide in the j-th group of nuclides

λ_i = decay constant of the i-the nuclide (1/s)

CF(x) = a factor that takes into consideration depletion of the plume due to deposition. This factor will depend on the stability of the atmosphere.

DF_{ip} = dose factor from the i-th nuclide through the p-th exposure pathway

x = distance from the reactor to the downwind location of interest [s]

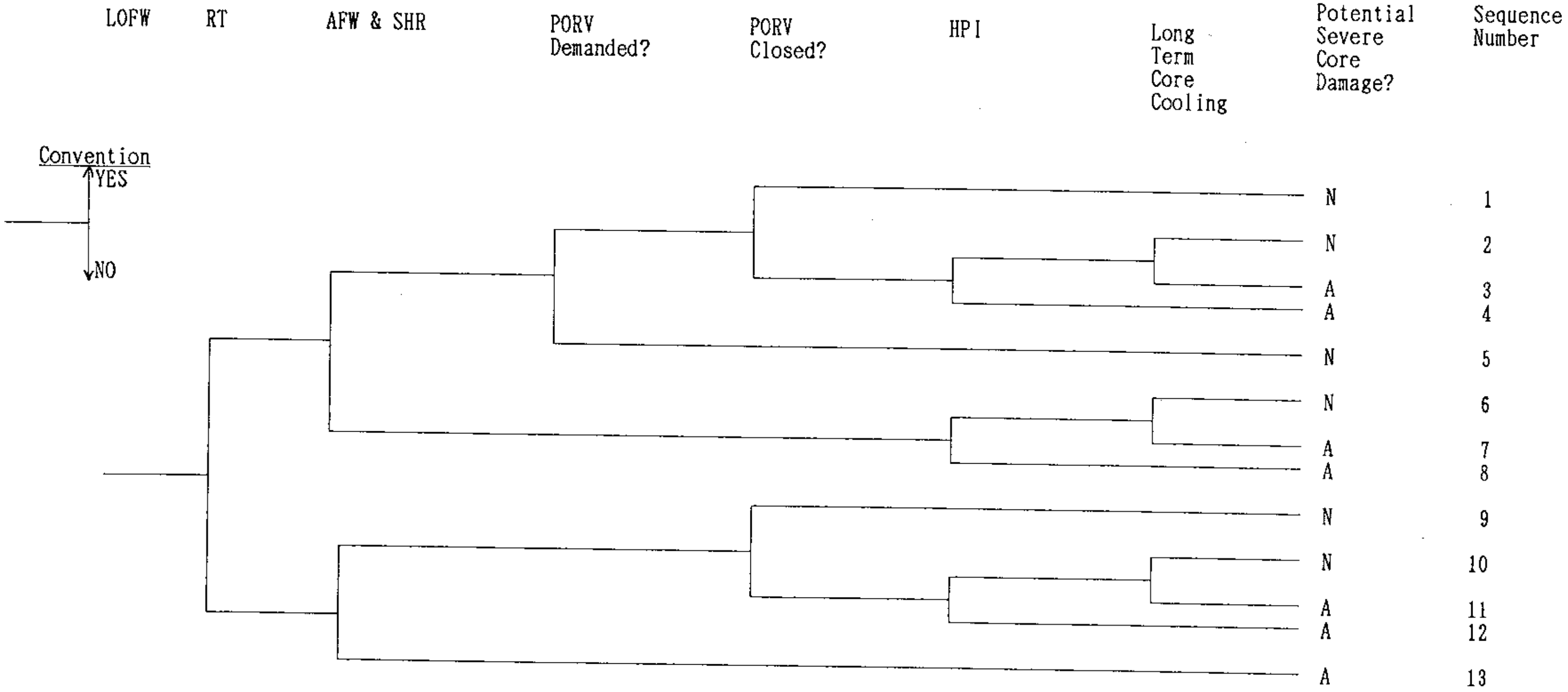
x_o = distance from the reactor to the downwind location of interest at a fixed location [m]

TUL = $2[RD + (x + 2\sigma_y)/u]$ [s]
RD = release duration [s]
u = wind speed [m/s]
σ_y = lateral dispersion parameter [m]

A.3 Subroutine NONRAD

The purpose of the subroutine NONRAD is to calculate those components of the loss function whose cause is not radiation (travel risk of evacuation, cost of evacuation, non-radiological risks of sheltering, risks of the shelters of relocation).

For the values of fatality per person mile and injury per person mile, the values obtained from Poisson analysis were used in IND code. NONRAD assumes total cost of 250 dollars per evacuee and a 200-mile round trip of an appropriate evacuation distance.



N -- Negative

A -- Affirmative

LOFW : Loss of Feed Water

RT : Reactor Trip

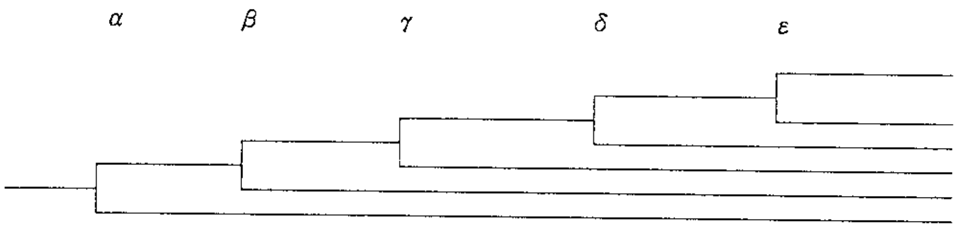
AFW : Auxiliary Feed Water

SHR : Secondary Heat Removal

PORV : Pilot-Operated Relief Vave

HPI : High Pressure Injection

Fig. A.1 Event tree for PWR loss of feed water incident(1).



α : Containment rupture due to steam explosion
β : Containment leakage due to inadequate isolation
γ : Containment rupture due to hydrogen burning
δ : Containment rupture due to over pressure
ε : Containment base-mat melt-through

Fig. A.2 BWR containment event tree(1).

Appendix B Example of JCL

```
// EXEC LMGO,
// LM='J4437.PRASMA',
// Q='.LOAD',
// PNM=IND,
// A='ERRCUT=0',
// GOSYSIN='DDNAME=SYSIN'
//RUN.SYSIN DD DSN=J4437.IND.DATA(BASE3),DISP=SHR
//RUN.FT02F001 DD DSN=J4437.IRISK.DATA,DISP=SHR
//RUN.FT06F001 DD SYSOUT=*
// EXEC LMGO,
// LM='J4437.PRASMA',
// Q='.LOAD',
// PNM=POP,
// A='ERRCUT=0',
// GOSYSIN='DDNAME=SYSIN'
//RUN.SYSIN DD DSN=J4437.POP.DATA(BASE3),DISP=SHR
//RUN.FT10F001 DD DSN=J4437.IRISK.DATA,DISP=SHR
//RUN.FT20F001 DD DSN=J4437.PRISK.DATA,DISP=SHR
//RUN.FT06F001 DD SYSOUT=*
// EXEC LMGO,
// LM='J4437.PRASMA',
// Q='.LOAD',
// PNM=GRAPH,
// A='ERRCUT=0',
// GOSYSIN='DDNAME=SYSIN'
//RUN.SYSIN DD DSN=J4437.GRAPHIC.DATA(BASE3),DISP=SHR
//RUN.FT10F001 DD DSN=J4437.IRISK.DATA,DISP=SHR
//RUN.FT20F001 DD DSN=J4437.PRISK.DATA,DISP=SHR
//RUN.FT06F001 DD SYSOUT=*
// EXPAND GRNLP,
// SYSOUT=H
//
```