Forschungszentrum Karlsruhe
Technik und Umwelt

Wissenschaftliche Berichte
FZKA 5772

Development of RODOS, a Comprehensive Real-time On-line Decision Support System for Nuclear Emergency Management in Europe

Final Report for Contract FI3P-CT92-0036

J. Ehrhardt, A. Weis

Institut für Neutronenphysik und Reaktortechnik
Projekt Nukleare Sicherheitsforschung

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1996

This work has been performed with support of the European Commission,
Radiation Protection Research Action (DGXII-F-6) under contract FI3P-CT92-0036

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ISSN 0947-8620

Abstract

The development of RODOS, a comprehensive, *R*eal-time, *O*n-line *D*ecisi*O*n *S*upport system for nuclear emergency management, that would be capable of finding broad application across Europe was included as a major item in the Radiation Protection Research Action of the European Commission's 3rd Framework Programme; it remains an important priority in the 4th Framework programme (1995-1998). When complete, the RODOS system is intended to be applicable from the vicinity of the release and the early phases of an accident to far distant areas and longer time periods. In this way it will be possible to achieve estimates, analyses, and prognoses of accident consequences with and without considering protective actions and countermeasures, which are consistent throughout all accident phases and distance ranges. It will also be possible to evaluate alternative combinations of measures in term of both, feasibility in the given situation, and public acceptability, socio-psychological and political implications.

This Final Report summarises the results achieved by the partners of the EC contract FI3P-CT92-0036 within the time period 1992 to 1995, and more generally, gives an overview of the development status of the RODOS system and its functionalities realised by the end of the contract period.

Entwicklung von RODOS, einem umfassenden Echtzeit- und On-line-Entscheidungshilfesystem für das nukleare Notfallschutzmanagement in Europa - Abschlußbericht des Vertrags FI3P-CT92-0036 -

Kurzfassung

Die Entwicklung des Echtzeit- und On-line-Entscheidungshilfesystems RODOS für den externen Notfallschutz nach kerntechnischen Unfällen in Europa bildete einen wesentlichen Bestandteil des Strahlenschutzprogramms der Europäischen Kommission innerhalb ihres 3. Rahmenprogramms; es bleibt auch im 4. Rahmenprogramm (1995-1998) eines seiner bedeutenden Vorhaben. Das RODOS System ist konzipiert für die Anwendung vom Nahbereich und der Frühphase eines Unfalls bis hin zu großen Entfernungen und späteren Zeiten. Damit werden Abschätzungen, Analysen und Prognosen von Unfallfolgen mit und ohne Berücksichtigung von Katastrophenschutz- und Strahlenschutzvorsorgemaßnahmen ermöglicht, die konsistent sind über alle Phasen und Zeiträume. Das System wird auch die Möglichkeit bieten, alternative Maßnahmenszenarien im Hinblick sowohl auf ihre Machbarkeit in der aktuellen Situation als auch die öffentliche Akzeptanz und sozio-psychologische und politische Aspekte zu bewerten.

Der Abschlußbericht faßt die im Rahmen des Vertrags FI3P-CT92-0036 im Zeitraum 1992 bis 1995 von den beteiligten Instituten erzielten Ergebnisse zusammen und gibt darüberhinaus einen Überblick über den Entwicklungsstand des RODOS Systems und seine am Ende der Vertragsperiode realisierte Funktionalität.

Authorship

The following institutions and staff members were involved in the work performed within the contract FI3P-CT92-0036 and contributed to this report:

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1. Project summary (FZK)

1.1 Objectives of the RODOS project

The need for and importance of a coherent and consistent response of the off-site emergency management to any nuclear accident that might in future affect Europe were amply demonstrated during and following the Chernobyl accident; differences in the countermeasures then taken by national authorities contributed greatly to a loss of public confidence. Computerised systems which provide the emergency management with fast and reliable predictions and evaluations of the radiological impact of accidents can greatly assist quick and well founded decisions about the imposition of emergency actions and countermeasures. To minimise the parallel development of many different systems, which may provide information of different kinds and quality, coordinated R&D activities are required to harmonise the methods, models and databases used in such systems.

The development of RODOS, a *R*eal-time *O*n-line *D*ecisi*O*n *S*upport system for off-site emergency management, which would be comprehensive and capable of finding broad application across Europe, was included as a major item within the Radiation Protection Research Action of the European Commission's 3rd Framework Programme in late 1990. The main objectives of the RODOS project are to provide the methodological basis, develop models and data bases and install the hardware and software framework of a system which offers comprehensive decision support from the very early stages of an accident up to many years after the release and from the vicinity of the site to far distant areas unperturbed by national boundaries. In this way it will be possible to provide estimates, analyses, and prognoses of accident consequences, protective actions and countermeasures which are consistent throughout all accident phases and distance ranges. In particular, all relevant environmental data, including radiological and meteorological information and readings, are to be processed, by means of models and mathematical procedures, into understandable, interpretable pictures of the current and predicted future radiological situation. Simulation models for protective actions and countermeasures are designed to permit

- the estimation of the extension in both time and space;
- the estimation of dose and health effects, with quantification of advantages and disadvantages in terms of (averted) radiation doses or (averted) health injuries;
- the quantification of the costs for society and the economy.

It will be possible to evaluate alternative combinations of countermeasures and protective actions in term of feasibility in the given situation, and to support judgements by the decision makers of the public acceptability of the actions, and of the socio-psychological and political implications. This will be achieved through the appropriate use of rule-based expert systems, weights, preference functions and other decision analytic methods. The application of these techniques will result in a ranked order of options together with an explanation of those rules and weights which predominantly have led to the evaluation. This ranking and supporting explanation will be offered to decision makers for them to take a final decision in the light of the understanding they have achieved. Naturally the decision makers will make this choice in the context of all the predictions and geographic plots presented to them by other modules within RODOS .

With these objectives being achieved, a decision support system will be delivered which provides benefits and functions unavailable elsewhere. These include /A1/:

- better use of resources allocated within the European Union to improve off-site emergency management, inter alia, minimising unnecessary duplication;
- models, methods and data bases drawn from the best available at national and international levels;
- comprehensive decision support will be provided (e. g. at all levels of information processing for each relevant countermeasure at all times and distances from a release);
- novel and enhanced technical features (e. g. assimilation of monitoring data and model predictions, integrated treatment of uncertainties);
- a seamless transition between all distance ranges and temporal phases of an accident offering continuity in providing public information and decision support;
- a design for operational use at local, regional, national and supra-national levels and for training and exercises at these levels;
- a modular design to facilitate long term development and adaptation to user requirements and local/regional conditions;
- a stand-alone interactive training tool for use, inter alia, by those responsible for making decisions on off-site emergency management and their technical advisers at local, regional, national and supra-national levels;
- a more general interactive training and educational tool for radiation protection, nuclear safety and emergency planning personnel with professional interest in or responsibility for off-site emergency management;
- a software framework for developing decision support systems for the management of non-nuclear emergencies with potential off-site consequences.

1.2 Contractual and management arrangements

During the 3rd Framework Programme, the RODOS project has been divided into four individual sub-projects, each with its own contractors and co-ordinator:

- Co-ordination of atmospheric dispersion activities for the real-time decision support system under development at FZK[1] (FI3P-CT92-0044):
  RISØ National Laboratory, DK (coordinator)
  Agenzia Nationale per la Protezione Del'Ambiente (ANPA), I
  Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), D
  National Centre for Scientific Research "Demokritos" (NCSR), GR
  Swedish Meteorological and Hydrological Institute (SMHI), S
  Danish Meteorological Institute (DMI), DK
  Imperial College Centre for Environmental Technology (ICCET), UK
  Central Research Institute for Physics (CRIP), HU

- Development of a comprehensive decision support system for nuclear emergencies in Europe following an accidental release to atmosphere (FI3P-CT92-0036 incl. the PECO contractors under Suppl. 1 and Suppl. 3)
  Forschungszentrum Karlsruhe GmbH (FZK), D (coordinator)
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  GSF-Forschungszentrum für Umwelt und Gesundheit GmbH, D
  School of Computer Studies, University of Leeds (UoL), UK
  National Radiological Protection Board (NRPB), UK
  Nuclear Electric, Plc, (NE), UK
  Studiecentrum voor Kernenergie/Centre d'Etude de l'Energie Nucleaire (SCK/CEN), B
  Institute of Atomic Energy (IAE), PL
  Institute for Physics and Nuclear Engineering, Laboratory for Environmental Radioactivity (IFIN-LAB), RO
  National Research Institute for Radiobiology and Radiohygiene (NRIRR), H
  Nuclear Power Plants Research Institute (NPPRI), SR

- Evaluation and management of post-accident situations (FI3P-CT92-0013b)
  CEA/CEN de Fontenay-aux-Roses, F (coordinator)
  School of Computer Studies, University of Leeds, UK
  Universidad Polotecnica de Madrid, E
  Universite Paris Dauphine, F

- The Joint Study Project 1 of the EC/CIS Collaborative Agreement for International Collaboration on the Consequences of the Chernobyl Accident (COSU-CT94-0087)
  Forschungszentrum Karlsruhe GmbH (FZK), D (EU coordinator)
  National Radiological Protection Board (NRPB), UK
  N. V. KEMA, NL
  Studiecentrum voor Kernenergie/Centre d'Etude de l'Energie Nucleaire (SCK/CEN), B
  Scientific Production Association TYPHOON, Russia (CIS coordinator)
  Institute of Control Science Problems (ICSP), Russia

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1 Kernforschungszentrum Karlsruhe (KfK) has changed the name to Forschungszentrum Karlsruhe (FZK)

Russian Institute of Agricultural Radiology (RIAR), Russia
Institute of Mathematical Machines and Systems, Cybernetics Centre (IMMS CC), Ukraine
Ukrainian Institute of Agricultural Radiology (UIAR), Ukraine
Institute of Power Engineering problems (IPEP), Belarus
Belorussian Institute of Agricultural Radiology (BIAR), Belarus
Committee for Hydrometeorology (HYDROMET), Belarus

The work performed within the first and the last two contracts is described in the corresponding Final Reports /A2, A3, A4/. This report refers to the results achieved by the institutes involved in the second RODOS contract .

The management and co-ordination of the working programme is organised on three levels of interaction: the RODOS Management Group (RMG), nine working groups on special topics (WGs) and contractors' meetings.

The RODOS Management Group has been established by the Commission's Services to assist them in the management and overall co-ordination of the second phase of the RODOS project (1992-1995). The RMG comprises the following members: J. Ehrhardt (Forschungszentrum Karlsruhe, D), G. Fraser, (European Commission DGXI-A-1, L), S. French (University of Leeds, UK), G. N. Kelly (European Commission DGXII-F-6, B), T. Mikkelsen (RISØ National Laboratory, DK) and V. S. Shershakov (SPA TYPHOON, Russia). The RMG is responsible for monitoring and reviewing progress; approving the work schedule; approving procedures for documentation, quality assurance, uncertainties, etc; resolving issues referred to it by RODOS Working Groups or individual contractors; and setting priorities for the next phases of the RODOS project. The minutes of the RMG meetings are distributed to all contractors.

Nine working groups have been established within the reporting period:

WG1 on system development and quality assurance
WG2 on meteorology and atmospheric dispersion
WG3 on countermeasures and consequences
WG4 on hydrological modelling
WG5 on source term estimation, data assimilation and uncertainties
WG6 on evaluation techniques
WG7 on training and exercises
WG8 on international data exchange
WG9 RODOS users group

In general, the membership of the WGs are drawn from different contracts and change with time, according to the scientific expertise required for the problems under discussion and the interaction with other areas. The WGs organise themselves with one contractor taking the lead in preparing meetings, agendas and minutes.The main aims of the WGs are to co-ordinate work in a specific R&D area of the RODOS project, to prepare detailed working programmes, to specify milestones and deliverables within the overall timescale of the project, and to identify problems and issues which need broader discussion. The results of the WG meetings are reported to the RMG via the responsible co-ordinators.

Since the RODOS project began, five full contractors' meetings were held:

Neuherberg, D, 5 to 6 July 1990
Athens, GR, 26 to 27 September 1991
Karlsruhe, D, 9 to 10 June 92
Interlaken, CH, 20 to 24 June 1994
Budapest, H, 18 to 22 September 1995.

The main objectives of these meetings have been:

- to present to the community of all involved in the RODOS project the progress achieved by the contractors individually or in co-operation with others,
- to support and enhance the co-operation between the institutes involved in the RODOS project, in particular to establish collaborative links between Western and Eastern European countries including the CIS Republics,
- to communicate the next project milestones and time phases and to focus the contractors' attention to the deliverable items at the corresponding points in time.

Information of common interest has been exchanged through the RODOS Newsletters, of which 5 issues were prepared by the Forschungszentrum Karlsruhe. A register of RODOS documents is kept by Forschungszentrum Karlsruhe with support of RISØ National Laboratory. Each document has a unique code, distinguishing between minutes of meetings, technical notes or draft reports for internal exchange, and publications (see also Annex).

1.3 Achievements

On the basis of a design study prepared by FZK in 1990 and its following updates expanded and modified with ideas and contributions of all the contractors, broad agreement was achieved on the objectives, overall structure and content of RODOS. As all partners considered it highly beneficial to develop the hardware and software components as soon as possible based on the features outlined in the design study, FZK laid down the structure of a detailed software framework and its internal logic. Open and lively debates on this issue led to a commonly accepted design, which was realised as prototype Version PRTY 1.0 of RODOS in 1992 /A5/.

The RODOS software framework has been developed as a transportable modular structured software package to run with a UNIX operation system and X-Windows user interface with OSF/MOTIF extensions. The data management is based on SQL standard. At present, it is implemented mainly on workstations HP 9000 models 755 and 735. The modular structure of the RODOS system and the Client-Server principle applied for modul intercommunication facilitates the integration of application software components developed by the project partners.

The current version RODOS- PRTY 1.3 comprises the following components, which are described in more detail in the various Sections of Chapter 3:

- the operating system OSY for overall system control, data management and user interface (FZK)
- the geographical information system RoGIS (FZK, SPA TYPHOON)
- a meteorological model chain, consisting of
  - the meteorological preprocessor PAD (ANPA)
  - the mass-consistent wind field models MCF (GRS) and LINCOM (RISØ)
  - the Lagrangian puff-model RIMPUFF (RISØ) and, alternatively,
  - the simplified Gaussian puff code ATSTEP (FZK)
- the special module DOSBAU for calculating potential early doses and dose segments (FZK) consistent with ECOAMOR
- the module ECOAMOR for dose calculations via early and late exposure pathways, in particular foodchains (GSF)
- the special module EMERSIM for simulating early emergency actions and corresponding dose calculations (FZK)
- the module FRODO for simulating intermediate and late countermeasures and corresponding dose calculations (NRPB)
- the modules HEALTH and ECONOM for calculating deterministic and stochastic health effects and economic consequences (FZK).

Not yet integrated but available as stand-alone programs are
- the module RETRACE for calculating run-off processes after deposition of radionuclides (SPA TYPHOON)
- the one- and two- dimensional modules RIVTOX and COASTOX for describing the behaviour of radionuclides in rivers (IMMS CC)
- the module LAKECO for calculating the bahaviour of radionuclides in lakes including biota (KEMA)
- the module EVSIM for simulating the temporal and spatial movement of people on the existing traffic network in case of evacuation (FZK)
- the module STOP for identifying the best-suited routes in case of evacuation (IMMS CC)
- the multi-attribute decision analysis software tools HERESY (UoL) and M-Crit (ICSP, SPA TYPHOON)

In addition to that, methodological investigations have been performed and the corresponding documents have been prepared on
- selection of a model chain for near range atmospheric disperson (RISØ)
- selection of a model chain for intermediate and far range atmospheric disperson (RISØ)
- treatment of uncertainties in RODOS (UoL)
- data assimilation (UoL, SCK/CEN)
- guidelines of documentation on RODOS (FZK)

Finally, the "Computer-based training course on off-site emergency response to nuclear accidents" has been developed by FZK, NE, SCK/CEN and EdF. It will be held first at FZK on 22 to 26 April 1996 (see Chapter 4).

The functionality of the current version PRTY 1.3 of RODOS is still limited to the early and intermediate stages of an accident in the distance range of a few tens of kilometres. It has been, or is in the process of being, implemented in partner institutes in Belarus, Germany, Greece, Hungary, Poland, Romania, Russia, the Slovak Republic and the Ukraine by the RODOS team of FZK; institutes in Portugal, Spain, Finland and Czech Republic have requested the system and discussions are proceeding with institutes in other European countries. Further development of the system and its component parts is now proceeding in parallel in many institutes.

Those institutes in Eastern and Western Europe, which run the current version of RODOS already or will do so in the near future , are directly or indirectly responsible for emergency management in their countries. It is their expressed objective that RODOS will become an integrated part of the national emergency management arrangements and thus will be widely used. In addition, the work on the realisation of a European wide network for the exchange of radiological information has started with the main partners of this proposal and the current RODOS users. In this way, the RODOS system will facilitate communication and exchange of information and promote a more coherent and harmonised emergency response within Europe to any future nuclear accident.

2. Concept, structure and development status of the RODOS system (FZK)

2.1 Basic features

Decisions of the emergency management are required from the very early stages of an accident up to many years after the release of radioactive material. Therefore, a key feature of the RODOS system is its real-time and on-line operation coupled to existing meteorological and radiological monitoring networks. For aiding decisions on early emergency actions in the near field, such as sheltering, evacuation and distribution of stable iodine tablets, cycle times of 10 min are realised. Decisions on countermeasures in the later phases of an accident (i.e. after the passage of the plume and/or in the far field), such as relocation, decontamination or agricultural countermeasures, are less urgent, so that longer computing times are not a constraint.

Two modes of operation are provided by the RODOS system: an automatic and an interactive one. In the early emergency situation, a pure dialogue system is inadequate, as - because of stress and psychological pressure - it could be subject to user mistakes and thus create confusion and nervousness. Therefore, RODOS offers the possibility of automatically presenting all information relevant for decision making. The interaction with the system is limited to a minimum of user input necessary to actualise data and to adapt models to reality. In parallel to the automatic mode and in particular at later stages of the accident, when very quick decisions are no longer necessary, the interactive mode is possible with a dialogue oriented communication between the user and the system.

RODOS is designed as a comprehensive system incorporating models and data bases for assessing, presenting and evaluating the accident consequences in the near, intermediate and far distance ranges under due consideration of the mitigating effect of countermeasure actions. Its flexible coding allows to cope with differing site and source term characteristics, differing amounts and quality of monitoring data, and differing national regulations and emergency plans. To facilitate its application over the whole of Europe, the software has been developed as a transportable package; in particular its software framework supports the integration of application software externally developed by many of the contractors. The modular structure of RODOS allows an easy exchange of models and data, and thus facilitates the adaptation of the system to the local/regional and national conditions. Finally RODOS offers a variety of access tools to cope with the different capabilities, knowledge and aims of the future users.

If connected to on-line meteorological and radiological monitoring networks, the RODOS system provides decision support on various stages of information processing which conveniently can be categorised into four distinct levels. The functions performed at any given level include those specified together with those applying at all lower levels.

Level 0: Acquisition and checking of radiological data and their presentation, directly or with minimal analysis, to decision makers, along with geographical and demographic information.

Level 1: Diagnosis and prognosis of the current and future radiological situation (i.e. the distribution over space and time in the absence of countermeasures) based upon monitoring data, meteorological data and models, incl. source term estimation.

Level 2: Simulation of potential countermeasures (e.g. sheltering, evacuation , issue of iodine tablets, relocation, decontamination and food-bans), in particular, determination of their feasibility and quantification of their benefits and disadvantages.

Level 3: Evaluation and ranking of alternative countermeasure strategies by balancing their respective benefits and disadvantages (e.g. costs, averted dose, stress reduction, social and political acceptability) taking account of societal preferences as perceived by decision makers.

Plant data as well as off-site radiological measurement and monitoring data, such as air concentrations, ground contamination and gamma dose rates, allow comparisons between measurements and model predictions. With the help of data assimilation techniques presently under development for level 1 and 2 applications, such as backfitting procedures and statistical forecasting, possibly combined with knowledge bases (expert) systems and components of fuzzy set theory (see Section 3.1.3), the model results and the observed data will be optimally used to achieve a consistent and realistic picture of the environmental contamination and to estimate the source term.

In connection with the development of data assimilation techniques, the quantification of the uncertainties in the predictions of the RODOS system are considered to be a key element of an advanced decision support system (see Section 3.4). Methodological investigations have already been performed on how to assess and propagate uncertainty estimates through the various modules of the RODOS system. The implementation of these techniques will be a main objective of the next Framework Programme.

The flexibility of RODOS described above will allow the system to be used not only in actual accidents, but also as a powerful tool for education and training of personnel involved in the decision making process and in preparing and exercising emergency plans.

2.2 Conceptual structure and development status

In the light of the objectives, requirements and potential applications, the conceptual design of RODOS is as follows (Fig. 1). RODOS is made up of three subsystems,the analysing subsystem (ASY), the countermeasure subsystem (CSY), and the evaluating subsystem (ESY). The modules building these subsystems, together with the database and the user interface, are controlled by the operating subsystem (OSY), which is supported by the supervising subsystem (SSY).

Each of the subsystems consists of a variety of modules developed for processing data and calculating endpoints belonging to the corresponding level of information processing. The modules are fed with data stored in four different data bases comprising real-

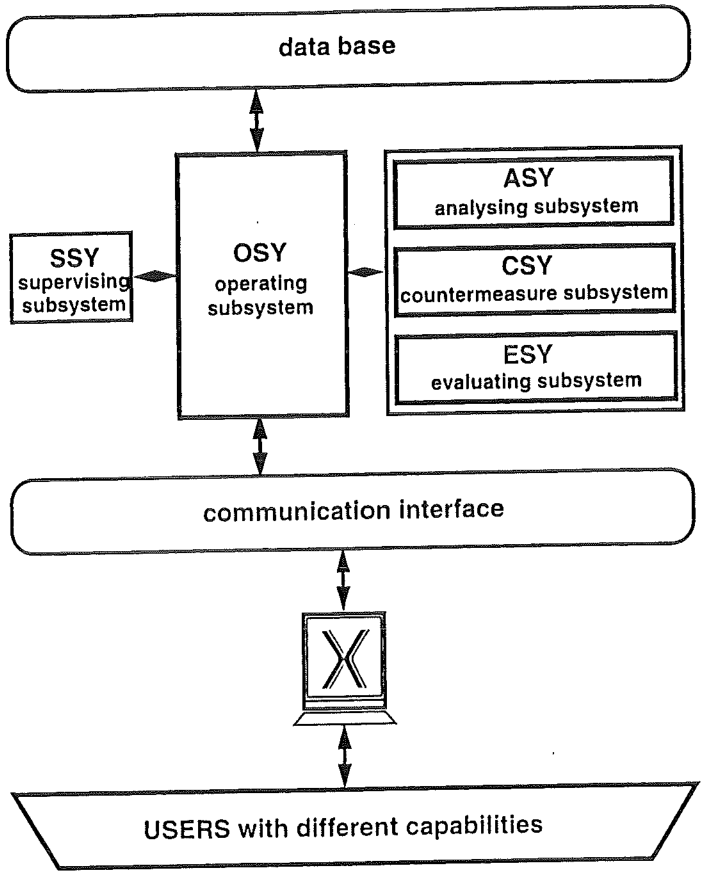


Fig. 1: Overall structure of RODOS

time data with information coming from regional or national radiological and meteorological data networks, geographical data defining the environmental conditions, program data with results obtained and processed within the system, and facts and rules reflecting feasibility aspects and subjective arguments.

The content of the subsystems and the data bases will change with the applicaton of RODOS in relation to a nuclear accident. The temporality of the decisions greatly influences both what information is available and how information is aggregated and integrated. At the different points in time different modules have to be chained together, at least one from each of the subsystems mentioned above, to produce the required output. For example, after the passage of the plume, meteorological forecasts are no longer necessary for the region considered, or after evacuation models for simulating sheltering or relocation in the same area are not needed. The Supervising Subsystem (SSY) will manipulate the components of RODOS in order to respond to user requests.

Characteristics and the current state of development of the subsystems are described in the following sections. For simplicity and better understanding, the stucture of the subsystems ASY, CSY and ESY distinguishes between different program packages, which again consist of individual modules corresponding to the modular design of the whole system.

2.2.1 The operating subsystem OSY

The interconnection of all program modules, the input, transfer and exchange of data, the display of results, and the control of the interactive and automatic modes of operation of the system are all controlled by OSY. The main tasks of OSY are the control of system operation, data management, and the exchange of information among various modules as well as the interaction with users in distributed computer systems. The flexibility of the whole system is defined by OSY, and is independent of the development of program modules. OSY has been designed and developed following the Client-Server Model and coded in the language C as a transportable package to run with a UNIX operation system and X-Windows user interface with OSF/MOTIF extensions. The data management is based on the SQL standard. At present, OSY is implemented on workstations HP 9000, models 755 and 735.

The dialogue between RODOS and a user may be organised in two modes. In the *automatic mode* the system automatically presents all information which is relevant to decision making and quantifiable in accordance with the current state of knowledge in the real cycle time (e.g., 10 minutes in the early phase of an accident). For this purpose, all the data entered into the system in the preceding cycle (either on-line or by the user) are taken into account. Interaction with the system is limited to a minimum of user input necessary to characterise the current situation and adapt models and data.

In parallel to the automatic mode, RODOS can be run optionally in the *interactive mode* with a dialogue oriented menu-driven communication between the user and the system. In particular in later phases of an accident, when longer-term protective actions and countermeasures must be considered and no quick decisions are necessary, this mode of operation becomes more important. Editors specially developed for this purpose allow specific modules to be called, different sequences of modules to be executed, input data and parameter values to be changed, and the output and representation of results to be varied. The Supervising Subsystem SSY supports the user by generating a suitable flowchart, by which subsystems and modules can be called and which is based on the inherent logic of the spatial and temporal sequence of physical processes and protective actions and countermeasures.

2.2.2 The analysing subsystem ASY

Task Description

The main aim of the analysing subsystem ASY is the continuously updated estimation of the present and future environmental distributions of activity concentrations and derived doses/dose rates in the absence of countermeasures. This comprises assessing the source term, calculating the transport of radionuclides released into the atmosphere and their deposition, and considering the subsequent behaviour of radionuclides in the various environmental compartments, both terrestrial and hydrological. These results have to be presented on maps with geographical information of the area of interest as grid specific or isolines of concentrations or doses together with monitoring/measurement data.

Sequence of Calculations

The basic conceptual software structure of ASY is described in the following for calculating air and ground contamination, food chain transfer and dose distributions.

(a) Source Term Program Package

Fig. 2 illustrates the task which is to supply the system with all information about the release of radionuclides. As long as the radioactive material is still inside the plant, estimates of release parameters, such as time, amount, duration and nuclide composition, are mainly based on expert judgements. During this period, the system uses standard source terms, which are derived from probabilistic safety analyses (PSA) of corresponding

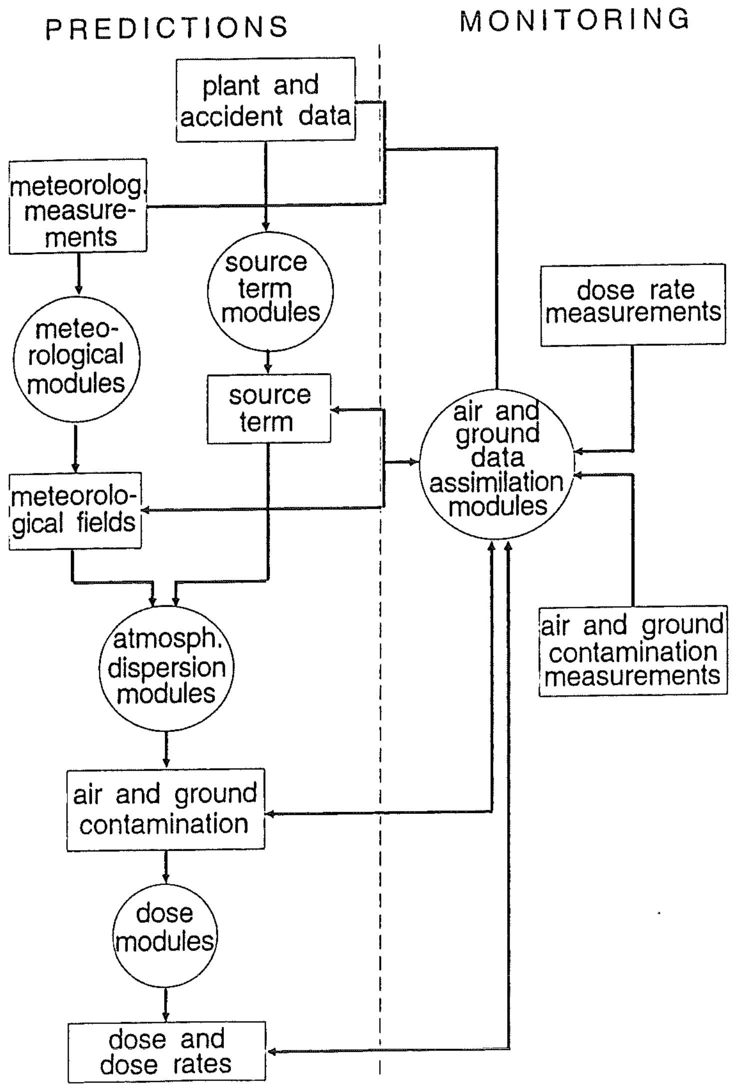


Fig. 2: Basic structure of ASY, air and ground contamination

plants, or a source term derived from radiological measurements inside the plant and other plant data. Optionally the user can generate his own release data by direct input. With the begin of the release, monitoring data will become available from measurements inside or at the plant. They can be directly used for the determination of the source term. Source term reconstructions from further monitoring measurements outside the plant will be supplied by the air and ground data assimilation program package.

(b) Meteorological Program Package

The task is to provide diagnoses of the present weather and analysis of the meteorological situation on the local and intermediate scale out to distances ranging between 20 to 50 km from the power plant. For the accident consequences assessment at further distances and for prognosis purposes, sequences of hourly updated present and forecast winds, turbulence and precipitation fields are on-line provided from National Weather Services or from the European Centre in Reading (ECMWF-UK). Such European-scale high-resolution Limited Area models (LAM's) presently operate on the European scale producing up to more than 36 hour forecasts with a spatial resolution now becoming less than 50 km by 50 km (see Fig. 3).

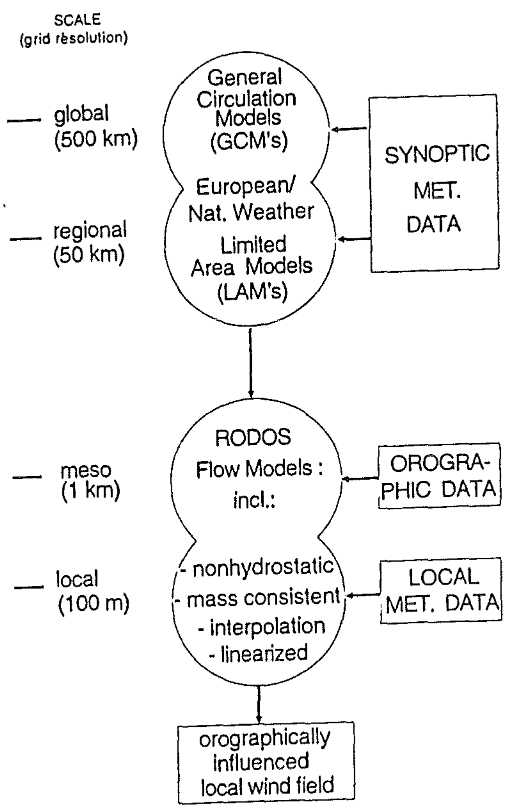


Fig. 3: Chain of meteorological flow models

National scale meteorological models (typical 20 km x 20 km grid) are in use in various European countries. They allow the coupling of non-hydrostatic flow models with a finer grid resolution of 500 m x 500 m. The results of such model chains are hourly updated forecasts for the next 24 hours of 3-dimensional meteorological fields.The problem of analysis and forecast of precipitation patterns will partially be solved by coupling of national rain radar system data to the meteorological models.

