Commission of the European Communities

Radiation protection

Cosyma
A new programme package
for accident consequence assessment

Report

EUR 13028 EN

Commission of the European Communities

Radiation protection

Cosyma
A new programme package
for accident consequence assessment

Commission of the European Communities

Report

EUR 13028 EN

Radiation protection

Cosyma
A new programme package
for accident consequence assessment

Contract Nos B16-F-128-D, B16-F-127-UK

Final report

LEGAL NOTICE

Cataloguing data can be found at the end of this publication

⋆ COSYMA ⋆

A NEW PROGRAM PACKAGE FOR ACCIDENT CONSEQUENCE ASSESSMENT

September 1990

A joint report by

KERNFORSCHUNGSZENTRUM KARLSRUHE GmbH (FRG)

and

NATIONAL RADIOLOGICAL PROTECTION BOARD (UK)

— III —

9403220226

The staff involved in the development of the COSYMA package were:

K f K	N R P B
K. Burkart	J. Brown
J. Ehrhardt	M.J. Crick (a)
D. Faude	S.M. Haywood
I. Hasemann	M.D. Hill (b)
C. Matzerath	J.A. Jones
D. Meyer (*)	C. Robinson
H.-J. Panitz	J.R. Simmonds
W. Raskob (*)	J. Smith
C. Steinhauer	A. Walmsley
	J.A. Williams (c)

(*) DTI Dr. Trippe	(a) Now at IAEA
Ing.-ges. mbH	(b) Now at Electrowatt
	(c) Now at SRD, UKAEA

The CEC's MARIA programme (Methods for Assessing the Radiological Impact of Accidents) was initiated in 1982 to review and build on the nuclear accident consequence assessment methods in use within the European Community (EC). The project includes a wide range of theoretical and experimental studies carried out by a variety of organisations within the EC. The main contractors are the Kernforschungszentrum Karlsruhe (KfK, FRG) and the National Radiological Protection Board (NRPB, UK). Earlier work carried out under the MARIA programme is described in a report by KfK and NRPB [1] written at the end of the first stage of the programme. Three seminars have also been held at which results of the programme were presented [2], [3], [4].

One of the objectives of the MARIA programme is to develop a computer program system for assessing the off-site consequences of accidental releases of radioactive material to atmosphere. This report describes a program system developed as part of the MARIA programme for this purpose. The new program system, called COSYMA (COde SYstem from MARIA), was developed jointly by KfK and NRPB and has been made generally available. COSYMA is based on the experience gained with the NRPB program MARC and the KfK program UFOMOD. The MARC and UFOMOD programs were developed for use in risk assessments in the UK and the FRG. MARC was originally developed in 1981 [5] and and has been used in several analyses, including some for the Public Inquiries into proposals to build PWRs at two sites in the UK, Sizewell [6] and Hinkley Point [7], [8]. UFOMOD was originally developed in 1979 and has been used for a variety of studies, including the German Risk Study [9] and and the risk-oriented analysis of the SNR-300 fast reactor [10]. More recently, it has been completely restructured and revised in all models and data sets and it was released in 1988 as the program system UFOMOD [11], [17]. COSYMA incorporates ideas and modules from these programs with new developments, including those from other MARIA contractors. The report written at the end of the first stage of the MARIA programme [1] identified a number of areas in which accident consequence models might be improved. Many of these improvements are included in COSYMA.

This report describes the suite of programs and data files which comprise COSYMA, the models included in the programs, the types of results which can be calculated and possible areas of application of the package. A separate user-guide for the programs is also available [18]. Other reports which describe in detail the models in MARC, UFOMOD and COSYMA have been or will be published (see [11] - [16] and [19], and the reports cited there). The method of obtaining the COSYMA package is given in Appendix 1.

COSYMA is intended to provide a flexible package which will allow users in a variety of institutions and in different European countries to investigate special problems by appropriate choice of parameter values and data sets. It enables users to carry out risk analyses,

and also to investigate and understand detailed aspects of the results obtained. COSYMA is also intended for use by people who are not specialists in accident consequence assessments (ACA). However, users of the programs must have some familiarity with this area to enable them to make informed choices of models and parameter values for the particular application considered. While the program is not intended for "quick and easy" risk calculations, some guidance is given on the choice of parameter values or simplifications of the system for such applications.

The possible areas in which accident consequence assessments may be of use were considered in the report written at the end of the first phase of the MARIA programme [1]. They can be summarised as evaluating the overall risk posed by a specific or representative nuclear site, evaluating the risk reduction potential of possible plant modifications, emergency planning, and some aspects of siting studies. The consequences of accidental releases in terms of the possible health effects, the impact of countermeasures which may be required, and the costs of the accident may be an input into such work, and can be evaluated by COSYMA. Details of the types of consequences which can be considered by COSYMA are given in Section 2 of this report. Different end-points may be required for the different applications indicated here. Equally the most appropriate way in which to present the results of the calculations can depend on the application being considered. COSYMA provides a number of different ways in which information can be presented, and the user must select the most appropriate method for his application. The types of output which are available from COSYMA are described in Section 7.

COSYMA is designed for use in probabilistic risk assessments. This means that the models included within the system only need to be applicable on average and need not be "correct" at a specific time and location. While this is particularly true of the atmospheric dispersion models, it also applies to some other models. Equally COSYMA uses parameter values which represent the average situation in the region considered, and so does not attempt to model the full spatial variation which might be encountered. This means that the COSYMA system is not suitable for use in real time in the event of an accident.

The COSYMA package consists of three large accident consequence assessment programs and a variety of supporting programs and data libraries. The different programs are intended for use in different parts of an overall analysis. Each of the large programs within COSYMA is written in a modular fashion. This provides a very flexible system for carrying out accident consequence assessments for a wide variety of source terms and applications. The system can be tailored so that the most appropriate program or model is used for each specific application. The programs within the overall package, and the structure of each program, are described in detail in Section 3 of this report. Section 4 considers the way in which the source term can be described. The models included in the programs and the data libraries included in COSYMA are described in Sections 5 and 6 of this report.

The CEC's MARIA programme (Methods for Assessing the Radiological Impact of Accidents) was initiated in 1982 to review and build on the nuclear accident consequence assessment methods in use within the European Community (EC). The project includes a wide range of theoretical and experimental studies carried out by a variety of organisations within the EC. The main contractors are the Kernforschungszentrum Karlsruhe (KfK, FRG) and the National Radiological Protection Board (NRPB, UK). Earlier work carried out under the MARIA programme is described in a report by KfK and NRPB [1] written at the end of the first stage of the programme. Three seminars have also been held at which results of the programme were presented [2], [3], [4].

One of the objectives of the MARIA programme is to develop a computer program system for assessing the off-site consequences of accidental releases of radioactive material to atmosphere. This report describes a program system developed as part of the MARIA programme for this purpose. The new program system, called COSYMA (COde SYstem from MARIA), was developed jointly by KfK and NRPB and has been made generally available. COSYMA is based on the experience gained with the NRPB program MARC and the KfK program UFOMOD. The MARC and UFOMOD programs were developed for use in risk assessments in the UK and the FRG. MARC was originally developed in 1981 [5] and and has been used in several analyses, including some for the Public Inquiries into proposals to build PWRs at two sites in the UK, Sizewell [6] and Hinkley Point [7], [8]. UFOMOD was originally developed in 1979 and has been used for a variety of studies, including the German Risk Study [9] and and the risk-oriented analysis of the SNR-300 fast reactor [10]. More recently, it has been completely restructured and revised in all models and data sets and it was released in 1988 as the program system UFOMOD [11], [17]. COSYMA incorporates ideas and modules from these programs with new developments, including those from other MARIA contractors. The report written at the end of the first stage of the MARIA programme [1] identified a number of areas in which accident consequence models might be improved. Many of these improvements are included in COSYMA.

This report describes the suite of programs and data files which comprise COSYMA, the models included in the programs, the types of results which can be calculated and possible areas of application of the package. A separate user-guide for the programs is also available [18]. Other reports which describe in detail the models in MARC, UFOMOD and COSYMA have been or will be published (see [11] - [16] and [19], and the reports cited there). The method of obtaining the COSYMA package is given in Appendix 1.

COSYMA is intended to provide a flexible package which will allow users in a variety of institutions and in different European countries to investigate special problems by appropriate choice of parameter values and data sets. It enables users to carry out risk analyses,

and also to investigate and understand detailed aspects of the results obtained. COSYMA is also intended for use by people who are not specialists in accident consequence assessments (ACA). However, users of the programs must have some familiarity with this area to enable them to make informed choices of models and parameter values for the particular application considered. While the program is not intended for "quick and easy" risk calculations, some guidance is given on the choice of parameter values or simplifications of the system for such applications.

The possible areas in which accident consequence assessments may be of use were considered in the report written at the end of the first phase of the MARIA programme [1]. They can be summarised as evaluating the overall risk posed by a specific or representative nuclear site, evaluating the risk reduction potential of possible plant modifications, emergency planning, and some aspects of siting studies. The consequences of accidental releases in terms of the possible health effects, the impact of countermeasures which may be required, and the costs of the accident may be an input into such work, and can be evaluated by COSYMA. Details of the types of consequences which can be considered by COSYMA are given in Section 2 of this report. Different end-points may be required for the different applications indicated here. Equally the most appropriate way in which to present the results of the calculations can depend on the application being considered. COSYMA provides a number of different ways in which information can be presented, and the user must select the most appropriate method for his application. The types of output which are available from COSYMA are described in Section 7.

COSYMA is designed for use in probabilistic risk assessments. This means that the models included within the system only need to be applicable on average and need not be "correct" at a specific time and location. While this is particularly true of the atmospheric dispersion models, it also applies to some other models. Equally COSYMA uses parameter values which represent the average situation in the region considered, and so does not attempt to model the full spatial variation which might be encountered. This means that the COSYMA system is not suitable for use in real time in the event of an accident.

The COSYMA package consists of three large accident consequence assessment programs and a variety of supporting programs and data libraries. The different programs are intended for use in different parts of an overall analysis. Each of the large programs within COSYMA is written in a modular fashion. This provides a very flexible system for carrying out accident consequence assessments for a wide variety of source terms and applications. The system can be tailored so that the most appropriate program or model is used for each specific application. The programs within the overall package, and the structure of each program, are described in detail in Section 3 of this report. Section 4 considers the way in which the source term can be described. The models included in the programs and the data libraries included in COSYMA are described in Sections 5 and 6 of this report.

The programs in COSYMA were developed without using formal procedures for quality assurance. The programmers used a variety of less formal techniques for testing the programs, but the results of these many checks were not suitable for documentation. The types of test carried out to demonstrate the correctness of the resulting programs are described in Section 8.

COSYMA was written in such a way that uncertainty and sensitivity analyses into the model predictions can easily be carried out. A number of programs have been developed for use with COSYMA in uncertainty analyses. While these programs are not considered to be a part of the system, they are described in Section 9 of this report, and could be made available if required.

The user of COSYMA must provide values for a considerable number of parameters either by user-input or from data libraries. Default values are provided for many of the parameters in the programs, and standard data libraries are included with the package. These are likely to be suitable for many applications of COSYMA. However the user of the system must select appropriate parameter values for special cases. In some parts of the programs it is possible to change the model by a suitable selection of parameter values. Some guidance is given in Section 10 of this report on the various options offered by user input. This section also gives guidance on how the full suite of programs can be simplified for certain applications.

This report refers to the version of COSYMA designated 90/1. There are a number of areas in which the models or data files included in COSYMA could be improved in future versions of the system. These areas include: the use of different interception factors by crops for material deposited in dry or wet conditions; the calculation of external y dose in urban areas; the method of including the effects of decontamination. The health effects models can be improved by incorporating the dependence of the parameters (LD_{50} or risk coefficient for late effects) on the dose rate, by improving the model for hereditary effects and the method of calculating the loss of life-expectancy. The calculation of age-dependent doses may also be included. The economic module will be extended to consider economic land use data, when this is more widely available.

1. INTRODUCTION

- 3 -

Accident consequence analyses could have as their objective the estimation of any of a wide range of consequences of the accident. These consequences, which are termed "end-points" of the analysis, encompass the air concentration or deposition of particular nuclides or their concentrations in foods at selected points, doses received by members of the population, the individual or collective risks of health effects in the exposed population, the extent and duration of countermeasures which might be imposed to reduce health effects, and the associated economic costs. COSYMA can offer the user a wide range of these end-points. This section gives a brief summary of the more important end-points which can be considered using COSYMA.

The techniques generally used in probabilistic accident consequence assessments lead to a very large number of results for one end-point, as a value is calculated in each of a set of conditions. Each of the calculated values has an associated probability of occurring. In general it is not possible to present each of the values calculated, but rather features of the probability distribution must be presented. The features of these distributions can be presented in a variety of ways, with different forms being appropriate for different applications or for different end-points. The ways in which the results can be presented are described in Section 7.

Health effects following an accident are generally split into two groups, those occurring within a few months of the accident which are termed "early effects", and those occurring over longer periods which are termed "late effects". The late effects include cancers in the exposed population and hereditary effects which occur in their descendants. The early effects and the cancers can be further split into those which are fatal and those which are not. COSYMA includes models allowing the risks of each of these groups of effects to be calculated. Table 1 gives a list of those health effects which are considered in COSYMA. Both the individual and the collective risks of each health effect can be calculated.

The impact of the different types of health effect is clearly very different, and therefore it would not be adequate to limit the results of COSYMA simply to the total number of health effects. Equally, however, information on each of these health effects separately may not be required, and some summation over similar effects is carried out within COSYMA. Thus the results of COSYMA for early death are presented as the total number as well as for each cause of death separately. In addition the number of fetal deaths is calculated. Not all cancers are fatal, and COSYMA provides estimates of both the cancer incidence and the number of fatalities. This is provided both in terms of the total numbers of cancers and the numbers of each of the types of cancer considered in COSYMA.

Cancers occur after a delay of up to some tens of years after exposure and, with irradiation from deposited material persisting for many years after the accident, can occur over a period of time well into the future, and even in people born after the accident occurred. COSYMA includes models for calculating the time at which these effects occur, and it gives information on the numbers of cancers induced in those people alive at the time of the accident, and in those born subsequently, as well as the total number of cancers. More detailed information on the time distribution of fatal cancers can be obtained if required.

A variety of countermeasures might be used to reduce the consequences of an accident. The ones which can be considered in COSYMA are sheltering, evacuation, relocation, administration of stable iodine tablets, decontamination of land and buildings, and bans on the consumption of foods. COSYMA allows the user considerable flexibility in the way in which the criteria for initiating or withdrawing the actions are specified. The criteria may be specified in terms of geometric areas or of dose levels. The food ban criteria may be specified in terms of dose criteria or activity concentrations in foods. Each of the emergency actions identified above can be considered in isolation. In addition, some of the actions can be combined. Thus, for example, sheltering may be the only action considered in the event of a small release, or it may be considered in combination with evacuation for a larger release.

COSYMA includes models which allow the effects of emergency actions in reducing doses and hence health effects to be calculated, and produces indicators of the impact of the countermeasures, in terms of the numbers of people, the amounts of food, or the areas affected by the actions, all as a function of time. Other features about the counter-measures, such as the probability of evacuation as a function of distance, can be presented, as described in Section 7.

The final group of items for which information can be obtained in COSYMA relate to the economic costs of the accident, in terms of the costs arising from the emergency actions and the costs associated with the health effects. The countermeasures involving movement of people, food restrictions and decontamination are considered in evaluating the costs of the accident. The costs of the different emergency actions and of health effects can be obtained separately, or as a total.

3.1 The General Layout of the System

COSYMA comprises a series of programs and data libraries for accident consequence assessments. There are three major programs within the system intended for different aspects of the overall analysis. Other programs are used for detailed analysis or the preparation of input files for the major programs. The system does not include programs for all the calculations which are required, using instead data libraries of values calculated with suitable programs. These libraries are part of COSYMA, and are included in the package. This section describes the programs which form the overall system, indicating the reasons why there are different programs. Section 5 describes the models which are included directly within the programs, while Section 6 describes the models adopted in deriving the data libraries which are included.

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 carried out for each of a number of areas, defined in COSYMA in terms of angular segments and distance bands; throughout each area a uniform level of dose, and hence associated emergency actions and risks, are assumed. The doses in each of these areas are calculated at a single point, the "grid point".

The first process to be considered in an accident consequence assessment is the dispersion of the released material in the atmosphere, and its deposition. There are a considerable number of models which could be used for this part of the assessment, and the different models have different strengths and weaknesses and even different areas in which they are applicable. Most previous ACA programs have been based on the straight line Gaussian plume dispersion model. Some recent ACA programs have used the straight line Gaussian puff model or trajectory models. Strictly, models assuming linear trajectories are only applicable for travel distances up to a few tens of kilometres, though they can be extended for application at longer distances. However, t... become increasingly inaccurate or unreliable at such distances. Other models, which are mr c appropriate for use at longer distances, may not be appropriate for use at short distances either because of assumptions they make or because of their limited spatial resolution. Therefore different dispersion models should be applied in areas which can very loosely be described as "near" to, or "far" from, the site of the release. The COSYMA package includes a set of programs for atmospheric dispersion. They are based on different approximations and are appropriate in different regions or for different applications. The models included are described in Section 5; some guidance on the choice of model for a particular application is given in Section 10.

There are other cases where different models or different considerations apply at different distances from the site. The early effects of radiation only occur if the dose over a short time period is above some threshold value. They are therefore restricted to areas "near" to the site of the release, and only occur following "large" releases of radioactive material. However the late effects of radiation are assumed to occur at any level of dose, and these can therefore occur at any distance. A similar division can also be made between the emergency actions which may be considered following the accidental release, with some concerned with avoiding doses in the short term and some with avoiding long term doses.

There are many source terms for which there is no need to consider early health effects or the emergency actions intended to reduce the high short-term doses which lead to these effects. As the amount of computation required for these aspects of an analysis can be significant, it is logical to further divide the near distance version of COSYMA into two sub-systems concerned with early and late effects.

This emphasis on different distance ranges and different health effects and emergency actions leads to the structure of COSYMA in which there are three principal sub-systems, each of which is an ACA program for one of the different areas of application. The applications of the different programs are illustrated in Figure 1.

The three ACA programs, designated the NE, NL and FL sub-systems 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 the main programs within the package. The structure of each of these programs is described in Section 3.2. These programs can be used for calculating the quantities identified as end-points of COSYMA in Section 2.

This division will enable the system to be extended in a very flexible manner as other dispersion programs are developed to the point where they can be used in ACA programs. It allows a more detailed model to be used for the region close to the site, in which site-specific or terrain effects might be important. It also means that trajectory models can be used for the longer range without having to apply them in the near regions where their predictions may not be so accurate, or where they would require considerable computer time if used with a fine distance grid.

In addition to the three main sub-systems of COSYMA, the package contains a number of other programs for particular facets of an analysis or for preparing input data files for use by the main programs. These subsidiary programs are indicated in Table 2 and their functions are indicated below. The models and assumptions incorporated in these programs are described in Section 5, which also describes the models in the main sub-systems.

3.2 Program Structure of the Sub-systems

The three sub-systems, NE, NL and FL, of COSYMA 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 2. Each of the modules is concerned with one part of the overall analysis. This section summarises the function of each of the modules, and indicates the differences between the three sub-systems.

The results calculated by each of the modules are written to files, which are read by the subsequent modules. The main routine of each of the sub-systems controls the choice of and flow through the modules. The sub-systems can be run in their entirety or certain modules only can be selected. There is no need to run all the modules within the sub-system if the required results can be obtained from only some of the modules. Runs of the program can use results from earlier runs if the results of the modules are stored in permanent files. This allows sensitivity or uncertainty analyses of single modules to be performed without repeating all the preceding computational steps. It also means that a complex and time-consuming model can be used for some parts of the calculation if required. The model may only have to be run a few times, with the results stored and used for many subsequent COSYMA runs.

Each of the modules identified in Figure 2, has an "evaluation routine" which enables the user of COSYMA to output details of the quantities calculated by the module. The output from these routines is described in Section 7. All point values calculated in each module are read by the corresponding evaluation routine and processed for tabular or graphical presentation. The collective results of the program are also calculated within the evaluation routines.

The INDAT module is used to read the data required to define the conditions of the particular ACA run, and to read the changes to default parameter values. In addition to the values of the parameters controlling the program flow, the module reads the starting times of the sequences of atmospheric conditions considered, the population and agricultural production distribution around the site (if they are required) and the data describing the release. These data sets can be created by other programs within the COSYMA package which are not contained in the NE, NL or FL sub-systems or be provided by user input. The input module must be used in all runs of the programs.

The ATMOS module in the NE and NL sub-systems calculates the time-integrals of air concentration and deposition at each point affected by the plume. The dispersion calculations are done for a unit release of a group of idealised nuclides representing a noble gas, an aerosol and the different forms of iodine; these groups of nuclides have different values for the deposition parameters. It also calculates the plume arrival time at each grid point, and correction factors for determining cloud γ doses from the air concentrations, but does not consider radioactive decay. The version of ATMOS contained in the NE sub-system

contains the atmospheric dispersion model MUSEMET, while that in the NL sub-system implements both the ISOLA and MUSEMET models. The FL sub-system is designed for use with the MESOS dispersion program, which is provided as a stand-alone program. For this reason the version of ATMOS contained in the FL sub-system is merely a processing routine to select the required information from the output of a MESOS run. These dispersion models are described in Section 5.1.

The CONCEN module reads the results of the atmospheric dispersion calculations, carried out either using the module ATMOS or using one of the separate atmospheric dispersion programs in the COSYMA package. CONCEN combines these results (for unit release of idealised nuclides) with the source term information and calculates the air concentrations and deposition for each nuclide at each grid element, including the effects of radioactive decay and daughter build-up during the period of the plume travel. It calculates an effective air concentration which allows other modules to calculate the cloud y dose allowing for the finite size of the cloud.

The COSYMA package contains other dispersion models, contained in programs which are used independently of the COSYMA sub-system. The RIMPUFF program can be used in place of the ATMOS module, while the COSGAP program can replace both the ATMOS and CONCEN modules. Any other atmospheric dispersion program can be used with the COSYMA system provided that it writes its output in the appropriate format. The dispersion model does not need to consider radioactive decay but must evaluate time-integrated air concentration and deposition, plume arrival time and correction factors for calculating the finite cloud y dose.

The PROTEC module is designed to determine the extent and duration of the protective actions assumed for the consequence assessment. Different actions are considered in the different sub-systems, because of the different distances and end-points considered. Table 3 lists the actions which are included in each of the three sub-systems. The areas in which the various countermeasures are considered can be defined in terms of geometrical figures (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 and withdrawn. The options available and the effect of the action on the dose to exposed individuals are described in Section 5.5.

The AMOUNT module combines the information from PROTEC on the actions taken at each grid point with the distributions of population or agricultural production around the site to calculate the numbers of people, amounts of agricultural produce, and areas and their time integrals affected by countermeasures.

