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COSYMA:

Health Effects Models

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**Institut für Neutronenphysik und Reaktortechnik
Projekt Nukleare Sicherheitsforschung**

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COSYMA :

Modelle zur Berechnung gesundheitlicher Schäden

Kurzfassung

Als eines der wesentlichen Ziele des von der Kommission der Europäischen Gemeinschaften initiierten Projekts MARIA ("Methods for Assessing the Radiological Impact of Accidents") wurde das Programmsystem COSYMA ("COde SYstem from MARIA") zur Abschätzung der radiologischen und ökonomischen Folgen unfallbedingter luftgetragener Radionuklid-freisetzungen gemeinsam vom Kernforschungszentrum Karlsruhe (KfK), BRD, und dem National Radiological Protection Board (NRPB), GB, entwickelt.

COSYMA enthält Modelle und Datensätze zur Abschätzung eines breiten Spektrums von Unfallfolgen, die in einzelnen Programmmodulen implementiert sind. In diesem Bericht werden diejenigen Module behandelt, die Modelle und Daten zur Abschätzung individueller und kollektiver Risiken für deterministische und stochastische Gesundheitsschäden enthalten. Es werden sowohl die Modelle als auch deren Implementierung zusammen mit den mathematischen Algorithmen und den benötigten Daten beschrieben. Anhand von Beispielen wird die Ein- und Ausgabe der Module erläutert.

Abstract

As one of the main objectives of the MARIA project ("Methods for Assessing the Radiological Impact of Accidents") initiated by the Commission of the European Communities the program package COSYMA ("COde SYstem from MARIA") for assessing the radiological and economic off-site consequences of accidental releases of radioactive material to the atmosphere has been jointly developed by the Kernforschungszentrum Karlsruhe (KfK), FRG, and the National Radiological Protection Board (NRPB), UK.

COSYMA includes models and data for assessing a broad spectrum of accident consequences, and they are implemented in independent modules. The subject of this report are those modules, which incorporate models and data for assessing individual and collective risks for deterministic and stochastic health effects. It describes the models implemented, the mathematical algorithms and the required data. Examples are given and explained for the input and output part of the modules.

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List of abbreviations

Exposure pathways :

CL	cloudshine
EP	exposure pathway
GR	groundshine
IH	inhalation
IHR	inhalation after resuspension
IG	ingestion
SK	contamination of skin and clothes

Organs :

BM	bone marrow
BR	breast
BS	bone surface
CO	colon
EN	effective dose, weighting factors according to ICRP-60
EO	effective dose equivalent, weighting factors according to ICRP-26
EY	eye lens
GO	gonads
GI	gastrointestinal tract
LI	large intestine
LU	lung
LV	liver
OV	ovaries
PA	pancreas
RE	remainder
SK	skin
TH	thyroid
UT	uterus

Others :

ACA	Accident Consequence Assessment
ARC	Activity Risk Coefficient
ARCO	program for calculating Activity Risk COefficients
FARC	Activity Risk Coefficient for Future generations

LARC	Activity Risk Coefficient for Living generations
CCFD	Complementary Cumulative Frequency Distribution
CEC	Commission of the European Communities
COSYMA	Code SYstem from MARIA
FG	Future Generations
FL	Subsystem "Far Late" of COSYMA
GSF	GSF-Forschungszentrum für Umwelt und Gesundheit, Neuherberg, Germany
GSD	Genetically Significant Dose
KfK	Kernforschungszentrum Karlsruhe GmbH, Karlsruhe, Germany
LG	Living Generations
MARIA	Methods for Assessing the Radiological Impact of Accidents
NE	Subsystem "Near Early" of COSYMA
NL	Subsystem "Near Late" of COSYMA
NRPB	National Radiological Protection Board, Chilton, Didcot, UK
RBE	Relative Biological Effectiveness
USNRC	US Nuclear Regulatory Commission

1. Introduction

In 1982, the Commission of the European Communities (CEC) initiated the **MARIA** (**M**ethods for **A**ssessing the **R**adiological **I**mpact of **A**ccidents) programme with the aim to review and build on the nuclear accident consequence assessment methods in use within the European Community. One of the main objectives of the MARIA programme has been to develop a computer code for the probabilistic assessment of the off-site consequences of accidental releases of radioactive material to the atmosphere. The new program system, called **COSYMA** (**C**ode **S**ystem from **M**ARIA) [1], was developed jointly by the Kernforschungszentrum Karlsruhe (KfK), FRG, and the National Radiological Protection Board (NRPB), UK.

COSYMA incorporates models and data for assessing and evaluating all types of accident consequences under due consideration of countermeasure actions. Subject of this report are the modules for calculating health effects. The descriptions refer to version 95/1 of COSYMA, which will be released in 1995.

The report is one of a series of documents about the COSYMA program system. Some basic knowledge about the structure and the features of COSYMA is presumed here; however, Chapter 2 gives a brief summary of this for easier reading.

In Chapter 3, a more general description of the models, data and methods is given which are used in COSYMA for the calculation of individual and collective health effects risks. The health effects models for deterministic (or early) effects and for both stochastic somatic and genetic (or late) effects are described here. Details of their implementation in COSYMA, especially when considering countermeasures, are given in Chapter 4. In Chapter 5 the paper printout of the health effects modules is described together with an example from a run of these modules.

The calculational method adopted for the stochastic effects requires so-called activity risk coefficients which are precalculated for use in COSYMA. The theoretical formulation, the numerical approach, the required data and the program ARCO to calculate these coefficients are subject of Appendices A to C.



2. General structure of COSYMA

A detailed description of the structure of COSYMA is given in the Main Report [1] and in the User Guide [2]. The reader is referred to these publications and to the collection of papers about COSYMA in [3] for more details on the program package as a whole. However, some key features of the structure of COSYMA are summarized below.

Accident consequence assessments (ACAs) require a series of calculations to give the doses received by people, the associated emergency actions and the resulting health effects and economic costs. The calculations are based on a polar coordinate grid system with the centre point at the location of the nuclear facility; they are carried out for each of a number of areas ("grid elements"), defined in COSYMA in terms of angular segments and distance bands as shown in Figure 1. Throughout each area a uniform level of activity concentration, and hence individual doses, associated emergency actions and individual risks, are assumed. The consequences in each of these areas are calculated at a single point, the "grid point" representative for the whole "grid element".

The program package COSYMA is subdivided into three principal subsystems, each of which is an ACA program with a specific area of application. The ranges of application for each subsystem are illustrated in Figure 2.

The three ACA programs, designated the NE, NL and FL subsystem of COSYMA (where the first letter refers to Near or Far distance and the second to Early or Late health effects and the appropriate countermeasures) are written in a modular form to allow the maximum possible flexibility in their use. The modular structure of the systems and the data flow between modules is illustrated in Figure 3. Each of the modules is concerned with one part of the overall analysis. The function of the modules treated in this report are summarised below. They require as input data the results of the previous module: Deterministic health effects which are calculated in subsystem NE need a special type of individual doses determined in POTDOS and EARLY, respectively. For stochastic health effects, which are assessed in subsystems NL and FL, the results of CONCEN (i.e. nuclide specific activity concentrations) are used.

When taking countermeasures into account also the information from PROTEC about the actions taken in each grid element are required. The PROTEC module is designed to quantify the extent and duration of the protective actions and countermeasures. Different action types are considered in the different subsystems, because of the different distance ranges and endpoints considered. Table 1 lists the actions modelled in each of the three subsystems. The areas on which the various countermeasures are to be assumed can be defined geometrically in terms of angles and distances or by isodose lines derived from criteria specified by the user. The coding of COSYMA allows the user a great deal of flexibility in specifying the

criteria at which emergency actions are assumed to be initiated or withdrawn. The options available and the effect of the action on the doses and risks to exposed individuals are described in detail in [4].

The module **POTRSK** calculates individual health effects risks at each grid point, assuming that there are no protective actions. It calculates the risks to people outdoors (default in subsystem NE) or risks for people with average behaviour ("normal activity", default in the NL and FL subsystems). In the three subsystems, each module POTRSK considers different routes of exposure and different health effects as indicated in Table 1 and described in Chapter 3.

The exposure pathways considered in the NE subsystem are external irradiation from the cloud and from material deposited on the ground and on the skin, and inhalation of material from the cloud and from resuspension. A description of the modelling of these exposure pathways is given in [4]. The NL and FL subsystems also contain models for calculating doses and risks from the ingestion of contaminated food documented in [5].

The module **EARLY** in the NE subsystem calculates individual doses and early health effects risks taken countermeasures into account. It includes a detailed modelling of the effects of early emergency actions in reducing the potential doses and thus the individual risks. It uses the output of the PROTEC module to identify which actions should be assumed to be taken at each of the grid points. The module considers different groups of people who, after an initial delay, are sheltering in different types of buildings, or evacuating spontaneously or remaining outdoors for some reason (perhaps they could not be located and warned). After the sheltering period, the remaining people are assumed to be evacuated. The effects of stable iodine tablets in reducing risks are also considered in this module. The flexibility and complexity of the countermeasures model prevented a division into separate dose and risk modules because of the amount of storage which would be required to pass the information between two such modules. This report only focusses on the risk part of EARLY; the dose models are described in a separate document [4].

The module **LATRSK** of the NL and FL subsystems calculate the individual stochastic health effects risks at each grid point including the effects of countermeasures. The calculation of late health effects from irradiation over extended periods of time is a complex problem involving the time variation of dose (including the time variation of intake and of the concentration in food after deposit for ingestion doses), the variation of risk with the age and life-expectancy of the exposed individuals and the age distribution of the exposed population. Much of this can be pre-calculated for unit air concentration or deposition of each nuclide. This is done in COSYMA, the results being termed "activity risk coefficients". These coefficients, which are contained in a data library, are described in detail in Chapter 4.

An optional LATRSK module of the FL subsystem allows the detailed evaluation of the time distribution of the occurrence of cancers in the exposed population. The standard

LATRSK module of the NL and FL subsystems can be used to obtain an approximative estimate of this distribution.

The individual risks of health effects (actual or potential) are combined with the distribution of the population in the module COLLEC which calculates the number of health effects in the population for each deterministic health effect and each cancer type considered in COSYMA, subsystem NE and NL/FL, respectively and the overall number of deterministic and stochastic health effects.

The results of the modules described above are stored on files for subsequent modules or as an endpoint for the corresponding evaluation program.

The calculations in all modules are based on the same loop structure as shown in Figure 4. Thus, individual risks are assessed for each weather sequence L, each grid point defined by radius I and azimuthal sector J (representative for the corresponding grid element as shown in Figure 1) and each release phase NP. To save computing and storage time the calculations are only performed for those grid elements affected by the plume; this is controlled by the index array JUSED which is stored together with the results on a file. In the following sections all formulas describing the risk calculation refer to one grid point (I,J); for clarity the corresponding indices are always omitted in the formulas.

3. Health effects models

3.1 Overview

The exposure of individuals to ionising radiation can lead to health detriments. Such radiation-induced detrimental effects are called "somatic", if they become manifest in the irradiated population group, and "hereditary" if they affect their descendents. The somatic effects may be either "deterministic" (also called "early") or "stochastic" (also called "late"). Deterministic effects can occur shortly after exposure to high levels of radiation and are those for which the severity of the effects varies with the dose and for which a threshold may exist. Stochastic effects generally appear long after irradiation and are those for which the probability of the effect occurring, rather than its severity, is taken to be a function of dose without threshold. At levels of dose encountered in accidental situations after the imposition of protective actions and countermeasures, hereditary effects are regarded as being stochastic [6].

The risk of deterministic effects is calculated using 'hazard functions', as recently recommended by the US Nuclear Regulatory Commission (USNRC) [7] and NRPB [8]. The deterministic fatal effects specified in COSYMA comprise those following the irradiation of the bone marrow (hematopoietic syndrome), the lung (pulmonary syndrome), the GI-tract (gastrointestinal syndrome) and skin (skin burns). In addition, the mortality of pre- and neonates after exposure in utero is quantified. Of the possible non-fatal effects the only ones included are those which lead to a severe disability of the affected persons for the rest of their life or which require medical treatment and/or social care. Dose-rate dependent models are used whenever proposed by USNRC or NRPB.

As stochastic effects, eleven different cancer types and hereditary effects are considered in COSYMA. Numbers of both fatal and non-fatal effects can be estimated using linear dose-response relationships without dose thresholds. The age-, sex- and time-dependent dose-risk coefficients for leukemia and bone cancer are based on the assumption of an absolute risk model, for all other coefficients, relative (or multiplicative) models have been used. The default risk coefficients included in COSYMA are those recommended by GSF (GSF-Forschungszentrum für Umwelt und Gesundheit, Neuherberg, Germany; [9]).

The method adopted in COSYMA for calculating the numbers of late effects makes allowance for the variation of dose and risk as a function of time and age, using precalculated "activity risk coefficients". During an ACA run, cancer risks are simply calculated by multiplication of these coefficients with the initial activity concentrations; an intermediate dose assessment step is not necessary. With this new algorithm, COSYMA gives the possibility

of estimating numbers of fatal stochastic somatic health effects as a function of distance and time after the accident.

Deterministic effects are calculated with the COSYMA subsystem NE and the stochastic effects are calculated by the subsystems NL and FL. The individual risks for these effects are calculated for each grid point (I,J) which is representative for a whole grid element. The number of people living within the corresponding grid element is used to calculate the number of health effects in the population. The main features of the models underlying the program are described in the following sections.

Outputs of COSYMA are the individual risk of each of the health effects and their sum and the number of persons affected. Individual risks may be presented in the form of expectation values and percentiles as a function of distance or complementary cumulative probability distributions for each distance. The number of health effects are given as CCFDs or in tables showing statistical quantities such as expectation values, percentiles or probabilities that no effects occur. Example printouts are presented in Chapter 8; their description is given in Chapter 5.

3.2 Individual risks of deterministic effects

Models for a range of fatal and non-fatal deterministic effects are included in the subsystem NE of COSYMA, as indicated in Table 2. This section describes the dose-response relationships and the default parameter values which are used in calculating those effects.

All those causes of death, for which a dose-response relationship has been specified either by USNRC [7], [10] or by NRPB [8] are considered. However, the list does not include all the non-fatal effects of radiation which have been identified. The subset selected for inclusion in COSYMA consists of those effects which lead to a severe disability of the affected persons for the rest of their life or which require continuous medical treatment and/or social care. Those non-fatal effects which are transitory and leave no permanent health detriment, such as prodromal vomiting, temporary erythema, transitory depilation etc., are not quantified.

The risk of suffering from these effects following irradiation increases rapidly as the dose increases above a threshold value. This is modelled in COSYMA according to [7] using a "Hazard function", in which the probability of an individual being affected, R , is given by

$$R = 1 - e^{-H} \quad [3.1]$$

In general, the cumulative hazard H is a function of dose and dose-rate. In the present COSYMA modelling, H is taken to be a two-parameter Weibull function of the form

$$H = \ln 2 \cdot \left(\frac{D}{D_{50}} \right)^V, \quad [3.2]$$

where

- D is the (average absorbed) dose to the relevant organ
- D_{50} is the dose which causes the effect in 50% of the exposed population
- V is the shape parameter, which characterises the slope of the dose-risk function

Doses which are protracted over a period of time are less effective than those delivered over a very short period. This is included in the model by summing over doses delivered in different time periods, with each normalized by an appropriate D_{50} . The equation above is then replaced by

$$H = \ln 2 \cdot \left(\sum_i \frac{D^i}{D_{50}^i} \right)^V, \quad [3.3]$$

where

- D^i is the dose delivered in the time period i
- D_{50}^i is the dose which will cause the effect in 50% of the exposed population if it is delivered in time period i

The values of the shape parameter V and the time periods i depend on the effect *eff* considered¹ and can be selected by the user of COSYMA. The default values included are based on [7], [10], [11] and given in Table 2. The time periods chosen as default values are those contained in the dose per unit intake file [13].

In the revised version of the USNRC health effects model [10], [12] and in the NRPB recommendations [11] based on a review of the USNRC reports dose-rate dependent D_{50} -values are proposed for some deterministic effects. These account for the fact that the radiation doses accumulated at low dose rates over longer periods are less effective than those resulting from short term exposure at high dose rates. For each of the deterministic health effects considered in COSYMA the value D_{50}^i assigned to each of the time intervals i used in Eq. [3.3] is calculated by the formula

$$D_{50}^i = D_{\infty} + \frac{D_0}{DR^i}, \quad [3.4]$$

where

- D_0 model parameter (in Gy) being identical with the value of D_{50} at high dose rates
- D_{∞} model parameter (in Gy^2/h) describing the increase in D_{50} with

¹ for easier reading the dependency on the health effect is omitted in the formulas given in this chapter

$$DR^i = \frac{D^i}{dur(i)} \quad \begin{array}{l} \text{decrease of dose rate} \\ \text{average dose rate in the time interval } i \text{ with a duration of } dur(i) \end{array}$$

The default values shown in Table 2 have been taken from [11]; they can be changed by the user. These values refer to minimal treatment. The user can model other types of medical treatment with the NAMELIST parameter TREAT. Then the values of D_0 and D_∞ specified for the corresponding effect will be multiplied by this factor. In the program a default value of 1.5 is assigned to TREAT for hematopoietic syndrome assuming supportive treatment according to USNRC.

For the gastrointestinal syndrome, the NRPB-report gives different D_{50} -values for internal and external exposure. As the D_{50} -value for internal exposure is so much larger than that for external exposure, the internal exposure will not contribute much to the total risk and is not taken into account. Death from GI-tract exposure is only a small contribution to the overall risk of death in any case.

For pre- and neonatal death, the NRPB-report gives three different D_{50} -values and shape parameters, depending on the age of the fetus. The values used in COSYMA are those for the 18 - 150 day period. This gives a pessimistic prediction for the 150 - 270 day period, and presumably applies to about seven times as many cases as the 1 - 18 day value. The risk would apply to all pregnancies.

For mental retardation, the NRPB-report gives two different D_{50} -values, depending on the age of the fetus. The values used in COSYMA are those for the 8 - 15 week period and are only applied to this "age group". This means that the risk would apply to about one fifth of all pregnancies. The D_{50} -value for the 16 - 25 week period is so much larger than the D_{50} -value used for pre-/neonatal death, that there will not be many cases of severe mental retardation to the survivors.

In these equations above, the inhalation dose is given by

$$dose = (low \text{ LET dose}) + RBE \cdot (high \text{ LET dose}) \quad [3.5]$$

For all organs the high LET dose is multiplied by the appropriate quality factor RBE (relative biological effectiveness) given in [11] and shown in Table 2. In many cases the RBE is 0, which means that the α -contribution will not be included in the dose estimates used. The current COSYMA libraries for the dose conversion factors of α -emitting nuclides give the dose equivalent assuming that the RBE for the α -dose is 20. Therefore, the values from the library are multiplied by RBE/20 to get the dose equivalent used for calculating the individual risks for deterministic health effects.

The values calculated for individual risks as described above refer broadly to an average adult of a population, except for effects to the fetus and skin burns. The individual risks for pre- and neonatal death and for mental retardation refer to the individual affected. Effects

on skin will lead to early death only for persons older than 50 years at the time of accident. From this age group at risk a fraction of 15% is expected to die from skin burns [8]. The NAMELIST parameter SKMORT defines the fraction of the total population suffering from early death by skin effects. The default value of 0.05 is determined assuming that 33% of the population are over 50 years old representing the German age distribution. Applying this fraction to the individual risk for skin burns of an individual affected, the individual risk for fatal skin burns for an average member of the population is calculated; thus, the maximal value can never exceed the value of SKMORT.

Parameter values for the hazard function can be selected which give a good description of the variation of risk with dose over a wide range of doses. However, they do have the problem of predicting a non-zero risk at any dose, however, small. Acute doses of radiation below a certain threshold are assumed not to carry any risk of causing deterministic effects. In COSYMA, the threshold for each single effect is set to correspond to an individual risk of 1% as default value (input parameter THRESH). Individual risks below this value are cut off. The individual risks for fatal skin burns are compared to this threshold before applying the population fraction SKMORT.

The individual health risks are calculated separately for each effect *eff* and then combined to obtain the total *tot* individual risk of a deterministic health effect in a way which prevents the overall risk exceeding unity. The overall individual risk of early **mortality** *mt* is calculated according to

$$R_{mt}^{tot} = 1 - e^{-(H_b + H_p + H_g + H_s)} \quad [3.6]$$

where H_b , H_p , H_g , H_s are the cumulative hematopoietic (*b*), pulmonary (*p*), gastrointestinal (*g*) and skin (*s*) hazards. The risk of pre- and neonatal death is presented separately, as it refers to another population group.

The risk $R_{eff,mb}$ of each single effect *eff* of **morbidity** *mb* is reduced to account for early mortality according to

$$R_{eff,mb} = (1 - e^{-H_{eff,mb}}) \cdot (1 - R_{mt}^{tot}) \quad [3.7]$$

The total individual risk of non-fatal effects represents the combined risk of suffering from morbidity but not early death. It is not limited to 1, as an individual can experience non-lethal diseases from more than one cause. Therefore the overall risk R_{mb}^{tot} of non-fatal effects is calculated by summation of the single effects according to

$$R_{mb}^{tot} = \sum_{eff} R_{eff,mb} \quad [3.8]$$

Mental retardation from brief exposures in utero is presented separately, and is corrected for individual risk of fetal death.

The exposure pathways which are assumed to contribute to the incidence of deterministic health effects are external exposure from the cloud and from deposited material, and inhalation of material in the cloud or after its deposition and subsequent resuspension. In addition the dose from material deposited on the skin and clothing is assumed to contribute to mortality and morbidity from skin exposure. Ingestion of contaminated food is not considered to contribute to these effects, because countermeasures would certainly be applied in time if doses from ingestion were estimated to be high enough to cause deterministic effects.

Besides the results calculated for individual risks information on the breakdown by exposure pathways and nuclides of the mean value can be obtained during a run. As in the dose-rate dependent model the actual D_{50} -value is different for each grid element (and in the case of countermeasures for each population group and driving time class), it was not possible to evaluate the weighted protracted dose used in the risk assessment. Instead, the breakdown is given for the mean dose integrated only over the first time period of the health effects model.

3.3 Individual risks of stochastic somatic health effects

The principal stochastic somatic health effects are the increased incidence of cancers, both fatal and non-fatal, in the irradiated population. Their appearance is likely to spread over several decades following an accidental release [6]. The eleven late somatic effects considered in COSYMA are listed in Table 3.

There has been a number of extensive studies of the incidence of late health effects in irradiated populations (see, for example, [8], [10] and [14]). These studies have identified the health effects in the irradiated population and also the methods which should be used to calculate the risks in other populations having different age structures and different natural cancer risks from the population studied.

There are two models for assessing the risk of a cancer being induced in an irradiated person and population after a single radiation exposure. The absolute risk or additive model assumes that radiation produces a risk of cancer which is independent of the natural cancer risk and is the same in all populations for the same dose. The relative risk or multiplicative model assumes that radiation increases the natural cancer risk by a multiplicative factor which is the same for all populations independent of any differences in the natural cancer risk between the populations. This means that the overall cancer risk in a population depends on the natural cancer risk and on the age distribution of the population at the time of the exposure. Different models are considered appropriate for different cancers. Therefore, some of the risk coefficients used in COSYMA were derived from the additive model, and some from the multiplicative model depending upon the particular cancer being considered.

Estimates of the radiation induced incidences of cancers are generally based on the assumptions of a linear dose response function without dose threshold. For low LET radiation, linear-quadratic modifications are under discussion at low doses and dose-rates. In the present version of COSYMA, a linear dose-response function is used.

The calculation of the risk of suffering a late health effect as a result of an accident is complicated by a number of features. The exposed population consists of individuals of various ages. As late effects may not appear for some tens of years after exposure, some of the possible risk may not be expressed in the population as people may die naturally before the radiation induced effect occurs. Most of the routes of irradiation lead to doses being delivered over a period of time. Even for the case of inhalation where the intake occurs at a specific time, material can remain in body tissues for extended periods, leading to doses over these extended periods. This extended period of irradiation must be considered in calculating the probability that a particular person will suffer a radiation-induced effect. Intakes of contaminated food and external exposure from deposited activity may continue over extended periods of time, so that people who are born after the accident occurred can also be irradiated, and therefore suffer health effects.

The calculation of the risk of health effects allowing for the time variation of dose, the age distribution of the population and the delay between exposure and the effect occurring requires the evaluation of complicated multiple integrals. These integrals have been precalculated for use in COSYMA, for the risk of each cancer type for unit air concentration and unit deposition of each nuclide. Separate values were calculated for the risk in the population living at the time of the accident (referred to as "the living generations" LG), and in those people born after the accident (referred to as "future generations" FG). The integrals relating risk to air or ground concentration are referred to as "activity risk coefficients" LARC for the living generations and FARC for the future generations. A detailed description of the theory and its numerical approximation is given in Appendix A to C.

To take into account the mitigating effect of countermeasures such as relocation or food-bans, the values of the activity risk coefficients are calculated for exposure starting at a series of times $t(n_0)$ after the accident indicating the end of the action. The risk of cancer allowing for, for example, a food ban of 1 year duration is then calculated using activity risk coefficients in which the ingestion is assumed to start 1 year after the accident. Data sets of activity risk coefficients $LARC(EP,eff,K,t(n_0))$ and $FARC(EP,eff,K,t(n_0))$ for each exposure pathway EP , health effect eff , nuclide K and time $t(n_0)$ after the accident for withdrawal of countermeasures are contained in the COSYMA package. For areas with no actions $t(n_0) = 0$. As cloudshine and inhalation affect people only during the passage of the plume, activity risk coefficients are calculated only for $t(n_0) = 0$ and only for the living generations.

The individual risk $r_{mi,eff}^{EP,LG}$ for fatal (mortality mi) health effect eff for exposure starting at time $t(n_0)$ via the exposure pathway EP for a person living at the time of the accident LG is given by

$$r_{mt,LG}^{CL,eff} = SF_{CL} \cdot \sum_K (AC(K) \cdot LARC(CL,eff,K)) \quad [3.9]$$

for cloudshine EP = CL

$$r_{mt,LG}^{GR,eff} = SF_{GR} \cdot \sum_K (AG(K) \cdot LARC(GR,eff,K,t(n_0))) \quad [3.10]$$

for groundshine EP = GR

$$r_{mt,LG}^{IH,eff} = ARATIH \cdot SF_{IH} \cdot \sum_K (AA(K) \cdot LARC(IH,eff,K)) \quad [3.11]$$

for inhalation EP = IH

$$r_{mt,LG}^{IHR,eff} = ARATIR \cdot SF_{IHR} \cdot \sum_K (AG(K) \cdot LARC(IH,eff,K,t(n_0))) \quad [3.12]$$

for inhalation after resuspension EP = IHR

$$r_{mt,LG}^{IG,eff} = \sum_K \sum_F (AG(K) \cdot LARC(IG,eff,K,t(n_0),F)) \quad [3.13]$$

for ingestion EP = IG

where

- $AA(K)$ = time-integrated activity concentration in the air near ground [$Bq \times s/m^3$]
- $AC(K)$ = time-integrated "effective cloud concentration" [$Bq \times s/m^3$]
 $AC(k) = AA(k) \cdot PCF$, already calculated in CONCEN / COSGAP
- $AG(K)$ = concentration of activity initially deposited on the ground [Bq/m^2]
- $ARATIH$ = breathing rate [m^3/s] for inhalation
- $ARATIR$ = breathing rate [m^3/s] for inhalation of resuspended activity
- F = index of foodstuff
- K = index of radionuclide
- PCF = plume correction factor
- SF_{EP} = average shielding factor for exposure pathway EP (normal activity or staying outdoors)

The individual risk $r_{mt,FG}^{EP,eff}$ for fatal (mortality mt) health effect eff for exposure starting at time $t(n_0)$ via the exposure pathway EP for a person born after the accident FG is given by (same notations as above):

$$r_{mt,FG}^{GR,eff} = SF_{GR} \cdot \sum_K (AG(K) \cdot FARC(GR,eff,K,t(n_0))) \quad [3.14]$$

for groundshine EP = GR

$$r_{mt,FG}^{IHR,eff} = ARATIR \cdot SF_{IHR} \cdot \sum_K (AG(K) \cdot FARC(IH,eff,K,t(n_0))) \quad [3.15]$$

for inhalation after resuspension EP = IHR

$$r_{mt,FG}^{IG,eff} = \sum_K \sum_F (AG(K) \cdot FARC(IG,eff,K,t(n_0),F)) \quad [3.16]$$

for ingestion EP = IG

The individual risk resulting from all exposure pathways is obtained by summing up:

$$r_{mt,LG}^{eff} = \min \left\{ 1.0, \sum_{EP} r_{mt,LG}^{EP,eff} \right\} \quad [3.17]$$

$$r_{mt,FG}^{eff} = \min \left\{ 1.0, \sum_{EP} r_{mt,FG}^{EP,eff} \right\} \quad [3.18]$$

A further set of activity risk coefficients is available for use with a special version of the FL subsystem which allows the calculation of fatal cancer rate as a function of time after an accident for each of the cancer types considered and their sum. These coefficients are evaluated over limited ranges of the integrals to give the risk of the health effects occurring in a series of defined time periods after the accident. The calculation of the time-dependent occurrence of cancer death requires large computing times. Therefore, normalized time functions have been derived from assessments for various PWR source terms, which approximately describe the time dependence of mortality for each cancer type. These functions have been implemented in the standard version of the COSYMA subsystems NL and

FL to allow quick estimations of the time dependent occurrence of fatal cancers. Examples are published in [15].

The activity risk coefficients included in COSYMA incorporate risk coefficients for late effects recommended by GSF [9], [14], [16]. The risk coefficients are given in Table 3; they are expressed in terms of the number of fatal cancers per million people for a single exposure of 10^{-2} Sv, assuming the age structure and natural cancer incidence of the German population. As an example Table 46 shows the detailed risk coefficients provided by GSF for use in COSYMA to calculate cancer fatalities in the population for lung cancer in men. These coefficients give the cumulative numbers of radiation induced effects per unit dose equivalent as a function of time after a single radiation exposure and are parameterised with respect to the age at exposure and sex.

The user of COSYMA can only change the default risk coefficients for late effects by providing a new set of activity risk coefficients. At present only one set of these coefficients is provided with the COSYMA package. However, with the ARCO-program described in Appendix C other sets of activity risk coefficients can be calculated.

A linear dose response function can formally lead to an individual risk for mortality r_{mt} from a stochastic somatic health effect eff greater than one. Therefore, the program limits risks r_{mt}^{eff} to values smaller than or equal to 1. From these values the individual risk for incidence r_{inc}^{eff} is calculated applying the BEIR-correction factors CFINC shown in Table 3, which relate the number of fatal cancers to the total incidence of cancer, and limiting the risk to 1 according to

$$r_{inc}^{eff} = \min \left\{ 1.0, \frac{r_{mt}^{eff}}{CFINC^{eff}} \right\} \quad [3.19]$$

The overall risk r_{mt}^{tot} for mortality from any stochastic somatic effect eff is obtained from

$$r_{mt}^{tot} = 1 - \prod_{eff} (1 - r_{mt}^{eff}) \quad [3.20]$$

The overall risk r_{inc}^{tot} for incidence of any stochastic somatic effect is calculated by summation of the risk of each single effect eff and then limiting the sum to 1 according to

$$r_{inc}^{tot} = \min \left\{ 1.0, \sum_{eff} r_{inc}^{eff} \right\} \quad [3.21]$$

As the individual risk for breast cancer is calculated to apply to women only, the totals in Eq. [3.20] and Eq. [3.21] are calculated separately for males and females; then they are averaged to obtain the individual total risk for a mean individual of the population according to

$$r_{mt}^{tot} = (r_{mt}^{tot} (males) + r_{mt}^{tot} (females)) \cdot 0.5 \quad [3.22]$$

and

$$r_{inc}^{tot} = (r_{inc}^{tot} (males) + r_{inc}^{tot} (females)) \cdot 0.5 \quad [3.23]$$

Whenever late effects are calculated in areas with non-zero overall risk for fatal deterministic effects R_{mt}^{tot} (only possible in the NL subsystem of COSYMA), the risk of a single stochastic somatic effect r^{eff} as well as the overall risk r^{tot} are corrected for the living generations to avoid double counting of fatalities:

$$\begin{aligned} r_{y,corr}^x &= 1 - (1 - r_y^x) \cdot (1 - R_{mt}^{tot}) - R_{mt}^{tot} \\ &= r_y^x \cdot (1 - R_{mt}^{tot}) \end{aligned} \quad [3.24]$$

where

x = single effect (*eff*) or total (*tot*)

y = mortality (*mt*) or incidence (*inc*)

COSYMA can also calculate the impact of fatal cancers in terms of the loss of life expectancy in the exposed population. The loss of life expectancy, averaged over all members of the exposed population, is indicated in Table 46 for the particular cancer type considered there. For further details see Section 4.2.6.

3.4 Individual risks of hereditary effects

Hereditary effects in the offspring of the exposed population are estimated in the NL and FL subsystems of COSYMA. The degree of inherited health defects may range between slight deviations in metabolism or physical characteristics, which can often only be detected by special techniques, and severe diseases involving life-long illness and premature death. The dominant radiation-induced mutations will predominantly result in the manifestation of inherited defects in the children and grand-children of the population involved. Recessive mutations will in general become manifest only after many generations, i.e. after having been sufficiently spread in the genetic pool of the whole population.

In COSYMA primarily the genetically significant dose of the population living at the time of the accident GSD(LG) and of those born after the accident GSD(FG) is estimated. This can be related to the collective genetically significant doses from other sources of radiation, e.g. natural background radiation.

To allow the user rough estimation of the overall number of children with genetic defects (all effects excluding multifactorial effects) in the various offspring generations, two different risk

coefficients r_1 and r_2 can be provided by user input. The coefficient r_1 is multiplied with the collective genetically significant dose of the living generations; as result the number of genetic effects for the children born to this population group are obtained. The coefficient r_2 multiplied with the collective genetically significant dose of all persons irradiated (living plus future generations) gives the total number of inherited health defects caused by the accidental release of radioactive material. Present default values in COSYMA are $r_1 = 10^{-3} \text{ manSv}^{-1}$ [17] and $r_2 = 10^{-2} \text{ manSv}^{-1}$ [18] for low dose rates (NAMELIST parameters HERED1 and HERED2).

The number of hereditary effects HE is calculated according to

in the living generation (LG):

$$HE(LG) = GSD(LG) \cdot r_1 \quad [3.25]$$

in all generations (LG + FG):

$$HE(LG + FG) = (GSD(LG) + GSD(FG)) \cdot r_2 \quad [3.26]$$

in the future generations (FG):

$$\begin{aligned} HE(FG) &= HE(LG + FG) - HE(LG) \\ &= GSD(LG) \cdot (r_2 - r_1) + GSD(FG) \cdot r_2 \end{aligned} \quad [3.27]$$

The calculation of GSD(LG) and GSD(FG) is performed according to Eqs. [3.9] to [3.16] using the activity dose coefficients LGSD and FGSD determined in analogy to the LARC and FARC values (see Appendix A.4).

3.5 Number of health effects

3.5.1 Calculation of collective risks using individual risks

The collective risks CR^{eff} and cr^{eff} which give the number of deterministic and stochastic health effects, respectively, in the population, are calculated by combining the individual risks with the underlying population distribution. The grid point specific individual risks R^{eff} for a deterministic health effect eff and r^{eff} for a stochastic health effect eff , respectively, are multiplied with the number of people $P(I,J)$ in the corresponding grid element (I,J) and then summed up over the whole area under consideration:

$$CR^{eff} = \sum_{(I,J)} R^{eff} \cdot P(I,J) \quad [3.28]$$

$$cr^{eff} = \sum_{(I,J)} r^{eff} \cdot P(I,J) \quad [3.29]$$

In the case of mental retardation and pre- and neonatal death 1% of the population is assumed to be pregnant women. Thus, the collective risk for these effects according to Eq. [3.28] is divided by 100. As the age group considered for mental retardation affects only one fifth of the pregnancies, this number is then divided by 5. The individual fatal risk for skin burns already refers to the average population, i.e. the factor SKMORT determining the fraction of the population dying from skin burns is included in the individual risk. To calculate the number of breast cancer, the collective risk according to Eq. [3.29] is divided by 2 assuming that 50% of the population are female.

3.5.2 Special aspects for the ingestion pathway

For the individual and collective risks from the ingestion pathway, the activity risk coefficients method is based on the assumption of local production and consumption of the foodstuffs. Although the ARC method provides a good approximation for many of the processes involved, the local production and consumption assumption may lead to a rather crude representation of the individual and collective activity intake for many foodstuffs and accident scenarios. The ARC method is chosen by setting NAMELIST parameter CIGCOL to 'L-P&C'.

By this reason, COSYMA provides an alternative method to calculate the collective risks from ingestion. This method is based on the assumption of a linear dose-response-relationship, which means that the total incidence of health effects in an exposed population is related to the collective dose. In this mode, the number of the health effects is obtained by multiplication of the collective dose calculated from agricultural production data under the assumption that all contaminated food produced is consumed somewhere, with a risk factor averaged over the whole population. This method will in general give a better representation of the collective activity intake; however, effects as for example the age structure of the population and the aging of the affected individuals can only be taken into account on the average, and no information about the individual risks is available. This method is used when CIGCOL is set to 'APROD'.

4. Implementation of the health effects models in COSYMA

4.1 Subsystem NE: Deterministic health effects

The following sections explain in detail how the dose-rate dependent modelling of deterministic health effects is implemented in the code, in particular when considering different emergency actions as described in detail in [4]. The timing of early emergency actions in relation to the time periods of the health effects model is shown in Figure 5.

The following abbreviations are used:

$DEP(IZ)$ dose due to exposure pathway EP accumulated within the health effects model specific time period with index IZ and duration $\Delta T(IZ)$; $DEP(IZ)$ is defined as

$$DEP(IZ) := DEP(t_2(IZ)) - DEP(t_1(IZ))$$

$$\text{with } DEP(t) := \int_0^t \dot{D} dt \quad \text{and} \quad \Delta T(IZ) = t_2(IZ) - t_1(IZ)$$

Accordingly $DEP(IZ, T)$ is defined as the dose due to exposure pathway EP accumulated within the health effects model specific time period with index IZ and from intake during time T.

IZ	index of the time periods of the health effects model
NP	index of the release phases
$NTE(NP)$	duration of external exposure time for release phase NP: time interval between arrival time of the plume belonging to release phase NP and end of early countermeasures (evacuation or sheltering)
$TIZNTE$	total external exposure time in evacuation area (summed over all release phases)
$TSKIN$	time after which people sheltered or evacuated are assumed to be decontaminated
RF_{EP}	effective dose reduction factors for exposure pathway EP resulting from early countermeasures
SF_{EP}	average shielding factors for normal behaviour (no action or staying outdoors) for exposure pathway EP
RF_{EP}^T	effective dose reduction factors for exposure pathway EP related to time T resulting from early countermeasures (only used for EP = IHR)
SF_{EP}^T	average shielding factors for normal behaviour (no action or staying outdoors) for exposure pathway EP related to time T (only used for EP = IHR)

The lower t_1 and upper t_2 time points [days] of the different time periods IZ of the health effects model for the different deterministic health effects considered are given in Table 4. The number of time periods depends on the health effect; for easier reading the general notation "For IZ=2 to n" is used in the following sections. It is only relevant for those effects for which more than one time period exists and has to be limited to the number n of existing time periods.

4.1.1 General features of individual risk calculation

If the user selects the option calling one of the modules for individual risks (NAMELIST parameters NOAKUT and NORISK or, when emergency actions are excluded, NOPOTR), the dose-rate dependent $LD50$ -values are calculated according to Eq. [3.4] for all time periods i and all organs relevant for the deterministic health effects (see Table 4). Using these $LD50$ -values, individual risks are calculated as described by Eq. [3.1] and Eq. [3.3] for all deterministic health effects considered. For easier reading the organ-dependency of the individual doses and risks is omitted in the formulas given in the following sections. The individual doses and risks are calculated for a mean adult at a certain grid point (I,J); this location-dependency is removed from the formulas, too.

To save computing time the calculations can be reduced to determine only the doses and risks for the fatal health effects considered in COSYMA (NAMELIST parameter IMOR). From the individual risks of single effects the total individual risk is calculated. The total individual risk for early mortality is transferred to subsystem NL to correct the individual risk for stochastic effects calculated there.