For use in real-time and early phase applications of RODOS the two diagnostic flow models MCF (mass consistent flow model) and LINCOM (non-hydrostatic flow model) have been selected. Meteorological preprocessors, such as PAD, are necessary to convert the meteorological data in the format required by the flow and dispersion models. For planning and post-accident assessments, ADREA-FLOW (non-hydrostatic flow model) and HIRLAM (3D-forecast model), have been identified as candidates for difficult topographic terrain and forecasts on regional scale, respectively /A2, A6/.

(c) Atmospheric Dispersion Program Package

The task of the atmospheric dispersion program package is to link the source term with the meteorological fields in order to obtain activity concentrations in air and on ground surface at the locations of interest. The cloud gamma doses in the vicinity of the plant are calculated in this program unit. Models for calculating atmospheric dispersion and deposition have been selected due to the availability of data, the complexity of the meteorological situation, the topographic structure, the distance range from the source, for which results are needed, and the computing times required.There is a variety of models available or under development and the simpler ones are based on Gaussian dispersion, such as straight-line models or plume/puff trajectory models. Lagrange particle models and Eulerian grid models are more sophisticated and are potentially applicable to more complex situations but require more input data and larger computing times. A universal real-time on-line system should have access to a hierarchy of models together with selection criteria, which allow the assignment of the model appropriately adapted to the actual meteorological and environmental situation. A problem which remains to be solved is the assessment of gamma dose rates from a plume whose temporal and spatial distribution of activity concentrations cannot be described by Gaussian atmospheric dispersion models. Quick and reliable integration algorithms are required for use close to a site, where the semi-infinite cloud approximation is not valid. In this case more sophisticated models may be used to calculate the gamma dose-rate contributions from the individual nuclides and from various parts of the radioactive plume.

For operational use in real-time and early phase applications of RODOS, the simplified Gaussian puff model ATSTEP and the puff code RIMPUFF have been implemented (see Sect. 3.1.2). For complex orographic terrain, the Lagrangian particle model ADREA-DIFF is suitable in connection with the ADREA-FLOW model /A2, A6/. Both ATSTEP and RIMPUFF have their own gamma dose rate modules; the one for RIMPUFF has been developed by CRIP.

(d) Air and Ground Data Assimilation Program Package

The task is to provide a consistent picture of the spatial and temporal distributions of activity concentrations and dose rates together with an improved estimation of the source term and other data by the combined evaluation of both monitoring data and model predictions. From the start of the release, monitoring data become available from gamma dose-rate meters and other survey facilities but nuclide specific data in air and on ground surface will come later. All these data are be used to derive the most important release characteristics for reconstructing the source term and dispersion/deposition data.

(e) Foodchain Transport Program Package

The task is to calculate specific activities of radionuclides in foodstuffs and to transfer them to the dose module. The deposition of radionuclides to and interception by vegetation and soil are estimated taking into account the season of the year. Time-dependent specific activities in feed - and foodstuffs are calculated taking into account processes such as the translocation of activity in the vegetation, migration of activity in the soil, uptake of activity from the soil by plant roots, etc., and assumptions about agricultural practices.The specific activities in foodstuffs are input data for the dose module. RODOS contains the ECOAMOR (see Section 3.1.4) module system which incorporates a dynamic foodchain transport module based on the radioecological model ECOSYS-87 /A7/.

Measured specific activities for elements of the foodchain are compared in the next module.

(f) Food-chain Data Assimilation Program Package

This is illustrated in Fig. 4 and the task, which is similar to (d), is to compare measured specific activities in environmental media with the respective calculated data to provide a consistent picture of the spatial and temporal contamination patterns in the various foodstuffs (see Section 3.1.4). Corresponding mathematical procedures are under development by GSF.

(g) Dose Rate and Dose Estimation Program Package

The task is to perform dose calculations from activity concentrations in air, activity depositions onto the ground and specific activities in foodstuffs. Exposure pathways which lead to an immediate irradiation of the affected persons are external irradiation from the passing cloud, from contaminated rural and urban surfaces, and radionuclides deposited on skin and clothes, and internal irradiation after inhalation of radioactive material directly from the cloud or after resuspension from ground surfaces. Long-term exposure pathways are the external exposure from radionuclides deposited onto the ground and the internal irradiation after ingestion of contaminated foodstuffs. From time-dependent activity concentrations in foodstuffs given by the foodchain module together with age dependent consumption rates and assumptions about food-distribution, the resulting ingestion doses for individuals and in the population can be estimated . The corresponding computer models are part of the ECOAMOR module system integrated in RODOS.

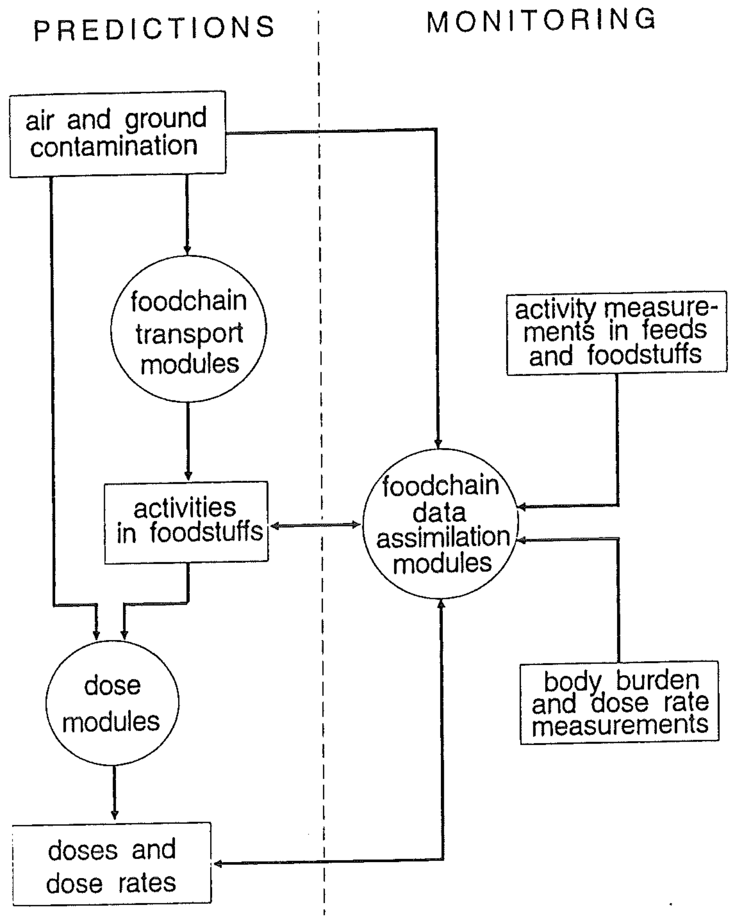


Fig. 4: Basic structure of ASY, food contamination and dose assessment

2.2.3 The countermeasure system CSY

Task Description

The countermeasures required after an accident are in general combinations of a variety of single actions, such as sheltering, evacuation, distribution of stable iodine tablets, relocation, decontamination and banning of foodstuffs. The selection of the best-suited combination is a very complex undertaking and a large number of influences will determine the decisions, such as radiological, economic, ecological, socio-psychological and political consequences. The main task of the countermeasure subsystem CSY is to quantify the benefits and disadvantages of various countermeasure combinations, such as individual/collective doses (averted), health effects and economic costs, areas and number of people affected, together with the technical and personnel aids required. To achieve these results, mathematical models simulating the spatial and temporal patterns of emergency actions under the actual environmental and economic conditions have been and are being developed by the RODOS contractors.

Sequence of Calculations

The quantification of the benefits and drawbacks of countermeasures requires mathematical models which allow the simulation of time and distance dependent actions. Fig.5 shows the principle structure for analysing the effectiveness and implications of the various countermeasures strategies. The sequence of calculations can be separated into two parts:

(a) Description and quantification of the consequences of countermeasures already adopted or presently in progress (actual situation). These are a prerequisite to get reliable predictions about the usefulness of further actions.

(b) Description and quantification of the consequences of supplementary countermeasure actions potentially leading to a further reduction of the radioactive exposure of people or the recovery of contaminated areas (future scenarios).

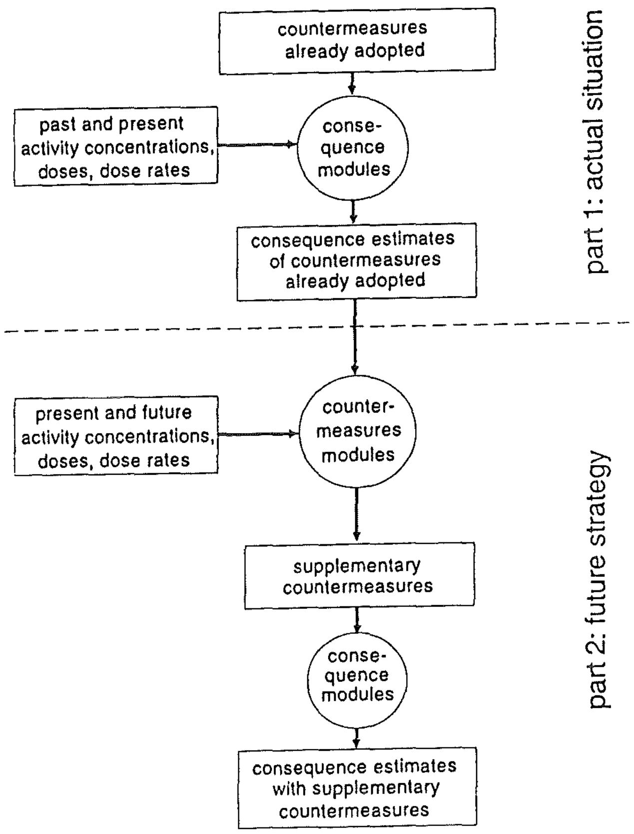


Fig. 5: Basic structure of CSY

Both parts contain models and procedures to simulate single actions and to provide information about their spatial and temporal dependencies allowing for dose reductions of the actions to be calculated. By comparison with the doses which would be received in the case of no action, the net benefit of each single action and the complete countermeasure strategy can be obtained. Various kinds of action consequences are assessed to give a list of consequences for each countermeasure strategy presented on an action-consequence matrix which consists of only one or a few columns or a large number of countermeasure strategies, respectively.

RODOS contains the EMERSIM software for simulating early emergency actions (see Section 3.2.1) and the FRODO module package (see Section 3.2.2), which considers long-term countermeasures, such as relocation, decontamination and food-bans. The EVSIM module (see Section 3.2.1), which builds part of EMERSIM, models the evacuation of the population from areas in the close vicinity of nuclear power plants on the existing road network.

Consequence Program Packages

Six principle types of consequences occur when single or multiple courses of actions are introduced:

(a) radiation doses to individuals and the public,
(b) radiation induced health effects,
(c) areas, number of people and amount of agricultural products affected by countermeasures,
(d) health effects caused by the countermeasures actions,
(e) monetary costs quantifying the economic impact of countermeasures and health effects,
(f) socio-psychological and political implications.

Accident consequence models have been and are being developed for quantifying comprehensively the spectrum of consequences belonging to types (a), (b), (c) and (e). They are implemented in the RODOS module systems EMERSIM, FRODO, HEALTH and ECONOM (see Section 3.2.3). No methods exist for (f) and more information is needed for (d).

2.2.4 The evaluating subsystem ESY

Task Description

Whenever there is an option of two or more actions or action combinations, a choice has to be made. Evaluation techniques may support this task of the decision maker by proposing those courses of actions, which are practicable under the actual or future conditions, and which are ranked by balancing of benefits and effort. Practicability comprises three factors

(a) consistency with the aims and rules of emergency planning
(b) consideration of the environmental situation and the behaviour of the population
(c) availability of technical and administrative support.

If more than one option remains after the selection procedure, a decision problem exists and this can be decided on subjective arguments based on the decision makers opinions. Preferences and judgements can be derived from interviews supported by formal information elicitation procedures.

The evaluating subsystem ESY is being developed mainly to evaluate alternative countermeasure strategies under the aspects of feasibility in a given situation, public acceptance of the actions, socio-psychological and political implementations, and subjective arguments reflecting the judgements of the decision maker. These parameters can be taken into account in ESY using mathematical formulations as rules, weights, and preference functions. The application of these rules results in a ranked order of options together with those rules and preference functions which, above all, have led to this evaluation. This ranking order can be great help to a decision maker in taking a final decision. At present, both multi-attribute decision analysis techniques and expert systems are being studied as potential methodological tools in the evaluation of combinations of alternative actions. The present conceptual structure of ESY is shown in Fig. 6 (see also Section 3.3).

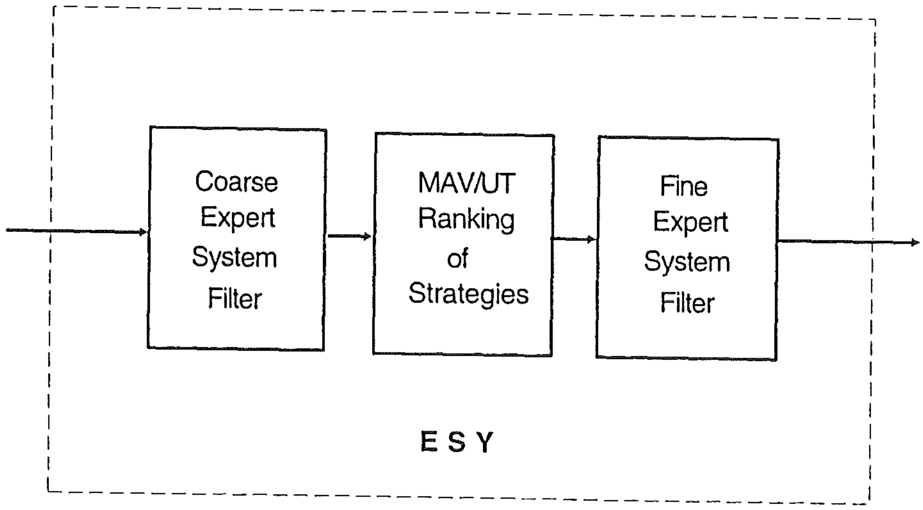


Fig. 6: The conceptual structure of ESY

Sequence of calculations

First, a very simple expert system will be used to discard strategies which are incompatible with the principles of radiological protection, which do not give continuity of treatment, or which fail very coarse practicability rules. The remaining strategies will be passed to a multi-attribute value ranking module, which will identify the top 10 or 20 ranked strategies. The operator will be able to use interactive sensitivity analyses, such as that in the software packages HERESY and M-CRIT, to confirm that these strategies are worth careful consideration. These strategies would then be passed to an expert system with a much finer and more sophisticated system or rules, each of which could be applied to each of the candidate strategies. The small number of strategies would allow a full set of explanations to be developed, which would give a critique of each of the strategies. Thus the output of RODOS will be a short list of strategies, each of which satisfies the constraints implied by intervention levels, practicability, etc. together with a detailed commentary on each strategy explaining its strength and weaknesses.

2.2.5 The hydrological model chain

The evaluation of the radiological and environmental consequences of the Chernobyl accident demonstrated the significant contribution of contaminated water bodies /A8/. To complete the RODOS methodology and system, a hydrological model chain has been developed, which covers all the relevant processes such as the direct inflow into rivers, the migration and the run-off of radionuclides from watersheds, the transport of radionuclides in large river systems including the exchange with sediments and the behaviour of radionuclides in lakes. The corresponding run-off model RETRACE (SPA TYPHOON), the river models RIVTOX and COASTOX (IMMS CC) and the lake model LAKECO (KEMA) have been coupled, implemented in RODOS and adapted to the Rhine river system and the lake IJsselmeer, NL /A9, A10/. Other rivers can be readily implemented in RODOS using the same model chain subject to gathering appropriate data.

A link has been established between the hydrological models and the dose assessment module. Thus, feeding of contaminated water to domestic animals for milk and meat production, and consumption of contaminated drinking water and fish can be considered in estimating the ingestion dose.

3. Content and functions of RODOS

3.1 Diagnosis and prognosis of the radiological situation

3.1.1 Source term estimation (NPPRI)

In the event of a nuclear accident resulting in the dispersion of radioactive materials into environment, the effective implementation of measures for the protection of the public will be largely dependent upon the adequacy of advance preparation, including the preparation of environmental monitoring programs and source terms evaluation. In predicting the consequences of accidents, a source term, or a range of source terms, is usually the starting point of the assessment. The brief overview of the overall status of the environmental monitoring network manned by NPP Bohunice and a method for the source term determination during an accident based on a on-line data measured by the environmental monitoring system are presented.

Environmental monitoring system

NPP Bohunice have set up computer based monitoring system for the permanent surveillance of radioactivity of the environment at distances up to 30 km. During accidents this system will provide valuable information on the status of plant and radioactivity in environment.

The main purpose of the environmental monitoring system is to follow continuously chosen values in the surrounding of NPP Bohunice and to display measured data. The parameters, which are available in a on-line mode, are summarised in Table 1. The typical integration time of the on-line data is 5 minutes.

The environmental monitoring network is divided to the three groups:

1) the two rings of "fence monitors" at the NPP territory:

    a) a ring EBO-V1 consists of 24 measure points with 3 stable measure points,
    b) a ring EBO-V2 consists of 24 measure points with 2 stable measure points;

2) a ring consists of 15 stable measure points at the vicinal villages at distances up to 6km;

3) 4 measure stable points in significant agglomerations with the greatest concentration of people (Trnava, Hlohovec, Piestany, Vrbove). Details of the geographical positions of the monitors are given in /B1-5/.

The data from the environmental monitoring system are transmitted, and cumulated and stored at the central station situated at the Laboratory of environmental radioactivity control in Trnava.

There are two data transmission points: (a) the retransmission station which cover radio communication between the central station and the inferior stations, and (b) the retransmission station, situated at the local meteorological station, for the transmission of the meteorological data to the central computing system in the central station. The actual local meteorological data such as wind speed and wind direction, stability class and precipitation are also available every 5 minutes.

Type	parameter
release rate	noble gases (stack) gamma dose rate (stack) I131 activity (stack) activity concentration (aerosols, stack) air flow temperature activity concentration (liquid effluent) water flow activity concentration (cooling water)
site specific meteorology	wind direction wind velocity air temperature precipitation atmospheric pressure stability category
environmental situation	gamma dose rate activity concentration of air (aerosol and iodine)

Tab. 1 Parameters of on-line monitoring of the NPP Bohunice environmental monitoring network.

Methodology for interpretation of measured dose rates

For the estimation of the source term the gamma dose rates from the first ring ("fence monitors") are used. The 24 values of the gamma-dose rate from the first ring EBO-V1 are measured with a pair of collimated detectors of type DC-4D-84/N and DC-4D-84/V which cover demanded measure range. The first ring EBO-V2 has also 24 gamma-dose rate measuring points. A detailed description is given in /B4/.

"Sensitive curves" - gamma dose rates [Gy/s] for a 1 Bq/s release in dependence of the distance from the plume axis for each detector from this ring were precalculated with a gaussian-puff dispersion model.

The total gamma dose rate in air from a monoenergetic point source in Gy s^{-1} can be written

$$\dot{D}(x,y) = \frac{1.6\times10^{-13}\, Q_0}{2\pi^{3/2} u} \sum_i f_i E_i \,(\mu_{en}/\rho)\, I_T(E_i) \qquad (1)$$

where Q_0 is the release rate in Bq s^{-1}, f_i is the fraction of photons of initial energy E_i emitted per disintegration, E_i is the initial energy of the photon in MeV and the constant $1.6 \cdot 10^{-13}$ has the unit kgGy per MeV . In terms of the reference system given in Fig. 7 the general equation for I_T can be written

$$I_T(E) = \frac{1}{2^{3/2}\sigma} \int_{-\infty}^{\infty} \int_{0}^{\infty} \frac{B_{en}(\mu r)\, \exp(-\mu r)}{m r} \times \left[\exp\left(-\frac{(m-r)^2}{2\sigma^2}\right) - \exp\left(-\frac{(m+r)^2}{2\sigma^2}\right)\right] d\xi\, dr \qquad (2)$$

where $m = (\zeta^2+y^2+h^2)^{1/2}$, $\sigma=(\sigma_y+\sigma_z)^{1/2}$ is used for the solution of the problem of correcting for a nonisotropic cloud, $B_{en}(\mu r) = 1 + A\mu r \exp(B\mu r)$ is the Berger form of the buildup factor.

Real data which characterise the location of measurement points, source of release (dimensions of a reactor building, sensible heat) and meteorological conditions (wind direction, wind speed, stability class) were taken into account for the calculation of gamma dose rates for a 1 Bq/s release for given measurement points. Selected "sensitive curves" for the fence monitors of ring EBO V1 are shown as an example on Fig. 8 /B4/.

The ratio between measured dose rates and predicted dose rates gives the set of source terms Q_i [Bq/s] where i is number of detectors where measured values are beyond the background level. This data set has a limited number of Q_i with unknown distribution. Thus, it is important to know the uncertainties that are associated with the source term estimation. Standard analytical methods for uncertainty estimation are not generally applicable since the distribution of partial source terms are not easily transferred to a Gaussian shape. The bootstrap resampling procedure was selected as an alternative method to determine the mean value of Q and confidence limits, since it does not depend on the form of the underlying distribution function. The method is based on the random generating of independent random samples with range i from the empirical function.

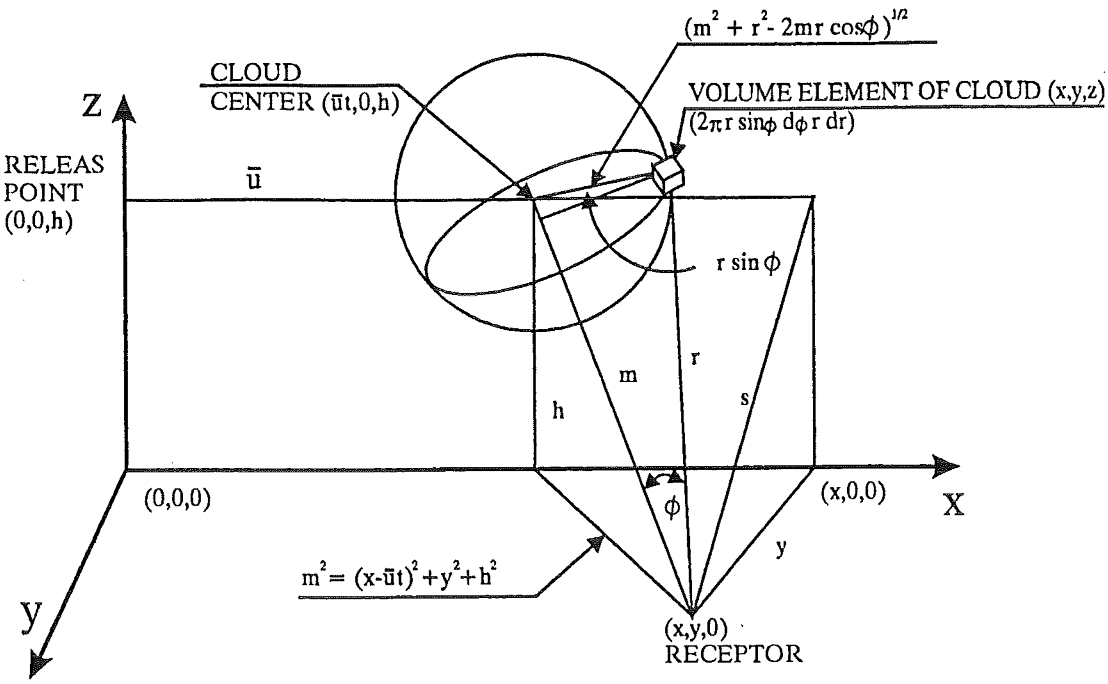


Fig. 7: Coordinate system for cloud gamma-dose calculations

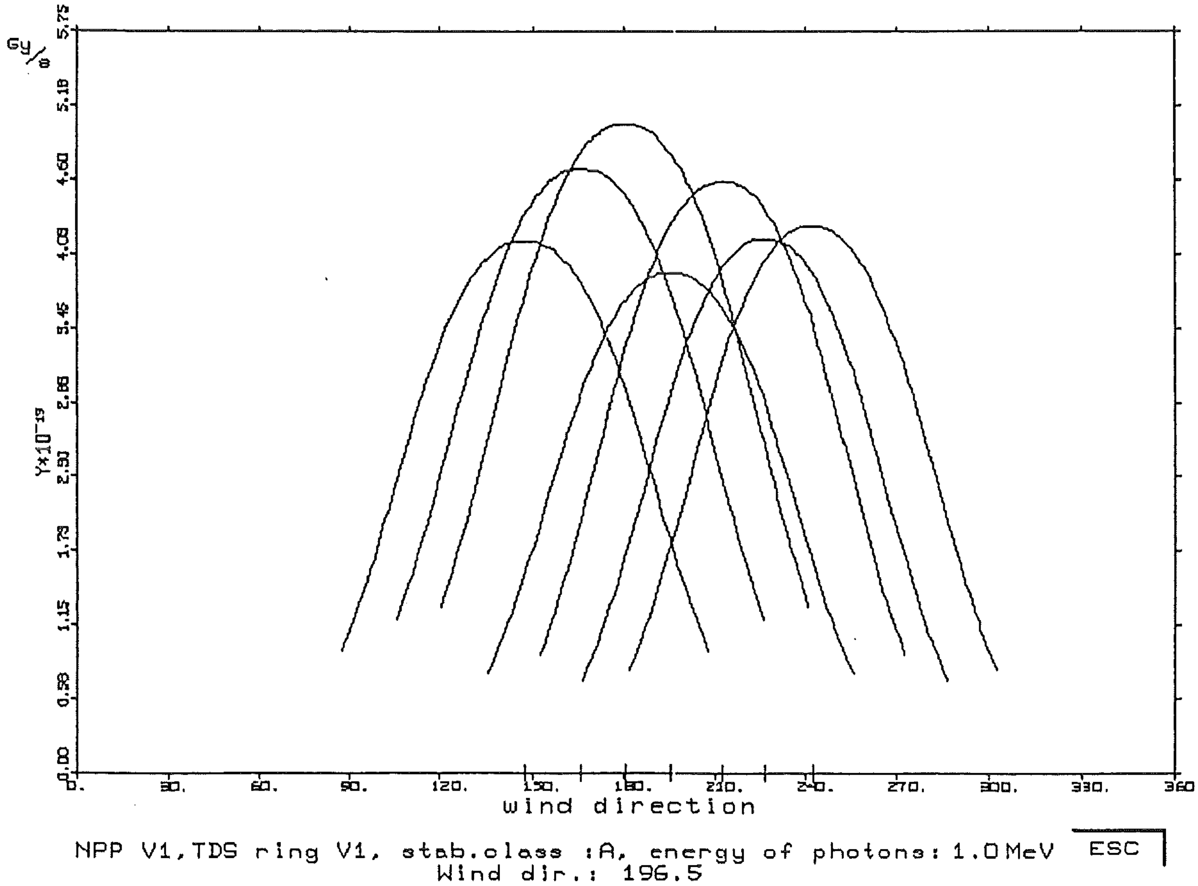


Fig. 8: Selected "sensitive curves" of the ring EBO-V1 in choosen wind direction

The nonparametric percentile method and the bias-corrected percentile method were used for the calculation of the confidence intervals. The fractional bias (FB) which estimates how much the mean over the predictions differs from the mean over the observations was used for the comparison of the empirical and predicted values. Estimates for FB and 95% confidence intervals were computed by two different resampling procedures: bootstrap method and jackknife method. The applied statistical methods are described in more details in /B4, B5/.

Program modules for on-line source term estimation and their implementation to the Bohunice NPP TDS software

The TDS PC net consists of two nets which are connected by telephone modems and internal telephone lines. The first PC net is the base control PC system under QNX operating system. The second PC net is working under Novell operating system. These nets are connected by the QNX-DOS interface and are used for the supporting and interpretation of the values from the teledosimetric system.

The following programs were developed for the estimation of the source term based on gamma dose rates from first ring:

CHARDET — calculation of sensitive curves for 1 Bq/s release in dependence of the distance from the plume axis and construction of special functions for the approximation of these curves,

TDSMDATA — transfer the current measured data of dose rates and meteorological data from the TDS under QNX to DOS; data preparation for the next calculations,

SOURCE — the main program for the estimation of the source term included following main sets of subroutines:

S_READ — reading of input data, calculation of source terms Qi, storing of data,

EST_Q — estimation of source term Q by Bootstrap resampling method and confidence intervals estimation,

CHECK — calculation of dose rates with estimated source Q in measured points with dose rates over background for comparison of measured and calculated dose rates,

S_SCREEN — the set of subroutines which form an interactive mode for working with program,

S_GRAPH — graphical presentation of results,

TIME — time procedures.

The system chart for the SOURCE code is given in Fig. 9. A detailed description of the computation flow is given in /B4/.

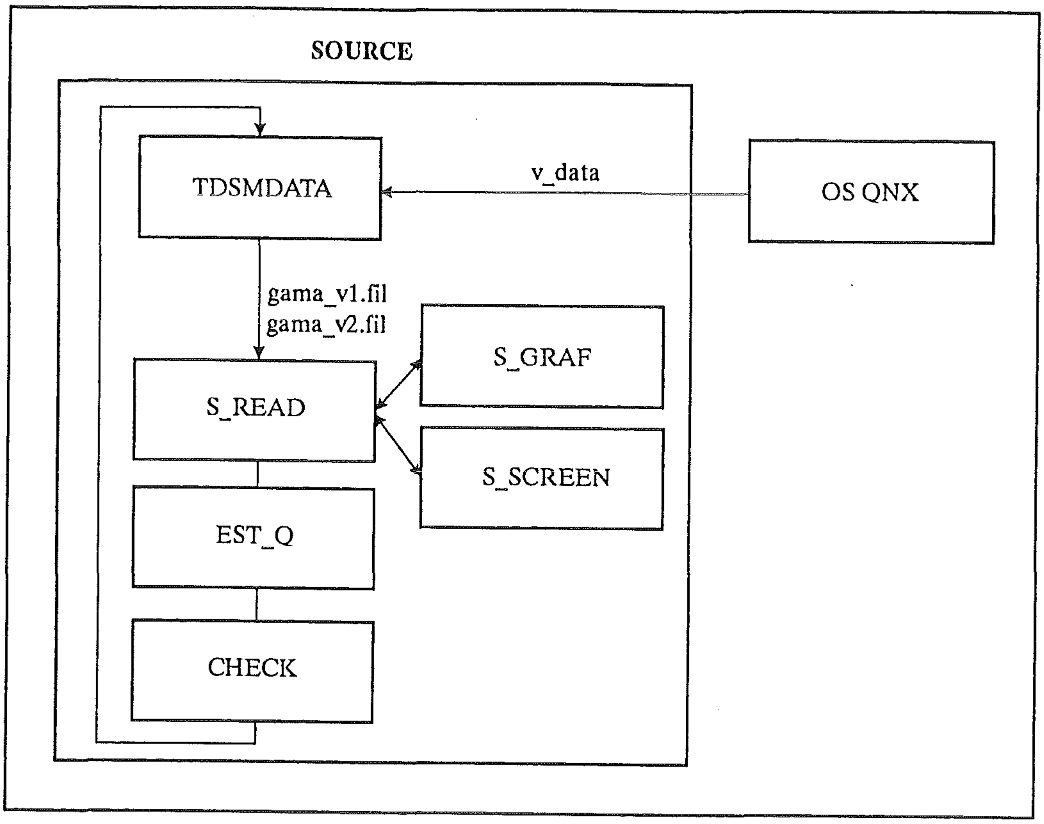


Fig. 9: System chart for the SOURCE code

The program SOURCE was developed as a prototype under DOS and was written in FORTRAN. The SVS FORTRAN 77 compiler was used. Some of procedures were written in C language (TDSMDATA, WIN). All statistical procedures are collected at EST_Q. For the estimation of the source term by bootstrap the procedure CALC_SOURCE is used. CONFID_B, CONFID, MONTE are procedures for the calculation of confidence intervals, BIASES, VYPOCET, STATIST, CONFID_J are procedures for the comparison of predicted and measured dose rates by fractional biases and calculation of the confidence intervals of fractional biases. The following statistical programs were used:

GEN1 generator of random numbers from the interval (0,1) (multiplicative method),

GENN1 generator of random numbers from normal distribution with parameters N(μ,σ),

NORM generator of numbers with normal distribution from the interval (a,b),

ROVDST generator of numbers with uniform distribution from the interval (a,b),

DNORM calculation of distribution function of normal distribution,

DFIN calculation of critical values of normal distribution,
STUD calculation of critical values of Student's distribution with N degrees of freedom,
MONTE calculation of confidence intervals: symmetrical interval, percentile interval, bias-corrected percentile interval. This procedure assign the using of following algorithms:
PPDN calculation of quantiles of normal distribution,
ALNORM calculation of distribution function of normal distribution.