The modules POTDOS and POTRSK calculate organ doses and individual health risks at each grid point considered, assuming that there are no emergency actions. The NE sub-sys-

tem calculates doses and risks to people out of doors, while the NL and FL sub-systems offer optionally the possibility to calculate doses and risks for people with average behaviour. The three sub-systems consider different times over which the doses are integrated, different routes of exposure, and different health effects as indicated in Table 3.

The exposure pathways considered in the NE sub-system are external irradiation from the cloud and from material deposited on the skin and the ground, and inhalation of material from the cloud and from resuspension. The NL and FL sub-systems also consider doses from the ingestion of contaminated food. The dose-conversion factors for the different exposure pathways are not calculated within the COSYMA sub-systems, but instead obtained from precalculated data libraries. The models used in deriving the libraries supplied with the package are identified in Section 6. Note that while the data libraries are part of the COSYMA package, the programs used to generate them are not included in the package.

The modules LATDOS and LATRSK of the NL and FL sub-systems calculate the doses and individual health 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 Section 5.4.

The module EARLY in the NE sub-system is equivalent to LATDOS and LATRSK in the late sub-systems. It includes a detailed modelling of the effects of early emergency actions in reducing the potential doses. 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 module allows for the time taken to travel out of the contaminated area, with the travelling time being related to the density of the population. The model is described further in Section 5.5. 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.

An optional LATRSK module of the FL sub-systems allows the detailed evaluation of the time distribution of cancer in the exposed population. The same modules of the NL sub-system can be used to give an estimate of this distribution.

3. STRUCTURE OF COSYMA

The individual risks of health effects (actual or potential) are combined with the distribution of the population in the module COLLEC which calculates the overall number of the health effects considered for the run of COSYMA. The results of these calculations can be presented in a variety of ways by the evaluation programs, as described in Section 6.

The module ECONOM estimates the economic consequences of the release, in terms of the costs of the emergency actions, and the costs associated with health effects. The counter-measures for which costs are considered are movement of the population (both evacuation and relocation), restrictions on the production and consumption of food, and decontam-ination of land and buildings. The costs of evacuation and relocation include those arising from transport and accommodation, loss of income and loss of capital.

3.3 Stand-alone Programs in COSYMA

SOURCE is a program for preparing the input source term in the form required by the main analysis programs, and describing the time variation of the release.

Ideally, consequence calculations would be carried out for all possible combinations of atmospheric conditions which can occur in the area affected by the plume of dispersing material. However this is not possible because of constraints imposed by computer resources. METSAM is a flexible system for selecting sequences of atmospheric conditions for analysis with the major ACA programs of COSYMA. METSAM contains three different programs for use with the different dispersion models available in COSYMA. The programs within COSYMA derive the conditions to be considered from an analysis of historical meteorological data for the affected region. The calculations are either carried out for sequences of atmospheric conditions in the historical data chosen to represent the range of possible conditions in the data set, or for groups of constant atmospheric conditions.

The programs RIMPUFF, COSGAP and MESOS are atmospheric dispersion programs based on different assumptions and approximations, and appropriate for different applica-tions. Other models for atmospheric dispersion are included within the NE and NL sub-systems of COSYMA.

The program COSING estimates food chain related consequences of the accident. It was developed as a stand-alone supplement to COSYMA to allow faster and more detailed investigations of the consequences arising from the food chain pathways than are possible with the NL or FL sub-systems. Age-dependent individual ingestion doses and time-depen-dent individual health risks from ingestion of contaminated foods can be estimated. A detailed breakdown of the contribution of the various foods and nuclides considered to the ingestion dose can also be derived. For the calculations, COSING uses initial ground con-

centrations in each grid element calculated by the module CONCEN of the NL and FL sub-systems of COSYMA.

The program GRIDS is used to obtain distributions of population or agricultural production in angular segments and distance bands around the site from information on a regular grid.

The program UFOTRI is a program for assessing the consequences of tritium releases. It incorporates a dispersion model allowing for material to deposit, evapora and subsequently disperse again, and a dynamic model for the behaviour of tritium in food ins.

The program ARCOS is used to create files of activity risk coefficients which are required in the calculation of late health effects.

Programs are also provided for presenting the output of the main COSYMA sub-s ems in a variety   ys, as the best form of presentation can depend on the application of the system. These   ograms supplement the methods available in the main sub-systems of COSYMA.

3. STRUCTURE OF COSYMA

4. PREPARATION OF RELEASE DATA

The description of the source term includes the amount of material released and its time variation, together with the heat content or vertical momentum of the material. A description of the height of the release or the size of the building is also required. If the objective of the analysis is to calculate the risk posed by the plant, then information on the frequency of the postulated releases is also required, and must be provided by the user.

A comprehensive safety study of a nuclear installation leads to the identification of a wide range of possible accident sequences. Limitations on the available time (both computer and human) means that the consequences of each of these accident sequences cannot be analysed separately. Therefore accident sequences which lead to similar amounts of material released are grouped together, so that a detailed analysis can be carried out for the limited number of representative groups so identified. The time variation and duration of the release are also important features, as they affect both the atmospheric dispersion of the material and the time during which emergency actions may be undertaken.

Recent investigations on accident sequences in PWRs suggest that the time between the end of the nuclear reactions and the release to atmosphere may be long. Some sequences in which material is released over a prolonged period have been identified. However prompt releases are still considered possible. Source terms are described in COSYMA in terms of release "phases" with duration one hour in the NE and NL sub-systems and three hours in the FL sub-system. The phases can be separated from each other by periods in which no releases are considered. These periods are multiples of the phase length.

A stand-alone program SOURCE is provided in the COSYMA package to assist in creating the input file describing the source term in the correct format for the program. The program considers the release of 141 nuclides, and selects those nuclides which contribute more than a specified proportion of the dose from each of the pathways considered in COSYMA. This selection is done by defining quantities which are related to the doses received from each of the routes of exposure and which can be calculated easily. For example, the nuclides to be considered for inhalation are determined by considering the dose in each organ and taking those nuclides which contribute more than a desired fraction (perhaps 99.9%) of the total for all nuclides. The program also suggests a way in which the release can be split into separate phases; the user can accept this description or combine the releases in a different pattern. Material released over more than one hour can be considered to be released in a single phase of one hour duration.

5. BASIC FEATURES OF THE MODELS IN COSYMA

Following an accidental release to atmosphere, people can be irradiated by a number of routes from material both in the atmosphere and after its deposition to the ground. The routes considered in COSYMA are:

1. external β and γ irradiation from material in the cloud,
2. inhalation of material in the cloud,
3. external β irradiation from material deposited on skin or clothing,
4. external γ irradiation from material deposited on the ground,
5. inhalation of resuspended material,
6. ingestion of foodstuffs contaminated by deposited material.

Not all routes of exposure are considered for each health effect, or included in each of the sub-systems as indicated in Table 3. The first three routes of exposure only affect those people who are exposed to the plume of material as it passes overhead. External irradiation from the cloud clearly only occurs while the person is in the contaminated plume. Material is inhaled similarly only while the plume is present, but some materials can be retained in the body for long periods after inhalation so that the exposure can persist over the rest of the person's lifetime. The third route also affects only those people under the plume during its passage, and irradiation stops once the material is removed from the skin. The other routes however can lead to irradiation over a considerable period of time and can even irradiate those people who were not yet born at the time of the accident. The distribution of food can expose people who live outside the area which was affected by the original plume of dispersing material.

The section gives a brief description of the models which are contained within the three sub-systems of COSYMA, or are provided as stand-alone programs for calculating radiation doses for the routes of exposure listed above and the risks of health effects from those doses. The models used to generate the data libraries which are part of the package are described in Section 6. The models are described here in outline only. More complete descriptions are given in other reports specifically about the models which were adopted for COSYMA, or about the models in the MARC and UFOMOD programs which have been incorporated in COSYMA.

5.1 Atmospheric Dispersion

The COSYMA package contains five different models for atmospheric dispersion, based on different assumptions and hence appropriate for different applications. The choice of model for a particular application is considered in Section 10. However, any model can be used with the package provided it can meet the appropriate interfaces with the remainder of the system. The method adopted in the ATMOS and CONCEN modules means that other atmospheric dispersion models to be coupled with COSYMA need not consider radioactive decay, but need to provide correction factors to allow the cloud γ dose from the finite plume to be calculated.

The inclusion of five different dispersion models allows the user to select the model which is most appropriate for the application being considered, and which is commensurate with the meteorological data available. It also enables users of COSYMA to take advantage of as much of the EC expertise in this area as possible.

5.1.1 The COSGAP, MUSEMET and RIMPUFF Models

These three models are all Gaussian models allowing for variation of atmospheric conditions during plume travel. The principal difference between the three models is the way in which they describe the trajectory followed by the dispersing material, and the meteorological data required. The differences between the ways in which the models describe the trajectory is illustrated in Figure 3. The MUSEMET model is included as part of the ATMOS module for the NE and NL sub-systems of COSYMA.

COSGAP is a modified version of the dispersion model from the NRPB program MARC [19], and is available within the COSYMA package as a stand-alone program. This model could be used with the NE and NL versions of COSYMA, and would replace both the ATMOS and CONCEN modules of the COSYMA sub-system. The original version is described in detail in [20]. It is a Gaussian plume model in which the dispersing material is assumed to follow a linear trajectory after its release. However material released in different phases of the accident can be assumed to travel in different directions depending on the wind direction at the time each part of the material is released. The atmospheric conditions, other than wind direction, affecting the plume are assumed to be the same as those at a single meteorological station near the site of the release.

The MUSEMET model is included in the ATMOS module of the NE and NL sub-systems of COSYMA. This model was originally written at KFA Jülich, and was modified and extended by KfK for use in UFOMOD and COSYMA. It is described in detail in [21] and [12]. It is a segmented Gaussian plume model which assumes that the atmospheric conditions affecting the plume are determined from those at a single meteorological station

representing the site of the release. The model allows three options for describing the trajectory followed by the dispersing material. The first is to assume all material travels in the direction of the wind at the start of the release. The second is to assume that the material released in each phase travels in the wind direction at the start of that phase for the whole of its travel. The third is to assume that the wind direction changes every hour throughout the release and the subsequent travel. In this case, the dispersing material is assumed to follow a trajectory which consists of a series of straight line segments. With the second and third options, all material released in a particular phase follows the same trajectory, but material released in different phases can follow different trajectories.

A modified form of the RIMPUFF dispersion model is provided in the COSYMA package as a stand-alone program. It is appropriate for use with the NE and NL sub-systems of COSYMA, in place of the ATMOS module. The model was originally written at Riso, and was modified by KfK for use with UFOMOD and COSYMA. It is described in detail in [12] and [22]. RIMPUFF is a Gaussian puff dispersion model, in which the release is described as a series of puffs emitted at intervals of a few minutes, and the trajectory followed by each puff is determined. In this way the model assumes that changes of atmospheric conditions affect all the dispersing material at the same time, rather than at the same distance as is assumed in MUSEMET. RIMPUFF can use meteorological data from a single station or from a series of stations in the area affected by the dispersing plume. In the second case, the atmospheric conditions affecting each of the puffs are derived by interpolating between the values at the different meteorological stations. This means that different puffs can travel in different directions at the same time.

All the models allow for the effects of hourly changes of wind speed, stability category, and rainfall rate. In addition the COSGAP model allows for hourly changes of mixing layer depth, with the possibility of material being left above the top of the mixing layer as its height is reduced. This material is assumed to travel in the same direction and at the same speed as material remaining in the mixed layer.

COSGAP includes a description of the horizontal plume dimension σ_y which includes contributions caused by turbulent diffusion about the instantaneous wind direction and fluctuations in the wind direction. The magnitude of the turbulent spreading is based on work by Pasquill and Gifford and depends on the atmospheric stability. The spread due to wind direction fluctuations is based on work by Moore, and is assumed to depend on the windspeed and release duration but not the atmospheric stability [23]. The model is not restricted to assuming a one hour duration of each phase, but can calculate a value of σ_y for any phase duration specified by the user. The vertical plume dimension σ_z is based on the work of Smith using the formulae derived by Hosker, and includes an allowance for the effects of ground roughness on dispersion [24]. The top of the mixing layer is assumed to act as a barrier to further vertical dispersion.

5. BASIC FEATURES OF THE MODELS IN COSYMA

MUSEMET and RIMPUFF use horizontal and vertical dispersion parameters which are functions of atmospheric stability and release height, with two sets of parameters for smooth and rough underlying surf :es. The sets of parameter values were derived experimentally, with the values for smooth surfaces based on work at SCK/CEN Mol [25] and those for rough surfaces from the Karlsruhe - Jülich experiments [26]. However, these dispersion parameters are of the form $\sigma = px^q$ and the values of p and q can be changed by user-input. The horizontal dispersion parameters are applicable to a release duration of 1 hour, which must therefore be the duration of each phase. The height of the mixing layer is assigned for each category, and the dispersion model does not allow for decreases in this height during plume travel.

All three models allow for dry and wet deposition. Dry deposition is calculated using the deposition velocity, with the amount of material remaining in the plume calculated using the source depletion model, in which the vertical profile of the plume is assumed to remain Gaussian. The value of deposition velocity depends on the underlying surface, with higher values applicable to forests than to grass, for example. The value used in the dispersion calculations is an average value for the various underlying surfaces. Correction factors can be applied when calculating doses so that the effect of different deposition velocities to the different surfaces can be simulated. Wet deposition is included using a washout coefficient, which increases with increasing rainfall rate. The value of the deposition velocity and washout coefficient can be specified separately for each nuclide in COSGAP; in MUSEMET or RIMPUFF values can be assigned for noble gases, aerosols, and iodine in elemental and organic forms, or bound to aerosols.

All three models include the effects of plume rise using the model developed by Briggs. COSGAP considers rise due to vertical plume momentum and to its buoyancy, while the other models only consider rise due to plume buoyancy. The details of the models used for the height of the plume centre-line and for terminating the rise are described in [20] and [12].

COSGAP allows for the effects of buildings on the dispersion of material released within the main building wake by using the virtual source model as developed by Barker, and recommended for use by a UK Working Group on Atmospheric Dispersion [23]. The user must specify the effective height and initial plume dimensions.

The effects of down-wash and mixing in the wake of a building are included in MUSEMET and RIMPUFF using a virtual source model based on the work of Hanna et al [27]. These models also consider the down-wash of material released from stacks.

5.1.2 The ISOLA Dispersion Model

The ISOLA dispersion model [28] is provided in the COSYMA package as part of the NL sub-system of COSYMA. ISOLA is intended primarily for use with quasi-stationary releases of duration weeks to months, and thus closes the gap between accidental releases and normal operation. ISOLA is a statistical Gaussian plume model in which changes of atmospheric conditions during the travel of material are not considered. The program requires information on the relative frequency of meteorological conditions in terms of the joint probability distribution of wind speed, wind direction, stability class and rainfall rate, derived from one or more year's data. The concentration is averaged across the sectors considered, assuming that the wind direction is evenly spread throughout the sector and allowing for material crossing the boundaries between the sectors. The plume dispersion parameters are the same as those used in MUSEMET.

Dry deposition is included, with plume depletion calculated using the source depletion model. Wet deposition is included by using washout coefficients. The values of the deposition parameters can be assigned for the same five groups of nuclides considered in MUSEMET.

Building effects are included by increasing the plume dimensions by an amount which allows for the initial dispersion in the building wake. The ISOLA model does not allow for plume rise.

5.1.3 The MESOS Dispersion Model

The MESOS dispersion model [29] is provided in the COSYMA package as a stand-alone program. It is appropriate only for use with the FL sub-system of COSYMA.

MESOS uses a data base of atmospheric conditions over a wide region, the data base included in the COSYMA package covering the whole of Europe. Conditions at the position of the dispersing puff are calculated by interpolation from this data base.

MESOS considers the release as a series of puffs released at intervals of 3 hours. The trajectory followed by the puffs is obtained from the atmospheric pressure field, by solving the equations of motion. The growth of each puff due to small scale turbulence and wind-shear is also considered. The synoptic spreading is represented by assuming that the material released over the 3 hour period is spread uniformly between the trajectories calculated for the puffs released at the start and end of the period.

Vertical dispersion is calculated at short distances using plume dispersion parameters based on the work of Smith [30]. Once the plume has spread through the mixing layer, the concentration distribution is assumed to be uniform between the ground surface and the top of

the layer. Changes in the depth of the mixing layer are modelled with material being left above the mixing layer as its depth decreases. This material is prevented from diffusing to the ground until the mixing layer depth subsequently increases to include it. It is assumed to travel at the same speed and direction as material inside the mixing layer.

Wet deposition is included in the model using a washout coefficient which varies with rainfall rate. The rainfall rate is obtained by interpolating from the values on the meteorological data base, and is assumed to apply over the whole of the puff being considered. MESOS also allows for dry deposition, using the source depletion model to calculate the amount of material remaining in the plume.

As the MESOS model is intended for use only beyond some tens of kilometres from the site, it does not include models for plume rise or building wake effects, as these effects are not important at such distances.

5.2 Meteorological Sampling

Four of the atmospheric dispersion models included in the COSYMA package allow for the variation of conditions during the travel of the plume. In probabilistic consequence assessments using these models, the atmospheric dispersion and dose calculations must be repeated for a large number of sequences of conditions selected from the meteorological data file used in order to predict the full distribution of consequences which may occur. Ideally the calculations should be performed for every possible sequence of conditions in the data file, in other words for an accident starting at each hour on the file. Computer resources are not sufficient for this to be done, and a representative selection of the sequences must be used instead. The selection should be made in such a way that the sequences chosen represent the complete range of possible sequences, and yield the correct probability distribution of consequences.

The simplest methods of selecting starting times for the sequences are to do so either at random or by selecting every n'th sequence (cycle sampling). These methods tend to sample the more common sequences frequently, whilst overlooking the more unusual ones. They can only be used for predicting the higher percentiles of the distributions of consequences if a very large number of sequences is considered for analysis. However cyclic sampling can be selected with the MESOS, MUSEMET and RIMPUFF models by setting a parameter in the input file. It could also be used with COSGAP by providing an appropriate input file.

A more sophisticated method of sampling is stratified sampling, in which the intention is to group all those sequences of conditions on the meteorological data file for which the consequences are similar. Sequences can then be chosen at random from those within each of the groups, and assigned a probability based on the number of sequences allocated to each

group and the number selected from within each group. The sampling procedure adopted must be tailored in some ways to features of the atmospheric dispersion model used, and to other features of the consequence calculations [31]. In particular, one of the criteria in designing a sampling scheme is to give an adequate description of the high consequence part of the overall probability distribution. The atmospheric conditions for which high consequences are predicted should be identified, and the category scheme adapted to concentrate on these conditions.

Experience, particularly with the MARC program [32], shows that following a major release of activity the dose from deposited activity can be a significant contributor to early deaths, and that sequences in which the plume encounters heavy rain over densely populated areas near the site can lead to large numbers of early deaths. Experience with UFOMOD suggests that releases in initial stable conditions tend to be the ones with high consequences for releases near ground level. These features should therefore be considered in designing a sampling scheme.

The COSYMA package includes three different programs for selecting sets of sequences for analysis. These different programs are similar in their aims and are based on similar criteria for grouping the sequences occurring in the meteorological data used for the analysis. The procedures used to group the sequences must however be tailored to some details of the atmospheric dispersion model to be used, and this is the reason for providing three different sampling programs in the COSYMA package. The programs are intended for use with the COSGAP, the MUSEMET and the RIMPUFF dispersion models. The versions of the sampling program for use with MUSEMET and RIMPUFF differ only in the way that the atmospheric conditions at the plume are estimated from the meteorological data files used. The version for use with COSGAP differs in not allowing for changes of wind direction during plume travel, and in using some different categorisation schemes. The three programs are very flexible and allow the user to define his own criteria for grouping the sequences of atmospheric conditions.

As indicated above, following a major release of activity sequences in which the plume encounters heavy rain over densely populated areas near the site can lead to the prediction of large numbers of early deaths. The sampling programs are designed to identify such sequences. While all the sampling programs attempt to identify such sequences, the criteria adopted differ between the COSGAP and the MUSEMET/RIMPUFF programs, because the modelling of wet deposition within these programs is different. Two basic sets of criteria are available for grouping the wet sequences, although both sets have several options within them.

The sampling program for use with the COSGAP model can group atmospheric conditions in terms of the amount of material deposited in a short distance band. MUSEMET and RIMPUFF do not have the same description of the variation of wet deposition with dis-

5. BASIC FEATURES OF THE MODELS IN COSYMA

tance, and hence this particular option is not appropriate 'r use with those models. However the deposition can be characterised in terms of the ratio of washout coefficient to wind speed. This option is available within all the sampling programs. The other options for wet sequences within the programs are based on the rainfall rate observed within a specified distance f   the site. Details of the schemes are given in the user guide [18].

The conditions leading to large numbers of early effects in the absence of wet deposition are likely to be those in which the air concentration remains high, either for a long period or for a long distance. The atmospheric conditions leading to this situation are those where the wind speed is low or the mixing layer is shallow for some hours, where the wind speed drops at some distance from the site, or in initial stable conditions. All the sampling programs include a set of options to identify these conditions.

Most of the work done so far on meteorological sampling has been based on categorising sequences in terms of early effects, and identifying sequences in terms of atmospheric features occurring within some tens of kilometres of the site. However, the programs provided in the COSYMA package are very flexible and could be used to identify sequences in terms of features occurring at much greater distances from the site, if required.

To date, little work has been carried out to derive a sampling scheme appropriate for use with the MESOS atmospheric dispersion model, and further investigations are required before recommended methods can be given. Calculations of consequences carried out using sampling schemes developed for short distance applications have a number of unsatisfactory features. This is because the probabilities of weather sequences selected for short distance may not be valid at larger distances. If the application considered does not require results from the NL and FL sub-systems to be combined, then cyclic or random sampling seem to give the best results at present. However, further work is required on this topic.

There is no meteorological sampling model for use with ISOLA as this model does not consider changes of conditions during plume travel. ISOLA is used with statistics of the joint frequency of atmospheric stability category, wind speed and direction, and rainfall rate. The air concentration and deposition in each of the groups considered is calculated, and the sequence is assigned the frequency of that group.

5.3 Dose Calculations

Doses are calculated within COSYMA either for presentation as an end-point of the assessment or for use in further calculations of health effects. Both individual and collective doses can be evaluated. This section describes the methods adopted for calculating doses in the absence of any emergency actions taken to reduce the doses. The method of allowing for these actions in calculating doses and health effects is described in Section 5.6. Doses may

be calculated for any duration of exposure and for a number of organs. The organs considered in the NE sub-system of COSYMA are those required for use with the dose response relationships adopted for the calculation of the different health effects. The times considered can be set by the user with the maximum time considered being 1 year; the default times are those used in the dose response relationships. Dose response relationships are described in Section 5.4.