For the dose-rate dependent modelling the $LD50$ -value is different for each grid element (and in the case of countermeasures for each population group and driving time class) and is calculated inside the health effects subroutine RISKAB and RISKSC, respectively. Because these values are only internal results, it was not possible to provide the weighted protracted dose used in the risk assessment for evaluation as it was done in earlier versions of COSYMA using fixed $LD50$ -values. Instead, the breakdown by exposure pathways and nuclides as a function of distance is given for the mean dose integrated only over the first time period of the health effects model. The user should be aware, that for health effects protracted over longer time periods up to one year, the breakdown can be different when calculated over the whole protraction period. The results for the dose-type used can be stored for evaluation on NUNITS(23); the breakdown can be stored on NUNITS(35) for the user's plot program.²

² COSYMA offers the possibility to calculate individual doses for deterministic health effects as well as individual doses as endpoint integrated over a user-defined time period (NAMELIST parameter IDTIME) in the same run; if both dose-types are calculated in the same run, only the doses as

The detailed modelling of emergency actions in COSYMA described in [4] considers up to five population groups NA with different behaviour and shielding factors during the sheltering period. The spectrum of driving times for leaving the evacuation areas is approximated by four 3-step distribution functions each applying for a certain range of the population density of the evacuation area. The individual doses and risks are calculated in module EARLY for each population group NA and, in the areas with evacuation, each population density group NF and driving time class NFZ. Each single individual risk value is compared with the cut-off threshold THRESH. Then all the single individual doses and risks are reduced for storage and for the corresponding evaluation programs. The individual doses are averaged over the population density groups NF and the driving time classes NFZ using the probabilities defined by the NAMELIST parameter PFD and are stored as a function of the population group NA. The individual risks are averaged over the population groups NA and the driving time classes NFZ (this average value can of course be < THRESH) and are stored as a function of the population density group NF on NUNITS(24) for the non-fatal effects and on NUNITS(25) for fatal effects for evaluation in the evaluation program EVARSK or for further use by COLLEC to calculate the number of health effects in the population.

4.1.2 Potential individual risks in areas without countermeasures

Results without taking into account the mitigating effects of countermeasures are calculated in COSYMA in the module POTDOS where people are assumed to stay outdoors or where a mean shielding factor is applied to the whole population. In module EARLY no actions are taken in those grid points belonging neither to the evacuation areas A and B nor to area S where sheltering without subsequent evacuation is modelled. In these grid points up to five population groups with different shielding factors can be assumed. The individual doses and risks are calculated separately for each of these groups.

The dose within each period IZ of the health effects model for each exposure pathway is summed up over all phases NP. The exposure pathway CL affects only the first time period (IZ = 1).

$$\text{Cloudshine dose: } DCL = \sum_{NP} D_{CL}^{NP} \cdot SF_{CL}$$

$$\text{Groundshine dose: } DGR(IZ) = \sum_{NP} D_{GR}^{NP}(IZ) \cdot SF_{GR}$$

$$\text{Inhalation dose: } DIH(IZ) = \sum_{NP} D_{IH}^{NP}(IZ) \cdot SF_{IH}$$

endpoint are stored and evaluated; the health effects doses are then only an intermediate result used for assessing the individual risks; for details see [4]

Resuspension dose: $DIHR(IZ) = \sum_{NP} D_{IHR}^{NP}(IZ, t_2(IZ)) \cdot SF_{IHR}$

Skin dose: $DSK(IZ) = \sum_{NP} D_{SK}^{NP}(IZ) \cdot SF_{SK}$

Total dose EDOS(IZ):

Then the pathway-specific doses are summed up for each time period IZ of the health effects model resulting in the total dose EDOS(IZ) which is assumed to accumulate homogeneously over the duration $\Delta T(IZ)$ of the time period IZ.

For IZ= 1: $EDOS(1) = DCL + DGR(1) + DIH(1) + DIHR(1) + DSK(1)$

For IZ= 2 to n: $EDOS(IZ) = DGR(IZ) + DIH(IZ) + DIHR(IZ) + DSK(IZ)$

Individual risk R:

For each time period IZ the mean dose rate $DR(IZ)$ is calculated by dividing $EDOS(IZ)$ by the duration $\Delta T(IZ)$ of the time period IZ:

$$DR(IZ) = \frac{EDOS(IZ)}{\Delta T(IZ)}$$

The dose-rates $DR(IZ)$ are used to calculate the dose-rate dependent $D_{50}(IZ)$ for each time period IZ according to

$$D_{50}(IZ) = D_{\infty} + \frac{D_0}{DR(IZ)}$$

The doses EDOS(IZ) are weighted with $1 / D_{50}(IZ)$ and summed up over the time periods IZ. To avoid numerical errors only values of EDOS $\geq 1.E-3$ are taken into account. If the resulting dose DOS

$$DOS = \sum_{IZ} \frac{EDOS(IZ)}{D_{50}(IZ)}$$

is below an effect-specific value GRW, it is put into the dose response relationship:

$$H = \ln 2 \cdot DOS \nu$$

The individual risk R for a deterministic health effect is given by

$$R = 1 - e^{-H}$$

and cut off if it is below the threshold THRESH.

For doses $> GRW$, the individual risk R is set to 1.0; this is done to avoid numerical errors and to save computing time.

The total individual risks of mortality and morbidity are then calculated following the procedure described in Chapter 3.2.

4.1.3 Individual risks in the evacuation areas A and B

The individual doses and risks are calculated separately for each population group NA with different shielding factors, each driving time class NFZ and population density group NF. As evacuation is assumed to be completed within one day [4], for external exposure only doses for the first time period have to be considered. The exposure time for each release phase starts with the arrival time of the plume at the grid point and ends when evacuation is completed; for skin doses it is prolonged by TSKIN. The dose for each external exposure pathway during this period is calculated for each release phase separately using the effective reduction factors RF (calculated in ZONABS and reflecting the effect of sheltering and evacuation) and then summed up over all release phases. As the external dose after evacuation is assumed to be zero, the dose received during the first period of the health effects model is always represented by the dose received before and during evacuation summed up over the release phases.

$$\text{Cloudshine dose: } DCL = \sum_{NP} D_{CL}^{NP} \cdot RF_{CL}(NP)$$

$$\text{Groundshine dose: } DGR(1) = \sum_{NP} D_{GR}^{NP}(NTE(NP)) \cdot RF_{GR}(NP)$$

$$\text{Skin dose: } DSK(1) = \sum_{NP} \sum_K (D_{SK,K}^{NP}(1d) \cdot CORRSK(K)) \cdot RF_{SK}(NP)$$

$$\text{with } CORRSK(K) = \frac{1 - e^{-\lambda(K) \cdot (NTE(NP) + TSKIN)}}{1 - e^{-\lambda(K) \cdot (1d)}}$$

CORRSK(K) ratio of the dose accumulated within the exposure time NTE(NP) to that resulting from 1 day exposure of nuclide K (simplified), as it is assumed that after about one day people are decontaminated; for long living nuclides a linear interpolation is used

$\lambda(K)$ radioactive decay constant of nuclide K

For the **inhalation pathways** the dose accumulation is not terminated with the end of evacuation; therefore the other periods of the health effects model have to be considered. To synchronize the time intervals for external and internal exposure, the dose within the first time period of the health effects model is split into two parts (see Figure 5). TIZNTE is the time which starts with the first arrival of a plume (which does not need to belong to the first release phase) and which ends with end of evacuation; it corresponds to the total time interval for external exposure and is used to calculate the dose in the first time period of the health effects model. TIZ2 is the remaining time of the first time period ($\Delta T(1) = TIZNTE + TIZ2$); the dose contribution DHR2 within TIZ2 is calculated separately and treated as a further time period. The doses received during the later time periods

(IZ > 1) accumulate according to the calculation of DIH(IZ) and DIHR(IZ), respectively, by using the effective reduction factors RF.

Thus, the algorithm for doses due to the inhalation pathways is as follows:

Inhalation dose:

For IZ = 1: $DIH(1) = \sum_{NP} \sum_K D_{IH,K}^{NP}(1) \cdot CORRIH(K) \cdot RF_{IH}(NP)$

$DIH2 = \sum_{NP} \sum_K D_{IH,K}^{NP}(1) \cdot (1 - CORRIH(K)) \cdot RF_{IH}(NP)$

with $CORRIH(K) = \frac{1 - e^{-\lambda(K) \cdot TIZNTE}}{1 - e^{-\lambda(K) \cdot \Delta T(1)}}$

DIH(1) contribution of the first time period's dose coming from total exposure time TIZNTE (until evacuation is terminated)

DIH2 contribution of the first time period's dose coming from the remaining time period TIZ2 between TIZNTE and $t_2(1)$

CORRIH(K) ratio of the dose accumulated within the exposure time TIZNTE to that resulting from a $\Delta T(1)$ -day exposure of nuclide K (simplified), as it is assumed that after about one day people are decontaminated; for long living nuclides a linear interpolation is used

$\lambda(K)$ radioactive decay constant of nuclide K

For IZ = 2 to n: $DIH(IZ) = \sum_{NP} D_{IH}^{NP}(IZ) \cdot RF_{IH}(NP)$

Resuspension dose:

For IZ = 1: $DIHR(1) = \sum_{NP} \sum_K D_{IHR,K}^{NP}(1,1d) \cdot CORRIH(K) \cdot RF_{IHR}(NP)$

$DIHR2 = \sum_{NP} \sum_K D_{IHR,K}^{NP}(1,1d) \cdot (1 - CORRIH(K)) \cdot RF_{IHR}(NP)$

DIHR(1) contribution of the first time period's dose coming from total exposure time NTE (starting with first release phase)

DIHR2 contribution of the first time period's dose coming from the remaining time period TIZ2 between TIZNTE and $t_2(1)$

For IZ = 2 to n: $DIHR(IZ) = \sum_{NP} D_{IHR}^{NP}(IZ,1d) \cdot RF_{IHR}(NP)$

Total dose EDOS(IZ):

To get the total dose EDOS(IZ), the pathway-specific doses are summed up for each time period IZ of the health effects model. For the inhalation pathways only the contribution

from TIZNTE is considered in EDOS(1); the remaining contribution $DHR2 = DIH2 + DIHR2$ is treated separately.

$$\text{For } IZ=1: \quad EDOS(1) = DCL + DGR(1) + DSK(1) + DIH(1) + DIHR(1)$$

$$\text{For } IZ=2 \text{ to } n: \quad EDOS(IZ) = DIH(IZ) + DIHR(IZ)$$

Individual risk R:

For each time period IZ the mean dose rate $DR(IZ)$ is calculated by dividing $EDOS(IZ)$ by the duration $\Delta T(IZ)$ of the time period IZ:

$$\text{For } IZ=1: \quad DR(1) = \frac{EDOS(1)}{TIZNTE}$$

$$\text{For } IZ=2 \text{ to } n: \quad DR(IZ) = \frac{EDOS(IZ)}{\Delta T(IZ)}$$

For the inhalation pathways IZ=1 contains only the part coming from TIZNTE. A dose rate DR2 is calculated for the remainder of this time period (TIZ2).

$$DR2 = \frac{DHR2}{TIZ2}$$

The dose-rates $DR(IZ)$ are used to calculate the dose-rate dependent $D_{50}(IZ)$ for each time period IZ (and the time period TIZ2 containing only doses due to the inhalation pathways) according to

$$D_{50}(IZ) = D_{\infty} + \frac{D_0}{DR(IZ)}$$

$$D_{250} = D_{\infty} + \frac{D_0}{DR2}$$

The doses $EDOS(IZ)$ are weighted with $1 / D_{50}(IZ)$ and summed up over the time periods IZ; additionally the contribution from the time period TIZ2 is added in the same way. To avoid numerical errors only values of EDOS and DHR2 $\geq 1.E-3$ are taken into account. If the resulting dose DOS

$$DOS = \sum_{IZ} \frac{EDOS(IZ)}{D_{50}(IZ)} + \frac{DHR2}{D_{250}}$$

is below an effect-specific value GRW, it is put into the dose response relationship:

$$H = \ln 2 \cdot DOS \nu$$

The individual risk R for a deterministic health effect is given by

$$R = 1 - e^{-H}$$

and cut off if it is below the threshold THRESH.

For doses $> GRW$, the individual risk R is set to 1.0; this is done to avoid numerical errors and to save computing time.

The total individual risks of mortality and morbidity are then calculated following the procedure described in Chapter 3.2.

4.1.4 Individual risks in the sheltering area S

The individual doses and risks are calculated separately for each population group NA with different shielding factors. The method of calculating individual weighted protracted doses for deterministic health effects in area S is a combination of those used in the areas with evacuation and with no action. There are two assumptions for the sheltering period: during the passage of the plume people are sheltered; sheltering does not last longer than one day.

The doses received during the first day and thus within the first time period of the health effects model have to be reduced by sheltering during a certain time period NTE(NP) starting with the arrival time of the plume at the grid point and ending when sheltering is withdrawn; for skin doses it is prolonged by TSKIN. The dose for each external exposure pathway during this period is calculated for each release phase separately using the effective reduction factors RF (calculated in ZONABS and reflecting the effect of sheltering) and then summed up over all release phases. To this dose the contribution of the remaining part of the first time period has to be added using average shielding factors for normal activity. Groundshine is the only relevant pathway during this remaining time period. For cloudshine it is always assumed that people are sheltered during the plume passage. For skin the dose accumulation ends after NTE + TSKIN.

For the other time periods only doses due to groundshine are relevant. They are calculated as described for potential doses (see Section 4.1.2).

Cloudshine dose:
$$DCL = \sum_{NP} D_{CL}^{NP} \cdot RF_{CL}(NP)$$

Groundshine dose: The first and the later time periods have to be considered separately.

For IZ=1: Sheltering is taken into account during NTE(NP), afterwards normal behaviour up to end of first time period $t_2(1)$ of the health effects model is assumed.

$$DGR1 = \sum_{NP} D_{GR}^{NP}(NTE(NP)) \cdot RF_{GR}(NP)$$

$$DGR2 = \sum_{NP} D_{GR}^{NP} (t_2(1) - NTE(NP)) \cdot SF_{GR}$$

$$DGR(1) = DGR1 + DGR2$$

For IZ=2 to n: No early countermeasures have to be considered

$$DGR(IZ) = \sum_{NP} D_{GR}^{NP}(IZ) \cdot SF_{GR}$$

Skin dose: $DSK(1) = \sum_{NP} \sum_K D_{SK,K}^{NP}(1d) \cdot CORRSK(K) \cdot RF_{SK}(NP)$

with $CORRSK(K) = \frac{1 - e^{-\lambda(K) \cdot (NTE(NP) + TSKIN)}}{1 - e^{-\lambda(K) \cdot (1d)}}$

$CORRSK(K)$ ratio of the dose accumulated within the exposure time to that resulting from 1 day exposure of nuclide K (simplified), as it is assumed that after about one day people are decontaminated; for long living nuclides a linear interpolation is used

$\lambda(K)$ radioactive decay constant of nuclide K

As it is assumed that people shelter during the passage of the plume, the **inhalation dose** is calculated for all time periods IZ of the health effects model applying the effective reduction factors reducing the intake:

Inhalation dose: $DIH(IZ) = \sum_{NP} D_{IH}^{NP}(IZ) \cdot RF_{IH}(NP)$

Resuspension dose: The doses for all time periods IZ of the health effects model are split into two parts to distinguish between the intake within the first day modified by sheltering and afterwards. The contributions of intake during the first day are calculated using the effective reduction factor RF related to 1 day for the sheltering period plus the shielding factor for normal behaviour for the rest of the first day together with the resuspension function for 1 day. For intakes after the sheltering period the resuspension function for IZ is used (end of intake is considered to be identical with the lower time point of the corresponding time period of the health effects model) together with the average shielding factors for normal behaviour.

Dose from intake within the 1st day (reduced by sheltering):

$$DIHR1(IZ) = \sum_{NP} D_{IHR}^{NP}(IZ, 1d) \cdot (RF_{IHR}^{1d}(NP) + SF_{IHR}^{1d-NTE})$$

Dose from intake after 1st day up to $t_2(IZ)$ days (no or average reduction):

$$DIHR2(IZ) = \sum_{NP} D_{IHR}^{NP}(IZ, t_2(IZ) - 1d) \cdot SF_{IHR}$$

$$DIHR(IZ) = DIHR1(IZ) + DIHR2(IZ)$$

Total dose EDOS(IZ):

Then the pathway-specific doses are summed up for each time period IZ of the health effects model resulting in the total dose EDOS(IZ).

$$\text{For } IZ=1: \quad EDOS(1) = DCL + DGR(1) + DIH(1) + DIHR(1) + DSK(1)$$

$$\text{For } IZ=2 \text{ to } n: \quad EDOS(IZ) = DGR(IZ) + DIH(IZ) + DIHR(IZ)$$

Individual risk R:

For each time period IZ the mean dose rate $DR(IZ)$ is calculated by dividing $EDOS(IZ)$ by the duration $\Delta T(IZ)$ of the time period IZ:

$$DR(IZ) = \frac{EDOS(IZ)}{\Delta T(IZ)}$$

The dose-rates $DR(IZ)$ are used to calculate the dose-rate dependent $D_{50}(IZ)$ for each time period IZ according to

$$D_{50}(IZ) = D_{\infty} + \frac{D_0}{DR(IZ)}$$

The doses $EDOS(IZ)$ are weighted with $1 / D_{50}(IZ)$ and summed up over the time periods IZ. To avoid numerical errors only values of $EDOS \geq 1.E-3$ are taken into account. If the resulting dose DOS

$$DOS = \sum_{IZ} \frac{EDOS(IZ)}{D_{50}(IZ)}$$

is below an effect-specific value GRW, it is put into the dose response relationship:

$$H = \ln 2 \cdot DOS \nu$$

The individual risk R for a deterministic health effect is given by

$$R = 1 - e^{-H}$$

and cut off if it is below the threshold THRESH.

For doses $>$ GRW, the individual risk R is set to 1.0; this is done to avoid numerical errors and to save computing time.

The total individual risks of mortality and morbidity are then calculated following the procedure described in Chapter 3.2.

4.1.5 Collective risks in the population

In module COLLEC the individual risks calculated in POTRSK and EARLY, respectively, are combined with the underlying population distribution as described in Chapter 3.5. In the case of mental retardation and pre- and neonatal death 1% of the population is assumed to be pregnant women. As for mental retardation, the risk values for the "age group" 8-15 weeks are used, the individual risk is applied to one fifth of all pregnancies, i.e. 0.2% of the population. The individual fatal risk for skin burns already refers to the average population, i.e. the factor SKMORT determining the fraction of the population dying from skin burns is included in the individual risk.

The number of health effects in the population can be assessed in the same run for different sites each with a different population distribution. When considering evacuation, the individual risks are influenced by the driving times which are determined by the population density within the evacuation area. The results are stored in EARLY for all population density classes NF required for the sites under consideration. The information about the actual population density class is obtained from a data file (unit NUNITS(37)) stored by AMOUNT.

The number of each of the early health effects (if IMOR = 2 only for mortality) and the sums are stored for each site and weather sequence on NUNITS(28) for further use in the economics module or for evaluation in EVACOL.

4.1.6 NAMELIST parameters

Name	Input group	NAMELIST	Description
<u>Steering parameters</u>			
IDSART	RESULTS	OPTION	selects countermeasures
IEVCOL	RESULTS	OPTION	calls evaluation program EVACOL
IEVRSK	RESULTS	OPTION	calls evaluation program EVARSK
NOAKUT	RESULTS	OPTION	calls module EARLY
NOCOLL	RESULTS	OPTION	calls module COLLEC
NOPTR	RESULTS	OPTION	calls module POTRSK
NORISK	RESULTS	OPTION	selects calculation of risks for deterministic health effects
<u>Output parameters</u>			
IACT	PRINTOUT	OUTPAR	selects distances for printout of results
ICCFD	PRINTOUT	OUTPAR	prints CCFDs in the evaluation program
IIROUT	PRINTOUT	OUTPAR	prints detailed mean individual risk results
LKZ	PRINTOUT	OUTPAR	selects weather sequences for detailed results printout

NOOPOP	PRINTOUT	OUTPAR	prints detailed collective risk results
NOORSK	PRINTOUT	OUTPAR	prints detailed individual risk results
NOOSIT	PRINTOUT	OUTPAR	prints detailed collective risk results

Model parameters

IMOR	DOSRISK	DORPAR	doses and risks to organs considered for lethal effects only
IZP1	DOSRISK	DORPAR	number of time points in the health effects model (morbidity)
IZP2	DOSRISK	DORPAR	number of time points in the health effects model (mortality)
KONST	DOSRISK	DORPAR	time points in the health effects model (morbidity, mortality)
NFG	PROTECT	PRTPAR	number of population density groups
NFZV	PROTECT	PRTPAR	number of driving time classes within each density group
VPAR	DOSRISK	DORPAR	shape parameter for all health effect (morbidity, mortality)
SKMORT	DOSRISK	DORPAR	fraction of population for which skin effects are lethal
THETA1	DOSRISK	DORPAR	model parameter D_{∞} used in Eq. [3.4]
THETA0	DOSRISK	DORPAR	model parameter D_0 used in Eq. [3.4]
THRESH	DOSRISK	DORPAR	threshold below which individual risks are cut off
TREAT	DOSRISK	DORPAR	treatment factor

Evaluation program

IORGNR	DOSRISK	DORPAR	index of organs evaluated
MAXI	EVALUATE	EVAPAR	index of outer radius for evaluation
NCRMIN	EVALUATE	EVAPAR	lower limit for evaluation interval, collective risks; the number of decades evaluated is 5
NRSMIN	EVALUATE	EVAPAR	lower limit for evaluation interval, individual risks; the number of decades evaluated is 7
PERC	EVALUATE	EVAPAR	percentiles to be calculated
ROYFS1	EVALUATE	EVAPAR	upper value of special risk interval evaluated (morbidity)
ROYFS2	EVALUATE	EVAPAR	upper value of special risk interval evaluated (mortality)
RUYFS1	EVALUATE	EVAPAR	lower value of special risk interval evaluated (morbidity)
RUYFS2	EVALUATE	EVAPAR	lower value of special risk interval evaluated (mortality)

4.2 Subsystems NL and FL: Stochastic health effects

4.2.1 General features of individual risk calculation

Individual risks for stochastic health effects can be calculated without and with considering the mitigating effects of countermeasures in the separate modules POTRSK and LATRSK of subsystems NL and FL. This section describes the basic features valid for both risk types.

The input data needed are the activity concentrations calculated in module CONCEN (NUNITS(22)) and the pathway-specific activity risk coefficients (NUNITS(71) to NUNITS(77) and NUNITS(64) and NUNITS(65)). The fatal individual risks are calculated for each pathway by multiplying the initial activity concentrations summed up over all release phases with the activity risk coefficients as described in Chapter 3.2. For the inhalation pathways this product has to be multiplied by a breathing rate (NAMELIST parameters ARATIH and ARATIR). For skin contamination the fraction of the body which is contaminated is needed (NAMELIST parameter PSKIN). As the values of the activity risk coefficients for skin refer to incidence a factor defining the fraction of fatal cancer has to be multiplied with this product (see Table 3). Details about the modelling of the exposure pathways can be found in [4] and [5].

If the ingestion pathway is considered in the risk calculation, individual results can only be obtained if the local production and consumption method L-P&C (NAMELIST parameter CIGCOL) is used. In this case for each weather sequence the activity risk coefficients for the season to which the corresponding starting time belongs are used (NUNITS(64) for starting times from LSEAS1 (default: 2160) to LSEAS2 (default: 7296) and marked by 'S' representing summer (default: 1 April to 31 October), NUNITS(65) for the rest of the year). If the agricultural production method is used (CIGCOL='APROD'), no individual risks from ingestion can be calculated and therefore no activity risk coefficients are needed. However, the submodule for calculating the collective risks by ingestion is called by the risk module POT/LATRSK; the results are stored separately for ingestion on NUNITS(69) for module COLLEC where they are added to the collective risks from the other exposure pathways. In the following, descriptions refer to the L-P&C approach. More details about the APROD method can be found in [5].

The fatal individual risks are summed up over all exposure pathways taken into account in the calculations and then limited to 1. The individual risks for incidence are calculated from these fatal risks by using the BEIR-factors *CFINC* given in Table 3 and are limited to 1. The total individual risks for incidence and mortality are calculated as described in Section 3.3. To avoid numerical problems, the product in Eq. [3.20] is replaced by a sum if an individual risk is below 10^{-3} .

If the source term or scenario under consideration gives rise to deterministic fatal health effects, the individual risks for stochastic effects in the near range (i.e. in subsystem NL only) can be corrected for early mortality (NAMELIST parameter IEARLY). The formulas are given in Section 3.3. If IEARLY is set to 1, results obtained from the corresponding run of POTRSK or EARLY of subsystem NE have to be transferred to NL; the information needed are the total individual risk for early mortality stored on NUNITS(25) and - if countermeasures are taken into account - the index of the relevant population density group of driving times stored on NUNITS(37).

The individual risks are calculated for the living and future generations separately and stored on NUNITS(24) for module COLLEC or for the evaluation program EVARSK. For the mean individual risks a breakdown by exposure pathways and by nuclides is calculated and stored on NUNITS(45) for plotting, and partly on NUNITS(24) for use in COLLEC.

The evaluation program EVARSK offers the possibility to combine the results for the single organs stomach, colon, liver and pancreas to get a total result for GI-tract (NAMELIST parameter IORGGI).

4.2.2 Potential individual risks

When no protective actions are taken into account (module POTRSK), only the activity risk coefficients for the countermeasure time $t(t_0)=0$ are needed. The time period up to which individual risks due to contamination of skin and clothes have to be considered is defined by the NAMELIST parameter TSKIN. The program offers the possibility to apply pathway-specific average shielding factors for the potential results, which refer to normal living conditions (NAMELIST parameter SFLATE having default values of 0.2 for CL, 0.3 for GR and 1.0 for IH, IHR and SK).

4.2.3 Individual risks with countermeasures

The extent and duration of the countermeasures taken into account are calculated in module PROTEC as described in detail in [4] and [5]. The results are stored as flags on NUNITS(26) for emergency actions implemented in subsystem NE, such as evacuation, sheltering and distribution of stable iodine tablets, and on NUNITS(19) for long-term countermeasures implemented in subsystems NL and FL, such as relocation, foodbans, forced land decontamination and sheltering only.

Dependent on the countermeasure imposed, up to three time periods contributing to the individual risks have to be considered:

1. before the countermeasure is implemented (relevant for evacuation and relocation)
2. during the period in which the countermeasure is active (relevant for sheltering and stable iodine tablets)
3. after the countermeasure is withdrawn (relevant for evacuation, relocation and food-bans)

As people not evacuated are not relocated before the passage of the plume, no reduction of the risks due to cloudshine and inhalation can be achieved by relocation. Because the model does not allow for a preceding period of sheltering, there is no reduction of the risks for these two pathways. As cloudshine and direct inhalation are only relevant during the passage of the plume there is no contribution to risk during the other time periods.

If the distribution of stable iodine tablets is modelled, the risks to the thyroid by inhalation of radioactive iodine are reduced by the efficiency factor specified by the user (NAMELIST parameter TABIOD).

Subsystem NL offers the possibility to use the information about evacuation calculated in NE (NAMELIST parameter IFAST). For those grid elements affected by evacuation, the contribution to stochastic risks from the period before people have left the area is calculated using the mean effective reduction factors determined in EARLY and stored on NUNITS(18).

For groundshine and resuspension, risk accumulation is interrupted when people are evacuated or relocated. After resettlement the risk is calculated as in the potential case using the activity risk coefficients for the corresponding countermeasure time $t(n_0)$ and - if applicable - reducing the concentration by the maximal decontamination factor (NAMELIST parameter DFMAX). For return times within the first year after the accident ($t(n_0) < 365$ days), the activity risk coefficients applied are derived from the activity risk coefficients $ARC(EP,K,1a)$ for the withdrawal time 1 year by exponential interpolation considering the half-life of the nuclides K.

For groundshine these activity risk coefficients are calculated according to

$$ARC(GR,K,t(n_0)) = \frac{ARC(GR,K,0) - FAK(t(n_0),K) \cdot (ARC(GR,K,0) - ARC(GR,K,1a))}{1 - e^{-\lambda(K) \cdot 365d}} \quad [4.1]$$

where

$$FAK(t(n_0),K) = \frac{1 - e^{-\lambda(K) \cdot t(n_0)}}{1 - e^{-\lambda(K) \cdot 365d}} \quad [4.2]$$

for each nuclide K is implemented in FUNCTION ARCORR. For long-lived nuclides linear interpolation is used: $FAK(t(n_0),K) = t(n_0)/365d$.

For resuspension these activity risk coefficients are given by

$$ARC(IHR,K,t(n_0)) = ARC(IHR,K,0) - RES(t(n_0),K) \cdot (ARC(IHR,K,0) - ARC(IHR,K,1a)) \quad [4.3]$$

where

$$RES(t(n_0),K) = \frac{RESUS(t(n_0),K)}{RESUS(365d,K)} \quad [4.4]$$

corrects for nuclide K the amount of material resuspended into the air until resettlement time $t(n_0)$ using the resuspension function RESUS (see Section 2.4.5 in Appendix C).

If the user defines resettlement times (NAMELIST parameter NT) greater than 1a for which no activity risk coefficients have been calculated, the values applied are obtained by linear interpolation between the lower and upper ARC-values of the corresponding time interval.

For people affected by evacuation the individual risks due to groundshine and resuspension within the time period before having left the area are calculated using the mean effective reduction factors determined in NE and interpolated activity risk coefficients for the first day (only relevant in subsystem NL). In the case of relocation the early risk contribution is calculated applying average shielding factors for normal activity (NAMELIST parameter SFLATE) and activity risk coefficients referring to the time at which all people have left the area. This time point is specified either directly by the user (NAMELIST parameter ITUMS) or determined using a daily relocation rate (NAMELIST parameter AUMS) [4]. If T_{rel} denotes the time period at which all people have left the area, the activity risk coefficients $ARC(GR,K, T_{rel})$ and $ARC(IHR,K, T_{rel})$, respectively, for calculating the risk contribution coming from this period due to groundshine and resuspension, respectively, are given by

$$ARC(GR,K, T_{rel}) = FAK(T_{rel},K) \cdot (ARC(GR,K,0) - ARC(GR,K,1a)) \quad [4.5]$$

respectively

$$ARC(IHR,K, T_{rel}) = RES(T_{rel},K) \cdot (ARC(IHR,K,0) - ARC(IHR,K,1a)) \quad [4.6]$$

The time period relevant for individual risks due to contamination of skin and clothes is either a fraction of one day (for people evacuated) or is defined by NAMELIST parameter TSKIN. In the case of evacuation the individual risks are multiplied by the mean effective reduction factors determined in NE. Relocation does not influence dose accumulation and thus risks from skin contamination.

Sheltering as the only countermeasure in subsystem NL [4] is modelled in a simplified approach and cannot be combined with evacuation or relocation. It is assumed that sheltering starts with the arrival time of the plume and lasts for a user specified period (NAMELIST parameter ITSH). Doses and risks are reduced by the pathway-specific shielding factor $SFSH_{EP}$. The activity risk coefficients used for groundshine and resuspension are interpolated and refer to the duration of the sheltering period. After the end of the shel-

tering period the risks due to groundshine and resuspension are calculated using mean shielding factors as in the potential case (see Chapter 4.2.2). The individual risks due to skin contamination are considered up to time point TSKIN and reduced by the corresponding shielding factor $SFSH_{SK}$.

The ingestion pathway is modelled separately and contributes to the individual risks only after the withdrawal of foodbans at time $t(n_0)$. The risks are calculated using the activity risk coefficients for the corresponding countermeasure time.

4.2.4 Collective risks in the population

In module COLLEC the individual risks calculated in POTRSK and LATRSK, respectively, are combined with the underlying population distribution as described in Chapter 3.5. In the case of breast cancer only 50% of the population is taken. The number of health effects in the population can be assessed in the same run for different sites each with a different population distribution. They calculated for mortality and incidence, both for living and future generations separately and summed up over all generations. All results are stored on NUNITS(28) for further use in the economics module or for evaluation in EVACOL which offers the possibility to combine organs for GI-tract (NAMELIST parameter IORGGI).

For the mean number of health effects a breakdown by exposure pathways is calculated using average percentage contributions stored on NUNITS(24) by POT/LATRSK. As in deriving these average values the population distribution is not yet taken into account the mean values can slightly differ from those calculated in the evaluation program EVACOL.

If ingestion is taken into account in the calculation using the agricultural production method (CIGCOL = 'APROD'), the individual risks stored on NUNITS(24) in POTRSK/LATRSK do not contain a contribution due to ingestion as only collective results can be obtained from this pathway. They are stored on NUNITS(69) during the POTRSK/LATRSK run, read in by COLLEC and added to the collective risks from the other exposure pathways. In this case collective results are only calculated for all generations, because for the ingestion pathway the results are only available in this form.

4.2.5 Time dependent occurrence of cancer

A special time dependent version of subsystem FL allows to assess the number of stochastic somatic health effects as a function of time after the accident. As these calculations require long computing times an approximation is implemented in the evaluation program EVACOL of the subsystems NL and FL. From various typical PWR source terms describing approximately the time dependence of mortality for each cancer type (except skin) normal-

ized time functions have been derived giving the time dependent distribution (in %) of the occurrence of cancer. With these values shown in Table 5 the mean numbers of fatal cancer summed up over all generations (LG + FG) are calculated approximately as a function of time.

4.2.6 Loss of life expectancy

The model adopted in COYSMA to assess the impact of fatal cancers in terms of the loss of life expectancy in the living generations is a very simple approach. It is implemented in the evaluation programs EVARSK for the individual loss (in hours) for a mean person of the exposed population and in EVACOL for the collective loss (in years) for all members of the exposed population with the loss per individual affected (in years) being a constant. Loss of life expectancy is determined for each cancer type except skin. Table 3 shows the number of days of life lost per manSv $DLL(eff)$ due to different cancer types together with the average risk coefficients $RC(eff)$. These values were derived from the data provided by GSF together with the age-dependent risk factors given exemplarily in Table 46 for lung cancer in men by averaging over the age distribution of the German population. The mean loss of life expectancy $ILLA$ for an individual affected by fatal cancer eff is given by

$$ILLA(eff) = \frac{DLL(eff)}{RC(eff)} \quad [4.7]$$

The individual loss of life expectancy (in hours) ILL for a mean member of the population at a certain grid point is calculated in EVARSK for each cancer type eff (where eff can also be the 'total') according to

$$ILL(eff) = r(eff) \cdot ILLA(eff) = r(eff) \cdot \frac{DLL(eff)}{RC(eff)} \quad [4.8]$$

where $r(eff)$ = individual risk for health effect eff . For probabilistic runs maximal, mean and percentile values of $ILL(eff)$ are calculated using the corresponding individual risks $r(eff)$.

In EVACOL the collective loss of life expectancy (in years) CLL in the exposed population is calculated for each single cancer type eff according to

$$CLL(eff) = cr(eff) \cdot ILLA(eff) \cdot \frac{1}{365} = cr(eff) \cdot \frac{DLL(eff)}{RC(eff)} \cdot \frac{1}{365} \quad [4.9]$$

where $cr(eff)$ = collective risk, i.e. number of fatal cancer of type eff in the population. For probabilistic runs maximal, mean and percentile values of $CLL(eff)$ are calculated using the corresponding collective risks $cr(eff)$.

For calculating the total number of years lost in the exposed population, first a mean individual loss of life expectancy $ILTOT$ is calculated averaged over all cancer types. As these calculations are done outside the loop over the weather sequences, the mean values $\bar{cr}(eff)$ averaged over the weather sequences are used in Eq. [4.10]

$$ILTOT = \frac{\sum_{eff} \overline{CLL}(eff)}{\sum_{eff} \bar{cr}(eff)} \quad [4.10]$$

The total number of years lost in the population $CLTOT$ is then given by the product of $ILTOT$ and the total number of cancers according to:³

$$CLTOT = ILTOT \cdot \sum_{eff} cr(eff) \quad [4.11]$$

For probabilistic runs maximal, mean and percentile values for $CLTOT$ are calculated using in Eq. [4.11] the corresponding collective risk values for $cr(eff)$.

4.2.7 NAMELIST parameters

Name	Input group	NAMELIST	Description
------	-------------	----------	-------------

Steering parameters

IDSART	RESULTS	OPTION	selects countermeasures
ICOLRS	RESULTS	OPTION	calls COLRSK-part of COLLEC
IEVCOL	RESULTS	OPTION	calls evaluation program EVACOL
IEVRSK	RESULTS	OPTION	calls evaluation program EVARSK
NOCOLL	RESULTS	OPTION	calls module COLLEC
NOLATR	RESULTS	OPTION	calls module LATRSK
NOPTR	RESULTS	OPTION	calls module POTRSK

Output parameters

IACT	PRINTOUT	OUTPAR	selects distances for printout of results
IAROUT	PRINTOUT	OUTPAR	prints activity risk coefficients
ICCFD	PRINTOUT	OUTPAR	prints CCFDs in the evaluation program
ILFOUT	PRINTOUT	OUTPAR	selects generations for printout
LKZ	PRINTOUT	OUTPAR	selects weather sequences for detailed results printout

³ it is not the total number of years lost summed up over all cancer types

NOOPOP	PRINTOUT	OUTPAR	prints detailed collective risk results
NOORSK	PRINTOUT	OUTPAR	prints detailed individual risk results
NOOSIT	PRINTOUT	OUTPAR	prints detailed collective risk results

Model parameters

ARATIH	DOSRISK	DORPAR	breathing rate, inhalation
ARATIR	DOSRISK	DORPAR	breathing rate, resuspension
AUMS	PROTECT	PRTPAR	relocation rate (area relocated per day)
CONFAK	DOSRISK	DORPAR	factor for activity deposited on skin
DFMAX	PROTECT	PRTPAR	decontamination factors
IEARLY	DOSRISK	DORPAR	consideration of early individual risk (NL only)
IEXPO	DOSRISK	DORPAR	pathways to be considered for risk calculation
IFAST	PROTECT	PRTPAR	consideration of evacuation (NL only)
ITSH	PROTECT	PRTPAR	duration of sheltering only period (NL only)
ITUMS	PROTECT	PRTPAR	time needed to relocate all people affected
NFG	PROTECT	PRTPAR	number of population density groups considered in NE
NNT	PROTECT	PRTPAR	number of time points considered for resettlement
NT	PROTECT	PRTPAR	time points considered for resettlement
PSKIN	DOSRISK	DORPAR	fraction of the skin which is contaminated
RESE	DOSRISK	DORPAR	parameter of resuspension model
RES0	DOSRISK	DORPAR	parameter of resuspension model
SFLATE	DOSRISK	DORPAR	shielding factors for normal activity
SFSH	PROTECT	PRTPAR	shielding factors for sheltering only (NL only)
TABIOD	PROTECT	PRTPAR	risk reduction factor of stable iodine tablets
TBIO	DOSRISK	DORPAR	biological half-life of skin
TSKIN	DOSRISK	DORPAR	time defining decontamination of people
WLAMR	DOSRISK	DORPAR	parameter of resuspension model

Evaluation program

IORGGI	EVALUATE	EVAPAR	combines organs to GI-tract
IORGNR	DOSRISK	DORPAR	index of organs evaluated
MAXI	EVALUATE	EVAPAR	index of outer radius for evaluation
NCRMIN	EVALUATE	EVAPAR	lower limit for evaluation interval, collective risks; the number of decades evaluated is 6
NRSMIN	EVALUATE	EVAPAR	lower limit for evaluation interval, individual risks; the number of decades evaluated is 7
PERC	EVALUATE	EVAPAR	percentiles to be calculated
ROYSS	EVALUATE	EVAPAR	upper value of special risk interval evaluated
RUyss	EVALUATE	EVAPAR	lower value of special risk interval evaluated

5. Output description

This section describes all printout available from the risk modules (POTRSK, EARLY and COLLEC of subsystem NE; POTRSK, LATRSK and COLLEC-COLRSK of subsystems NL and FL) and the corresponding evaluation programs. Examples of the printout are contained in Chapter 8. Some of the tables are self-explanatory and need no further discussion here.

5.1 Subsystem NE

For accident consequence assessments without countermeasures all point values can be printed by choosing appropriate values for the different printout options. A point value is the result for a specific grid element, weather sequence and - for collective results - site. When countermeasures are taken into account, the number of point values increases rapidly due to the detailed probabilistic modelling of the population behaviour during evacuation (specific shielding group, driving time class, population density group). Therefore it is not possible to print every value calculated and only the dependence of the population density group NF is kept for printout. Thus, with countermeasures a point value in the printout and for storage means the value for a specific grid element, weather sequence, population density group and - for collective results - site averaged over the shielding groups NA and driving time classes NFZ.

Whenever individual or collective risks are printed they are given for each non-lethal (morbidity, only if IMOR = 1) and lethal deterministic health effect considered and the sum.

Table 6: Module INDAT: Control output

This table is printed from subroutine DOWIPR; it belongs to the control printout of module INDAT and informs about the values of the health effects parameters in NAMELIST DOSRISK chosen by the user for the calculations.