Data collection is repeated every 5 minutes. In each interval a new calculation of the source term is performed.

Program SOURCE written in FORTRAN requests continuous work and connection with main system under OS QNX, it means this program would have required the next computer for work. Due to the technical and economical reasons this program was rewritten to C 86 language (C language under OS QNX) and in this form was implemented to the main control system TDS under OS QNX. This solution of problem has following advantages:

1) initialisation part of program BKG is done automatically during the configuration of TDS system at the beginning,

2) the main part of the software COMPUTE will be incorporated in the base control software, it means at the moment when all data from the detectors are available the calculation of source term will be done,

3) interpretation software RTARC will have data about source term immediately after the end of the data completion cycle,

4) a visualisation of source term data will be a part of the visualisation of the instantaneous TDS state.

Interface program connecting on-line source term estimation with RTARC computer code

Output data files from SOURCE program package with information about source term and meteorological situation are used as the input data files for program package RTARC, (Real Time Accident Release Consequence) which works under MS-DOS.

The source term estimated by the methodology described above is an integral value. An isotopic composition of release is unknown during an accident and can be assumed only on the base of computational analysis. The results obtained on the base of sampling, e.g. PASS, are useful but these results are available much more later as the data of dose rates from on-line teledosimetric system. Therefore, the precalculated characteristics of isotopic composition of release are needed for dose projection. Totally 54 sequences of the accidents and 46 corresponding isotopic compositions were evaluated for VVER 440/213 reactors for LOCA and containment by-pass releases. The information are collected and performed as an event tree for source term evaluation. A detailed description is given in /B4/.

The real-time on-line decision support software for off-site emergency management of the computer based part of environmental monitoring system provides models for atmospheric dispersion and deposition to predict the spatial and temporal distribution of activity up to distances of 40 km, taking into account the site specific meteorological conditions prevailing during the release and the subsequent time of travel of the plume, and models for dose and consequence assessment taking into account the countermeasures involved to mitigate the effects of the accident. For dose assessment the major exposure pathways are considered, i.e. external dose from the plume and from material deposited on the ground, and internal irradiation from activity taken into the body by inhalation. The countermeasures which may be considered in calculation are sheltering, evacuation and the issue of stable iodine tablets. The final step of an accident consequence assessment is to evaluate the incidence of early health effects based on irradiation of the red bone marrow.

Summary

A methodology and computer code for interpretation of environmental data, i.e. source term assessment, from on-line teledosimetric network was developed. The method is based on the conversion of measured dose rates to the source term, i.e. airborne radioactivity release rate, taking into account real meteorological data and location of the measure points. Due to an unknown distribution of the measured dose rates the bootstrap method for the estimation of the mean value of source term Q and confidence interval of Q was selected. The program module for on-line calculation of Q was developed and implemented to the environmental monitoring system manned by the Nuclear Power Plant Bohunice, Slovakia. The interface program connecting on-line source term estimation program module with computer code for radioactivity dispersion and dose calculation **RTARC** (**R**eal **T**ime **A**ccident **R**elease **C**onsequence) was developed.

3.1.2 Meteorology and Atmospheric Dispersion in RODOS (FZK)

Meteorology and atmospheric dispersion are essential parts of the Analysing Subsystem ASY of RODOS. The main purpose of ASY is the assessment of present and future distributions of activity concentrations and radiation doses and dose rates, irrespective of any protective actions or countermeasures taken. The present software structure of ASY is shown in Fig.10. ASY can work both with actual data (real-time mode) and with forecast data (prognostic mode); depending on the mode of operation, different meteorological data and source term data are entered. In the former case, these are on-line data from nuclear reactor remote monitoring networks and other measurement networks, while in the latter case the data are forecasts of meteorological fields and source term predictions.

Meteorological data are processed in the modules PAD, MCF, and LINCOM. The preprocessor program PAD was developed by the Agencia Nazionale per la Protezione Del`Ambiente (ANPA) /C1/ and made available for implementation in RODOS. It is the

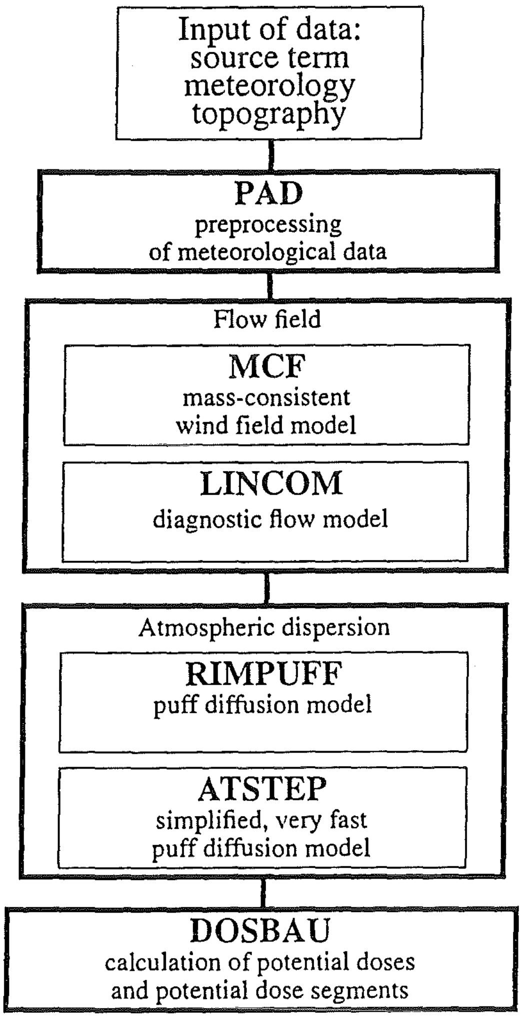


Fig. 10: Sequence of modules in ASY

link between the measured meteorological data entering the system from individual stations and the modules describing the wind field and dispersion. These modules require prepared data indicating the condition of the atmospheric boundary layer. PAD computes these boundary layer data from the measured meteorological data.

The mass-consistent wind field model MCF was made available for implementation in RODOS by the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) /C2/. It allows a spatial wind vector field free from divergences to be set up over the area covering the computation grid. For this design to be achieved, the boundary layer and wind profile data are required which are calculated in the meteorological preprocessor program PAD. In addition, the topography of the base area is entered; as a consequence, the influence of mountain structures on the wind vector field is taken into account.

The module MCF can be used in the real-time on-line mode to integrate local measured wind data from nuclear reactor remote monitoring stations and other stations into the wind field. In the prognostic mode, large wind fields taken from the weather forecast (e. g. with a resolution of 14 km from the German weather service) can be used as input data in MCF to produce a wind field with higher resolution in the computation area of RODOS.

The flow model LINCOM is a non-hydrostatic diagnostic model /C4/ based on the solution of linearised continuity and momentum equations with a first order spectral turbulent diffusion closure. As an example it processes a single layer of 100x100 grid points in less than 10 seconds on a 486 PC. Its truncated physics of course restricts its application over severe non-uniform terrain, but considerable realism in the flow fields is achieved by use of assimilation techniques to match results to measured tower or forecast winds. LINCOM can be used in a similar way as MCF.

Atmospheric dispersion and deposition as well as nuclide specific activity concentration and gamma radiation fields are calculated in the modules RIMPUFF and ATSTEP.

RIMPUFF is a fast and operational puff diffusion code /C4/ that is suitable for real-time simulation of puff and plume dispersion during time and space changing meteorology. Also optimised for fast response on a PC this model is provided with a puff splitting feature to deal with plume bifurcation and flow divergence due to channeling, slope flow and inversion effects in non-uniform terrain /C5/. RIMPUFF includes fast subroutines for the calculation of gamma doses from airborne and deposited radioactive isotopes, released to the atmosphere from a nuclear power plant. These subroutines have been developed in cooperation with CRIP, Budapest. For real-time applications, RIMPUFF can be driven by wind data from a combination of:

1) A permanent network of meteorological towers,

2) The flow models LINCOM and/or MCF (or similar), and

3) Numerical Weather Forecast data.

The puff or plume diffusion process in RIMPUFF is controlled by the local turbulence levels, either provided directly from on-site measurements, or provided via PAD preprocessor calculations /C1/. RIMPUFF is further equipped with plume rise formulas, inversion and ground level reflection capabilities, gamma dose algorithms and wet/dry depletion.

ATSTEP developed by FZK /C6/ is a very fast, but simplified Gaussian puff diffusion code with lower spatial and temporal resolution than in RIMPUFF. It has all important features of a short range, non-stationary atmospheric dispersion code for radioactive releases. ATSTEP is the dispersion module integrated first into the RODOS system. Its future purpose is the application as a fast dispersion code for emergency training and exercises aided by RODOS.

In the ATSTEP code the atmospheric release and dispersion are modelled by a time series of non- spherical, long puffs shaped similar to Gaussian plume segments, i. e. even for a release duration of several hours only a small number of puffs is needed. Therefore, the computer time needed for a 12 hours real time prognosis of the dispersion and radiological situation with a release duration of several hours is only 3 minutes on a workstation. Each new release step (of either 10 or 30 minutes duration) corresponds to the emission of another long puff. During dispersion all puffs travel along their own trajectories according to the time series of wind or wind field input data. The growth of the puffs by turbulent diffusion is modelled by using sigma parameters depending on Pasquill Gifford diffusion category, roughness length, and effective release height. If the release contains heat energy thermal rising of the puffs is considered. Furtheron dry and wet deposition and the corresponding cloud depletion is modelled for different deposition groups. The near ground nuclide specific gamma radiation field of each puff is calculated by using line source, cloud correction factor, and gamma submersion methods. In the computation the puffs are represented as fields of air concentration data on an orthogonal coordinate grid with the dimension of 41 x 41 points. In the same way time integrated concentration fields, contaminations, and gamma radiation fields are represented. During a dispersion calculation ATSTEP is operated in a time step loop. After each time step all concentration and radiation field data are available for the graphical presentation on the screen.

The data of a prognosis of a radiological situation calculated in ASY are transferred to the CSY subsystem not in the form of time series of nuclide specific concentration and radiation fields but in the form of "potential dose histories" on the whole computation grid. In a PROGNOSE run of ASY the module DOSBAU calculates the potential dose histories in the form of series of half hour dose segments. These series of dose segments contain all information about the temporal development of doses on the whole computation grid during a release and dispersion time interval of several hours. The dose histories are specific for the pathways cloud radiation, ground radiation, and inhalation, and for the organs lung, bone marrow, thyroid, uterus, and effective. Dose integration times are 1, 7, 14, and 30 days, 0.5, 1, and 50 years. In CSY the dose segments allow for the computation of any special dose desired with and without simulated time dependent countermeasures.

3.1.3. Data assimilation - part 1 : contribution from SCK/CEN

Introduction

RODOS is a decision support system with primary objective to assist decision makers (DM) to define interventions during radiological emergencies. Therefore, the actual as well as the prognosed radiological situation must be assessed as reliable and as soon as possible.

Four phases can be discerned during a nuclear emergency.

- The pre-release phase : based on available on-site data (e.g. analysis accidental sequence, plant-status, expert judgment) anticipative counter-measures (CM) will possibly be taken. An uncertainty of several orders of magnitude concerning the potential release is to be expected rendering the optimisation of the intervention difficult.
- The release and immediate post-release phase (called release-phase). This is the most critical phase for the DM as severe effects can be expected in the near-range (i.e. deterministic effects, high individual doses), the time constraints will be very tight and the available information will be scarce and conflicting. However intervention (early CM) which is not optimised can lead to unacceptable consequences (radiological,socio-economical,...).
- The longer-term post-release phase. This is a much more comfortable situation for the DM: as no urgent CM have to be taken, enough time will be available to obtain a comprehensive picture based on measurements, thus allowing the required optimisation.

Objectives

Once the release starts the DM wants to know how it compares to the previously forecasted release. Next he wants to know the potential doses to the environment. Three situations can occur:

- Near-range doses remain well below early intervention levels (IL). This situation is easily recognised and no intervention is needed.
- Near-range doses are well above early IL's. This situation is again easily recognised and the emergency plans must be deployed to their full extent.
- Near-range doses are comparable to IL's. This situation is more difficult to recognise and requires an optimisation.

The objective is to develop a module in ASY to reconstruct the source term (ST) during the release phase with an uncertainty within one order of magnitude. This will allow to obtain an overall picture and to assist the DM in his task (by means of CSY,ESY). The ST and its components have been defined in /D1/.

Methodology and achievements

The base of the methodology has been given in /D2/. Basic requirements for the methodology is given in /D1/. Monitoring data (MD) expected to become available in the near range during the early phase will be assimilated in a data-base.

For any observed "contamination field" CF_O (i.e. monitoring of certain type, e.g. air concentrations) the associated calculated (predicted) contamination field CF_P can be obtained in the following way :

$CF_P(x,y;t) = Q(t) \cdot f(x,y,z;t;\{p_i\})$
where :
Q is the source term
f is the transfer function based on a physical model
$\{p_i\}$ are the input and model parameters

The methodology developed consists of a set of rules that have to be activated depending on the particular accidental situation : that is the type, amount and time-space distribution of MD, the meteorological conditions and the initial knowledge of the accident. Basically two types of rules can be defined :

1) Absolute rules to be applied on data of the same type measured during the same time interval to calculate the magnitude of (a part of) the ST.

2) Relative rules which allow to combine and relate to each other different data types measured during different time intervals to acquire a more detailed knowledge (e.g. nuclide composition) of the ST. The different monitoring types which can reasonably be assumed to be at least partially available are mentioned in /D1/.

Up to now, most of the work have been directed towards ST reconstruction algorithms for use of MD of a single type under time-invariant conditions (i.e. air concentrations during tracer experiments conditions). Tracer experiments (near-range simple topography) have been used to check the methods.

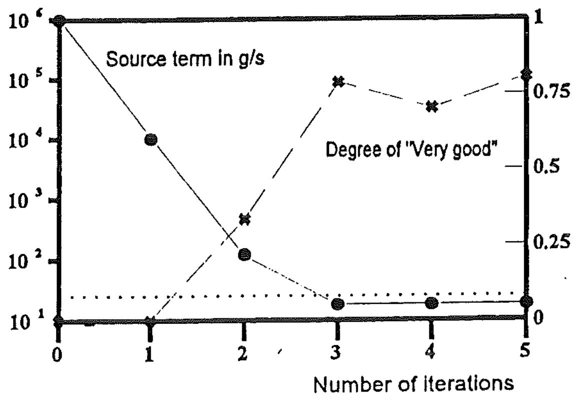
Fuzzy logic

An increasing number of optimisation systems use fuzzy logic instead of numerical optimisation techniques. Fuzzy logic is appropriate to translate a qualitative judgment into a degree of membership to a given group. A logic has been developed to derive a degree of "possibility" or "necessity" to conclusions, based on the combination of several fuzzy information /D3/.

A PC-module based on fuzzy logic has been developed to reconstruct the ST, to adjust the winddirection and,if enough MD are available, to estimate the release height. First, for each observation O a prediction P is calculated using a simple Gaussian model with initial best estimate input parameters. Depending on its value of P/O , five degrees of membership (corresponding to the membership functions very good, good, neutral, bad, very bad) can be associated to each monitoring point /D4/ giving an idea of the misprediction. The optimisation is based on the application of three operators which change the spatial distribution of P/O's. The three operators are :

- The ST-operator which changes ST-value. E.g. an overprediction in the ST tends to overestimate the predictions with the same value for all monitoring points.
- The DD-operator which changes the winddirection. E.g. a misprediction in the winddirection tends to overestimate the predictions at one side of the (mispredicted) advection direction and to underestimate the predictions at the other side.
- The H_{eff} -operator which changes the plume height. E.g. an overprediction of H_{eff} tends to underestimate the predictions more strongly at short distance than at longer distances. This operator can only be applied if enough MD in function of distance is available,which is not trivial during the release phase.

These operators are applied in a two step procedure. First the system aims to obtain a situation where the largest number of ratios P/O lies in the set "very good". Then a global optimisation is performed on the membership function "Very Good" for all points together. The method was checked against tracer experiments for simple terrain and gave a ST within a factor of 3 in most cases /D5/. The figure below shows, in function of the number of iterations, the behaviour of the calculated source term (for which an arbitrary input value was used) together with the membership function " Very good". The exact source term is given by the dashed line. The example is taken from a tracer experiment realised in Karlsruhe in September 1977 . The advantage of the method is its speed, its main disadvantage is the arbitrary way to define membership functions which makes it non-trivial to use it in conditions deviating from those used in tracer experiments. Therefore a more universal method to be applied under less restricted conditions has been sought.



Least Squares Method

The least-square methodology discussed here can be regarded as a spin-off of the JSP-1 research programme /D6/. It is based upon the assumption that the modelled quantities (e.g. air concentrations) satisfy the relation: $L_i(Q, P) = Q\, L_i(P)$, where i is a given point, Q is the source term and P represents the different parameters such as release height, wind speed, atmospheric stability, etc. Thus, it is possible to define a so-called objective function F such that $F = \Sigma (Q L_i - Z_i)^2$, where Zi are observable quantities. The determination of the source term using the least-squares method is equivalent to minimise the sum of residuals, i.e. minimise F. When one minimises F, $Q = \Sigma L_i Z_i / \Sigma L_i^2$. This is the expression that enables one to relate the source term with model predictions obtained using a default value of Q and field observations. As it will be seen below the accuracy of this procedure depends, to a large extent, on the method used to determine model predictions at the exact location where the observations took place.

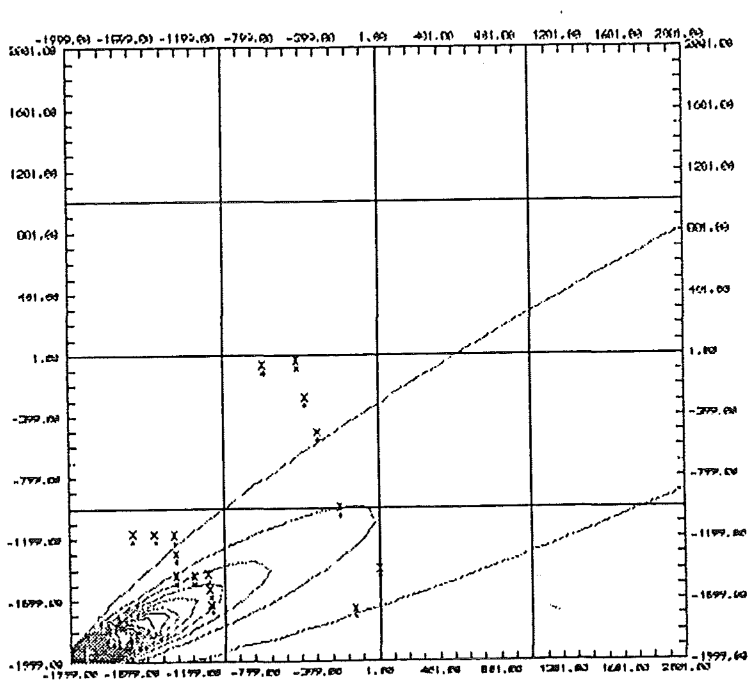
A variation to this approach is the normalisation of F to the sum of the squares of the observations, which confines all possible values of F between 0 and 1, allowing a better interpretation of the results.

The above approach was tested using the segmented-puff dispersion-deposition model ATSTEP, which is currently included in ASY, and that has the advantage of being user friendly and that requires a reduced number of input parameters namely, the release height, wind speed, wind direction, atmospheric stability and the source term. The set of observations corresponds to data from tracer experiments carried out in the location of Mol, Belgium.

The first step in the source term reconstruction procedure was the calculation of model estimates under the meteorological conditions observed during the tracer experiments. The release height was known and the emission rate was set to 1 g s^{-1}. At this stage, the default value of the emission rate does not matter very much since the quantity resulting from the minimization of F will determine the exact value of Q for which model predictions and field observations are in agreement. The second step, which perhaps is the most crucial in the whole approach, is the determination of model values at the location where an observation took place. This was done by interpolation using the four grid points with known concentrations that surround the point under consideration. This step is repeated until there is one model estimate for each observation point. Once this is achieved, the determination of Q and F is straight forward. The table below lists the values for the real source term, the calculated one, its standard deviation, the value of the objective function F, as well as the grid size used in the calculations. The idea here is to explain why the agreement predicted-observed is not always as desired, and also to establish the grounds for further developments and improvements.

Mol Tracer Experiments			
	Mol1	Mol2	Mol3
Qreal	3.33	3.20	4.20
Qcalc	4.09	1.62	0.72
std.dev	0.09	0.03	0.11
F	0.16	0.01	0.18
Grid Size (m)	200	200	400

It can be seen in this table that in the first case the reconstructed source term is in good agreement with the real one, while in the second and third case the calculated source term lies between a factor of two (still acceptable) to six. There are a number of possible causes that produce such a large discrepancy. First, in some cases (see figure below) a significant number of observations were performed away from the plume's center line, which implies that those measurements are prone to large errors. Secondly, the presence of strong concentration gradients implies that in a few hundred meters concentrations can vary by up several orders of magnitude, and this can also be a source of error when measurements are carried out not taking this into account. Third, the accuracy of the above mentioned method relies on the fact that one should have as many observations under the plume's axis as possible. Last but not least, the method of determining model values at specific coordinate points is crucial, in particular when due to the spread of the observation field one is forced to choose a gross grid resolution. Thus, interpolating using a very spaced grid in areas with strong concentrations gradients has proven to produce undesired results (see results for Mol3). It would be necessary that further improvements of this method should include the ability of ATSTEP to calculate estimates at individual points.



Relative position of the observation points (X)
with respect to the plume for Mol3

An alternative methodology has been developed in order to account for effects like those shown in the figure above, i.e. measurements carried out away from the plume's center line, or in case when abrupt and unaccounted changes of wind direction occur, or when there is a displacement between the observed and modelled concentration fields. This method consists of introducing a number of randomly generated transformations such as rotation and translation. All these transformations act on the space containing the observations. This was chosen due to the constraints imposed by computing time. It is faster to perform a transformation on 30 points than on 1681 points, which is the total number of grid points in ATSTEP. Once the observations points have been altered, new modelled values are calculated and then fitted using the approach discussed above. The best solution is basically the one that is achieved when the objective function F has a small value and the magnitude of the transformation introduced is small.

This procedure produced an even better result for Mol1, being the calculated source term 3.25 instead of 4.09 and F was 0.08 instead of 0.16. For Mol2 and Mol3 this approach did not yield significant improvements, which could be due to an interpolation problem as mentioned above. It is worthy to mention that the above results were obtained after performing 100,000 random transformations, which took about 4 min on a 486 33 MHz CPU.

The third stage in this research, still under development, consists of using decision making support software to assist in the selection of the best solution. In other words, the user can establish his preferences a priori and let the system determine which of the results satisfy the above condition, i.e., best fit with small transformation of the observation plane.

As far as uncertainty is concerned, two approaches are still under consideration. One determines the relative error of the reconstructed source term as a function of F (objective function), however it was seen that the magnitude of the transformations often seems more adequate to represent the overall uncertainty, since the measure of uncertainty and F are correlated. The second approach has been proposed by /D7/ and is based upon the quantiles of the F-distribution, which seems more advantageous because it not only gives an idea about uncertainty but also establishes the confidence limits of the source term reconstruction, which is of interest for further error propagation assessments.

Single point method

Above mentioned methods can only work given minimal requirements on MD. A simple method, in case some profiles are available on arcs transversal to the winddirection, is to take the measurement with maximal value and to simply inverse the model to estimate the ST, holding the other input parameters to their best estimate. Checked against tracer experiments it gives mostly acceptable results. Its major advantage is that it eliminates the wind direction which is a major source of uncertainty and it is realistic to obtain MD fulfilling these requirements.

Lessons learned and future developments

Several algorithms can be used with reasonable results for the real-time ST estimation for not too complex situations under conditions similar to tracer experiments. Elaborated methodologies (fuzzy logic, least squares, ...) require an extensive set of simultaneous measurements, which is not trivial to obtain during the release phase. Therefore also more simple methods (e.g. single point) should be used, in function of available data /D8/.

The most important reason for difficulties during the optimisation are:

- Disagreement in location and shape between observed and calculated contamination fieds. This can partially be circumvented (single-point method, least squares method + transformations).

- Complex meteorological conditions (e.g. plume in stable layer, unstable situation at ground level, windshear, ...) . This is more difficult to circumvent and not trivial to recognise.

In principle, some of the methodologies can cope with an unknown plume height. This can however lead to absurd results during the optimisation. It is strongly desirable to have an idea about the plume height (accident analysis, air-borne measurements).

A meaningful optimisation during the release phase is only possible in case of an adapted monitoring strategy /D8/ : locate the areas of maximum contamination and monitor them. It is advised to develop real-time monitoring guidelines for RODOS.

The quantification and propagation of uncertainty in real-time conditions is still under study and development.

3.1.3 Data assimilation - part 2: contribution from UoL

Overview

The University of Leeds in cooperation with the University of Warwick have developed a version of RIMPUFF Gaussian puff atmospheric dispersion model, coded in C++, which integrates directly into both the RODOS system and the RODOS kernel and which:

- allows for the assimilation of instantaneous and integrated concentration monitoring data;
- provides an estimate of and uncertainty bounds on release height;
- reports means and variances of predicted concentration at given sites;
- estimates the source term with allowance for autoregression;
- make allowances for modelling error.

This version of RIMPUFF is implemented upon HP and SGI workstations.

The algorithm is fast enough for 'real-time' use and only exhibits linear time complexity as the volume of data and number of puffs increase. In achieving this we have developed Bayesian forecasting methodology by extending the theory and algorithms for dynamic junction trees, which underpin the belief net formulations of Bayesian models: see /E1/, /E2/, /E3/, /E9/, /E10/, /E11/.

The SGI version of the software has been validated (without data assimilation) in benchtesting at RISØ in the Spring of 1995.

A version of the software has also been developed which is underpinned by a fully relational data model implemented within an INGRES database. This version runs upon SUN sparcstations.

The puff model and associated uncertainty has been visualised using
3-d colour graphics. Animations of plume spread are provided on SGI workstations. However, the software used is not licensed for HP workstations and the software should be thought of a demonstrator.

Other simpler static plots have been developed to show the fit of the model to data at detector sites, and also to enable 'management by exception'. These have not been fully integrated into the RIMPUFF module nor the full RODOS system.

Introduction to the methodology

An ASY module for an early phase of an accident needs to address the following questions:

What is the likely spread of contamination?

How can this prediction be updated in the light of monitoring data?

What are the uncertainties in the predictions?

A simple and flexible statistical model was built in order to address all three questions, using Bayesian dynamic linear model (DLM) forecasting methodology. This model was integrated into the RIMPUFF atmospheric dispersion model. RIMPUFF is a mesoscale dispersion model in which the continuous release of these airborne contaminants is approximated by a sequence of puffs that are released at regular time intervals and then diffuse and disperse independently. Being a puff model, RIMPUFF is simple to work with and has several advantages. For example, the uneven pattern of accidental releases can be tackled successfully by associating different masses under puffs. The different characteristics of the wind field at puff locations can be represented by merely allocating different parameters to each puff dispersal. Hence, the RIMPUFF model was chosen to be combined with a DLM methodology in order to form the ASY module.

The puffs are indexed such that puff i is released at time $t = i$. Assume that the mass under puff i is q_i. The vector of puff masses approximates the release profile of the source term. Standard priors are used on the shape of the time profile - in statistical terms, time series - of the release. Such priors can model uncertainty about the mass release and its duration. If some engineering activity that will lead to a sudden change in the scale of the release is known, it is possible to intercede in the model and capture that. Away from times when sudden changes in the release are expected, 'smoothness' is encoded in the release profile through the covariances between the q_i. Parameterising on masses under puffs has two significant results. First, the time averaged or instantaneous concentrations at monitoring sites are linear functions of q_t. Second, Kalman filtering - a technique of performing Bayesian updating in linear models without needing to invert large covariance matrices - and other linear techniques to assimilate monitoring data can be used. In this case, normality is assumed for simplicity, but the methods generalise in a straightforward way to assimilate non-normal data: see for example /F10/. Running this DLM leads to estimates of the source term profile and predictions of the contamination spread. However, this model presents some omissions which need to be addressed directly. It clearly does not consider either uncertainty on release height or uncertainty on wind field.

The solution to the above problems is to run mixed models. Uncertainty on release height is dealt with by running models at different release heights for each source term. Probabilities are allocated to each model depending on how likely these models are to run at the real release height. The probabilities and the heights are chosen in such a way that gives a three point approximation to the prior on the release height (e.g. obtained by expert judgement from site engineers). Then, the distribution on the release height of each model is updated in the light of monitoring data by applying Bayesian methods. This results in giving most weight to the most likely model.

The uncertainty on the wind field is dealt with in a similar way. The wind field is non-uniform and reflects local topography. The wind field model can be rotated by a few degrees on the wind direction at the source. Three models - associated with the same source term - run at different wind directions are considered with different probabilities to approximate the uncertainty in the wind direction. The probabilities and the directions are chosen to give a three point approximation to the prior on the wind direction at the source (obtained again by expert judgement from local meteorologists or staff on site). In the above examples nine models run for the different combinations of the release height and the wind direction. The number of the models which run is not a constraint of the methodology.

The model as described so far estimates and provides distributions for: source term, release height and wind direction at the source. But what about:

possibility of plume splitting (to branch around hills)

puffs implying below ground spread (if using spherical puffs)

local wind effects

shearing?

The RIMPUFF model allows puffs to pentify. When a puff's diameter reaches a certain value, it pentifies in the horizontal plane. To model the possibility that the original puff was drifting away from its predicted trajectory, a random component associated with the distribution of mass between the siblings is introduced.

Although the above model would theoretically meet the requirements of an asy module within RODOS, it had several deficiencies. The first problem was its speed. An ASY module has to process the incoming data as quickly as possible and produce usable results within a limited time. The second problem was that the methods described were not easy to generalise for non-Gaussian processes. Thirdly, the emissions themselves would not form a non-trivial stochastic process. Another method, which would incorporate such a stochastic process simply and in a way which preserved efficiency, was required. In order to overcome the above difficulties the fragmenting puff model was restructured and belief networks and dynamic junction trees were introduced.