The other COSYMA sub-systems (NL and FL) consider different types of health effects, and different time periods from 1 to 70 years over which the doses are integrated.

The pathways considered in COSYMA by which people are exposed to irradiation are listed earlier in Section 5; the ones considered by the different sub-systems are shown in Table 3. The early health effects of radiation exposure are only observed in those people exposed to high doses for short periods of time. Ingestion doses over short time periods, and their contribution to early health effects, are not considered in COSYMA because bans on the consumption of food would be enforced if doses from this route might be high. Models are described in this section for calculating doses from each of the routes of exposure considered by COSYMA.

The doses are calculated for an average adult member of the population in the current versions of the NE, NL, and FL sub-systems of COSYMA. However, age-dependent doses and doses to members of critical groups can be calculated for the ingestion pathway using the more detailed models within the COSING program. The calculated doses (from COSING and the other sub-systems) can be evaluated and presented with or without allowing for the effects of countermeasures. The method of calculating late health effects using activity risk coefficients, described in Section 5.4.2, allows for doses to all age groups of the population.

5.3.1 External Exposure Pathways

External γ exposure from material in the cloud and from material deposited to the ground is calculated within each of the sub-systems of COSYMA. The doses are calculated by multiplying the time integrated air concentration or deposit by a precalculated factor obtained from a data library. In the case of cloud γ exposure this factor is the dose per unit air concentration, while for deposited γ dose it is the dose per unit deposit to the appropriate time period. The models used for calculating these dose conversion factors are described in Section 6.

The factor for cloud γ dose in the data library was calculated assuming that the plume is semi-infinite and of uniform concentration. Correction factors for plume geometry and distance from the plume centre-line are included in the dose calculation. Because the dose calculation must take account of the size and shape of the plume of dispersing material, the

5. BASIC FEATURES OF THE MODELS IN COSYMA

correction factors are evaluated in the atmospheric dispersion module. Methods of calculating these factors are included in the COSGAP, MUSEMET and RIMPUFF dispersion models. The COSGAP dispersion model contains a further method for calculating cloud γ doses for use when the plume is very narrow in the vertical direction and the centre-line is well above the ground [20]. The dispersing material is approximated by a horizontal line source at the plume centre line height, and the dose obtained by integrating along the line source.

The deposited γ doses in the data library were calculated allowing for shielding by the soil from material in the deeper soil layers. The doses from cloud or deposited γ exposure calculated with these factors are therefore appropriate for people who are outdoors. Factors to allow for shielding by buildings must be specified by the user of COSYMA. The NE subsystem allows the user considerable flexibility in describing the location of the population and the shielding effects of buildings for those people assumed to be indoors. The way in which this is done, and the options for describing the fractions of the population in different types of housing with different shielding factors, are described in Section 5.6. Calculations for groups of people with different shielding factors require the use of the countermeasures routines of the NE sub-system. However an average shielding factor can be included when calculating potential doses.

Doses from material deposited on skin and clothes are also considered in COSYMA. These are calculated using a data library giving the dose rate per unit deposit and information on the biological half-life of the material on skin. The dose response relationships for non-stochastic effects are applied with the dose to a small area of skin, and therefore the dose calculated can be used directly. However, for stochastic effects the average dose throughout the skin should be used in the dose-response relation. COSYMA includes an allowance for only part of the body being contaminated in calculating this average skin dose. The deposition density on skin or clothes is taken to be a multiple of that to the ground at the same location. The user of COSYMA can specify this multiple of the deposition and also the half-life of material on skin.

5.3.2 Internal Exposure Pathways

5.3.2.1 Inhalation Dose

Material can be inhaled either directly from the radioactive cloud as it passes overhead, or following the resuspension of material which has been deposited. This second pathway can lead to intakes over prolonged periods of time. The dose from inhaled material can occur over a prolonged period as some radionuclides can be retained in the body for considerable periods after inhalation.

The direct inhalation dose is obtained as the product of the inhalation rate, the time integrated air concentration and a precalculated dose per unit activity inhaled. Values of dose per unit activity inhaled are contained in a library; the models from which they were derived are described in Section 6. The inhalation rate can be specified by the user.

Resuspension can be caused by the wind or by human activities (eg. traffic or ploughing). The relationship between the air concentration and the amount of material deposited is described in COSYMA using a time-dependent resuspension factor. In practice, this factor depends on the fixation of the material onto soil, climatic conditions and the amount and type of human activity in the area. As there is no detailed reliable model for the resuspension factor, a simple approach is taken in COSYMA and the resuspension factor is taken to be the sum of two terms, a constant and one varying exponentially with time [20]. The user can change the values of each of the coefficients in the relationship.

The air concentrations inside and outside buildings may be different, and COSYMA incorporates this by using a "shielding factor" when calculating the amount of material inhaled. The user can specify different factors for different groups of the population in the NE subsystem if the countermeasures routines are used. An average factor is used with the other sub-systems. The factors adopted for direct inhalation of the cloud and for inhalation of resuspended material need not be the same.

5.3.2.2 Ingestion doses

Ingestion doses are calculated from the amount of activity deposited, the concentration of material in foods for unit deposition, the consumption rate and the dose per unit activity ingested. Information about the concentration of material in foods and the doses per unit activity ingested are obtained from data libraries, as described in Section 6.

Nine foodstuffs (milk, milk products, beef, pork, sheep meat, grain products, potatoes, leafy vegetables, non-leafy vegetables, and root vegetables) are considered in COSYMA, and information on the concentration of material in each of these foods as a function of time after deposit is given in the data library. Previous investigations have shown that the time of year at which the accident occurs may have a marked effect on the concentration in foods. COSYMA therefore uses different data libraries for accidents occurring at different times of the year. In theory a large number of such files could be used, but considerations on the amount of data which could be handled restrict the number, and COSYMA approximates the seasonal effects by using two data sets, one for winter (November to March) and one for summer (April to October). The appropriate data set is selected by considering the date of the release from the starting time for the atmospheric sequence.

The individual ingestion dose can be calculated in COSYMA using the assumption that all food is produced at the point at which it is consumed, together with an assumed consump-

5. BASIC FEATURES OF THE MODELS IN COSYMA

tion rate for each of the nine foodstuffs indicated above. Collective doses can be calculated using one of two assumptions. The first calculates the individual dose as above, multiplies this by the number of people at the grid point, and sums over grid points. The second uses information on food production patterns and assumes that all food produced is consumed somewhere. The collective dose arising from the production at each grid point is then calculated and summed.

5.4 Dose Response Relationships

The health effects which can be calculated with COSYMA were indicated in Section 2 and Table 1. This section lists the dose-response relationships and the default parameter values which are used in calculating those effects.

5.4.1 Early Effects

The calculations of early effects of irradiation is only included in the NE version of COSYMA. Models for a range of fatal and non-fatal early effects are included, as indicated in Table 1. This list of health effects includes all those causes of death for which a dose-response relationship has been specified either by NRPB [34] or by USNRC [35]. 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 person 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 are not quantified.

The risk of suffering from early effects following irradiation increases rapidly as the dose increases above a threshold value. This is modelled in COSYMA using a "hazard function", in which the probability of an individual being affected, r, is given by

$$r = 1 - \exp(-H)$$

where

$$H = \ln 2 \left(\frac{D}{D_{50}}\right)^S \quad \text{for } D > T$$

D is the dose received in the appropriate period,

D_{50} is the dose which causes the effect in 50% of the exposed population,

S is the shape parameter, which characterises the slope of the dose-risk function,

T is the threshold dose.

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 normalised by an appropriate D_{50}. The equation above is then replaced by

$$H = \ln 2 \sum_i \left(\frac{D^i}{D^i_{50}} \right)^S \quad for \ D^i > T_i$$

where

D^i is the dose delivered in the time period i,

D_{50} is the dose which causes the effect if 50% of the exposed population if delivered in time period i,

T_i is the threshold dose for time period i.

In the revised version of the USNRC health effects model [35], dose rate dependent models are proposed for fatal early effects. These account for the fact that dose received at low dose rate is less harmful than dose received at high dose rate. This dependency is included by expressing the median lethal dose, LD_{50}, as a function of dose rate. However the modelling in COSYMA is still based on the fixed time interval approach; therefore the approximating functions described above are used. Future revised versions of COSYMA may account for dose rate dependencies.

An allowance is made for irradiation of more than one organ when calculating the total individual risk of an early health effect. The risks of death from each organ are combined in a way which prevents the overall risk exceeding unity.

Parameter values for the hazard function can be selected which give a very 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 early effects. Therefore threshold doses are included in COSYMA with the hazard functions. This threshold is different for each of the health effects and for each of the dose periods considered. The default values of the parameters D_{50}, S and the dose thresholds for each period included in COSYMA are given in Table 4.

The default parameter values adopted in COSYMA are derived from extensive studies of the effects of radiation on both humans and animals, as indicated in [34] and [35]. The dose-response relationships adopted for death from irradiation of bone marrow are based on studies of those people exposed to radiation from the atomic bombs in Japan, exposure to fallout in the Marshall Islands and of casualties after the Chernobyl accident, and several other sources of information. The default parameter values for death from lung exposure are

5. BASIC FEATURES OF THE MODELS IN COSYMA

based largely on experiments with dogs, though there is also some human data and information on other species of animals.

Using a hazard function form for the dose-response relationships provides a very flexible program. The user of COSYMA can simulate a wide variety of other dose response relationships by modifying the parameter values, each of which can be changed through the input file.

5.4.2 Late Effects

The late effects considered in COSYMA are a range of fatal and non-fatal cancers in the exposed population, and hereditary effects in their offspring. The incidence of these health effects is calculated in COSYMA using a linear dose-response relationship without a dose threshold.

There has been a number of extensive studies of the incidence of late health effects in irradiated populations (see, for example, [34], [35] and [36]). 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. The absolute risk or additive model assumes 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 and is independent of any differences in the natural cancer risks 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.

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 complex multiple integrals. These integrals have been pre-calculated 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 generation"), and in those people born after the accident (referred to as "future generations"). The integrals relating risk to air concentration or deposition are referred to as "activity risk coefficients".

Similar methods are used to calculate risks allowing for the effects of countermeasures such as relocation or food bans. Values of the activity risk coefficients are calculated for exposure starting at a series of times after the accident. The risk of cancer allowing for, for example, a food ban of 1 year duration is then calculated using activity risk coefficients in which ingestion is assumed to start one year after the accident.

A further set of activity risk coefficients is available for use with the special version of the FL sub-system which calculates the time at which health effects occur. These coefficients are evaluated over limited ranges of the integrals to give the risk of the health effect occurring in a series of defined time periods after the accident. These coefficients are summed over the living and future generations.

The activity risk coefficients included in COSYMA incorporate risk coefficients for late effects recommended by GSF [36]. The risk coefficients are given in Table 5 where they are expressed in terms of the number of fatal cancers per million people for an acute exposure of 10^{-2} Sv, assuming the age structure and natural cancer incidence of the FRG population. The table also shows the factors relating the number of fatal cancers to the total incidence of cancer (i.e. the number of fatal and non-fatal cancers). The detailed risk coefficients used in deriving the cancer incidence in the population for one of the cancer types are given in Table 6, which shows the risk as a function of age at exposure and time after exposure.

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 6 for the particular cancer type considered there.

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, but other sets may be made available in the future.

5. BASIC FEATURES OF THE MODELS IN COSYMA

5.5 Countermeasures Options and Criteria

The countermeasures which are included in the different COSYMA sub-systems were outlined in Section 3.2 and indicated in Table 3. This section describes in more detail the countermeasures which can be considered, and the criteria which may be used to initiate and withdraw the actions. The effects of the actions on the doses received by the affected population are also described in this section. Section 5.6 gives a detailed description of the methods used to calculate doses and health effects allowing for the countermeasures adopted. Some of the countermeasures can be assumed to be initiated automatically in an area which can be defined by the user. The countermeasures can also be initiated on the basis of dose criteria. These criteria are summarised in Table 7, and described for each option below. The default values for the parameters are also indicated in Table 7.

In many cases the dose criteria are sums of doses from specified routes of exposure, but the user has the option of selecting which of these routes should be considered in the summation. In this way the user can simulate the adoption of various types of countermeasures criteria.

Some of the countermeasures are intended as immediate actions against short term doses, while others are intended as continuing actions against exposure over longer periods of time. Therefore different combinations of countermeasures are considered in the early and the late sub-systems of COSYMA.

COSYMA considers both evacuation and relocation as means of moving people from their homes to avoid exposure. The only difference between these two countermeasures in the COSYMA system is the criterion used for their initiation. The same criterion is used for return from both evacuation and relocation.

5.5.1 Sheltering Only

Sheltering as a single countermeasure is considered only in the NL version of COSYMA. Sheltering as the only action is initiated automatically in a circle with a radius defined by the user. The duration of sheltering must be specified by the user.

Sheltering may reduce the external γ doses from both deposited material and the cloud, and internal doses from inhalation of material both in the initial plume and following resuspension. It may also reduce the amount of material deposited on the skin or clothes if different deposition factors are used for people indoors or outdoors when the plume passes. The sets of reduction factors can be specified by the user, and can include the value of 1.0, corresponding to no reduction in doses during sheltering.

5.5.2 Sheltering Followed by Evacuation

Evacuation is considered in COSYMA to be an action aimed at reducing short-term exposure, and is therefore considered in the NE version of COSYMA only. It can be assumed to be initiated automatically in an area defined by the user, and/or on the basis of a dose criterion, and can be assumed to be preceded by a period of sheltering. The program assumes that evacuation is carried out within 24 hours of the release. The timing of early protective actions is shown in Figure 4.

The area in which evacuation is assumed to be implemented automatically is defined in terms of a circle and a sector, as illustrated in Figure 5. The direction of the centre of the sector is defined in relation to the wind direction at the start of the release. The user can specify the radius of the circle, the outer radius of the sector and the angular width of the sector. The program is sufficiently flexible to cope with two special cases, namely:

- limiting the area to a circle by making the radii of the circle and sector equal,

- limiting the area to a sector by making the radius of the circle zero.

Automatic evacuation does not need to be considered if it is not required for a particular application. In this case the radii of both the circle and the sector should be set to zero.

The dose considered in the criterion is any combination of the inhalation, deposited γ and cloud γ doses, with the periods over which the doses should be integrated specified by the user. The doses considered are those to people out of doors at the time of plume passage. COSYMA allows the user to specify criteria for several organs, with different dose levels and integration periods for each. Evacuation is assumed if the doses in any of the organs exceeds the level specified.

COSYMA gives the user the option of increasing the intervention dose level at a selected downwind distance. Following an accident, it may be considered undesirable to evacuate large areas, and particularly major cities, at some distance from the release unless the doses there are larger than those considered in evacuating smaller areas. This enables the user to model this type of decision.

The detailed sequences of actions assumed, and the method of calculating doses are described in Section 5.6.

5.5.3 Relocation

Relocation is considered in COSYMA to be an action aimed at reducing long-term exposure, and is therefore considered in the NL and the FL sub-systems, but not in the NE sub-sys-

5. BASIC FEATURES OF THE MODELS IN COSYMA

tem. It can be assumed to be initiated only on a criterion based on the effective dose. Relocation cannot be combined with an earlier period of sheltering in COSYMA.

The doses considered in the criterion are the external γ doses from the cloud or from deposited material, and the internal dose from inhalation of material in the cloud or of resuspended material. The user can specify the periods over which the doses and the intakes from resuspension are integrated. This period can be any time up to 1 year, and could be sufficiently short that the criterion becomes essentia   ie of instantaneous dose rate. If the periods specified are not ones for which doses are cont ned in the data files, then the doses are obtained by interpolation. The user has the option of increasing the intervention dose level at two selected downwind distances, similar to that done for evacuation.

COSYMA assumes that all people to be relocated will leave the area at the same time. This time can be derived in two ways. The first option is simply to specify the time through the input data set. The second option is to specify the relocation rate (i.e. the area per day from which people can be moved); the time at which people are relocated is then derived from the area affected and the relocation rate.

5.5.4 Return from Evacuation or Relocation, Decontamination of Land and Buildings

The same criterion is assumed to be used for returning from evacuation and relocation. Returning from evacuation or relocation and decontamination are considered together in COSYMA.

Return is assumed once the effective dose in any period specified by the user falls below a level which is also specified by the user. The dose considered in this criterion can be any combination of the external γ dose from deposited material and the internal dose from inhalation of the cloud and of resuspended material.

Return is only considered at a discrete series of times selected by the user, with the possibility of returning in each time period checked in order of increasing time. The program first checks to see if people could return at the end of a period because natural processes have reduced the doses to below the level specified in the criterion for return. If this has occurred then return is assumed and decontamination is not considered. If return is not possible at the end of a period, then the effects of decontamination are considered. Decontamination is assumed to be carried out if it allows people to return during a time period when they would not be able to do so without the decontamination occurring. The user can specify decontamination factors which may be different for each time period considered.

- 34 -

5.5.5 Stable Iodine Tablets

The distribution of stable iodine tablets is considered in all the sub-systems of COSYMA. The effect of taking stable iodine tablets on the thyroid dose from radioactive iodine depends on the time delay between inhaling the radioactive iodine and taking the stable iodine tablets. However, a simple approach is adopted in COSYMA, and the user is required to input a value for the dose-reduction factor which is used for all locations, irrespective of the assumed times of plume arrival and of taking the tablets. Iodine tablets are assumed to be distributed automatically within a circle whose radius is specified by the user.

5.5.6 Food Restrictions

Food restrictions are considered in the NL and FL sub-systems of COSYMA, and in the detailed COSING food modelling program. Restrictions can be assumed to be imposed on the basis of either the radionuclide levels in food or on dose criteria. In either case the intervention level for imposing and withdrawing the bans need not be the same, and the user has considerable freedom to specify his requirements.

If based on levels in food, the user can input the levels for a range of food categories and nuclide groups (e.g. total iodine). The program will sum concentrations of the nuclides in each group, for comparison with the criteria. For comparison with the criteria, the concentrations make no allowance for delay between harvesting and consumption.

If restrictions are assumed to be based on potential doses then the user can input the organs to be considered. The dose considered is the committed dose from intakes in one year. The program can consider several organs with different dose levels and can impose bans on whichever criterion is most restrictive at each point. The user can input the consumption rate to be used for each food, and can specify whether the calculation is to be for infants, children or adults. If the dose level is based on an average person rather than one with extreme habits, the calculations will allow for delay between harvest and consumption. Loss of activity during normal food processing will be included in calculating the doses.

5.6 Calculations Including the Effects of Countermeasures

This section describes the methods used in COSYMA for calculating doses and risks including the effects of countermeasures. It also describes the sequences of actions considered in the early sub-system when sheltering and evacuation are considered.

5.6.1 Allowance for Sheltering and Evacuation

The modelling adopted in COSYMA to allow for the effects of sheltering and evacuation when calculating the doses received is complex and allows the user a great deal of flexibility in modelling the likely actions. The area of automatic evacuation is denoted "Area A", while that where evacuation is triggered by a dose criterion is denoted "Area B". Any area which meets the criteria for both areas A and B is assumed to be within area A.

The sequence of events assumed is illustrated in Figure 4. The actions are assumed to take place first in area A. It is assumed that, after a delay for the authorities to initiate the actions, people take shelter while the plume remains overhead. Evacuation is assumed to begin at a specified time after the end of the release. However the program is written in such a way that it can calculate doses correctly if people are evacuated while the plume is still overhead. The parameter identified in Figure 4 as TREND, the time at which the release ends, is not used anywhere else within COSYMA and can be set to whatever time the user needs to model the required timings of the emergency actions. The dose received during the period while people are evacuating is taken to be that which would be received at the initial point for the time taken to travel out of area A. Evacuation of area B is assumed to begin after the automatic evacuation has been completed but, by assigning negative values to delay times, an earlier evacuation can be modelled. The sequence of events in area B is the same as that in area A. The risk of an early health effect does not increase linearly with the dose, and consequently it is not adequate to calculate an average dose to groups of people at a single grid point if those groups are assumed to behave in different ways so that they have different doses. The description adopted in the NE sub-system considers a number of groups of people with different doses and different risks, as described below. The individual risk is calculated for each group separately.

Up to five groups of people are considered within the areas which are to be evacuated. Some people are assumed to follow the instructions issued by the authorities and shelter and evacuate as ordered. Allowance is made in COSYMA for these people sheltering in different locations with different shielding factors, and three such locations can be considered. Some other people are assumed to evacuate as soon as they are told to shelter. The final group of people are assumed to remain out of doors during the sheltering period because they could not be located and warned; they are however assumed to be evacuated at the same time as the other people. The user can specify the fraction of the population in each group and the shielding factors for each. The default values are given in Table 8.

The doses received by people while they are evacuating allows for the time taken to travel out of the area considered. The spectrum of individual travelling times for leaving the area is approximated by considering the times taken for three fractions of the population to drive for a specified distance for four different population densities. Values for leaving 6 and 10 km circles have been derived [37], and are used as the defaults in COSYMA. They are given

in Table 9. The choice between them is made separately for areas A and B, based on the outer radius of the area to be evacuated, and the population density within the evacuation area.

If the individual risk is presented as an end-point, then it is averaged over the travel time, and the risks to each of the groups of people with different shielding factors are presented. When calculating the number of health effects, a further average over the shielding groups is carried out.

Outside the evacuation area, further groups of the population in different locations and therefore having different shielding factors are considered in the NE sub-system. This is because the program allows for the possibility of there being early health effects outside the area covered by evacuation. This means that an average dose does not give an adequate description of the overall risk, and the dose in each group of people must be considered separately. The shielding factors and the fraction of the total population in each of the groups of people considered can be set by the user; the default values are given in Table 10. In the NL and FL sub-systems only one group having average habits is considered, as linear dose response relationships are used for the health effects considered there.

It is assumed in COSYMA that people who are evacuated will also be decontaminated, and so the dose from material deposited on skin is assumed to be terminated at a user-specified time after the end of the evacuation period.

5.6.2 Allowance for Sheltering Only

COSYMA allows for reduction factors for doses received during periods when people are indoors. Different factors are used for the external γ doses from the cloud or from deposited material. Reduction factors are also included in calculating the doses from inhalation of material in the plume or of resuspended material. The calculation of the amount of material deposited on the skin also takes into account whether people are indoors or outdoors at the time of the deposition. The same factors are used when people are indoors as part of their normal activities or because they have been told to shelter.

5.6.3 Allowance for Stable Iodine Tablets

The issue of stable iodine tablets to the population is considered in the NE and NL sub-systems of COSYMA. The reduction in the thyroid dose from the inhalation of iodine produced by taking stable iodine tablets depends on the time at which the tablets are taken in relation to the time at which material is inhaled. This complex relation is simplified in COSYMA, where a reduction factor specified by the user is adopted for all times of inhalation and of taking the iodine tablets.