Table 9: Modules POTRSK and EARLY: Printout of results of point values

This printout of point values for individual risks is obtained only if NOORSK \neq 0. For a value of 1 the information for each weather sequence is given, a value of 2 reduces the output to up to 20 weather sequences specified by LKZ. The distances are selected by IACT. Starting with the azimuthal sector J = 1 (sector due to North) the point results for all JMAX sectors are given (the sectors count clockwise). If countermeasures are taken into account this information is printed only for the first population density group of driving times (NF = 1). If for a weather sequence this group does not belong to any of the sites considered

all printed values are zero. By changing the value of NFGOUT in the DATA-statement another population density group can be selected for printout.

Table 10: Modules POTRSK and EARLY: Printout of results of averaged point values

This printout of point values for averaged individual risks is obtained only if IIROUT \neq 0. The distances are selected by IACT. Starting with the azimuthal sector $J=1$ (sector due to North) the mean point results for all JMAX sectors averaged over the weather sequences are given (the sectors count clockwise). If countermeasures are taken into account the point values are also averaged over the population density groups NF of driving times (only if more than one site is considered).

Table 11: Modules POTRSK and EARLY: Distance-dependent mean individual risks

This information cannot be suppressed. It gives for each distance the mean individual risk averaged over all weather sequences and azimuthal sectors. When taking countermeasures into account, the printed values are additionally averaged over the population density groups NF of driving times (only if more than one site is considered).

Table 13: Module COLLEC: Printout of results of point values

This printout of point values for collective risks is obtained for each site only if NOOPOP \neq 0. For a value of 1 the information for each weather sequence is given, a value of 2 reduces the output to up to 20 weather sequences specified by LKZ. The distances are selected by IACT. Starting with the azimuthal sector $J=1$ (sector due to North) the point results for all JMAX sectors are given (the sectors count clockwise). When countermeasures are taken into account they are valid for the site-specific population density group NF. Additionally the numbers of health effects summed up over all sectors of a distance band are shown.

Table 14: Module COLRSK: Printout of results integrated over the grid area for each site

This printout is obtained for each site only if NOOSIT \neq 0. A value of 1 gives the information for all weather sequences calculated, a value of 2 only for those up to 20 weather sequences specified by LKZ. The numbers of health effects printed are summed up over all grid elements of the area under consideration. When countermeasures are taken into account, NFA and NFB give the index of the population density group calculated and used for the evacuation areas A and B.

Table 15: Module COLLEC: Distance-dependent mean number of health effects

This information cannot be suppressed. It gives for each distance the mean number of deterministic health effects averaged over all weather sequences, azimuthal sectors and sites.

Table 16 and Table 17: Evaluation program EVARSK

After some information about the input parameters the radius-dependent statistical evaluation of the point values is printed for all health effects specified by IORGNR (index refers to morbidity and mortality). The first line gives the index of the weather sequence (not the starting time) leading to the maximal point value printed in the second line. The maximal

point value is the maximum individual risk of all weather sequences and azimuthal sectors (and population density groups used when countermeasures are taken into account; the maximal point values are, however, averaged over the shielding groups NA and the driving time classes NF). The mean value is identical to that described for Table 11.

SUM P (JUSED): Gives the fraction of each distance band affected by the plume (i.e. with a normalized air concentration $> \text{CHIMAX}$). This fraction is averaged over the weather sequences. Because of the threshold effect the zero-probability for individual risks cannot be derived from this value.

SUM P < RSKMIN: Gives the fraction of grid elements under the plume having a risk value below $\text{RSKMIN} = 10^{\text{NRSMIN}}$; NRSMIN is a NAMELIST parameter. If for RSKMIN a very low value is chosen (below all non-zero risks calculated), the zero-probability for individual risks can be obtained by subtracting this result from P(JUSED).

SU P RU = ... RO = ... : Gives the probability that the individual risk value lies in a risk interval. This interval is specified by the NAMELIST parameters RUYFS1/2 and ROYFS1/2. Setting the lower interval boundary to a very low value (e.g. 1.E-30) and the upper boundary to 1.0, the probability for a non-zero individual risk is calculated.

FRACTILE ... : Gives the fractile values for the percentiles specified by NAMELIST parameter PERC. They are derived from the CCFD which is printed only on request (see Table 18). A value of -0.10E+01 indicates that the corresponding percentile cannot be found in the CCFD. There can be two reasons: either the starting value NRSMIN for the evaluation interval has not been chosen appropriately or the zero-probability for individual risks is above the specified PERC-value.

Table 18: Evaluation program EVARSK: CCFDs for individual health effects risks

If the NAMELIST parameter ICCFD is set to 1, a printout of the CCFD (Complementary Cumulative Frequency Distribution) will be given for the point values of the individual health effects risks evaluated by IORGNR and the distances specified with IACT. For calculating the CCFD the risk range from the lower limit 10^{NRSMIN} to the upper limit $10^{\text{NRSMIN}+\text{NDEKAR}}$ is taken into account with the number of decades NDEKAR being 7. Each of these decades is subdivided into 100 logarithmically equidistant risk intervals. Each single risk value belongs to one of these intervals. The probability for this interval is increased by the probability of the single risk value. The CCFD starts with the risk value 10^{NRSMIN} and ends with $10^{\text{NRSMIN}+\text{NDEKAR}}$. In the printout of the CCFD every 5th value is shown. If the probability value for $10^{\text{NRSMIN}+\text{NDEKAR}}$ is not 0, a higher value for NRSMIN should be chosen, because the maximum risk result is not contained in the evaluation decades.

Table 19 and Table 20: Evaluation program EVACOL

After some information about the input parameters the statistical evaluation is printed for each non-lethal and lethal health effect considered and the total number. The first line gives the maximal number of health effects of all weather sequences and sites.

SUM P < POPMIN: Gives the probability that the number of health effects summed up over the whole grid area is below $POPMIN = 10^{NCRMIN}$; NCRMIN is a NAMELIST parameter.

FRACTILE ... : Gives the fractile values for the percentiles specified by NAMELIST parameter PERC; they are derived from the CCFD which is printed only on request (see explanations for Table 17).

If ICCFD is set to 1, the CCFD will be printed for each health effect. The algorithm for calculating the CCFDs has already been described for Table 18. The number of decades considered for collective risks is 5 starting with NCRMIN.

5.2 Subsystems NL and FL

In the modules POTRSK and LATRSK for calculating **individual** risks of stochastic health effects, the contribution from the ingestion pathway is only contained in the results, if CIGCOL is set to 'L-P&C' (local production and consumption method). For CIGCOL = 'APROD' (agricultural production method) no individual results from ingestion can be obtained (see [5]).

In submodule COLRSK of module COLLEC for calculating **collective** results the grid point and distance dependent printouts contain the risks from the ingestion pathway only for CIGCOL = 'L-P&C'. The results are available separately for the living (LG) and future (FG) generations and for their sum (L + FG). Using the APROD-method the collective contribution from ingestion is added to the results integrated over the whole grid area. In this case only results summed up over all generations (L + FG) are calculated.

Table 21: Module LATRSK: Title page with information about parameter values

The values of some of the NAMELIST parameters needed for the calculation of individual risks are printed after the title page. A similar printout is obtained from module POTRSK.

Table 22: Module POTRSK: Printout of activity risk coefficients

This printout is obtained only if IAROUT \neq 0. It gives for each nuclide considered and each organ the activity risk coefficients for the exposure pathways taken into account (i.e. IEXPO \neq 0). For groundshine (GR) and resuspension (IHR) pathway 'L' refers to living, 'F' to

future generations. $T_0=0$ denotes that these factors are valid for resettlement time 0, i.e. for areas not interdicted within any time period.

For contamination of skin and clothes the coefficients refer to incidence and are integrated only over a short time period (TSKIN days). 'SK-P' contains the contribution coming from the parent of the nuclide.

Table 23 and Table 24: Module LATRSK: Printout of activity risk coefficients

This printout is obtained only if countermeasures are taken into account and IAROUT \neq 0. It gives for each nuclide considered and each organ the activity risk coefficients for groundshine and resuspension for living (L) and future (F) generations and the resettlement times within the first year after the accident and later (defined by NAMELIST parameter NT).

For contamination of skin and clothes the coefficients refer to incidence and are integrated only over short time periods (TSKIN days and for subsystem NL also 1 day). 'SK-P' contains the contribution coming from the parent of the nuclide.

Table 25: Modules POTRSK and LATRSK: Printout of results of point values

This printout is obtained only if NOORSK \neq For a value of 1 the information for each weather sequence is given, a value of 2 reduces the output to up to 20 weather sequences specified by LKZ. The distances are selected by IACT. With ILFOUT the results for living and/or future generations can be chosen. Starting with the azimuthal sector $J=1$ (sector due to North) the point results for all JMAX sectors are given (the sectors count clockwise). The individual risks printed here are given for all organs considered and their sum; the first set of values refers to mortality, the second one to incidence. If in subsystem NL the NAMELIST parameter IEARLY is set to 1 to consider the individual risk for deterministic effects, the results assessed in subsystem NE are also printed at the end of this table.

Table 26 to Table 28: Modules POTRSK and LATRSK: Breakdown of mean individual risks by exposure pathways and for each pathway by nuclides

This information is printed for all distances selected by IACT and for living and/or future generations according to ILFOUT. The necessary calculations are done in subroutine TABWT. The individual risks are averaged over all weather sequences and all azimuthal sectors. Nuclides with a contribution of $< 0.005\%$ for all organs are skipped. The ingestion pathway is included in these results only for CIGCOL = 'L-P&C'. In this case the individual risks due to ingestion are also broken down by foodstuffs.

Table 29: Modules POTRSK and LATRSK: Distance-dependent mean individual risks

This information is printed for living and/or future generations according to ILFOUT. It gives for each distance the mean individual risk for all organs (mortality and incidence) and the total. The results are averaged over all weather sequences and azimuthal sectors. The ingestion pathway is included in these results only for CIGCOL = 'L-P&C'.

Table 30: Module COLLEC-COLRSK: Title page with information about parameter values
After the title page the index of the distance up to which (subsystem NL) or beyond which (subsystem FL) the collective risks are integrated is printed.

Table 31: Module COLLEC-COLRSK: Printout of results of point values

This printout is obtained for each site only if NOOPOP \neq 0. For a value of 1 the information for each weather sequence is given, a value of 2 reduces the output to up to 20 weather sequences specified by LKZ. The distances are selected by IACT. With ILFOUT the results for living, future and/or all generations can be chosen. Starting with the azimuthal sector J = 1 (sector due to North) the point results of number of stochastic health effects are given for all JMAX sectors (the sectors count clockwise). The information is printed for all organs for mortality and incidence. The ingestion pathway is included in these results only for CIGCOL = 'L-P&C'. For CIGCOL = 'APROD', only results summed up over all generations can be obtained (not including the contribution from ingestion).

Table 32: Module COLLEC-COLRSK: Printout of results for each site integrated over the grid area

This printout is obtained for each site only if NOOSIT \neq 0. A value of 1 gives the information for all weather sequences calculated, a value of 2 only for those up to 20 weather sequences specified by LKZ. ILFOUT the results for living, future and/or all generations can be chosen. The collective risks printed are integrated over the grid area up to IRMAX (subsystem NL) or starting with IRMIN (subsystem FL). The ingestion pathway is included in these results whenever it is considered. However, for CIGCOL = 'APROD', only results summed up over all generations can be obtained.

Table 33: Module COLLEC-COLRSK: Distance-dependent mean collective risks

This information cannot be suppressed. It gives for each distance the mean collective risk for all organs (mortality and incidence), for living and future generations and their sum. The results are averaged over all weather sequences, azimuthal sectors and sites. The ingestion pathway is included in these results only for CIGCOL = 'L-P&C'. For CIGCOL = 'APROD', only results summed up over all generations can be obtained (not including the contribution from ingestion).

Table 34: Module COLLEC-COLRSK: Breakdown of mean collective risks by exposure pathways

This information cannot be suppressed. It gives for each organ the mean collective risk for mortality and incidence, for the living and the future generations and their sum integrated over the grid area up to IRMAX (subsystem NL) or starting with IRMIN (subsystem FL), and the breakdown by exposure pathways to this risk. For the total number of stochastic health effects (lower part of the table) the breakdown by organs and exposure pathways is presented. The mean collective risks are averaged over all weather sequences, azimuthal sectors and sites. The ingestion pathway is included in these results whenever it is considered.

However, for CIGCOL='APROD' only results summed up over all generations can be obtained.

Table 35 and Table 36: Evaluation program EVARSK

After some information about the input parameters the radius-dependent statistical evaluation is printed for all organs (mortality and incidence) specified by IORGNR and for living and/or future generations according to ILFOUR. The first line gives the index of the weather sequence (not the starting time) leading to the maximal risk value printed in the second line. Maximal means the maximum individual risk of all weather sequences and azimuthal sectors. The mean value is identical to that described for Table 29. The ingestion pathway is included in these results only for CIGCOL='L-P&C'. However, for CIGCOL='APROD' only results summed up over all generations can be obtained.

SUM P (JUSED): Gives the fraction of each distance band affected by the plume (i.e. with a normalized air concentration > CHIMAX); this fraction is averaged over the weather sequences.

SUM P < RSKMIN: Gives the fraction of grid elements under the plume having a risk value below $RSKMIN = 10^{NRSMIN}$; NRSMIN is a NAMELIST parameter.

SU P RU = ... RO = ... : Gives the probability that the individual risk value lies in a risk interval; this interval is specified by the NAMELIST parameters RUYSS and ROYSS.

FRACTILE ... : Gives the fractile values for the percentiles specified by NAMELIST parameter PERC; they are derived from the CCFD which is printed only on request (see explanations for Table 17).

If ICCFD is set to 1, the CCFD will be printed for the organ risks evaluated and the distances specified with IACT. The algorithm for calculating the CCFDs has already been described for Table 18.

Table 37: Evaluation program EVARSK

For the living generations the individual loss of life due to each cancer type is also calculated and evaluated.

Table 38 and Table 39: Evaluation program EVACOL

After some information about the input parameters the statistical evaluation is printed for all organs (mortality and incidence) and for living and future generations and their sum. The first line gives the maximal collective risk value of all weather sequences and sites. The mean value is identical to that described for Table 33. The ingestion pathway is included in these results whenever it is considered.

SUM P < POPMIN: Gives the probability that the collective risk summed up over the grid area is below $POPMIN = 10^{NCRMIN}$; NCRMIN is a NAMELIST parameter.

FRACTILE ... : Gives the fractile values for the percentiles specified by NAMELIST parameter PERC; they are derived from the CCFD which is printed only on request (see explanations for Table 17).

If ICCFD is set to 1, the CCFD will be printed for all organ risks. The algorithm for calculating the CCFDs has already been described for Table 18. For collective stochastic risks 6 decades are considered starting with NCRMIN.

Table 40: Evaluation program EVARSK

For the living generations the collective loss of life due to each cancer type is also calculated and evaluated. For the number of lethal effects summed up over all generations an approximate time dependency of the occurrence of cancer in the various organs is calculated.

6. Figures

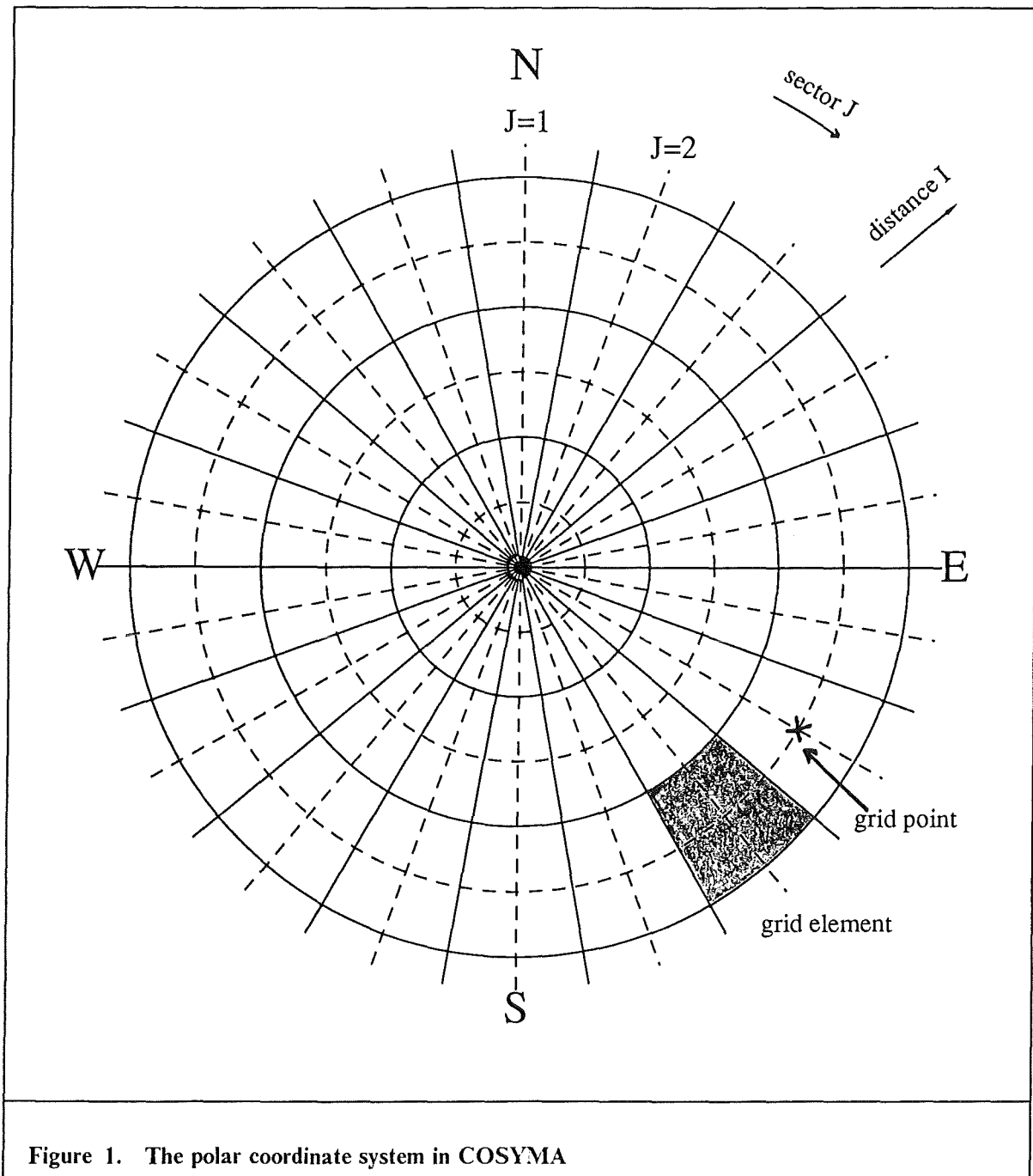
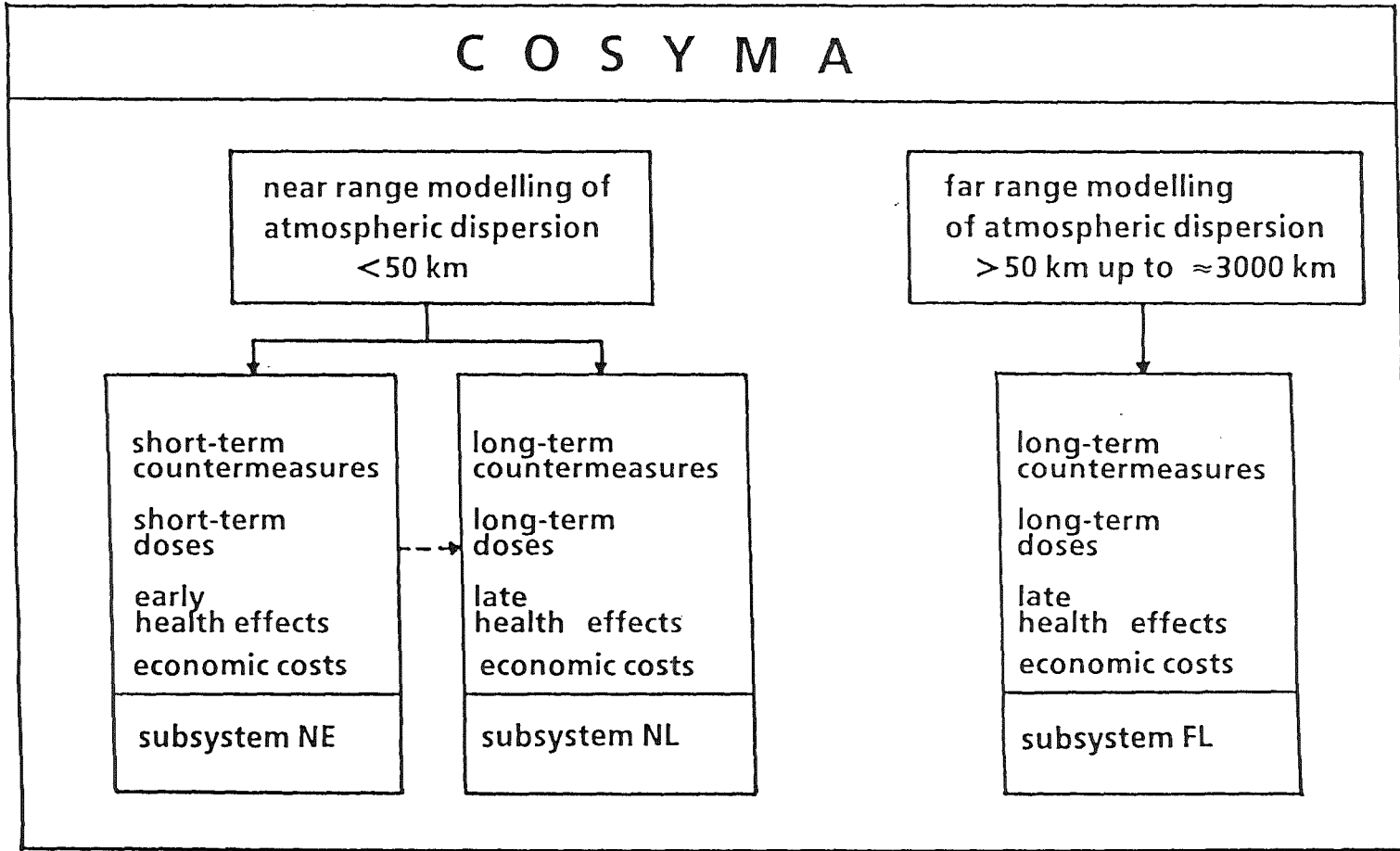


Figure 1. The polar coordinate system in COSYMA

Figure 2. General structure of COSYMA



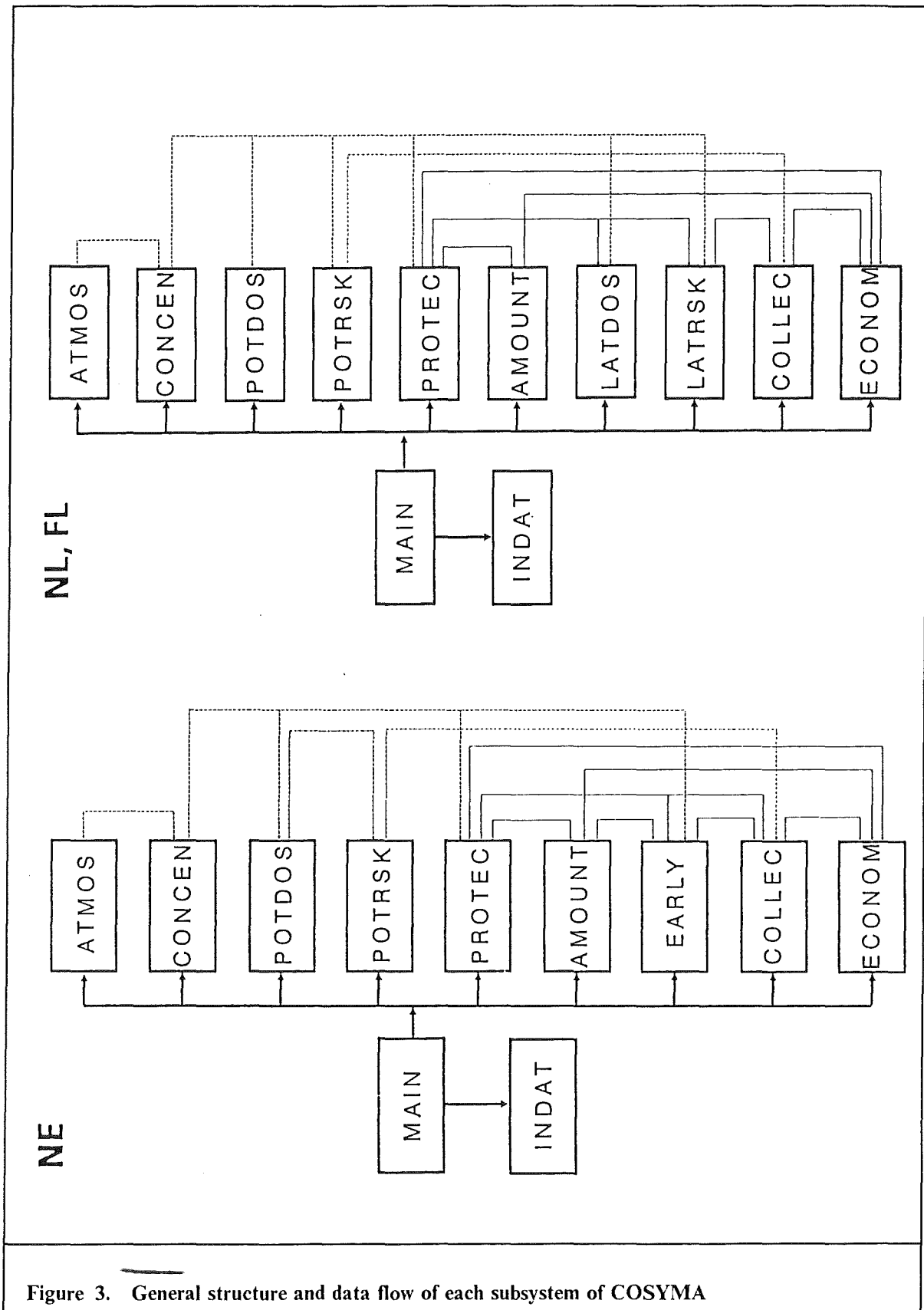


Figure 3. General structure and data flow of each subsystem of COSYMA

```

sites                NS = 1, NSTMAX (if required)

weather sequences    L  = 1, LMAX

radii                I  = 1, IMAX

azimuthal sectors    J  = 1, JMAX

release phases       NP = 1, NPHMAX

IF(JUSED.EQ.0) GOTO "END OF LOOP"

further loops over
    nuclides K=1,NUKRED
    organs NOG=1,NOGM
    shielding groups NA=1,NAG
    population density groups NF=1,NFG
    driving time classes NFZ=1,NFZV
as far as required

END OF LOOP

```

Figure 4. General loop structure of the modules in COSYMA

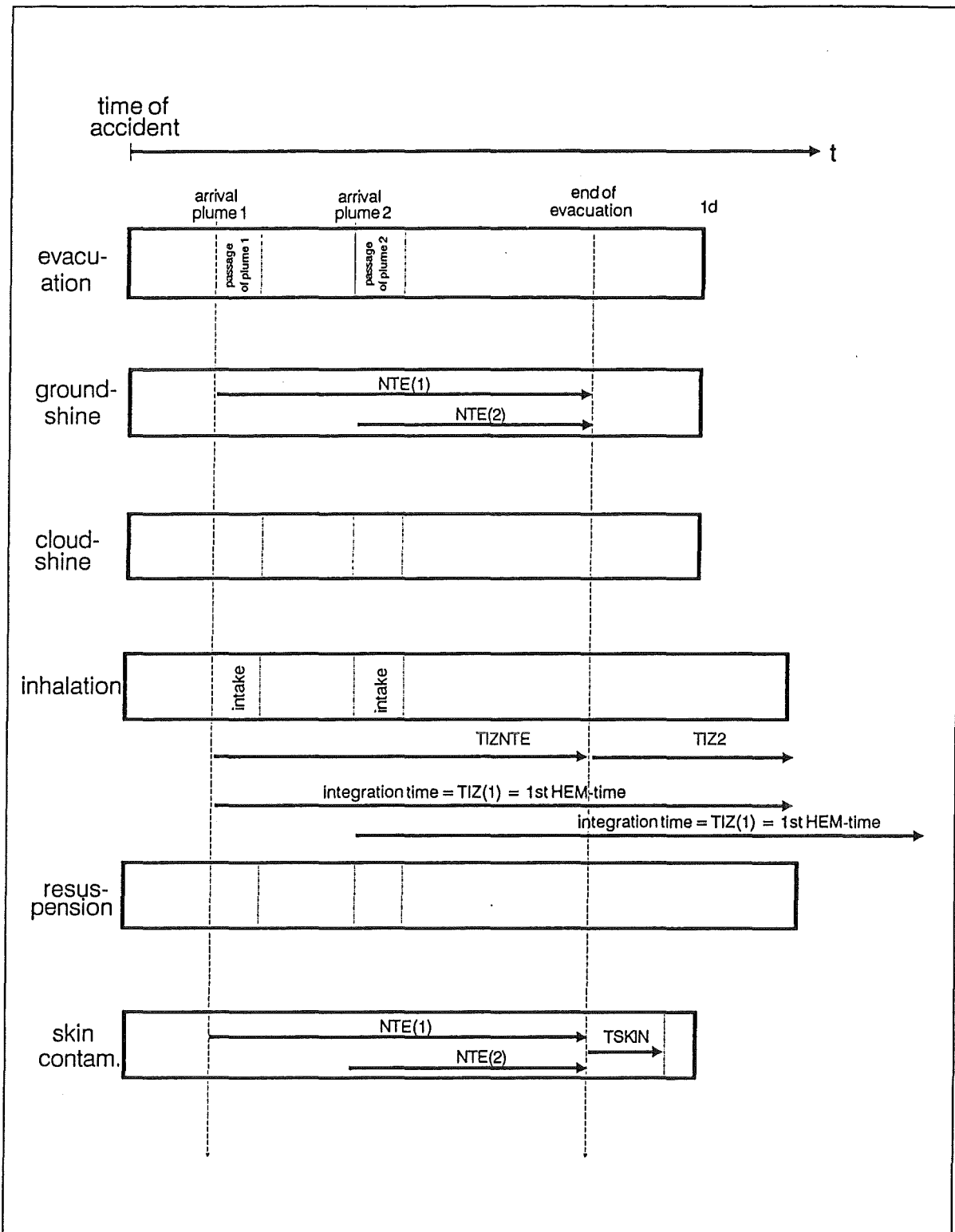


Figure 5. Timing of emergency actions in relation to time periods of health effects model

7. Tables

E F F E C T	COSYMA-Subsystem		
	N E	N L	F L
<u>Exposure Pathways</u>			
External irradiation from the cloud	*	*	*
External irradiation from deposit on the ground	*	*	*
Inhalation from the cloud	*	*	*
Inhalation of resuspended material	*	*	*
External irradiation from deposit on skin and clothes	*	*	*
Ingestion of contaminated food		*	*
<u>Organ doses</u>			
Acute doses (integration times ≥ 1 d, ≤ 1 a)	*		
Lifetime doses (integration times ≥ 1 a, ≤ 70 a)		*	*
<u>Countermeasures</u>			
Sheltering	*	*	
Evacuation	*		
Relocation		*	*
Land decontamination		*	*
Stable iodine tablets	*	*	*
Food restrictions		*	*

Table 1. Contents of the different subsystems of COSYMA

health effect	D_{∞} [Gy]	D_0 [Gy ² /h]	shape para – meter V	quality fac – tor RBE ¹	treatm.fac – tor TREAT
lung function impairment	5.0	15.0	7.0	7.0	1.0
hypothyroidism	60.0	30.0	1.3	0.0	1.0
cataracts	3.0	0.01	5.0	0.0	1.0
mental retardation	1.5	0.0	1.0	20.0	1.0
effects on skin	20.0	5.0	5.0	0.0	1.0
pulmonary syndrome	10.0	30.0	7.0	7.0	1.0
hematopoietic syndrome ²	3.0	0.07	6.0	2.0	1.5
GI-syndrome (internal)	35.0	0.0	10.0	0.0	1.0
Pre-/neonatal death	1.5	0.0	3.0	20.0	1.0
death from skin burns	20.0	5.0	5.0	0.0	1.0

NOTE:
¹ The α -dose is multiplied by RBE/20
² These values refer to minimal treatment; the treatment factor is set per default to 1.5; thus the values in the table have to be multiplied by 1.5 to obtain the actually used values.

Table 2. Default values for the health effects model for deterministic effects

organ/tissue	effect	model ¹	fraction of cancers which are fatal (<i>CFINC</i>)	effects per 10 ⁶ persons and 10 ⁻² Sv (<i>RC</i>) ²	days of life lost per manSv (<i>DLL</i>)
bone marrow	leukemia	A	1.0	52	59.00
bone surface	cancer	A	1.0	1	1.61
breast	cancer	R	0.4	80	57.00
lung	cancer	R	0.75	90	41.00
stomach	cancer	R	0.85		36.40
colon	cancer	R	0.55	224 ³	14.50
liver	cancer	R	1.0		22.40
pancreas	cancer	R	0.9		21.80
thyroid	cancer	R	0.1	17	12.00
remainder	cancer	R	0.6	38	19.00
skin	cancer		0.01	138 ⁴	
gonads	hereditary			200	
sum				502	284.00

NOTE:

¹ A = absolut risk model; R = relative risk model

² the numbers given are the numbers of fatal cancers or of serious hereditary effects, averaged over males and females (including breast), assuming linear dose-risk relationship

³ sum for the GI-tract

⁴ morbidity

Table 3. Stochastic health effects considered and model parameters

	IZ = 1		IZ = 2		IZ = 3		IZ = 4	
	$t_1[d]$	$t_2[d]$	$t_1[d]$	$t_2[d]$	$t_1[d]$	$t_2[d]$	$t_1[d]$	$t_2[d]$
lung effects	0	1	1	7	7	30	30	365
hematopoietic syndrome	0	1	1	7	7	30		
gastrointestinal syndrome	0	1	1	7				
skin effects	0	1	1	7	7	30		
hypothyroidism	0	1	1	30				
cataracts	0	1	1	7	7	30		
fetal effects	0	1	1	30				

Table 4. Lower and upper time points of the different time periods IZ of the health effects model for different deterministic health effects

	years after the accident									
	- 5	- 10	- 20	- 30	- 40	- 50	- 70	- 90	- 150	- 200
bone marrow	3.33,	13.85,	24.45,	17.50,	12.12,	8.22,	9.74,	5.63,	4.87,	0.32
bone surface	0.00,	9.04,	21.13,	23.40,	15.65,	10.23,	11.03,	5.02,	4.23,	0.31
breasts	0.00,	0.28,	1.46,	3.40,	7.34,	12.26,	31.26,	23.26,	18.96,	1.75
lung	0.00,	1.33,	4.01,	6.03,	9.02,	12.88,	32.00,	19.85,	13.54,	1.30
stomach	0.00,	1.04,	3.38,	5.05,	7.43,	10.50,	28.34,	23.64,	18.60,	2.00
colon	0.00,	1.30,	4.10,	5.60,	8.30,	11.25,	29.28,	22.10,	16.38,	1.70
liver	0.00,	0.85,	3.22,	5.73,	9.11,	12.81,	30.38,	20.34,	16.02,	1.55
pancreas	0.00,	1.14,	3.65,	5.24,	7.75,	10.90,	28.62,	22.64,	18.18,	1.88
thyroid	0.00,	0.60,	3.21,	6.08,	9.56,	14.52,	39.58,	22.80,	3.30,	0.33
remainder	0.00,	1.48,	4.82,	6.56,	8.96,	11.60,	28.22,	20.17,	16.56,	1.58
skin	- - -	- - -	- - -	- - -	no time function available			- - -	- - -	- - -
sum	0.32,	2.24,	5.53,	6.74,	8.94,	12.08,	30.00,	20.24,	12.72,	1.24

Table 5. Derived normalized time function for each cancer type.

8. Output of risk modules

8.1 *Subsystem NE*

Table 6. INDAT: Control output of parameters for the deterministic health effects model

*** PROGRAM COSYMA ***

PARAMETERS OF THE DOSE-RISK RELATIONSHIPS

MORBIDITY

=====

EFFECT	SHAPE PARAMETER	UPPER TIME INTERVALS (D)				THETA-1 SV	THETA-INFINI GY**2/H	TREATM GY
(*) LUNG IMPAIRMENT	7.0	1	7	30	365	1.50E+01	5.00E+00	1.00E+00
(*) HYPOTHYROIDISM	1.3	1	30	0	0	3.00E+01	6.00E+01	1.00E+00
(*) CATARACTAE	5.0	1	7	30	0	1.00E-02	3.00E+00	1.00E+00
(*) MENTAL RETARD.	1.0	1	30	0	0	0.00E+00	1.50E+00	1.00E+00
(*) EFFECTS ON SKIN	5.0	1	7	30	0	5.00E+00	2.00E+01	1.00E+00

MORTALITY

=====

EFFECT	SHAPE PARAMETER	UPPER TIME INTERVALS (D)				THETA-1 SV	THETA-INFINI GY**2/H	TREATM GY
(*) PULMONARY SYNDR	7.0	1	7	30	365	3.00E+01	1.00E+01	1.00E+00
(*) HEMATOP.SYNDR.	6.0	1	7	30	0	7.00E-02	3.00E+00	1.50E+00
(*) GASTROINT.SYNDR	10.0	1	7	0	0	0.00E+00	1.50E+01	1.00E+00
(*) PRE/NEON. DEATH	3.0	1	30	0	0	0.00E+00	1.50E+00	1.00E+00
(*) SKIN BURNS	5.0	1	7	30	0	5.00E+00	2.00E+01	1.00E+00

(*) FOR THE EFFECTS MARKED BY (*) DOSE-RATE DEPENDENT LD50-VALUES ARE APPLIED

THE INDIVIDUAL RISKS FOR EACH HEALTH EFFECT AND POPULATION GROUP ARE CUT AT 1.00E-03 (= THRESH)

RATIO OF ACTIVITY CONCENTRATIONS ON SKIN TO DRY DEPOSITED ACTIVITY CONCENTRATIONS ON GROUND SURFACE (=CONFAK(NN)):

1	NOBLE GASES:	1.000
2	AEROSOLS:	1.000
3	ELEMENTAL IODINE:	1.000
4	ORG. BOUND IODINE:	1.000
5	AEROSOL-TYPE IODINE:	1.000

FACTOR FOR CALCULATING RISK OF FATAL SKIN BURNS FOR THE AVERAGE INDIVIDUAL (=SKMORT): 0.05

PPPPPPPPPP	0000000000	TTTTTTTTTTTT	RRRRRRRRRR	SSSSSSSSSS	KK	KK
PPPPPPPPPP	0000000000	TTTTTTTTTTTT	RRRRRRRRRR	SSSSSSSSSS	KK	KK
PP	PP 00 00	TT	RR RR RR	SSS SSS	KK	KK
PP	PP 00 00	TT	RR RR RR	SSS SS	KK	KKK
PP	PP 00 00	TT	RR RR RR	SSS	KK	KKK
PPPPPPPPPP	00 00	TT	RRRRRRRRRR	SSS	KKKKK	
PPPPPPPPPP	00 00	TT	RRRRRRRRRR	SSS	KKKKK	
PP	00 00	TT	RR RR	SSS	KK	KKK
PP	00 00	TT	RR RR	SS SSS	KK	KKK
PP	00 00	TT	RR RR	SSS SSS	KK	KK
PP	0000000000	TT	RR RR	SSSSSSSSSS	KK	KK
PP	0000000000	TT	RR RR	SSSSSSSSSS	KK	KK

POTRSK READS THE RESULTS OBTAINED IN CONCEN
AND CALCULATES THE INDIVIDUAL RISKS OF EARLY HEALTH EFFECTS
UNDER THE CONDITION OF ABSENT ACTIONS

Table 7. POTRSK: Title page.

EEEEEEEEEEEE	AAAAAAAAAA	RRRRRRRRRR	LL	YY	YY
EEEEEEEEEEEE	AAAAAAAAAA	RRRRRRRRRR	LL	YY	YY
EE	AA AA	RR RR	LL	YY	YY
EE	AA AA	RR RR	LL	YY	YY
EE	AA AA	RR RR	LL	YY	YY
EEEEEEEE	AAAAAAAAAA	RRRRRRRRRR	LL	YYYY	
EEEEEEEE	AAAAAAAAAA	RRRRRRRRRR	LL	YY	
EE	AA AA	RR RR	LL	YY	
EE	AA AA	RR RR	LL	YY	
EE	AA AA	RR RR	LL	YY	
EEEEEEEEEEEE	AA AA	RR RR	LLLLLLLLLLLL	YY	
EEEEEEEEEEEE	AA AA	RR RR	LLLLLLLLLLLL	YY	

EARLY READS THE RESULTS OBTAINED IN CONCEN
AND CALCULATES SHORT-TIME INTEGRATED ORGAN DOSES AND INDIVIDUAL
RISKS OF NONSTOCHASTIC HEALTH EFFECTS, TAKING INTO ACCOUNT THE
PATTERNS OF DOSE MITIGATING ACTIONS, DETERMINED IN PROTEC

Table 8. EARLY: Title page.