A belief network is a graphical representation of a problem domain consisting of the statistical variables discerned in the domain and their probabilistic interrelationships. The relationships between the statistical variables are quantified by means of 'local' probabilities together defining a total probability function on the variables. A belief network comprises of two parts: a qualitative representation of the problem domain and an associated quantitative representation.

The present problem domain was represented as a belief network in the following way. Puffs are related either as neighbouring source puffs or parent/child puffs. A collection of related puffs is represented by a clique. Each clique becomes a single node in a junction tree which is the qualitative representation of the belief network of our problem domain. The nodes in the junction tree contain a local distribution. An arc between two cliques represents their shared puff. Information arrives at a given node and is then propagated to the other nodes via the arcs (i.e. the shared puffs). Each pair of adjacent cliques in the tree shares a common puff, the separator. This implies that the joint distribution over the masses in all the puffs factorises into a very simple form that allows extremely efficient updating algorithms to be developed. Algorithms were developed from standard Bayesian updating algorithms for the case, as here, in which the trees themselves evolve dynamically /E3/. The modified methodology has been defined, explored and illustrated within the RIMPUFF model. However, it is much more generally applicable and allows the quick absorption of information on a junction tree of cliques.

Initial simulations have shown that the algorithm is fast enough to provide forecasts within the requirements of the RODOS decision support system. Indeed, the computational times of the algorithm are of the same order, although longer, as those for the algorithm without any updating for monitoring data. The algorithm seems to behave sensibly in the manner it assimilates data. Currently, it is being tested on data sets derived from tracer experiments. Not only is this a fairer test in absolute terms but also other data assimilation algorithms developed by other groups within the RODOS project and elsewhere are also being tested on the same data.

The algorithm was tested on simulated data sets derived from the Lundtoft Nord tracer experiment. It fitted data which had been simulated from the results of the experiment. However, a more rigorous test was needed. For this purpose, the Siesta data was used. The Siesta data comes from a real experiment, held on November the 30th 1985. It lasted approximately 6 hours and observation data was supplied for the last hour. Having this data as input the program found the scale of the release satisfactorily. The program does not delimit the start of the release, but this might be expected since the nature of the input data - integrated air concentrations taken over a single hour is probably not sufficient to identify this.

3.1.4 Dose Assessments (GSF)

3.1.4.1 General overview

For the assessment of human radiation exposure within the analysing system (ASY) of RODOS, the module ECOAMOR (**ECO**SYS **ASY** **Mo**dules for **R**ODOS) /G1/ has been developed. It is based on the dynamic radioecological model ECOSYS-87 /G2/ and the ECOSYS application EURALERT-89 /G3, G4/.

ECOAMOR considers all exposure pathways which might be of importance during and after passage of the radioactive plume:

- external exposure from radionuclides in the plume,
- external exposure from radionuclides deposited on the ground, and on skin and clothes of people,
- internal exposure due to inhalation of radionuclides during passage of the plume as well as afterwards from resuspended soil particles, and
- internal exposure due to ingestion of contaminated foodstuffs.

In the assessment of doses in RODOS, most of the calculational effort is spent in the simulation of the transfer of radionuclides through the foodchain in order to estimate activity concentrations in foodstuffs.

The ECOAMOR module can be used in a very flexible way within the RODOS system. In the automatic mode, it calculates all data which are needed for the subsequent estimation of countermeasures, and it provides a lot of "standard" information about the radiological situation to the user. In the interactive mode of RODOS, ECOAMOR can be used to answer special requests from the user concerning specific exposure pathways, radionuclides, grid points etc. within short time.

Some submodules of ECOAMOR are being used also by the long term countermeasure module FRODO for assessment of doses with countermeasures applied. Figure 11 shows schematically the data flow and structure of the ECOAMOR and FRODO modules within RODOS.

3.1.4.2 Input to the food chain and dose modules

Principal event specific input data for modelling the food chain transfer and dose assessment in ECOAMOR are

- the time-integrated activity concentration in air, and
- the activity deposited during precipitation for the nuclides and locations (grid points) considered,
- the amount of rainfall at these locations,
- the date of deposition, and
- the time dependent activity concentrations in drinking water, animal feeding water and fish in the aftermath of the deposition.

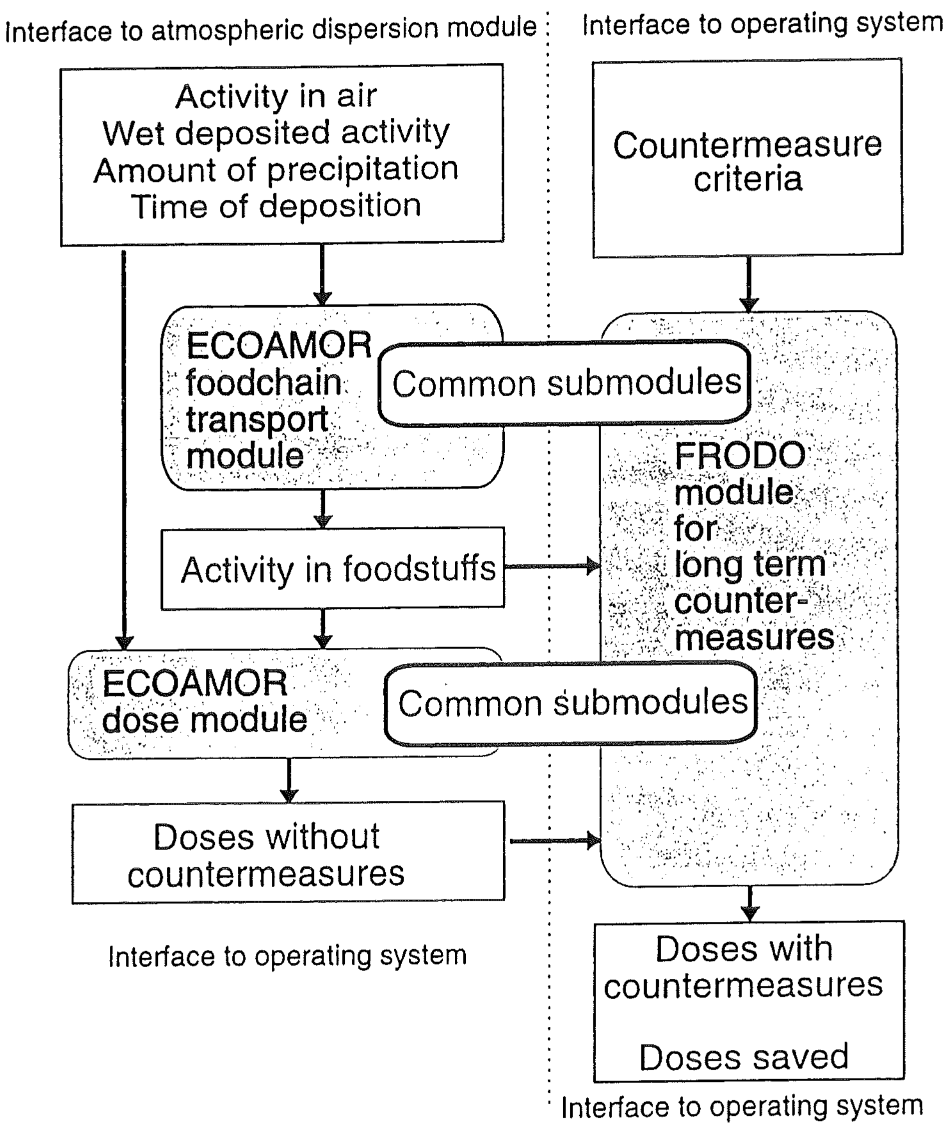


Fig. 11: Data flow in the food chain transfer and dose module ECOAMOR and the long term countermeasure module FRODO within the RODOS system

Moreover, data on population and foodstuff production at the locations of the calculation grid have to be provided by the RODOS data bank if collective doses are to be estimated. In addition to these data, ECOAMOR requires many model parameters characterising transfer processes in the radioecological scenario. Many of these parameters depend on the radioecological (e.g. climatical or agricultural) characteristics of the region considered which vary to a wide extend over different parts of Europe. Therefore, the modules are designed to facilitate the adaptation to different radioecological regions, and they allow to apply different site-specific data sets among the calculation grid points.

3.1.4.3 Methods of food chain transfer modelling and dose assessment

Food chain transfer

Assessment of the activity in foodstuffs after deposition of activity from the atmosphere onto agricultural production areas is performed in five main steps (Fig. 12), i.e. calculation of

- activity deposition onto plant canopies and onto ground,
- time dependent activities in edible parts of the plants (raw products),
- time dependent activities in feedstuffs, taking into account processing and storage,
- time dependent activities in animal products, and
- time dependent activities in foodstuffs, taking into account processing, storage and culinary preparation of vegetable and animal foodstuffs.

For dose assessment after radioactive contamination of water, direct consumption of drinking water and fish, as well as feeding of contaminated water to domestic animals with subsequent transfer to animal products is taken into account.

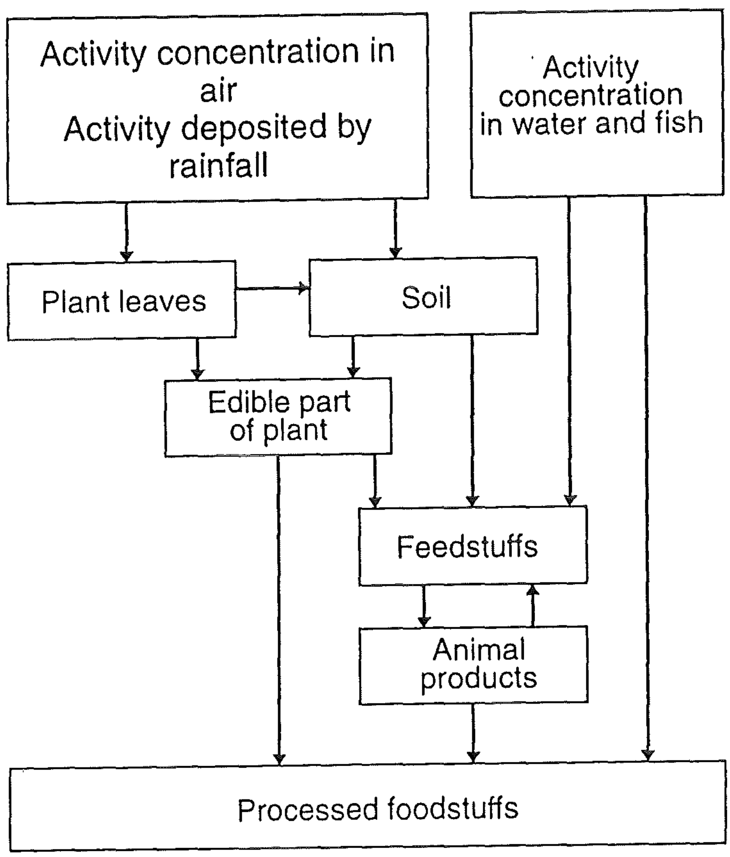


Figure 12: Calculation steps in the assessment of foodstuff contamination

Presently, the products considered include 31 food products (20 plants or plant products and 11 animal products), 22 feedstuffs (17 based on plants, 4 based on animal products, and feeding water), and 35 processed foodstuffs (see Table 1). This relatively large number of products results on the one hand from the diversification of plant species which is necessary to properly reflect radioecological reality: thus, e.g. 6 species of cereals are distinguished, including winter and spring wheat and barley, since they are affected quite differently by depositions in springtime or early summer. For pasture, both intensive and extensive agricultural management (i.e. fertilisation) is assessed; the latter is an attempt to take care of the radioecological behaviour in certain regions to be found in the uplands of Northern Europe, in parts of the Alps and in Eastern Europe. On the other hand, the model includes also foodstuffs with small average consumption but of possibly high importance to critical groups, as e.g. sheep or goat's milk or meat from animals living in natural environments (roe deer).

Type of product	Individual products considered	Remarks
Plant Products	Summer wheat Winter wheat Rye	Whole grain, flour, and bran can be considered individually for these cereals
	Oats Potatoes Leafy vegetables Root vegetables Fruit vegetables Fruit Berries	
Milk Products	Cow's milk Condensed milk Cream Butter Cheese Goats milk Sheep milk	Cheese from rennit and from acid coagulation can be considered individually
Meat and other animal products	Beef Veal Pork Lamb Roe deer Chicken	Beef from cows and from bulls can be considered individually
Beverages	Drinking water Beer	

Table 1:Foodstuffs considered in the food chain and dose assessment module

For an adequate modelling of the foodchain transfer, the dynamics of the different transfer processes - e.g. the seasonality in the growing cycles of plants, the feeding practices of domestic animals and human dietary habits - are considered, since equilibrium in the model compartments is not reached for a long time. Any day of the year can be used as time of deposition, which results in a pronounced season dependency of the radiological consequences. As an example, Fig. 13 shows the lifetime ingestion dose of an adult as function of the time of the year, when the deposition occurs. The module is flexible to simulate temporally limited changes in the feeding regimes of animals as well as in the human food consumption habits in response to environmental radioactive contamination.

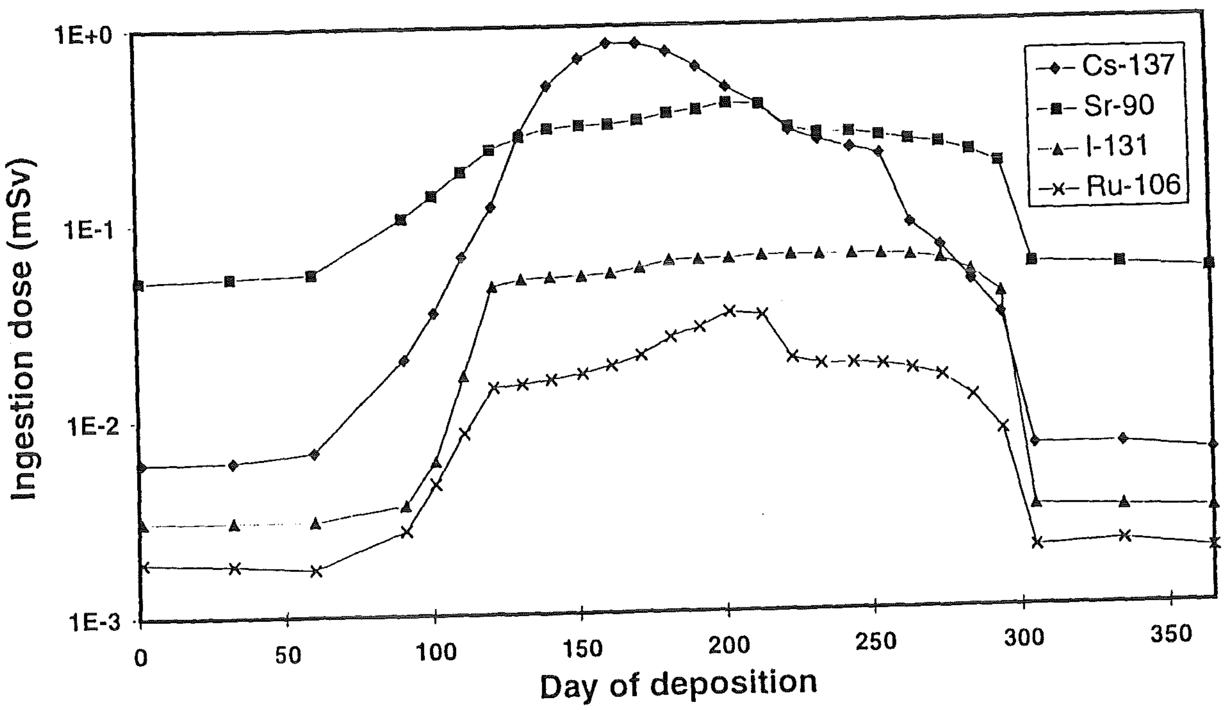


Figure 13: Dependency of lifetime ingestion dose of a 20 year old (at time of deposition) person on the time of deposition. A time-integrated activity concentration in air of 10^6 Bq · s/m^3 and dry deposition only has been assumed for each radionuclide and time of deposition.

The model considers dry and wet deposition of radionuclides separately. Dry deposition to the plant canopies is calculated using a deposition velocity depending on the nuclide considered, the plant type and the seasonal stage of development (expressed by the leaf area index) of the plant canopy. Wet deposition is calculated by taking into account that only a certain fraction of the wet deposited activity remains on the plant leaves. This interception fraction depends on the leaf area index, the total amount of rainfall and the ability of the radionuclide to be fixed on the leaves. For the calculation of root uptake the total deposition onto vegetated soil is estimated.

Direct contamination of the leaves by dry and wet deposition as well as activity transfer from the soil, by root uptake and resuspension, cause the contamination of plant products. For totally consumed plants like grass and leafy vegetables, the time dependence of the contamination is controlled by the activity loss due to growth dilution and weathering effects. For partly eaten plants like potatoes and cereals, the translocation from the leaves to the edible part and the direct deposition onto these edible parts are taken into account. Root uptake is estimated using transfer factors between soil and plant, and considering decreasing availability of radionuclides due to migration into deep soil, and fixation in the soil of the root zone layers for arable and pasture land.

The contamination of animal products results from the activity intake of the animals and the kinetics of the radionuclides within the animals. The activity intake is calculated from the activity in feedstuffs and the season and age dependent feeding rates. Soil eating is included by applying an additional soil-plant transfer factor. Animal feeding water contaminated by radionuclides can be an additional source of activity intake by the animals. The radionuclide transfer from fodder into the animal product is calculated by an equilibrium transfer factor and one or two exponentials describing the biological excretion.

The contamination of animals' feedstuffs and human foodstuffs is calculated from the activity in the raw plant or animal products by applying processing factors describing the activity enrichment or dilution during processing and culinary preparation. For example, the fractionation in milling products due to the enrichment of minerals in the outer layers of grain is considered. Furthermore, radioactive decay during the processing and storage period is taken into account.

Ingestion dose

In the dose module, the ingestion doses are calculated from the activities in foodstuffs, age and possibly season dependent intake rates, and age dependent dose factors. Default mean values for foodstuff consumption are used but also those for critical groups can be applied. For the simulation of temporary changes in the dietary habits during and after an accident correctional factors can be applied. Age dependent doses per unit intake based on the models of ICRP 30 are used.

The collective dose from ingestion is estimated using the contamination and the amount of foodstuffs produced in the considered area, irrespective of where they are consumed. For the estimation of the collective dose saved by certain countermeasures, this is regarded to be an appropriate assumption.

Inhalation dose

Inhalation doses are calculated using age dependent breathing rates and dose factors; reduction factors due to the lower indoor activity concentrations may be taken into account. Short term inhalation from the passing plume as well as long-term inhalation of resuspended material is considered. Age dependent doses per unit intake based on the models of ICRP 30 are used.

For a rough estimation of the collective dose from inhalation (as well as from external exposure) the individual dose for adults and the number of inhabitants at the grid areas is used, without considering the actual age distribution of the population.

External exposure

The assessment of external exposure from radionuclides in the plume is done by two different approaches: at locations sufficiently far away from the emission source it is based on the time-integrated activity concentration in air assuming a semi-infinite homogeneous cloud. For locations in the vicinity of the emission source this approximation by a semi-infinite homogeneous cloud is not justified; here integration over the plume is performed in the atmospheric dispersion module of RODOS and the kerma in air is passed to the dose module which estimates the organ doses and/or effective dose from it. Shielding effects due to staying at different types of location outside and inside houses are considered. Mean data for a population is used as a default, but data for critical groups as e.g. agricultural workers can also be applied.

The external exposure from nuclides deposited on the ground is calculated on the basis of the total deposited activity onto vegetated soil. Dose reductions from nuclide migration into deeper soil layers and by the shielding of houses are considered, as well as the influence of variable deposition patterns at different urban environments.

As an additional pathway of external exposure, irradiation from radionuclides deposited onto skin and clothes is considered. For all external exposure pathways, age dependent dose conversion factors are used which are based on Monte Carlo calculations using human phantoms /G5, G6/.

3.1.4.4 Output of the food chain and dose modules

Results for direct presentation to the user

ECOAMOR is designed to produce a wide range of output data the user may be interested in. For a number of presently up to 400 locations, the following output can be calculated:

- nuclide-specific activity concentrations in feed and foodstuffs,
- nuclide-specific individual doses from external exposure (from cloud, ground, skin and cloth contamination), inhalation, and the sum of all exposure pathways,
- nuclide- and foodstuff-specific individual doses from ingestion,
- doses due to ingestion for groups of nuclides (e.g. all Iodine isotopes) and groups of foodstuffs (e.g. milk and milk products),
- all doses can be estimated for 5 age groups (1 year infants, 5, 10 and 15 year old children, and adults 20 years old at time of deposition) and 22 organs (including effective dose)
- rough estimation of collective doses for all exposure pathways.

The activity concentrations in feed and foodstuffs, and the doses from ingestion can be given with a detailed time resolution of up to 158 time steps within 70 years after deposition. For external exposure from deposited radionuclides and inhalation of resuspended radionuclides a time resolution of 49 time steps within 70 years after deposition is used. Short term doses due to external exposure from the ground, external exposure from the cloud, inhalation and the sum of these exposure pathways can be assessed with a time resolution as given by the atmospheric dispersion calculations.

Different ways of presenting the results to the user can be chosen (e.g. time series, maps, frequency distributions).

Interface to the long-term countermeasures module

As a basis for the assessment of necessity and effect of countermeasures, the following information is transferred from the ECOAMOR module to the long-term countermeasure module FRODO:

- Specific activities in feed and foodstuffs,
- individual and collective doses from ingestion,
- long-term external exposure from radionuclides deposited on the ground,
- long-term inhalation doses from resuspended radionuclides.

3.2 Simulation of countermeasures and quantification of consequences

3.2.1 Early emergency actions (FZK)

The simulation of the effect of early emergency actions on individual doses and the assessment of other radiological and economic consequences without and with these actions is the main objective of the program group EMERSIM, HEALTH and ECONOM in the Countermeasure Subsystem CSY. The emergency actions considered in EMERSIM are:

Sheltering,
Evacuation,
Administration of iodine tablets.

These actions are typically limited to areas within a circle of a few ten kilometres around a nuclear power plant (NPP), and to time intervals from a few hours before the beginning of the release to several hours after the cloud of released nuclides has left the near range. In a given accident situation the areas with emergency actions are defined by a number of dose intervention levels. Whether, where and when the actions really can be carried out is a question of the time left in comparison to the time needed for them, and of the availability of technical and personal support. This question has to be answered by the decision maker. EMERSIM allows the decision maker for choosing different temporal and spatial patterns of countermeasure combinations and quantifies the resulting doses.

Computation grid

All calculations of doses and consequences are carried out on the same coordinate grid as it is used in the ASY Subsystem for calculating the concentration and radiation fields. It is an orthogonal 41 x 41 cells grid. Typical cell size for near range problems is 1 x 1 km2 or 2 x 2 km2, corresponding to a grid extension of 41 x 41 km2 or 82 x 82 km2. All quantities on the grid are assigned to the cells; for area specific quantities (like population) the number contained in the cell is assigned, for location specific quantities (like dose) the average or central point value is assigned.

Modelling of emergency actions and dose calculation in EMERSIM

For the calculation of doses with protective actions a scenario has to be defined. On the one hand it consists of a prognosis of the radiological situation including its temporal development from the beginning of the release (ASY PROGNOSE), and - on the other hand - of an action scenario during the prognosis time interval. As mentioned above, in the module DOSBAU the temporal development of the radiological situation is archived in the form of potential dose histories in each grid cell during a PROGNOSE run in ASY. A dose history is a time sequence of half hour dose segments in the prognosis time interval. All histories begin with the start of the release which is identical with the beginning of the prognosis. The definition of an action scenario includes the action areas and the action time intervals. In the interactive version of EMERSIM action areas can be defined indirectly by starting from dose intervention levels which can be edited by the user, or directly by graphical input of these areas in the form of sectors and zones around the NPP or of arbitrary shape. Finally the action areas are sets of grid cells marked with action specific tags. The tags for sheltering and evacuation are 0, 1, 2, and 3: 0 for no action, 1 for sheltering, 2 and 3 for evacuation with lower and upper intervention level. The tags for administration of iodine tablets are 0 and 1: 0 for no action, 1 for administration. The action time intervals define when a certain action begins and ends in relation to the beginning of the prognosis time interval. The action times are user input to EMERSIM. Furtheron the user can select action components of the action scenario and swich them on or off.With given potential dose histories, action areas, and action time intervals the dose field calculations under consideration of emergency actions can be carried out (a dose field is an array of dose values for all grid cells). For this purpose in each grid cell with the action tag 0 the potential dose segments are summed up. The cells with an action tag 1, 2, or 3 are treated in a different way: the potential dose segments are summed up only at times before the action has started. During or after the action the value of each dose segment is modified by a specific factor or function modelling the effect of actions on dose. Then all cell dose segments are added to get the cell dose. In the upper part of Fig.14 examples of time series of potential dose segments are shown, in the lower part the corresponding time series modified by different actions are shown. The time intervals of the actions are given in the middle:

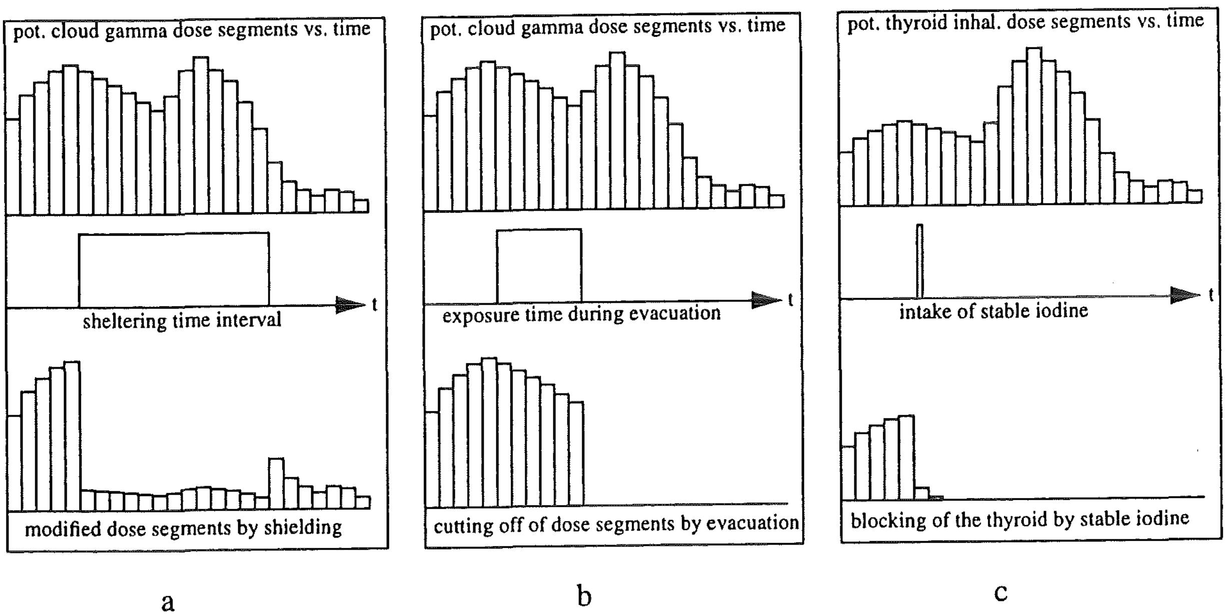
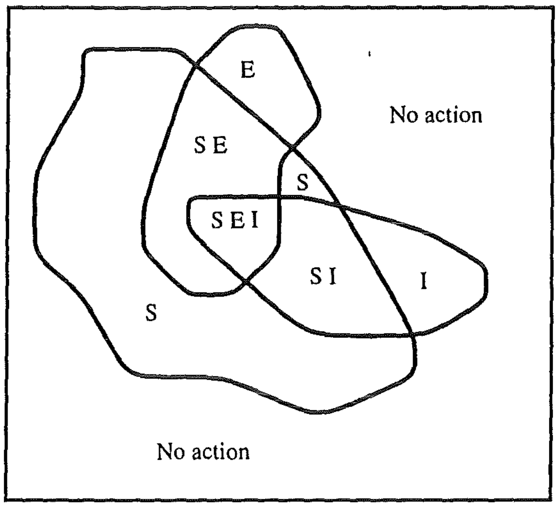


Fig. 14: Modelling of the effect of protective actions on doses
a) Sheltering, b) Evacuation, c) Administration of stable iodine tablets

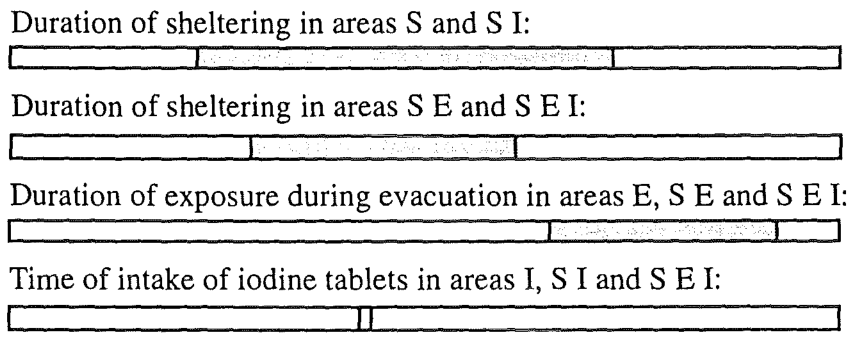
In Fig. 14a the effect of sheltering against external gamma radiation is shown. The dose reduction during sheltering is simulated in EMERSIM by using building type specific shielding factors for external cloud and ground gamma radiation. The shielding factors are defined as average values for each grid cell and are derived from the building types in that cell. In Fig. 14 b the effect of an evacuation on dose is shown. In the present version of EMERSIM the simplifying assumption is made that before the start of and during the evacuation people get the potential dose of their home location. After the exposure no additional dose is added (dose cut off). In a future version of EMERSIM a more realistic modelling of exposure during the evacuation will be possible by using the results of the evacuation simulation module EVSIM described below. In Fig.14 c the effect of the administration of iodine tablets is shown. The blocking of the thyroid amounts 100% a short time after the intake. The time dependence of the reduction factor is modelled by an exponential function.

Patterns of action scenarios

In the interactive mode of EMERSIM the user can define several overlapping action areas, starting times, and durations. Fig. 15 gives an example. The capital letters denote the action tags of the areas: **S**heltering, **E**vacuation, intake of stable **I**odine, the combination **SEI** means that sheltering, evacuation, and intake of stable iodine take place in the area tagged with it. "No action" denotes areas without emergency actions with normal living conditions:



a) action areas: S = area with sheltering, E = area with evacuation, I = area with iodine tablets intake.



b) action timings

Fig. 15: Example action areas and timings

The starting times and durations of the actions can be chosen independently in different areas as follows: the sheltering time intervals in S and SI areas are equal; the sheltering time interval in areas with additional E tag (SE and SEI areas) may be completely different. The evacuation starting time is independent of the sheltering times and is the same for all E areas. An evacuation starting before the end of sheltering terminates sheltering. The intake of stable iodine is assumed to occur synchronously in all I tag areas. It is not carried out in E areas if evacuation starts before the time of iodine intake.

Dose results of EMERSIM

Each dose is estimated for 7 different integration times: 24 h, 7 d, 14 d, 30 d, 0.5 y, 1 y, 50 y (except the external cloud gamma dose). The doses are calculated separately for the 3 exposure pathways cloudshine, groundshine, inhalation, and as the sum of all three pathways. All doses are fields defined on the 41 x 41 cells grid. The organ doses calculated are: lung dose, bone marrow dose, thyroid dose, uterus dose and effective dose.