5. BASIC FEATURES OF THE MODELS IN COSYMA

5.6.4 Dose Received before Relocation

COSYMA does not consider relocation in combination with sheltering. Therefore the doses received before relocation are calculated assuming normal activity, with people spending part of their time indoors and part outdoors. If the area considered has already been evacuated, then the dose reduction factors calculated in the NE sub-system are used.

5.6.5 Dose Received after Return from Evacuation or Relocation

The method of determining when people can return from evacuation and/or relocation was described in Section 5.5. The doses received after return are calculated assuming normal activity. Decontamination can be assumed to be carried out in some areas. Here all doses from deposited activity are calculated by dividing the dose which would be received in the absence of decontamination by the decontamination factor appropriate for the time period at which the decontamination was assumed to occur. In calculating the individual risk of late health effects, it is assumed that people return to the same point from which they evacuated or relocated.

5.7 The Tritium Model

The COSYMA package includes a separate program, UFOTRI, for calculating the consequences of a release of tritium gas or tritiated water [38]. The program combines an atmospheric dispersion model which describes the dispersion and deposition of the material released and the dispersion of the material returning from the ground to the atmosphere with a dynamic model for tritium transfer through food chains [39].

The present version of UFOTRI is based on the Gaussian trajectory model MUSEMET which is in use within the program system COSYMA. MUSEMET was modified for describing the behaviour of tritium in the environment of both gaseous tritium and tritiated water vapour. The importance of the re-emission process necessitates dual modelling of the atmospheric dispersion. MUSEMET calculates the dispersion after a single release event and the subsequent deposition on soil and plants. In a second step, the re-emission of tritium from soil (evaporation) and plants (transpiration) is taken into account by an area source model specially developed for that purpose and combined with the original model. UFOTRI uses a simplified assumption which replaces the area source by a single source point in the centre of the area, with a given initial widening of the plume. An area source is represented as a number of smaller area sources, each of which combines several grid points from the original atmospheric dispersion step.

1

IMAGE EVALUATION
TEST TARGET (MT-3)

1.0
1.1
1.25

1.4
1.6

1.8
2.0
2.2
2.5
2.8
3.2

150mm

6"

1

IMAGE EVALUATION
TEST TARGET (MT-3)

150mm

6"

1

IMAGE EVALUATION
TEST TARGET (MT-3)

150mm

6"
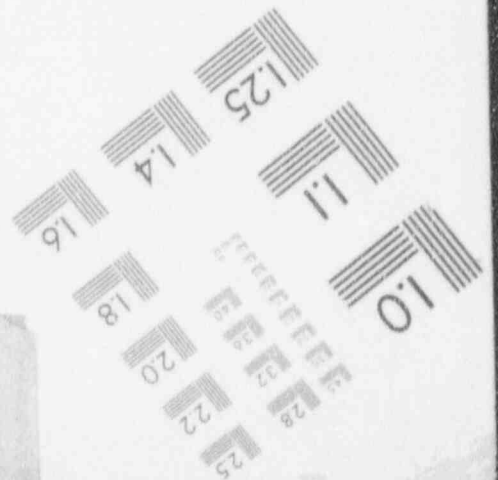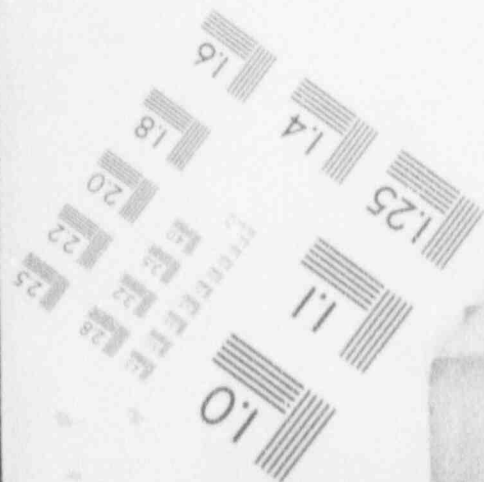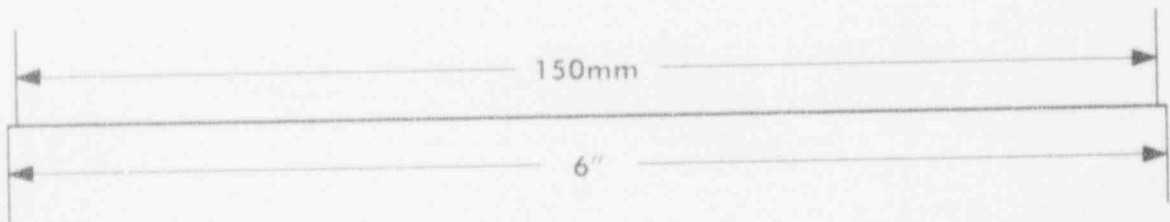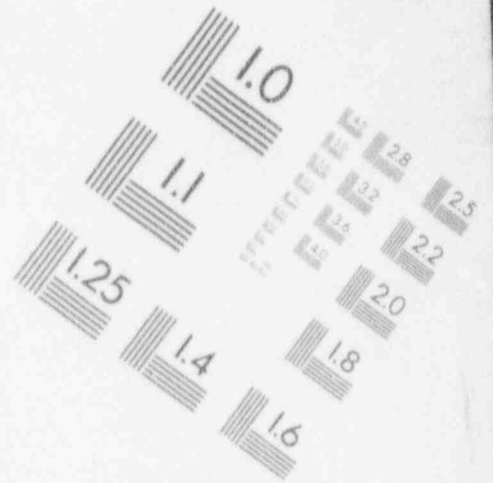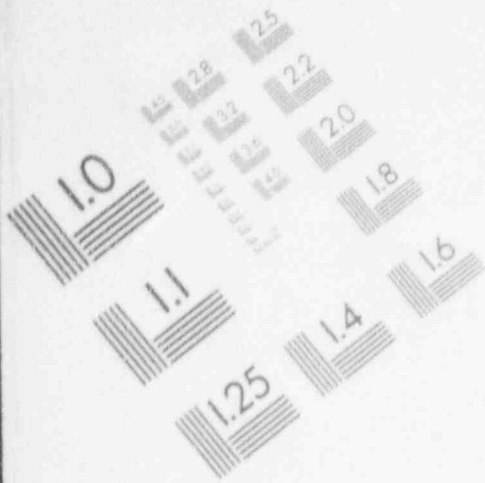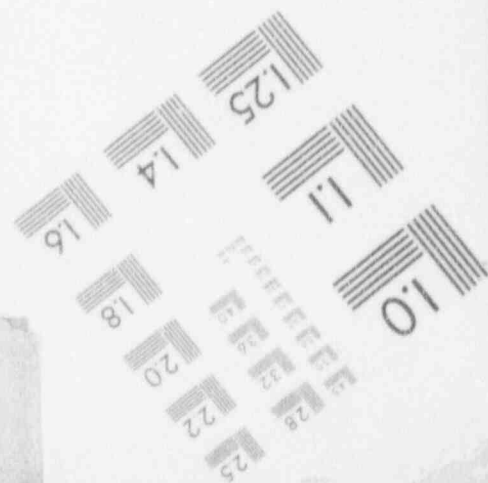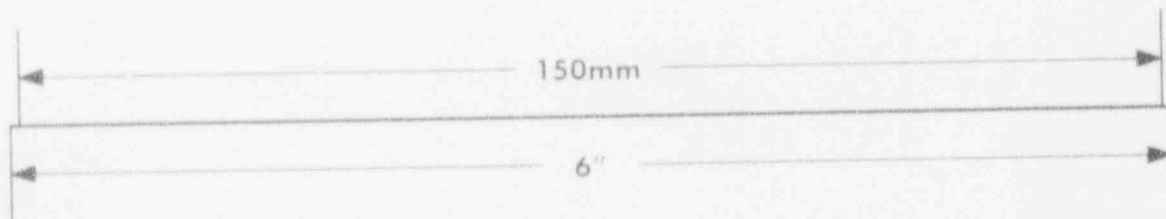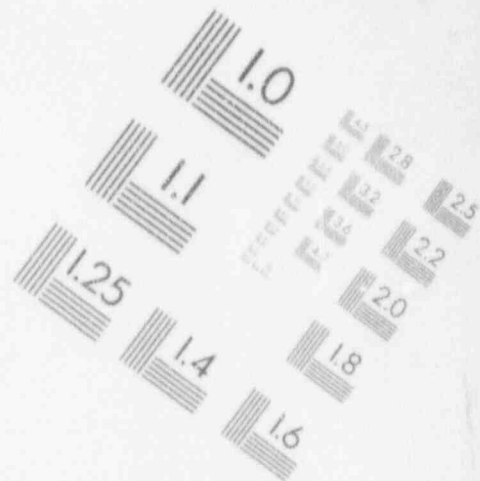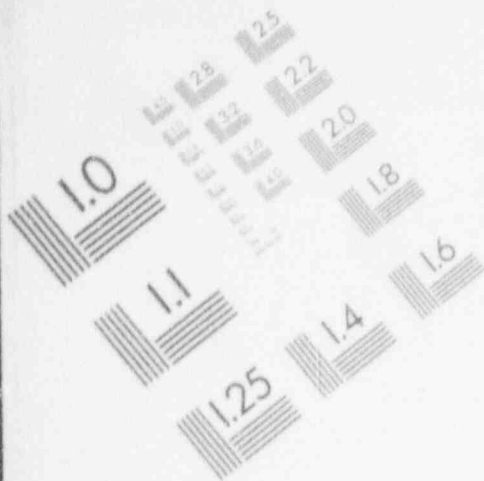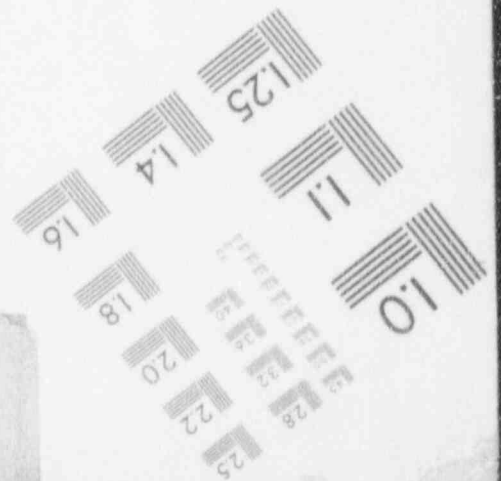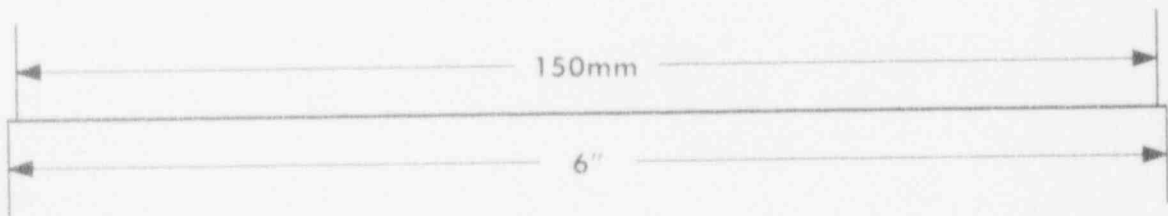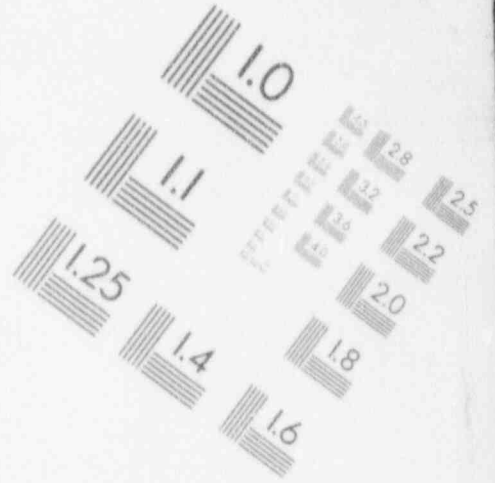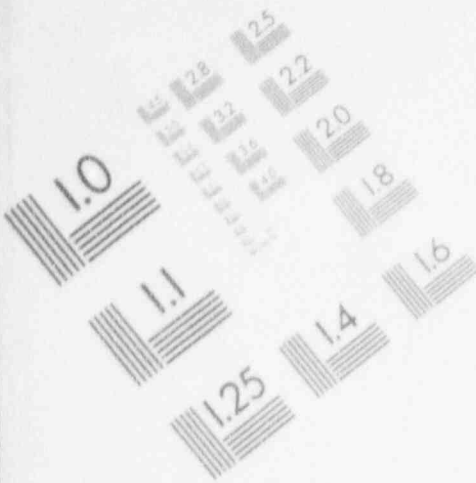
The conversion of tritium gas into tritiated water (HT into HTO), the transport of tritium into deeper soil layers, the uptake of tritium by the plant root system, and the conversion of HTO into organically bound tritium (OBT), are processes which may modify the total balance of the available HT or HTO. Therefore, they are taken into account in the atmospheric dispersion module, and in the foodchain pathways such as the production of milk, milk products and beef. Conversion of tritium gas into tritiated water during atmospheric dispersion is not included in the program because the conversion rate is very slow in comparison with the transportation times.

UFOTRI considers two different plant species, namely nutriment plants and pasture grass. Because of the plant specific parameters describing the exchange processes between plant and its environment, the model had to account for two different areas, one covered with the nutriment plants and one for the pasture grass. The temperature, the anorganic content of plant matter and the transfer resistances (aerodynamic, boundary layer and stomata resistance) determine the uptake of tritium in the vegetation as well as the loss of tritium from the vegetation.

The re-emission rate of HTO is assessed on the basis of the soil and plant evapotranspiration, and the plant transpiration determines the amount of water which must be transported from the root system to the plant in order to balance the loss of water. The potential evapotranspiration is derived using Penman's empirical equation which combines the radiation balance with the wind effects. All exchange processes between cow and atmosphere, cow and plant, and cow and soil, which are important for the ingestion pathways via milk, beef and dairy products, are also considered in the atmospheric part of UFOTRI.

In the ingestion module of UFOTRI, the long term behaviour of tritium in the environment and the assessment of the long term doses of the population from the consumption of tritium contaminated foodstuffs up to about 50 km from a site are described. The exchange processes between the individual compartments are treated by first order differential equations which describe linear dependencies of tritium concentrations or concentration differences.

5.8 Economic Costs of Accidents

COSYMA includes a module for assessing the off site economic costs of an accident. The model incorporated into COSYMA is based on one developed by NRPB and KfK [40], [16]. The costs calculated are a measure of the benefit foregone as a result of the accident. The model considers the costs of countermeasures (evacuation, relocation, sheltering, food restrictions and decontamination) and the cost associated with health effects. It does not consider less tangible costs such as the impact on the nuclear power programme or ecological damage, nor does it consider the costs of damage to the plant itself. The following sum-

marises the items included, and methods which may be used to derive the costs for each item. The default values adopted within COSYMA for each of the costs considered are given in Tables 11 and 12, for estimating economic consequences in the UK and FRG.

All costs occurring after one year may be adjusted using a discount factor. This factor should be consistent with the annual rate of interest, and for those costs which are dominated by labour costs, the annual increase in wages should be included by means of an adjusted discount factor. The user must specify the discount factor he wishes to use; this may be zero to represent no discounting.

5.8.1 Movement of People (evacuation/relocation)

Transport costs:

The emphasis in the model is on the transport costs of evacuation. Representative costs per journey have been estimated for organised transport using buses and private transport by cars. These two costs were combined into a single cost for use in COSYMA.

Loss of income costs:

It is assumed that, if people are removed from their homes through evacuation or relocation, then they will also be unable to reach their workplace and the contribution they would have made to the economy will be lost.

An individual's contribution to the economy is assumed to be the per caput Gross Domestic Product (GDP) for the country or region containing the affected area. Loss of income costs occur from the beginning of the evacuation or relocation period and continue up to the time when recovery of labour income is assumed to have occurred due to individuals finding re-employment outside the affected area, or to the time when people return to their original homes. A mean value of two years is the default value.

Accommodation costs:

There are two alternative methods by which accommodation costs may be calculated, and the user must specify which method he wishes to use. Accommodation costs may either be included by retaining the housing component in the GDP-based costs which are used in the calculation of loss of income costs, or by applying a daily cost per person evacuated or relocated. For the latter, the default costs are based on the market value of housing. If the latter method is used, the GDP costs used for loss of income calculations must have the housing component removed to avoid double counting. The costing of accommodation ceases at a time when it is assumed that the people relocated will have obtained new permanent accommodation to replace the lost accommodation and the contributions to the

economy from rents and mortgages will have recommenced. The default assumption in COSYMA is that this is equivalent to the time when recovery of labour income is assumed to occur.

Cost of lost capital services:

After the recovery process has occurred, the only cost remaining is that representing the lost services of the capital value of land and assets, due to depreciation, and loss of interest on the original investment. The value of land and its assets is subdivided into the categories of capital stock (excluding housing and consumer durables), housing, consumer durables and land. For each of these categories there are default values for the original (net) value at the time of the accident of land and assets. The proportion of the original value that is lost during the relocation period is then determined by applying annual depreciation and interest rates. The depreciation rate varies for housing, consumer durables and other stock.

5.8.2 Food Restrictions

Cost of lost food and capital values:

The basic quantity for expressing the cost of the lost food is in terms of its lost contribution to the country's GDP. In the first year after the accident the gross output value is used, to include the cost of investment made by the farmer upon which there will be no return. In subsequent years, GDP values are applied, in terms of GDP per unit quantity (eg, head of livestock, area of crop producing land, amount of crop lost, and litre of milk produced). These values include an allowance for the effect on food processing industries of bans on the raw produce, where this is likely to be significant.

In the same way as has been assumed for long-term relocation, a cut-off time is applied to represent the recovery of this part of the economy. The default value is three years. After the assumed agricultural economic recovery time, the loss of capital value of the land is calculated in the same way as the lost capital value of land during relocation, using data on the capital value of agricultural land per unit area.

Cost of food disposal:

The costs of food disposal are considered in the model, but those of storage, processing or feeding of contaminated food to animals are not. The default assumptions are that crops and livestock are disposed of on the farm and therefore incur no additional cost, and that milk is transported away from the area before being disposed of. The only direct disposal costs are therefore those due to the milk transport. It is assumed that milk production will cease 100 days after the accident, and that no further disposal will be necessary after this time. Other values can be provided by the user of COSYMA.

5. BASIC FEATURES OF THE MODELS IN COSYMA

5.8.3 Decontamination

COSYMA allows the user to specify decontamination factors for even of the periods in which decontamination and return from relocation are considered, as described in Section 5.5. A decontamination cost can also be specified for each of these periods. At present COSYMA does not consider the type of area (e.g. rural or urban) when using these factors, and the cost used must be an average for the types of land which are likely to be decontaminated. The default costs reflect the processes likely to be required to achieve the specified decontamination factors at the time after the accident for which they are applied. The default data are appropriate to decontamination occurring in the first year after the accident, and are in terms of the cost per area of land decontaminated.

5.8.4 Radiation Induced Health Effects

Five main categories of radiation health effects are considered in the economics model. These are non-fatal early and continuing effects, fatal early effects, non-fatal cancer, fatal cancer and hereditary effects.

The model includes the ability to calculate the costs of radiation-induced health effects by two alternative methods: the human capital approach and a method utilising a subjective valuation of detriment. The human capital method represents those costs which have a directly measurable effect on the economy. The components of cost considered are the costs of medical treatment and the loss of an individual's contribution to the economy. The subjective valuation approach has been included to enable the non-pecuniary element of the cost of health effects to be evaluated where required by assigning to each health effect a monetary value representing an individual aversion to that type of effect. These valuations do not include the cost of treatment, and this should be included separately, as in the human capital approach.

The COSYMA package includes a number of data libraries which contain either the results of models which are not included in the accident consequence programs or other information required in running the programs. This section identifies the libraries in the package, and summarises the sources of the information in them. As discussed in earlier sections, there are a number of areas in which the data included in COSYMA could be improved in future versions of the system. The data described below are those included in the current version, designated 90/1.

6.1 Radionuclide Data

All of the sub-systems of COSYMA require values for the half-lives of the nuclides considered. A suitable library is included in the package. The COSGAP dispersion model also requires information on the γ decay schemes of the nuclides considered. A suitable library, which is derived from the information in ICRP-38 [41], is included in the COSYMA package.

6.2 Meteorological Data

The COSYMA programs require information on the atmospheric conditions affecting the dispersing material. The package includes five different atmospheric dispersion models, which require very different amounts and types of data. The ISOLA, MUSEMET and COSGAP models require only site-specific data, and it is up to the user of COSYMA to provide the data for the sites considered. The RIMPUFF model requires data on the conditions at a series of locations in the area considered or can use data from a single station. It is up to the user of COSYMA to provide suitable data for this model. The data required for these dispersion models are described in detail in the COSYMA user guide [18].

The MESOS model requires information on the pressure field covering the whole of Europe and suitable data for the years 1982 and 1983 are included in the COSYMA package. The form of the data is described in the user guide.

6.3 Dosimetric Data

The calculation of doses from each of the routes of exposure considered in COSYMA uses information from libraries, and a series of libraries containing this information is included

in the COSYMA package. Alternative data libraries may be provided in future based on other models.

The calculation of cloud γ dose in the CONCEN module of the COSYMA sub- systems uses a library giving the cloud γ dose per unit air concentration for a series of nuclides and a set of correction factors for the effects of plume size. The values included are based on work by GSF [42]. The COSGAP dispersion model uses a different method of evaluating the cloud γ dose [20], and suitable libraries for use with this program are provided in the COSYMA package.

The calculation of external γ dose from deposited material uses a data library giving the dose per unit deposit at a series of times for each of a large number of nuclides. The values in the library, which were derived from the GSF model [43], [44] include the contribution from daughter products formed after the original material is deposited. The model used allows for shielding by ground roughness and the air in calculating photon fluxes above the ground by a Monte Carlo technique. Organ doses are calculated allowing for the non-uniform pattern of irradiation of the body. This model does not in general allow for movement of the deposited material into the soil column. Alternative models, which could be used for obtaining the values in the library, are available. They treat the various steps in the calculation differently. For example, the model developed at NRPB [19] allows for movement into the soil column but uses a simpler method of calculating the γ flux above the ground.

Doses from deposition on skin are calculated using a library which contains values of the dose rate per unit deposit, derived using the models described in [45].

The COSYMA package contains libraries of values for the dose per unit intake by inhalation and ingestion which are obtained from metabolic models derived by GSF [46]. The model includes a description of the ways in which radioactive material moves through the body after intake and the doses received by organs from material in that organ as well as material in other body organs. Other models are available for calculating the required values in these libraries [47].