MEAN INDIVIDUAL RISK FOR EARLY HEALTH EFFECTS (MORBIDITY) IN EACH SECTOR, AVERAGE OVER ALL WEATHER SEQUENCES

RADIUS R(4) = 875.00 M

EFFECT NO. 1 LUNG FUNCT. IMP.

0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
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 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00

EFFECT NO. 2 HYPOTHYROIDISM

0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.12449E-01 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00

.....

EFFECT NO. 5 EFFECTS ON SKIN

0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.94813E-01 0.79380E+00 0.71526E-06 0.71526E-06 0.71526E-06 0.71526E-06 0.71526E-06 0.71526E-06
 0.94807E-01 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00

SUM OF EFFECTS 1 TO 3 + 5

0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.88949E+00 0.16383E+01 0.15631E-05 0.16831E-05 0.16831E-05 0.16831E-05 0.16831E-05 0.16831E-05
 0.88948E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00

Table 10. POTRSK/EARLY: Printout of individual risks, averaged point values

CCCCCCCCCC	000000000	LL	LL	EEEEEEEEEEE	CCCCCCCCCCC
CCCCCCCCCCC	00000000000	LL	LL	EEEEEEEEEEE	CCCCCCCCCCC
CC	00	00	LL	EE	CC
CC	00	00	LL	EE	CC
CC	00	00	LL	EE	CC
CC	00	00	LL	EEEEEEEEEE	CC
CC	00	00	LL	EEEEEEEEEE	CC
CC	00	00	LL	EE	CC
CC	00	00	LL	EE	CC
CC	00	00	LL	EE	CC
CCCCCCCCCCC	00000000000	LLLLLLLLLLLLL	LLLLLLLLLLLLL	EEEEEEEEEEE	CCCCCCCCCCC
CCCCCCCCCCC	0000000000	LLLLLLLLLLLLL	LLLLLLLLLLLLL	EEEEEEEEEEE	CCCCCCCCCCC

COLLEC READS THE RESULTS OBTAINED IN POTDOS AND EARLY, RESPECTIVELY, AND DETERMINES THE NUMBER OF EARLY HEALTH EFFECTS IN THE EXPOSED POPULATION

Table 12. COLLEC: Title page

EARLY HEALTH EFFECTS FOR EACH SITE AND THE WEATHER SEQUENCE L (MORBIDITY)

L = 1	T-SITE-1		T-SITE-2	
	NFA=0	NFB=0	NFA=0	NFB=0
LUNG FUNCT. IMP.	0		0	
HYPOTHYROIDISM	13		16	
CATARACTS	14250		17812	
MENT.RETARDAT.	2		2	
EFFECTS ON SKIN	111		138	
TOTAL	14375		17968	

Table 14. COLLEC: Printout of results integrated over the whole grid for each site

RESULTS OF THE EVALUATION PROGRAM FOR THE INDIVIDUAL RISKS
 CALCULATED IN THE MODULES POTRSK AND EARLY, RESPECTIVELY
 SUBROUTINE EVARSK

***** PRINTOUT OF THE INPUT *****

NRSMIN: -7
 NDEKAR: 7
 MAXI: 20

EFFECTS MORB.: MORT.:	LUNG FUNCT. IMP. PULMONARY SYNDR.	HYPOTHYROIDISM HEMATOPOIETIC S.	CATARACTS GASTROINTEST. S.	MENT.RETARDAT. PRE-/NEONATAL D.	EFFECTS ON SKIN SKIN BURNS	TOTAL TOTAL
IORGNR(IOR):	1	1	1	1	1	1
IORGNR(IOR):	1	1	1	1	1	1
RUYFS1(IOR):	0.1000E-29	0.1000E-29	0.1000E-29	0.1000E-29	0.1000E-29	0.1000E-29
ROYFS1(IOR):	0.1000E+01	0.1000E+01	0.1000E+01	0.1000E+01	0.1000E+01	0.1000E+01
RUYFS2(IOR):	0.1000E-29	0.1000E-29	0.1000E-29	0.1000E-29	0.1000E-29	0.1000E-29
ROYFS2(IOR):	0.1000E+01	0.1000E+01	0.1000E+01	0.1000E+01	0.1000E+01	0.1000E+01

EVALUATION INTERVALS:

LOWER LIMIT FOR RISK: 0.10E-06
 UPPER LIMIT FOR RISK: 0.10E+01

A PRINTOUT OF CCFDS IS GIVEN FOR THE RADII DEFINED BY IACT:

ICCFD = 1
 IACT = 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0

LEGEND FOR THE PRINTOUT OF THE EVALUATION PROGRAM

VALUE = RISK : INDIVIDUAL HEALTH EFFECTS RISKS

MAX. VALUE : MAXIMAL VALUE DETERMINED IN THE CALCULATIONS
 MEAN VALUE : MEAN VALUE, AVERAGED OVER WEATHER SEQUENCES AND AZIMUTHAL SECTORS
 SUM P (JUSED) : PROBABILITY FOR GRID ELEMENTS AFFECTED BY THE PLUME
 SUM P < ...MIN : PROBABILITY FOR VALUES < ...MIN AT GRID ELEMENTS AFFECTED BY THE PLUME
 SU P RU= RO= : PROBABILITY FOR VALUES IN THE INTERVAL FROM RU TO RO
 FRACTILE 99.0 : 99.0%-FRACTILE VALUE

Table 17. POTRSK/EARLY-EVARSK: Statistical quantiles of individual risks

***** MORBIDITY *****						
EVALUATION OF THE DISTRIBUTION OF INDIVIDUAL RISKS FOR HYPOTHYROIDISM						

RADIUS (M)	250.0	400.0	625.0	875.0	1150.0	1550.0
MAX. RISK	0.3822E-01	0.3590E-01	0.3944E-01	0.5072E-01	0.2711E-01	0.2780E-01
MEAN RISK	0.1101E-02	0.9983E-03	0.1095E-02	0.1755E-02	0.7532E-03	0.1079E-02
SUM P (JUSED)	0.2917E+00	0.2639E+00	0.2361E+00	0.2361E+00	0.2083E+00	0.2083E+00
SUM P < RISKMIN	0.1111E+00	0.1111E+00	0.1111E+00	0.1111E+00	0.1389E+00	0.1528E+00
SU P RU=.1E-29 RO=.1E+01	0.1806E+00	0.1528E+00	0.1250E+00	0.1250E+00	0.9722E-01	0.9722E-01
FRACTILE 99.9	0.3822E-01	0.3590E-01	0.3944E-01	0.5072E-01	0.2711E-01	0.2780E-01
FRACTILE 99.0	0.3822E-01	0.3590E-01	0.3944E-01	0.5072E-01	0.2711E-01	0.2780E-01
FRACTILE 95.0	0.1413E-02	0.4266E-04	0.4266E-06	0.1259E-01	0.1549E-06	0.1122E-01
FRACTILE 90.0	0.7079E-06	0.5370E-06	0.1175E-06	0.1349E-06	-0.1000E+01	-0.1000E+01
FRACTILE 50.0	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01
RADIUS (M)	2100.0	2700.0	3700.0	4900.0	6550.0	8750.0
MAX. RISK	0.2097E-01	0.1390E-01	0.1549E-01	0.1300E-01	0.8360E-02	0.0000E+00
MEAN RISK	0.5824E-03	0.6890E-03	0.6132E-03	0.4156E-03	0.1161E-03	0.0000E+00
SUM P (JUSED)	0.1806E+00	0.1806E+00	0.1806E+00	0.1528E+00	0.1528E+00	0.1250E+00
SUM P < RISKMIN	0.1250E+00	0.1111E+00	0.1389E+00	0.1111E+00	0.1389E+00	0.1250E+00
SU P RU=.1E-29 RO=.1E+01	0.6944E-01	0.6944E-01	0.4167E-01	0.4167E-01	0.1389E-01	0.0000E+00
FRACTILE 99.9	0.2097E-01	0.1390E-01	0.1549E-01	0.1300E-01	0.8360E-02	-0.1000E+01
FRACTILE 99.0	0.2097E-01	0.1390E-01	0.1549E-01	0.1300E-01	0.8360E-02	-0.1000E+01
FRACTILE 95.0	0.1479E-05	0.1096E-01	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01
FRACTILE 90.0	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01
FRACTILE 50.0	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01
.....						
RADIUS (M)	65500.0	87500.0				
MAX. RISK	0.0000E+00	0.0000E+00				
MEAN RISK	0.0000E+00	0.0000E+00				
SUM P (JUSED)	0.9722E-01	0.6944E-01				
SUM P < RISKMIN	0.9722E-01	0.6944E-01				
SU P RU=.1E-29 RO=.1E+01	0.0000E+00	0.0000E+00				
FRACTILE 99.9	-0.1000E+01	-0.1000E+01				
FRACTILE 99.0	-0.1000E+01	-0.1000E+01				
FRACTILE 95.0	-0.1000E+01	-0.1000E+01				
FRACTILE 90.0	-0.1000E+01	-0.1000E+01				
FRACTILE 50.0	-0.1000E+01	-0.1000E+01				

Table 18. POTRSK/EARLY-EVARSK: CCFDs for the health effects risks evaluated

CCFDS OF INDIVIDUAL RISKS FOR THE RADIUS 875.00 M (MORBIDITY)						
INTERVAL	LUNG FUNCT.IMP.	HYPOTHYROIDISM	CATARACTS	MENT.RETARDAT.	EFFECTS ON SKIN	TOTAL
>= 0.1000E-06	0.00000	0.12500	0.12500	0.12500	0.12500	0.12500
>= 0.1122E-06	0.00000	0.12500	0.12500	0.12500	0.12500	0.12500
.....						
>= 0.1122E-05	0.00000	0.05556	0.05556	0.11111	0.05556	0.12500
>= 0.1259E-05	0.00000	0.05556	0.05556	0.11111	0.05556	0.12500
>= 0.1413E-05	0.00000	0.05556	0.05556	0.11111	0.05556	0.12500
>= 0.1585E-05	0.00000	0.05556	0.05556	0.11111	0.05556	0.09722
>= 0.1778E-05	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.1995E-05	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.2239E-05	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.2512E-05	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.2818E-05	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.3162E-05	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.3548E-05	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.3981E-05	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.4467E-05	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.5012E-05	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.5623E-05	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.6310E-05	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.7079E-05	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.7943E-05	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.8912E-05	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.1000E-04	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.1122E-04	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.1259E-04	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.1413E-04	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.1585E-04	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.1778E-04	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.1995E-04	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.2239E-04	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.2512E-04	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.2818E-04	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.3162E-04	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.3548E-04	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.3981E-04	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.4467E-04	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.5012E-04	0.00000	0.05556	0.05556	0.11111	0.05556	0.05556
>= 0.5623E-04	0.00000	0.05556	0.05556	0.08333	0.05556	0.05556
>= 0.6310E-04	0.00000	0.05556	0.05556	0.08333	0.05556	0.05556
>= 0.7079E-04	0.00000	0.05556	0.05556	0.08333	0.05556	0.05556
.....						
>= 0.7079E+00	0.00000	0.00000	0.05556	0.00000	0.02778	0.05556
>= 0.7943E+00	0.00000	0.00000	0.00000	0.00000	0.00000	0.05556
>= 0.8912E+00	0.00000	0.00000	0.00000	0.00000	0.00000	0.02778

Table 19. COLLEC-EVACOL: Information about input parameter values

RESULTS OF THE EVALUATION PROGRAM FOR THE NUMBER OF
EARLY HEALTH EFFECTS IN THE POPULATION
CALCULATED IN THE MODULE COLLEC
SUBROUTINE EVACOL

***** PRINTOUT OF THE INPUT *****

NCRMIN: 0
NDEKCR: 5

EVALUATION INTERVALS:

LOWER LIMIT FOR NUMBER OF HEALTH EFFECTS: 0.1000E+01
UPPER LIMIT FOR NUMBER OF HEALTH EFFECTS: 0.1000E+06

NO PRINTOUT OF CCFDS IS GIVEN: ICCFD = 0

LEGEND FOR THE PRINTOUT OF THE EVALUATION PROGRAM

VALUE = NUMBER : NUMBER OF HEALTH EFFECTS

MAX. VALUE : MAXIMAL VALUE DETERMINED IN THE CALCULATIONS
MEAN VALUE : MEAN VALUE, AVERAGED OVER WEATHER SEQUENCES
SUM P < ...MIN : PROBABILITY FOR VALUES < ...MIN (VALUE = SUM OVER THE GRID ELEMENTS)
FRACTILE 99.0 : 99.0%-FRACTILE VALUE

Table 20. COLLEC-EVAGOL: Statistical quantiles of number of early health effects

***** MORBIDITY *****						
HEALTH EFFECT:	LUNG FUNCT.IMP.	HYPOTHYROIDISM	CATARACTS	MENT.RETARDAT.	EFFECTS ON SKIN	TOTAL
MAX. NUMBER	0.7666E-05	0.1667E+02	0.1781E+05	0.2563E+01	0.1388E+03	0.1797E+05
MEAN NUMBER	0.5786E-05	0.1446E+02	0.1544E+05	0.2221E+01	0.1204E+03	0.1557E+05
SUM P < POPMIN	0.1000E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
FRACTILE 99.9	-0.1000E+01	0.1667E+02	0.1781E+05	0.2563E+01	0.1388E+03	0.1797E+05
FRACTILE 99.0	-0.1000E+01	0.1667E+02	0.1781E+05	0.2563E+01	0.1388E+03	0.1797E+05
FRACTILE 95.0	-0.1000E+01	0.1667E+02	0.1781E+05	0.2563E+01	0.1388E+03	0.1797E+05
FRACTILE 90.0	-0.1000E+01	0.1667E+02	0.1781E+05	0.2563E+01	0.1388E+03	0.1797E+05
FRACTILE 50.0	-0.1000E+01	0.1349E+02	0.1445E+05	0.2089E+01	0.1122E+03	0.1445E+05

***** MORTALITY *****						
HEALTH EFFECT:	PULMONARY SYNDR.	HEMATOPOIETIC S.	GASTROINTEST.S.	PRE-/NEONAT.D.	SKIN BURNS	TOTAL
MAX. NUMBER	0.3949E+01	0.3986E+03	0.5863E+01	0.2645E+01	0.2509E+02	0.4058E+03
MEAN NUMBER	0.2640E+01	0.3449E+03	0.3953E+01	0.2285E+01	0.2171E+02	0.3511E+03
SUM P < POPMIN	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
FRACTILE 99.9	0.3949E+01	0.3986E+03	0.5863E+01	0.2645E+01	0.2509E+02	0.4058E+03
FRACTILE 99.0	0.3949E+01	0.3986E+03	0.5863E+01	0.2645E+01	0.2509E+02	0.4058E+03
FRACTILE 95.0	0.3949E+01	0.3986E+03	0.5863E+01	0.2645E+01	0.2509E+02	0.4058E+03
FRACTILE 90.0	0.3949E+01	0.3986E+03	0.5863E+01	0.2645E+01	0.2509E+02	0.4058E+03
FRACTILE 50.0	0.1995E+01	0.3236E+03	0.3020E+01	0.2138E+01	0.2042E+02	0.3311E+03

8.2 Subsystems NL and FL

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LL          AAAAAAAAAA  TTTTTTTTTTTT  RRRRRRRRRR  SSSSSSSSS  KK          KK
LL          AAAAAAAAAA  TTTTTTTTTTTT  RRRRRRRRRR  SSSSSSSSSS  KK          KK
LL          AA          AA          TT          RR          RR  SSS          SSS  KK          KK
LL          AA          AA          TT          RR          RR  SSS          SS   KK          KKK
LL          AA          AA          TT          RR          RR  SSS          SSS  KK          KKK
LL          AAAAAAAAAA  TT          RRRRRRRRRR  SSS          KKKKK
LL          AAAAAAAAAA  TT          RRRRRRRRRR  SSS          KKKKK
LL          AA          AA          TT          RR          RR  SSS          SSS  KK          KKK
LL          AA          AA          TT          RR          RR  SS          SSS  KK          KKK
LL          AA          AA          TT          RR          RR  SSS          SSS  KK          KK
LLLLLLLLLLLL  AA          AA          TT          RR          RR  SSSSSSSSSS  KK          KK
LLLLLLLLLLLL  AA          AA          TT          RR          RR  SSSSSSSSS  KK          KK

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LATRSK READS THE RESULTS OBTAINED IN CONCEN
AND CALCULATES THE INDIVIDUAL RISKS OF STOCHASTIC HEALTH EFFECTS TAKING INTO ACCOUNT
THE PATTERNS OF DOSE MITIGATING ACTIONS DETERMINED IN PROTEC

FOR THE LIVING GENERATIONS (LG) AND THE FOLLOWING GENERATIONS (FG)

THE FOLLOWING MEAN SHIELDING FACTORS ARE CONSIDERED:

FOR CLOUDSHINE (CL):	0.300	(= SFLATE(1))
FOR GROUNDSHINE (GR):	0.200	(= SFLATE(2))
FOR INHALATION (IH):	1.000	(= SFLATE(3))
FOR RESUSPENSION (IHR):	1.000	(= SFLATE(5))
FOR SKIN CONTAM. (SK):	1.000	(= SFLATE(6))

BREATHING RATE, INHALATION (ARATIH) : 0.2667E-03 M**3/S

BREATHING RATE, RESUSPENSION (ARATIR) : 0.2667E-03 M**3/S

FOR INGESTION LOCAL PRODUCTION AND CONSUMPTION METHOD IS ASSUMED (CIGCOL) : L-P&C

BIOLOGICAL HALFLIFE FOR SKIN CONTAMINATION (TBIO) : 30.00 DAYS

INTEGRATION TIME FOR SKIN DOSES (TSKIN) : 3.00 DAYS

PART OF THE SKIN CONTAMINATED (PSKIN) : 0.10

Table 21. LATRSK: Title page with information about input parameter values

***** ACTIVITY RISK COEFFICIENTS FOR THE ORGAN BM FOR T0=0

NUCLIDE NO.	NUCLIDE NAME	CL 1/(BQ*S/M**3)	GR/L 1/(BQ/M**2)	GR/F	IH 1/BQ	IHR/L 1/(BQ*M/S)	IHR/F
25	KR- 88	0.4790E-15	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
28	RB- 88	0.1549E-15	0.2838E-14	0.1365E-15	0.8003E-14	0.1230E-15	0.3039E-17
83	I -131	0.8462E-16	0.1825E-11	0.8778E-13	0.2737E-12	0.2338E-11	0.3579E-13
95	CS-134	0.3672E-15	0.2588E-09	0.3562E-10	0.3992E-10	0.2197E-08	0.9343E-11
98	CS-137	0.1269E-15	0.2499E-09	0.1417E-09	0.2828E-10	0.1652E-08	0.1254E-10

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***** ACTIVITY RISK COEFFICIENTS FOR THE ORGAN RE FOR T0=0

NUCLIDE NO.	NUCLIDE NAME	CL 1/(BQ*S/M**3)	GR/L 1/(BQ/M**2)	GR/F	IH 1/BQ	IHR/L 1/(BQ*M/S)	IHR/F
25	KR- 88	0.2870E-15	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
28	RB- 88	0.9189E-16	0.1624E-14	0.7342E-16	0.4801E-14	0.7382E-16	0.1645E-17
83	I -131	0.5146E-16	0.1045E-11	0.4722E-13	0.2019E-12	0.1725E-11	0.2309E-13
95	CS-134	0.2170E-15	0.1489E-09	0.1964E-10	0.2351E-10	0.1293E-08	0.5568E-11
98	CS-137	0.7732E-16	0.1343E-09	0.9253E-10	0.1558E-10	0.9098E-09	0.7567E-11

***** GENETICALLY SIGNIFICANT DOSE FOR T0=0

NUCLIDE NO.	NUCLIDE NAME	CL SV/(BQ*S/M**3)	GR/L SV/(BQ/M**2)	GR/F	IH SV/BQ	IHR/L SV/(BQ*M/S)	IHR/F
25	KR- 88	0.4892E-13	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
28	RB- 88	0.1569E-13	0.2790E-12	0.0000E+00	0.7614E-12	0.1171E-13	0.0000E+00
83	I -131	0.8266E-14	0.1795E-09	0.0000E+00	0.1317E-10	0.1128E-09	0.0000E+00
95	CS-134	0.3542E-13	0.2766E-07	0.8883E-10	0.5314E-08	0.2905E-06	0.6841E-12
98	CS-137	0.1253E-13	0.2672E-07	0.1128E-07	0.3704E-08	0.2145E-06	0.7753E-09

***** "ACTIVITY RISK COEFFICIENTS" (INCIDENCE, 1/(BQ/M**2)) FOR CONTAMINATION OF SKIN AND CLOTHES, INTEGRATED OVER 3.00 (=TSKIN) DAYS

NUCLIDE NO.	NUCLIDE NAME	SK	SK-P
28	RB- 88	0.6394E-12	0.6107E-11
83	I -131	0.1225E-09	0.0000E+00
95	CS-134	0.1040E-09	0.0000E+00
98	CS-137	0.1388E-09	0.0000E+00

Table 23. LATRSK: Printout of activity risk coefficients, resettlement times < 1 year

***** GR - ACTIVITY RISK COEFFICIENTS (1/(BQ/M**2)) FOR THE ORGAN BM FOR RESETTLEMENT TIMES < 1 A							
NUCL.NO.	NUCL.NAME	30 D/L	30 D/F	90 D/L	90 D/F	180 D/L	180 D/F
25	KR- 88	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
28	RB- 88	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
83	I -131	0.1370E-12	0.6588E-14	0.7720E-15	0.3713E-16	0.8674E-18	0.5421E-19
95	CS-134	0.2507E-09	0.3524E-10	0.2352E-09	0.3449E-10	0.2136E-09	0.3345E-10
98	CS-137	0.2471E-09	0.1416E-09	0.2416E-09	0.1413E-09	0.2333E-09	0.1409E-09
***** IHR - ACTIVITY RISK COEFFICIENTS (1/(BQ*M/S)) FOR THE ORGAN BM FOR RESETTLEMENT TIMES < 1 A							
NUCL.NO.	NUCL.NAME	30 D/L	30 D/F	90 D/L	90 D/F	180 D/L	180 D/F
25	KR- 88	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
28	RB- 88	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
83	I -131	0.1125E-12	0.1723E-14	0.2611E-15	0.3998E-17	0.0000E+00	0.0000E+00
95	CS-134	0.1372E-08	0.5862E-11	0.5361E-09	0.2336E-11	0.1322E-09	0.6315E-12
98	CS-137	0.1061E-08	0.9578E-11	0.4401E-09	0.6472E-11	0.1215E-09	0.4878E-11
.....							
***** GR - GENETICALLY SIGNIFICANT DOSE (SV/(BQ/M**2)) FOR RESETTLEMENT TIMES < 1 A							
NUCL.NO.	NUCL.NAME	30 D/L	30 D/F	90 D/L	90 D/F	180 D/L	180 D/F
25	KR- 88	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
28	RB- 88	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
83	I -131	0.1347E-10	0.0000E+00	0.7587E-13	0.0000E+00	0.2776E-16	0.0000E+00
95	CS-134	0.2687E-07	0.8883E-10	0.2534E-07	0.8883E-10	0.2321E-07	0.8883E-10
98	CS-137	0.2644E-07	0.1128E-07	0.2590E-07	0.1128E-07	0.2508E-07	0.1128E-07
***** IHR - GENETICALLY SIGNIFICANT DOSE (SV/(BQ*M/S)) FOR RESETTLEMENT TIMES < 1 A							
NUCL.NO.	NUCL.NAME	30 D/L	30 D/F	90 D/L	90 D/F	180 D/L	180 D/F
25	KR- 88	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
28	RB- 88	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
83	I -131	0.5430E-11	0.0000E+00	0.1260E-13	0.0000E+00	0.0000E+00	0.0000E+00
95	CS-134	0.1814E-06	0.6841E-12	0.7091E-07	0.6841E-12	0.1749E-07	0.6841E-12
98	CS-137	0.1377E-06	0.7753E-09	0.5698E-07	0.7753E-09	0.1557E-07	0.7753E-09

Table 24. LATRSK: Printout of activity risk coefficients, resettlement times ≥ 1 year and for skin contamination

***** ACTIVITY RISK COEFFICIENTS FOR THE ORGAN BM FOR RESETTLEMENT TIME NTY = 1 YEARS

NUCLIDE NO.	NUCLIDE NAME	CL 1/(BQ*S/M**3)	GR/L 1/(BQ/M**2)	GR/F	IH 1/BQ	IHR/L 1/(BQ*M/S)	IHR/F
25	KR- 88	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
28	RB- 88	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
83	I -131	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
95	CS-134	0.0000E+00	0.1743E-09	0.3156E-10	0.0000E+00	0.8652E-11	0.1103E-12
98	CS-137	0.0000E+00	0.2164E-09	0.1401E-09	0.0000E+00	0.1452E-10	0.4342E-11

***** ACTIVITY RISK COEFFICIENTS FOR THE ORGAN BS FOR RESETTLEMENT TIME NTY = 1 YEARS

NUCLIDE NO.	NUCLIDE NAME	CL 1/(BQ*S/M**3)	GR/L 1/(BQ/M**2)	GR/F	IH 1/BQ	IHR/L 1/(BQ*M/S)	IHR/F
25	KR- 88	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
28	RB- 88	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
83	I -131	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
95	CS-134	0.0000E+00	0.5013E-11	0.6687E-12	0.0000E+00	0.2190E-12	0.2081E-14
98	CS-137	0.0000E+00	0.6103E-11	0.3811E-11	0.0000E+00	0.3663E-12	0.1256E-12

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***** GENETICALLY SIGNIFICANT DOSE FOR RESETTLEMENT TIME NTY = 1 YEARS

NUCLIDE NO.	NUCLIDE NAME	CL SV/(BQ*S/M**3)	GR/L SV/(BQ/M**2)	GR/F	IH SV/BQ	IHR/L SV/(BQ*M/S)	IHR/F
25	KR- 88	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
28	RB- 88	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
83	I -131	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
95	CS-134	0.0000E+00	0.1935E-07	0.8883E-10	0.0000E+00	0.1151E-08	0.6841E-12
98	CS-137	0.0000E+00	0.2342E-07	0.1128E-07	0.0000E+00	0.1668E-08	0.7753E-09

***** "ACTIVITY RISK COEFFICIENTS" (INCIDENCE, 1/(BQ/M**2)) FOR CONTAMINATION OF SKIN AND CLOTHES, INTEGRATED OVER 1 DAY AND 3.00 (=TSKIN) DAYS

NUCLIDE NO.	NUCLIDE NAME	SK	SK-P	SK	SK-P
28	RB- 88	0.6394E-12	0.6088E-11	0.6394E-12	0.6107E-11
83	I -131	0.4538E-10	0.0000E+00	0.1225E-09	0.0000E+00
95	CS-134	0.3550E-10	0.0000E+00	0.1040E-09	0.0000E+00
98	CS-137	0.4736E-10	0.0000E+00	0.1388E-09	0.0000E+00

Table 26. POTRSK/LATRSK: Breakdown of mean individual risks by exposure pathways

CONTRIBUTIONS (IN %) OF EXPOSURE PATHWAYS AND NUCLIDES TO MEAN INDIVIDUAL HEALTH EFFECTS RISKS
(FOR THE GONADS: MEAN GENETICALLY SIGNIFICANT DOSE)

RADIUS R(1) : 0.250 KM

	CLOUD- SHINE	GROUND- SHINE	INHALATION	INGESTION	RESUS- PENSION	LG
BONE MARROW	0.799	61.020	36.277	0.082	1.822	
BONE SURFACE	0.885	63.051	34.278	0.065	1.721	
BREAST	1.060	74.499	23.229	0.021	1.190	
LUNG	0.710	53.001	43.724	0.042	2.523	
STOMACH	0.811	58.704	38.477	0.061	1.947	
COLON	0.773	56.339	40.795	0.065	2.028	
LIVER	0.819	59.177	38.050	0.054	1.900	
PANCREAS	0.823	57.591	39.546	0.064	1.976	
THYROID	0.010	0.759	92.343	0.001	6.887	
REMAINDER	0.830	60.507	36.752	0.057	1.855	
GONADS	0.730	54.463	42.663	0.040	2.105	

Table 27. POTRSK/LATRSK: Breakdown of mean individual risks by nuclides for each exposure pathway

EXPOSURE PATHWAY:			CLOUDSHINE									
NO.	NUCLIDE	BM	BS	BR	LU	ST	LI	LV	PA	TH	RE	GO
25	KR- 88	52.96	50.28	52.51	53.93	53.49	54.07	53.38	54.38	52.37	52.99	53.77
28	RB- 88	18.66	17.12	18.51	17.81	18.65	18.70	18.81	18.60	19.03	18.49	18.79
83	I -131	17.90	21.65	18.62	18.14	17.74	17.13	17.71	16.87	18.10	18.18	17.39
95	CS-134	10.48	10.95	10.36	10.12	10.12	10.10	10.10	10.16	10.51	10.34	10.05
EXPOSURE PATHWAY:			GROUNDSHINE									
NO.	NUCLIDE	BM	BS	BR	LU	ST	LI	LV	PA	TH	RE	GO
83	I -131	84.49	84.50	84.54	84.51	84.51	84.51	84.51	84.51	84.54	84.51	84.52
95	CS-134	13.15	13.15	13.15	13.15	13.15	13.15	13.15	13.15	13.15	13.15	13.16
98	CS-137	2.36	2.35	2.31	2.34	2.34	2.34	2.34	2.34	2.31	2.34	2.33
EXPOSURE PATHWAY:			INHALATION									
NO.	NUCLIDE	BM	BS	BR	LU	ST	LI	LV	PA	TH	RE	GO
83	I -131	3.60	3.52	7.59	33.15	5.06	1.63	2.44	2.54	99.81	4.54	1.34
95	CS-134	70.79	70.22	67.01	47.84	70.02	73.52	72.30	71.83	0.14	71.31	72.76
98	CS-137	25.61	26.26	25.40	19.01	24.92	24.85	25.26	25.63	0.05	24.15	25.91
EXPOSURE PATHWAY:			INGESTION									
NO.	NUCLIDE	BM	BS	BR	LU	ST	LI	LV	PA	TH	RE	GO
83	I -131	0.00	0.01	0.03	0.01	0.03	0.00	0.00	0.00	71.41	0.01	0.00
95	CS-134	12.15	14.30	28.77	17.30	17.39	17.68	19.60	17.05	8.25	17.78	29.03
98	CS-137	87.84	85.69	71.19	82.69	82.58	82.31	80.40	82.94	20.35	82.22	70.97
EXPOSURE PATHWAY:			RESUSPENSION									
NO.	NUCLIDE	BM	BS	BR	LU	ST	LI	LV	PA	TH	RE	GO
83	I -131	5.35	5.24	11.05	42.87	7.47	2.44	3.64	3.80	99.87	6.72	2.03
95	CS-134	69.43	68.90	64.43	40.84	68.18	72.84	71.34	70.83	0.09	69.62	72.20
98	CS-137	25.22	25.86	24.52	16.29	24.35	24.72	25.02	25.37	0.04	23.66	25.77

Table 28. POTRSK/LATRSK: Breakdown of mean individual risks by nuclides for skin contamination and breakdown by risks from ingestion by foodstuffs

CONTRIBUTIONS (IN %) OF NUCLIDES TO MEAN INDIVIDUAL HEALTH EFFECTS RISKS BY CONTAMINATION OF SKIN AND CLOTHES

RADIUS (KM)	NUCLIDE: RB- 88	I -131	CS-134	CS-137
1 0.250	0.03	98.06	1.13	0.77

CONTRIBUTIONS (IN %) OF FOODSTUFFS TO MEAN INDIVIDUAL RISK BY INGESTION - LG

RADIUS NO.	1	0.250 KM									
FOODSTUFF	BM	BS	BR	LU	ST	LI	LV	PA	TH	RE	GO
MILK	3.36	4.06	8.20	4.94	4.84	4.74	5.37	4.73	3.64	4.77	8.32
COWSMEAT	3.92	4.64	7.67	5.47	5.37	5.32	5.96	5.29	5.47	5.26	8.98
COWLIVER	0.36	0.44	0.82	0.53	0.52	0.51	0.58	0.51	0.68	0.51	0.92
PORK	54.97	54.65	48.31	53.48	53.40	53.37	53.21	53.52	13.72	53.43	47.60
SHPMEAT	1.45	1.75	3.57	2.12	2.09	2.06	2.32	2.04	1.39	2.07	3.59
SHPLIVER	0.22	0.26	0.51	0.32	0.31	0.31	0.35	0.31	0.20	0.31	0.55
GREENVEG	6.25	6.02	6.14	5.90	5.98	5.98	5.75	5.96	67.31	6.00	5.47
ROOTVEG	1.52	1.46	1.38	1.42	1.43	1.44	1.38	1.44	0.54	1.44	1.30
POTATOES	9.36	8.84	6.82	8.40	8.49	8.58	8.09	8.57	2.20	8.53	7.03
GRAINPRD	18.57	17.88	16.59	17.42	17.57	17.70	17.00	17.64	4.83	17.68	16.24

MEAN INDIVIDUAL HEALTH EFFECTS RISKS (LG) FOR EACH RADIUS

EFFECT NO. 1 (BM) INDIVIDUAL HEALTH EFFECTS RISKS - LG

I	R(I)	MORTALITY	INCIDENCE
1	250.0	0.9004E-02	0.9004E-02
2	400.0	0.4532E-02	0.4532E-02
3	625.0	0.2319E-02	0.2319E-02
4	875.0	0.1408E-02	0.1408E-02
5	1150.0	0.9487E-03	0.9487E-03
6	1550.0	0.6265E-03	0.6265E-03
7	2100.0	0.4088E-03	0.4088E-03
8	2700.0	0.2940E-03	0.2940E-03
9	3700.0	0.1975E-03	0.1975E-03
10	4900.0	0.1352E-03	0.1352E-03
11	6550.0	0.9832E-04	0.9832E-04
12	8750.0	0.6815E-04	0.6815E-04
13	11500.0	0.5396E-04	0.5396E-04
14	15500.0	0.4064E-04	0.4064E-04
15	21000.0	0.2703E-04	0.2703E-04
16	27000.0	0.2493E-04	0.2493E-04
17	37000.0	0.2256E-04	0.2256E-04
18	49000.0	0.1449E-04	0.1449E-04
19	65500.0	0.9659E-05	0.9659E-05
20	87500.0	0.2217E-04	0.2217E-04

.....

TOTAL INDIVIDUAL HEALTH EFFECTS RISKS - FG

I	R(I)	MORTALITY	INCIDENCE
1	250.0	0.3498E-02	0.1474E-01
2	400.0	0.2065E-02	0.8054E-02
3	625.0	0.1262E-02	0.4553E-02
4	875.0	0.8321E-03	0.2914E-02
5	1150.0	0.8350E-03	0.2488E-02
6	1550.0	0.6616E-03	0.1857E-02
7	2100.0	0.4090E-03	0.1184E-02
8	2700.0	0.5285E-03	0.1284E-02
9	3700.0	0.4616E-03	0.1061E-02
10	4900.0	0.4516E-03	0.9985E-03
11	6550.0	0.5130E-03	0.1060E-02
12	8750.0	0.4579E-03	0.9166E-03
13	11500.0	0.4281E-03	0.8509E-03
14	15500.0	0.3630E-03	0.7065E-03
15	21000.0	0.2574E-03	0.5054E-03
16	27000.0	0.2562E-03	0.4981E-03
17	37000.0	0.1666E-03	0.3297E-03
18	49000.0	0.1099E-03	0.2191E-03
19	65500.0	0.6333E-04	0.1294E-03
20	87500.0	0.5804E-04	0.1325E-03

Table 29. POTRSK/LATRSK: Distance-dependent mean individual risks

```

CCCCCCCCCCCC 0000000000 LL LL EEEEEEEEEEEE CCCCCCCCCCCC
CCCCCCCCCCCC 000000000000 LL LL EEEEEEEEEEEE CCCCCCCCCCCC
CC 00 00 LL LL EE CC
CC 00 00 LL LL EE CC
CC 00 00 LL LL EE CC
CC 00 00 LL LL EEEEEEEE CC
CC 00 00 LL LL EEEEEEEE CC
CC 00 00 LL LL EE CC
CC 00 00 LL LL EE CC
CC 00 00 LL LL EE CC
CCCCCCCCCCCC 000000000000 LLLLLLLLLLLLLL LLLLLLLLLLLLLL EEEEEEEEEEEE CCCCCCCCCCCC
CCCCCCCCCCCC 0000000000 LLLLLLLLLLLLLL LLLLLLLLLLLLLL EEEEEEEEEEEE CCCCCCCCCCCC

```

COLLEC READS THE RESULTS OBTAINED IN POTRSK AND LATRSK, RESPECTIVELY
AND DETERMINES THE NUMBER OF LATE HEALTH EFFECTS IN THE EXPOSED POPULATION

FOR THE LIVING GENERATIONS (LG), THE FOLLOWING GENERATIONS (FG) AND FOR THE SUM (L+F)
IF CIGCOL=APROD : ONLY FOR ALL GENERATIONS (L+F)

SUBROUTINE COLRSK

```

RRRRR EEEEE SSSS U U L TTTTTT SSSS
R R E S S U U L T S S
R R E S U U L T S
RRRRR EEEEE SSSS U U L T SSSS
R RR E S U U L T S
R RR E S S U U L T S S
R RR EEEEE SSSS UUUUUU LLLLLL T SSSS

```

O F M O D U L E C O L L E C

IRMAX = 18

Table 30. COLLEC-COLRSK: Title page with information about input parameter values

LATE HEALTH EFFECTS FOR EACH SITE AND THE WEATHER SEQUENCE L (MORTALITY) LG

L = 1	T-SITE-1	T-SITE-2	LG
BONE MARROW	49	62	
BONE SURFACE	1	1	
BREAST	56	70	
LUNG	58	72	
STOMACH	47	59	
COLON	18	23	
LIVER	26	33	
PANCREAS	26	33	
THYROID	321	404	
REMAINDER	25	32	
SKIN	1	2	
TOTAL	623	781	

Table 32. COLLEC-COLRSK: Printout of results integrated over the whole grid for each site

BREAKDOWN BY EXPOSURE PATHWAYS OF EACH STOCHASTIC SOMATIC HEALTH EFFECT - (MORTALITY) LG

	CL	GR	IH	IG	IHR	MEAN
BONE MARROW	0.446	70.096	5.785	21.129	2.544	0.54008E+02
BONE SURFACE	0.508	73.595	5.680	17.718	2.498	0.14013E+01
BREAST	0.714	85.995	4.479	6.871	1.941	0.60863E+02
LUNG	0.508	72.866	8.923	14.194	3.510	0.62991E+02
STOMACH	0.510	71.454	6.897	18.123	3.016	0.51677E+02
COLON	0.490	69.412	7.363	19.475	3.260	0.20481E+02
LIVER	0.528	72.772	6.994	16.619	3.087	0.28807E+02
PANCREAS	0.517	70.261	7.070	19.032	3.120	0.28952E+02
THYROID	0.028	3.649	74.045	0.652	21.627	0.34919E+03
REMAINDER	0.520	73.169	6.588	16.836	2.887	0.27720E+02

BREAKDOWN BY EXPOSURE PATHWAYS AND HEALTH EFFECTS OF THE TOTAL NUMBER OF HEALTH EFFECTS - (MORTALITY) LG

	CL	GR	IH	IG	IHR	SUM
BONE MARROW	0.035	5.518	0.455	1.663	0.200	7.872
BONE SURFACE	0.001	0.150	0.012	0.036	0.005	0.204
BREAST	0.063	7.629	0.397	0.610	0.172	8.871
LUNG	0.047	6.690	0.819	1.303	0.322	9.181
STOMACH	0.038	5.382	0.519	1.365	0.227	7.532
COLON	0.015	2.072	0.220	0.581	0.097	2.985
LIVER	0.022	3.056	0.294	0.698	0.130	4.199
PANCREAS	0.022	2.965	0.298	0.803	0.132	4.220
THYROID	0.014	1.857	37.686	0.332	11.007	50.896
REMAINDER	0.021	2.956	0.266	0.680	0.117	4.040
SUM	0.278	38.275	40.967	8.072	12.409	100.00

Table 34. COLLEC-COLRSK: Breakdown of number of health effects by exposure pathways

RESULTS OF THE EVALUATION PROGRAM FOR THE INDIVIDUAL RISKS
CALCULATED IN THE MODULES POTRSK AND LATRSK, RESPECTIVELY
SUBROUTINE EVARSK