Program structure of EMERSIM

The program structure of EMERSIM is shown in Fig. 16. together with the modules HEALTH and ECONOM (see Section 3.2.3).

EMERSIM starts with the INPUT module, where geographic and demographic data of the region of the NPP are read in from files. Furtheron the prognosis data calculated before with ASY, i.e. the potential dose segments, are loaded from the data bank.

The first dose calculations are carried out in the module NOACDOS. In this module fields of individual doses are calculated under the conditions of "no action", i. e. no protective actions are assumed. Two cases are distinguished: "open air" doses equal to potential individual organ doses, and doses under "normal living" conditions, where shielding factors for external gamma radiation are applied.

In the health effects module HEALTH the numbers of people with deterministic and stochastic somatic health effects are estimated. This is done both for "open air" and for "normal living" conditions.

In the module ECONOM the monetary costs of medical treatment and the productivity losses to society are quantified both for "open air" and for "normal living" conditions.In the interactive mode the user can define her/his action scenario in ACTIONS by putting in emergency action dose intervention levels, a list of actions to be simulated, and starting times and durations. AREAS then determines the areas with grid cells in which the doses exceeded the intervention levels. Once these areas are determined the user can modify them graphically on the screen. Now the action scenario is fully defined and the dose calculation under consideration of the actions is performed in the module ACDOS. At this point the information about the movement of people during an evacuation which is provided by the module EVSIM will enter into ACDOS and allow a more realistic dose calculation. Again in the health effects module HEALTH the numbers of poeple with determinisic and stochastic somatic health effects are estimated from the doses with protective actions, and finally, in the module ECONOM the monetary costs are assessed (see also Sec. 3.2.3).

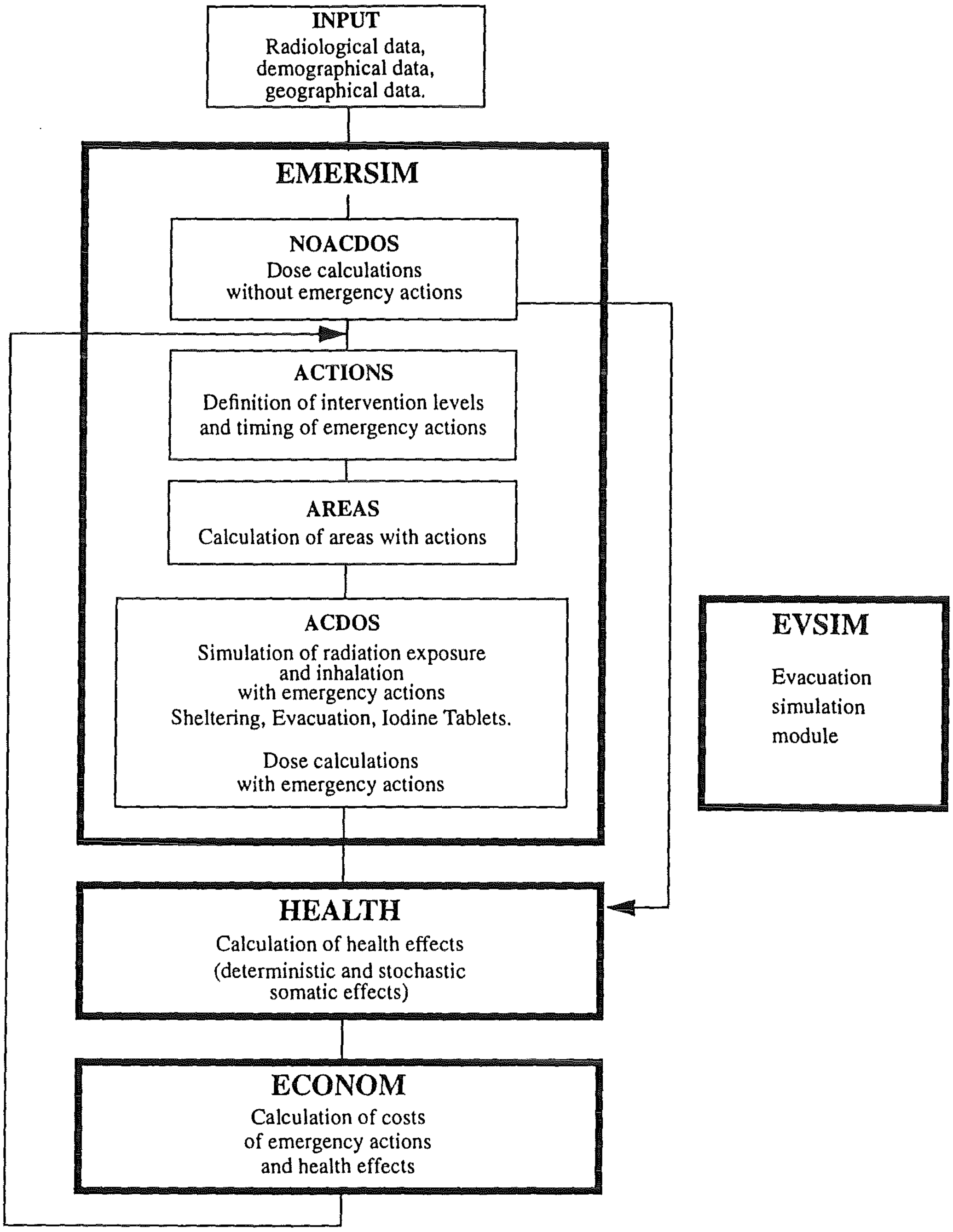


Fig. 16: Sequence of modules for calculating radiological and economic consequences

Model description of the module EVSIM

The task of the evacuation simulation module EVSIM /C7/ is, to estimate the time evolution of the spatial population distribution in the early countermeasure phase. It is not sufficient for EVSIM only to compute the driving times of the individuals since the individual doses depend on the time evolution of the radionuclide distribution and the time evolution of the spatial population distribution in the area of interest. Therefore both the topology and the geometry of the traffic net have to be considered in the model. Because of the need of a very fast evacuation simulation the traffic net in EVSIM is modelled on a grid. The time evolution of the population distribution is calculated using constant timesteps. In the present version of EVSIM the length of a grid element is 1 kilometerand a timestep of a typical run is one minute of evacuation time. To improve the model efficiency, EVSIM uses the concept of representatives. All individuals which have the same history in the model world will be simulated by one representative in EVSIM. The computed spatial population distributions for every timestep are output data from EVSIM which will be used by other RODOS modules (e.g. to estimate the doses of the individuals arriving at emergency stations). Very important program units of the EVSIM code are the User Interface and the Analysing Module.

User Interface

The objects of evacuation decisions are communities (villages, cities, districts of cities, ...). The time schedule of the evacuations of the communities in the evacuation zone is very important for the success in dose reduction. Therefore an evacuation scenario in EVSIM defines which communities will be evacuated at which time. In EVSIM the user can use predefined scenarios or define by means of the User Interface scenarios completely by himself. Furthermore it is possible to adapt the simulation data to the acual situation using the User Interface (e.g. setting traffic blocks)

Analysing Tool

The analysing module evaluates the efficency of the simulated evacuation. It presents

- Simulation data which describe in summary the evacuation process simulated by EVSIM
- Driving time distributions
- Dose distributions computed during an EVSIM run

Furthermore it calculates so called "countermeasure indices", which are indicators for the efficiency of the evacuation decisions.

Simulation Data

The summary information comprises the following data:

- Starting time of the whole evacuation
- Duration of the evacuation
- Number of evacuated persons
- Number of persons per private car
- Mean transport performance in persons per hour
- Mean transport performance in cars per hour
- Mean individual driving time in minutes
- Collective driving times
- Quality measure indices for the evacuation process

Driving Times and Countermeasure Indices

The analysing module builds the driving time distributions for communities and for the complete evacuated population from the simulation data. The distributions are presented as data files and as diagrams. The following diagrams are available:

- Driving Times: Absolute Frequency Distribution
- Driving Times: Normalised Frequency Distribution
- Driving Times: Cumulative Absolute Frequency Distribution
- Driving Times: Cumulative Normalized Frequency Distribution
- Countermeasure Quality Index 0 presents the inverse mean personal driving time in $(hour)^{-1}$ for every evacuated community and the whole evacuation zone.
- Countermeasure Quality Index 1 presents the inverse collective driving time in $(hour)^{-1}$ for every evacuated community and the whole evacuation zone.

Individual Doses

Furthermore the user can specify during an EVSIM-run that EVSIM uses dose field data from the EMERSIM module of RODOS for computing individual doses in the evacuation zone. In this case the analysis module of EVSIM calculates a set of histograms for each combination of organs (lungs, bone marrow, thyroid gland, uterus and effective body), exposure pathways integration times (8.5 hours, 1 day, 7 days, 14days, 30 days, 182 days, 1 year and 50 years). A set of histograms consists of the following distributions and moments of distributions:

- Absolute Dose Frequency Distribution
- Normalised Dose Frequency Distribution
- Cumulative Absolute Dose Frequency Distribution
- Cumulative Normalised Dose Frequency Distribution
- Mean Dose presents the mean dose the evacuated individuals got for every evacuated community and the whole evacuation zone.
- Collective Dose presents the sum dose of all evacuated individuals for every evacuated community and the whole evacuation zone.

3.2.2 Late countermeasures (NRPB)

3.2.2.1 Introduction

Models to assess the consequences of the following late countermeasures have been developed by the National Radiological Protection Board, UK:

- temporary and permanent relocation
- decontamination of urban and agricultural land
- agricultural countermeasures applied to land and foodstuffs

These models have been included in a module, FRODO (Food, RelOcation and Decontamination Options), which has been implemented within the RODOS system.

Relocation, decontamination and agricultural countermeasures are countermeasures applicable in the intermediate and later phases following an accident. The exposure pathways of importance in these phases are: external exposure from deposited activity, inhalation of resuspended material, and ingestion of contaminated food. Relocation is intended to protect against the first two. It is unlikely to be implemented to protect people against ingestion of food, since this can be more readily achieved by placing restrictions on the consumption of food and the implementation of agricultural countermeasures. The decontamination of buildings or land in the vicinity of buildings is intended to reduce external exposure from deposited activity and inhalation of resuspended material whereas the decontamination of agricultural land is intended to reduce ingestion doses from contaminated food.

The FRODO module includes models for the three countermeasure options described above. The options can be considered individually or the impact of each of the different options on the others can be evaluated to varying extents. The effect of decontamination on the extent and duration of relocation and the need for and duration of food restrictions is evaluated for a number of endpoints including the additional dose saving. Relocation is linked to agricultural countermeasures in so far as endpoints are calculated to provide information on the potential agricultural areas and amounts of food produced and banned in relocation areas. This enables the evaluation of the use of this land and possible agricultural countermeasures that may be considered to make the area agriculturally productive to be made.

The modelling of the countermeasure options, the structure of FRODO and its implementation within RODOS, and the databases developed in support of the models are described below.

3.2.2.2 Modelling

Relocation

Within FRODO endpoints related to the imposition of relocation in the presence or absence of land decontamination are evaluated. Two types of relocation are considered, temporary and permanent. These are defined, as follows:

> **Permanent relocation**
> The removal of people from an area with no expectation of their return, however, the land may be released at a later stage and resettled by different individuals.
>
> **Temporary relocation**
> The removal of people from an area for an extended but limited period of time.

The model uses criteria for the imposition and relaxation of relocation in the form of dose levels. The doses compared to the relocation dose criteria are the sum of the doses from external irradiation fromdeposited activity and the inhalation of resuspended material. The dose quantity compared with the relocation criteria is effective dose; this is in line with current recommendations. The first stage in the model is to decide whether and if so what type of relocation is implemented at each spatial grid point, and the duration of land interdiction. This is done by comparing doses against relocation criteria. If the dose at a location is less than the criterion for the imposition of relocation then no relocation occurs. If the dose is greater than the criterion for the imposition of relocation, the duration of land interdiction is determined by comparing doses with the criteria for the relaxation of relocation. If the predicted duration of relocation is greater than the "maximum temporary relocation duration" then permanent relocation occurs. If the predicted relocation duration is less than the "maximum temporary relocation duration" then temporary relocation occurs. Figure 17 illustrates the modelling of permanent relocation of the population and the possible resettlement of the area.

It is important to have some indication of the extent of the potential overlap between evacuation and relocation. Although this is not modelled in detail in the current version of RODOS, the numbers of people who are both evacuated and relocated are evaluated within FRODO.

The endpoints evaluated relate to the areas of land interdicted, the time periods over which this occurs, the numbers of people relocated, the doses saved as a result of relocation, the doses received by those temporarily relocated following their return, and the doses received by individuals resettling in an area following the lifting of land interdiction after the permanent relocation of the original population. More details of the modelling and the endpoints evaluated are provided in /F1/.

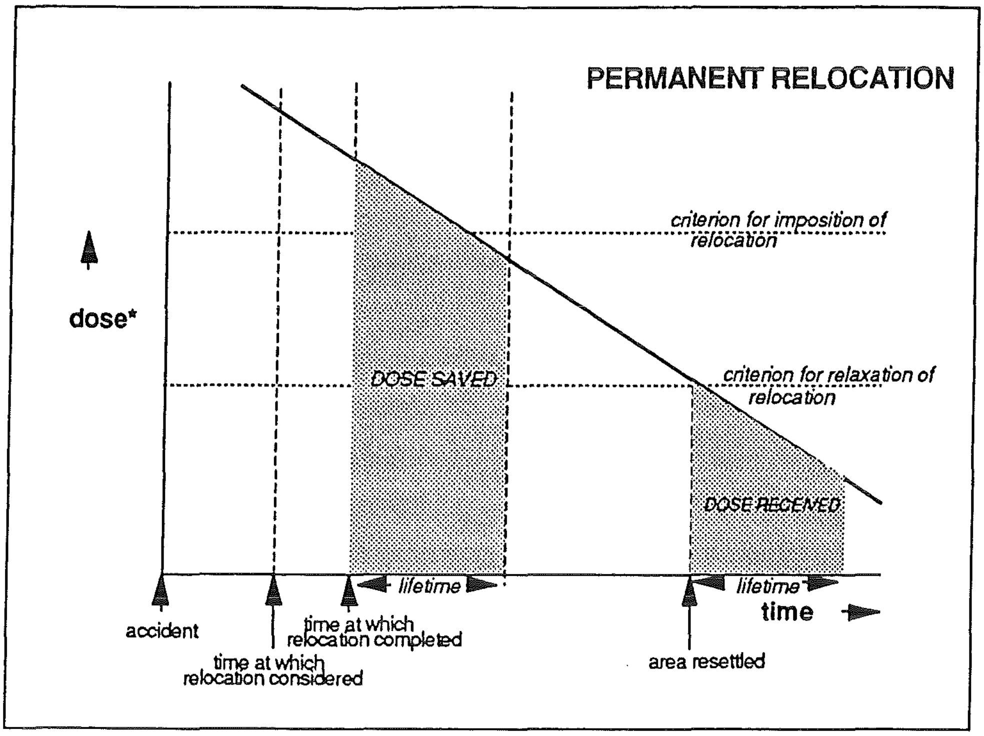


Fig. 17: Modelling of permanent relocation

Decontamination

Decontamination as a countermeasure is considered as a means to prevent or reduce the extent of relocation and as a countermeasure in its own right both to reduce doses due to external exposure from deposited material and to reduce ingestion doses.

The impact of decontamination is modelled using a dose reduction factor which is defined as the fraction that the dose received before decontamination is reduced by, for a given decontamination technique. This factor is used to modify all doses following decontamination. The reduction in individual dose achieved by decontamination depends upon a number of factors including: the decontamination technique employed; the nature of the area of land; the time following deposition that decontamination is carried out; the time following decontamination and the habits of the individual. A robust approach has been taken to the estimation of dose reduction factors in the current version of FRODO and no account is taken of the time dependence in dose reduction following decontamination and the different behaviour of individuals. A database of dose reduction factors has been developed in support of the modelling, this is described in section 3.2.2.5.

The impact of decontamination on relocation can be evaluated for decontamination occurring either before or after relocation is implemented. Figure 18 illustrates the calculation of the dose saved by temporary relocation and decontamination.

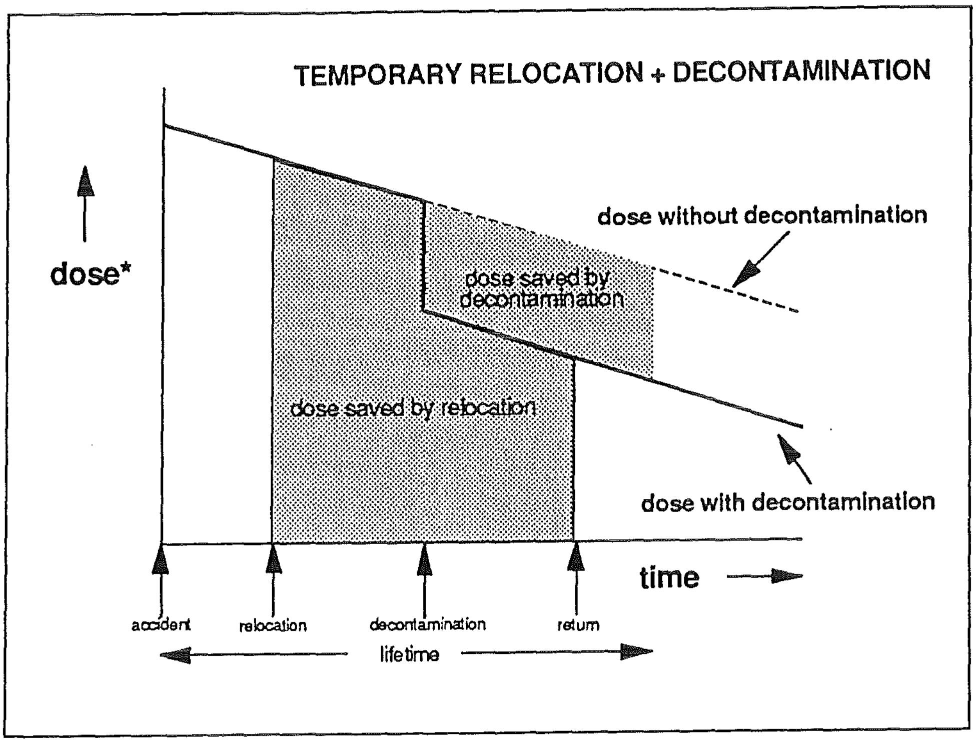


Fig. 18: Doses saved by decontaminating after temporary relocation

The decontamination of agricultural land is included in so far as its impact on the need for or reduction in food restrictions is evaluated. Decontamination of agricultural land by ploughing and soil removal is considered and the effectiveness of the techniques is assessed in terms of the reduction in activity concentrations found in food following decontamination. A database addressing the effectiveness of decontamination in reducing activity concentrations in crops has been developed in support of the model, this is described in section 3.2.2.5. In the current version of FRODO decontamination of agricultural land is not considered in conjunction with any other agricultural countermeasures.

Decontamination can be considered as a countermeasure on its own. The endpoints calculated are the doses saved by decontamination, the doses received following decontamination and the area of land decontaminated. More details of the modelling of decontamination are provided in /F1/.

Agricultural Countermeasures

Within FRODO endpoints related to the imposition of countermeasures on food are evaluated. The agricultural countermeasures considered are:

- banning and disposal

- food storage
- food processing
- supplementing animal feedstuffs with uncontaminated, lesser contaminated or different feedstuffs
- use of sorbents in animal feeds, or boli
- changes in crop variety and species grown
- amelioration of land
- change in land use.

The foodstuffs that each countermeasure can be applied to are given in Table 2. The effects of relocation and decontamination of agricultural land on the imposition of food restrictions are also considered, as described above.

The approach taken to modelling agricultural countermeasure is outlined in Figure 19. The aim of the module is to determine if there is a problem and, if there is, to evaluate the effectiveness of a number of countermeasure options to determine if the need for food restrictions can be avoided, or, if not, how the duration of the restrictions can be reduced. The criteria for banning the consumption of food are defined in terms of the activity concentrations in foods. As a default the European Commission maximum permitted levels in food are used although the user of the system can change the criteria. The activity concentrations in foods are compared with the criteria as a function of time, nuclide and spatial grid point to determine if a ban is required. If a ban is not required for any of the foods then no further agricultural countermeasures are considered. If food bans are implemented a number of countermeasure options are considered for each food. In the current version of RODOS, agricultural countermeasures are not combined other than with a food ban. If restrictions on food are still required following the implementation of a countermeasure option, the user of the system will be informed of this requirement and the length of the restriction that would still be required to reduce activity concentrations below the criteria for banning.

A brief description of the countermeasure options included is given below. In all cases where the timing of the implementation of an option or the duration of a given husbandry or farming practice is included this can be changed by the user of the system to look at a range of possible scenarios. A robust approach is taken in the modelling of the countermeasure options some of which become very complex if the full flexibility of user choice is implemented. This approach is consistent with the aim of the module which is to in provide information to enable an assessment of possible courses of action for removing the need for or mitigating food bans.

The banning of foods is linked with disposal and the stopping of food production depending on the duration of the ban.

Agricultural Countermeasure	Foodstuffs/Feedstuffs
Banning and disposal	33 foods (see reference 1)
Food storage	33 foods (see reference 1) Note: Assumed to be stored in processed form.
Food processing	Cow's milk, summer wheat, winter wheat Note: For other foods processing implicitly implies storage (see above).
Supplementing animal feedstuffs with uncontaminated, lesser contaminated or different feedstuffs	Cow's milk, beef (cow and bull), sheep milk, goat's milk, lamb, pork chicken, eggs
Use of sorbents in animal feeds, or boli	Cow's milk, beef (cow and bull), sheep milk, goat's milk, lamb, pork
Amelioration	Foodstuffs: Spring wheat, winter wheat, rye, oats, potatoes, leafy vegetables, root vegetables, fruit Feedstuffs: Grass/hay, maize, winter barley, winter wheat
Changes in crop variety and species	Leafy vegetables, root vegetables, winter wheat, spring wheat, potatoes, fruit
Change in land use	Not applicable. Note: Assumption is that land cannot be used for food production.

Table 2: Foodstuffs considered for each agricultural countermeasure

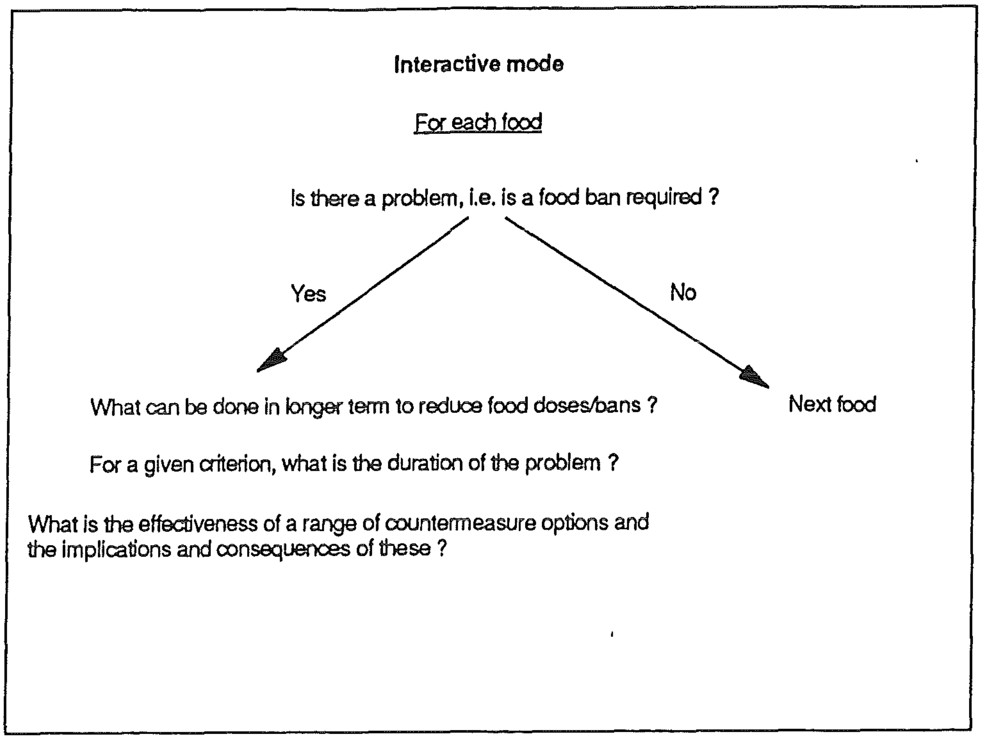


Fig. 19: Approach to modelling agricultural countermeasures

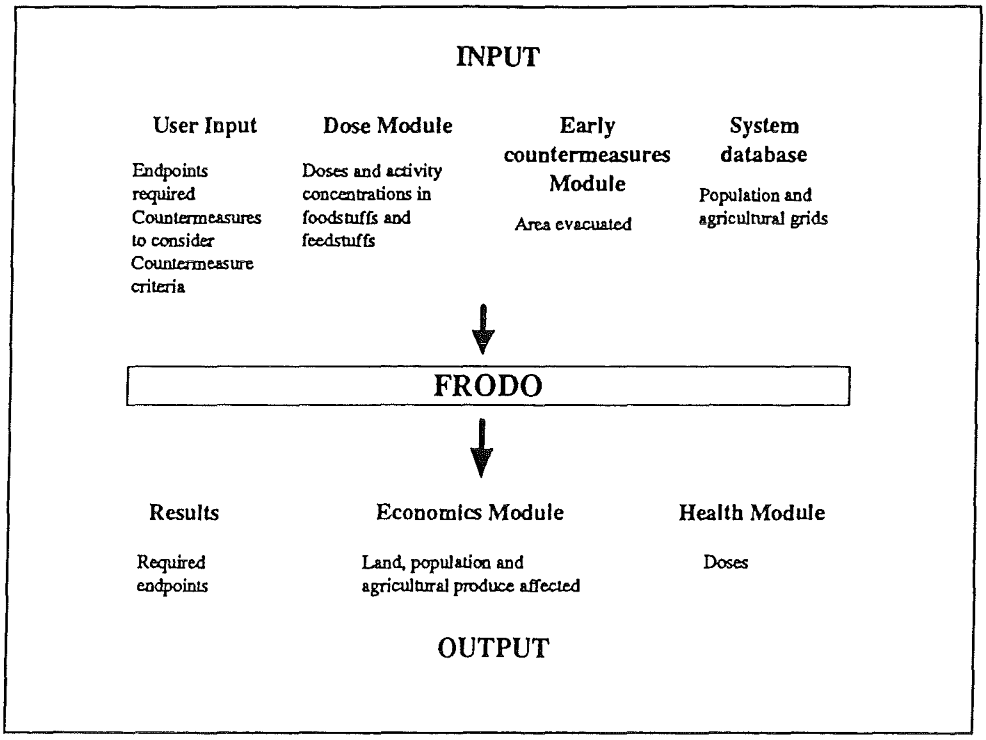


Fig. 20: FRODO Interfaces

Food processing and the storage of food are closely linked. The processing of fresh foods, eg milk, into a form that can be stored is considered only if a ban would not be required on the processed product. Storage is considered with or without processing for all foods. It is, however, only considered for a limited period of time to limit storage to lengths of time that are practicable in terms of the 'shelf life' of processed or fresh foods and so that in practice storage is only considered when the release comprises short-lived radionuclides.The removal of animals from contaminated feed is modelled. The effect of the time at which the animals are removed from contaminated feed and the duration 'clean' feed is given for can be evaluated. In addition a reduction in the amount of contaminated feed given can be considered.

Sorbents can be added to animal feedstuffs or directly to the animals gut in the form of boli. The effectiveness of the sorbent is modelled by reducing all activity concentrations in the animal by a factor for the period over which the sorbents are administered or, in the case of boli, for the period of efficacy in the gut.

The countermeasure of substituting different feedstuffs into animal diets is considered. The activity concentrations in the "new" diet are determined and the revised activity concentrations in the animal are calculated.

The treatment of soils to improve their quality, for example, the addition of fertilisers, and the subsequent reduction or otherwise of the uptake of radionuclides by plants is considered. This countermeasure is not considered until a minimum of 1 year after the accident in the current version of RODOS. Data for a range of techniques are utilised and are represented as a factor by which the activity concentrations in crops are reduced. The effect of repeated applications can be considered.

The change of the crop variety or crop species grown is included as a countermeasure. The assumption is made that this option would only be considered if the crop could not be grown on the land over a chosen time and that by growing another crop the activity concentrations could be reduced to below the criteria for banning.

The change of land use from agricultural production to forestry is considered. The criteria for this option is that the land can not produce food at activity concentrations below the banning criteria for a chosen period of time. In this case the land will be written off for food production.

A database of information on the effectiveness of the agricultural countermeasures has been compiled in support of the modelling, this is described in detail in section 3.2.2.5.

A wide range of endpoints are calculated. These include the individual and collective doses received following the implementation of agricultural countermeasures and the doses saved by implementing the countermeasure. The extent and duration of food restrictions are evaluated and additional information on the impact of the agricultural countermeasures is also calculated, for example, the numbers of animals affected, quantities of materials such as fertilisers and uncontaminated feedstuffs for animals required in order to estimate the economic cost of the countermeasures.

More details of the modelling and the endpoints evaluated are provided in /F1/.

3.2.2.3 FRODO structure

FRODO comprises a control submodule and submodules for relocation, decontamination and agricultural countermeasures. The purpose of the control submodule is to call the relevant subroutines within each of the other three submodules to perform the calculations which will produce the endpoints requested by the user. Each submodule consists of a set of subroutines, thus ensuring a flexible system for implementation within RODOS. More information on the detailed structure of the module is provided in /F1, F 2/

The input data required by FRODO and the output produced are described in general terms below. The data required and results generated for any particular run will depend upon the detailed requirements of the user. More information on input data requirements and output produced is given in /F1/. The FRODO module inputs and outputs are also presented in Figure 20.

Input

Input is required from the user defining the countermeasures to be considered and the implementation criteria to use. The user can also define the endpoints the module will calculate.

The primary data inputs to FRODO are: activity concentrations in foods and animal feedstuffs as a function of location, nuclide and time; doses without countermeasures from external irradiation from activity deposited on the ground, inhalation of resuspended activity, and ingestion of contaminated foodstuffs, as a function of location, nuclide, time and age group. These data are generated by the dose module ECOAMOR /F3, F4/ (see Section 3.1.4). In addition, databases on the effectiveness of decontamination and agricultural countermeasures in reducing doses and activity concentrations in foods, and gridded information on agricultural production and population sizes are required. If the user requires as an endpoint the number of people relocated following earlier evacuation then the area evacuated is required as input from the early countermeasures module (see Section 3.2.1).

Output

FRODO produces direct output which can be viewed by the user in the framework of the RODOS graphical user interface. FRODO also calculates endpoints which are used by further modules. Doses with countermeasures are required as input to the module which determines numbers of health effects (see Section 3.2.4). Numbers of people, areas of land, quantities of food banned and other factors which relate to the implementation of agricultural countermeasures, such as the quantity of sorbents required if this countermeasure is considered, are evaluated for input to the economics module of RODOS (see Section 3.2.3)

Interfaces

The exact form of the FRODO input and output interfaces with other RODOS modules were discussed and agreed with the developers of associated modules following various meetings. The interfaces are defined in /F1, F 2/.

3.2.2.4 Implementation of FRODO within RODOS

Several visits were made to FZK to assist in the implementation of various versions of FRODO within the RODOS system. These visits allowed problems to be identified and the links with the system to be refined. The final version of FRODO produced under this contract was successfully implemented in RODOS in summer 1995.