6.4 Activity Risk Coefficients

The method of calculating the numbers of late health effects adopted in COSYMA, described in Section 5.4, uses "activity-risk coefficients". These coefficients require information on the time variation of concentrations of activity in food, dose per unit intakes by inhalation and ingestion, the time variation of external γ dose per unit deposit and of the air concentration from resuspension. They also require information on the risk coefficients for the different effects considered. The COSYMA package includes activity risk coefficients

which were derived from the data sets identified earlier in this section, and the risk coefficients described in Section 5.4.

6.5 Food Chain Information

COSYMA could be used with results of any food chain model which is capable of calculating the concentration of each of a range of nuclides in the foods of interest at a series of times after the deposit. Results of two food chain models are included in COSYMA, and libraries giving the concentration in food per unit deposit calculated with each model are provided. The activity risk coefficients included in the package were calculated using results obtained with a version of the GSF model ECOSYS [48]. Results obtained with the NRPB model FARMLAND [49], [50], [51] are also provided. While these are not yet incorporated in the activity risk coefficients, they can be used for calculations in which the collective food intake is considered, and in calculations where food bans are implemented on the basis of the concentration in foodstuffs. A recent study by NRPB and GSF resulted in an agreed set of food chain models and parameter values [52]. A data base obtained using these models and values is being prepared and will be made available in due course. Activity risk coefficients will also be provided based on these new food chain concentration values.

6.6 Gridded Data

The COSYMA package includes data libraries giving the population and agricultural production on a grid covering the whole of Europe. Population and agricultural production distributions are required for input to COSYMA in a different format, giving the quantities in distance bands and angular sectors around the site. A program, GRIDS, to transform the data from the form used in the library to that required for a COSYMA run for any site in Europe is provided in the package. This program can be used for population and agricultural production distributions.

The program assigns the whole population from each "square" on the grid to the distance band and sector corresponding to a single point (the "bottom left- hand corner"). The distance and direction of this point from the site are calculated for the great circle joining the point to the site, and assuming that the earth is a perfect sphere. The GRIDS program allows for the use of a population grid with a finer resolution (500 m squares) close to the site. This grid must be provided by the user.

6. DATA LIBRARIES IN THE COSYMA PACKAGE

6.6.1   Population Distribution

The package includes a library giving the population of Europe on a latitude-longitude grid with a resolution of approximately 5 kilometres. The information contained in the library is a composite from a number of sources. The information for countries which were in the EC in 1979 comes mainly from data obtained at that time [53]. This has been extended using data from atlases for other parts of Europe [54] and more recent information for Spain.

6.6.2   Agricultural Production Distributions

COSYMA includes two models for calculating collective doses from consumption of contaminated food. One is based on the assumptions that all food is derived at the point of consumption, and that the required amount of food is produced at each grid point. If this model is used, then no information on the agricultural production distribution is required. The second model is based on the assumption that all food produced is consumed somewhere, and a library giving the amount of each product considered which is produced at each location of a grid of approximately 10^4 km^2 is provided in this package. The source of the data for each country is described in [54].

6.6.3   Land-Sea Matrix

COSYMA calculates the areas from which people are evacuated or relocated. The area calculated is the total area of land over which the evacuation or relocation criteria are exceeded. It includes areas where there are no people living, but does not include areas of the sea. A matrix giving the position of the coast is used in this calculation, and provided in the COSYMA package.

The end-points which are considered by COSYMA were outlined in Section 2. Section 7.1 describes these end-points in more detail. Section 7.2 describes the way in which probability distributions are calculated, while Section 7.3 describes the ways in which the results can be presented.

7.1 Endpoints Considered

Accident consequence assessment programs calculate information on the numbers of health effects in the exposed population, the numbers of people or the area affected by different countermeasures, the amounts of agricultural production for which restrictions may be needed and the off-site economic costs of an accident. Other quantities, such as the concentrations of radionuclides in air, on the ground or in foods, or doses from different routes of exposure or at different times, which must be calculated in order to derive these collective effects may also be required as the end-point for some applications of the system. This section describes the many quantities which can be calculated with COSYMA to represent these broad categories of effects. The user of COSYMA can select which of the available endpoints are considered in a particular run.

The health effects considered in COSYMA were indicated in Section 2 and Table 1. Probability distributions of the numbers of effects can be presented, with separate results for early and late effects. The results for early effects can be given in terms of the numbers of fatal effects (totals and in different organs) and of each of the non-fatal effects considered. Information on the incidence and the numbers of deaths from cancers, both in total and from different types of cancer, can be obtained, with a breakdown of the numbers of fatal cancers in different time periods being given. The total number of years of life lost as a result of all health effects and for each health effect separately can also be calculated, as can the total number of hereditary effects in all future generations.

The countermeasures which can be considered in COSYMA were described in detail in Section 5.5. Information on the extent of the countermeasures adopted is given in terms of the numbers of people and the areas affected by relocation and by evacuation, together with the numbers of people remaining away from their home and the area from which these people have been moved at a series of times. The number of people who shelter is also available. The countermeasures considered in COSYMA include decontamination, and the total area which is decontaminated and the areas decontaminated at different times are given. The information on the countermeasures affecting food is represented in terms of the areas and amounts of food affected by restrictions, with results given separately for the nine foods

considered. Information on the time variation of the amount of food affected is also available.

Information on the off-site costs of the accident are also calculated within COSYMA. Information on various components of the cost in addition to the total is available. Thus the contributions from evacuation and relocation, decontamination, food bans and health effects can be obtained separately, both in total and in a series of time periods. The costs can be further sub-divided so that the costs arising from evacuation and relocation can be expressed in terms of the costs of transport, of the inability to work, and of the lost capital value of the land and of assets. The costs of food bans can be subdivided into the contributions from crops, milk and livestock with the costs of food disposal, lost capital costs and GDP related costs separately identified. The costs associated with health effects can be divided into the contributions from the different categories of effects.

7.2 Probabilistic Information

The consequences of an accidental release will depend on the values of a number of parameters, including those describing the atmospheric conditions during the release and the subsequent dispersion of the material over the area of interest and the travel times out of the contaminated area for different groups of people. Unique values can be assigned to many of the parameters, but it is not possible to do this for the atmospheric conditions at the time of the postulated accidental release. The wind direction determines the groups of people who are exposed and the areas of land contaminated, while other conditions determine the rate at which the material disperses and hence the levels of dose and the magnitude of effects. The method used in accident consequence assessments is to consider the consequences should the accident happen in any set of conditions, and describe the spread of different consequences for all conditions which might be experienced. Therefore the results of an accident consequence assessment are normally expressed in probabilistic terms, and particular features of the distribution of consequences are used to describe the overall distribution. The following section briefly describes the probabilistic treatment of the results in COSYMA. A more detailed example of the construction of probability distributions is given in an appendix of [1].

Consider a release which gives rise to a value $C(i)$ for a particular consequence in a set of conditions which occur with a probability $f(i)$. The probability of the sets of conditions considered must be defined in such a way that the sum over all sets of conditions is equal to unity. The overall probability distribution for this consequence is then constructed by evaluating the consequences for all possible set of conditions.

One way used in COSYMA to present the probabilistic information is the complementary cumulative frequency distribution (CCFD) which is the probability of equalling or exceeding a particular number of consequences as a function of that number, i.e.

$$P(\geq C) = \sum f(i)$$

summed over those conditions for which the consequences equal or exceed C. An example of this form of presentation of the consequences is given in Figure 6. An alternative form of presentation is to represent the probability that the consequences lie within a particular range. This probability, Q(C1-C2), is determined by the difference between the appropriate values of the CCFD, as

$$Q(C1 - C2) = P(\geq C1) - P(\geq C2) = \sum f(i)$$

summed over those conditions for which the consequences are within the range C1 to C2.

An example of this form of presentation of the consequences is also given in Figure 6. This form of presentation is also known as the class frequency distribution.

A number of characteristic quantities can be determined to represent these distributions, and some are calculated by COSYMA. The mean or expectation value of the distribution E is the average level of consequences should the accident happen. It is given by

$$E = \sum f(i) \, C(i)$$

summed over all sets of conditions.

Other characteristic values are the percentiles, the value of the consequence exceeded with a given probability. These are defined so that the n'th percentile is the level of consequence which is exceeded with a probability of $(100-n)\%$. Some of the consequences considered in accident consequence assessments only occur if the dose to some of the exposed population is above a threshold value. For some releases this threshold will be exceeded in some but not all atmospheric conditions. In these cases there will then be some non-zero probability of there being no effects. The probability of zero consequences is an important parameter which can be obtained from COSYMA.

The above descriptions represent the consequences conditional upon the accident having occurred. In some applications it is desirable to also consider the frequency of a range of accidental releases postulated for an installation. If a particular size r of accident is postulated to occur with a frequency F(r), then the probability per unit time of consequences equalling or exceeding a value C is given by

7. PRESENTATION OF RESULTS

- 49 -

$$P(\geq C) = \sum f(i) F(r)$$

summed over those values of r and i such that the consequences equal or exceed C. Other features of this distribution can be obtained in the same way as for the distributions for a single release.

7.3 The Form of Results

COSYMA can be used to produce estimates of consequences from a wide range of conditions, or from a small number of sets of conditions. The main sub-systems and the stand-alone evaluation programs allow this information to be presented in a wide variety of ways, so that the method which is most appropriate for a particular application can be chosen. In addition a large amount of detailed information is written to files for passing between the different modules of the system. Further programs could be written by users who require access to this detailed information.

The various end-points from probabilistic runs of COSYMA are most easily presented in terms of the complementary cumulative frequency distribution (CCFD) described in Section 7.2. The COSYMA programs write files giving information enabling these distributions to be plotted, using a graph-plotting package provided by the user. The results can be presented either in terms of cumulative probability distributions or in terms of the class frequency distributions. In addition characteristic quantities of the distribution, such as the expectation value, the value at a series of percentiles and the probability of zero effects, are tabulated by the program. Results can also be presented in the form of pie charts, and tables of contributions to some selected consequence.

In obtaining the results for the end-points identified above, values for a large number of intermediate results must be calculated. COSYMA allows the user to print out information on many of these intermediate quantities, either in terms of their values in selected atmospheric sequences or in terms of their probability distributions over all atmospheric sequences considered. The three sub-systems NE, NL and FL can themselves give considerable information on these intermediate results. In addition a group of evaluation programs, which run independently of the three sub-systems, are available to give alternative presentations of the results.

Information on the variation with distance from the site of air concentration and amount of material deposited can be presented in terms of the probability distribution at selected distances or the variation with distance of the characteristic quantities of the distribution. The value of the quantity concerned is calculated in each atmospheric sequence at each grid point at a particular distance. These values form the set for which the probability distrib-

ution is presented. Many of the values are zero as the plume rarely covers all grid points around the site. The expectation value is averaged over all atmospheric sequences and angles from the site before being presented. An example of this form of presentation is given in Figure 7. The results can also be given in terms of the areas where the deposition lies within different ranges. COSYMA allows the user to obtain a considerable amount of information on the contributions to doses made by different nuclides and different pathways. Probability distributions of each dose considered at each distance can be obtained. These can be presented in terms of the characteristic quantities at each distance, or the variation of the characteristic quantities with distance. Information on the collective dose can also be obtained. The information on doses can be presented for potential doses (those which would be received in the absence of countermeasures) or for actual doses taking account of the effects of countermeasures. Information on the distribution of collective dose in individual dose bands is also available. The fraction of the total dose received from the different routes can be obtained for each distance considered, as illustrated in Figure 8. The contribution of each nuclide to the dose from each of the routes considered at selected distances can also be presented. A further breakdown in terms of the contribution of each route of exposure to each of the late health effects is also available.

The consideration of countermeasures to reduce doses is an important part of any accident consequence analysis, and COSYMA can be used to provide a considerable amount of information on the effects of countermeasures. The end-points reflecting the impact on the population as a whole were described in Section 7.1. In addition to these, results for the probability of imposing different countermeasures as a function of distance are available.

Information on health effects is available in terms of both the numbers of effects in the whole population and of the risk to an individual at a particular distance from the site. The results for the whole population are presented in terms of probability distributions and their characteristic quantities, as described in the previous section. Time-dependent results can also be obtained as illustrated in Figure 9. The individual risk can be presented in terms of the probability distribution at each distance, or the variation of its characteristic quantities with distance.

COSYMA also allows the user to investigate the correlations between different end-points and between individual and collective doses. An example of the collective dose in individual dose bands is given in Figure 10.

7. PRESENTATION OF RESULTS

As stated earlier, the programs in the COSYMA package were written without using any formal quality assurance procedures. However, a number of tests have been carried out on the programs, both while they were being written and subsequently. Large parts of the programs in COSYMA are derived from the MARC and UFOMOD programs which have been tested [55] and have been used extensively. Those tests and their results are equally applicable to parts of COSYMA.

A number of these tests consisted of identifying calculations which are sufficiently simple that they can be done by hand, but sufficiently complex that they test the computer program. A comparison of the results of hand and computer calculations then acts as a test for the programs.

Further tests have been carried out by comparing the results of programs in the COSYMA package with those obtained by other computer programs or given in reports. This is particularly appropriate for atmospheric dispersion programs, as a number of reports giving model calculations are available.

The COSYMA package contains some programs which can be made to generate the same results, such as doses at specified times. As the programs were written independently of each other, demonstrating consistent results gives confidence in the correctness of the programs. The countermeasures calculations of the NL and FL modules are very similar so that results of the two sub-systems can be compared and used to check those parts of the programs. The countermeasures calculations have been checked by selecting criteria which do not involve any actions and showing that the results of POTDOS and LATDOS are the same.

Many parts of the COSYMA programs consist of simple operations on precalculated quantities taken from data libraries. The correctness of results of the COSYMA package depends on the correctness of these data libraries. The values contained in the libraries were generated either in the FRG, though not necessarily at KfK, or by NRPB. In virtually all cases data sets of equivalent values have been compiled totally independently at both NRPB and KfK. The two sets have been checked for consistency where possible, and in the majority of cases agree sufficiently to give confidence in the correctness of the data sets included in the COSYMA package. The contents of some of the libraries have also been checked against equivalent results from other sources. Benchmark studies have been undertaken for food chain models (see, for example, [52]). These studies help to demonstrate the correctness of the data libraries.

9. UNCERTAINTY ANALYSES USING COSYMA

An important part of accident consequence assessments is to estimate the likely uncertainty in any of the results obtained. The COSYMA package does not include any programs specifically for carrying out uncertainty analyses. However the programs forming the main sub-systems are written in such a way that all the variables can be set from the input which must be supplied by the user. The COSGAP dispersion program also allows many of the model parameters to be set from the input data.

Techniques are available for describing the range in which the most appropriate value for each parameter used in calculations might lie. Techniques are also available for selecting values for each parameter from their range to form the input for a number of runs of programs such as those in COSYMA. Further techniques are available for analysing the relationships between the output values generated and the sets of input values.

Uncertainty analyses of parts of UFOMOD have been carried out, and the techniques are equally applicable to analyses of the same parts of COSYMA. Programs [56] have been written which form an interface between the parts of UFOMOD considered and the uncertainty analysis programs written at Sandia National Laboratories [57], [58]. The programs [56] will read the output file produced by the Sandia sampling program and write input files for COSYMA in the correct format. They also read the output files of COSYMA and write files in a form which can be read by the Sandia analysis program.

While these programs are not part of the COSYMA package, they could be made available if required. They could be modified moderately easily for use with other programs for selecting parameter values and analysing the relationships between input and output values.

10. CHOICE OF SUB-SYSTEMS AND PARAMETER VALUES

10.1   Choice of Sub-System

The structure of COSYMA, with its different sub-systems and its stand-alone programs, is described in Section 3. This section guides the user to the choice of the sub-system or program which is most appropriate for his particular application. The sub-systems and their contents are indicated in Figure 2 and Tables 2 and 3.

10.1.1   Choice of "Early" or "Late" Sub-System

The first question which must be resolved is whether it is necessary to use both "early" and "late" sub-systems, or whether only one of these is required. The early and late sub-systems include different health effects and emergency actions, and the choice here must be made on the basis of which set of actions or effects are to be considered.

If the amount of material released is such as to cause early health effects in the exposed population, then the "early" sub-system must be used for any study involving health effects. This sub-system must also be used if evacuation, with or without relocation, is being considered, whatever the size of the release. The difference between evacuation and relocation, described in Section 5.5, can for this purpose be described in terms of the different criteria used to initiate the actions. The user must ensure that the combination of sub-systems which includes all the desired options is used.

However, if the amount of material released is not sufficiently large as to cause early health effects or if evacuation is not being considered, there is no need to use the "early" sub-system. If evacuation (as understood in COSYMA) is being considered but there will not be any early health effects, only those parts of the "early" sub-system concerned with countermeasures need to be run. For these cases the PROTEC and EARLY modules are required. Parts of the EARLY module may also be required for some calculations of doses involving countermeasures. There is no need to use the "early" sub-system for any studies which are limited to the agricultural consequences only. Conversely, if the study is concerned only with early health effects and short term emergency actions, there is no need to consider the "late" sub-systems, and only the "early" sub-system is required.

10.1.2   Choice of "Near" or "Far" Sub-System

The second question to be resolved is the split between the "near" and the "far" version of the "late" sub-system, if this is being used. The maximum distance for which the "near"

sub-systems should be used depends to a large extent on the source term and the applicability of the dispersion model being used. Calculations can be carried out using both the NL and FL sub-systems and the results added to give the overall consequences of the release.

There is no sub-system for early effects at large distances, and hence the NE version must be used at all distances with a non-zero probability of those effects or countermeasures considered only in that system. The greatest distance at which these effects need to be considered defines the minimum distance at which the "far" sub-system can be used. However this is not the only criterion to be considered when separating the near and far distance ranges.

A further reason for providing different sub-systems for use at near and far distances was to enable different dispersion models to be used at different distances. In this way, dispersion models need only be used in the region for which they are appropriate. Therefore the main consideration in determining the dividing line between the regions is the applicability of the different dispersion models at different distances.

The models which are available in the COSYMA package have been summarised in Section 5.1. The simple Gaussian models used with the "near" sub-systems are based on the assumption that atmospheric conditions at the plume are the same as those at the site for which the meteorological data are applicable. These models therefore become less reliable with increasing distance from the site, and are most appropriate for use at distances up to some tens of kilometres. However, the RIMPUFF dispersion model may use meteorological information from a number of locations in the region. This model could be used with the "near" sub-system at any distance for which the appropriate meteorological data can be obtained. However the model requires a considerable amount of computer time, and it may be better to use the MESOS model and the "far" sub-system beyond a few tens of kilometres from the site.

There are some situations in which it may be better to use only one of the NL and FL sub-systems, even if they are not ideal for part of the distance range considered. This could be because by far the greater part of the consequences arise in a limited part of the distance range considered. When calculating the consequences occurring within the country containing the site, it may be adequate to use only the NL sub-system. Conversely, if calculating consequences over a very wide region it may be sufficient to make approximations near to the site, and use only the FL sub-system.

Where results from the NL and the FL sub-systems must be added together, then the same set of sequences and probabilities of atmospheric conditions must be used for both sub-systems. The results can then be added together on a sequence by sequence basis. A separate program to do this is available.

- 58 -

10.2 Default Values for Parameters and Data Libraries

The user of the COSYMA package must provide values for all the parameters used in the analysis programs. These parameter values may be input to the programs from data libraries or from the user-specified input files. In many cases the programs provide default values for the parameters, and standard versions of the data libraries are contained in the package. The user-guide shows which parameters in the user-specified input streams have a default value, and gives the value. Earlier sections of this report have described the models used to derive the values in those libraries (such as dose per unit intake) containing the results of pre-calculations made with models which are not included in the COSYMA package, and also the contents of those libraries (such as the population data) containing gridded information. This section gives some indication of the conditions for which the default values are applicable. However it cannot cover each of the parameter values required in a COSYMA run, and the user must ensure that the values assigned to the many parameters involved are appropriate to the particular application of the system being undertaken, or must use other models.

Perhaps one of the main areas where the parameter values must be chosen with care is in specifying the criteria for the countermeasures to be considered, both in terms of the dose levels at which the actions are assumed to be undertaken and the assumed timing of those actions. The COSYMA system allows a wide range of emergency actions to be considered, and leaves the user a considerable flexibility in setting the criteria.

The COSYMA package contains a library of deposited γ doses which was calculated allowing for shielding by "surface roughness". The values from this library are applied, with further shielding factors for people in different (urban and rural) locations, and also for people inside buildings. Studies with the NRPB model EXPURT have examined the relationship between doses in different areas [59]. Similar studies have examined the relationship between doses inside and outside buildings, including the contribution to dose from material deposited in the building. This type of work should be considered in selecting values for shielding factors. Consideration should also be given to the type of building for which the shielding factors are being applied. Brown [60] has reviewed information on shielding factors for different types of building.

Some of the quantities in the data libraries have concealed in them parameter values which the user may wish to alter. For example, the "activity risk coefficients" are derived from a process which considers the time-variation of concentration of material in food and of the deposited γ dose after deposition, and the risk coefficients for late health effects. Concentrations in food reflect agricultural practices which can vary between countries, particularly for the duration of the growing season or the time when animals are fed on stored food. Deposited γ dose rates are calculated assuming some shielding by the rough nature of the

10. CHOICE OF SUB-SYSTEMS AND PARAMETER VALUES

surface, and this must be considered when selecting shielding factors for various building types. The risk coefficients for late health effects are mostly based on the relative risk model, and therefore their values imply assumed values for the underlying natural cancer rate and the age structure of the population considered.

Gridded data for population and agricultural production for the whole of Europe are provided in the package, along with programs to generate distributions in sectors and distance bands around a site. The agricultural data, in particular, were produced on a coarse grid and information with a finer resolution may be available in the immediate vicinity of the site. The user should combine the data supplied with any better information available.

10.3 Simplified Running of the System

As stated in Section 1, one of the aims in developing the COSYMA system is to provide a flexible tool for analysing the consequences of accidental releases, and for studying the importance of different assumptions or models. Another aim was to enable people who are not specialists to carry out accident consequence assessments. These two aims are somewhat contradictory, as the first implies a complex program system and the second a much simpler system. The resulting program system tends towards the first of these objectives, in that it is a complex and flexible system. However by suitable choice of some of the parameter values, simple runs of the program can be carried out. A number of studies using COSYMA or the MARC and UFOMOD programs from which the COSYMA package was derived have been carried out. Some of these enable a limited amount of advice on this topic to be given, and some general points are given here as indicators of possible simplifications. However, it is difficult to give general guidance and, in many respects, users must experiment with the system and determine for themselves what simplifications can be used for their particular applications.

Choice of dispersion model:

The choice of the model to be used for atmospheric dispersion is perhaps the one for which the greatest amount of advice can be given. Several studies have been carried out in which the consequences calculated with different models or different approximations have been compared. They have concentrated on comparisons of the overall number of consequences in the population, and their conclusions may not be relevant if other aspects of the analysis are important. The studies also show that results of probabilistic analyses, especially of the numbers of health effects, are much less sensitive to the choice of models than are those of analyses in selected single sequences of atmospheric conditions. Other end-points such as the areas above certain dose levels seem to be more sensitive to the choice of dispersion model.