*** IF CIGCOL=APROD HAS BEEN SPECIFIED, THE INDIVIDUAL RISKS DO NOT CONTAIN THE INGESTION PATHWAY ***

***** PRINTOUT OF THE INPUT *****

NRSMIN: -7
NDEKAR: 7
MAXI: 20
IORGNR: 0 0 0 1 0 0 0 0 0 0 0 0
IORGGI: 0

EVALUATION INTERVALS:

LOWER LIMIT FOR RISK: 0.10E-06
UPPER LIMIT FOR RISK: 0.10E+01

NO PRINTOUT OF CCFDS IS GIVEN: ICCFD = 0

LEGEND FOR THE PRINTOUT OF THE EVALUATION PROGRAM

VALUE = RISK	:	INDIVIDUAL HEALTH EFFECTS RISKS
MAX. VALUE :		MAXIMAL VALUE DETERMINED IN THE CALCULATIONS
MEAN VALUE :		MEAN VALUE, AVERAGED OVER WEATHER SEQUENCES AND AZIMUTHAL SECTORS
SUM P (JUSED) :		PROBABILITY FOR GRID ELEMENTS AFFECTED BY THE PLUME
SUM P < ...MIN :		PROBABILITY FOR VALUES < ...MIN AT GRID ELEMENTS AFFECTED BY THE PLUME
SU P RU= RO= :		PROBABILITY FOR VALUES IN THE INTERVAL FROM RU TO RO
FRACTILE 99.0 :		99.0%-FRACTILE VALUE

Table 36. POTRSK/LATRISK-EVARSK: Statistical quantities of individual risks

EVALUATION OF THE DISTRIBUTION OF INDIVIDUAL RISKS FOR LUNG		MORTALITY - LG					

RADIUS (KM)	0.250	0.400	0.625	0.875	1.150	1.550	
MAX. RISK	0.1700E+00	0.9421E-01	0.5260E-01	0.3393E-01	0.2393E-01	0.1649E-01	
MEAN RISK	0.1342E-01	0.6677E-02	0.3370E-02	0.2021E-02	0.1345E-02	0.8742E-03	
SUM P (JUSED)	0.2917E+00	0.2639E+00	0.2361E+00	0.2361E+00	0.2083E+00	0.2083E+00	
SUM P < RISKMIN	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
SU P RU=.1E-29 RO=.1E+01	0.2917E+00	0.2639E+00	0.2361E+00	0.2361E+00	0.2083E+00	0.2083E+00	
FRACTILE 99.9	0.1700E+00	0.9421E-01	0.5260E-01	0.3393E-01	0.2393E-01	0.1649E-01	
FRACTILE 99.0	0.1700E+00	0.9421E-01	0.5260E-01	0.3393E-01	0.2393E-01	0.1649E-01	
FRACTILE 95.0	0.1175E+00	0.5888E-01	0.2951E-01	0.1738E-01	0.1122E-01	0.6918E-02	
FRACTILE 90.0	0.3631E-01	0.1318E-01	0.4677E-02	0.2042E-02	0.1047E-02	0.6310E-03	
FRACTILE 50.0	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01	
RADIUS (KM)	2.100	2.700	3.700	4.900	6.550	8.750	
MAX. RISK	0.1140E-01	0.8458E-02	0.5851E-02	0.4224E-02	0.3096E-02	0.2292E-02	
MEAN RISK	0.5649E-03	0.4015E-03	0.2630E-03	0.1787E-03	0.1281E-03	0.8838E-04	
SUM P (JUSED)	0.1806E+00	0.1806E+00	0.1806E+00	0.1528E+00	0.1528E+00	0.1250E+00	
SUM P < RISKMIN	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
SU P RU=.1E-29 RO=.1E+01	0.1806E+00	0.1806E+00	0.1806E+00	0.1528E+00	0.1528E+00	0.1250E+00	
FRACTILE 99.9	0.1140E-01	0.8458E-02	0.5851E-02	0.4224E-02	0.3096E-02	0.2292E-02	
FRACTILE 99.0	0.1140E-01	0.8458E-02	0.5851E-02	0.4224E-02	0.3096E-02	0.2292E-02	
FRACTILE 95.0	0.4266E-02	0.2754E-02	0.1660E-02	0.1023E-02	0.6607E-03	0.3890E-03	
FRACTILE 90.0	0.2630E-03	0.2042E-03	0.1259E-03	0.9332E-04	0.1349E-03	0.4074E-04	
FRACTILE 50.0	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01	
.....							
RADIUS (KM)	65.500	87.500					
MAX. RISK	0.3032E-03	0.1205E-02					
MEAN RISK	0.1059E-04	0.2779E-04					
SUM P (JUSED)	0.9722E-01	0.6944E-01					
SUM P < RISKMIN	0.0000E+00	0.0000E+00					
SU P RU=.1E-29 RO=.1E+01	0.9722E-01	0.6944E-01					
FRACTILE 99.9	0.3032E-03	0.1205E-02					
FRACTILE 99.0	0.3032E-03	0.1205E-02					
FRACTILE 95.0	0.5370E-04	0.3236E-04					
FRACTILE 90.0	-0.1000E+01	-0.1000E+01					
FRACTILE 50.0	-0.1000E+01	-0.1000E+01					

Table 37. POTRSK/LATRSK-EVARSK: Statistical quantities of loss of life

EVALUATION OF THE DISTRIBUTION OF INDIVIDUAL LOSS OF LIFE (HOURS) FOR LUNG							LG
*****							*****
RADIUS (KM)	0.250	0.400	0.625	0.875	1.150	1.550	
MAX. LOSS	0.1859E+05	0.1030E+05	0.5751E+04	0.3709E+04	0.2617E+04	0.1802E+04	
MEAN LOSS	0.1467E+04	0.7300E+03	0.3685E+03	0.2209E+03	0.1471E+03	0.9558E+02	
FRACTILE 99.9	0.1859E+05	0.1030E+05	0.5751E+04	0.3709E+04	0.2617E+04	0.1802E+04	
FRACTILE 99.0	0.1859E+05	0.1030E+05	0.5751E+04	0.3709E+04	0.2617E+04	0.1802E+04	
FRACTILE 95.0	0.1285E+05	0.6438E+04	0.3227E+04	0.1900E+04	0.1227E+04	0.7564E+03	
FRACTILE 90.0	0.3970E+04	0.1441E+04	0.5114E+03	0.2232E+03	0.1145E+03	0.6898E+02	
FRACTILE 50.0	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01	
RADIUS (KM)	2.100	2.700	3.700	4.900	6.550	8.750	
MAX. LOSS	0.1247E+04	0.9247E+03	0.6397E+03	0.4618E+03	0.3385E+03	0.2506E+03	
MEAN LOSS	0.6176E+02	0.4389E+02	0.2876E+02	0.1954E+02	0.1400E+02	0.9663E+01	
FRACTILE 99.9	0.1247E+04	0.9247E+03	0.6397E+03	0.4618E+03	0.3385E+03	0.2506E+03	
FRACTILE 99.0	0.1247E+04	0.9247E+03	0.6397E+03	0.4618E+03	0.3385E+03	0.2506E+03	
FRACTILE 95.0	0.4664E+03	0.3011E+03	0.1814E+03	0.1119E+03	0.7224E+02	0.4254E+02	
FRACTILE 90.0	0.2876E+02	0.2232E+02	0.1376E+02	0.1020E+02	0.1475E+02	0.4454E+01	
FRACTILE 50.0	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01	-0.1000E+01	
.....							
RADIUS (KM)	65.500	87.500					
MAX. LOSS	0.3315E+02	0.1318E+03					
MEAN LOSS	0.1158E+01	0.3038E+01					
FRACTILE 99.9	0.3315E+02	0.1318E+03					
FRACTILE 99.0	0.3315E+02	0.1318E+03					
FRACTILE 95.0	0.5872E+01	0.3538E+01					
FRACTILE 90.0	-0.1000E+01	-0.1000E+01					
FRACTILE 50.0	-0.1000E+01	-0.1000E+01					

RESULTS OF THE EVALUATION PROGRAM FOR THE NUMBER OF
LATE HEALTH EFFECTS IN THE POPULATION
CALCULATED IN THE MODULE COLLEC-COLRSK
SUBROUTINE EVACOL

***** PRINTOUT OF THE INPUT *****

NCRMIN: 0
NDEKCR: 6

EVALUATION INTERVALS:

LOWER LIMIT FOR NUMBER OF HEALTH EFFECTS: 0.1000E+01
UPPER LIMIT FOR NUMBER OF HEALTH EFFECTS: 0.1000E+07

INTEGRATION ENDS WITH RADIUS : 18

NO PRINTOUT OF CCFDS IS GIVEN: ICCFD = 0

LEGEND FOR THE PRINTOUT OF THE EVALUATION PROGRAM

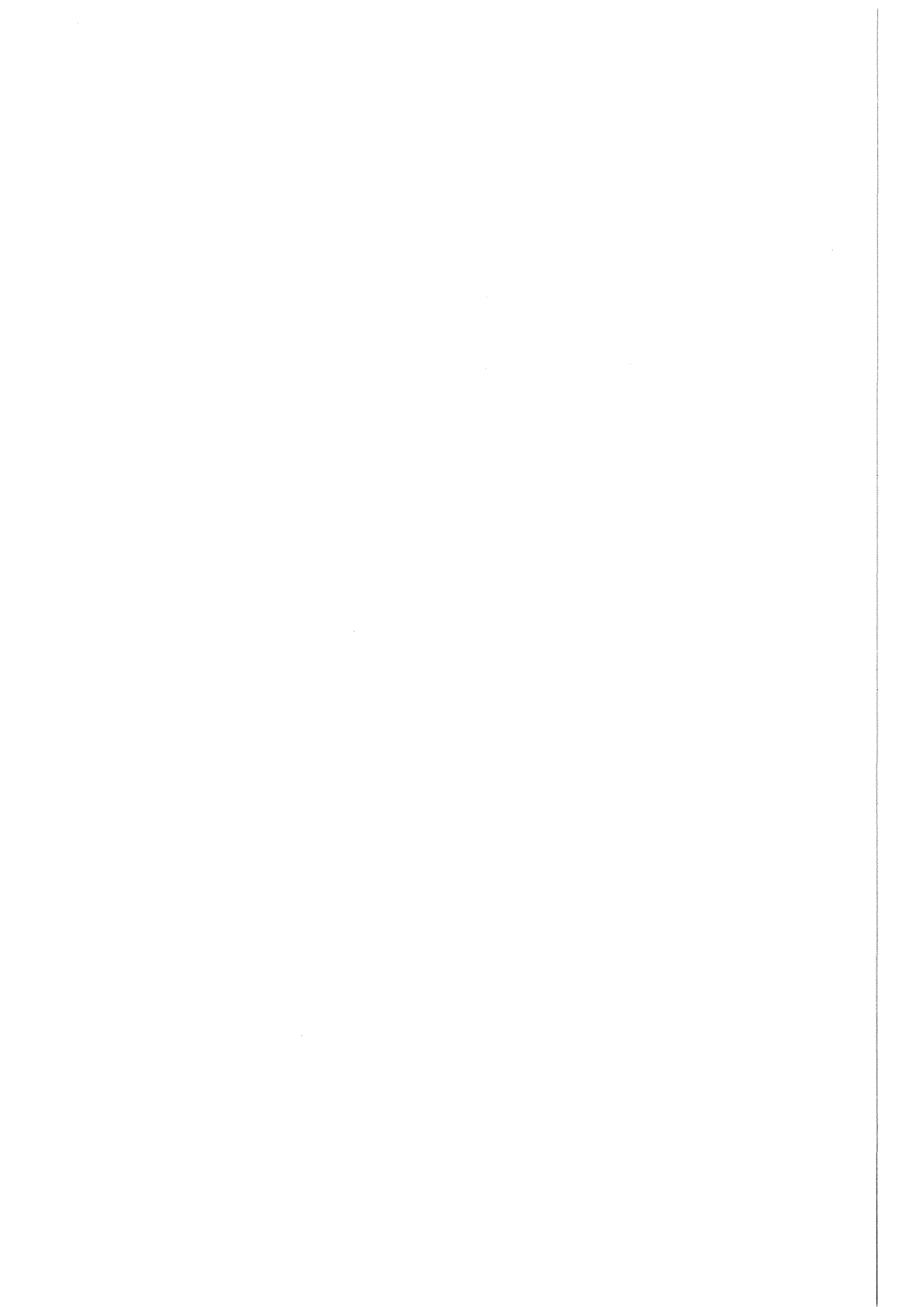
VALUE = NUMBER : NUMBER OF HEALTH EFFECTS
MAX. VALUE : MAXIMAL VALUE DETERMINED IN THE CALCULATIONS
MEAN VALUE : MEAN VALUE, AVERAGED OVER WEATHER SEQUENCES
SUM P < ...MIN : PROBABILITY FOR VALUES < ...MIN (VALUE = SUM OVER THE GRID ELEMENTS)
FRACTILE 99.0 : 99.0%-FRACTILE VALUE

Table 39. COLLEC-COLRSK-EVACOL: Statistical quantities of number of health effects and loss of life expectancy (for mortality and LG)

***** MORTALITY - LG *****						
HEALTH EFFECT:	BONE MARROW	BONE SURFACE	BREAST	LUNG	STOMACH	COLON
MAX. NUMBER	0.6240E+02	0.1619E+01	0.7033E+02	0.7280E+02	0.5971E+02	0.2367E+02
MEAN NUMBER	0.5401E+02	0.1401E+01	0.6086E+02	0.6299E+02	0.5168E+02	0.2048E+02
SUM P < POPMIN	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
FRACTILE 99.9	0.6240E+02	0.1619E+01	0.7033E+02	0.7280E+02	0.5971E+02	0.2367E+02
FRACTILE 99.0	0.6240E+02	0.1619E+01	0.7033E+02	0.7280E+02	0.5971E+02	0.2367E+02
FRACTILE 95.0	0.6240E+02	0.1619E+01	0.7033E+02	0.7280E+02	0.5971E+02	0.2367E+02
FRACTILE 90.0	0.6240E+02	0.1619E+01	0.7033E+02	0.7280E+02	0.5971E+02	0.2367E+02
FRACTILE 50.0	0.5012E+02	0.1318E+01	0.5623E+02	0.5888E+02	0.4786E+02	0.1905E+02
HEALTH EFFECT:	LIVER	PANCREAS	THYROID	REMAINDER	SKIN	TOTAL NUMBER
MAX. NUMBER	0.3329E+02	0.3345E+02	0.4042E+03	0.3203E+02	0.2214E+01	0.7817E+03
MEAN NUMBER	0.2881E+02	0.2895E+02	0.3492E+03	0.2772E+02	0.1906E+01	0.6764E+03
SUM P < POPMIN	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
FRACTILE 99.9	0.3329E+02	0.3345E+02	0.4042E+03	0.3203E+02	0.2214E+01	0.7817E+03
FRACTILE 99.0	0.3329E+02	0.3345E+02	0.4042E+03	0.3203E+02	0.2214E+01	0.7817E+03
FRACTILE 95.0	0.3329E+02	0.3345E+02	0.4042E+03	0.3203E+02	0.2214E+01	0.7817E+03
FRACTILE 90.0	0.3329E+02	0.3345E+02	0.4042E+03	0.3203E+02	0.2214E+01	0.7817E+03
FRACTILE 50.0	0.2692E+02	0.2692E+02	0.3236E+03	0.2570E+02	0.1778E+01	0.6310E+03
***** MORTALITY - LG *****						
COLLECTIVE LOSS OF LIFE EXPECTANCY (IN YEARS)						
HEALTH EFFECT:	BONE MARROW	BONE SURFACE	BREAST	LUNG	STOMACH	COLON
MAX. LOSS	0.1940E+04	0.5370E+02	0.1373E+04	0.9086E+03	0.6544E+03	0.2765E+03
MEAN LOSS	0.1679E+04	0.4648E+02	0.1188E+04	0.7862E+03	0.5663E+03	0.2393E+03
FRACTILE 99.9	0.1940E+04	0.5370E+02	0.1373E+04	0.9086E+03	0.6544E+03	0.2765E+03
FRACTILE 99.0	0.1940E+04	0.5370E+02	0.1373E+04	0.9086E+03	0.6544E+03	0.2765E+03
FRACTILE 95.0	0.1940E+04	0.5370E+02	0.1373E+04	0.9086E+03	0.6544E+03	0.2765E+03
FRACTILE 90.0	0.1940E+04	0.5370E+02	0.1373E+04	0.9086E+03	0.6544E+03	0.2765E+03
FRACTILE 50.0	0.1558E+04	0.4372E+02	0.1098E+04	0.7349E+03	0.5245E+03	0.2226E+03
YEARS/INDIVIDUAL	0.3109E+02	0.3317E+02	0.1952E+02	0.1248E+02	0.1096E+02	0.1168E+02
HEALTH EFFECT:	LIVER	PANCREAS	THYROID	REMAINDER	SKIN	TOTAL NUMBER
MAX. LOSS	0.4441E+03	0.3770E+03	0.7817E+04	0.4388E+03	0.0000E+00	0.1407E+05
MEAN LOSS	0.3843E+03	0.3263E+03	0.6753E+04	0.3797E+03	0.0000E+00	0.1217E+05
FRACTILE 99.9	0.4441E+03	0.3770E+03	0.7817E+04	0.4388E+03	0.0000E+00	0.1407E+05
FRACTILE 99.0	0.4441E+03	0.3770E+03	0.7817E+04	0.4388E+03	0.0000E+00	0.1407E+05
FRACTILE 95.0	0.4441E+03	0.3770E+03	0.7817E+04	0.4388E+03	0.0000E+00	0.1407E+05
FRACTILE 90.0	0.4441E+03	0.3770E+03	0.7817E+04	0.4388E+03	0.0000E+00	0.1407E+05
FRACTILE 50.0	0.3591E+03	0.3033E+03	0.6258E+04	0.3521E+03	0.0000E+00	0.1136E+05
YEARS/INDIVIDUAL	0.1334E+02	0.1127E+02	0.1934E+02	0.1370E+02	0.0000E+00	0.1800E+02

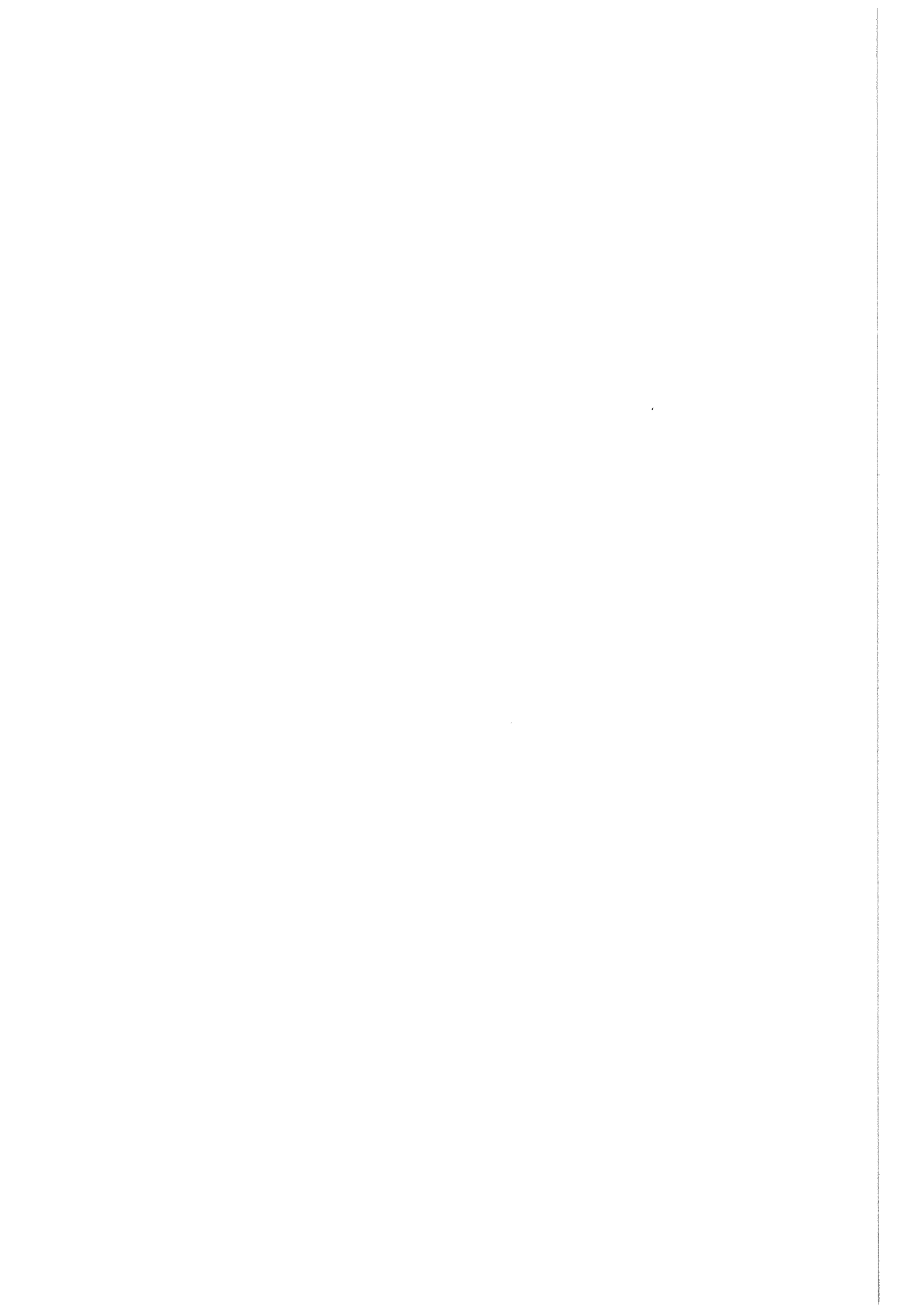
Table 40. COLLEC-COLRSK-EVACOL: Statistical quantities of number of health effects and time dependency (for mortality and L+FG)

***** MORTALITY - L+FG *****										
HEALTH EFFECT:	BONE MARROW	BONE SURFACE	BREAST	LUNG	STOMACH	COLON				
MAX. NUMBER	0.1181E+03	0.3171E+01	0.1637E+03	0.1492E+03	0.1294E+03	0.5086E+02				
MEAN NUMBER	0.1023E+03	0.2747E+01	0.1418E+03	0.1292E+03	0.1121E+03	0.4404E+02				
SUM P < POPMIN	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00				
FRACTILE 99.9	0.1181E+03	0.3171E+01	0.1637E+03	0.1492E+03	0.1294E+03	0.5086E+02				
FRACTILE 99.0	0.1181E+03	0.3171E+01	0.1637E+03	0.1492E+03	0.1294E+03	0.5086E+02				
FRACTILE 95.0	0.1181E+03	0.3171E+01	0.1637E+03	0.1492E+03	0.1294E+03	0.5086E+02				
FRACTILE 90.0	0.1181E+03	0.3171E+01	0.1637E+03	0.1492E+03	0.1294E+03	0.5086E+02				
FRACTILE 50.0	0.9550E+02	0.2570E+01	0.1318E+03	0.1202E+03	0.1047E+03	0.4074E+02				
HEALTH EFFECT:	LIVER	PANCREAS	THYROID	REMAINDER	SKIN	TOTAL NUMBER				
MAX. NUMBER	0.7287E+02	0.7207E+02	0.4295E+03	0.6734E+02	0.2214E+01	0.1244E+04				
MEAN NUMBER	0.6311E+02	0.6242E+02	0.3711E+03	0.5832E+02	0.1906E+01	0.1077E+04				
SUM P < POPMIN	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00				
FRACTILE 99.9	0.7287E+02	0.7207E+02	0.4295E+03	0.6734E+02	0.2214E+01	0.1244E+04				
FRACTILE 99.0	0.7287E+02	0.7207E+02	0.4295E+03	0.6734E+02	0.2214E+01	0.1244E+04				
FRACTILE 95.0	0.7287E+02	0.7207E+02	0.4295E+03	0.6734E+02	0.2214E+01	0.1244E+04				
FRACTILE 90.0	0.7287E+02	0.7207E+02	0.4295E+03	0.6734E+02	0.2214E+01	0.1244E+04				
FRACTILE 50.0	0.5888E+02	0.5888E+02	0.3467E+03	0.5495E+02	0.1778E+01	0.1000E+04				
***** MORTALITY - L+FG *****										
MEAN NUMBER OF HEALTH EFFECTS IN DIFFERENT TIME PERIODS AFTER THE ACCIDENT										
	0 - 5	5 - 10	10 - 20	20 - 30	30 - 40	40 - 50	50 - 70	70 - 90	90 - 150	150 - 200 YEARS
BONE MARROW	0.341E+01	0.142E+02	0.250E+02	0.179E+02	0.124E+02	0.841E+01	0.996E+01	0.576E+01	0.498E+01	0.327E+00
BONE SURFACE	0.000E+00	0.248E+00	0.580E+00	0.643E+00	0.430E+00	0.281E+00	0.303E+00	0.138E+00	0.116E+00	0.851E-02
BREAST	0.000E+00	0.397E+00	0.207E+01	0.482E+01	0.104E+02	0.174E+02	0.443E+02	0.330E+02	0.269E+02	0.248E+01
LUNG	0.000E+00	0.172E+01	0.518E+01	0.779E+01	0.117E+02	0.166E+02	0.413E+02	0.256E+02	0.175E+02	0.168E+01
STOMACH	0.000E+00	0.117E+01	0.379E+01	0.566E+01	0.833E+01	0.118E+02	0.318E+02	0.265E+02	0.208E+02	0.224E+01
COLON	0.000E+00	0.573E+00	0.181E+01	0.247E+01	0.366E+01	0.496E+01	0.129E+02	0.973E+01	0.721E+01	0.749E+00
LIVER	0.000E+00	0.536E+00	0.203E+01	0.362E+01	0.575E+01	0.808E+01	0.192E+02	0.128E+02	0.101E+02	0.978E+00
PANCREAS	0.000E+00	0.712E+00	0.228E+01	0.327E+01	0.484E+01	0.680E+01	0.179E+02	0.141E+02	0.113E+02	0.117E+01
THYROID	0.000E+00	0.223E+01	0.119E+02	0.226E+02	0.355E+02	0.539E+02	0.147E+03	0.846E+02	0.122E+02	0.122E+01
REMAINDER	0.000E+00	0.863E+00	0.281E+01	0.383E+01	0.523E+01	0.677E+01	0.165E+02	0.118E+02	0.966E+01	0.921E+00
TOTAL NUMBER	0.345E+01	0.241E+02	0.595E+02	0.726E+02	0.962E+02	0.130E+03	0.323E+03	0.218E+03	0.137E+03	0.134E+02



9. Acknowledgement

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Appendix A. Activity risk coefficients - analytical formulation

A.1 Introduction

After the short term exposure of an individual to ionizing radiation, there is a certain probability that this individual will experience a stochastic somatic health effect. The probability to die from such an effect at a certain time after exposure is commonly calculated using dose-risk coefficients, which are derived from epidemiological studies and which depend on the age at exposure, the gender of the individual and the time after exposure.

After an accidental release of radionuclides from a nuclear facility, the risk for an individual representative of the whole population is made up by many different contributions of individual risks, because the general population consists of persons of both sexes and various ages, and also because countermeasures do not affect the whole exposed population but only parts of it. Moreover, for some exposure pathways the radiation exposure is not limited to a relatively short time interval but may persist for longer time periods, as for instance for internal exposure following inhalation or ingestion of radioactive material, or for external exposure from activity deposited on the ground.

By these reasons, the calculation of the number of fatal stochastic somatic effects at a given time after the accident will require an integration over the age and life expectancy distribution of the population, the time patterns of exposure, and the time patterns of the manifestation of the health effect. Hereby it must be taken into account that people may die from other causes before the radiation-induced effect is expressed. The numerical solution of the resulting set of integral equations is in general time-consuming even on fast main-frame computers and cannot be carried out multiple times in a probabilistic accident consequence assessment, where a large number of weather sequences is considered.

For COSYMA, a mathematical concept has been developed for this problem, which allows the calculation of the number of stochastic health effects using pre-calculated coefficients termed "activity risk coefficients (ARCs)". These coefficients are solutions of integral equations and quantify the risk for the expression of a fatal stochastic somatic effect as a function of time for an individual, which is representative for the general population; they depend on the exposure pathway and are normalized to initial unit air or ground concentrations, respectively. During an accident consequence assessment, the number of fatalities is simply calculated by multiplication of the ARCs with the initial concentration and the number of individuals affected. Since time is a free parameter in the ARC concept, the time-dependence of the occurrence of the effects in the affected population can be studied.

An exposed population consists of individuals alive at the time of the accident ("Living Generation (LG)"), and of individuals born after the accident ("Future Generations (FG)"). As time goes on, the LG-fraction decreases to zero due to the life expectancy of the individuals, and the FG-fraction increases to unity. This difference lead to the development of

a separate formalism for the Living and the Future Generations; the corresponding activity risk coefficients are called LARCs and FARCs, respectively.

The activity-risk coefficients formalism is applicable if the population under consideration is stationary, that is, the natural death rate is equal to the birth rate, and if the additional radiation-induced cancer deaths do not disturb the natural population distribution.

This appendix describes the theoretical background and the analytical formalism which is the basis of the activity risk coefficients concept. A numerical solution suitable for use on computers is given in Appendix B, and the corresponding computer programs and the required input data are described in Appendix C.

The algorithm described in the following for each exposure pathway separately is not used for contamination of skin and clothes. The activity risk coefficients used are derived from the dose conversion factors applying the risk coefficient for morbidity of $138.62 \cdot 10^{-4}$ per Sv and person for incidence of skin cancer. Thus, the data file for the skin pathway contains values referring to incidence, not to mortality as in the case of all other pathways. During run-time a factor describing the fraction of fatal skin cancer is used to calculate the individual risks for mortality.

A.2 Living Generations

A.2.1 Basic concept and quantities

There are in general five exposure pathways (EP), considered in the LARC calculations. These are cloudshine (CL), groundshine (GR), inhalation (IH), inhalation after resuspension (IHR) and ingestion (IG). The exposure pathways CL and IH are only relevant for those population groups staying under the radioactive plume. These two EPs are therefore not considered in the case of the future generations.

In order to simplify the reading of the document, firstly the quantities are defined which will be used in the model described below. A basic quantity is the natural life expectancy probability distribution in the population. If its probability density function for newborns is given by $p(l)$, where l is the life expectancy, i.e. expected duration of life of a newborn (in fact, this is the age at death), then

$$\int_0^{l_m} dl p(l) = 1 \quad (\text{A.1})$$

where l_m is the maximal value for l in the observed population. The mean life expectancy L_0 for the newborn is given by

$$L_0 = \int_0^{l_m} dl l p(l) \quad (\text{A.2})$$

The next assumption is that the total population P under consideration is constant with time, i.e. $P = \text{const}$. This means that the number of newborns in each year is equal to the number of deaths in the population P . If A is the number of newborns each year, then the mean life expectancy for the newborns can be expressed as

$$L_0 = \frac{P}{A} \quad (\text{A.3})$$

The next important quantity is the number of individuals at the age a , or the "age structure" of the population considered. It can be derived from the following consideration. In time interval da there are $A da$ newborn, and from that part a number of

$$A da \int_a^{l_m} dl p(l) \quad (\text{A.4})$$

individuals survives the age a . The corresponding fraction of the total population is according to Eq.[A.3]

$$\begin{aligned} q(a) da &= \frac{A da \int_a^{l_m} dl p(l)}{A L_0} \\ &= \frac{1}{L_0} \int_a^{l_m} dl p(l) da \end{aligned} \quad (\text{A.5})$$

The meaning of this density distribution $q(a)$ is the following: in the age interval $(a, a+da)$ the fraction of $q(a) da$ of the total population is alive. It is of course satisfied

$$\int_0^{l_m} da q(a) = \frac{1}{L_0} \int_0^{l_m} da \int_a^{l_m} dl p(l) = 1 \quad (\text{A.6})$$

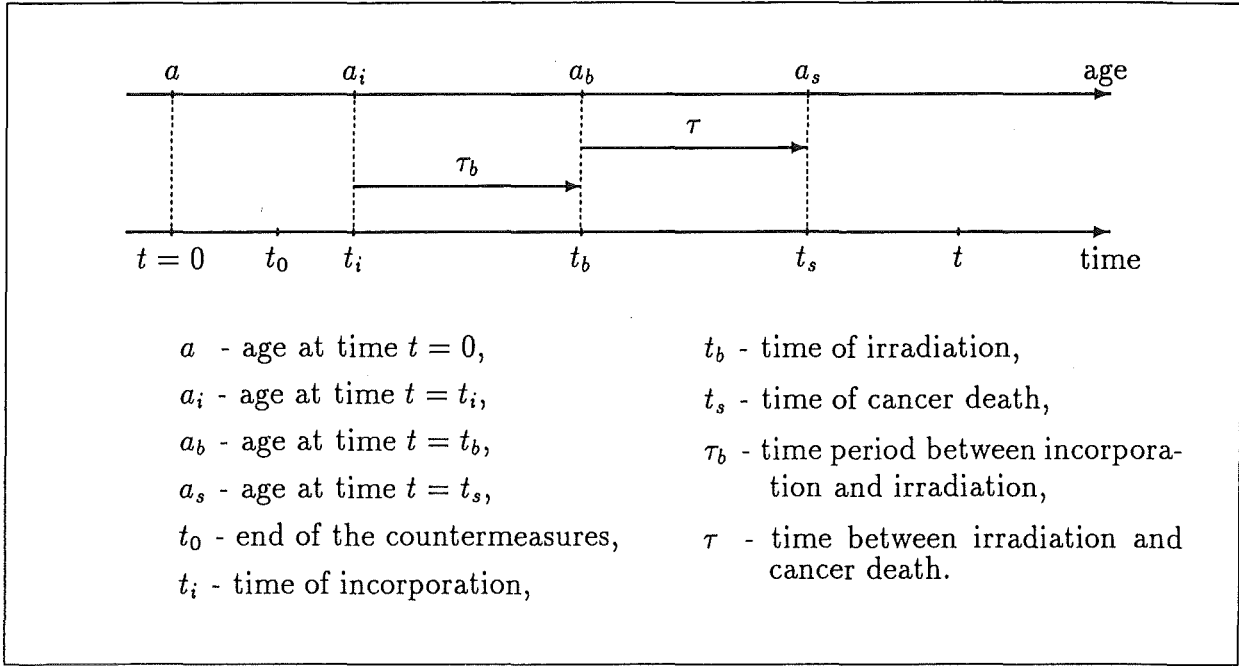


Figure A.1: Time and age parameters used in *LARC* calculations.

After having described the basic quantities defining the population distribution with respect to age and life expectancy, the situation in the case of an accident will be considered. Time and age parameters are defined in Fig.A.1. At time t_i an individual may incorporate radioactive material, what leads to an irradiation during the time period τ_b . According to the exposure up to time t_b , there exists a certain risk for the manifestation of a health effect during the time period τ ; at time t_s the cancer death may be experienced by the individual with a certain probability s (see below). If no incorporation takes place (e.g. in the case of exposure pathway GR), the time period $\tau_b = 0$ and $t_i = t_b$. The duration of countermeasures implemented before, during or short after the accident is denoted with t_0 (e.g. relocation or food bans).

According to Fig.A.1, an individual from the LG is at age a at time $t = 0$. At the moment of incorporation t_i that individual has the age a_i , at the moment of irradiation t_b the age is a_b , and, at the moment of cancer death, the age will be a_s . The ages are given on the "personal" scale above the actual time scale in Fig.A.1. The observation time is a variable, defined in the time interval $(0, l_m)$, because after l_m there will be no alive individuals from the initial cohort.

The part of the Living Generations $LG(t)$, which will survive up to the moment of observation time t is given by

$$LG(t) = \frac{P}{L_0} \int_t^{l_m} da \int_a^{l_m} dl p(l), \quad t \in (0, l_m) \quad (\text{A.7})$$

According to Eq.[A.7] it is satisfied

$$LG(0) = P, \quad LG(l_m) = 0 \quad (\text{A.8})$$

what is in accordance with the above mentioned definition of l_m , i.e. that no individual from the LG population will survive the time $t = l_m$. Eq.[A.7] can be interpreted as follows: at the time t the remaining part of the LG population is $LG(t)$. Of course, at the time t , all possible ages from the population LG are no longer possible, because all individuals older than $a = l_m - t$ at the time of the accident will die up to t due to natural causes. In other words, age a_t at the time t cannot be less than t . If a_t is less than t , the individual is born after the time $t = 0$, and does not belong to LG, but to FG.

There are two different processes which reduce the number of people belonging to the LG population: the natural causes of death and the deaths from stochastic health effects, induced by exposure to radioactive material in the environment. The first process drastically reduces the size of the population with time, and after $t = l_m$ nobody from the LG population will be alive. The second process is supposed to be small in comparison to the first one and does not observably influence the population, i.e. the number of late health effects is small compared to the number of deaths from natural causes. Under these assumptions only, equations Eq.[A.1] – Eq.[A.6] are valid in the model described below.

The basic quantity on which the activity risk method is based is the probability $s(t_s - t_b, a_b)$, that an individual will express a fatal cancer and die up to the moment t_s , if this individual was exposed at age a_b to a unit dose at time t_b . Denoting $\tau = t_s - t_b$ (see Fig.A.1) the quantity

$$\dot{s}(\tau, a + t_b) d\tau \quad (\text{A.9})$$

can be interpreted as the probability to express a fatal cancer in the time interval $(\tau, \tau + d\tau)$ for individuals irradiated at time t_b with a unit dose. According to Fig.A.1, $a_b = a + t_b$ is the age at exposure. Later in the text precalculated values DAM will be used representing the cumulative probabilities to express cancer due to exposure with a unit dose up to time T :

$$DAM(T, a_b) = \int_0^T d\tau \dot{s}(\tau, a_b) \quad (\text{A.10})$$

A.2.2 Exposure pathway Cloudshine (CL)

External doses from gamma irradiation may be received by individuals immersed within or near a radioactive plume. The exposed population consists of only those living at the moment of the passage of the plume. This EP is therefore considered in the case of the living generations only, what will be abbreviated as the “LG case”. If the radioactive cloud exposure time is compared to the time scale for the manifestation of cancer, which is years or tens of years, irradiation at time $t = 0$ can be assumed for this exposure pathway without losing accuracy. Consequently (see Fig.A.2)

$$t_i = t_b = 0 \quad (\text{A.11})$$

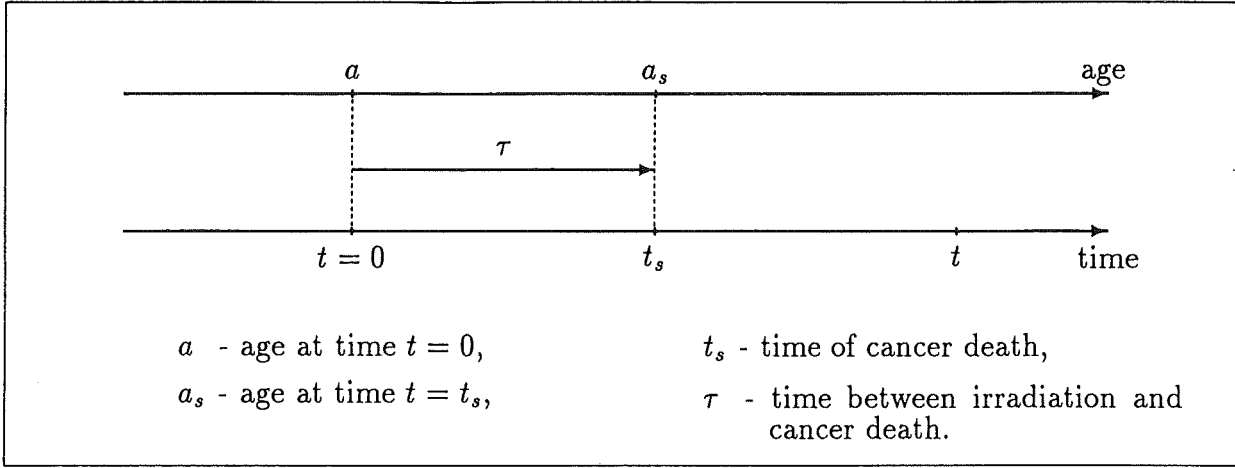


Figure A.2: Exposure pathway Cloudshine – time and age parameters

$$t_s = \tau \quad (\text{A.12})$$

$$a_s = a_b + \tau = a + \tau \quad (\text{A.13})$$

where a is the age at $t = 0$. After irradiation at $t = 0$, an irradiated individual will express cancer at time t_s with a probability $s(t_s - t_b, a_b) = s(\tau, a_b)$. At the moment of manifestation t_s of the effect, an irradiated individual will have reached age a_s . In the age interval $(a_s, a_s + da_s)$ there live

$$P q(a_s) da_s = \frac{P}{L_0} \int_{a_s}^{l_m} dl p(l) da_s \quad (\text{A.14})$$

individuals from the initial cohort. The probability $s(\tau, a_b)$ in this particular case becomes $s(\tau, a_s - \tau)$. Therefore, in time interval $(\tau, \tau + d\tau)$

$$P \dot{s}(\tau, a_s - \tau) q(a_s) da_s d\tau \quad (\text{A.15})$$

individuals from the initial cohort with age in the age interval $(a_s, a_s + da_s)$ will die due to exposure to a unit dose at $t = 0$. Taking into account all the possible ages a_s , where $a_s \in (\tau, l_m)$, the expression

$$\frac{P}{L_0} \int_{\tau}^{l_m} da_s \dot{s}(\tau, a_s - \tau) \int_{a_s}^{l_m} dl p(l) d\tau \quad (\text{A.16})$$

gives the number of individuals from the initial cohort which will die due to exposure to a unit dose in time interval $(\tau, \tau + d\tau)$. Taking into account all possible times of manifestation τ ,

$$\frac{P}{L_0} \int_0^t d\tau \int_{\tau}^{l_m} da_s \dot{s}(\tau, a_s - \tau) \int_{a_s}^{l_m} dl p(l) \quad (\text{A.17})$$

gives the number of individuals which will die up to time t due to irradiation with a unit dose. Multiplying the above expression with the dose conversion factor for cloudshine g_{cl} ,

$$\begin{aligned}
N_{cl}(t) &= \frac{P g_{cl}}{L_0} \int_0^t d\tau \int_{\tau}^{l_m} da_s \dot{s}(\tau, a_s - \tau) \int_{a_s}^{l_m} dl p(l) da_s \\
&= P \times LARC_{cl}(t) \quad (\text{A.18})
\end{aligned}$$

gives the time dependent number of health effects in the initial cohort due to exposure to the unit activity concentration from the radioactive cloud passing overhead. Multiplying $N_{cl}(t)$ defined by Eq.[A.18] with the time-integrated activity concentration of the passing cloud, the time dependent number of health effects in the observed population results. The quantity $LARC_{cl}(t)$ in Eq.[A.18] is called Activity Risk Coefficient for cloudshine. The manifold integral in the ARCO expression can be written in various forms, depending on the order of integration. Especially, taking the age at the accident as a variable instead of a_s , it can be written as

$$LARC_{cl}(t) = \frac{g_{cl}}{L_0} \int_0^t d\tau \int_0^{l_m} da \dot{s}(\tau, a) \int_{a+\tau}^{l_m} dl p(l) \quad (A.19)$$

Changing the order of integration from $\{\tau, a, l\}$ to $\{a, l, \tau\}$ and using the notation from Eq.[A.10], the following expression results which is used in the ARCO-program:

$$LARC_{cl}(t) = \frac{g_{cl}}{L_0} \int_0^{l_m} da \int_a^{l_m} dl p(l) DAM(\min(t, l - a), a) \quad (A.20)$$

More details about the advantage of this procedure together with the corresponding formulas for the other exposure pathways are given in Appendix B.