3.2.2.5 Databases

Agricultural countermeasures

A database of information on the effectiveness of the agricultural countermeasures has been compiled. FRODO utilises data provided by the foodchain model, ECOSYS, within the module ECOAMOR and a database of effectiveness factors. In addition supporting data are required to provide input for the economic costing of the countermeasure options.

The data in the database are largely based on a compilation of information from the Ukraine, Belarus and Russia on the effectiveness of agricultural countermeasures carried out following the Chernobyl accident. The work was carried out under the EC/CIS collaborative Joint Study Project (JSP1). Two reports have been written which contain the compiled data and supporting information/F5, F6/. Where data are available from the West these have been included either as supplementary data or to provide additional information. The database contains robust, representative data that can be applied to relatively large areas and potentially over long periods of time. Data at this level are applicable for use by people with responsibility for advising people who need to make policy decision. More detailed information on agricultural effectiveness has already been compiled under the JSP1 project. These detailed databases will enable the effect of local conditions to be taken into account and will provide data to enable problems on a local scale to be evaluated, eg on the level of advising local farming communities, as well as problems on a larger scale when more information on factors such as soil type are available. Databases of this type will be included in RODOS in the future.

A comprehensive database for use in RODOS should include information for a number of radionuclides. However, data available in the aftermath of the Chernobyl accident are predominantly for radiocaesium and a limited amount of data are available for strontium. The database reflects this situation.

As stated above the database uses data predominantly for the CIS. These data will not necessarily be applicable to the West where agricultural systems are very different. In particular, the fertility of the soil is, in general, much higher in the West. Cautions in the use of data are given in /F7/ for the various countermeasures considered, where appropriate.

The database is described in more detail in /F7/.

Decontamination

Decontamination dose reduction factors have been determined using the EXPURT urban dose model/F8/ developed for evaluating external doses from deposited material in urban areas. The effectiveness of a range of decontamination techniques which are feasible have been considered using current sources of data/F9, F10/. The dose reductions calculated for use in FRODO are based on the reduction in the dose integrated to 50 years. The techniques considered in the database are those that have been shown to be effective in reducing external doses, namely: grass cutting and collection, ploughing or rotovating or digging, removing soil to a depth of 5 cm, fire hosing metalled surfaces, vacuum sweeping metalled surfaces and planing metalled surfaces. As a default the combined strategy of grass cutting and either fire hosing or vacuum sweeping metalled surfaces has been considered. The time of implementation of decontamination has been chosen to be that when the optimum decontamination can be achieved for the particular surface, consistent with the decontamination factor chosen for the evaluation of dose reductions.

The effectiveness of decontamination in reducing activity concentrations in crops is determined from a review of available data, primarily from the states of the former Soviet Union and Europe following the Chernobyl accident/F5, F6/ and the use of a dynamic foodchain model, FARMLAND/F11/. A robust approach is taken consistent with the compilation of data from the former Soviet Union /F5, F6/ such that a single reduction factor is used for all crops following the decontamination of agricultural land.

The database is described in more detail in /F7/.

3.2.3 Health effects and economic consequences (FZK)

In the HEALTH part of RODOS, the numbers of people with deterministic and stochastic somatic effects are estimated. Up to version RODOS-PRTY 2.0 HEALTH is still an integral part of the module EMERSIM; the implementation as a module on its own will be realised in the next version.

Input to the health effects models are the organ dose fields calculated in the modules NOACDOS and ACDOS of EMERSIM (see Section 3.2.1) From these dose fileds, fields of individual risks are calculated. The numbers of people are calculated from the individual risk fields and the population data.

3.2.4.1 Deterministic effects

The version RODOS-PRTY 2.0 covers the following fatal and non-fatal deterministic health effects:

Fatal effects

- Haemotopoetic syndrome after irradiation of the red bone marrow.
- Pulmonary syndrome after irradiation of the lungs.
- Pre- and neonatal death after irradiation in utero.

Non-fatal effects

- Hypothyroidism from the internal irradiation of the thyroid following the inhalation of radioactive iodine.
- Mental retardation after irradiation in utero.

The risk of suffering from early effects is modelled using a "hazard function" approach, in which the doses which cause health effects in 50% of the exposed population are expressed as a function of dose rate /C8/.

The model in RODOS follows that described in /C9/, the parameter values used are taken from the version 93/1 of the probabilistic consequence assessment code COSYMA /C10/ and are based on extensive studies of the effects of radiation in both humans and animals /C8, C11/.

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

Output of HEALTH are the individual risk fields and the numbers of people affected for the different effects considered and the sum. It should be noted, that the input individual dose fields and the output individual risk fields refer to representative adult members of the population. For estimating the collective effects, it is assumed that the population consists entirely of adults.

3.2.4.2 Stochastic somatic health effects

In RODOS/RESY the overal number of fatal cancers in the affected population is calculated, but breakdown of different cancer types is made.

To obtain this number, the simplified approach is used to multiplify an average risk coefficient per unit effective dose for exhibiting a fatal cancer in an exposed representative population by the total collective dose in this population. In RODOS, a nominal fatality probability coefficient of $5 \cdot 10^{-2}$ Sv^{-1} is used, which is given in ICRP-60 /C12/ and applies to low doses at all dose rates and to high doses and low dose rates. The total collective effective dose is obtained by multiplication of the individual effective dose fields calculated in ACDOS or NOACDOS with the number of individual with the corresponding doses. The dose fields refer to representative adult individuals in the population, and in calculating the collective effects, it is assumed that the population consists entirely of adults.

3.2.4.3 The economic module ECONOM

In the ECONOM module various off-site consequences of the accident are assessed in the form of monetary costs; this procedure allows different effects to be expressed in the same terms and thus to make these effects comparable.

In the present version of the ECONOM module radiation-induced health effects and the consequences resulting from early evacuation of people are transferred into economic costs. The cost categories calculated in connection with health effects are: medical treatment costs and losses-to -society costs due to illness or premature death of people concerned. The cost categories calculated in connection with evacuation are: transport and accommodation costs due to the movement of people, and loss-of-income costs and costs of lost capital services due to the non-use of production facilities in the evacuated area.

Necessary input data to the ECONOM module are, on the one hand, population data and, if available, data describing the economic structure of the areas affected in terms of the number of employees in different economic sectors, and, on the other hand, specific unit cost data for the various costs categories. Data describing the impact of the accident consequences are the number of different health effects, and the number of people and the area affected by evacuation.

The modelling of the present ECONOM module is based on the corresponding economic module of the program package COSYMA for probabilistic assessments of accident consequences /C13, C14/.

3.3 Evaluation of countermeasure scenarios (UoL)

Much of the work reported here was carried out in conjunction with work undertaken under contract F13P-CT92-0013b. In particular, the HERESY software was written under that contract, as were prototypes of the coarse expert system.

Overview

The main task facing ESY modules is the evaluation of different countermeasure strategies such as issue of iodine tablets, sheltering, evacuation, food bans, decontamination measures and changes in the agriculture. Issues that should be considered during the evaluation stage are the practicability and cost of a countermeasure in the actual situation, public acceptability and behaviour, socio-psychological and political implications, and subjective preferences over the consequences of an action that decision makers may have. The ESY has as input the costs and benefits of possible countermeasures which were identified and quantified by the CSY subsystem. Rules, weights and preference functions are encoded in the esy and applied to a list of alternative countermeasures to provide a ranked short list to decision makers. Both the ASY and the CSY will use several models throughout the accident depending on the time, the location and the actual situation. However, the ESY may be based upon the same software module with different attribute trees and with the preference weights changing over time.

The subsystem will operate in interactive mode through graphical interfaces to communicate with a variety of decision makers who may posses: qualitatively different skills and perspectives such as scientists, medical personnel, engineers, emergency planners, government officials and senior politicians. It will present the countermeasures in a ranked short list together with those rules and preferences that determined the order of the list. Intuitive justifications for choices and underlying uncertainties inherent in the predictions will also be provided. The ESY will assist users in modifying rules, weights and preferences and other model parameters as well as indicating the consequences of each change. Thus, the user can verify and correct the existing model whereas the ESY explains and refines its proposed short list. The ESY will also operate in reporting mode in order to generate reports which will give a detailed commentary on each proposed countermeasure strategy, explaining its strengths and weaknesses. The above facilities will support the decision makers to lead up to a final choice.

The ESY will be split into 3 further subsystems:

A coarse expert system filter which rejects any strategies that are logically infeasible or do not satisfy some given constraints.

A multi-attribute utility theory (MAUT) ranking module which takes the remaining list of strategies as input. It ranks the strategies for their relative effectiveness according to previously elicited utility attributes and preference weights from the decision makers. It may be necessary to revise and re-evaluate these preference weights in any given situation before a particular decision is taken.

A fine expert system filter which takes the top 10-15 strategies and produces a management summary report detailing the costs and benefits of each.

The coarse expert system filter

Typically the region around a nuclear plant is notionally divided into small subregions for emergency planning purposes. A countermeasure strategy applies to a region and generally specifies different protective measures for each subregion depending on its level of contamination. It should be noted that the subregions will be defined after considering the particular geographic and demographic features of the region. For instance, a part only of a block of flats would never be evacuated because some arbitrarily drawn planning line divided it between two subregions.

Suppose that the number of subregions is N and the number of possible actions such as evacuation, sheltering and issue of iodine tablets is k. Then, the number of possible strategies is N^k: the number of strategies to be ranked grows combinatiorally. However, some constraints can reduce the number of alternative strategies considerably. They concern the feasibility of countermeasure strategies relating to national and international guidance on radiation protection, the practicability and the continuity of treatment that a strategy should exhibit.

The coarse expert system will discard strategies that do not satisfy these constraints. Thus, it will reduce the number of alternatives to be evaluated in manageable numbers. Infeasible strategies such as the issue of iodine tablets in an area which has been already evacuated should not be considered at later stages. Capacity constraints concern the number of available resources and equipment for decontamination measures like the transformation of contaminated milk to butter. For instance, factories that produce butter in a contaminated area may not be sufficient. This makes the countermeasure of converting all the milk to butter infeasible.

National and intervention guidance in the form of intervention levels result in additional constraints. The guidance is typically given in terms of upper and lower levels. A countermeasure is not advised if the contamination is below the lower level and expected if it is above the upper level. Between the two levels the decision is left to the discretion of the emergency managers. However, if the contamination in an area is above the upper level then only the countermeasures that can reduce the amount of contamination to a level below the upper one should be accepted. The remaining countermeasures should be rejected. Another complicating factor is the fact that different national intervention levels may exist. It has also been suggested that political pressures are such that it may be expected to adopt the countermeasures as soon as the lower level is exceeded.

The strategies must exhibit a continuity of treatment. For instance, the public would not understand nor accept the evacuation of only part of a village. A more specific example might occur in the areas adjacent to the plant. Suppose the meteorological conditions are such that the plume rises steeply in the vicinity of the plant and does not contaminate the areas close to the plant. However, some distance away the radiation exceeds the upper permissible level. Then a plausible strategy might suggest sheltering near the plant and evacuation far away. Nevertheless the public are unlikely to understand or to accept this advice. Any strategy would be acceptable only if the same treatment such as evacuation was applied to the region extending from the plant until far enough downwind where the expected dose was sufficiently small to be negligible.

Countermeasure strategies should provide equitable treatment of different population groups. However, when risk is involved the evaluation of different strategies is not straightforward. This is because reasonable approaches may have unreasonable effects. Suppose that there are two villages near a nuclear plant which have similar demographic and economic characteristics. An accidental release is expected to take place either in 1 or 3 hours time. Both villages will be put in risk from equal collective doses. There are enough buses to evacuate only one of the villages within one hour. If the accident occurs in three hours time, buses can come back to evacuate the other village. However, both strategies which evacuate only one of the villages should not be accepted because they do not treat equally all the villagers. Decisions makers would prefer another strategy which would evacuate half the population in each village despite the fact that it averts no more collective dose than the previous ones.

The MAV/UT ranking module

After discarding strategies in the coarse expert system filter, the remaining strategies will be passed to a multi-attribute value ranking module. This module will identify the top 10 or 20 ranking strategies. The operator will be able to use interactive sensitivity analysis to confirm that these strategies are worthy of careful consideration.

A prototype of the MAV ranking module, Heresy, has been written at Leeds (under contract F13P-CT92-0013b). The screen is divided into three areas. At the top the attribute hierarchy is shown. In the middle a histogram shows the overall scores (values) of the top ten strategies. At the bottom, a histogram shows the current weights w_i on the attributes. Not all w_i need to be shown at the same time. There may be cognitive advantages in concentrating attention on particular branches within the attribute hierarchy. All bars on the histogram are labelled appropriately.

The user selects a weight with a mouse by clicking on the appropriate bar in the bottom histogram. Then, she increases or decreases the weight either by the keyboard or by pulling with a mouse. As the weight is changed, the middle histogram changes accordingly. When either a change in the ranking of the top strategies occurs or one strategy drops out of the top ten and another one enters, the histogram would rearrange itself. The machine also beeps and informs the user of the change in a text window. This means that the user can identify the sensitivity of the ranking to the default weights in the model.

The computational speed of the prototype confirms that the identification of the top 50 ranking strategies of about 10000 countermeasure strategies and associated sensitivity analysis can be performed in a matter of seconds on a Silicon Graphics Indigo R3000. This machine is less powerful than the Hewlet Packard workstation planned as the support machine for RODOS.

At present, Heresy evaluates alternatives by using a multi-attribute value (MAV) function. This does not explicitly allow for risk attitude. However, a modification which would enable the use of exponential multi-attribute utility (MAU) functions is needed. This is because exponential MAU functions capture gross effects from risk aversion and are simple to elicit, explain and work with, even though they may require considerable computation. Thus, Heresy's interface can be modified to have a further window in which a single risk attitude parameter can be varied and the effect investigated.

The fine expert system filter

The MAV/UT ranking module identifies the top strategies and confirms that they are worthy of careful consideration. These strategies will then be passed on to a fine expert system filter. This is a much finer and more sophisticated system of rules which can be applied to each of the candidate strategies. The small number of strategies allows a full set of explanations to be developed, which give a critique of each strategy. This system will be prototyped and implemented in the next round of development.

Support for software development methodologies

Some work has begun on quality issues in the design and development of RODOS. Most software development technologies which seek to ensure quality in the resulting software have been designed for tightly knit development teams. The RODOS consortia are distributed widely over Europe and come from a variety of organisations. Many developers come from a research not an engineering background and are relatively untrained in quality software engineering. We have begun to look at these issues in some detail and are looking to develop some simple tools which will help the RODOS contractors build a more quality assured system /E4/.

In addition, some work has been undertaken on temporal databases /E13/. This has informed thinking about the software architecture of RODOS and the concept in the temporal control subsystem /E7/.

3.4 Treatment of uncertainties (UoL)

Overview

Leeds/Warwick have co-ordinated a small subgroup of the RODOS contractors to discuss and agree methodologies for assimilating data and handling uncertainty within the system. Building upon the work of this group, a conceptual framework for consistent handling of uncertainty and data assimilation throughout RODOS has been developed /E7, E12/. This framework is to be adopted in future versions of the RODOS system. One essential point is that, because different methodologies for handling uncertainty require different inputs and give different outputs, the choice of methodology cannot be made by the designers of individual submodules without consultation of those writing other interfacing submodules. All submodules must ensure compatibility with those submodules with which they interact. To achieve this, a fully Bayesian decision analytic approach is adopted.

Concerns and Issues

A great deal of uncertainty is inherent in emergency situations which cannot be ignored. Uncertainty handling techniques are being incorporated into RODOS to address the following requirements and issues:

Source term. Uncertainty arises from the incomplete specification of its composition, its time behaviour and its release co-ordinates and effective height.

Radiation monitoring data. These are used to locate the spread of the radiation. Observation errors (human or physical measurement errors) may occur. Local geographic errors and wind patterns result in heterogeneity of the contamination which makes the collected monitoring data less informative.

Weather conditions. Weather forecasting is unreliable. Wind fields, used as an input to the system, are interpolated from meteorological station data which may result in additional errors. Local wind fields, precipitation and stability class can also cause problems.

Expert judgement. Some of the inputs to RODOS such as source term, dispersion characteristics and deposition coefficients are likely to be derived by expert judgement. These estimates involve uncertainty and are subject to calibration and bias effects. Consequently, they have different and less clear characteristics to estimates derived from physical measurements.

Model uncertainty. RODOS is built upon a variety of models. However, models can only be considered as approximations to real world processes. For this reason, they should be tracked and checked.

Implementing countermeasures. The implementation of countermeasures or public compliance may not be satisfactory. Thus, uncertainty is associated with the effectiveness of the proposed countermeasures which is termed as volitional uncertainty.

Attitude to risk. The interplay of equity and risk in the evaluation of different strategies is far from straightforward. Societal attitude to risk involves difficult issues such as that of equity and fairness.

Coherence between modules. RODOS is built upon a client/server architecture which facilitates the exchange of information between modules. The design of conceptual tools to handle and represent uncertainty in one module should consider the needs of the other models. Handling uncertainty within a common framework throughout RODOS is important because it influences the overall quality of the decisions taken.

Feasibility of the methods involved. The methods of handling uncertainty should be verified in order to make sure that they result in a computationally feasible solution. If computational approximations are used they should be assessed.

Communicating uncertainty. Uncertainty should be presented in a number of ways for effective communication with the user. The RODOS system will be used in interactive mode to provide facilities for generating intuitive justifications for choices and for assisting users in modifying model parameters.

Decision makers' value systems. These are their interpretation of the preferences and values of the society which they represent. Such value systems are seldom fully defined. In any particular context, decision makers need to think through and refine their value systems. This need can make them feel uncertainty with regard to their beliefs. This uncertainty though is different from that relating to physical quantities. RODOS will help decision makers resolve any lack of clarity in their understanding of the value systems.

3.5 The Software Framework of RODOS (FZK)

3.5.1 The Modular Design

The RODOS system is based on the Client-Server principle. It is built of modules, which are connected via a Communication Interface. Each of these modules can either be a

- Server, which provides special services to other modules, or a
- Client, which requests services from other modules, or both. Well defined data structures allow the exchange of data between the client and the server.

This modular design is the key feature of the RODOS system. It allows the easy extension of the system by adding new modules for special applications and the flexible control of the calculations. All program control, data management, input and output is done by the appropriate modules of the Operating Subsystem OSY(c.f. Figure 21). The task of the modules of the Analysing, Countermeasure and Evaluation Subsystems is just performing the model calculations for providing the required results.

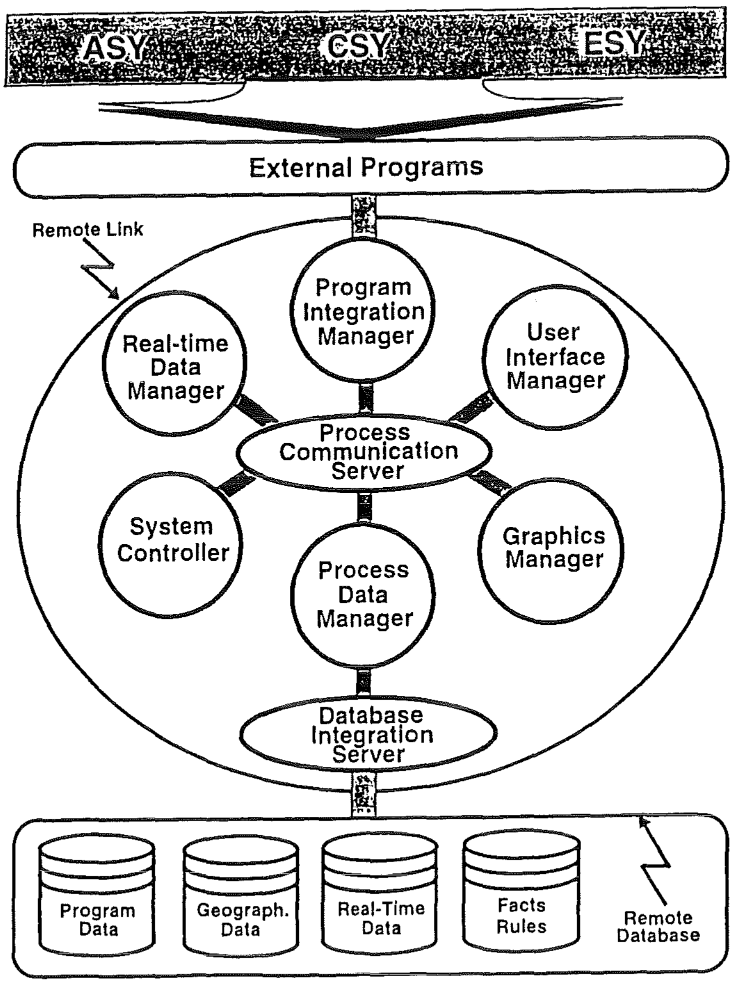


Fig. 21: Modular design of the operating subsystem OSY

The following sections give a brief overview of some of the modules of the Operating Subsystem OSY.

3.5.2 Interactive and Automatic Modes of Operation

Executing an application within the RODOS system requires mainly these steps to be taken:

1. Making available the necessary input data.
2. Executing the program.
3. Visualising the results.

Depending on the systems program, the first item comprises the provision of data for processing in the programs executing the algorithms of the computer models describing radiological events (ASY); the defined types of measures, action criteria, and factors for processing in the programs executing the algorithms for simulation and analysis of protective actions and countermeasures (CSY); the defined facts, rules, evaluation criteria, weights, and preferences for processing in the programs executing the algorithms of the methods for decision making and sensitivity analysis (ESY).

These steps are simultaneously supported by these activities:

- Preparation and generation of the user interface objects for the respective programs (Windows, menus).
- Preparation and generation of the numerical and graphic, respectively, representations of results from the respective programs.
- Management of, and response to, exceptional situations which may be initiated by an interruption caused by a user through the user interface (such as operation of the menu key: stop system), or by an event in measured data processing components via the message transfer in the system (such as a measured value exceeding a set quantity), or by a message from a message sending point through a link (such as reports about traffic congestions in an evacuation area).

In the interactive mode, communication between the user of the system and RODOS passes through a menu interface. Special problems can be formulated for answering by the system; input data and parameter values can be changed, and the output and representation of the results can be varied. Processing units (computer programs) of the system capture, check, transform, select, and represent on the screen the information from various resources. This mode is a straightforward dialogue mode presupposing knowledge both of the way in which the software modules are handled and of the factual contents of all components in the RODOS system. Sessions in the interactive mode take a long time and are more suitable for calculations and analyses of results and data in the medium and later phases of an emergency situation.

In contrast, relevant information in the early phase of a nuclear accident must be acquired and evaluated quickly and in a manner coordinated in time so that the necessary decisions can be taken.

For this purpose, the automatic mode is implemented in the RODOS system. It is characterised by the cyclic execution by a number of programs whose control sequence is predefined by a processing logic. The processing sequence can be modified by an authorised user via the control interface (query, stop, replace, continue). Cyclic processing is carried out in analogy with the real-time systems of the nuclear power plant remote monitoring system which monitor the operating and environmental status of plants in a quasi-continuous (time-discrete) mode.

Automatic operation comprises these steps, which are carried out automatically:

1. Setting up a configuration list of the computer programs involved.

2. Gathering and preparing the measured data, applying the predefined test criteria to measured data, and providing all the necessary predefined input data.

3. Executing the programs.

4. Peparing the data resulting from these programs.

5. Indicating a subset of these resulting data (the balance of the data will be kept in the background and may be displayed on request).

6. Repeating these steps at predefined time intervals.

3.5.3 Selected Modules of the Operating System

The Message Interface and Communication Server

The draft software is based on the communication and cooperation of a set of autonomous program units designed to offer a variety of services.

The OSY programs together with the external progams constitute a set of cooperating processes jointly executing the operations necessary to achieve the desired endpoints. From the point of view of the client-server model (the standard model for network applications), one process offers services (the server process) which are used by other processes (client process). The processes communicate with each other via the Communication Server by exchanging messages. The Communication Server has the functions of establishing the connections of a communication channel with the respective process through the local network, receiving messages from that process, and transmitting messages to it. In other words, the Communication Server acts as a central mediator of all messages for the processes involved in the system (see Fig. 22).

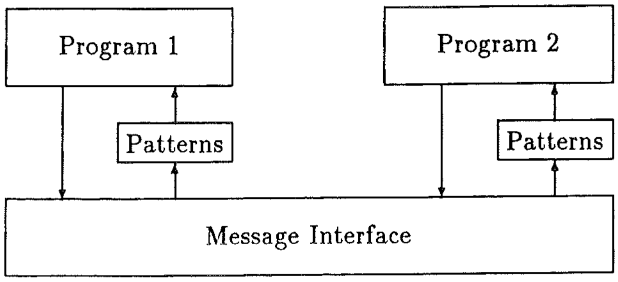


Fig. 22: Message interface of the RODOS System

The type and structure of a message is defined in the RODOS system uniformly. The messages contain fields which define the type, sender and recipient of the message. Three types of messages are considered by the Communication Server:

- Requests are send to other modules to ask for special services.
- Notification is send back by the recipient if the request was successfully completed.
- Failures are send back if some error occurred during the service.
- On startup, each module sends a message to the Communication Server, telling it the message patterns which should be send to this module.

Accordingly, all processes offering any services have a standardised program structure. Each program is made up of a communication segment, control flow segment, and local service segment. The communication segment uses the OSY message protocol and specifies the entire communication by way of the functions made available by the Communication Server. This is to say that the services rendered by other processes can be used if they are specified precisely in a message, and if the message is dispatched to the Communication Server.

Dialogue System

The dialogue system manages the user interface, monitors the subsystems, and controls the entire sequence of events in the RODOS/RESY system. Operationally, it is made up of the Resource Manager, System Controller, and Graphics System.

The Resource Manager supports these functions:

- It makes available the graphic user interface.

- It indicates standard information, such as the systems time, cycle time, process status, events, etc.
- It provides access to program interfaces, such as start, stop, hold, graphics, etc.
- It activates transfer operations, such as editors, data transfer lists, representations of results, etc.

The System Controller has these functions:

- Multiple (cyclic) or once-only sequencing control of the program groups.
- Management of memory access to program groups and programs.
- Initialisation of the OSY environment.
- Functioal checks of the OSY processes.
- Functional checks of the active program groups.
- Coordination of tasks.
- Assignment of tasks to memory segments.
- Treatment of all global events.

The Graphics System

The Graphics System must handle all graphics output from various modules of the system. A special graphics program for each module could not be the solution to this problem. It is better to have a universal graphics program, which can handle a large set of graphical output using a well defined data exchange format.

As an additional feature, it should be possible to use part sof the Graphics System to create a graphical user interface for programs outside of the RODOS system.

The main design aspects of the Graphics System are:

- Handling of graphics output from various external programs.
- Providing the main functionality of graphics programs, e.g zooming, scrolling, modification of graphics objects.
- Modular design to cope with different applications.
- Access to the functionality via a graphical user interface and a message interface.
- Providing functions to build graphical user interfaces for stand-alone programs.

The requirements for the Graphics System of RODOS led to a modular design. It is divided into three parts:

Graphics Interface Toolbox is a set of functions, which allow the construction of graphics programs and user interfaces.

Graphics Server	is a special graphics program designed for the needs of the RODOS system.
Graphics Manager	is the interface between the the Graphics Server and the RODOS system (mainly the Database Manager).

Each of the above parts uses the features of the previous parts. Graphics Server and Graphics Manager are independant programs, which communicate via a message interface. The user can select its configuration or create a new one using the above parts. Using this modular design, the Graphics System fits different requirements.

The Graphics Interface Toolbox

contains all functions needed to create a graphics user interface. This user interface can handle graphics output as well as menus to control program execution.

The Graphics Server

is a graphics program and user interface. It handles the graphics output, such as displaying results on geographical maps, histograms or function plots. A user interface gives the user the possibility to interact with the Graphics Server (e.g. zoom the output, modify graphics objects).

The basic features of the Graphics Server are:

- A graphical user interface allows the user to control the Graphics Server.
- A message interface is used to parse messages from external programs.
- The picture is handled as a set of graphics objects, which are collected in layers.
- The user can zoom and scroll the picture. Objects can be selected.
- Basic drawing capabilities for the input and modification of graphics data are available.
- A well defined interface is used to send graphics data from different applications to the Graphics Server.

In a complex system - e.g. RODOS - more than one Graphics Server can be run. This allows users to work with the graphics data from the external programs in RODOS on different screens.

The Graphics Manager

acts as an interface between external programs and the Graphics Server. The main task are

- Transformation of graphics requests from external programs to commands for the Graphics Server.
- Handling of graphics data from several external programs.
- Control of several Graphics Servers in the system.
- Transformation of graphics data to the data interface of the Graphics Server.

There exist several instances of the Graphics Manager. They are customised to

- handle the communication with the Database Manager of RODOS or
- select graphics output directly from the shared memory of external programs.

Both programs - the Graphics Server and the Graphics Manager - can be connected to other programs via the Message Server of RODOS . These programs which use the capabilities of the RODOS message server can access the functionality of the Graphics System or the Graphics Manager by sending requests to these programs.

The Database Manager

A basic feature of the RODOS system is the centralised management of data by a Database Manager. It has to cope with different kinds of information, such as

- program parameters,
- geographical and statistical data,
- on-line measurement data,
- forecast weather data,
- result data from external programs.

The data have to be kept in some databases, send to the programs on request and archived after calculations.

The Data Manager serves for the logical and physical data transfer among all RODOS processes. They cooperate closely with each other. Data transfer comprises these functions:·

- Archiving in the database of the data from memory segments.
- Loading the data from the database in a memory segment.
- Copying the data between memory segments.

The Data Manager analyses the incoming message, selects the appropriate record structure from the database tables, determines the memory address, and passes the information to the File Manager.

The File Manager, acting as an interface with the database, executes these functions:

- Management of the stored data in the database.
- Execution of access operations to the database.
- Execution of selection operations from the database.

The editor offers a Window-oriented user interface supporting users in the definition and description of input and output data.

In accordance with the use of different OSY data structures, the user interface is equipped with various menu and editing sectors and, as a consequence, can be operated easily and in a function-oriented way.

3.5.4 Integration of new Modules and Model Chains

The modular structure of the RODOS system and the Client-Server principle allows the integration of new modules in the system. Because the program control, data management, user input and graphical output is entirely handled by the Operating Subsystem OSY, the model developer can concentrate on the contents of his model. A further advantage of the use of RODOS to develop a new model is the possibility to test it in connection with other - already verified - modules of the model chain.

Adding new modules to the RODOS system is done in several steps:

- Define the services which are provided by the new module (e.g. calculation of organ doses).
- Enter information needed for the program flow into the database (e.g. input data needed by the module, data produced by the module). This will allow the System Controller and the Supervising Subsystem to integrate the module into the program flow.
- Define the input and output data structures of the module.
- Enter the above definitions into the program database of RODOS. This is needed by the Database Manager for the exchange of data.
- Code the module, using a template for the message interface.
- Test the module in the RODOS system.

The integration of already existing stand-alone programs into the RODOS system is done in a similar way. Normally, such a program defines a whole model chain. It is therefore split into its modules, which are integrated into RODOS as described below.

- Define the modules of the program and their interaction.
- For each module, perform the above steps for their integration.
- Enter the model chain into the database. This is done by defining the starting point and each calculation step based on the data flow of the model chain (e.g. start with meteorological data, calculate activity concentrations, calculate potential doses)

3.5.5 The Databases of RODOS

Systems like RODOS have to manage, process and evaluate a large amount of data of different kinds and quantity, such as geographical, meteorological, radiological and economic data, messages, criteria, statistics, and expert knowledge (facts, rules, preferences). They may be stored in different data bases and computers with their own data structures and formats. In addition, the concept of developing RODOS distinguishes a stepwise progress with versions of improving functionality and for applications with differing complexity. Therefore, it is impossible to realise from the beginning a data bank for all applications and data-specific aspects.