The need to consider models in which the variation of wind direction during the travel of the plume has been considered in several studies [61], [62], [63], [64]. These studies suggest that trajectory models may be required for source terms in which material is released over a period of several hours. However, at distances near to the site, results for releases of about 1 hour duration obtained with and without allowing for trajectories are very similar.

Jones [63] has compared results of analyses using the MARC dispersion model (incorporated in COSYMA as COSGAP) and a modified version of the RIMPUFF model. Panitz [64] has compared results using the MUSEMET and RIMPUFF models. Both studies showed that there is little difference between the results of probabilistic analyses obtained with the different models. RIMPUFF requires considerably more computer time than the other models. It seems reasonable to suggest that it should not be used for risk analyses where the overall number of effects in a population from a short release is the prime area of concern.

The ISOLA model requires very much less computer time than the other dispersion models, and so should be used for any application for which it is appropriate. Comparisons of contours of air concentration for a release of 144 hours duration calculated using MUSEMET and ISOLA show that the two models predict very similar dispersion patterns [12].

For simplicity only one of the NL and FL sub-systems should be used if the consequences arise largely in either the near or the far region. If the NE version of the program is used, the same dispersion calculations can be used for NL as for NE.

Description of the source term:

The COSYMA system allows any time variation of the source term to be modelled in detail, with releases in "phases" which are multiples of 1 hour for the NE and NL sub-systems or 3 hours for the FL sub-systems being considered separately. The amount of computer time required is almost proportional to the number of phases used in the analysis for the NE sub-system. Accident sequences in which a large part of the activity is released in a single hour with much smaller amounts in subsequent hours can usually be modelled adequately with all the release compressed into a single phase. A detailed description of the time variation of the source term is more important for those releases giving rise to early effects and the associated emergency actions.

Countermeasures:

The model adopted in the NE sub-system for describing the effects of evacuation is very complex. It allows a detailed description of the time taken by the population to leave the affected area. Sensitivity studies have shown that this may only have a small impact on the overall results, and that a description with fewer groups of driving times is probably ade-

10. CHOICE OF SUB-SYSTEMS AND PARAMETER VALUES

quate for many purposes. However, the model is included to allow detailed studies to be undertaken.

The methods required within the NE sub-system need a considerable amount of computer time, because of the complexity and flexibility of the models adopted. Therefore the NE sub-system should be used for the minimum number of distances for which emergency actions are likely to be required.

Groups of people:

The NE sub-system considers groups of people with different behaviour during the sheltering and evacuation periods. The number of health effects in the population represents the sum over those in the different groups. Unless the shielding factors for the groups are very different, the risks to the various groups may be similar, and calculations assuming a smaller number of groups may be adequate.

A large number of people at KfK and NRPB have been involved in the work leading up to the COSYMA program system. Those directly involved in the production of the package are listed at the front of the report. A number of other people have contributed to the development of the COSYMA system and to the models which are included in the package, and other organisations have contributed eit'ier programs or data libraries to the package. In particular:

- Riso National Laboratory pr /vided the original version of the RIMPUFF program;

- KFA Jülich provided the original version of the MUSEMET program;

- Imperial College, London University, provided the original version of the MESOS program which was partly developed under contract to CEC;

- GSF provided the data libraries of dose per unit intake and of dose per unit deposit, and the risk coefficients used for late health effects. Some of this work was funded by CEC;

- CEA provided data which forms the basis of the population and agricultural production grids for the EC. This work was partly funded by the CEC.

[1]   KfK and NRPB, Methods for assessing the off site radiological consequences of nuclear accidents. CEC Brussels EUR-10249 (1985).

[2]   Luykx, F and Sinnaeve, J, (editors) Workshop on methods for assessing the off-site radiological consequences of nuclear accidents. Luxembourg, April 1985. CEC EUR-10397 (1986).

[3]   Olast, M and Sinnaeve, J (editors) Joint CEC/NEA workshop on recent advances in reactor accident consequence assessment. Rome, January 1988 CEC, Luxembourg, EUR 11408 (1988).

[4]   CEC Seminar on methods and codes for assessing the off-site consequences of nuclear accidents. Athens, May 1990, CEC Brussels EUR-13013 (1990).

[5]   Clarke, R H and Kelly, G N, MARC - the NRPB methodology for assessing radiological consequences of accidental releases of activity. Chilton, NRPB-R127 (1981) (London, HMSO).

[6]   Kelly, G N and Clarke, R H, An assessment of the radiological consequences of releases from degraded core accidents for the Sizewell PWR. Chilton, NRPB-R137 (1982) (London. HMSO).

[7]   Jones, J A and Williams, J A, Assessment of the radiological consequences of releases from degraded core accidents for a proposed PWR at Hinkley Point: Results using MARC-1. Chilton, NRPB-M152 (1988).

[8]   Jones, J A and Williams, J A, Assessment of the radiological consequences of releases from containment bypass accidents from a proposed PWR at Hinkley Point, using MARC-1. Chilton, NRPB-M154 (1988).

[9]   Bayer, A, Burkart, K, Ehrhardt, J, Hübschmann, W, Schückler, M, Vogt, S, Jacobi, W and Trott, K R. The German Risk Study: accident consequence model and results of the study. Nucl. Technology 59 20-50 (1982).

[10] Bayer, A and Ehrhardt, J. The German 'Risk-oriented analysis of the SNR-300': Accident off-site consequence model and results of the study. Nucl. Technol. 65 232-249 (1984).

[11] Ehrhardt, J, Burkart, K, Hasemann, I, Matzerath, C, Panitz, H-J and Steinhauer, C. The program system UFOMOD for assessing the consequences of nuclear accidents. KfK-4330 (1988).

[12] Panitz, H-J, Päsler-Sauer, J and Matzerath, C. UFOMOD: Atmospheric dispersion and deposition. KfK-4332 (1989).

[13] Ehrhardt, J., Hasemann, I.
COSYMA: Dose models and countermeasures for external exposure and inhalation, Karlsruhe, Report KfK-4333 (1991)

[14] Steinhauer, C.
COSYMA: Ingestion pathways and foodbans, Karlsruhe, Report KfK-4334 (1991)

[15] Steinhauer, C., Matzerath, C., Ehrhardt, J.
COSYMA: Health effects models, Karlsruhe, Report KfK-4335 (1991)

[16] Faude, D.
COSYMA: Economic models, Karlsruhe, Report KfK-4336 (1991)

[17] Ehrhardt, J, Burkart, K, Fischer, F, Hasemann, I, Panitz, H-J and Steinhauer, C. Structure, important features and illustrative results of the new program system UFOMOD for assessing the radiological consequences of nuclear accidents. To be published in Nuclear Technology.

[18] COSYMA: User guide. Compiled by Hasemann, I and Jones, J A. CEC Brussels EUR 13045, KfK-4331B (1990).

[19] Hill, M D, Simmonds, J R., and Jones, J A, NRPB methodology for assessing the radiological consequences of accidental releases of radionuclides to atmosphere - MARC-1. Chilton, NRPB-R224 (1988) (London, HMSO).

[20] Jones, J A and Charles, D, AD-MARC: the atmospheric dispersion module in the methodology for assessing the radiological consequences of accidental releases. Chilton, NRPB-M72 (1982).

[21] Straka, J, Geiß, H and Vogt, K J. Diffusion of waste air puffs and plumes under changing weather conditions. Contr. Atmos. Phys. 54 207-221, 1981.

[22] Mikkelsen, T, Larsen, S E, Thykier-Nielsen, S. Description of the Riso puff model. Nuclear Technol. 76 56-65 (1984).

[23] Clarke, R H, The first report of a Working Group on Atmospheric Dispersion. A model for short and medium range dispersion of radionuclides released to the atmosphere. Harwell, NRPB-R91 (1979). (London, HMSO).

[24] Hosker, R P, Estimates of dry deposition and plume depletion over forests and grass-lands. IN Proc. Symposium on Physical Behaviour of Radioactive Contaminants in the Atmosphere, Vienna, Nov. 1973. Vienna IAEA (1974).

[25] Bultynck, H and Malet, L M. Evaluation of atmospheric dilution factors for effluents diffused from an elevated continuous point source. Tellus, 24, 455-472 (1972).

[26] Der Bundesminister der Justiz (Hrsg.), Bekanntmachung der Leitlinien zur Beurteilung der Auslegung von Kernkraftwerken mit Druckwasserreaktoren gegen Störfälle im Sinne des § 28 Abs. 3 der Strahlenschutzverordnung - Störfall-Leitline in - Bundesan-zciger, Jahrgang 35, Nummer 245a, 1983, Der Bundesminister der Justiz, 5300 Bonn, FRG.

[27] Hanna, S R, Briggs, G A and Hosker, R P. Handbook on atmospheric diffusion. Technical Information Center, US Department of Energy (1982).

[28] Hübschmann, W and Raskob, W. ISOLA V: A Fortran-77 code for the calculation of the long-term concentration distribution in the environment of nuclear installations. KfK-4604 (1990).

[29] ApSimon H M and Goddard, A J H. Atmospheric transport of radioisotopes and the assessment of population doses on a European scale. EUR-9128. CEC. Luxembourg (1983).

[30] Smith, F B. A scheme for estimating the vertical dispersion of a plume from a source near ground level. 3rd Meeting of an expert panel on air pollution modelling, Paris, October 1972, Brussels, NATO-CCMS Report 14, Chapter 17 (1973).

[31] Broomfield, M E, Meteorological sampling methods for use in probabilistic conse-quence assessments. IN Proc. Workshop on Methods for Assessing the Off-site Radiological Consequences of Nuclear Accidents, Luxembourg 1985. EUR-10397. CEC. Luxembourg (1986).

[32] Hemming, C R, Ferguson, L, Broomfield, M and Kelly, G N. The consequences of accidental releases of radioactive material in extreme conditions. Chilton, NRPB-M79 (1983).

[33] Linsley, G S, Resuspension of the transuranium elements - a review of existing data. Chilton, NRPB-R75 (1978) (London, HMSO).

[34] Stather, J W et al. Health effects models developed from the 1988 UNSCEAR report. Chilton, NRPB-R226 (1988). (London, HMSO).

12. REFERENCES

[35] Evans, J S, Moeller, D W, Cooper, D W. Health effects models for nuclear power plant accident consequence analysis. NUREG/CR-4214 (1985), Rev 1, (1990).

[36] Henrichs, K, Paretzke, H G, Chmelevsky, D and Gerken, M. New estimates for risk surfaces for late somatic effects of low doses of ionising radiation. IN Proc. CEC/NEA Workshop on Recent Advances in Reactor Accident Consequence Assessment. Rome 1988. EUR-11408. CEC. Luxembourg (1988).

[37] Pfeffer, W, Hofer, E, Nowak. E and Schnadt, H. Parameterization of the driving time in the evacuation or fast relocation model of an accident consequence code. IN Proc. CEC/NEA Workshop on Recent Advances in Reactor Accident Consequence Assessment. Rome, January 1988. EUR-11408. Luxembourg (1988).

[38] Raskob, W. UFOTRI: Program for assessing the off-site consequences from accidental tritium releases. KfK 4605 (1990).

[39] Shaw, P V and Haywood, S M. A dynamic model for predicting the movement of tritium in the environment. Rad. Prot. Dosim. 16 (1-2) 59-62 (1986).

[40] Haywood, S M, Robinson, C A and Heady, C. COCO-1: A model for assessing the cost of off-site consequences of accidental releases of radioactivity. NRPB report, to be published.

[41] ICRP, Radionuclide transformations energy and intensity of emissions. Oxford, Pergamon Press, ICRP Publication 38. Ann. ICRP, 11-13, (1983).

[42] Müller, H M, Jacob, P. Gamma exposures from Gaussian clouds. Gesellschaft für Strahlen-und Umweltforschung (GSF) mbH, report in preparation.

[43] Jacob, P, Paretzke, H G, Rosenbaum, H, Zankl, M. Effective Dose Equivalents for Photon Exposures from Plane Sources on the Ground. Radiation Protection Dosimetry, 14, 299-310 (1986).

[44] Jacob, P, Paretzke, H G, Rosenbaum, H, Zankl, M. Organ doses from radionuclides on the ground, Part I: Simple time dependencies. Health Physics 54, 617-634 (1988). Part II: Non-trivial time dependencies. Health Physics 55, 37-49 (1988).

[45] Jacobi, W, Paretzke, H G and Henrichs, K, Dosisfaktoren für inkorporierte Radionuklide und Kontamination der Haut, GSF report 14/89. Neuherberg (1989).

[46] Dosisfaktoren für Inhalation oder Ingestion von Radionukliden Bundesgesundheitsamt. ISH Berichte 63, 78, 79, 80, 81 (1985).

[47] NRPB. Committed dose equivalent to selected organs and committed effective dose equivalent from intakes of radionuclides. Chilton, NRPB-GS7 (1987) (London, HMSO).

[48] Matthies, M, Eisfeld, K, Müller, H, Paretzke, H G, Pröhl, G and Wirth, G. Simulation des Transfers von Radionukliden in landwirtschaftlichen Nahrungsketten. GSF-Bericht S-882 (1982).

[49] Simmonds, J R, Linsley, G S and Jones, J A, A general model for the transfer of radioactive materials in terrestrial foodchains. Chilton, NRPB-R89 (1979) (London, HMSO).

[50] Simmonds, J R and Crick, M J, Transfer parameters for use in terrestrial foodchain models. Chilton, NRPB-M63 (1982).

[51] Simmonds, J R, The influence of season of the year on the transfer of radionuclides to terrestrial foods following an accidental release to atmosphere. Chilton, NRPB-M121 (1985).

[52] CEC Research Programme Post-Chernobyl; Underlying data for Derived Intervention Levels. To be published by CEC.

[53] NRPB and CEA. Methodology for evaluating the radiological consequences of radioactive effluents released in normal operation. Luxembourg. CEC. Doc. V/3865/1/79 (1979).

[54] Broomfield, M, Simmonds, J R and Chapman, T, POP-MARC and AG-MARC: population and agricultural distributions for use in the methodology for assessing the radiological consequences of accidental releases. Chilton, NRPB-M75 (1982).

[55] Jones, J A and Simmonds, J R. Quality assurance of the MARC-1 computer programs. Chilton, NRPB-M158 (1988) (London, HMSO).

[56] Fischer, F. Procedures for uncertainty analyses of UFOMOD - a user guide. Report KfK-4626 (1990).

[57] Iman, R L, Shortencarier, M J. A FORTRAN 77 program and user's guide for the generation of Latin Hypercube and random samples for use with computer models. Sandia National Laboratories, Albuquerque, NM (USA). SAND 83-2365, NUREG/CR-3624 (March 1984).

[58] Iman, R L, Shortencarier, M J, Johnson, J D. A FORTRAN 77 program and user's guide for the calculation of partial correlation and standardised regression coefficients.

12. REFERENCES

Sandia National Laboratories, Albuquerque, NM (USA). SAND 85-0044, NUREG/CR-4122 (June 1985).

[59] Brown, J, Simmonds, J R, Ehrhardt, J and Hasemann, I. The modelling of external exposure and inhalation pathways in COSYMA. Paper presented at the CEC Conference on Methods and Codes for Assessing the Consequences of Nuclear Accidents. Athens, May 1990.

[60] Brown, J. The effectiveness of sheltering as a countermeasure in the event of an accident. Rad. Prot. Bull. 97, 9 (1988).

[61] Panitz, H-J. Improved atmospheric dispersion modelling in the new program system UFOMOD for accidental consequence assessments. IN Proc. CEC/NEA Workshop on Recent Advances in Reactor Accident Consequence Assessment. Rome 1988. EUR-11408. CEC. Luxembourg (1988).

[62] Jones, J A, Williams, J A and Hill, M D. The importance of trajectory modelling in accidental consequence assessment. IN Proc. CEC/NEA Workshop on recent Advances in Reactor Accident Consequence Assessment. Rome 1988. EUR-11408. CEC. Luxembourg (1988).

[63] Jones, J A. The importance of modelling aspects of atmospheric dispersion and deposition in assessing the consequences of hypothetical accidental releases of radioactive material. Submitted to Nuclear Safety.

[64] Panitz, H-J. Accidental consequence assessments with different atmospheric dispersion models. Karlsruhe KfK-4445 (1989).

Potential users interested in obtaining the COSYMA package should contact:

Dr. G N Kelly
Commission of the European Communities
DG XII.D.3, Arts 2/51
Rue de la Loi 200
B-1040 Brussels

The programs are written in FORTRAN-77. The only non-standard statements are the INCLUDE and NAMELIST statements. The programs were developed mainly on IBM-3090. Typical specifications for a complete standard COSYMA run, for 144 weather sequences and 3 release phases, are:

	NE	NL	FL
Typical CPU time [min]	100	60	40
Memory [MB]	4	4	4

Storage requirements
    data libraries
    intermediate and final results
	1
	200
		8
		200
			8
			200

Approximate number of statements	11 000	12 000	10 000

Typical specifications of a complete standard COSYMA run

Early effects:	
Death from irradiation of	bone marrow lung GI tract (external irradiation only) skin fetus
Morbidity from irradiation of	lung lens of the eye thyroid fetus (mental retardation only)
Late effects:	
Fatal and non-fatal cancers	leukaemia, breast, lung, thyroid, bone, GI-tract (colon, liver, pancreas, stomach), skin and "remainder"
Hereditary effects	

Table 1.   The health effects considered in COSYMA

COSGAP	Atmospheric dispersion model based on the Gaussian plume model for linear trajectories.
RIMPUFF	Atmospheric dispersion model based on the Gaussian puff model for non-linear trajectories.
MESOS	Atmospheric dispersion model appropriate for long distances for non-linear trajectories.
METSAM	Models for selecting atmospheric sequences for analysis.
COSING	Model for detailed analysis of food chain doses.
GRIDS	Model for transforming gridded data into distributions in radial bands and angular segments around the site.
UFOTRI	Model for calculating the consequences of a tritium release.
ARCOS	Model for calculaitng activity risk coefficients
SOURCE	Preparation of source term and split into phases
SUMS1	Program for summing the results of the NL and FL sub-systems for a single source term
SUMS2	Program for calculating the risks per year summed over a set of source terms.

Note:

Some of these consist of several programs.

Table 2.   Subsidiary programs included in the COSYMA package

Effect	COSYMA Sub-system		
	NE	NL	FL
Emergency Actions			
Sheltering only	☆	☆	
Sheltering followed by evacuation	☆		
Relocation		☆	☆
Decontamination		☆	☆
Food restrictions		☆	☆
Stable iodine tablets	☆	☆	☆
Routes of Exposure			
External from the cloud	☆	☆	☆
Inhalation from the cloud	☆	☆	☆
External β from deposit on skin and clothes	☆	☆	☆
External γ from deposit on the ground	☆	☆	☆
Inhalation of resuspended material	☆	☆	☆
Ingestion of contaminated food		☆	☆
Health Effect			
Early death	☆		
Early morbidity	☆		
Fatal cancers		☆	☆
Non-fatal cancers		☆	☆
Hereditary effects		☆	☆

Table 3.   Contents of the different sub-systems of COSYMA

Table 4. Non-stochastic effects considered in COSYMA and default model parameters

dose in organ/tissue		effect	slope parameter S	median dose D_{50} [Sv][1] upper end of exposure interval (days)							threshold for exposure during time interval Ti (Sv)			
external irradiation	internal irradiation			1	7	14	21	30	200	365	1	2	3	4
		mortality												
lung	lung	pulmonary syndrome	7.0	9.3	-	94.0	-	-	220.0	540.0	5.0	47.0	110.0	270.0
red bone marrow	red bone marrow	haematopoietic syndrome	6.0	4.7	-	8.5	-	17.1	-	-	2.3	4.2	8.5	-
remainder[2]	-	gastrointestinal syndrome	10.0	15.0	35.0	-	-	-	-	-	10.0	23.0	-	-
skin	-	skin burns (5%)	4.7	35.0	50.0	-	-	-	-	-	23.0	45.0	-	-
ovaries	uterus	pre- and neonatal death[3]	3.0	1.0	-	-	-	-	-	-	0.1	-	-	-
		morbidity												
lung	lung	lung function impairment	7.0	4.6	-	47.0	-	-	110.0	270.0	2.3	23.0	55.0	135.0
thyroid	thyroid	hypothyroidism	1.3	60.0	-	-	-	external exposure			2.0	-	-	-
				-	-	-		300.0 iodine inhalation			10.0	-	-	-
skin	-	skin burns	4.7	35.0	50.0	-	-	-	-	-	23.0	45.0	-	-
skin	-	cataracts	1.5	3.1	-	6.2	-	-	-	9.3	1.0	3.0	4.5	-
ovaries	uterus	mental retardation[3]	1.0	4.1	-	-	-	-	-	-	0.1	-	-	-

Notes

(1) In accidents involving releases of α-emitters, the absorbed dose should be multiplied by a factor to account for the relative biological effectiveness of acute α-irradiation

(2) Since the dose conversion factors for the GI-tract were not included in the GSF-data, the calculations are based on the dose to the remainder organs.

(3) Risks predicted using these parameters have to be multiplied by 0.01 to be applicable to the general population, to allow for the fraction of that population who are pregnant at any one time.

76

organ/tissue	effect	model[2]	Fraction of cancers which are fatal	effects[1] per 10^6 persons and 10^{-2} Sv
red bone marrow	leukaemia	A	1.0	52
bone surface	cancers	A	1.0	1
breast	cancers	R	0.4	80
lung	cancers	R	0.75	90
stomach	cancers	R	0.85	
colon	cancers	R	0.55	224[3]
liver	cancers	R	1.0	
pacreas	cancers	R	0.9	
thyroid	cancers	R	0.1	17
remainder	cancers	R	0.6	38
skin	cancers		0.0	138[4]
gonads	hereditary			200

(1) 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

(2) A absolute risk model. R: relative risk model

(3) Sum for the GI-tract.