A.2.3 Exposure pathway Groundshine (GR)

This exposure pathway results from the external gamma irradiation from activity deposited on the ground. In contrast to CL, GR is in general a long term exposure pathway which causes continuous exposure. GR is considered in the LG as well as in the FG case. Due to irradiation up to t_b , an individual will express fatal cancer at time t_s with the probability $s(t_s - t_b, a_b)$ (see Fig.A.3). At the time t_s of the manifestation of the health effect, the individual is at the age a_s . In the age interval $(a_s, a_s + da_s)$ there live

$$P q(a_s) da_s = \frac{P}{L_0} \int_{a_s}^{l_m} dl p(l) da_s \quad (A.21)$$

individuals. In the time interval $(\tau, \tau + d\tau)$

$$\dot{s}(\tau, a_s - \tau) d\tau q(a_s) da_s \quad (A.22)$$

individuals will express cancer due to irradiation up to time t_b (being at that time at the age $a_b = a_s - \tau$). In the time interval $(t_b, t_b + dt_b)$ an individual will receive the dose

$$\dot{g}_{gr}(t_b, a_s - \tau) dt_b \quad (A.23)$$

Therefore, in the time interval $(\tau, \tau + d\tau)$ we have

$$\dot{g}_{gr}(t_b, a_s - \tau) dt_b \dot{s}(\tau, a_s - \tau) d\tau q(a_s) da_s \quad (A.24)$$

stochastic effects in the population group with ages in the age interval $(a_s, a_s + da_s)$ due to exposure to the initial unit activity concentration on the ground in the time interval

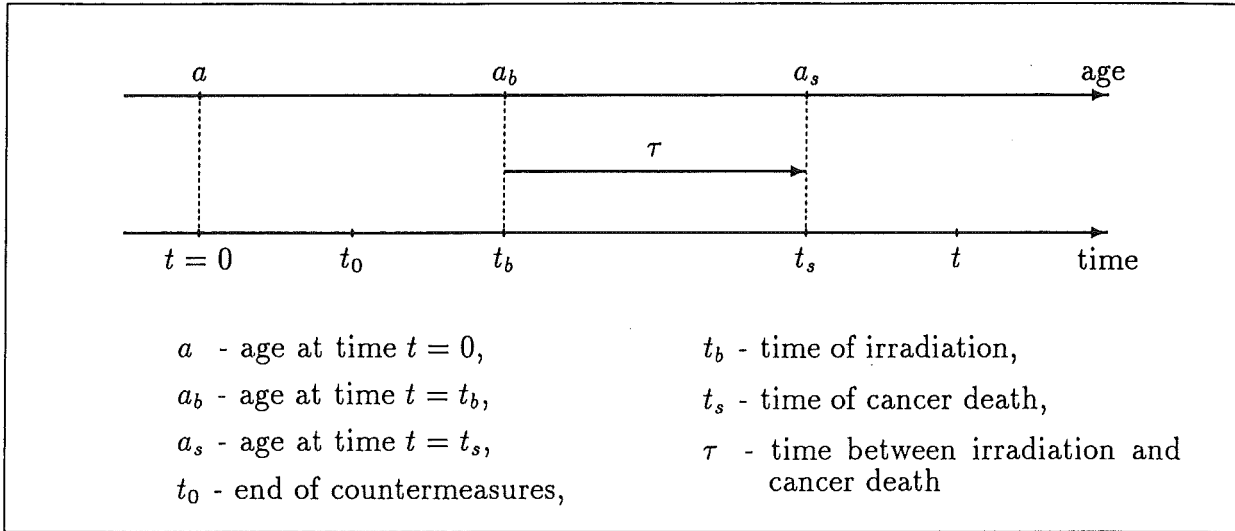


Figure A.3: Exposure pathway Groundshine - time and age parameters. Also valid for EP=IH.

$(t_b, t_b + dt_b)$. Eq.[A.24] gives the number of health effects for a differential age group of the population, having age around a_s . Taking into account all possible ages, i.e. summing up all effects with respect to the various a_s , the following expression is obtained:

$$\frac{P dt_b}{L_0} \int_{t_b+\tau}^{l_m} da_s \dot{g}_{gr}(t_b, a_s - \tau) \dot{s}(\tau, a_s - \tau) \int_{a_s}^{l_m} dl p(l) d\tau \quad (\text{A.25})$$

For fixed t_b and τ , the minimal value of a_s is $t_s = t_b + \tau$. If a_s is less than t_s , the observed individual was born after time $t = 0$, and does not belong to LG, but FG. Therefore, $(a_s \in (t_b + \tau, l_m))$. The above equation gives the number of deaths which will occur in the time interval $(\tau, \tau + d\tau)$ under the above conditions. The total number of effects with respect to τ , where $\tau \in (0, t - t_b)$ can be obtained summing up over all possible τ , resulting in

$$\frac{P dt_b}{L_0} \int_0^{t-t_b} d\tau \int_{t_b+\tau}^{l_m} da_s \dot{g}_{gr}(t_b, a_s - \tau) \dot{s}(\tau, a_s - \tau) \int_{a_s}^{l_m} dl p(l) \quad (\text{A.26})$$

as the number of individuals that will die up to the moment t , due to exposure to the unit activity concentration of deposits in the time interval $(t_b, t_b + dt_b)$. Assuming continuous irradiation, which starts with the end of countermeasures at t_0 and lasts up to the observation time t , summation with respect to the t_b gives the total number of cancer deaths that will occur in the LG population up to time t due to exposure to unit activity concentrations on ground surface.

$$\begin{aligned}
 N_{gr}(t, t_0) &= \frac{P}{L_0} \int_{t_0}^t dt_b \int_0^{t-t_b} d\tau \int_{t_b+\tau}^{l_m} da_s \dot{g}_{gr}(t_b, a_s - \tau) \dot{s}(\tau, a_s - \tau) \int_{a_s}^{l_m} dl p(l) \\
 &= P \times LARC_{gr}(t, t_0)
 \end{aligned} \quad (\text{A.27})$$

The actual number of the effects is obtained when multiplying the $N_{gr}(t, t_0)$ defined by Eq.[A.27] by the initial activity concentration on the ground $C_{gr}(0)$.

The quantity $LARC_{gr}(t, t_0)$ in Eq.[A.27] is called Activity Risk Coefficient for groundshine, for living generations. Let $\{l, a_s, \tau, t_b\}$ denote the order of integrations in Eq.[A.27], what simply means that the first integration is performed over l , then over a_s , etc. The other representations are easily obtained from the first one: the $\{l, a, \tau, t_b\}$ form is given by

$$LARC_{gr}(t, t_0) = \frac{1}{L_0} \int_{t_0}^t dt_b \int_0^{t-t_b} d\tau \int_0^{l_m-t_b-\tau} da \dot{g}_{gr}(t_b, a+t_b) \dot{s}(\tau, a+t_b) \\ \times \int_{a+t_b+\tau}^{l_m} dl p(l) \quad (\text{A.28})$$

where a is the age at the accident. Especially, it is important to note the $\{\tau, l, a, t_b\}$ form, which is used in the ARCO-program (see Appendix B):

$$LARC_{gr}(t, t_0) = \frac{1}{L_0} \int_{t_0}^t dt_b \int_0^{l_m-t_b} da \dot{g}_{gr}(t_b, a+t_b) \int_{a+t_b}^{l_m} dl p(l) \\ \times DAM(\min(t, l-a) - t_b, a+t_b) \quad (\text{A.29})$$

where DAM is defined by Eq.[A.10].

A.2.4 Exposure pathway Inhalation (IH)

This exposure pathway represents an internal exposure due to inhalation of the activity during the passage of the radioactive cloud. As the inhalation takes place only in the short time span of the passage of the plume, only the living generations are affected, similar to the EP cloudshine. The numerical transformations are very similar to the ones given for the EP groundshine. An individual who inhaled radioactive material during the passage of the plume at time $t = 0$ will be irradiated up to time t_b ; at time $t_s = t_b + \tau$ the individual with age a_s will experience cancer death with the already known probability $s(\tau, a_s - \tau)$. In the age interval $(a_s, a_s + da_s)$, there are

$$P q(a_s) da_s = \frac{P}{L_0} \int_{a_s}^{l_m} dl p(l) da_s \quad (\text{A.30})$$

individuals from the initial cohort. In the time interval $(\tau, \tau + d\tau)$

$$\dot{s}(\tau, a_s - \tau) d\tau q(a_s) da_s \quad (\text{A.31})$$

individuals will die due to internal irradiation at time t_b . The amount of dose received depends on the quantity of the inhaled radioactive material. It is therefore necessary to take into account the age dependent breathing rate at the moment of inhalation $b(a) = b(a_s - t_b - \tau)$. In the time interval $(t_b, t_b + dt_b)$ an individual will receive the dose

$$b(a_s - t_b - \tau) \dot{g}_{ih}(t_b, a_s - \tau) dt_b \quad (\text{A.32})$$

due to inhalation of one unit volume of activity per unit time, where $g_{ih}(t, a_s - \tau)$ is the age dependent dose conversion factor for inhalation. Therefore, the death rate in the

time interval $(\tau, \tau + d\tau)$ due to inhalation of the unit activity concentration from the passing cloud in time interval $(t_b, t_b + dt_b)$ for all individuals having age in the age interval $(a_s, a_s + da_s)$ is

$$b(a_s - t_b - \tau) \dot{g}_{ih}(t_b, a) dt_b \dot{s}(\tau, a_s - \tau) d\tau q(a_s) da_s \quad (\text{A.33})$$

Interesting are only those ages a_s , which satisfy $a_s \geq t_b + \tau$, because for fixed t_b and τ , a_s cannot be less than $t_b + \tau$, otherwise individuals from the Future Generations are considered. Summation over ages gives

$$\frac{P dt_b}{L_0} \int_{t_b+\tau}^{l_m} da_s b(a_s - t_b - \tau) \dot{g}_{ih}(t_b, a_s - \tau) \dot{s}(\tau, a_s - \tau) \int_{a_s}^{l_m} dl p(l) d\tau \quad (\text{A.34})$$

The above equation gives the number of effects which will, under the above conditions, occur in the time interval $(\tau, \tau + d\tau)$. The total number of effects with respect to τ , where $\tau \in (0, t - t_b)$, can be obtained summing up over all possible τ , what results in

$$\frac{P dt_b}{L_0} \int_0^{t-t_b} d\tau \int_{t_b+\tau}^{l_m} da_s b(a_s - t_b - \tau) \dot{g}_{ih}(t_b, a_s - \tau) \dot{s}(\tau, a_s - \tau) \int_{a_s}^{l_m} dl p(l) \quad (\text{A.35})$$

as the time dependent effect rate, due to inhalation of a unit activity concentration from the passing cloud in the time interval $(t_b, t_b + dt_b)$. After inhalation, the amount of the radioactive material inhaled causes a continuous irradiation of the exposed individual. Summation over all possible times of irradiation is therefore performed in the time interval $(0, t)$. The time dependent effect rate for the individuals from the initial cohort due to inhalation of the unit activity concentration from the passing cloud is

$$\begin{aligned} N_{ih}(t) &= \frac{P}{L_0} \int_0^t dt_b \int_0^{t-t_b} d\tau \int_{t_b+\tau}^{l_m} da_s b(a_s - t_b - \tau) \dot{g}_{ih}(t_b, a_s - \tau) \dot{s}(\tau, a_s - \tau) \\ &\quad \times \int_{a_s}^{l_m} dl p(l) \\ &= P \times LARC_{ih}(t) \end{aligned} \quad (\text{A.36})$$

The actual number of the effects is obtained by multiplication of the $N_{ih}(t)$ defined by Eq.[A.36], with the time integrated activity concentration contained in the passing cloud, for each particular radionuclide.

The quantity $LARC_{ih}(t)$ in Eq.[A.36] is called Activity Risk Coefficient for inhalation and defined by

$$\begin{aligned} LARC_{ih}(t) &= \frac{1}{L_0} \int_0^t dt_b \int_0^{t-t_b} d\tau \int_{t_b+\tau}^{l_m} da_s b(a) \dot{g}_{ih}(t_b, a_s - t_b - \tau) \dot{s}(\tau, a_s - \tau) \\ &\quad \times \int_{a_s}^{l_m} dl p(l) \end{aligned} \quad (\text{A.37})$$

It was already stated that LARC expressions can get various forms by changing the order of integrations. The $\{\tau, l, a, t_b\}$ form, implemented in the ARCO program (see Appendix

B), is

$$LARC_{ih}(t) = \frac{1}{L_0} \int_0^t dt_b \int_0^{l_m - t_b} da b(a) \dot{g}_{ih}(t_b, a) \int_{a+t_b}^{l_m} dl p(l) \\ \times DAM(\min(t, l - a) - t_b, a + t_b) \quad (A.38)$$

with DAM as defined by Eq.[A.10].

A.2.5 Exposure pathway Inhalation after resuspension (IHR)

This exposure pathway represents an internal irradiation by inhalation of activity which was resuspended in the air after being deposited. Experience shows that, for typical predicted releases of radioactivity from light-water reactors, the inhalation of resuspended radioactive material is relative unimportant. However, it may become important if significant fractions of actinides are released. In any case, this EP has a potential for long term exposure, and has to be considered in the case of Future Generations (FG), as well.

There are in general two main diluting processes regarding the activity deposited on the ground. The first one represents all the leaching processes (together with radioactive decay) into deeper layers of the soil. It is conventional to define the remaining part, available for resuspension by wind or human activities, using the function

$$f(t) = e^{-\lambda t} (0.63 e^{-\lambda_1 t} + 0.37 e^{-\lambda_2 t}) \quad (A.39)$$

where λ is the radioactive constant of the particular nuclide, with $\lambda_1 = 1.5 \cdot 10^{-8} s^{-1}$, and $\lambda_2 = 2.38 \cdot 10^{-10} s^{-1}$ as typical values.

Resuspension itself is modelled by means of such resuspension factor $r(t)$ which correlates the initial deposited concentration of a radionuclide with the concentration in the air near ground after time t :

$$r(t) = r_0 e^{-\lambda_r t} + r_e \quad (A.40)$$

where $r_0 = 10^{-5} m^{-1}$, $r_e = 10^{-9} m^{-1}$ and $\lambda_r = 1.62 \cdot 10^{-7} s^{-1}$ as typical values for humid climates.

Exposure via this EP is in fact the same as in the case of EP inhalation – the only difference is the origin of the inhaled activity. In the case of EP inhalation, it stems from the passing radioactive cloud; in this case it stems from the activity deposited on the ground. That means we consider the “radioactive cloud” made by wind or human activities at a certain time t_i with the activity concentration

$$C_{ihr}(t_i) = C_{gr}(0) f(t_i) r(t_i) \quad (A.41)$$

where $C_{ihr}(t)$ is the activity concentration in the air near ground, and $C_{gr}(0)$ is the activity concentration deposited on the ground at $t = 0$. As the same exposure mechanism as in

the previous case (IH) is considered, not all derivation steps are necessary to be repeated. The "radioactive plume" due to resuspension "passes" at time t_i . The factor $f(t_i) r(t_i)$ defined by Eq.[A.41] enables the transformation from the activity deposited into activity resuspended. Due to inhalation of the unit activity concentration resuspended in the air in time interval $(t_i, t_i + dt_i)$, up to the time t (see Fig.A.1)

$$\begin{aligned} & \frac{P}{L_0} f(t_i) r(t_i) \int_{t_i}^t dt_b \int_0^{t-t_b} d\tau \int_{t_b+\tau}^{l_m} da_s b(a_s - t_b + t_i - \tau) \\ & \times \dot{g}_{ih}(t_b - t_i, a_s - t_b + t_i - \tau) \dot{s}(\tau, a_s - \tau) \int_{a_s}^{l_m} dl p(l) dt_i \end{aligned} \quad (\text{A.42})$$

cancer deaths occur in the initial cohort (LG). The resuspension process is assumed to be continuous. It is therefore necessary to sum up over all possible times, where the possible inhalation time t_i may start at the end of the countermeasures defined by the time parameter t_0 . The summation with respect to t_i is therefore performed in the time interval $t_i \in (t_0, t)$. From Eq.[A.42]

$$\begin{aligned} N_{ihr}(t, t_0) &= \frac{P}{L_0} \int_{t_0}^t dt_i f(t_i) r(t_i) \int_{t_i}^t dt_b \int_0^{t-t_b} d\tau \int_{t_b+\tau}^{l_m} da_s b(a_s - t_b + t_i - \tau) \\ &\times \dot{g}_{ih}(t_b - t_i, a_s - t_b + t_i - \tau) \dot{s}(\tau, a_s - \tau) \int_{a_s}^{l_m} dl p(l) \\ &= P \times LARC_{ihr}(t, t_0) \end{aligned} \quad (\text{A.43})$$

gives the time dependent number of individuals from the initial cohort which will die due to inhalation of the resuspended unit activity concentration deposited on the ground.

The total number of health effects is calculated by multiplying $N_{ihr}(t, t_0)$ by the initial activity concentration deposited on the ground. The quantity $LARC_{ihr}(t, t_0)$ in Eq.[A.43] is called Activity Risk Coefficient for inhalation after resuspension for the living generations and defined by

$$\begin{aligned} LARC_{ihr}(t, t_0) &= \frac{1}{L_0} \int_{t_0}^t dt_i f(t_i) r(t_i) \int_{t_i}^t dt_b \int_0^{t-t_b} d\tau \int_{t_b+\tau}^{l_m} da_s b(a_s - t_b + t_i - \tau) \\ &\times \dot{g}_{ih}(t_b - t_i, a_s - t_b + t_i - \tau) \dot{s}(\tau, a_s - \tau) \int_{a_s}^{l_m} dl p(l) \end{aligned} \quad (\text{A.44})$$

The $\{\tau, l, a, t_b, t_i\}$ form, which is used in the ARCO-program (see Appendix B) is

$$\begin{aligned} LARC_{ihr}(t, t_0) &= \frac{1}{L_0} \int_{t_0}^t dt_i f(t_i) r(t_i) \int_{t_i}^t dt_b \int_0^{l_m-t_b} da \dot{g}_{ih}(t_b - t_i, a + t_i) b(a + t_i) \\ &\times \int_{a+t_b}^{l_m} dl p(l) DAM(\min(t, l - a) - t_b, a + t_b) \end{aligned} \quad (\text{A.45})$$

where the DAM values are defined by Eq.[A.10].

A.2.6 Exposure pathway Ingestion (IG)

This exposure pathway describes the internal irradiation from ingestion of contaminated foodstuffs. Ingestion of contaminated foodstuffs may start immediately after the deposition of radioactive material or at any time after the end of foodbans, whose duration may vary, depending on the particular nuclide and food type. This case therefore, together with the EPs GR and IHR, has to be considered for the Future Generations (FG) as well.

According to the time scenario given in Fig.A.1, at time t_i , an individual from the initial cohort consumes contaminated food, what caused an irradiation at time t_b . Due to this irradiation the individual will express cancer death at time t_s , with probability $s(t_s - t_b, a_b) = s(\tau, a_b)$, where a_b is the age at irradiation. At time t_s , the individual is at age $a_s = a_b + \tau$. In the age interval $(a_s, a_s + da_s)$ there are

$$P q(a_s) da_s = \frac{P}{L_0} \int_{a_s}^{l_m} dl p(l) da_s \quad (\text{A.46})$$

individuals from the initial cohort. Due to irradiation at t_b , in the time interval $(\tau, \tau + d\tau)$ the subgroup of

$$P \dot{s}(\tau, a_b) q(a_s) da_s d\tau \quad (\text{A.47})$$

individuals from the initial cohort will experience cancer death, being at age in the age interval $(a_s, a_s + da_s)$. Due to ingestion at t_i of the activity contained in the contaminated foodstuff, an individual will receive the dose $\dot{g}_{ig}(t_b - t_i, a_i) dt_b$ in the time interval $(t_b, t_b + dt_b)$, where $\dot{g}_{ig}(t_b - t_i, a_i)$ is the differential dose conversion factor and $a_i = a_s - t_b + t_i - \tau$. However, ingestion of foodstuffs is age dependent. If $V(a_i)$ denotes the age dependent consumption rate, the dose rate for an individual in the time interval $(t_b, t_b + dt_b)$ is given by

$$V(a_i) \dot{g}_{ig}(t_b - t_i, a_i) dt_b \quad (\text{A.48})$$

The death rate in the time interval $(\tau, \tau + d\tau)$ for individuals from the initial cohort with the age in the age interval $(a_s, a_s + da_s)$ due to irradiation in time interval $(t_b, t_b + dt_b)$ caused by ingestion of contaminated foodstuffs is given by

$$P V(a_i) \dot{g}_{ig}(t_b - t_i, a_i) \dot{s}(\tau, a_b) q(a_s) da_s d\tau dt_b \quad (\text{A.49})$$

Summing up over all possible ages a_s at the manifestation of the effect, where $a_s \in (t_b + \tau, l_m)$, and over all possible times of manifestation τ , where $\tau \in (0, t - t_b)$,

$$\frac{P}{L_0} \int_0^{t-t_b} d\tau \int_{t_b+\tau}^{l_m} da_s V(a_s - t_b + t_i - \tau) \dot{g}_{ig}(t_b - t_i, a_i) \dot{s}(\tau, a_b) \int_{a_s}^{l_m} dl p(l) dt_b \quad (\text{A.50})$$

gives the death rate in the initial cohort due to irradiation in the time interval $(t_b, t_b + dt_b)$, caused by ingestion of contaminated foodstuffs at time t_i . Irradiation starts after ingestion, and it is supposed to be continuous up to the observation time t . Summing up all the effects caused by different irradiation times t_b , the expression

$$\frac{P}{L_0} \int_{t_i}^t dt_b \int_0^{t-t_b} d\tau \int_{t_b+\tau}^{l_m} da_s V(a_s - t_b + t_i - \tau) \dot{g}_{ig}(t_b - t_i, a_i) \dot{s}(\tau, a_b)$$

$$\times \int_{a_s}^{l_m} dl p(l) \quad (\text{A.51})$$

gives the number of individuals from the initial cohort which will die up to the observation time due to ingestion of a unit activity concentration at time t_i .

Although the ingestion pathway is considered as one (internal) exposure mechanism, it in fact consists of many single pathways each representative of one single foodstuff; furtheron, each foodstuff is linked with specific consumption habits and activity concentrations. It is therefore necessary to normalize the mathematical formalism to the activity concentrations in order to facilitate the numerical precalculations.

Therefore the time dependent activity per unit mass in the foodstuff $I(t_i)$, normalized to the initial activity concentration on ground (e.g. $(Bq/kg)/Bq/m^2$) is introduced. Consequently, $I(t_i) dt_i$ is the normalized activity per kg foodstuff ingested in the time interval $(t_i, t_i + dt_i)$. Multiplying Eq.[A.51] by $I(t_i) dt_i$ the number of individuals from the initial cohort which will die up to observation time t due to consumption of foodstuffs contaminated by an initial unit activity concentration on ground surface in time interval dt_i is obtained. Ingestion may start after the end of foodbans, whose duration is modelled by the time parameter t_0 , and ingestion may last up to the time of observation t . After summation over all possible times of ingestion t_i , where $t_i \in (t_0, t)$ the expression

$$\begin{aligned} N_{ig}(t, t_0) &= \frac{P}{L_0} \int_{t_0}^t dt_i I(t_i) \int_{t_i}^t dt_b \int_0^{t-t_b} d\tau \int_{t_b+\tau}^{l_m} da_s V(a_s - t_b + t_i - \tau) \\ &\times \dot{g}_{ig}(t_b - t_i, a_s - t_b + t_i - \tau) \dot{s}(\tau, a_s - \tau) \int_{a_s}^{l_m} dl p(l) \\ &= P \times LARC_{ig}(t, t_0) \end{aligned} \quad (\text{A.52})$$

gives the time dependent number of deaths in the initial cohort, due to incorporation of foodstuffs contaminated due to an initial unit activity concentration on the ground. The number of cases is obtained from multiplication of $N_{ig}(t, t_0)$ by the initial activity concentration on ground. The quantity $LARC_{ig}(t)$ in Eq.[A.52] is called Activity Risk Coefficient for ingestion for living generations and defined by

$$\begin{aligned} LARC_{ig}(t, t_0) &= \frac{1}{L_0} \int_{t_0}^t dt_i I(t_i) \int_{t_i}^t dt_b \int_0^{t-t_b} d\tau \int_{t_b+\tau}^{l_m} da_s V(a_s - t_b + t_i - \tau) \\ &\times \dot{g}_{ig}(t_b - t_i, a_s - t_b + t_i - \tau) \dot{s}(\tau, a_s - \tau) \int_{a_s}^{l_m} dl p(l) \end{aligned} \quad (\text{A.53})$$

The ARCO form used in the ARCO-program (see Appendix B) with precalculated DAM values defined by Eq.[A.10] is

$$LARC_{ig}(t, t_0) = \frac{1}{L_0} \int_{t_0}^t dt_i I(t_i) \int_{t_i}^t dt_b \int_0^{l_m-t_b} da V(a + t_i) \dot{g}_{ig}(t_b - t_i, a + t_i)$$

$$\times \int_{a+t_b}^{l_m} dl p(l) DAM(\min(t, l - a) - t_b, a + t_b) \quad (\text{A.54})$$

A.3 Future Generations

A.3.1 Basic concept and quantities

As it was stated in the previous section, all individuals born after the accident belong to the Future Generations (FG), i.e. in the time interval $(0, l_m)$ after the accident, the whole population is divided into two parts – the LG part (see previous section) and the FG part. As it was stated before, the LG part is decreasing, reaching zero size at time $t = l_m$. On the other hand, the FG part increases and reaches its maximal size at $t = l_m$, staying then constant and equal to the size of the whole population. The population P is assumed to stay constant in time, what means that the processes studied here are not influencing the population size.

At time t after the accident an individual from FG cannot be older than t , as $t = 0$ is the earliest time for being born. The part of the population P , which belongs to FG at time t , is given by

$$FG(t) = \frac{P}{L_0} \int_0^t da \int_a^{l_m} dl p(l) , \quad t \in (0, l_m) \quad (\text{A.55})$$

with

$$FG(0) = 0 , \quad FG(l_m) = P \quad (\text{A.56})$$

At time $t = l_m$

$$FG(t) = P , \quad t \geq l_m \quad (\text{A.57})$$

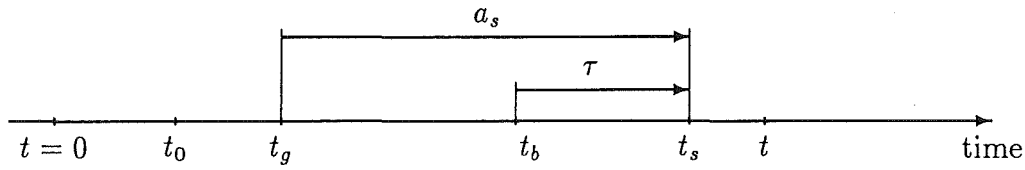
At any time, according to the definition of the $LG(t)$ (Eq.[A.7]), and according to Eq.[A.55] it follows

$$\begin{aligned} LG(t) + FG(t) &= \frac{P}{L_0} \int_t^{l_m} da \int_a^{l_m} dl p(l) + \frac{P}{L_0} \int_0^t da \int_a^{l_m} dl p(l) \\ &= \frac{P}{L_0} \left\{ \int_0^t da + \int_t^{l_m} da \right\} \int_a^{l_m} dl p(l) \\ &= P \times \frac{1}{L_0} \int_0^{l_m} da \int_a^{l_m} dl p(l) = P \end{aligned} \quad (\text{A.58})$$

Parameters used in the above equation are defined in Section 2.1 of this Appendix.

A.3.2 Exposure pathway Groundshine (GR)

Details about this EP are provided in the section dealing with the corresponding LG case. In the following the same formalism established there is used, with some extra attention given to the age parameters. Time and age parameters are defined in Fig.A.4.



a - age at time $t = 0$,	t_g - time of birth,
a_b - age at time $t = t_b$,	t_b - time of irradiation,
a_s - age at time $t = t_s$,	t_s - time of cancer death,
t_0 - countermeasure period,	τ - time between irradiation and cancer death.

Figure A.4: Time and age parameters used in $FARC_{gr}(t, t_0)$ calculations.

The range of values for each parameter strongly depends on the sequence of integrations. For example, an ARCO can be calculated by integrating first over the time of death t_s , then over life expectancies, etc. However, completely different ranges of values are obtained by changing the order of integration. Throughout the following chapters, first an “initial order” is used, which is used in the derivation of formulas for the corresponding LG case. For the GR pathway the initial order of integrations $\{l, a_s, \tau, t_b\}$ is used, what means that first the integration is done over l , then over a_s , etc. After that representation, the sequence of integrations is reordered according to $\{\tau, t_b, l, a_s\}$. Introducing the time of birth t_g for each individual, the $\{\tau, t_b, l, t_g\}$ representation is obtained, and then reordered according to $\{\tau, t_b, l, t_g\}$, in which the so-called DAM integrals (a precalculated data set in COSYMA) are used. It is not reasonable to load the text with such bulk of formulas. However, to illustrate the whole procedure a complete set is derived in the following.

In the age interval $(a_s, a_s + da_s)$

$$P q(a_s) da_s = \frac{P}{L_0} \int_{a_s}^{l_m} dl p(l) da_s \quad (\text{A.59})$$

individuals of FG are alive. Introducing the probability $s(\tau, a_s - \tau)$ in the same way as in the LG case,

$$\frac{P}{L_0} s(\tau, a_s - \tau) d\tau \int_{a_s}^{l_m} dl p(l) da_s \quad (\text{A.60})$$

individuals born and irradiated after $t = 0$ will die in the time interval $(\tau, \tau + d\tau)$ with an age in the age interval $(a_s, a_s + da_s)$. In the time interval $(t_b, t_b + dt_b)$ an irradiated individual receives the dose

$$\dot{g}_{gr}(t_b, a_s - \tau) dt_b \quad (\text{A.61})$$

what results in

$$\frac{P}{L_0} \dot{g}_{gr}(t_b, a_s - \tau) dt_b \dot{s}(\tau, a_s - \tau) d\tau \int_{a_s}^{l_m} dl p(l) da_s \quad (\text{A.62})$$

number of individuals in age group $(a_s, a_s + da_s)$ which will die in the time interval $(\tau, \tau + d\tau)$ due to exposure to groundshine in the time interval $(t_b, t_b + dt_b)$.

The age at cancer death cannot be less than τ , because $\tau = t_s - t_b$. According to Fig.A.4, at t_b the observed individual is irradiated, and the age at t_s cannot be less than τ , otherwise the individual was born after t_b . On the other hand, the age a_s at cancer death t_s , cannot be less than t_s itself. If at t_s an individual has the age greater than t_s , this individual was born before time $t = 0$, and therefore would belong to the living generations. However, setting $a_s^{max} = t_b + \tau$ may give wrong results. This comes from the fact that t_b and τ are time parameters, while a_s is the age parameter, limited by the maximal value of the life expectancy in the observed population. Expressing the age parameter by means of the time parameter(s) therefore necessarily implies limitation by l_m , because the time parameters in this case can exceed the value of l_m . Having in mind that t_b and τ are fixed at the moment, the range of values for the age at cancer death a_s can be written as

$$a_s \in (\tau, \min(t_b + \tau, l_m)) \quad (\text{A.63})$$

An integration over τ is performed as usually over the interval $(0, t - t_b)$, with one exception. Due to the fact that the time difference $t - t_b$ can exceed the maximal value of natural life expectancy l_m (fixed t_b and t are still assumed, which can have arbitrary values at the moment), the range of values for τ results:

$$\tau \in (0, \min(t - t_b, l_m)) \quad (\text{A.64})$$

Integrating over a_s and τ ,

$$\frac{P}{L_0} \int_0^{\min(l_m, t - t_b)} d\tau \int_{\tau}^{\min(t_b + \tau, l_m)} da_s \dot{g}_{gr}(t_b, a_s - \tau) \dot{s}(\tau, a_s - \tau) \int_{a_s}^{l_m} dl p(l) dt_b \quad (\text{A.65})$$

gives the number of effects which will occur up to observation time t among those born after the accident due to exposure to groundshine in the time interval $(t_b, t_b + dt_b)$. An irradiation can start at any time after $t = 0$, with one exception. If countermeasures are introduced, the irradiation via this EP will not start before they are withdrawn. Therefore, an irradiation starts at any time after $t = t_0$, and extends up to the observation time t . The irradiation time t_b is therefore defined within the time interval (t_0, t) . The last summation gives

$$\begin{aligned} N_{gr}(t, t_0) &= \frac{P}{L_0} \int_{t_0}^t dt_b \int_0^{\min(l_m, t - t_b)} d\tau \int_{\tau}^{\min(t_b + \tau, l_m)} da_s \dot{g}_{gr}(t_b, a_s - \tau) \dot{s}(\tau, a_s - \tau) \\ &\times \int_{a_s}^{l_m} dl p(l) \\ &= P \times FARC_{gr}(t, t_0) \end{aligned} \quad (\text{A.66})$$

as the total number of cancer deaths among those born after the accident, which will occur up to time t due to exposure to a unit activity concentration on ground surface. $FARC_{gr}(t, t_0)$ in Eq.[A.66] defined by

$$FARC_{gr}(t, t_0) = \frac{1}{L_0} \int_{t_0}^t dt_b \int_0^{\min(t_m, t-t_b)} d\tau \int_{\tau}^{\min(t_b+\tau, l_m)} da_s \dot{g}_{gr}(t_b, a_s - \tau) \dot{s}(\tau, a_s - \tau) \times \int_{a_s}^{l_m} dl p(l) \quad (A.67)$$

is called Activity Risk Coefficient for Groundshine for Future Generations. The above ranges of values for the parameters can easily be changed if the order of the integrals is altered.

It is also possible to define ARCOs for the FG by introducing the date of birth t_g . If the age at the time of death is expressed as the difference between the time t_s and the time of birth t_g , then

$$a_s = t_s - t_g \quad (A.68)$$

what gives

$$t_g = t_s - a_s = t_b + \tau - a_s \quad (A.69)$$

For t_b and τ fixed,

$$dt_g = -da_s \quad (A.70)$$

Substituting the corresponding values

$$a_s = \tau \Rightarrow t_g^{max} = t_b \quad (A.71)$$

results.

The upper limit for a_s gives

$$t_g^{min} = t_b + \tau - \min(t_b + \tau, l_m) \quad (A.72)$$

what can be also written in the form

$$t_g^{min} = \max(t_b + \tau - l_m, 0) \quad (A.73)$$

Inserting Eq.[A.68] – Eq.[A.73] in Eq.[A.67] the expression

$$FARC_{gr}(t, t_0) = \frac{1}{L_0} \int_{t_0}^t dt_b \int_0^{\min(t-t_b, l_m)} d\tau \int_{\max(t_b+\tau-l_m, 0)}^{t_b} dt_g \dot{g}_{gr}(t_b, t_b - t_g) \times \dot{s}(\tau, t_b - t_g) \int_{t_b-t_g+\tau}^{l_m} dl p(l) \quad (A.74)$$

results.

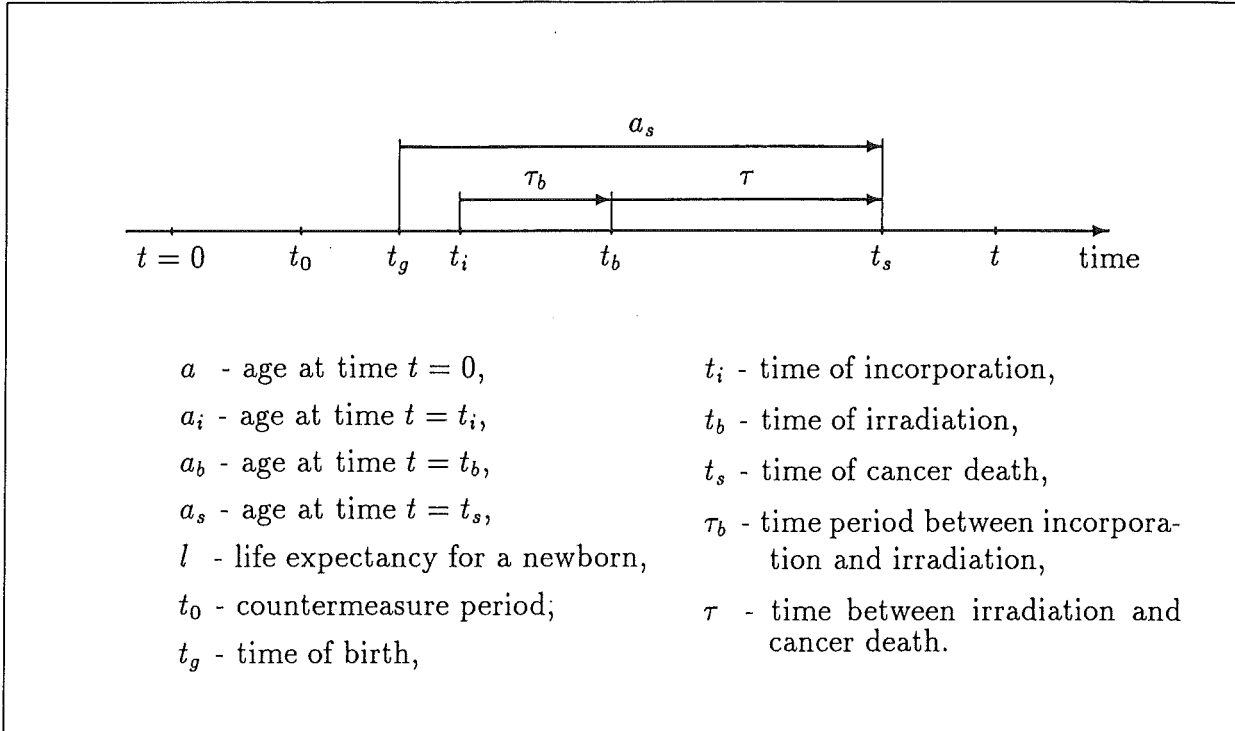


Figure A.5: Time and age parameters used in *FARC* calculations, for EP = IHR and EP = IG.