This led to the concept of a distributed data base allowing for a decentralised data management and the parallel execution of multiple task operations. A corresponding Database Interface Manager program transforms the different data formats in the format of the RODOS operating system and converts the system queries by means of the embedded SQL-interface, and thus increase the flexibility and efficiency of data access.

The data base of RODOS is designed as a distributed data base, which comprises special data bases for geographical information, real-time on-line monitoring data, program data and decision supporting rules (see Figure 23).

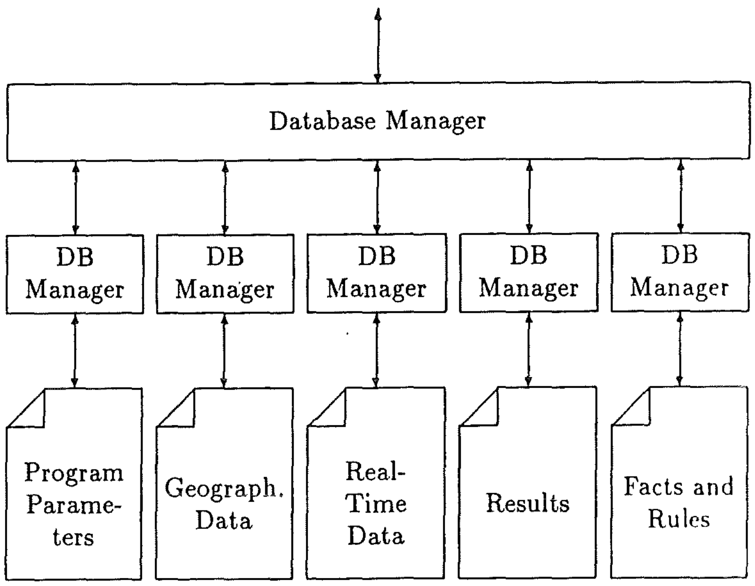


Fig. 23: Structure of the RODOS distributed data base

The program data base contains parameters and results of the application software implemented in RODOS . The real-time database will comprise all kinds of environmental monitoring data and measurements. The information in the rules database consists of expert judgment, facts, rules and preferences required for both evaluating alternative countermeasure combinations and controlling the user interaction and program flow in RODOS .

Each of the data bases of the RODOS system will be a stand-alone data base system, which has its own interface. A Database Interface Manager will give the programs of the RODOS system access to the data stored in these data bases with a unique interface format. The Interface Manager Program will convert the requests from the programs into a request to the appropriate data base. It will enable multiple clients to access multiple database servers. The Database Interface Manager will also facilitate access to external databases, such as the REM data bank of the ECURIE system maintained by JRC Ispra.

Program Data

Program data is a term characterising the data of an external program which are both processed internally and used outside the program (e.g., for transfer to another external program, for representation and visualisation, for storing the data in the OSY database), and are also processed externally and used within the program (e.g., for accepting data from some other external program, for influencing a program run from the outside). An external program can claim the OSY services for the data defined in the program if, at the same time, they are defined and assigned by OSY means. In that case, these data are known outside the program in the system and are considered global data.

The OSY system provides a working environment which manages and executes the communication between the programs and supplies data to the programs. It follows from the concept of the program architecture that, in addition to messages, there are local data objects which are processed by functional units of a program. The local data, or parts of the local data of a program, are characterised as program data if programs are supplied by the OSY system. The program data are organised in data blocks made up of a set of arranged data objects. This memory arrangement reflects the definition structure of global data and, hence, the local data definition in a program.

For transfers of the data for the respective submodule of a program, a logical memory image is construed in the database of OSY, which represents an unequivocal access structure of the working memory of the associated program.

To supply global data to programs, these activities must be carried out:

- Modelling data structures with respect to data availability in the RODOS system.

- Modelling data structures with respect to data use in the RODOS system.

The Real-Time Database and On-Line Connections

Main purpose of the Real Time Data Base is the collection, preprocessing and storage of real time data coming from on-line measurements. Its main tasks are

- handle the connection to the networks,
- preprocess the incomming data (handling various data formats),
- validation and quality assurance of the data,
- storage and retrival of data,
- backup of the data.

A preprocessor, which is located on a separate computer will handle the communication with the network. It will parse the incoming messages, do some preprocessing and validation on the data and transfer it to the Real-Time Database of the RODOS system. This preprocessor can be adapted to various networks and communication protocols.

RODOS will be coupled to on-line information networks. Figure 24 gives an example of such a connection in Germany with the nuclear reactor remote monitoring systems (KFÜ) of a German federal state and the integrated measurement system IMIS of the Federal Republic of Germany. The data will be delivered in 10 min (KFÜ) or 3 hours (IMIS) intervals via ISDN. The proposed data structure for this transfer is the ASCII-message structure of the IMIS system.

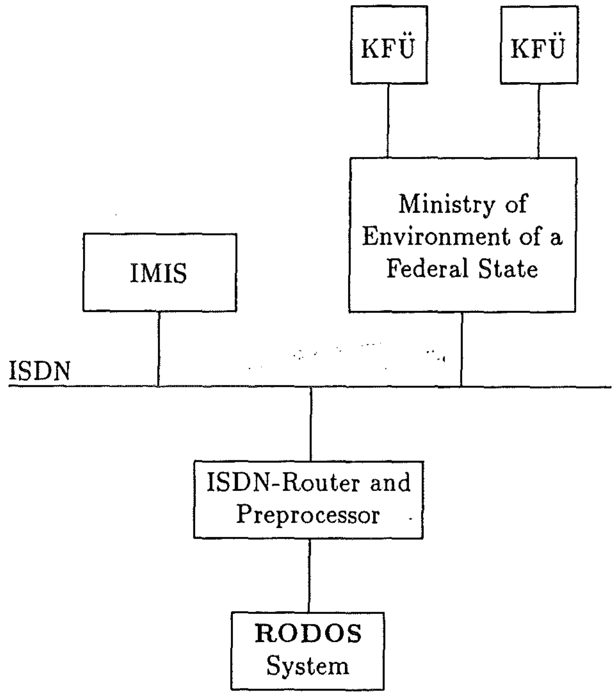


Fig. 24: Example on-line connection of the RODOS System

3.4.5.2 The Geographical Database RoGIS

The **Geographical Information System** RoGIS builds a system for

- handling various geographical and statistical information,
- storing environmental and radiological data,
- organising the access and interchange of data with other environmental data bases.

These features will make RoGIS to an interface between the external programs of the RODOS system and the geographical and statistical information stored as well as to external data bases.

RoGIS is designed as a stand alone program package, which includes all necessary tools for organising the data base and for handling various sets of data. Its structure allows an easy integration of different kinds of data structures. As a part of the RoGIS system, an interface package will give external programs access to the data stored in RoGIS .

Another possible configuration of the RoGIS data base is the integration into the RODOS data base. In this case, the access to the data sets of RoGIS is controlled by the data base of RODOS . The close connection between the RODOS system and the RoGIS data base will help to install RoGIS at various sites. Main advantage of this will be the possibility of exchanging geographical and environmental data in an easy way, especially to allow radiological forecasts across boundaries.

Although there exist several so called geographical information systems with various applications, the RODOS developers have decided to create such a system of their own. This decision is a consequence of the main aim of the RODOS system, to be a transportable package running on various hardware platforms. The main advantage of RoGIS will be that it is adapted to the needs of RODOS with functionalities not provided by commercial systems . It will be available to other RODOS contractors with no licensing problems and no charge.

The Contents of the Geographical Database RoGIS

The geographical information system RoGIS is designed to hold various sets of information. Main feature of the record structure used in RoGIS is the ability to cope with different data structures. RoGIS is an open data base system, which means, that new hierarchical class structures to describe the information can be defined. Some of them are described here.

The Class **Administrative Data** and its subclasses hold statistical data for Administrative Objects (e.g. countries, cities). Geometrical objects linked to these Administrative Objects define the political and administrative border.

The Class **Nuclear Installation** and its subclasses are used to store information about different types of nuclear installations. Until now there is only one defined subclass for Nuclear Installation - Nuclear Power Plant (NPP). Geometrical object linked to these NPP objects are points which define the geographical coordinates for the object.

3.5.6 The RODOS prototype version PRTY2.0

In 1995, the prototype version PRTY2.0 of RODOS was finished. This version implements most of the features described in the previous sections. The Operating System OSY of the prototype version PRTY2.0 contains the following modules:

System Controller

Message Interface based on the UNIX Socket mechanism.

Graphics System consisting of the Graphics Server and the Graphics Manager.

Database Manager for program parameters and results.

Real-Time Database

Geographical Information System RoGIS

The Operating System OSY contains tools for integrating of new external programs and for defining of new model chains. It supports the interactive and automatic mode.

The software of the Operating System OSY has been developed on Workstations Hewlett Packard 9000/7xx. It uses the programming language C, the X11 Windows Release 5 and OSF/Motif 1.2 user interfaces and the Allbase/SQL database management system.

4. Application of RODOS in training courses on radiation protection (NE, EdF, SCK/CEN, FZK)

4.1 Overview

From the outset, the use of the RODOS system as a didactic tool for training and education in radiological protection and emergency response has been one of the objectives of the RODOS project. To investigate, plan and organize such RODOS applications, in autumn 1992 the Working Group (WG) "Training" was constituted with the following participants:

- Electricité de France (EdF), F: O. Marchand and S. Renier;
- Forschungszentrum Karlsruhe (FZK), Fortbildungszentrum für Technik und Umwelt (FTU), D: K. Burkart;
- Forschungszentrum Karlsruhe (FZK), Institut für Neutronenphysik und Reaktortechnik (INR), D: C. Steinhauer;
- Nuclear Electric (NE), UK: B. Bleasdale (until January 1994) and R.Fox (from February 1994);
- Studiecentrum voor Kernenergie / Centre d'Etude de l'Energie Nucleaire (SCK/CEN), B: A. Sohier.

The activities of the WG "Training" were co-ordinated by FZK/INR.

EdF, NE and SCK/CEN already were involved in courses where in principle RODOS could be utilized; they provided a respective compilation [RODOS(B)-TN(93)01, RODOS(B)-TN(93)02, RODOS(B)-TN(93)03], which was reviewed by the WG during the 1st meeting of the group in September 1992. This review showed that it would be rather difficult to modify or extend the examined courses in order to allow for the inclusion of RODOS. As a consequence, it was decided to design a new course with the intention to convey principles of radiation protection and off-site emergency response as well as to demonstrate the functionality and applicability of the RODOS system.

Following this decision, the general objectives for the envisaged course were laid down. Three basic objectives were identified:

- The transfer of knowledge should be selective and praxis oriented rather than broad and unspecific.
- The participants should actively exercise as much as possible by themselves rather than listening passively to frontal presentations.
- A demonstration of the role and usefulness of RODOS as a decision aiding and training tool should be intervoven with the course.

The target group should consist of individuals with a basic knowledge of radiation protection who wish to develop and/or improve their skills and competence in the area of off-site emergency response to nuclear accidents. The lecturers should be specialists in the respective teaching areas which have background knowledge about decision making and emergen- cy management.

Utilizing the experience especially of FZK/FTU and NE in a systematic approach to training, it was decided to design the course in a modular training package structure, specifying for each package the learning aims and the information that shall be transmitted in lectures and exercises in form of a syllabus. Eight modules were identified, and the main responsibility for the sections was split between the organizations in the following way:

1. Basis of intervention (FZK/FTU)

2. The on-line decision support system RODOS and its role in off-site emergency management (FZK/INR)

3. Source terms and accident scenarios (EdF)

4. Atmospheric dispersion and deposition (SCK/CEN; in co-coperation with EdF)

5. Exposure pathways and doses without countermeasures (FZK/INR)

6. Countermeasures and their benefits and disadvantages (NE)

7. Monitoring strategies (SCK/CEN; in co-operation with EdF)

8. Decision support techniques and uncertainties (FZK)

In 5 meetings of the WG between 1993 and April 1995, the learning aims and the scientific content of the lectures were defined (see Section 2.3) and the corresponding syllabus worked out. Finally, potential lecturers were identified and contacted.

With respect to the practical sessions it was decided that the partic- ipants shall address the topics covered in the lectures and collect and consolidate experience through the evaluation of a variety of accident scenarios, using RODOS as a tool to provide the technical input for the problems considered. RODOS will be operated by experienced course staff, so that the course participants do not require computer skills. Until June 1995, EdF, NE and SCK/CEN provided some potential accident scenarios, and a fragmentary draft of an exercise syllabus was produced by the group. The detailed preparation of the practical sessions, and in particular the definition and preparation of accident scenarios, will be carried out by FZK/INR and the RODOS team in the 2nd half of 1995 / beginning of 1996.

The course was given the name "Computer-Based Training Course on OFF-SITE EMERGENCY RESPONSE TO NUCLEAR ACCIDENTS". Because of the need for access to computer equipment and course staff, it was decided that the first course should best take place at FZK/FTU. FZK/FTU is responsible for the course logistics and technical organization. An application was made by FZK to include it in the European Radiation Protection Education and Training (ERPET) activity of the European Commission, which was granted by then end of 1994. The course is summarized below; further detail are given in the Technical Report of the Working Group.

4.2 Topics addressed

The course is concerned with the estimation and evaluation of the off- site radiological situation following a nuclear accident and how this can be managed through the timely and effective introduction of countermeasures. Particular attention is given to accidents in LWRs involving the release of radioactive material to the atmoshpere, although the principles addressed are applicable to all types of accident. The course focuses on the early phase of an accident and the emergency actions of sheltering, evacuation, distribution of stable iodine, and food- and feedstuff contamination.

Apart from the assessment of the radiological situation in the different stages of the accident, particular emphasis will be given to the problems involved in the judgement of the situation and of the radiological, economic and other consequences of intervention. The course will not address topics such as legal bases for emergency planning, emergency managment structures and procedures, and responsibilities for decision making, as these topics are largely country specific or even different within a federal state.

It is assumed that all quantities relevant for the discussions, which can be available (source term, air- or ground concentrations, radiation doses), are in fact available, either directly from measurements or from model predictions. In particular, the assessment of the source term is not addressed in detail. The course does not intend to train the participants in manual skills for the assessment of the radiological situation under various circumstances of missing information. This is thought to be an item to be covered in national courses for the corresponding personnel.

4.3 Practical sessions

The two special features of the course are the use of the real time on- line decision support system RODOS to complement both presentations and discussions, and the ample time foreseen for practical sessions. Such sessions will accompany the course modules concerned with atmospheric dispersion and deposition, exposure pathways/potential doses, and protective actions.

Illustrative scenarios (source terms, maps, weather sequences) will be pre-defined to cover a representative range of possible accident situations and typical consequences. The scenarios will be introduced in the lectures and used throughout the course in the lectures as well as in the exercises. Also provided will be a set of predefined problems which act as a starting point and focus for discussions. The participants can vary relevant parameters of the scenarios, make own observations about the influence on the accident consequences and discuss the possible implications on decisions about actions. A special "easy to use" interface will allow an uncomplicated and fast realisation of the selected options with RODOS.

Before each practical session, an introduction is given to the respec- tive models in RODOS, the corresponding data input and the available output. During the sessions, the actual operation of the system will be carried out by a person familiar with RODOS. The maximum number of participants that can reasonably work with one unit "terminal+operator" is about five. Given the hardware (two workstations with the possibility to operate three terminals on each) and skilled RODOS personnel available at FZK in 1995, maximally six working groups can be formed, which consist of up to five participants, one operator and one terminal, which allows a maximum number of 30 participants.

4.4 Course plan

1st day

LECTURE: Basis of intervention (Dr. K. Burkart, FZK/FTU, D). Topics:

Summary of dose concepts; summary of health effects due to exposure;

protective actions: classes, aims, features and bases of decision making; principles of intervention; introduction to optimisation; bases of decision making.

Discussions and exercises

LECTURE: RODOS and its role in off-site emergency management (Dr. J. Ehrhardt, FZK/INR, D). Topics: Overview of the RODOS project; overview of the RODOS system; RODOS in off-site emergency management.

Introduction to the practical sessions

DEMONSTRATION: RODOS - Main Windows and Geographical Information (RODOS team, FZK/INR).

2nd day

LECTURE: Source terms (Mr. D. Manesse, Commissariat a l'Energie Atomique, F). Topics: Source term characteristics relevant for radiological consequences; Illustration of the different source terms for a PWR; Importance of the availability of data defining the source term in the decision making process regarding the methods of assessment and their uncertainties; Accident Scenarios used in the course.

LECTURE: Atmospheric dispersion and deposition (Dr.T. Mikkelsen, RISØ. National Laboratory, DK). Topics: Basic phenomena in the lower atmosphere; overview of models for different scales; atmospheric dispersion / deposition and contamination patterns.

LECTURE: RODOS - Source terms and atmospheric dispersion and deposition (RODOS team).

PRACTICAL SESSION: Source terms and atmospheric dispersion and deposition.

3rd day

LECTURE: Exposure pathways and doses without countermeasures (Dr. H. Müller, GSF-Forschungszentrum für Umwelt und Gesundheit, D). Topics: Overview of exposure pathways; details of each exposure pathway (Calculation of doses, characteristic features of pathway; uncertainties); doses from natural and anthropogenic sources.

LECTURE: Countermeasures and their benefits and disadvantages (Mrs. M. Morrey, National Radiological Protection Board, UK). Topics: Total dose and dose averted; intervention levels; details of countermeasures (effect on exposure pathways, factors influencing the dose reduction, required resources, benefits, disadvantages); impact of conditions on determining intervention levels; impact of non-tangible effects on countermeasures.

LECTURE: RODOS - Exposure pathways and countermeasures (RODOS team).

PRACTICAL SESSION: Exposure pathways.

4th day

PRACTICAL SESSION: Countermeasures

LECTURE: Monitoring strategies (Dr. W. Weiss, Bundesamt für Strahlenschutz, D). Topics: Role of monitoring during the three time phases; objectives and strategies to meet the objectives during the release phase, including the technical link between monitoring and required data; overview of monitoring philosophy and implementation in European countries; principles and problems of source term estimation; considerations about uncertainty.

EXERCISE

5th day

Discussion of exercise

LECTURE: Decision support techniques and uncertainties (Prof. S. French, University of Leeds, UK).

Filling out of course evaluation forms

4.5 Outlook

Dependent on the response to the course, it may be repeated not only at FZK, but also in other institutions within the EC, Central and Eastern European countries and CIS republics, eventually in other languages than English. When the full RODOS system will be available, the course could be extended to cover in detail the longer-term countermeasures relocation and foodbans and their optimisation.

Besides this special training course for technical advisors of the emergency management, the future planning foresees the development of courses for the training of RODOS users and the preparation of exercises for emergency management staff.

5. Implementation of RODOS in Central and Eastern Europe

5.1 Implementation of RODOS in Poland (IAE)

5.1.1 Project definition, main goals and realisators

The NDSS-NE/RODOS Project has been defined and initiated by the NDSS-NE/RODOS Research Team in the Institute of Atomic Energy (IAE), Otwock-Swierk for the National Atomic Energy Agency (NAEA). Its main goal - as already reported during 4-th RODOS Contractors Meeting in Interlaken and in the Special Warsaw RODOS Seminar, 17 - 18 November 1994 - is to develop and implement the National Decision Support System for Nuclear Emergency Action after a nuclear accident in Europe (NDSS-NE).

This system is to be compatible with the RODOS system and worked out in close relation and cooperation with the institutes involved in the RODOS project. The Polish project is sponsored by the State Committee for Research, the National Atomic Energy Agency and the European Commission within the Programme "Cooperation in Science and Technology with the Central and European Countries" (PECO).

The project is to be seen not only as a research and development activity but also as an implementation and integration programme oriented to work out hardware and communication structures together with their technical realisations as well as with development of country specific software modules and databases. To secure the realisation of its goals the Project Task Force has had to be defined and created consisting of many cooperating institutions and scientists as well as technical staff. Those institutions and staff shall be in the future considered as a Technical Support Organization of the Project and shall back up the National Nuclear Emergency Center, which is to be developed and maintained by the National Atomic Energy Agency and other governmental institutions responsible for the emergency handling in the country. The creation of National Nuclear Emergency Center and its Technical Support Organization is in fact the main goal of the ongoing organisational and development efforts.

NDSS-NE/RODOS Project is worked out by the NDSS-NE/RODOS Task Force, constituted by the NDSS-NE/RODOS Research Team at the IAE and by many research and development groups located at various research institutions in Poland and abroad. The list of those institutions, where such groups were created or are under the process of creation looks as follows:

- Institute of Meteorology and Water Management (IMWM) responsible in the country for all services connected with weather parameters and forecasting,
- Central Hydrometeorological Bureau of Air Polish Forces (CHB), responsible for meteorological services for aviation purposes,
- Warsaw Technical University, Institute of Environment Engineering, engaged in development of national scale weather forecasting model and problems connected with industrial pollution,
- Mission Research Corporation (MRC) *ASTER Division, and Colorado State University (CSU), Fort Collins, USA engaged in regional weather forecasting system and at-

mospheric dispersion of toxic pollution (for example for Kennedy Space Center in Florida),

- Warsaw University, Institute of Geophysics, specializing in microphysics of atmosphere and precipitation problems,
- Central Laboratory for Radiological Protection (CLRP), engaged mainly in radiological monitoring data collection and dose assessment,
- Topographic Service, General Staff of Polish Army (TSPA), responsible for providing digital maps of various scales and information levels,
- Institute of Geodesy and Cartography (IGC), engaged in photogrammetry and remote sensing activities,
- State Inspectorate for Environmental Protection (SIEP), involved in the development of the Integrated Information System "Environment" for ecosystem studies.

Talks and discussions with other institutions about their participation in the project are going on or are planned to be arranged in the next future. Delineated programme requires efforts of many specialized institutions, planned and implemented in close cooperation and under careful coordination. The main actors of the NDSS-NE/RODOS Task Force and their contribution to the Project were presented during the Special RODOS Seminar, held in Warsaw 17-18 November, 1994.

The global goals set out in the Project require many man-years of efforts and shall be reviewed and reformulated according to the progress achieved and needs met in the process of realisation of the project. Experience and tools developed and tested during the activity of the Project can be applied not only in case of nulear emergency but also in the case of other emergencies connected with industrial as well as natural accidents and hazards, particularly those which affect larger territories and whose limitations or liquidations require using of distributed resources and careful planning and coordination. The basic requirements is here connected with the gathering of specific data in real-time, characteristic for the nature of accidents and hazards.

On 17-18 November 1995, IAE organised a Special RODOS Seminar in Warsaw. The objectives of this special seminar were:

- to present the background to, and overall objectives of, the RODOS Project to relevant decision makers and their technical staff in Poland and other Central and East European Countries (especially Baltic countries). Particular consideration was given to the development and practical implementation of RODOS as an aid to off-site emergency management in the event of any future accident in Europe and its potential use in National Emergency Centres,

- to enable Polish institutes (i.e. members of the NDSS-NE/RODOS Task Force) to inform representatives of the RODOS Management Group and other participants of the range of activities being carried out in Poland on off-site emergency response. This will facilitate future interaction between the Polish programme, the RODOS project and related developments in other East European countries,

- to discuss collaboration, at both technical and administrative levels, between the East European institutes involved in the RODOS project, in particular with a view to minimising the administrative burden on the overall project coordinator, FZK, and to make best use of the technical resources available within the project.

More than 70 representatives of Polish research and governmental institutions, contractors of the RODOS project from the countries of EU and Central and Eastern Europe took part in the seminar. The RODOS Management Group (RMG) was represented by Dr.G.N.Kelly from the European Commission and Dr. J. Ehrhardt, FZK. The Proceedings of the Special Warsaw RODOS Seminar, published by IAE, contain full material of the meeting.

5.1.2 The basic concepts and directions of the Polish approach

The fundamental assumption of the Polish Project is that the RODOS system shall constitute the software framework of the NDSS-NE. The RODOS Project shall provide the majority of required computational moduli applicable for nuclear emergencies in Europe, ranging from the vicinity of the release and early phases up to far distant areas and later stages of the accident.Transforming RODOS into NDSS-NE, which will operate in real time and on-line coupled with meteorological and radiological monitoring networks requires the modification of the current version of the RODOS software and/or extension according to the national needs, priorities, available computer capacities and organisational constraints. In particular there must be a sound relation between the available databases for radiological and meteorological information and the software of NDSS-NE. The question where data are located, where they are needed, when and how fast they can be sent, should be accounted for in the functional structure of the system and its communication capabilities.

The structure of the system should then account for existence of specialised centers, such as IMWM with responsibilities relative to meteorological fields diagnoses, world numerical forecasting distribution and regional forecasting services, CLRP dealing with measured monitoring data collection, their consistency revision and maintenance of central bases of such data, planned National Emergency Office embedded in NAEA, where projections of radiological situations and feasibility of countermeasures will be examined to work out ranked list of rational decisions and SIEP, where a dedicated integrated computer system "Environment" is being developed, with data banks of accumulated information for ecosystem studies and other centers dealing with land use, demography, health and environmental long term monitoring data.

The structure of the system must also take into account the existence and operation of research reactors MARIA and EVA in Otwock-Swierk, where the Local Swierk Emergency Center must contitute a subsystem of the future National Nuclear Emergency Center with all the organisational and communication requirements.

The fact that the actual version RODOS-PRTY 2.0 is still focussed on near range dispersion and evaluation calculations allows relatively fast and reliable implementation of those moduli for the Local Swierk Emergency Center applications.

Therefore for ensuring high operational performance of NDSS-NE and effective use of resources and technical capabilities of all cooperating institutions and the emergency center organisation and responsibility structure the system should be both distributed and functionally integrated, it means:

- operational system of NDSS-NE should account for a network of the NDSS-NE software kernels implemented along with a dedicated moduli in specialised centers, with the software kernel providing basic function of communication, process and data management and graphic user interface,
- adequate tasks scheduling among the centers of the network should be designed to avoid intercenter transmissions of huge amount of data produced during the intermediate steps of the analysis phase,
- it should be possible to access all the needed resources, which are located on different machines of the network, under different data base systems,
- an appropriate data transfer between computers should be reliable and fast enough,
- individual modules can be executed and maintained on different machines under the supervision of teams of dedicated specialists.

These goals shall be realised by the Heterogeneous Distributed Computer Environment (HEDICE) described in the paper presented at the Special Warsaw RODOS Seminar. The HEDICE allows to constitute an appropriate infrastructure for NDSS-NE, accounting for already existing and further planned development of:

- radiological monitoring and data collection system,
- specialised centers and their services (eg. for weather forecasting and pollutant dispersion predictions),
- bilateral and international cooperation on radiological data exchange.

The structure of HEDICE is an extension of the prototype RODOS version, which at present can work on a single HP workstation. A first attempt to implement RODOS in a heterogeneous-type environment will take place at the Institute of Atomic Energy on a coupled HP and Convex machines environment. Basic elements of this configuration are:

- Convex C3210 (50 Mflops), 7.2 GB disks capacities,
- HP 735 (40 Mflops), 4 GB disks capacities, both connected to LAN (standard Ethernet, allowing data transfer with the 10 Mbits/sec speed).

Finally the software of the distributed NDSS-NE will be developed for a computer network configuration with Convex C3210 and HP-735 computers located at IAE, Cray EL-98 at the Warsaw University, providing services for IMWM, Dec-workstations at CLRP and other RISC workstations of SIEP, all connected to Metropolitan Area Network of Warsaw (WARMAN) based on the ATM technology, allowing the data transfer with the speed of 155 Mbits/sec (see Fig. 25).

Some of the quoted computers may be meantime upgraded or substituted by clusters of workstations or mainframes with enhanced capabilities for parallel processing.

The notion of distributed computer environment and its implementation and testing constitutes interesting contribution to the RODOS project development and should simplify and assist in its practical implementation not only in Polish conditions. Elaborated concepts and implementation experience may be a basis of exchange and cooperation with other countries.

5.1.3 RODOS software experience, comments and development

Using funds from the PECO contract a HP-735 workstation was bought by IAE. Shortly before the Special Warsaw RODOS Seminar the RODOS-PRTY 1.2 version was installed.

Contribution to testing RODOS-PRTY 1.2

The following tests have been carried out by IAE:

a) for distributed computer environment:

- portability for Convex C3210 mainframe, concerning mainly interprocess communication mechanisms, particularly shared memory facilities, and X-Windows/OSF Motif graphics,
- transfer speed based on standard Ethernet line between Convex C3210, HP-735 and Silicon Graphics computers using Internet domain socket facility

b) for operation of RODOS system:

- using editors for integration of external programs,
- simulation of real-time mode of operation,
- graphic user interface,
- visualisation of results

All the results of these tests as well as comments aiming at improving the current RODOS version were delivered to developers of the generic software (Forschungszentrum Karlsruhe).

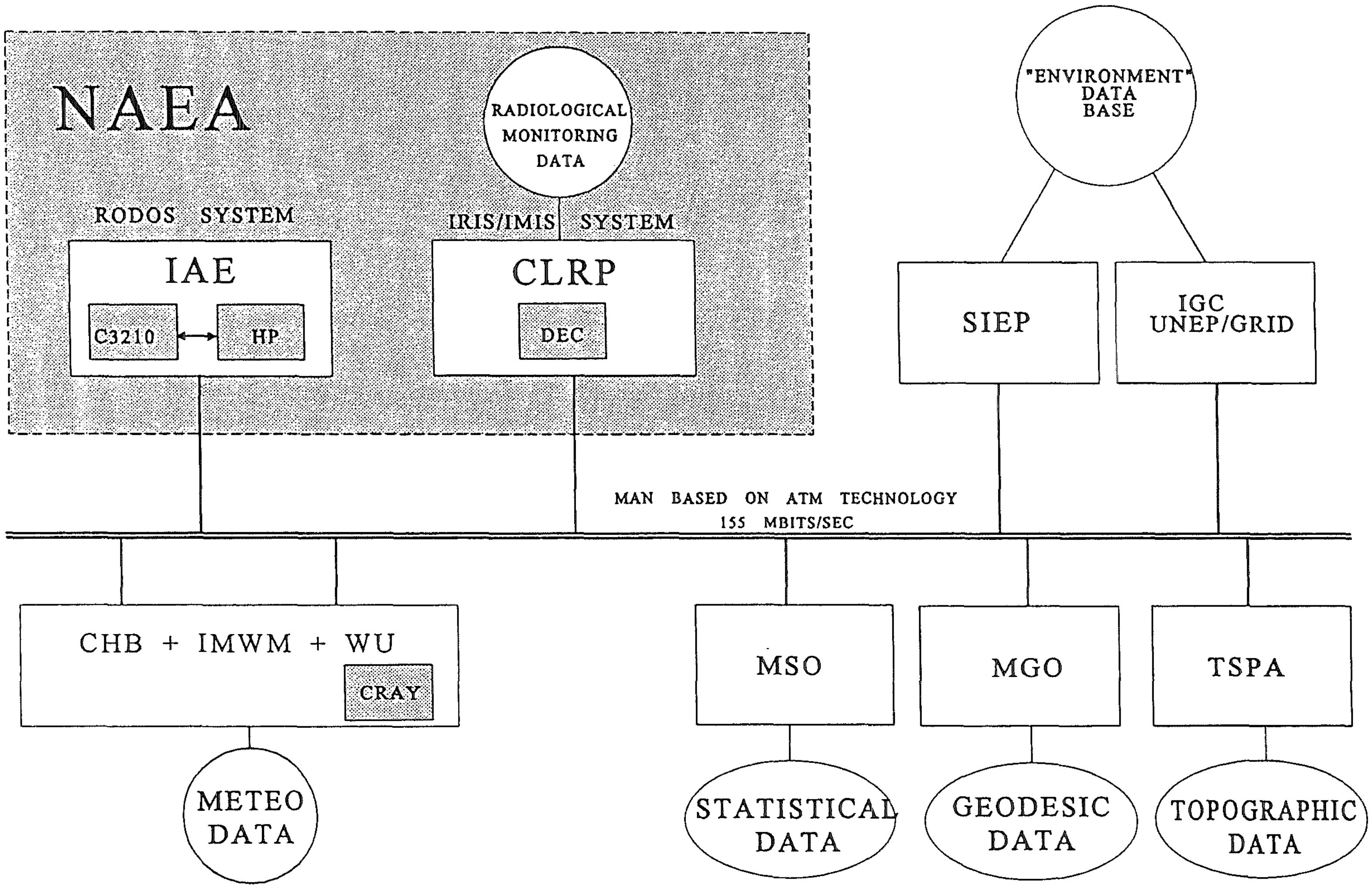


Fig. 25: Computer and data bases environment

Development of Heterogeneous Distributed Computer Environment (HEDICE) - a basic tool for National Decision Support System for Nuclear Emergencies.