(4) morbidity

Table 5.   Stochastic somatic effects considered and model parameters

Age at exposure (years) / Time after exposure (years)	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	Life[2] lost (days)
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	1	2	4	8	18	33	55	80	102	117	124	126	126	126	125	.568
10	0	0	0	0	1	2	4	8	18	34	55	80	103	118	124	126	126	126	–	–	.569
15	0	0	0	1	2	4	9	18	34	55	80	103	118	125	126	127	127	–	–	–	.571
20	0	0	1	2	4	8	18	34	55	80	103	118	125	127	127	127	–	–	–	–	.572
25	0	0	1	3	8	16	31	50	74	94	108	114	116	116	116	–	–	–	–	–	.522
30	0	1	2	5	11	20	33	48	62	72	76	77	77	77	–	–	–	–	–	–	.342
35	0	1	3	7	14	23	34	44	51	53	54	54	54	–	–	–	–	–	–	–	.239
40	0	2	5	10	18	26	34	39	42	42	42	42	–	–	–	–	–	–	–	–	.181
45	0	3	7	14	21	28	32	34	34	35	35	–	–	–	–	–	–	–	–	–	.142
50	0	4	10	17	23	28	29	30	30	30	–	–	–	–	–	–	–	–	–	–	.114
55	0	6	13	20	24	26	26	26	26	–	–	–	–	–	–	–	–	–	–	–	.090
60	0	8	15	20	22	22	23	23	–	–	–	–	–	–	–	–	–	–	–	–	.067
65	0	9	15	18	19	19	19	–	–	–	–	–	–	–	–	–	–	–	–	–	.046
70	0	10	14	15	15	15	–	–	–	–	–	–	–	–	–	–	–	–	–	–	.029
75	0	7	9	10	10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	.015
80	0	4	4	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	.005

Note: Excess cases[1]

Notes:

(1) Assuming the natural cancer risk for men in the FRG population.

(2) This is the average period of life lost for the members of the population.

- 78 -

Action invoked	Dose combination[1] considered	Integration period (default value)
Sheltering only	Automatic only	_[2]
Sheltering and Evacuation	Cloud gamma dose Deposited gamma dose Inhalation dose	- see below -
Relocation	Deposited gamma dose Inhalation of resuspended material Inhalation of plume Cloud gamma	365 days - - -
Stable iodine tablets	Automatic only	-
Return from evacuation or relocation	Deposited gamma dose Inhalation of resuspended material Inhalation	365 days - -
Food bans	Ingestion doses (or concentrations in foods)	365 days intake

Action invoked	Organ considered	Dose level considered Sv (default value)
Sheltering and Evacuation	Bone marrow Lung GI Tract Thyroid Effective	0.5 (7d) 0.5 (7d) 0.5 (7d) - -
Relocation	Effective	0.05
Resettlement	Effective	0.025
Food Bans[2]	Effective Thyroid	0.005 0.05
Withdrawal of food[2] bans	Effective	0.0005

Notes:

(1) The actions other than food bans may also be initiated automatically.

(2) Food bans may also be imposed and withdrawn on the basis of concentrations in food.

Table 7. Dose criteria for initiating countermeasures

percentage of population	residence	shielding factor	
		cloudshine	groundshine [1]
30 %	in cars (spontaneous evacuation)	1.00	0.70
30 %	in cellars	0.05	0.03
15 %	in buildings with low shielding	0.30	0.10
15 %	in buildings with high shielding	0.01	0.01
10 %	outside, rural area	1.00	1.00
[1]normalized to external radiation from ground surface with shielding factor of about 0.7			

Table 8. COSYMA: Probabilistic treatment of population behaviour in areas A and B and corresponding shielding factors

population density PD ($1/km^2$)	percentage of population	driving time [min] for	
		R = km	R = 10 km
PD ≤ 100	10	13	14
	40	11	12
	50	6	6
100 < PD ≤ 500	10	25	50
	40	18	35
	50	8	12
500 < PD ≤ 1000	10	70	125
	40	50	85
	50	15	15
1000 < PD	10	160	500
	40	110	290
	50	25	60

Table 9. Parameterization of driving time

percentage of population	residence	shielding factor	
		cloudshine	groundshine [1]
8 %	outside, rural area	1.00	1.00
8 %	outside, urban area	0.30	0.50
9 %	in buildings with low shielding	1.00	0.50
35 %	in buildings with medium shielding	0.30	0.10
40 %	in buildings with high shielding	0.01	0.01

[1] normalized to external radiation from ground surface with shielding factor of about 0.7

Table 10.   COSYMA: Probabilistic treatment of population behaviour outside areas A and B and corresponding shielding factors

	Default cost
Transport journey[1]	
- private means	£2.00 per person
- public means	£2.50 per person
Accommodation	£3.10 per person per day[2,3]
Annual GDP per capita	£6059 per person[2]
Default general economic recovery time	2 years
Default agricultural economic recovery time	3 years
Capital stock per capita (excluding housing and consumer durables)	£11,000 per person[2]
Capital stock of dwellings per capita	£7,400 per person[2]
Capital stock of consumer durables per capita	£1,425 per person[2]
Average land value	£3,000,000 per km^2[2]
GDP contribution from food[4]	
- crops	£370 per km^2
- livestock	£80 per head
- milk	£0.08 per litre
Disposal costs of food	
- crops	£0 per kg
- livestock	£0 per head
- milk	£0.02 per litre
Decontamination costs, medium effectiveness[5]	
- average	£6.1e6 per km^2
Average gross yearly earnings	£11,200 per year
Health effects treatment costs	
- early mortality	£30,000[6,7]
- early morbidity	£1,500[6,7,8]
- cancers	£15,000[6,9]
- hereditary effects	£200,000[6,10]
Treatment duration[11]	
- early mortality	1 month
- early morbidity	1 month[8]
- cancers	1 year
- hereditary effects	16 years

Subjective health effects costs	
- early mortality	£1,000,000
- early morbidity	£100,000
- fatal cancers	£1,000,000
- non-fatal cancers	£100,000
- hereditary effects	£1,000,000
Default annual interest rate	5%
Default annual depreciation rate - housing	2%
Default annual depreciation rate - stock	6%
Default annual depreciation rate - consumer durables	10%

Table 11. Summary of default economic data for the UK

NOTES

1. As a default, it is assumed that 80 % evacuate by private means and 20 % by public means.

2. UK average value; regional data also available for the UK, see [40].

3. Assuming annual depreciation rate of 2 % and annual interest rate of 5 %.

4. Gross output values should be used in the first year of food restrictions, see [40].

5. Default data are also available for low and high levels of effectiveness, see [40].

6. Costs are averages for the categories; for default costs for individual health effects see [40].

7. Costs are for hospitalisation; different levels of treatment are also discussed, see [40].

8. This average cost does not apply to cataracts and mental retardation, see [40].

9. This cost is for fatal effects; for default values for the costs of certain non-fatal cancers, see [40].

10. This is the discounted cost of hospital treatment for a period of 16 years.

   An average yearly cost of £ 20,000 was assumed and a discount rate of 3 %.

   For applications for which the undiscounted value is appropriate, a cost of £ 320,000 may be assumed.

11. The loss of income during treatment will be the product of the average gross yearly earnings and the treatment duration in years discounting during the treatment period is not included in the default case.

	Default Cost	
<u>Evacuation / Relocation</u>		
Unit transport costs (private, public)		
evacuation/relocation	10/50	DM/cap
Unit accommodation costs		
evacuation	30	DM/cap-day
relocation	2,300	DM/cap-yr
Unit costs loss-of-income	30,300	DM/cap-yr
Unit costs lost capital service		
- non-residential	17,300	DM/cap
- housing	81,300	DM/cap
- land	20,000,000	DM/km^2
- consumer durables	15,000	DM/cap
Recovery time	2	yr
Interest rate	5	%
Discount rate	7	%
Depreciation rate		
non-resid., housing, cons. durables	16 / 2 / 16	%
<u>Decontamination</u>		
Unit decontamination costs (DF = 3)	7,200,000	DM/km^2
<u>Food Bans</u>		
Unit costs loss-of-agricultural production		
(1st value: gross output, 2nd value: GDP-value)		
- crops	0.33 / 0.18	DM/kg-yr
- livestock	2.64 / 1.42	DM/kg-yr
- milk	0.66 / 0.36	DM/kg-yr
Unit costs lost services of agricultural capital		
(1st value: non-residential, 2nd value: housing)		
- crops	0.31 / 0.45	DM/kg
- livestock	2.49 / 3.61	DM/kg
- milk	0.62 / 0.90	DM/kg
Disposal costs		
- crops	0	DM/kg
- livestock	0	DM/kg
- milk	0.06	DM/kg
<u>Health Effects</u>		
Medical treatment costs		
early health effects, non-fatal	2,000 - 6,000	DM/case
early health effects, fatal	85,000 - 170,000	DM/case
late health effects	9,000 - 57,000	DM/case
Gross yearly earnings (for calculation of		
losses-to-economy costs)	28,700	DM/cap-yr

Table 12.   Summary of default economic data for the FRG

NOTES

1 DM = 0.5 ECU

Data for relocation: values derived from publications of the German Federal Statistical Office, value for the Federal Republic of Germany, adjusted to base year 1989.

Data for food ban (without disposal costs): values derived from the German Statistical Yearbook on Food, Agriculture and Forestry, value for the Federal Republic of Germany, adjusted to base year 1989. Data may be used if no agricultural production grid is available; in this case a homogeneous production is assumed over the total area with the following production rates:

$$crops = 74 \text{ t km}^2,$$
$$livestock = 37 \text{ t km}^2,$$
$$milk = 100 \text{ t km}^2.$$

Data for decontamination, disposal of food and health effects: values derived from NRPB publications and converted into DM with a factor of 3 DM £.

Figure 1. COSYMA : General structure of the program system
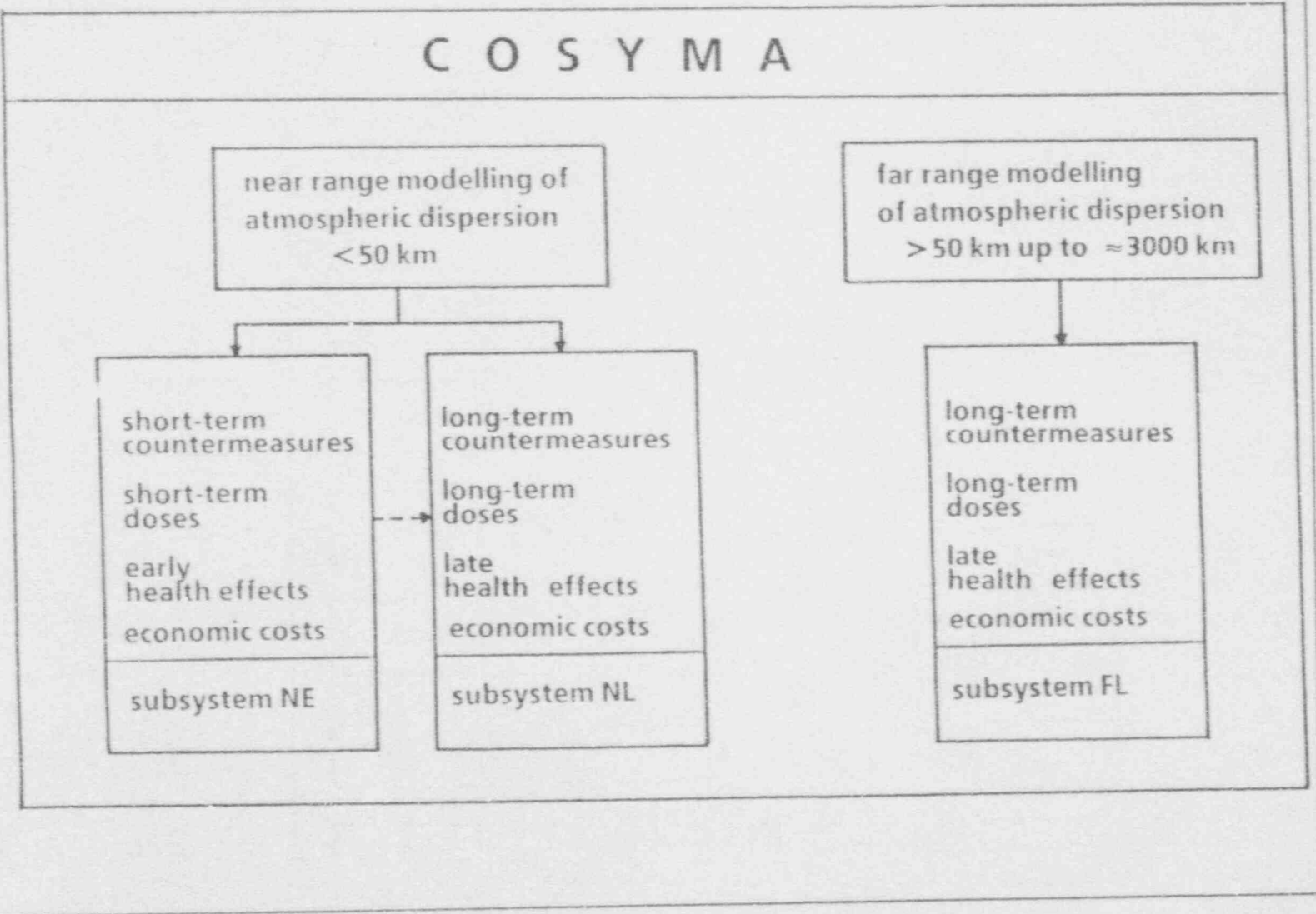
Figure 2. Structure and data flow for the sub-systems

Linear model (COSGAP)
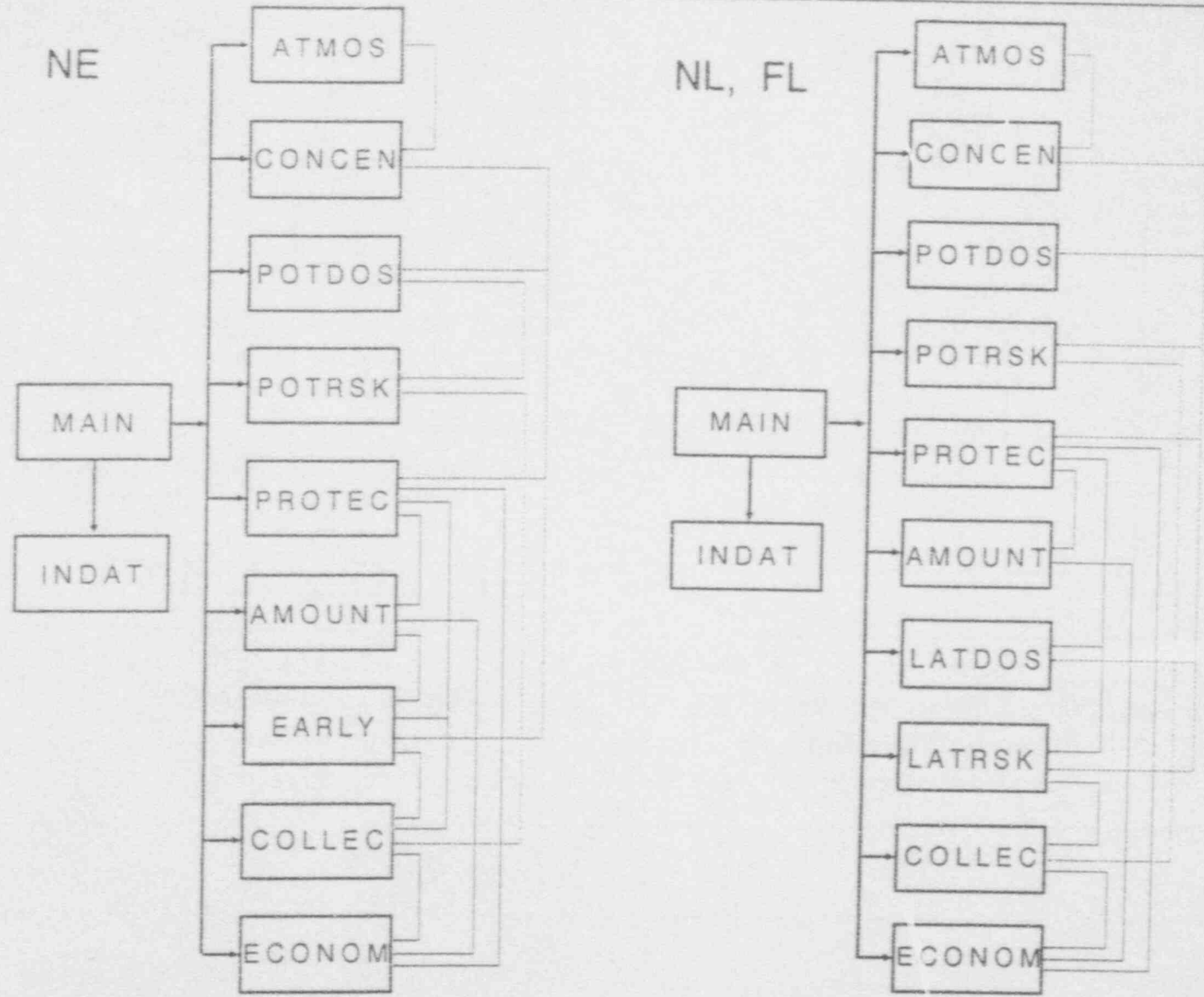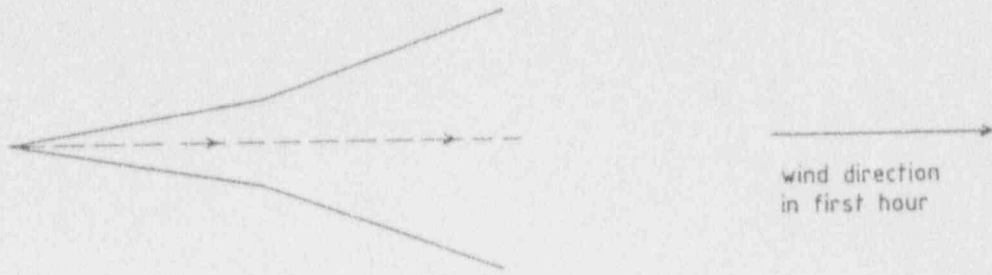
wind direction
in first hour

Segmented plume model (MUSEMET)

wind direction in
second hour
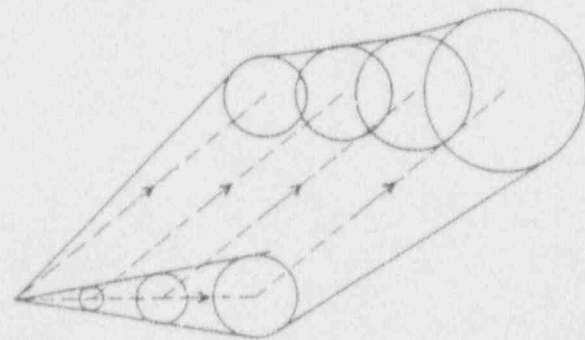
Multiple puff model (RIMPUFF)

Figure 3. The different patterns of contamination predicted using different models for describing changes of wind direction during plume travel

TACC   TREND

area A | TINA | TSHA | TDRA | TSKIN |

TDELA

area B | TINB | TSHB = TSHA + TDRA + TDELB + TINA - TINB | TDRB | TSKIN |
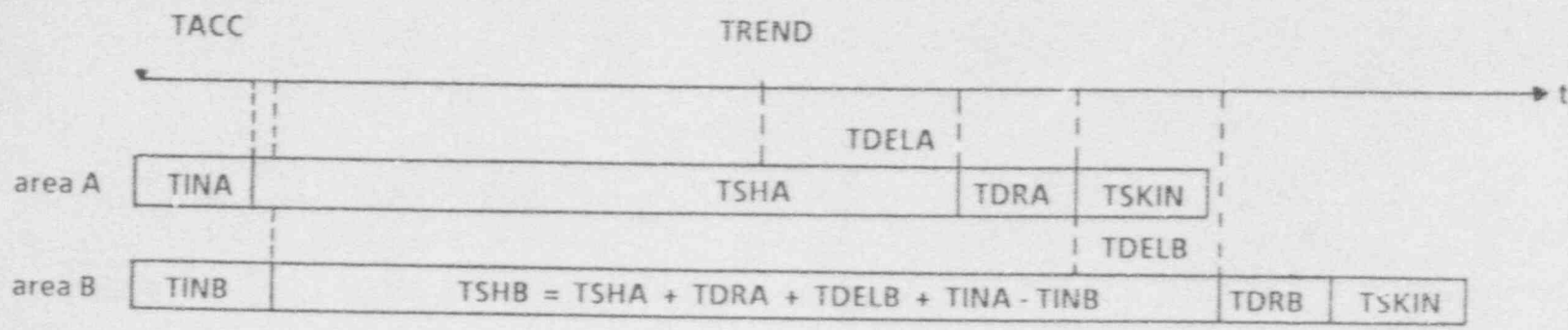
TDELB

TACC	=	time of accident (end of chain reaction)
TREND	=	time of end of release ($\approx$ 95 %)
TINA, TINB	=	initial delay, area A, B
TSHA, TSHB	=	duration of sheltering period, area A, B
TDELA	=	delay time between end of release and end of sheltering period, area A
TDELB	=	delay time between end of evacuation in area A and begin of evacuation in area B
TDRA, TDRB	=	driving time to leave area A, B
TSKIN	=	time between leaving area A, B and skin decontamination

Figure 4. Timing of early protective actions
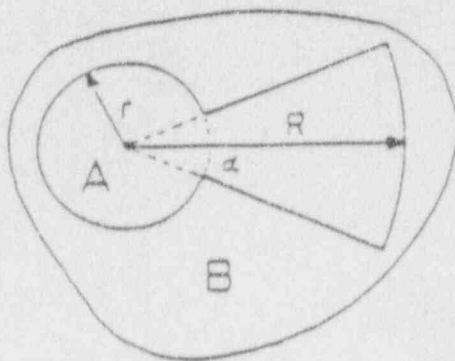
area A:

actions: sheltering and/or evacuation

definition: keyhole shaped area with inner radius r,
outer radius R and sector angle α
(e.g., r = 2.4 km, R = 5.6 km, α = 60°)

area B:

actions: sheltering and/or evacuation

definition: dose to lung, bone marrow GI-tract, thyroid or
effective dose above organ specific thresholds

Figure 5. Modelling of protective actions in the early phase

a) <u>Integral representation</u>

Probability that consequences will exceed, N

90th percentile

99th percentile

Median

Mean
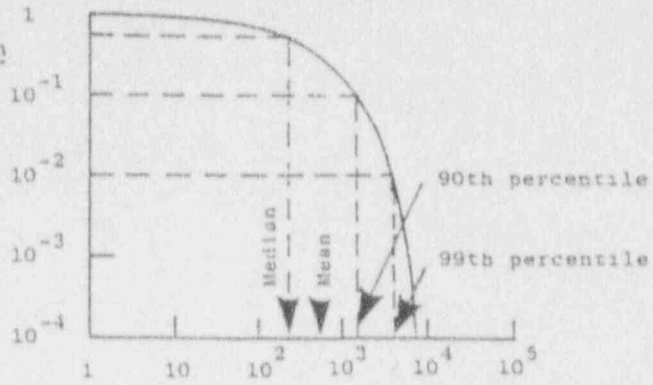
Number of consequences, N - arbitrary units

b) <u>Differential representation</u>

Probability that consequences will be in the range indicated

Median

Mean

| 0 to 1 | 1 to 10 | 10 to 10^2 | 10^2 to 10^3 | 10^3 to 10^4 |
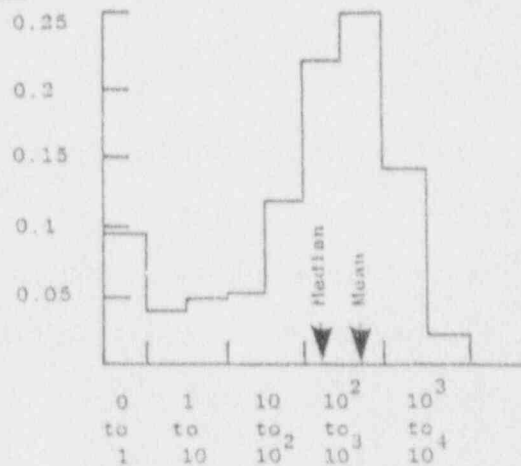
Number of consequences in specified ranges - arbitrary units

c) <u>Characteristic quantities</u>

Quantity	Number of consequences, N (arbitrary units)
Mean	530
Median	210
Percentiles	
1st	0
80th	820
90th	1,400
99th	3,900