Reordering the integrals, Eq.[A.74] can be written in the form, which is used in the ARCO-program (see Appendix B):

$$\begin{aligned}
 FARC_{gr}(t, t_0) &= \frac{1}{L_0} \int_{t_0}^t dt_b \int_{\max(t_b - l_m, 0)}^{t_b} dt_g \dot{g}_{gr}(t_b, t_b - t_g) \int_{t_b - t_g}^{l_m} dl p(l) \\
 &\times DAM(\min(l + t_g, t) - t_b, t_b - t_g)
 \end{aligned} \tag{A.75}$$

with DAM defined by Eq.[A.10].

A.3.3 Exposure pathway Inhalation after resuspension (IHR)

More details about this EP can be found in the section dealing with the corresponding LG case. As in the previous section, it is possible to replace the age parameter a_s with the time parameter t_g . Time and age parameters are defined in Fig.A.5, which shows the age/time scale for the EP ingestion. The time of inhalation of resuspended radioactive material is referred to as the time of incorporation in Fig.A.5, to emphasize that incorporation at time t_i may be ingestion also.

Let us consider the time scenario, given in Fig.A.5. At time $t = t_i$ an individual, born after time $t = 0$, inhales radioactive material resuspended in the air. As a consequence,

the individual is irradiated at times t_b , and consequently at t_s it suffers cancer death with the known probability $s(t_s - t_b, a_b)$. All the derivation steps are identical to the corresponding LG case. Therefore they will not be repeated. The only difference results from the fact that the individual is born after the accident. Attention will therefore be given to the age parameters.

Using the result already obtained in the previous section concerning the age at cancer death, in the case of the EP IHR an additional effect has to be considered which modifies Eq.[A.63]. The minimal value for a_s is obtained from a similar consideration as in the previous section. At the time t_s , when an irradiated individual reaches age a_s , her or his age cannot be less than $\tau_b + \tau$. If a_s is less than $\tau_b + \tau$, the individual was born after time t_i , i.e. after the inhalation of the resuspended activity. The maximal value for a_s is the same as before, i.e. $\min(t_i + \tau_b + \tau)$, where t_b is written as $t_i + \tau_b$. Thus, the a_s interval is defined as

$$a_s \in (\tau_b + \tau, \min(t_i + \tau_b + \tau, l_m)) \quad (\text{A.76})$$

As already derived in the previous section (Eq.[A.64]), the range of values for the parameter τ is given by

$$\tau \in (0, \min(t - t_b, l_m))$$

According to Fig.A.5, the parameter τ_b is defined as $\tau_b = t_b - t_i$ in the time interval

$$\tau_b \in (0, \min(t - t_i, l_m)) \quad (\text{A.77})$$

Further in the text the parameter t_b will be used; therefore Eq.[A.76] becomes

$$a_s \in (t_b - t_i + \tau, \min(t_b + \tau, l_m)) \quad (\text{A.78})$$

Taking these age/time intervals for a_s , τ_b and τ , Eq.[A.42] can be written as

$$\begin{aligned} & \frac{P}{L_0} f(t_i) r(t_i) \int_{t_i}^t d\tau_b \int_0^{\min(t-t_b, l_m)} d\tau \int_{t_b-t_i+\tau}^{\min(t_b+\tau, l_m)} da_s b(a_s - t_b + t_i - \tau) \\ & \times \dot{g}_{ih}(t_b - t_i, a_s - t_b + t_i - \tau) \dot{s}(\tau, a_s - \tau) \int_{a_s}^{l_m} dl p(l) dt_i \end{aligned} \quad (\text{A.79})$$

what represents the number of cancer deaths which will occur up to the observation time t due to inhalation of activity resuspended in the air in time interval $(t_i, t_i + dt_i)$ for those born after $t = 0$. The integration over all possible times t_i gives $N_{ihr}(t, t_0)$, the number of cancer deaths which will occur in FG due to inhalation of resuspended activity deposited on the ground

$$\begin{aligned} N_{ihr}(t, t_0) &= \frac{P}{L_0} \int_{t_0}^t dt_i f(t_i) r(t_i) \int_{t_i}^t dt_b \int_0^{\min(t-t_b, l_m)} d\tau \int_{t_b-t_i+\tau}^{\min(t_b+\tau, l_m)} da_s \\ &\times b(a_s - t_b + t_i - \tau) \dot{g}_{ih}(t_b - t_i, a_s - t_b + t_i - \tau) \dot{s}(\tau, a_s - \tau) \int_{a_s}^{l_m} dl p(l) \\ &= P \times FARC_{ihr}(t, t_0) \end{aligned} \quad (\text{A.80})$$

Contrary to the LG case, the observation time t is not limited by time interval $(0, l_m)$ only. Typical times used in the COSYMA calculations extend up to a few l_m . The current default value for the maximal observation time after the accident in the FG case in the ARCO-program (see Appendix B) is $t_{max} = 200$ years after the accident.

The quantity $FARC_{ihr}(t, t_0)$ in Eq.[A.80] is called Activity Risk Coefficient for inhalation after resuspension in FG case and is defined by

$$\begin{aligned}
FARC_{ihr}(t, t_0) &= \frac{1}{L_0} \int_{t_0}^t dt_i f(t_i) r(t_i) \int_{t_i}^t dt_b \int_0^{\min(t-t_b, l_m)} d\tau \\
&\times \int_{t_b-t_i+\tau}^{\min(t_b+\tau, l_m)} da_s b(a_s - t_b + t_i - \tau) \\
&\times \dot{g}_{ih}(t_b - t_i, a_s - t_b + t_i - \tau) \dot{s}(\tau, a_s - \tau) \int_{a_s}^{l_m} dl p(l) \quad (A.81)
\end{aligned}$$

It is also possible to define ARCOs for the FG case by means of the date of birth t_g . Using the transformations Eq.[A.68] – Eq.[A.73] the ARCO expression Eq.[A.81] can be written in the form

$$\begin{aligned}
FARC_{ihr}(t, t_0) &= \frac{1}{L_0} \int_{t_0}^t dt_i f(t_i) r(t_i) \int_{t_i}^t dt_b \int_0^{\min(t-t_b, l_m)} d\tau \\
&\times \int_{\max(t_b+\tau-l_m, 0)}^{t_i} dt_g b(t_i - t_g) \\
&\times \dot{g}_{ih}(t_b - t_i, t_i - t_g) \dot{s}(\tau, t_b - t_g) \int_{t_b+\tau-t_g}^{l_m} dl p(l) \quad (A.82)
\end{aligned}$$

Reordering the integrals, Eq.[A.82] can be written in the form, which is used in the ARCO-program (see Appendix B):

$$\begin{aligned}
FARC_{ihr}(t, t_0) &= \frac{1}{L_0} \int_{t_0}^t dt_i f(t_i) r(t_i) \int_{t_i}^t dt_b \int_{\max(t_b-l_m, 0)}^{t_i} dt_g b(t_i - t_g) \\
&\times \dot{g}_{ih}(t_b - t_i, t_i - t_g) \int_{t_b-t_g}^{l_m} dl p(l) \\
&\times DAM(\min(t_g + l, t) - t_b, t_b - t_g) \quad (A.83)
\end{aligned}$$

where the DAM values are defined by Eq.[A.10].

A.3.4 Exposure pathway Ingestion (IG)

Internal irradiation due to ingestion of contaminated foodstuffs is presented in more detail in the corresponding LG section. The mathematical structure of the ARCO integrals is

identical with those for the IHR case. The time and age parameters relevant for this EP are presented in Fig.A.5. The only difference results from the meaning of the parameter t_i , which is now the time of consumption of contaminated foodstuffs.

According to Eq.[A.53] and Eq.[A.81], the ARCO for IG in the population group FG is given by

$$\begin{aligned}
 FARC_{ig}(t, t_0) &= \frac{1}{L_0} \int_{t_0}^t dt_i I(t_i) \int_{t_i}^t dt_b \int_0^{\min(t-t_b, l_m)} d\tau \\
 &\times \int_{t_b-t_i+\tau}^{\min(t_b+\tau, l_m)} da_s V(a_s - t_b + t_i - \tau) \\
 &\times \dot{g}_{ig}(t_b - t_i, a_s - t_b + t_i - \tau) \dot{s}(\tau, a_s - \tau) \int_{a_s}^{l_m} dl p(l) \quad (A.84)
 \end{aligned}$$

All the parameters used in Eq.[A.84] are given earlier, together with Eq.[A.53].

The other forms of representation can easily be obtained, using the same transformations given in the previous chapter. The one, which is used in the ARCO-program (see Appendix B), can be written as

$$\begin{aligned}
 FARC_{ig}(t, t_0) &= \frac{1}{L_0} \int_{t_0}^t dt_i I(t_i) \int_{t_i}^t dt_b \int_{\max(t_b-l_m, 0)}^{t_i} dt_g V(t_i - t_g) \\
 &\times \dot{g}_{ig}(t_b - t_i, t_i - t_g) \int_{t_b-t_g}^{l_m} dl p(l) \\
 &\times DAM(\min(t_g + l, t) - t_b, t_b - t_g) \quad (A.85)
 \end{aligned}$$

with DAM defined by Eq.[A.10].

A.4 Activity dose coefficients for determining the genetically significant dose

Much less information exists on the manifestation of genetic defects in children due to radiation exposure of their ancestors. As described in Section 3.4, two different overall risk coefficients are used to quantify the individual risks in the various offspring generations, which are multiplied by the genetically significant dose of the living generations and of all generations born after the accident. Therefore the ARCO procedure cannot be applied for estimating the hereditary risks, however, the methodology can be used for determining the genetically significant dose with the help of precalculated activity dose coefficients LGSD and FGSD as described in Section 3.4.

The birth distribution $z(L)$ with

$$z(L) = \frac{N(L)}{\sum_L N(L)} \quad (\text{A.86})$$

where

L = age

$N(L)$ = number of live births at age L

$\sum_L N(L)$ = total number of live births

specifies the number of new-borns according to the age of the mother, normalized to the total number of births. Corresponding to (A.1) and (A.2)

$$\int z(L) dL = 1 \quad (\text{A.87})$$

and

$$Z_0 = \int z(L) L dL \quad (\text{A.88})$$

denotes the mean age of the mothers at birth of their children. Following the methodology described in Chapters A.2 and A.3, activity dose coefficients LGSD and FGSD can be derived for each exposure pathway and nuclide. The only difference in the formulas is due to the time τ between irradiation and cancer death, which is not applicable for the genetically significant dose. As a consequence, the corresponding integrals (DAM-values) have to be omitted in all expressions, the mean life expectancy L_0 has to be replaced by Z_0 and the integration variable l has to be interpreted as the age of the mother at birth.

The Sections in Appendix B describe the analytical and numerical formulations for the LGSD and FGSD coefficients; the birth distribution $z(L)$ as a function of the age L of the mother is given in Appendix C.2.4.2.

Appendix B. Activity risk coefficients - numerical approach

The preceding section has set out the mathematical formulation of the activity risk coefficients. For numerical calculations the integrals have to be transformed into sums by discretisation of the variables and by defining the boundary conditions. Where it is possible, the expressions have to be simplified for further reducing the computing time.

All data sets required for the calculations were modified in such a way, that a smallest timestep of $\Delta T = 1$ year resulted. In the following the so processed data sets are written in capital letters.

In the transformation the following variables and expressions are used:

$$t = n * \Delta T, t_0 = n_0 * \Delta T, t_b = n_b * \Delta T, t_i = n_i * \Delta T, t_g = n_g * \Delta T, l = i * \Delta T, a = j * \Delta T$$

Individuals with age below 1 year and living at the time of the accident are those in the first age group ($j=1$). The maximum age of exposed people is 94 years. Considering a person with a certain age j at the time of irradiation and calculating the probability for this person to die in a certain age $l > j$ by cancer explains that a difference of at least one year between j and l is necessary, that means $l \geq j + 1$ and the limit of l is therefore 95 years. The variables n_i and n_b , the time of incorporation and the time of the begin of irradiation can start at the earliest at $n_0 = 0$, i.e. - without countermeasures - at the time of accident. As n_i and n_b are related to the begin of a period, they start with the value 0. n_g is the time of birth and starts at $n_g = 0$, i.e. persons, which are born in the first year after the accident. For the calculation of the genetically significant dose, the age of the considered population is limited to the period between 13 and 44 years. The first values for the activity risk coefficients are calculated at $n = 1$, one year after exposure.

In the following sections it will be shown for each exposure pathway the transformation from the integral form into sums for living generations LG, and for future generations FG specific for each exposure pathway. Additionally, for each pathway the same procedure will be described for the calculation of the genetically significant dose, which is treated in the structure of the programs as an additional "organ".

The calculations for the living generations are made with the implicit condition $t \leq l_m$ to avoid unnecessary computation for non-existing population groups.

B.1 Exposure pathway Cloudshine (CL)

The integral-formulation is according to Eq. [A.20]

$$LARC_{cl}(t) = \frac{g_{cl}}{L_0} \int_0^{l_m} da \int_a^{l_m} dl p(l) DAM(\min(t, l - a), a) \quad [B.1]$$

The dose conversion factors for cloudshine refer to an adult reference person, they are multiplied during run-time with age-dependent correction factors:

$$LARC_{cl}(t) = \frac{g_{cl}}{L_0} \int_0^{l_m} da \text{ corrf}(a) \int_a^{l_m} dl p(l) \text{ DAM}(\min(t, l - a), a) \quad [B.2]$$

With respect of the limits in the age of the population defined above, the integral can be transformed into the following sum:

$$LARC_{cl}(n) = \frac{g_{cl}}{L_0} \sum_{j=1}^{94} \text{CORRF}(j) \sum_{i=j+1}^{95} P(i) \text{ DAM}(\min(n, i - j), j) \quad [B.3]$$

The corresponding integral for the genetically significant dose is:

$$LGSD_{cl}(t) = \frac{g_{cl}}{Z_0} \int_{l_1}^{l_2} da \text{ corrf}(a) \int_a^{l_2} dl z(l) \quad [B.4]$$

The transformation into sums gives:

$$LGSD_{cl}(n) = \frac{g_{cl}}{Z_0} \sum_{j=13}^{44} \text{CORRF}(j) \sum_{i=j+1}^{45} Z(i) \quad [B.5]$$

B.2 Exposure pathway Groundshine (GR)

B.2.1 Living generations

Also in this case age-dependent correction factors for the dose conversion factors have to be introduced into the integral:

$$LARC_{gr}(t, t_0) = \frac{1}{L_0} \int_{t_0}^t dt_b \int_0^{l_m - t_b} da \text{ corrf}(a + t_b) \dot{g}_{gr}(t_b) \int_{a+t_b}^{l_m} dl p(l) \text{ DAM}(\min(t - t_b, l - a - t_b), a + t_b) \quad [B.6]$$

The transformation into sums gives:

$$LARC_{gr}(n, n_0) = \frac{1}{L_0} \sum_{n_b=n_0}^{n-1} \sum_{j=1}^{94-n_b} \text{CORRF}(j + n_b) \text{ DDF}(n_b) \sum_{i=j+n_b+1}^{95} P(i) \text{ DAM}(\min(n - n_b, i - j - n_b), j + n_b) \quad [B.7]$$

The genetically significant dose is given by:

$$LGSD_{gr}(t, t_0) = \frac{1}{Z_0} \int_{t_0}^t dt_b \int_{\max(0, l_1 - t_b)}^{\max(0, l_2 - t_b)} da \text{ corr}f(a + t_b) \dot{g}_{gr}(t_b) \int_{a+t_b}^{l_2} dl z(l) \quad [B.8]$$

The integration limits in the second integral result from the condition $l_1 \leq a + t_b \leq l_2$.

With the introduction of a δ -function it can be written as:

$$LGSD_{gr}(t, t_0) = \frac{1}{Z_0} \int_{t_0}^t dt_b \int_0^{\max(0, l_2 - t_b)} da \delta(a + t_b - l_1) \text{ corr}f(a + t_b) \dot{g}_{gr}(t_b) \int_{a+t_b}^{l_2} dl z(l) \quad [B.9]$$

with

$$\delta(x) = \begin{cases} 1 & \text{for } x \geq 0 \\ 0 & \text{for } x < 0 \end{cases}$$

In the expression in sums the first condition is not necessary, because during a calculation automatically a sum will be calculated only if the lower limit is not greater than the upper limit:

$$LGSD_{gr}(n, n_0) = \frac{1}{Z_0} \sum_{n_b=n_0}^{n-1} \sum_{j=1}^{\max(1, 44-n_b)} \delta(j + n_b - 13) \text{ CORR}F(j + n_b) \text{ DDF}(n_b) \sum_{i=j+n_b+1}^{45} Z(i) \quad [B.10]$$

Programming this sums with the help of DO-loops the maximum condition in the second sum is not necessary, because a DO-loop only with ascending order will be executed. The upper boundary for the summation index j is therefore $44 - n_b$.

B.2.2 Future generations

The integral form for the future generations can be written:

$$FARC_{gr}(t, t_0) = \frac{1}{L_0} \int_{t_0}^t dt_b \int_{\max(t_b - l_m, 0)}^{t_b} dt_g \dot{g}_{gr}(t_b) \text{ corr}f(t_b - t_g) \int_{t_b - t_g}^{l_m} dl p(l) \text{ DAM}(\min(l + t_g - t_b, t - t_b), t_b - t_g) \quad [B.11]$$

With the introduction of a δ -function the maximum condition in the lower limit of the second integral can be substituted:

$$FARC_{gr}(t, t_0) = \frac{1}{L_0} \int_{t_0}^t dt_b \int_0^{t_b} dt_g \delta(t_b - l_m - t_g) \dot{g}_{gr}(t_b) \text{corrff}(t_b - t_g) \int_{t_b - t_g}^{l_m} dl p(l) \text{DAM}(\min(l + t_g - t_b, t - t_b), t_b - t_g) \quad [B.12]$$

Formulated in sums:

$$FARC_{gr}(n, n_0) = \frac{1}{L_0} \sum_{n_b = n_0}^{n-1} \text{DDF}(n_b) \sum_{n_g = 0}^{n_b} \delta(n_b - 94 - n_g) \text{CORR}(n_b - n_g) \sum_{i = n_b - n_g + 1}^{95} P(i) \text{DAM}(\min(n - n_b, n_g + i - n_b), n_b - n_g) \quad [B.13]$$

The dose conversion factors only depend on the time of irradiation; therefore in the calculation of sums they can be moved outside the summation.

The genetically significant dose can be written as follows:

$$FGSD_{gr}(t, t_0) = \frac{1}{Z_0} \int_{t_0}^t dt_b \int_{\max(0, t_b - l_2)}^{\max(0, t_b - l_1)} dt_g \dot{g}_{gr}(t_b) \text{corrff}(t_b - t_g) \int_{t_b - t_g}^{l_2} dl z(l) \quad [B.14]$$

With the introduction of the δ -function the conditions in the lower and upper limit of the second integral can again be substituted:

$$FGSD_{gr}(t, t_0) = \frac{1}{Z_0} \int_{t_0}^t dt_b \int_0^{t_b} dt_g \delta(l_2 - t_b + t_g) \delta(t_b - l_1 - t_g) \dot{g}_{gr}(t_b) \text{corrff}(t_b - t_g) \int_{t_b - t_g}^{l_2} dl z(l) \quad [B.15]$$

Transformed in sums:

$$FGSD_{gr}(n, n_0) = \frac{1}{Z_0} \sum_{n_b = n_0}^{n-1} \text{DDF}(n_b) \sum_{n_g = 0}^{n_b} \delta(44 - t_b + t_g) \delta(t_b - 13 - t_g) \sum_{i = n_b - n_g + 1}^{45} Z(i) \quad [B.16]$$

B.3 Exposure pathway Inhalation (IH)

Like cloudshine the exposure pathway inhalation is only relevant for people who are living at the time of accident:

$$LARC_{ih}(t) = \frac{1}{L_0} \int_0^t dt_b \int_0^{l_m - t_b} da b(a) \dot{g}_{ih}(t_b, a) \int_{a+t_b}^{l_m} dl p(l) DAM(\min(t - t_b, l - a - t_b), a + t_b) \quad [B.17]$$

The transformation into sums gives:

$$LARC_{ih}(n) = \frac{1}{L_0} \sum_{n_b=0}^{n-1} \sum_{j=1}^{94-n_b} ATEMRA(j) DDF(n_b, j) \sum_{i=j+n_b+1}^{95} P(i) DAM(\min(n - n_b, i - j - n_b), j + n_b) \quad [B.18]$$

For the genetically significant dose

$$LGSD_{ih}(t) = \frac{1}{Z_0} \int_0^t dt_b \int_{\max(0, l_1 - t_b)}^{\max(0, l_2 - t_b)} da b(a) \dot{g}_{ih}(t_b, a) \int_{a+t_b}^{l_2} dl z(l) \quad [B.19]$$

can be written using again a δ -function as:

$$LGSD_{ih}(t) = \frac{1}{Z_0} \int_0^t dt_b \int_0^{\max(0, l_2 - t_b)} da b(a) \delta(a + t_b - l_1) \dot{g}_{ih}(t_b, a) \int_{a+t_b}^{l_2} dl z(l) \quad [B.20]$$

The expression in sums gives:

$$LGSD_{ih}(n) = \frac{1}{Z_0} \sum_{n_b=0}^{n-1} \sum_{j=1}^{\max(0, 44 - n_b)} ATEMRA(j) \delta(j + n_b - 13) DDF(n_b, j) \sum_{i=j+n_b+1}^{45} Z(i) \quad [B.21]$$

Programming this sums with the help of DO-loops the maximum condition in the third sum is not necessary, because a DO-loop only with ascending order will be executed. The upper boundary for the summation index j is $44 - n_b$.

B.4 Exposure pathway Inhalation after resuspension (IHR)

B.4.1 Living generations

For the pathway inhalation after resuspension the ARCs are given by:

$$LARC_{ihr}(t, t_0) = \frac{1}{L_0} \int_{t_0}^t dt_i f(t_i) r(t_i) \int_{t_i}^t dt_b \int_0^{l_m - t_b} da \dot{g}_{ih}(t_b - t_i, a + t_i) b(a + t_i) \int_{a+t_b}^{l_m} dl p(l) DAM(\min(t - t_b, l - a - t_b), a + t_b) \quad [B.22]$$

In sums it can be written as follows:

$$LARC_{ihr}(n, n_0) = \frac{1}{L_0} \sum_{n_i=n_0}^{n-1} F(n_i) R(n_i) \sum_{n_b=n_i}^{n-1} \sum_{j=1}^{94-n_b} DDF(n_b - n_i, j + n_i) ATEMRA(j + n_i) \sum_{i=j+n_b+1}^{95} P(i) DAM(\min(n - n_b, i - j - n_b), j + n_b) \quad [B.23]$$

The genetically significant dose is given by:

$$LGSD_{ihr}(t, t_0) = \frac{1}{Z_0} \int_{t_0}^t dt_i f(t_i) r(t_i) \int_{t_i}^t dt_b \int_{\max(0, l_1 - t_b)}^{\max(0, l_2 - t_b)} da \dot{g}_{ih}(t_b - t_i, a + t_i) b(a + t_i) \int_{a+t_b}^{l_2} dl z(l) \quad [B.24]$$

With the δ -function it can be simplified:

$$LGSD_{ihr}(t, t_0) = \frac{1}{Z_0} \int_{t_0}^t dt_i f(t_i) r(t_i) \int_{t_i}^t dt_b \int_0^{\max(0, l_2 - t_b)} da \delta(a + t_b - l_1) \dot{g}_{ih}(t_b - t_i, a + t_i) b(a + t_i) \int_{a+t_b}^{l_2} dl z(l) \quad [B.25]$$

In sums it can be written as follows:

$$LGSD_{ihr}(n, n_0) = \frac{1}{Z_0} \sum_{n_i=n_0}^{n-1} F(n_i) R(n_i) \sum_{n_b=n_i}^{n-1} \sum_{j=1}^{\max(1, 44-n_b)} \delta(j + n_b - 13) DDF(n_b - n_i, j + n_i) ATEMRA(j + n_i) \sum_{i=j+n_b+1}^{45} Z(i) \quad [B.26]$$

Programming this sums with the help of DO-loops the condition of maximum in the third sum is not necessary, because a DO-loop only with ascending order will be executed. The upper boundary for the summation index j is $44 - n_b$.

B.4.2 Future generations

For the future generations the ARCs are given by:

$$FARC_{ihr}(t, t_0) = \frac{1}{L_0} \int_{t_0}^t dt_i f(t_i) r(t_i) \int_{t_i}^t dt_b \int_{\max(t_b - l_m, 0)}^{t_i} dt_g \dot{g}_{ih}(t_b - t_i, t_i - t_g) b(t_i - t_g) \int_{t_b - t_g}^{l_m} dl p(l) DAM(\min(t - t_b, t_g + l - t_b), t_b - t_g) \quad [B.27]$$

With the δ -function it follows:

$$FARC_{ihr}(t, t_0) = \frac{1}{L_0} \int_{t_0}^t dt_i f(t_i) r(t_i) \int_{t_i}^t dt_b \int_0^{t_i} dt_g \delta(t_b - l_m - t_g) \dot{g}_{ih}(t_b - t_i, t_i - t_g) b(t_i - t_g) \int_{t_b - t_g}^{l_m} dl p(l) DAM(\min(t - t_b, t_g + l - t_b), t_b - t_g) \quad [B.28]$$

Transformation into sums:

$$FARC_{ihr}(n, n_0) = \frac{1}{L_0} \sum_{n_i = n_0}^{n-1} F(n_i) R(n_i) \sum_{n_b = n_i}^{n-1} \sum_{n_g = 0}^{n_i} \delta(n_b - 94 - n_g) DDF(n_b - n_i, n_i - n_g) ATEMRA(n_i - n_g) \sum_{i = n_b - n_g + 1}^{95} P(i) DAM(\min(n - n_b, n_g + i - n_b), n_b - n_g) \quad [B.29]$$

The genetically significant dose is given by:

$$FGSD_{ihr}(t, t_0) = \frac{1}{Z_0} \int_{t_0}^t dt_i f(t_i) r(t_i) \int_{t_i}^t dt_b \int_{\max(0, t_b - l_2)}^{\min(\max(0, t_b - l_1), t_i)} dt_g \dot{g}_{ih}(t_b - t_i, t_i - t_g) b(t_i - t_g) \int_{t_b - t_g}^{l_2} dl z(l) \quad [B.30]$$

With the introduction of a δ -function it follows:

$$FGSD_{ihr}(t, t_0) = \frac{1}{Z_0} \int_{t_0}^t dt_i f(t_i) r(t_i) \int_{t_i}^t dt_b \int_0^{t_i} dt_g \delta(l_2 - t_b + t_g) \delta(t_b - l_1 - t_g) \dot{g}_{ih}(t_b - t_i, t_i - t_g) b(t_i - t_g) \int_{t_b - t_g}^{l_2} dl z(l) \quad [B.31]$$

Finally the following sums result:

$$\begin{aligned}
FGSD_{ihr}(n, n_0) = & \frac{1}{Z_0} \sum_{n_i=n_0}^{n-1} F(n_i) R(n_i) \sum_{n_b=n_i}^{n-1} \sum_{n_g=0}^{n_i} \delta(44 - t_b + t_g) \delta(t_b - 13 - t_g) \\
& DDF(n_b - n_i, n_i - n_g) ATEMRA(n_i - n_g) \sum_{i=n_b - n_g + 1}^{45} Z(i)
\end{aligned} \tag{B.32}$$

B.5 Exposure pathway Ingestion (IG)

B.5.1 Living generations

For the pathway ingestion the ARCs are given by:

$$\begin{aligned}
LARC_{ig}(t, t_0) = & \frac{1}{L_0} \int_{t_0}^t dt_i i(t_i) \int_{t_i}^t dt_b \int_0^{l_m - t_b} da \dot{g}_{ig}(t_b - t_i, a + t_i) v(a + t_i) \\
& \int_{a+t_b}^{l_m} dl p(l) DAM(\min(t - t_b, l - a - t_b), a + t_b)
\end{aligned} \tag{B.33}$$

The sums can be written as follows:

$$\begin{aligned}
LARC_{ig}(n, n_0) = & \frac{1}{L_0} \sum_{n_i=n_0}^{n-1} I(n_i) \sum_{n_b=n_i}^{n-1} \sum_{j=1}^{94-n_b} DDF(n_b - n_i, j + n_i) V(j + n_i) \\
& \sum_{i=j+n_b+1}^{95} P(i) DAM(\min(n - n_b, i - j - n_b), j + n_b)
\end{aligned} \tag{B.34}$$

The genetically significant dose is given by:

$$\begin{aligned}
LGSD_{ig}(t, t_0) = & \frac{1}{Z_0} \int_{t_0}^t dt_i i(t_i) \int_{t_i}^t dt_b \int_{\max(0, l_1 - t_b)}^{\max(0, l_2 - t_b)} da \dot{g}_{ig}(t_b - t_i, a + t_i) v(a + t_i) \\
& \int_{a+t_b}^{l_2} dl z(l)
\end{aligned} \tag{B.35}$$

With the δ -function it can be simplified:

$$\begin{aligned}
LGSD_{ig}(t, t_0) = & \frac{1}{Z_0} \int_{t_0}^t dt_i i(t_i) \int_{t_i}^t dt_b \int_0^{\max(0, l_2 - t_b)} da \delta(a + t_b - l_1) \dot{g}_{ig}(t_b - t_i, a + t_i) v(a + t_i) \\
& \int_{a+t_b}^{l_2} dl z(l)
\end{aligned} \tag{B.36}$$

The sums can be written as follows:

$$LGSD_{ig}(n, n_0) = \frac{1}{Z_0} \sum_{n_i=n_0}^{n-1} I(n_i) \sum_{n_b=n_i}^{n-1} \sum_{j=1}^{\max(1, 44-n_b)} \delta(j+n_b-13) DDF(n_b-n_i, j+n_i) V(j+n_i) \sum_{i=j+n_b+1}^{45} Z(i) \quad [B.37]$$

Programming this sums with the help of DO-loops the maximum condition in the third sum is not necessary, because a DO-loop only with ascending order will be executed. The upper boundary for the summation index j is $44 - n_b$.

B.5.2 Future generations

For the future generations the ARCs are given by:

$$FARC_{ig}(t, t_0) = \frac{1}{L_0} \int_{t_0}^t dt_i i(t_i) \int_{t_i}^t dt_b \int_{\max(t_b-l_m, 0)}^{t_i} dt_g \dot{g}_{ig}(t_b-t_i, t_i-t_g) v(t_i-t_g) \int_{t_b-t_g}^{l_m} dl p(l) DAM(\min(t-t_b, t_g+l-t_b), t_b-t_g) \quad [B.38]$$

With the δ -function it follows:

$$FARC_{ig}(t, t_0) = \frac{1}{L_0} \int_{t_0}^t dt_i i(t_i) \int_{t_i}^t dt_b \int_0^{t_i} dt_g \delta(t_b-l_m-t_g) \dot{g}_{ig}(t_b-t_i, t_i-t_g) v(t_i-t_g) \int_{t_b-t_g}^{l_m} dl p(l) DAM(\min(t-t_b, t_g+l-t_b), t_b-t_g) \quad [B.39]$$

Transformation into sums:

$$FARC_{ig}(n, n_0) = \frac{1}{L_0} \sum_{n_i=n_0}^{n-1} I(n_i) \sum_{n_b=n_i}^{n-1} \sum_{n_g=0}^{n_i} \delta(n_b-94-n_g) DDF(n_b-n_i, n_i-n_g) V(n_i-n_g) \sum_{i=n_b-n_g+1}^{95} P(i) DAM(\min(n-n_b, n_g+i-n_b), n_b-n_g) \quad [B.40]$$

The genetically significant dose is given by:

$$FGSD_{ig}(t, t_0) = \frac{1}{Z_0} \int_{t_0}^t dt_i i(t_i) \int_{t_i}^t dt_b \int_{\max(0, t_b-l_2)}^{\min(\max(0, t_b-l_1), t_i)} dt_g \dot{g}_{ig}(t_b-t_i, t_i-t_g) v(t_i-t_g) \int_{t_b-t_g}^{l_2} dl z(l) \quad [B.41]$$

With the introduction of a δ -function it follows:

$$\begin{aligned}
FGSD_{ig}(t, t_0) = \frac{1}{Z_0} \int_{t_0}^t dt_i i(t_i) \int_{t_i}^t dt_b \int_0^{t_i} dt_g \delta(l_2 - t_b + t_g) \delta(t_b - l_1 - t_g) \\
\dot{g}_{ig}(t_b - t_i, t_i - t_g) v(t_i - t_g) \int_{t_b - t_g}^{t_2} dl z(l)
\end{aligned}
\tag{B.42}$$

From that, the following representation in sums results:

$$\begin{aligned}
FGSD_{ig}(n, n_0) = \frac{1}{Z_0} \sum_{n_i = n_0}^{n-1} I(n_i) \sum_{n_b = n_i}^{n-1} \sum_{n_g = 0}^{n_i} \delta(44 - t_b + t_g) \delta(t_b - 13 - t_g) \\
DDF(n_b - n_i, n_i - n_g) V(n_i - n_g) \sum_{i = n_b - n_g + 1}^{45} Z(i)
\end{aligned}
\tag{B.43}$$

Appendix C. The computer program ARCO for calculating activity risk coefficients

C.1 General structure of the ARCO program

Depending on the exposure pathway the calculation of the activity risk coefficients needs rather long computing times. Therefore separate modules have been developed for each exposure pathway and for the population living at the time of the accident (referred to as "living generations" LG), and for those born after the accident (referred to as "future generations" FG) separately. Thus the ARCO-program consists of a set of eight modules with a similar internal structure and input-/output possibilities:

ARCO-CL	activity risk coefficients for cloudshine
ARCO-GR-LG	activity risk coefficients for groundshine, living generations
ARCO-GR-FG	activity risk coefficients for groundshine, future generations
ARCO-IH	activity risk coefficients for inhalation
ARCO-IG-LG	activity risk coefficients for ingestion, living generations
ARCO-IG-FG	activity risk coefficients for ingestion, future generations
ARCO-IR-LG	activity risk coefficients for resuspension, living generations
ARCO-IR-FG	activity risk coefficients for resuspension, future generations

All ARCO-modules have a similar structure resulting from the mathematical algorithm described in Appendix A and the numerical solution described in Appendix B. The formulations in COSYMA are Eqs. [A.20], [A.29], [A.38], [A.45] and [A.54] for living generations, and Eqs. [A.75], [A.83] and [A.85] for future generations. The advantage of the chosen integration order - $\{\tau, l, a, t_b, t_i\}$ for living generations and $\{\tau, l, t_g, t_b, t_i\}$ for future generations - can be expressed by the following two reasons:

- calculating first the integral over the variable τ allows the use of the precalculated values DAM (see Eq. [A.10])
- it allows to define a so-called differential risk coefficient $DARC(t, t_x)$ so that

$$ARC(t, t_0) = \int_{t_0}^t DARC(t, t_x) dt_x$$

where t_x means the incorporation time t_i in case of ingestion and inhalation after resuspension and the time of irradiation t_b for the other exposure pathways, respectively; the program calculates for each observation time t the expression $DARC(t, t_x)$ as a function of t_x .

Successively, the integral $ARC(t, t_0)$ is evaluated for each value of t_0 using the precalculated differential risk coefficient $DARC(t, t_x)$. This procedure avoids a great number of repetitions of the same calculational steps and saves so very effectively computing time.

Each ARCO-program consists of this basic part with the loop of the time t after the accident, which is run for each foodstuff (if required), each organ and nuclide. For the organ gonads an analogous procedure is adopted.

Activity risk coefficients are calculated for a number ($nmax$) of discrete time points (n) after the accident what enables the calculation of the time-dependent occurrence of each cancer type. The time span covered and the number of time points considered is different for the living and the future generations. Their values are fixed in the program by a DATA-statement and are set as follows (given in years):

for living generations: $nmax^{LG} = 8$
 $t(n) = 5, 10, 20, 30, 40, 50, 70, 90$ years
 for $n = 1, \dots, nmax^{LG}$

for future generations: $nmax^{FG} = 10$
 $t(n) = 5, 10, 20, 30, 40, 50, 70, 90, 150, 200$ years
 for $n = 1, \dots, nmax^{FG}$

Additionally, the activity risk coefficients depend on the start of exposure defined by the withdrawal of the countermeasures relocation (relevant for the exposure pathways groundshine and inhalation after resuspension) and foodbans (relevant for ingestion pathway). The exposure pathways cloudshine and inhalation affect only those people staying inside or near the plume at the time of accident. Therefore they are neither related to the withdrawal of countermeasures nor are they needed for the future generations. The number n_0 max of withdrawal times n_0 and the time points $t(n_0)$ are identical for living and following generations. Their values are fixed in the program by a DATA-statement and are set as follows (given in years):

for exposure pathways GR and IHR: n_0 max = 10
 $t(n_0) = 0, 1, 2, 5, 10, 20, 30, 40, 50, 70$ years
 for $n_0 = 1, \dots, n_0$ max

These values broadly refer to the default values of NAMELIST parameter NT defining the times of resettlement [4]; if the user changes the values of NT, the risks will be calculated by interpolation between the available activity risk coefficients.

for exposure pathway IG: $n_0 \text{ max} = 10$
 $t(n_0) = 0, 1, 2, 5, 10, 20, 30, 40, 50, 70$ years
for $n_0 = 1, \dots, n_0 \text{ max}$

for exposure pathway CL and IH: $n_0 \text{ max} = 1$
 $t(n_0) = 0$ years for $n_0 = n_0 \text{ max} = 1$

For calculations without considering countermeasures, the activity risk coefficients for $t(n_0) = 0$ are used.

The ARCO program needs several input data files which are described in Chapter 2 of this Appendix. Further the module for each exposure pathway contains a NAMELIST called RLBERW offering the user the possibility to change some of the input values. The parameters of the NAMELIST and their meaning is described in Section 3 of this Appendix.

C.2 Preparation of input data

For the calculation of the activity risk coefficients the following data are required:

- differential time- and age-dependent dose conversion factors for the exposure pathways cloudshine, groundshine, inhalation and ingestion
- dose risk factors for mortality due to stochastic somatic health effects, as a function of age and integrated over different times
- correction factors to include the age dependency for the external dose conversion factors which are available for adults only
- age-dependent breathing rates [19]
- statistical informations as the age-dependent distribution of life expectancy and the age-dependent birth-distribution [20]
- foodstuff specific data for the ingestion pathway as age-dependent consumption rates and time- and nuclide-dependent normalized activity concentrations in foodstuffs [5]
- time-dependent activity in air near ground after deposition due to resuspension

For the following ten cancer types (indicated by the name of the affected organ or tissue) activity risk coefficients are calculated for each exposure pathway. Additionally, for the organ gonads coefficients referring to the genetically significant dose used for hereditary effects are calculated with the same method. For simplification also these coefficients are denoted by ARCOs. The numbers given in brackets refer to the order of organs in the ARCO-programs and data files required for use in COSYMA (it is not the COSYMA-internal order):

(1) breast	(7) stomach
(2) bone surface	(8) colon
(3) lung	(9) liver
(4) bone marrow	(10) pancreas
(5) thyroid	
(6) remainder	(11) gonads

Table 41. Order of organs for which activity risk coefficients are calculated

activity risk coefficients are calculated for all nuclides contained in the basic nuclide list of COSYMA ; only for the ingestion pathway a subset with ingestion-relevant nuclides is taken into account (see [2]).

C.2.1 Differential dose conversion factors

The transformations done to the basic data sets of dose conversion factors to meet the requirements of COSYMA are described in [5] for the ingestion pathway and in [4] for all other exposure pathways. The dose conversion factor data files used in COSYMA for the dose calculations contain values integrated from time zero up to different upper time points. For calculating the activity risk coefficients they are, however, needed with a yearly resolution and in a differential form. In the following the necessary changes for use in the ARCO-programs is described. For all exposure pathways the data for the organs not used in the risk modules of COSYMA had to be removed and the order of the organs had to be rearranged as given above.

As for **cloudshine** only one integral value exists for each organ and nuclide, no modification of the data was necessary. The file used in the dose modules of COSYMA had only to be transformed into a sequential file.

The resulting data file has the following structure:

```

DIMENSION DDFCL(11)
C----- LOOP OVER THE NUCLIDES
DO 777 K=1,NUCALL
C----- ARRAY CONTAINING VALUES FOR ALL ORGANS
WRITE(4) DDFCL
20 CONTINUE
777 CONTINUE

```

Table 42. Structure of the data file with differential dose conversion factors for cloudshine

For **groundshine** the dose conversion factor data file of COSYMA contains values for 26 integration times. The data for the integration times shorter than one year were removed. The remaining data were linearly interpolated to get a value for yearly integration times. Then the differential values for yearly time spans were determined. The correction factors

CORRF for different ages are considered in the program during run-time and not incorporated into the differential dose conversion factor data file.