Number of consequences, N (arbitrary units)	Probability of exceeding N (%)
1	93
10	81
100	64
1,000	17
10,000	0

Figure 6. Illustrative example of output from COSYMA showing the distribution of consequences (arbitrary units) expressed in different formats
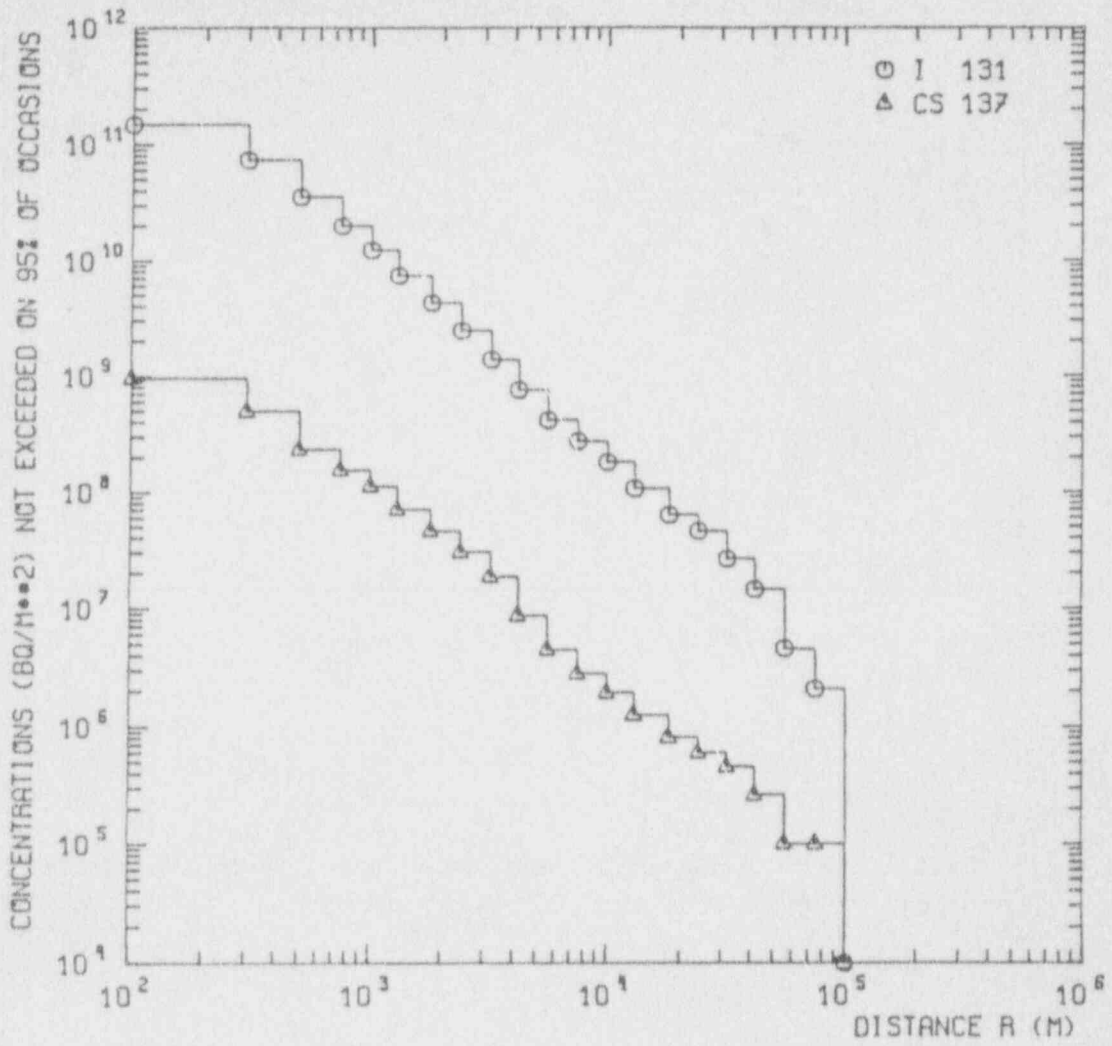
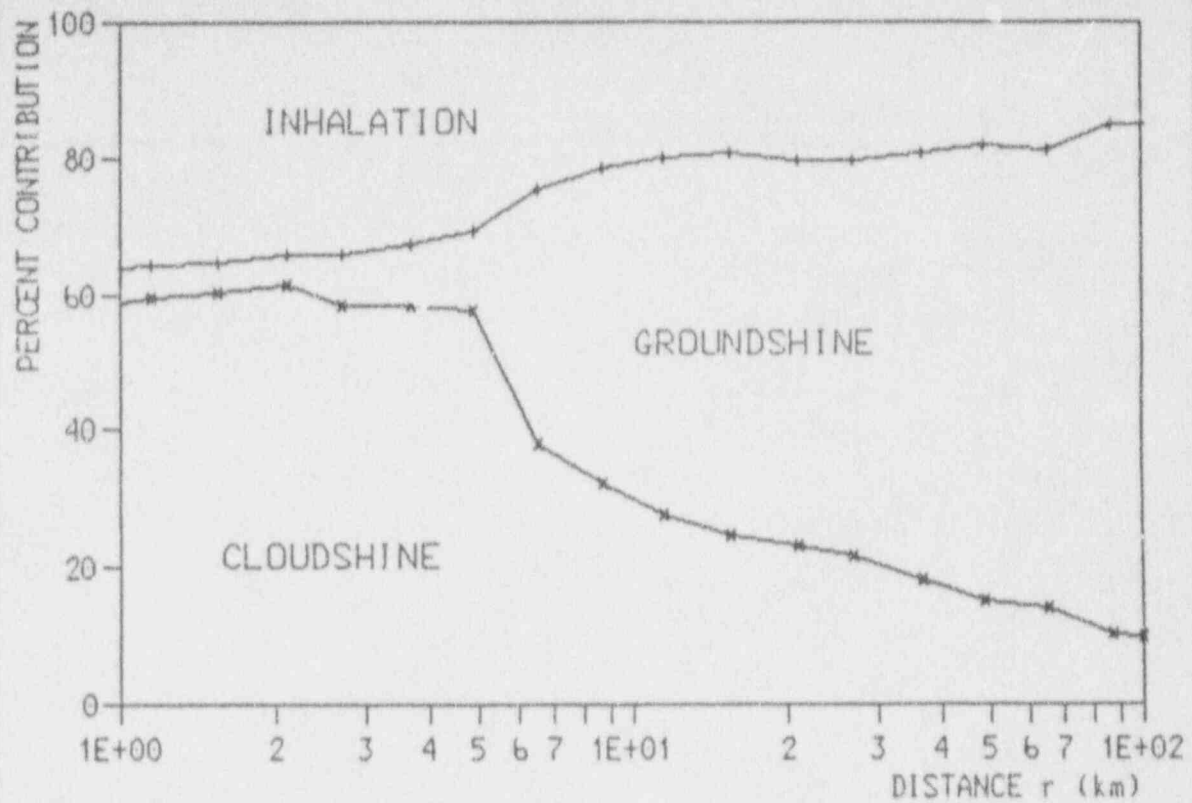Figure 7. Example of the 95th percentiles of the activity concentrations on ground surface

Figure 8. Illustration of the contribution of various exposure pathways to acute bone marrow dose
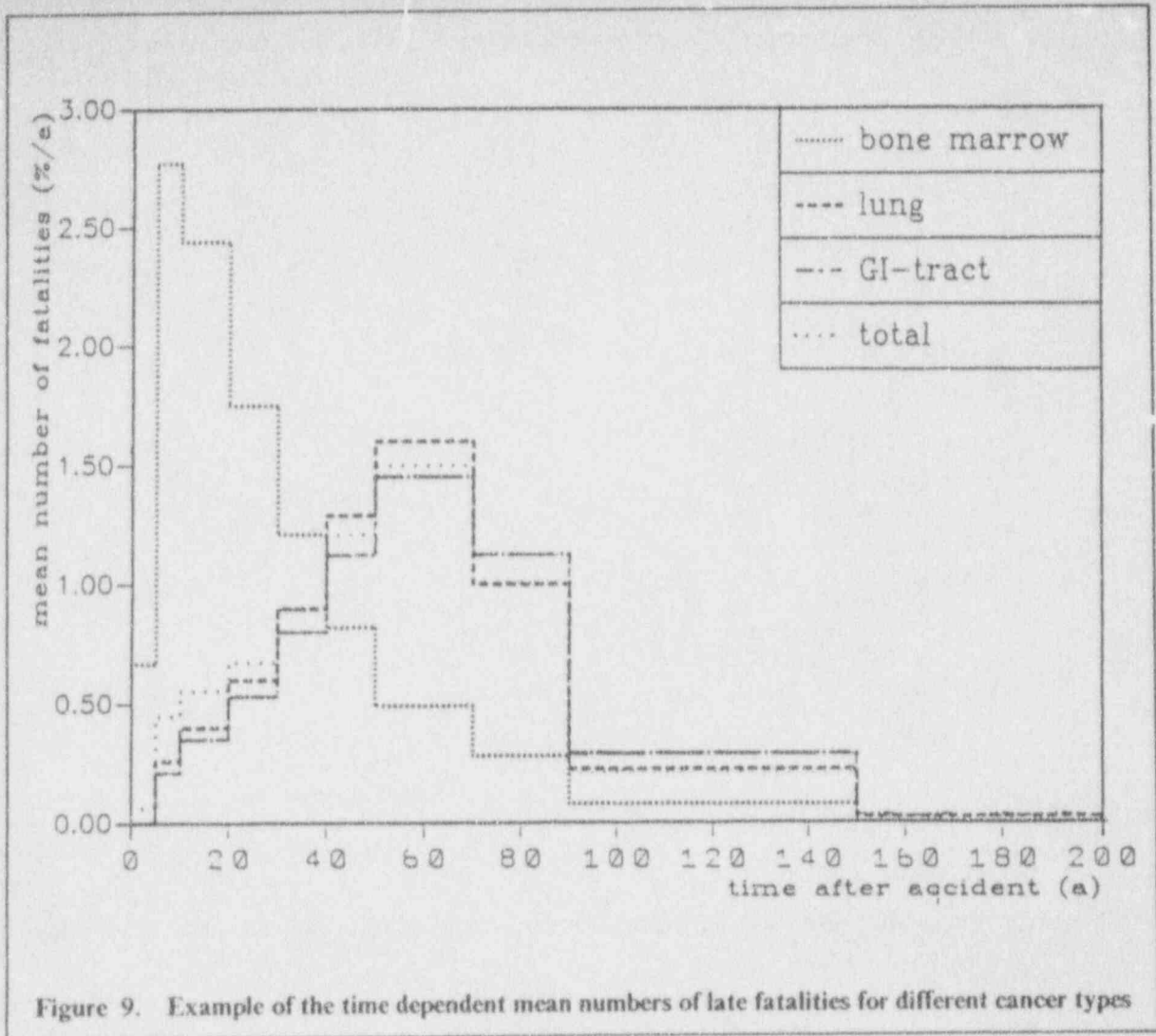
Figure 9. Example of the time dependent mean numbers of late fatalities for different cancer types
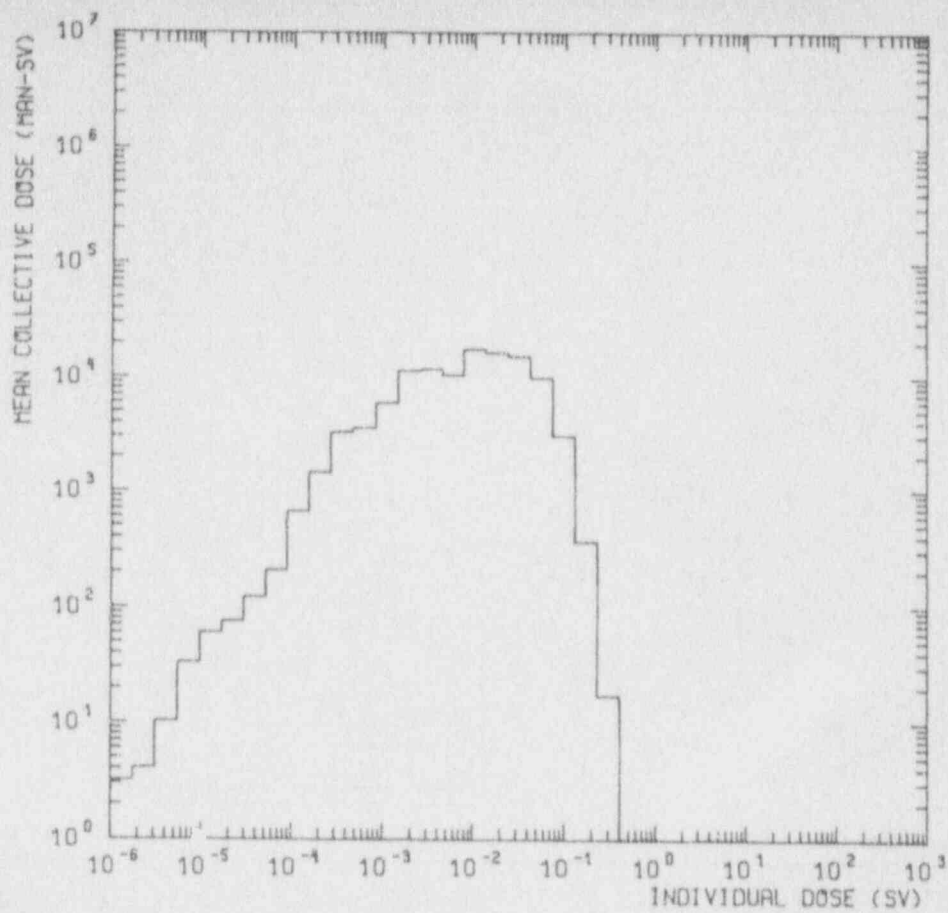
Figure 10. Illustration of the correlation between mean collective dose and individual 70 year dose for bone marrow

This report gives details of a new programme package for accident conse-
quence assessment, prepared under the CEC's Maria programme (Methods
for assessing the radiological impact of accidents) initiated in 1982 to
review and build on the nuclear accident consequence assessment methods
in use within the European Community.

Venta y suscripciones • Salg og abonnement • Verkauf und Abonnement • Πωλήσεις και συνδρομές
Sales and subscriptions • Vente et abonnements • Vendita e abbonamenti
Verkoop en abonnementen • Venda e assinaturas

BELGIQUE / BELGIË

**Moniteur belge /
Belgisch Staatsblad**
Rue de Louvain 42 / Leuvenseweg 42
1000 Bruxelles / 1000 Brussel
Tél. (02) 512 00 26
Fax 511 01 84
CCP / Postrekening 000-2005502-27

Autres distributeurs /
Overige verkooppunten

**Librairie européenne/
Europese Boekhandel**
Avenue Albert Jonnart 50 /
Albert Jonnartlaan 50
1200 Bruxelles / 1200 Brussel
Tél. (02) 734 02 81
Fax 735 08 60

Jean De Lannoy
Avenue du Roi 202 /Koningslaan 202
1060 Bruxelles / 1060 Brussel
Tél. (02) 538 51 69
Télex 63220 UNBOOK B
Fax (02) 538 08 41

CREDOC
Rue de la Montagne 34 / Bergstraat 34
Bte 11 / Bus 11
1000 Bruxelles / 1000 Brussel

DANMARK

**J. H. Schultz Information A/S
EF-Publikationer**
Ottiliavej 18
2500 Valby
Tlf. 36 44 22 66
Fax 36 44 01 41
Girokonto 6 00 08 86

BR DEUTSCHLAND

Bundesanzeiger Verlag
Breite Straße
Postfach 10 80 06
5000 Köln 1
Tel. (02 21) 20 29-0
Fernschreiber:
ANZEIGER BONN 8 882 595
Fax 20 29 278

GREECE

G.C. Eleftheroudakis SA
International Bookstore
Nikis Street 4
10563 Athens
Tel. (01) 322 63 23
Telex 219410 ELEF
Fax 323 98 21

ESPAÑA

Boletín Oficial del Estado
Trafalgar, 27
28010 Madrid
Tel. (91) 44 82 135

Mundi-Prensa Libros, S.A.
Castelló, 37
28001 Madrid
Tel. (91) 431 33 99 (Libros)
431 32 22 (Suscripciones)
435 36 37 (Dirección)
Télex 49370-MPLI-E
Fax (91) 575 39 98

Sucursal:
Librería Internacional AEDOS
Consejo de Ciento, 391
08009 Barcelona
Tel. (93) 301 86 15
Fax (93) 317 01 41

**Llibreria de la Generalitat
de Catalunya**
Rambla dels Estudis , 118 (Palau Moja)
08002 Barcelona
Tel. (93) 302 68 35
302 64 62
Fax 302 12 99

FRANCE

**Journal officiel
Service des publications
des Communautés européennes**
26, rue Desaix
75727 Paris Cedex 15
Tél. (1) 40 58 75 00
Fax (1) 40 58 75 74

IRELAND

**Government Publications
Sales Office**
Sun Alliance House
Molesworth Street
Dublin 2
Tel. 71 03 09

or by post

**Government Stationery Office
EEC Section**
6th floor
Bishop Street
Dublin 8
Tel. 78 16 66
Fax 78 06 45

ITALIA

Licosa Spa
Via Benedetto Fortini, 120/10
Casella postale 552
50125 Firenze
Tel. (055) 64 54 15
Fax 64 12 57
Telex 570466 LICOSA I
CCP 345 509

Subagenti:

**Libreria scientifica
Lucio de Biasio - AEIOU**
Via Meravigli, 16
20123 Milano
Tel. (02) 80 76 79

Herder Editrice e Libreria
Piazza Montecitorio, 117-120
00186 Roma
Tel. (06) 679 46 28/679 53 04

Libreria giuridica
Via XII Ottobre, 172/R
16121 Genova
Tel. (010) 59 56 93

GRAND-DUCHÉ DE LUXEMBOURG

Abonnements seulement
Subscriptions only
Nur für Abonnements

Messageries Paul Kraus
11, rue Christophe Plantin
2339 Luxembourg
Tél. 499 88 88
Télex 2515
Fax 499 88 84 44
CCP 49242-63

NEDERLAND

SDU Overheidsinformatie
Externe Fondsen
Postbus 20014
2500 EA 's-Gravenhage
Tel. (070) 37 89 911
Fax (070) 34 75 778

PORTUGAL

Imprensa Nacional
Casa da Moeda, EP
Rua D. Francisco Manuel de Melo, 5
P-1092 Lisboa Codex
Tel. (01) 69 34 14

**Distribuidora de Livros
Bertrand, Ld.ª**
Grupo Bertrand, SA
Rua das Terras dos Vales, 4-A
Apartado 37
P-2700 Amadora Codex
Tel. (01) 49 59 050
Telex 15798 BERDIS
Fax 49 60 255

UNITED KINGDOM

HMSO Books (PC 16)
HMSO Publications Centre
51 Nine Elms Lane
London SW8 5DR
Tel. (071) 873 9090
Fax GP3 873 8463
Telex 29 71 138

Sub-agent:

Alan Armstrong Ltd
2 Arkwright Road
Reading, Berks RG2 0SQ
Tel. (0734) 75 18 55
Telex 849937 AAALTD G
Fax (0734) 75 51 64

ÖSTERREICH

**Manz'sche Verlags-
und Universitätsbuchhandlung**
Kohlmarkt 16
1014 Wien
Tel. (0222) 531 61-0
Telex 11 25 00 BOX A
Fax (0222) 531 61-81

SVERIGE

BTJ
Box 200
22100 Lund
Tel. (046) 18 00 00
Fax (046) 18 01 25

SCHWEIZ / SUISSE / SVIZZERA

OSEC
Stampfenbachstraße 85
8035 Zürich
Tel. (01) 365 51 51
Fax (01) 365 54 11

MAGYARORSZÁG

Agroinform
Központ:
Budapest I., Attila út 93. H-1012

Levélcím:
Budapest, Pf.: 15 H-1253
Tel. 36 (1) 56 82 11
Telex (22) 4717 AGINF H-61

POLAND

Business Foundation
ul. Wspólna 1/3
PL-00-529 Warszawa
Tel. 48 (22) 21 99 93/21 84 20
Fax 48 (22) 28 05 49

YUGOSLAVIA

Privredni Vjesnik
Bulevar Lenjina 171/XIV
11070 - Beograd
Tel. 123 23 40

TÜRKIYE

Pres Dagitim Ticaret ve sanayi A.Ş.
Narlibahçe Sokak No. 15
Cağaloğlu
Istanbul
Tel. 512 01 90
Telex 23822 DSVO-TR

AUTRES PAYS
OTHER COUNTRIES
ANDERE LÄNDER

**Office des publications officielles
des Communautés européennes**
2, rue Mercier
L-2985 Luxembourg
Tél. 49 92 81
Télex PUBOF LU 1324 b
Fax 48 85 73
CC bancaire BIL 8-109/6003/700

CANADA

Renouf Publishing Co. Ltd
Mail orders — Head Office:
1294 Algoma Road
Ottawa, Ontario K1B 3W8
Tel. (613) 741 43 33
Fax (613) 741 54 39
Telex 0534783

Ottawa Store:
61 Sparks Street
Tel. (613) 238 89 85

Toronto Store:
211 Yonge Street
Tel. (416) 363 31 71

UNITED STATES OF AMERICA

UNIPUB
4611-F Assembly Drive
Lanham, MD 20706-4391
Tel. Toll Free (800) 274 4888
Fax (301) 459 0056

AUSTRALIA

Hunter Publications
58A Gipps Street
Collingwood
Victoria 3066

JAPAN

Kinokuniya Company Ltd
17-7 Shinjuku 3-Chome
Shinjuku-ku
Tokyo 160-91
Tel. (03) 3439-0121

Journal Department
PO Box 55 Chitose
Tokyo 156
Tel. (03) 3439-0124

1/91

CD-NA-13028-EN-C