The upper time period was taken to be 95 years as for the other exposure pathways. As the highest integration time in the data base is 70 years and because the value for infinity gives unrealistic high values for long lived nuclides, for all time periods longer than 70 years the 70a value was used. For many short lived nuclides the differential value becomes zero after a few time steps. To save computing times only the values > 0 are stored; a pointer in front of each record indicates the number of values > 0 .

The resulting data file has the following structure:

```

      DIMENSION DDFGR(95)
C----- LOOP OVER THE NUCLIDES
      DO 777 K=1,NUCALL
C----- LOOP OVER THE ORGANS
      DO 20 IOG=1,11
C----- IZMAX = NUMBER OF DIFFERENTIAL VALUES > 0
          WRITE(4) IZMAX
          WRITE(4) (DDFGR(IZ), IZ=1, IZMAX)
      20 CONTINUE
      777 CONTINUE
```

Table 43. Structure of the data file with differential dose conversion factors for groundshine

The original data base contains for **inhalation** age-dependent dose conversion factors for six age groups. As in the dose calculations of COSYMA only the dose conversion factors for adults are used, these age-dependent factors are not included in the COSYMA data-file. As the calculation of the activity risk coefficients requires age-dependent values the transformations described for the data for adults in [4] had to be done also to the other age groups.

The generation of differential values for each age group is done as described for groundshine, i.e. between the 11 integration times available yearly values were derived by linear interpolation. The missing values for time points from 71 to 90 years were filled with the differential for 70 years.

Another transformation had to be done for the age for which a resolution of one year is required. This was achieved by assigning to each of the first 20 ages (beyond the age of 20 years the same values are applied up to age 70) the value of the corresponding age class; e.g. for the age 2-3 years and for the age 3-4 years the same value was taken, i.e. the value for the class 2-5 years.

To limit computing time a pointer indicating the number of values > 0 is used. This pointer is an array of size 20 (according to the 20 different ages); for each age it gives the number of differential values having a maximal value of 90 and a minimum of 1.

For **resuspension** the same differential dose conversion factor data file is used as for inhalation. It has the following structure:


```

        DIMENSION IZMAX(11,20),DDFIH(11,20,90)
C----- LOOP OVER THE NUCLIDES
        DO 777 K=1,NUCALL
C----- LOOP OVER THE ORGANS
        DO 700 IOG=1,11
C----- IZMAX = NUMBER OF DIFFERENTIAL VALUES
C----- > 0 FOR AGE IAG AND ORGAN IOG
C----- IZ = TIME AFTER ACCIDENT
            WRITE(4) (IZMAX(IOG,IAG),IAG=1,20)
            DO 300 IAG=1,20
                WRITE(4) (DDFIH(IOG,IAG,IZ),IZ=1,IZMAX(IOG,IAG))
        300 CONTINUE
        700 CONTINUE
        777 CONTINUE

```

Table 44. Structure of the data file with differential dose conversion factors for inhalation

The data base contains for **ingestion** age-dependent dose conversion factors for the same six age groups as for inhalation. As the file with the differential dose conversion factors is also used in the separate program UFOING, it includes all age groups. Details how these factors are derived from the original data base can be found in [5].

The resulting file has the following structure:

```

        PARAMETER(MAXORK=22,MAXJAG=100,MXXTIME=100)
        CHARACTER*8 CFIL14(10),CNUK,CORK
        CHARACTER*8 ORKNAM(MAXORK)
        DIMENSION JGTMAX(MAXJAG),DDFIG(MXXTIM,MAXJAG)
C----- FILE HEADER
        READ(23) CFIL14
        READ(23) NDCF, NORK, MJAG, MJGT
        READ(23) (ORKNAM(I),I=1,NORK)
C----- LOOP OVER THE IG-NUCLIDES
        DO 100 INU=1,NDCF
            READ(23) CNUK
C----- LOOP OVER THE ORGANS
        DO 200 IORG=1,MAXORK
            READ(23) CORK,JGTMAX
C----- LOOP OVER THE AGE
        DO 202 JAG=1,MAXJAG
C----- JGTMAX = NUMBER OF DIFFERENTIAL
C----- VALUES > 0 FOR AGE JAG
C----- KT = TIME AFTER ACCIDENT
            IF(JGTMAX(JAG).GT.0) READ(23) (DDFIG(KT,JAG),KT=1,JGTMAX(JAG))
        202 CONTINUE
        200 CONTINUE
        100 CONTINUE

```

Table 45. Structure of the data file with differential dose conversion factors for ingestion

C.2.2 Time- and age-dependent dose risk factors

The dose risk factors were provided by GSF [9] and give the probability for fatal stochastic somatic effects as a function of time after irradiation. The values refer to a population of 1 million people irradiated with 0.01 Sv and depend on the organ, sex and age of the individuals. They are not needed for the calculation of the genetically significant dose.

1 leukemia (M)	10 leukemia (F)	20 skin (M)
2 bone surface (M)	11 bone surface (F)	21 skin (F)
3 thyroid (M)	12 thyroid (F)	22 leukemia (M, fine)
	13 breast (F)	23 bone surface (M, fine)
4 lung (M)	14 lung (F)	24 leukemia (F, fine)
5 stomach (M)	15 stomach (F)	25 bone surface (F, fine)
6 colon (M)	16 colon (F)	
7 liver (M)	17 liver (F)	
8 pancreas (M)	18 pancreas (F)	
9 others (M)	19 others (F)	

M = male; F = female
fine means: finer time resolution up to 40 years

The basic data consist of 24 tables, each subdivided into 17 age groups (0, 5, 10, 15, 20, ..., 80 years). Except for the last four tables, each age group contains 20 values giving the integral values of the risk factors for the time periods from 0 to 100 years after single irradiation with a resolution of 5 years. An example is given in Table 46 for lung cancer (male). Additionally, the last four tables give further information for a more detailed time resolution (steps of two years) for the period 0 to 40 years after irradiation.

Apart from the reorganization of the file structure and the order of the organs, the following changes have been made to the original data:

- Averaging the values over the sexes $((M + F)/2)$
- Conversion into values per individual (factor 10^{-6})
- Linear interpolation of the time after irradiation using the data with fine resolution where available
- Extension of the age grouping to yearly age steps up to age 94; assignment of the value for the age group 80 to the ages 81 to 94

Finally a binary data file is obtained which is used as input file for the ARCO-programs; the file used for all exposure pathways except ingestion has the following structure in FORTRAN-notation:

```

    DIMENSION DAM(100,94,10)
    DO ## IOG=1,10
    DO ## IAG=1,94
        READ(9) (DAM(ITIM,IAG,IOG),ITIM=1,100)
    ## CONTINUE

```

DAM = array containing the integral risk factors for a single irradiation
 IOG = loop over the organs; order according to Table 41
 IAG = loop over the age at irradiation, steps of one year
 ITIM= loop over the years after irradiation

The structure of the file used for the ingestion pathway is slightly different as it contains a file header at the beginning:

```

    PARAMETER (MAXTIM=200, MXXTIM=100, MAXORG=12,MXXORG=11)
    PARAMETER (MAXJAG=100, MXXJAG=94)
    CHARACTER*8 CFIL13(10),ORGNAM(MXXORG)
    DIMENSION DAM(MAXTIM,MAXJAG,MAXORG)
    READ(24) CFIL13
    READ(24) IDUM
    READ(24) (ORGNAM(IOR),IOR=1,IDUM)
    DO ## IOR=1,MXXORG
    DO ## JAG=1,MXXJAG
        READ(24) (DAM(JTI,JAG,IOR),JTI=1,MXXTIM)
    ## CONTINUE

```

Table 46. Number of excess cases of lung cancer in men

		cancer type: lung (in men)										life lost ² (days)									
		for 0.01 Sv irradiation of a population of 1 million																			
		integral number of excess cases for years after the irradiation ¹																			
		-10-	-20-	-30-	-40-	-50-	-60-	-70-	-80-	-90-	-100										
age at expos.																					
0	0	0	0	0	0	0	1	2	4	8	18	33	55	79	102	117	123	125	125	125	.565
5	0	0	0	0	0	0	1	2	4	8	18	33	55	80	102	117	124	126	126	126	.568
10	0	0	0	0	1	2	4	8	18	34	55	80	103	118	124	126	126	126	126	126	.569
15	0	0	0	1	2	4	9	18	34	55	80	103	118	125	126	127	127	127	127	127	.571
20	0	0	1	2	4	8	18	34	55	80	103	118	125	127	127	127	127	127	127	127	.572
25	0	0	1	3	8	16	31	50	74	94	108	114	116	116	116	116	116	116	116	116	.522
30	0	1	2	5	11	20	33	48	62	72	76	77	77	77	77	77	77	77	77	77	.342
35	0	1	3	7	14	23	34	44	51	53	54	54	54	54	54	54	54	54	54	54	.239
40	0	2	5	10	18	26	34	39	42	42	42	42	42	42	42	42	42	42	42	42	.181
45	0	3	7	14	21	28	32	34	34	35	35	35	35	35	35	35	35	35	35	35	.142
50	0	4	10	17	23	28	29	30	30	30	30	30	30	30	30	30	30	30	30	30	.114
55	0	6	13	20	24	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	.090
60	0	8	15	20	22	22	23	23	23	23	23	23	23	23	23	23	23	23	23	23	.067
65	0	9	15	18	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	.046
70	0	10	14	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	.029
75	0	7	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	.015
80	0	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	.005

Note:

¹ Assuming the natural cancer risk for men in the German population

² Average period of life lost for men in the German population per person and 0.01 Sv

C.2.3 Additional data for ingestion pathway

To calculate the activity risk coefficients for the ingestion pathway information is needed on the consumption rates and the activities in foodstuffs. The consumption rates have to be available as a function of age (100 years) and foodstuff (10). The activities in foodstuffs depend on the time after irradiation (time span of 200 years), the foodstuffs and nuclides. All values are given in steps of 1 year. More details about these data can be found in [5].

C.2.4 Other data files

The following data files are generated by hand and are input to the ARCO-program via NAMELIST as they are relatively few.

C.2.4.1 *Distribution of life-expectancy for new-born*

The distribution of life-expectancy describes the probability that a new-born reaches a certain age. The data used are based on data for certain age classes as given in [20]. The numbers refer to a stationary population and are given in Table 47. They have been linearly interpolated to get a yearly resolution and are available up to age 95.

117.20E-04,	8.70E-04,	4.80E-04,	4.80E-04,	4.80E-04,	3.00E-04,
3.00E-04,	3.00E-04,	3.00E-04,	3.00E-04,	2.52E-04,	2.52E-04,
2.52E-04,	2.52E-04,	2.52E-04,	7.73E-04,	7.73E-04,	7.73E-04,
7.73E-04,	7.73E-04,	9.07E-04,	9.07E-04,	9.07E-04,	9.07E-04,
9.07E-04,	8.84E-04,	8.84E-04,	8.84E-04,	8.84E-04,	8.84E-04,
10.61E-04,	10.61E-04,	10.61E-04,	10.61E-04,	10.61E-04,	15.37E-04,
15.37E-04,	15.37E-04,	15.37E-04,	15.37E-04,	23.84E-04,	23.84E-04,
23.84E-04,	23.84E-04,	23.84E-04,	37.96E-04,	37.96E-04,	37.96E-04,
37.96E-04,	37.96E-04,	59.00E-04,	59.00E-04,	59.00E-04,	59.00E-04,
59.00E-04,	86.00E-04,	86.00E-04,	86.00E-04,	86.00E-04,	86.00E-04,
127.00E-04,	127.00E-04,	127.00E-04,	127.00E-04,	127.00E-04,	185.00E-04,
185.00E-04,	185.00E-04,	185.00E-04,	185.00E-04,	265.00E-04,	265.00E-04,
265.00E-04,	265.00E-04,	265.00E-04,	338.00E-04,	338.00E-04,	338.00E-04,
338.00E-04,	338.00E-04,	351.00E-04,	351.00E-04,	351.00E-04,	351.00E-04,
351.00E-04,	269.00E-04,	269.00E-04,	269.00E-04,	269.00E-04,	269.00E-04,
173.00E-04,	173.00E-04,	173.00E-04,	173.00E-04,	173.00E-04,	173.00E-04,

Table 47. Distribution of life-expectancy (for 95 ages; NAMELIST parameter PI)

This data file is used by all exposure pathways to calculate the activity risk coefficients for all ten cancer types in the living and future generations. The gonads which are used for the genetically significant dose require another data set giving the birth distribution and described in the next section.

C.2.4.2 Birth distribution

The birth distribution specifies the number of new-borns according to the age of the mother and normalized to the total number of births:

$$z(L) = \frac{N(L)}{\sum_L N(L)} \quad [C.1]$$

where

- L = age
- N(L) = number of live births at a certain age
- $\sum_L N(L)$ = total number of live births

It is: $\sum_L z(L) = 1$

With

$$Z_0 = \int L z(L) dL = \sum_L L z(L), \quad [C.2]$$

the genetically significant dose D^{GSD} due to exposure pathway EP for a mean individual is calculated according to:

$$D_{GSD}(EP) = \frac{1}{Z_0} \int_0^\infty \int_A^\infty z(L) D_{GO}(EP) dL dA \quad [C.3]$$

where $D^{GO}(EP)$ = gonad dose for exposure pathway EP .

The number of births broken down by age classes have been taken from [20]; from these data a data set for $z(L)$ with $L = 14$ to 45 years has been derived (see Table 48) and Z_0 has been calculated to be 26.92 years.

9.13E-05,	4.69E-04,	2.54E-03,	0.01,	0.02,	0.03,	0.04,
0.05,	0.06,	0.07,	0.07,	0.08,	0.08,	0.07,
0.07,	0.07,	0.06,	0.05,	0.04,	0.03,	0.02,
0.02,	0.01,	0.01,	0.01,	0.01,	0.01,	4.29E-03,
2.76E-03,	1.68E-03,	8.71E-04,	1.16E-03			

Table 48. Birth distribution for ages 14 to 45 of the mother (NAMELIST parameter ZI)

C.2.4.3 Age-correction factors for external exposure pathways

As the dose conversion factors for cloudshine and groundshine refer to an adult reference person, they are multiplied during run-time with age-dependent correction factors. These factors were provided by GSF for six age groups and are shown in Table 49. By linear interpolation a file with a yearly resolution up to age 15 has been derived.

age [a]	cloudshine	groundshine
0	1.5	1.8
1 (for 1, 2, 3)	1.5	1.8
5 (for 4, 5, 6, 7)	1.4	1.5
10 (for 8, 9, 10, 11, 12)	1.3	1.4
15 (for 13, 14, 15)	1.15	1.15
20 (from 16 onwards)	1.0	1.0

Table 49. Age-correction factors for external irradiation (NAMELIST parameter CORRF)

C.2.4.4 Breathing rates for inhalation

The exposure pathways inhalation and resuspension need information on the amount of air incorporated as a function of age.

Table 50 shows breathing rates for different age groups valid for light activity [19]. The breathing rate for adults was assumed to be 100%; for younger persons the percentage was determined. With linear interpolation values for the ages 0 to 19 years were derived as shown in Table 51.

age group	breathing rate in [l/min] resp [m ³ /s]
adult	20 resp. 3.33 10 ⁻⁴
child, 10 a	13 " 2.17 10 ⁻⁴
child, 1 a	4.2 " 7.00 10 ⁻⁵
new-born	1.5 " 2.50 10 ⁻⁵

Table 50. Age-dependent breathing rates

age	fraction	age	fraction	age	fraction
0 - 1	0.08	7 - 8	0.54	14 -15	0.83
1 - 2	0.21	8 - 9	0.60	15 -16	0.86
2 - 3	0.27	9 -10	0.65	16 -17	0.90
3 - 4	0.32	10 -11	0.69	17 -18	0.93
4 - 5	0.38	11 -12	0.72	18 -19	0.97
5 - 6	0.43	12 -13	0.76	19 -94	1.00
6 - 7	0.49	13 -14	0.79		

Table 51. Derived age-dependent fractions of the breathing rate related to adults (NAMELIST parameter ATEMRA)

C.2.4.5 Resuspension function

Resuspension is the inhalation of material already deposited on the ground and then resuspended into the air. Two functions are used to describe the resuspended air concentration:

The time-dependent behaviour of the activity concentration on ground for nuclide k is modelled by the soil migration function $f(t,k)$ according to

$$f(t,k) = e^{-\lambda_k t} \cdot (0.63 \cdot e^{-\lambda_1 t} + 0.37 \cdot e^{-\lambda_2 t}) \quad [C.4]$$

where

$$\begin{aligned} \lambda_k &= \text{radioactive decay constant of nuclide k} \\ \lambda_1 &= 1.50 \cdot 10^{-8} \text{ s}^{-1} \\ \lambda_2 &= 2.38 \cdot 10^{-10} \text{ s}^{-1} \end{aligned}$$

The resuspension factor $r(t)$ describes the time-dependent relationship between the amount of material deposited on ground and the resuspended air concentration. The ratio of resuspended air concentration to deposit is given by

$$r(t) = r_0 \cdot e^{-\lambda_r t} + r_e \quad [C.5]$$

where

$$\begin{aligned} r_0 &= 10^{-5} \text{ m}^{-1} \\ r_e &= 10^{-9} \text{ m}^{-1} \\ \lambda_r &= 1.62 \cdot 10^{-7} \text{ s}^{-1} \end{aligned}$$

The functions and parameter values are described in more detail in [4]. The functions depend only on the time of inhalation and on the half-life of the nuclide.

The integral values RESUS are calculated for 300 yearly time-steps IT for all nuclides considered in COSYMA according to

$$RESUS(IT,k) = \int_0^{IT} f(t,k) \cdot r(t) dt \quad [C.6]$$

These integral values are then differentiated to get yearly differentials RESDIF and stored on a binary data file which is used as input file for the resuspension ARCO-programs; it has the following structure in FORTRAN-notation:

```

PARAMETER(NUCALL=145)
DIMENSION RESDIF(300,NUCALL)
DO ## NUK=1,NUCALL
  READ(10) (RESDIF(IT,NUK),IT=1,300)
## CONTINUE

RESDIF = array containing the differential values of the
        resuspension function r(t) * f(t,k)
NUK    = loop over the nuclides k
IT     = loop over the time t (years) after the accident

```

C.3 Input and output description

C.3.1 Exposure pathways cloudshine, groundshine, inhalation, resuspension

For cloudshine, groundshine, inhalation and resuspension the following I/O-files are required:

- input unit 7 nuclide list with all nuclides considered in COSYMA and their half-lives
- input unit 8 pathway-specific differential dose conversion factors, identical for inhalation and resuspension
- input unit 9 dose risk factors (identical for all pathways)

input unit 10 precalculated values of the resuspension function for each nuclide (only required for resuspension pathway)

output unit 4 results data file in binary form with the calculated activity risk coefficients; its structure is in FORTRAN-notation as follows:

```
DO ## NUK=1,NUCALL            (loop over the nuclides)
DO ## LOG=1,11                (loop over the organs)
DO ## NO =1,NOMAX             (loop over countermeasure times)
WRITE(4) (HLG(N),N=1,8) (loop over the time after accident)
                              respectively
WRITE(4) (HFG(N),N=1,10)
## CONTINUE
```

This is not yet the input file for COSYMA. A transformation into a direct access file is required for each of these pathways and for LG and FG separately.

Parameters defined by the user are contained in NAMELIST RLBERW:

PI(95) distribution of life-expectancy for 95 ages (identical for all exposure pathways); the values used in the calculations are shown in Table 47

ZI(32) birth-distribution for ages 14 to 45 of the mother (identical for all exposure pathways); the values used in the calculations are shown in Table 48

CORRF(94) age-dependent correction factors for the dose conversion factors of cloudshine and groundshine; as from age = 16 onwards the factors have the value of 1.0, only the first 15 values have to be specified; the values used in the calculations are shown in Table 49

ATEMRA(94) age-dependent breathing rates for inhalation and resuspension; as from age = 20 onwards the factors have the value of 1.0, only the first 19 values have to be specified; the values used in the calculations are shown in Table 51

ISEL = 0: calculations are done for all nuclides
 = 1: calculations are done for one nuclide only which is selected by NUKSEL (default)

NUKSEL identification number of the nuclide selected for the calculations (default = 98 = Cs-137); only required if ISEL = 1

The following file gives an example input file for use on an IBM for groundshine and living generations:

```
// EXEC F7CLG,PARM.C='LANGLVL(77)'  
//*  
//*            data file containing the ARCO-program  
//C.SYSIN DD DSN=ARCOS.FORT(ARCOGRLF),DISP=SHR
```

```

/**
/** -----
/**
/**      printer output file
/**G.FT06F001 DD SYSOUT=*,DCB=(LRECL=133,BLKSIZE=133)
/**
/**      input file with basic nuclide list in COSYMA
/**G.FT07F001 DD DISP=SHR,DSN=HEADERN.DATA
/**
/**      input file with differential dose conversion factors for groundshine
/**G.FT08F001 DD DISP=SHR,DSN=DDFGR.DATA
/**
/**      input file with dose risk factors
/**G.FT09F001 DD DISP=SHR,DSN=MORINT.DATA
/**
/**      output file with the calculated activity risk coefficients for GR-LG
/**G.FT04F001 DD DISP=SHR,DSN=MORTGRLG.DATA
/**
/** -----
/**
/**      NAMLIST input data
/**
/**G.SYSIN DD *
&RLBERW
  PI = 117.20E-04,  8.70E-04,  4.80E-04,  4.80E-04,  4.80E-04,  3.00E-04,
        3.00E-04,  3.00E-04,  3.00E-04,  3.00E-04,  2.52E-04,  2.52E-04,
        2.52E-04,  2.52E-04,  2.52E-04,  7.73E-04,  7.73E-04,  7.73E-04,
        7.73E-04,  7.73E-04,  9.07E-04,  9.07E-04,  9.07E-04,  9.07E-04,
        9.07E-04,  8.84E-04,  8.84E-04,  8.84E-04,  8.84E-04,  8.84E-04,
        10.61E-04, 10.61E-04, 10.61E-04, 10.61E-04, 10.61E-04, 15.37E-04,
        15.37E-04, 15.37E-04, 15.37E-04, 15.37E-04, 23.84E-04, 23.84E-04,
        23.84E-04, 23.84E-04, 23.84E-04, 37.96E-04, 37.96E-04, 37.96E-04,
        37.96E-04, 37.96E-04, 59.00E-04, 59.00E-04, 59.00E-04, 59.00E-04,
        59.00E-04, 86.00E-04, 86.00E-04, 86.00E-04, 86.00E-04, 86.00E-04,
        127.00E-04,127.00E-04,127.00E-04,127.00E-04,127.00E-04,185.00E-04,
        185.00E-04,185.00E-04,185.00E-04,185.00E-04,265.00E-04,265.00E-04,
        265.00E-04,265.00E-04,265.00E-04,338.00E-04,338.00E-04,338.00E-04,
        338.00E-04,338.00E-04,351.00E-04,351.00E-04,351.00E-04,351.00E-04,
        351.00E-04,269.00E-04,269.00E-04,269.00E-04,269.00E-04,269.00E-04,
        173.00E-04,173.00E-04,173.00E-04,173.00E-04,173.00E-04,

  ZI = 9.13E-05, 4.69E-04, 2.54E-03, 0.01,    0.02,    0.03,    0.04,
        0.05,    0.06,    0.07,    0.07,    0.08,    0.08,    0.07,
        0.07,    0.07,    0.06,    0.05,    0.04,    0.03,    0.02,
        0.02,    0.01,    0.01,    0.01,    0.01,    0.01,    4.29E-03,
        2.76E-03, 1.68E-03, 8.71E-04, 1.16E-03

  CORRF = 1.8, 1.8, 1.8, 1.5, 1.5, 1.5, 1.5,
          1.4, 1.4, 1.4, 1.4, 1.4, 1.15,1.15,1.15,

  NUKSEL=98,ISEL=1
&END

```

C.3.2 Exposure pathway ingestion

For ingestion the following I/O-files are required:

- input unit 20 IG-nuclide master file containing all those nuclides considered for the ingestion pathway in COSYMA
- input unit 21 activities in foodstuffs, for winter or summer season
- input unit 22 consumption rates
- input unit 23 differential ingestion dose conversion factors
- input unit 24 dose risk factors
- output unit 7 results data file in binary form with the calculated activity risk coefficients; its structure is in FORTRAN-notation as follows:

```
DO ## NUK=1,NDCF          (loop over the nuclides)
DO ## IOG=1,11            (loop over the organs)
DO ## IFO=1,NFOO          (loop over the foodstuffs)
DO ## NO =1,NBAN          (loop over countermeasure times)
  WRITE(7) (HLG(N),N=1,8) (loop over the times after accident)
  respectively
  WRITE(7) (HFG(N),N=1,10)
## CONTINUE
```

For summer and winter season separate calculations are required. Thus, in total four files with activity risk coefficients for IG have to be created. These are not yet the input file for COSYMA. The files for LG and FG have to be combined before with a post-processor which also creates values for bantimes < 1 year.

NAMelist RLBERW is similar as for the other pathways. However, the parameters ATEMRA and CORRF are not needed and the option to select one or all nuclides is different.

Parameters defined by the user are contained in NAMelist RLBERW:

- PI(95) distribution of life-expectancy for 95 ages (identical for all exposure pathways)
- ZI(32) birth-distribution for ages 14 to 45 of the mother (identical for all exposure pathways)
- NNSEL = 0: calculations are done for all nuclides
= 1: calculations are done for one nuclide only which is selected by CNSEL
- CNSEL name (CHAR*8) of the nuclide selected for the calculations; only required if NNSEL = 1

IDEBUG option to get detailed printout of input data files (default: 0, i.e. no printout)

The following file gives an example input file for use on an IBM for ingestion in the summer season and future generations:

```
// EXEC F7CLG,PARM.C='LANGVL(77)'  
/**  
/**      data file containing the ARCO-program  
//C.SYSIN DD DSN=ARCOS.FORT(ARCOIGFG),DISP=SHR  
/**  
/** -----  
/**  
/**      printer output file  
//G.FT06F001 DD SYSOUT=*,DCB=(LRECL=133,BLKSIZE=133)  
/**  
/**      input file with IG-nuclide master file  
//G.FT20F001 DD DISP=SHR,DSN=COSING.INPUT(INGNUKLS)  
/**  
/**      input file with activities in food for summer  
//G.FT21F001 DD DISP=SHR,DSN=IG39AX.INPUT(FARJULSP)  
/**  
/**      input file with consumption rates for ingestion  
//G.FT22F001 DD DISP=SHR,DSN=COSING.INPUT(FCBRD10)  
/**  
/**      input file with differential dose conversion factors for ingestion  
//G.FT23F001 DD DISP=SHR,DSN=COSING.INPUT(NRPDPUID)  
/**  
/**      input file with dose risk factors  
//G.FT24F001 DD DISP=SHR,DSN=COSING.INPUT(GSFRCF88)  
/**  
/**      output file with the calculated activity risk coefficients for IG-FG  
//G.FT07F001 DD DISP=SHR,DSN=MORTIGFG.DATA  
/**  
/** -----  
/**  
/**      NAMLIST input data  
/**  
//G.SYSIN DD *  
&RLBERW  
PI= 117.20E-04, 8.70E-04, 4.80E-04, 4.80E-04, 4.80E-04, 3.00E-04,  
3.00E-04, 3.00E-04, 3.00E-04, 3.00E-04, 2.52E-04, 2.52E-04,  
2.52E-04, 2.52E-04, 2.52E-04, 7.73E-04, 7.73E-04, 7.73E-04,  
7.73E-04, 7.73E-04, 9.07E-04, 9.07E-04, 9.07E-04, 9.07E-04,  
9.07E-04, 8.84E-04, 8.84E-04, 8.84E-04, 8.84E-04, 8.84E-04,  
10.61E-04, 10.61E-04, 10.61E-04, 10.61E-04, 10.61E-04, 15.37E-04,  
15.37E-04, 15.37E-04, 15.37E-04, 15.37E-04, 23.84E-04, 23.84E-04,  
23.84E-04, 23.84E-04, 23.84E-04, 37.96E-04, 37.96E-04, 37.96E-04,  
37.96E-04, 37.96E-04, 59.00E-04, 59.00E-04, 59.00E-04, 59.00E-04,  
59.00E-04, 86.00E-04, 86.00E-04, 86.00E-04, 86.00E-04, 86.00E-04,  
127.00E-04, 127.00E-04, 127.00E-04, 127.00E-04, 127.00E-04, 185.00E-04,  
185.00E-04, 185.00E-04, 185.00E-04, 185.00E-04, 265.00E-04, 265.00E-04,  
265.00E-04, 265.00E-04, 265.00E-04, 338.00E-04, 338.00E-04, 338.00E-04,  
338.00E-04, 338.00E-04, 351.00E-04, 351.00E-04, 351.00E-04, 351.00E-04,  
351.00E-04, 269.00E-04, 269.00E-04, 269.00E-04, 269.00E-04, 269.00E-04,  
173.00E-04, 173.00E-04, 173.00E-04, 173.00E-04, 173.00E-04,  
  
ZI= 9.13E-05, 4.69E-04, 2.54E-03, 0.01, 0.02,  
0.03, 0.04, 0.05, 0.06, 0.07,  
0.07, 0.08, 0.08, 0.07, 0.07,  
0.07, 0.06, 0.05, 0.04, 0.03,  
0.02, 0.02, 0.01, 0.01, 0.01,  
0.01, 0.01, 4.29E-03, 2.76E-03, 1.68E-03,
```

```
      8.71E-04,  1.16E-03,  
  IDEBUG=0,NNSEL=1,CNSEL='CS-137  '  
&END
```

C.3.3 Creation of input data files for COSYMA

As the data files for ingestion are also used in the separated program system UFOING [5], their structure is different from that of the other exposure pathways. The following descriptions refer only to the other four exposure pathways.

COSYMA needs the activity risk coefficients for all countermeasure times and for the time point 90 years after the accident (in the case of living generations) and 200 years (future generations), respectively. In the special version of COSYMA (FL-T) calculating the time-dependent occurrence of cancer data files containing all 8 and 10, respectively, time points after the accident are required. Thus, a set of six direct access files is needed for the standard version and another set for the time-dependent version of COSYMA.

The following table shows the structure of the data files containing the activity risk coefficients for use in the subsystems NL and FL of COSYMA. The I/O-unit number refers to the input number via which the data is read in in COSYMA.

Name	no of unit	structure (from inside to outside)			observation times		
		nuclides	organs	counterm times n0	nnz		
ARCOCL.DATA	71	NUCALL	11	1	1	(value for 90a)	
ARCOGRLG.DATA	72	"	"	10	1	"	"
ARCOIH.DATA	73	"	"	1	1	"	"
ARCOIRLG.DATA	74	"	"	10	1	"	"
ARCOIRFG.DATA	75	"	"	10	1	(value for 200a)	
ARCOGRFG.DATA	76	"	"	10	1	"	"
ARCTCL.DATA	81	"	"	1	8		
ARCTGRLG.DATA	82	"	"	10	8		
ARCTIH.DATA	83	"	"	1	8		
ARCTIRLG.DATA	84	"	"	10	8		
ARCTIRFG.DATA	85	"	"	10	10		
ARCTGRFG.DATA	86	"	"	10	10		

General structure in FORTRAN-notation:

To achieve the same record structure the data for the pathways having only one countermeasure time are filled up with zeros.

Standard files (71-76):

Only the value for the last observation time NNZ is stored.

```

C      PARAMETER ( NNZ= 8, NOMAX=10 )          (* for LG *)
      PARAMETER ( NNZ=10, NOMAX=10 )         (* for FG *)
      DIMENSION ARCO(NNZ,NOMAX)

      OPEN(UNIT= $$,ACTION='WRITE',ACCESS='DIRECT',RECL=40)
      ISNR=0
      DO ## NUK=1,NUCALL
      DO ## IOG=1,11
         ISNR=ISNR+1
         WRITE($$,REC=ISNR) (ARCO(NNZ,NO),NO=1,NOMAX)
      ## CONTINUE
      CLOSE $$

```

Time-dependent files (81-86):

The values for all observation times are stored; the number of times considered is different for LG and FG.

```

C      PARAMETER ( NNZ= 8, NOMAX=10 )          (* for LG *)
      PARAMETER ( NNZ=10, NOMAX=10 )         (* for FG *)
      DIMENSION ARCO(NNZ,NOMAX)

C      OPEN(UNIT= $$,ACTION='WRITE',ACCESS='DIRECT',RECL=320) (* for LG *)
      OPEN(UNIT= $$,ACTION='WRITE',ACCESS='DIRECT',RECL=400) (* for FG *)
      ISNR=0
      DO ## NUK=1,NUCALL
      DO ## IOG=1,11
         ISNR=ISNR+1
         WRITE($$,REC=ISNR) ((ARCO(NZ,NO),NZ=1,NNZ),NO=1,NOMAX)
      ## CONTINUE
      CLOSE $$

```

Table 52. Structure of the ARCO-files required by COSYMA

C.4 Some example results

The following tables show the results of the activity risk coefficients for the nuclides I-131 and Cs-137 and for the exposure pathways groundshine (organs lung and bone marrow, LG and FG) and inhalation (all organs).

Table 53. Activity risk coefficients for groundshine, living generations

nuclide	organ	time	5. year	10. year	20. year	30. year	40. year	50. year	70. year	90. year
I -131	lung	0	0.00E+00	7.90E-14	2.44E-13	4.76E-13	8.16E-13	1.28E-12	2.18E-12	2.36E-12
I -131	lung	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I -131	lung	2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I -131	lung	5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I -131	lung	10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I -131	lung	20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I -131	lung	30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I -131	lung	40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I -131	lung	50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I -131	lung	70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
nuclide	organ	time	5. year	10. year	20. year	30. year	40. year	50. year	70. year	90. year
I -131	b.marrow	0	2.40E-13	9.15E-13	1.52E-12	1.73E-12	1.80E-12	1.82E-12	1.83E-12	1.83E-12
I -131	b.marrow	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I -131	b.marrow	2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I -131	b.marrow	5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I -131	b.marrow	10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I -131	b.marrow	20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I -131	b.marrow	30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I -131	b.marrow	40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I -131	b.marrow	50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I -131	b.marrow	70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

NOTE:

The lines of the matrix give for a specific countermeasure time (3rd row) the values for all observation times (time points after the accident)

Table 54. Activity risk coefficients for groundshine, living generations (cont'd)

nuclide	organ	time	5. year	10. year	20. year	30. year	40. year	50. year	70. year	90. year
CS-137	lung	0	0.00E+00	4.29E-12	2.26E-11	5.24E-11	9.67E-11	1.58E-10	2.82E-10	3.09E-10
CS-137	lung	1	0.00E+00	2.84E-12	1.81E-11	4.37E-11	8.18E-11	1.35E-10	2.42E-10	2.65E-10
CS-137	lung	2	0.00E+00	1.32E-12	1.27E-11	3.30E-11	6.34E-11	1.06E-10	1.93E-10	2.12E-10
CS-137	lung	5	0.00E+00	0.00E+00	5.42E-12	1.77E-11	3.69E-11	6.37E-11	1.21E-10	1.33E-10
CS-137	lung	10	0.00E+00	0.00E+00	9.92E-13	6.93E-12	1.73E-11	3.19E-11	6.39E-11	7.09E-11
CS-137	lung	20	0.00E+00	0.00E+00	0.00E+00	5.37E-13	3.65E-12	8.76E-12	2.02E-11	2.29E-11
CS-137	lung	30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.98E-13	1.94E-12	6.25E-12	7.29E-12
CS-137	lung	40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.65E-13	1.81E-12	2.30E-12
CS-137	lung	50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.78E-13	6.36E-13
CS-137	lung	70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.04E-14
nuclide	organ	time	5. year	10. year	20. year	30. year	40. year	50. year	70. year	90. year
CS-137	b.marrow	0	7.24E-12	5.40E-11	1.43E-10	1.96E-10	2.25E-10	2.40E-10	2.49E-10	2.50E-10
CS-137	b.marrow	1	2.84E-12	3.72E-11	1.15E-10	1.64E-10	1.93E-10	2.07E-10	2.16E-10	2.16E-10
CS-137	b.marrow	2	6.83E-13	1.96E-11	8.14E-11	1.26E-10	1.52E-10	1.66E-10	1.75E-10	1.75E-10
CS-137	b.marrow	5	0.00E+00	2.39E-12	3.62E-11	7.08E-11	9.41E-11	1.07E-10	1.15E-10	1.16E-10
CS-137	b.marrow	10	0.00E+00	0.00E+00	8.20E-12	3.03E-11	4.93E-11	6.40E-11	6.92E-11	6.98E-11
CS-137	b.marrow	20	0.00E+00	0.00E+00	0.00E+00	3.61E-12	1.33E-11	2.20E-11	2.93E-11	3.00E-11
CS-137	b.marrow	30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-12	6.31E-12	1.20E-11	1.26E-11
CS-137	b.marrow	40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.54E-13	4.25E-12	4.81E-12
CS-137	b.marrow	50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.13E-12	1.52E-12
CS-137	b.marrow	70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.99E-14

NOTE:

The lines of the matrix give for a specific countermeasure time (3rd row) the values for all observation times (time points after the accident)

Table 55. Activity risk coefficients for groundshine, future generations

I-131, lung										
time	5. year	10. year	20. year	30. year	40. year	50. year	70. year	90. year	150. year	200. year
0	0.00E+00	0.00E+00	0.00E+00	4.38E-16	3.05E-15	1.07E-14	6.61E-14	9.95E-14	9.96E-14	9.96E-14
1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I-131, bone marrow										
time	5. year	10. year	20. year	30. year	40. year	50. year	70. year	90. year	150. year	200. year
0	1.26E-14	5.50E-14	7.77E-14	8.27E-14	8.51E-14	8.63E-14	8.78E-14	8.78E-14	8.78E-14	8.78E-14
1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

NOTE:
The lines of the matrix give for a specific countermeasure time (1st row) the values for all observation times (time points after the accident)

Table 56. Activity risk coefficients for groundshine, future generations (cont'd)

Cs-137, lung										
time	5. year	10. year	20. year	30. year	40. year	50. year	70. year	90. year	150. year	200. year
0	0.00E+00	0.00E+00	0.00E+00	1.12E-13	1.57E-12	6.60E-12	5.48E-11	1.36E-10	2.02E-10	2.05E-10
1	0.00E+00	0.00E+00	0.00E+00	1.04E-13	1.52E-12	6.41E-12	5.36E-11	1.34E-10	2.00E-10	2.03E-10
2	0.00E+00	0.00E+00	0.00E+00	8.75E-14	1.39E-12	5.95E-12	5.07E-11	1.30E-10	1.95E-10	1.98E-10
5	0.00E+00	0.00E+00	0.00E+00	5.76E-14	1.05E-12	4.79E-12	4.28E-11	1.16E-10	1.82E-10	1.85E-10
10	0.00E+00	0.00E+00	0.00E+00	2.95E-14	6.11E-13	3.18E-12	3.08E-11	9.33E-11	1.58E-10	1.61E-10
20	0.00E+00	0.00E+00	0.00E+00	5.16E-15	1.59E-13	1.16E-12	1.40E-11	5.19E-11	1.14E-10	1.17E-10
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.53E-14	2.93E-13	5.44E-12	2.49E-11	7.92E-11	8.24E-11
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.69E-14	1.78E-12	1.07E-11	5.51E-11	5.82E-11
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.21E-13	4.30E-12	3.88E-11	4.19E-11
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.30E-13	2.03E-11	2.34E-11
Cs-137, bone marrow										
time	5. year	10. year	20. year	30. year	40. year	50. year	70. year	90. year	150. year	200. year
0	4.67E-13	8.32E-12	3.59E-11	6.15E-11	8.08E-11	9.52E-11	1.14E-10	1.29E-10	1.42E-10	1.42E-10
1	2.36E-13	7.31E-12	3.45E-11	6.00E-11	7.92E-11	9.37E-11	1.13E-10	1.28E-10	1.40E-10	1.40E-10
2	7.74E-14	5.04E-12	3.08E-11	5.61E-11	7.52E-11	8.96E-11	1.09E-10	1.24E-10	1.36E-10	1.36E-10
5	0.00E+00	7.28E-13	2.06E-11	4.48E-11	6.35E-11	7.77E-11	9.65E-11	1.11E-10	1.24E-10	1.24E-10
10	0.00E+00	0.00E+00	6.63E-12	2.77E-11	4.56E-11	5.93E-11	7.77E-11	9.27E-11	1.05E-10	1.05E-10
20	0.00E+00	0.00E+00	0.00E+00	4.39E-12	1.83E-11	3.07E-11	4.83E-11	6.29E-11	7.52E-11	7.53E-11
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.81E-12	1.22E-11	2.84E-11	4.28E-11	5.50E-11	5.51E-11
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.87E-12	1.48E-11	2.87E-11	4.09E-11	4.09E-11
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.60E-12	1.86E-11	3.06E-11	3.06E-11
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.37E-12	1.76E-11	1.76E-11

NOTE:
The lines of the matrix give for a specific countermeasure time (1st row) the values for all observation times (time points after the accident)