The structure of HEDICE has been designed. The main features of HEDICE are the following:

- a heterogeneous distributed data base manager allowing for such operations like to find, retrieve and update on different types of database management systems (Oracle, Ingres, Informix etc.),
- process initialisation and execution on both local and remote hosts (machines) by process manager of the NDSS-NE kernel residing in each node of the network,
- client-server architecture, but in such a way that the same machines can play both roles depending on needs.

The HEDICE can be also treated as a set of nodes (machines) representing autonomous computer systems embedded into the whole environment. Each node provides some specific services of well defined type, like collecting some data, or performing some actions. However, the configuration of the system can be dynamically changed. In such a way HEDICE constitutes a tool for "open distributed computing". This allows also for full integration of emergency data management and RODOS system, that is for interoperability of different elements of the whole system. Two tasks (or nodes) are interoperable if they can interact to execute tasks jointly. This is more than interconnectivity, which means only exchanging messages (for example data) between nodes or tasks.

The HEDICE is based on object oriented approach and message passing concept. The full usage of object orientation technology, that is encapsulation, abstraction and polymorphism leads to flexible and intelligent tool, which will be able to operate in different circumstances during dynamically changing situations. The well-defined interfaces, hiding internal operations will clarify all the available actions for any element of the system.

The implementation of HEDICE will be partially based on freely distributed software, such like: Parallel Virtual Machine (PVM), developed at the University of Tennessee, Oak Ridge Laboratory and Emory University, TCL and TK (tool command language and graphic user interface toolkit) developed at the Sun Microsystems Laboratories by Dr. John Ousterhout and well known GNU software (C/C++ language). The PVM library is the wide used package for parallel computation in heterogeneous computer environment and stands de facto as a standard tool for such calculations. Similarly like RODOS, PVM is based on message passing concept, hence it allows for quite easy integration with generic RODOS software.

All the above mentioned packages are available for almost every hardware platform working under UNIX operating system. This allows for unified approach in integration of basic radiological and meteorological systems in Poland with the RODOS system. The packages have been installed on Convex C3210 and HP-735 computers at IAE. Several tests have been carried out concerning mainly cooperation of these computers. Currently the packages are being tested on other hardware platforms i.e. Silicon Graphics, Sun, Cray and PC under LINUX system.

5.1.4 Radiological Monitoring Aspects

At present the radiological monitoring system is under reconstruction. A software for collecting monitored radiological data and transmitting them to NAEA has been developed and is being tested. Documentation and installation procedures will follow. Integration of emergency data management and decision support systems will be based on described previously HEDICE tools. A part of the monitoring stations will be probably operated under ARGOS-NT system developed at the Danish Emergency Management Agency (an appropriate agreement between Danish and Polish governments is to ne signed). The ultimate goal of all efforts is approach gradually the technical standards and organizational structures of the system IMIS implementation in Germany. The CLRP is cooperating in this subject with the Institute of Atmospheric Radioactivity, Freiburg. However, at any rate HEDICE will still constitute the basic tool for integration of the used systems.

5.1.5 Meteorological Aspects

The fundamental change in the scope and the role of DSS in nuclear emergency handling lies in the possibility of simulating the radionuclides transport accross the continent after the accidental release in nuclear power plant anywhere in Europe. This transport heavily depends on the hydrometeorological conditions during and after the accident. Having a possibility to calculate the deposition and resulting doses one can select and plan the possible emergency actions, taking into account the benefit to costs considerations.

This approach is fundamentally different to the approach based solely on the radiological monitoring data, which are collected simply too late for the purposes of realistic mitigation of the accident consequencies. This is the reason why meteorological data are so fundamental for the success of DSS.

A. It has been decided to add a node to the existing METPAK communication system, for rendering the world and national observational data to the NDSS-NE/RODOS system. Within the METPAK network main forecasting offices are connected with the speed of transmission 19.2Kb/s and others with 9.6 Kb/s. Communication between the node for NDSS-NE/RODOS located at IAE or NAEA and IMWM will be based on dedicated line or satellite VSAT system provided by Telbank, one of the main telecommunication institution in Poland. Up to the time of the commencing the routine communication links the archive set of meteorological data has been created and delivered to be used as a basis for exercises and initialization purposes.

B. Another agreement with CHB has been reached to use all the military and civilian data from aerodroms and special hydrometeorological stations used for aviation purposes. Those data are complementary to the data obtained from IMWM. The agreement will allow also to use the mobile stations in emergency situations to get meteorological data from requested points on Poland territory.

C. As reported on the Warsaw Special RODOS Seminar a common project of the IMWM and IAE on the application a unified model from the Meteorological Office at Bracknell for numerical weather forecasting purposes has been started. The model has been installed on the Cray EL-98 of the Warsaw University with the assistance of Bracknell specialists and should deliver in next future routinely twice a day forecasting data covering the territory of Poland. It is being assumed that the Bracknell model shall be used for stand-by purposes, allowing to start necessary assimilation and initialisation preprocessing for emergency calculation of numerical forecasts connected with the atmosphere dispersion simulations of the NDSS-NE/RODOS system. The necessary data shall be transmitted to the NDSS-NE/RODOS system.

D. The RAMS model from MRC *ASTER and CSU shall constitute the basis for downscaling and special emergency mode operations for local weather predictions. The RAMS package has been installed on Convex C3210 computer of the IAE and a team of specialists has been created to run it for emergency purposes and for preparing the exercises which shall be carried out routinely to keep staff of the future National Emergency Center prepared for the emergency actions. The RAMS package shall use the data from the Bracknell model (an appropriate interface has been developed) and observational data from public, military, mobile and Doppler radar stations. It will be run on a cluster of machines consisting of Convex C3210 mainframe and HP735 workstation using freely distributed PVM software supported by NCAR and AVS packages for graphics and visualisation..

This approach will in particular concern enhacement of capabilities of uniform approach to the mesoscale and local weather forecasting (downscaling of 12-24 hours time period and large area weather forecasting provided by regional meteorological centers, to the purpose of an emergency situation development tracking). The regional atmospheric system RAMS of CSU and ASTER with its grid nesting features, objective analysis and initialisation, and physical phenomena capability simulation seems to be a tool particularly suitable for achieving that goal, however current testing suggests, that a computer platform of 250-350 Mflops performance will be required to ensure by RAMS an operational support of the NDSS-NE. A relatively low cost solution would be an implementation of a parallelized version of RAMS in a heterogeneous cluster of workstations and/or mainframes. For this purpose the PVM software can be used.

E. Since the potential nuclear power plants accidents may happen relatively far from Polish territory the NDSS-NE/RODOS Research Team decided to pursue in cooperation with MRC *ASTER and CSU the development of HYPACT code for long distance transport of radionuclides, taking advantage of hybrid Lagrangean and Eulerian characteristics of the code.

F. The system RAMS-HYPACT shall be loosely coupled with the existing RODOS system to take advantage of the dose assesment capabilities of the RODOS system. Necessary interface shall be elaborated by the NDSS-NE/RODOS Task Force, as the basic software contribution to the RODOS system in the field of for transport of radionuclides.

G. Under appropriate licence certificates the meteorological preprocessor PAD from the ANPA (Italy), ADREA code from the NSCR Demokritos (Greece) and RIMPUFF/LINCOM program from the RISØ National Laboratory (Denmark) have been acquired. An appropriate interface between RIMPUFF/LINCOM and Polish meteo data available in the RADMET system (based on radio) has been developed.

5.1.6 Topographic aspects

Transport of radionuclides depends not only on meteorogical conditions, distributed over the relevant teritory but also on orography, land use with canopy distribution and others data which must be stored together with numerical maps and terrain reliefs in the form of multilevel geographical databases.

After detailed studies the following specific results have been achieved:

A. According to the presentation on the Warsaw RODOS Seminar TSPA has delivered the 1:1000000 scale numerical map of Poland. Its use depends on delivery of RoGIS package, which is under development at Forschungszentrum, Karlsruhe. This is the very first step in securing the basic content of the topographic data base of NDSS-NE/RODOS System.

B. Digital Terrain Elevation Data for the grid 1km x 1km is now under preparation by TSPA and will be delivered to IAE by the end of this year. These data should become operational together with the digital map quoted above under the item A after the delivery of RoGIS package.

C. The new partner of NDSS-NE/RODOS Task Force is the Institute of Geodesy and Cartography. It has elaborated in cooperation with CORINE Project of European Union the 1:100000 scale maps of Poland devoted to land use. The whole teritory of Poland will be available at the end of this year. A contract with IGC is under negotiation and is to be signed soon.

   The CORINE project seems to be a very good source of digital maps for the RODOS project as it was from the very beginning devoted to environmental studies.

   In June 1991, at the European Conference of Dobris Castle, the European Ministers of the Environment stressed the need to improve environental information and monitoring systems in Europe. They asked for the production of a report describing the state of the environment in Europe, which among other things should become a basis for the effective implementation of environmental policies and strategies. They welcomed the European Commission's proposal to provide information and assistance for the application of the CORINE methodology in other countries as a first step towards the integration of environment information systems throughout Europe.

Three CORINE inventories are applied in six of the CEECs (Bulgaria, the Czech Republic, Hungary, Poland, Slovakia and Romania): CORINE Land Cover, Corinair and CORINE Biotopes.

The project of CORINE Land Cover maps the land cover at the scale 1:100 000 and stores the data in a geographical information system (GIS) in accordance with a nomenclature of 44 items, such as dense urban areas, crop land, grassland, forests, bogs, etc. The methodology involves satellite imagery, together with thematic maps and field observations.

Here also, the status of implementation is different from one country to the other. The main hurdle for starting the projects was the availability of topographic (military) maps; this difficulty has been solved.

The project is well ahead and is expected to be concluded by the end of 1995 for Poland, Hungary, the Czech Republic and Slovakia, and in mid-1996 for Romania and Bulgaria.

The expert team which assumes the technical follow-up and uniformity of the data in the project, stated that the quality achieved in the work is high.

Other initiatives were taken in the frame of this project.

A small expert working group is defining now a CORINE nomenclature and methodology for a more precise cartographic scale 1:50 000, since a demand has been often expressed by local or regional authorities for more detailed land cover information.

A study of land cover changes by means of retrospective imagery will start directly after implementation of the land cover databases.

D. There is a national programme of creating a digital map of Poland in the scale 1:50000. The programme is being sponsored also by the National Energy Agency. These maps, which are to be available about 1999, should become a part of the NDSS-NE/RODOS system as the final solution of the topographic aspect of the Polish Project. The solutions presented under items A, B and C are considered as preliminary or temporary solution to enable the implementation of NDSS-NE/RODOS system, to study relevant technical problems and prepare qualified staff.

5.1.7 Implementation the for Local Swierk Emergency Centre

Two research reactors are located in Swierk: MARIA and EVA. Both are or were exploited by the Institute of Atomic Energy.

Reactor MARIA:

Water-berilium reactor, high fuel enrichment 80%, power 30 MW, square lattice. The reactor started operation in 1974 and after the Chernobyl accident was under reconstruction to improve safety features and is still operating.

Reactor EVA:

Water reactor, fuel enrichment 30%, power 8 MW, hexagonal lattice. The reactor started operation in 1956 and closing procedure begun in the spring of 1995.

Existing elements of RODOS system have been applied to give the foundation for the Local Swierk Emergency Centre Decision Support System of the type forseen by the RODOS system. The decision has been undertaken to use the existing version of RODOS to establish the local DSS for emergency handling, as an element of the national project:

To implement it the following steps have been undertaken:

A. Local observational meteorogical data and local radiological data are delivered on-line to feed the ATSTEP programme on HP 735 workstation.

B. Programmes RIMPUFF and LINCOM have been tested using both local data and data obtained from the Central Hydrometeorological Bureau.

C. Source term for reactor MARIA accidents has been implemented and tested on ATSTEP programme taking into account the exploitation data from the Reactor Operating Console.

D. Topographic, digitalized maps of detailed scale for the Local Swierk Emergency Center are under preparation and will be ready by the end of this year.

5.1.8 Conclusions

The global goals set out for the project could not be achieved within the reported period. Therefore work on the topics listed above in Sec. 5.1.1 will be continued in the next years with priorities determined by the availability of software and material provided by the system developers of FZK and cooperating institutions. The emphasis will be put on implementation and testing in shortest possible time period a pilot version of NDSS-NE, whose basic constituents will be distributed configuration of the RODOS kernels, national radiological monitoring data system and communication to IMWM. The high priority will be also given to completing the set of digitalized maps of Poland and country specific countermeasures evaluation. The existing capabilities of the RODOS system will be extensively used for achieving till the end of 1996 an operational pilot version of a local decision support system for the nuclear centre at Swierk, along the lines set out in Germany for the RODOS/RESY application.

5.2 Implementation of RODOS in Hungary (NRIRR)

5.2.1 Objectives

According to the initiation of the Hungarian Atomic Energy Comission in relation to the environmental radiation, a country-wide information network should be established and it has to include

- the early warning system operated by the Hungarian Army and Civil Defence,
- the laboratory type monitoring networks and
- the local systems around the main nuclear facilities.

A closer co-operation is to be promoted for both accident and normal situations in a number of important areas. These include the monitoring programme as a whole, together with data analysis, dose assessments, decision making procedures, international co-operations, to provide information for the Authorities, specialists and the public.

The information network is to be supplied with real-time data collection, telemetric data transmission and resources of hardware and software for data processing both for normal and accidental situations. The software tool of RODOS is planned for off-site dicision support. For the effective use of the decision support system the on-line access of the meteorological data provided by the Hungarian Meteorological Service and national data bases of population distributions, consumption habits etc. have to be established.

5.2.2 Achievements

The early warning system with 50 field stations equipped with dose rate proportional counters and meteorological sensors for determination the temperatures, the air pressure, the wind direction and speed and the humidity. Each station is equipped with a PC-computer and the data are transmitted automatically to the national center of the Civil Defence. The stations are mainly placed at the meteorological stations and Civil Defence ports, within the country. The Nuclear Emergency Information Centre has already installed a home made software to simulate the radionuclide dispersion in the air for accidental cases.

The responsibility of the data collection, processing of laboratory type of data, the regularly information and the decision-making with respect to the radiation impact of the population are addressed to the institutes of Ministry of Welfare, mainly to the National Research Institute for Radiobiology and Radiohygiene (NRIRR).

To establish the Information Centre of the Nationwide Environmental Radiation Monitoring System (NERMS) the NRIRR has already installed the facilities of

- SUN SPARCserner-20 workstation with UNIX operation system, C+, C++, FORTRAN and PASCAL compilers
- INGRES data management software
- three local stations each one with PC-server, Novell Netware and PC- workstations.

The structure of the information system of the NERMS is outlined in Figure 26. The central facilities including the license for INGRES are ready to extend the number of the local stations up to 30. Due to the restricted financial resources the extention is delayed and at the beginning of the next year 10 stations are planned to start. The work is supported by the IAEA as well.

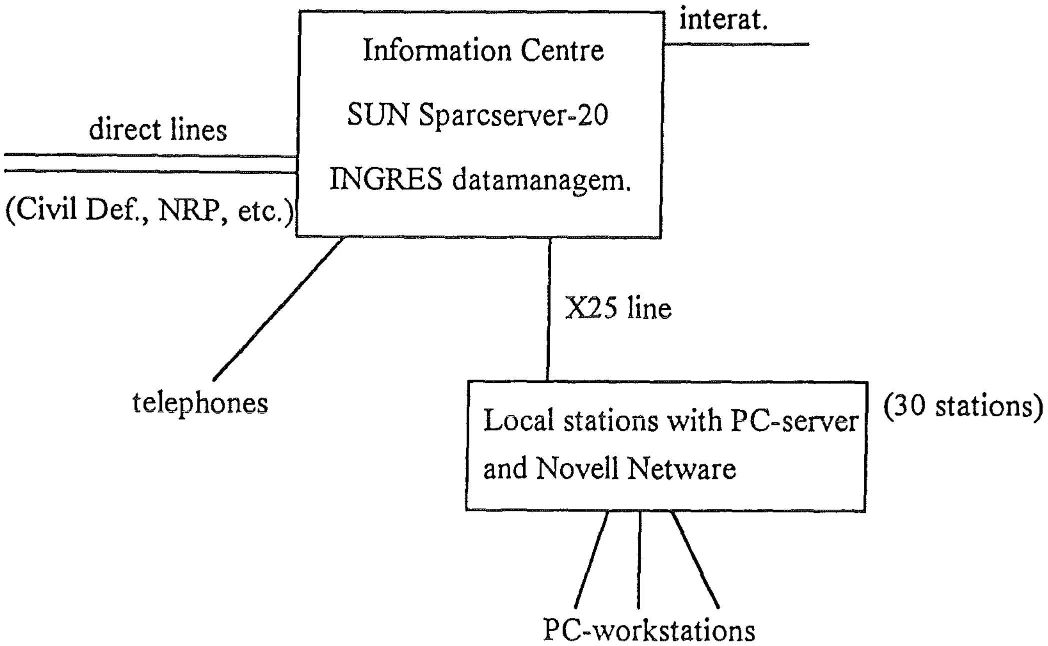


Fig. 27: Structure of the NERMS information system

The user software for the on-line and remote collection and processing of laboratory type of data has been developed in INGRES and tested. The main functions of the software are the followings:

- data collection from the local stations installed in the radiological laboratories,
- selection of data for special purpose, mainly for verifying the data and export the files to an input of statistical etc. pachages,
- provide simple results and outputs like main statistics, time series, scatter plots and maps.

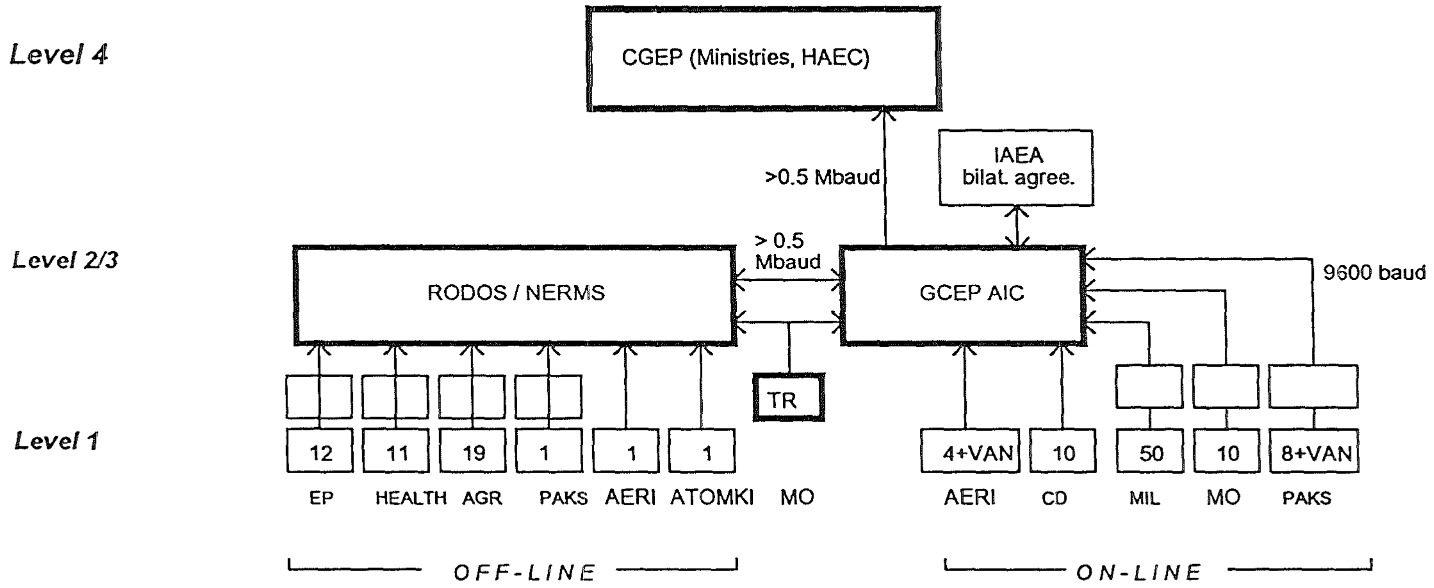
The software is ready to collect data types of

- dose, dose rates both for indoor and outdoor, even for caves etc.
- radionuclide concentration of environmental samples (terrestrial, river etc. ones)
- radionuclide releases from nuclear installations
- radionuclide contents of whole bodies both for animals and man, including organs.

The radionuclides might be natural (like Rn-222) and artifical ones. Plans are to connect the information centres of the early warning system (managed by the Civil Defence), of the Meteorological Service and of the NERMS ones. The dedicated lines are already installed but the proper software for communications are not yet bought.The structure of the planned - and partly already in operation - network is given in Figure 27.

The RODOS System is to be implemented in the Information Centre of the NERMS, by the NRIRR. Therefore the institute has already begun collection of non-nuclear data, mainly consumption habits of the Hungarian population (nearly from 20 thousands inhabitants) to be used for site-specific and more effective management of the software.

The first plan was to install the RODOS to the SUN SPARCserver-20 workstation used for monitoring date management. The latest version is to be installed on an extra computer, probable an HP-725 type one. The financial costs are to be covered by the support of the EC in frame of the contract underlying this Final Report.



RODOS: Real Time On Line Decision Support System
NERMS: National Environmental Radiation Monitoring System
GCEP: Governmental Commission for Nuclear Emergency Prep.
AIC: Accidental Information Centre
HAEO: Hungarian Atomic Energy
EP: laboratories of Minsitry of Environmental Protection and Regional Policy
HEALTH: laboratories of Ministry of Health and Welfare
AGR: laboratories of Ministry of Agriculture

ATOMKI: Nuclear Research Institute (Debrecen)
AERI: Atmomic Energy Research Institute (Budapest)
TR: Trajectory Model
PAKS: Nuclear Power Plant (Paks)
MO: Meteorological Office
MIL: Military Service
CD: Civil Defence

Fig. 28: System concept for a countrywide Hungarian Monitoring Information System with four logical levels of data collection (Level 1), data processing (Level 2), data evaluation (Level3) and decision making (Level 4)

5.3 Implementation of RODOS in Romania (IFIN-LAB)

5.3.1. Project summary

5.3.1.1. Objectives of the RODOS project for IFIN-LAB

The main objectives of IFIN-LAB within the framework of RODOS project during the contract period were:

a) the establishment, with the FZK's approval and help, of the optimum sized hardware/software (H/S) computing configuration necessary both for transfer from FZK to IFIN-LAB and further development in Romania of the RODOS software system and, consequently, the price negociation, purchase, installation and operation of the chosen H/S computing configuration;

b) the training at FZK on RODOS structure and operation of some IFIN-LAB's researchers and engineers;

c) the transfer from FZK and installation at IFIN-LAB of the actual version of RODOS;

d) the realisation at IFIN-LAB of an experimental basis interfaceable to the RODOS H/S configuration for the realisation of on-line and real-time features;

e) the planning and organisation the IFIN-LAB's R&D RODOS activities so that according to our feasibility prospects they match the RODOS project schedule in the next Framework Programme until mid of 1999.

5.3.1.2 Achievements of the IFIN-LAB

The main achievements of IFIN-LAB within the framework of RODOS project during the contract period are as follows:

a) the acquisition of a Hewlett Packard (HP) workstation 735 under UNIX operating system; this HP H/S configuration has been put into operation and now is working at IFIN-LAB inside of a specially arranged room;

b) three researchers from IFIN-LAB have been trained on the RODOS structure and operation (June 1995) at FZK; a lecture on the RODOS project and system has been given by the RODOS project coordinator (Dr.J.Ehrhardt) within the IFIN seminar framework in Bucharest-Magurele;

c) the installation, under countersigned written RODOS agreement conditions, dated 13 July, 1995, of the software of RODOS prototype 1.3 by the FZK's RODOS team;

d) the construction at the IFIN-LAB site of a 60m height meteorological and radiological surveying tower (MRST) equipped with appropriate detectors and sensors and designing the interface with the RODOS H/S configuration;

e) the developing of domestic research activities in the field of accident consequences assessment (ACA), as potential contributions of IFIN-LAB to the RODOS system; we started also preliminary studies for CANDU reactor source-term evaluation as a future module to be included in RODOS, keeping in mind that the Romanian NPP is based upon this kind of power reactor;

f) the connection of RODOS to E-mail and preparedness for long distance communication of data and information by using phone digital equipment installation.

5.3.2 Diagnosis and prognosis of the radiological situation

A physical data bank has been created for gamma and beta emission of the fission product radionuclides. It stores the gamma energies and intensities for 62 radionuclides with decay schemes of different degrees of complexity; these data have been obtained by a proper method of simulation of the radionuclide decay and coding of each radionuclide decay scheme. The data for the beta decay of the radionuclides of interest in nuclear accident and nuclear medicine have been processed to obtain a beta spectra library for use in the radionuclide identification and for precise interpretation of the dosimetric measurements. In this view a computer program has been elaborated which stores up-dated data in the field. The computation of the mean energy of the beta spectra and of the shape of the spectra of 42 radionuclides is made based on the characteristic data. The formulas used in computation are those proposed and checked by the US National Bureau of Standard Computational Laboratory, according to the atomic number of radionuclide, forbidden laws about spin and parity and of the type of the beta spectrum (simple or compound ones). (The results of the (proposed) adopted model are described in "Computer simulation of beta ray spectra for some isotopes of interest in accidental releases" in press, Romanian Journal of Physics, authors: D.Vamanu, G.Ochiana et all.).

5.3.3 Source term estimation

During this year a CANDU power reactor-based NPP, located at Cernavoda city, near Danube large river, will be put into operation. Because, for the time being, this kind of NPP is proper only for Romania and due to its relatively big releases of tritium into the atmosphere (even in normal operation), it requires a particular approach for its source-term evaluation; the IFIN- LAB started already studies and data gathering activities for a CANDU reactor source term evaluation module, as a future component of RODOS.

Bearing this in mind, during the last years, some of our research works were dedicated to studies concerning tritium:

- determination of a method for evaluation of low concentration of atmospheric HTO, by trapping the water vaporous on solid absorbent (molecular sieves, Drierita, silica gel), followed by vacuum extraction of water and liquid scintillation measurement of this water;
- determination of a method for HT/HTO evaluation, by trapping the HTO on solid absorbent, oxidation of HT to HTO on Pd-molecular sives and adsorbing of water;

- assessment of operational release limits for CANDU NPP, taking in consideration the last recommendations of ICRP and AIEA for maximum admissible dose (1 mSv/year for population);
- uncertainty and sensitivity analysis for the environmental tritium code UFOTRI;
- analysis of transfer parameters for routine release of HTO;
- study of the deposition of atmospheric tritium on soil covered with snow;
- the validation of model prediction for tritium in the international program BIOMOVS;
- assessment of operational release for CANDU-600 nuclear generating station in Cernavoda, Romania.

5.3.4 Application software

ACA modules for estimating doses, health effects and intervention zones from field measurements of relevant data on environmental contamination following an accidental release to atmosphere has been elaborated during the reported period at the IFIN-LAB.

A comprehensive and non-contradictory integration of data given by field measurements of radioactive release with generic data given by numerical modelling and simulation is an important exigence among reference terms in the realisation of automatic decision support systems for nuclear emergencies. The problem presents a number of scientific and technical aspects regarding the methodologies, measurement systems and techniques, data acquisition systems, telemetry systems methods and systems of data processing, etc., used. The approach used in this work takes into account the last mentioned domain, data processing given by the measurement in the field of environmental contamination (air and soil) in order to obtain information about the spatial distribution of doses, expected health effects and the recommended intervention zones.

To solve these problems a computer code was written which it is based on the assumption that in a reasonable scenario, in nuclear emergency, two types of field measurements are available:

a) fix points - environmental measurement stations of the surveillance and monitoring network;

b) aleatory points-in field measurements performed by mobile teams.

To solve these problems many interpolation techniques are available and were programmed for each specific spatial distribution of the field measurements. The computer code, FIELD of 2,367 MBytes, consists of 81 files, 7 executable files and 74 GIS data base files. The validation of the code confirms the quality of the solutions with smooth interpolations, absolute precise in the measurement points (fix or mobile) if a convenient density of measurement is provided. (D.Vamanu, Internal Report, 1994).

5.3.5 Dose assessments

A fast and easy to use method has been elaborated at IFIN- LAB for the computation of irradiation doses in case of human exposure due to post-accident irradiation. In order to restrict to acceptable levels the radiation risks to people, the quantity recommended by ICRU for control and limitation of doses to people is considered in the effective dose equivalent (EDE). A computer program has been elaborated for the evaluation of:

1. external doses (total body) due to the ground deposition;
2. external doses due to water and/or air immersion;
3. internal irradiation in case of inhalation of radionuclides and due to the consumption of contaminated food.

Total doses to be considered are the sum of the dose equivalents for the three mentioned exposure pathways. The main assumptions of the proposed model are:

a) the concentration levels of radionuclides in air, water and on the ground are known and,

b) the radioactive content of the food is given as a function of the ground deposition.

Accounting for the type of the release which occurs, the computer programme stores the nuclear data of the radionuclides; the input data are the measured or calculated values of the radionuclide concentrations for each pathway. In case of evaluation of internal irradiation due to the consumption of contaminated food an average individual daily dietary is assumed and it is supposed that the main contribution is given by Cs-137, Cs-134, Sr-90, I-131, I-132 + Te-132 radioisotopes. The total value for EDE is to be compared with dose levels for the introduction of sheltering and evacuation (stored in the computer program too) as recommended by international agencies. A detailed description of the proposed method is given in: "Computational model for human irradiation in post- accidental evaluations" in press, Romanian Journal of Physics, authors: G.Ochiana, D.Vamanu.

5.3.6 Organisational and functional status and perspectives

To underline IFIN-LAB's potential for RODOS project implementation in Romania, a comprehensive study has been elaborated which comprises: basic requirements, regulations and governmental authorities involved in nuclear accident, RODOS system's structure, objectives and requirements, quality assurance and control matters, feasibility potential and demands (including scientifical, technical, logistical and financial aspects), the necessary R&D activities to be developed by IFIN-LAB from 1994 until the mid of the 1999 year and their scheduling, etc. (IFA Internal Report, September 1994). On the other hand the IFIN-LAB RODOS R&D group is at present enlarged with young graduates both in mathematical theory of the expert systems, physics of the atmosphere, computer science, nuclear instrumentation and nuclear physics.

For a better definition of the research tasks and responsibilities three subgroups within the IFIN-LAB RODOS group have been settled as follows:

1) the first one will be permanently responsible for RODOS-HP configuration maintenance and operation; this subgroup will also work as a human interface between the RODOS system and both the other Romanian participants in the RODOS project and the Romanian end-users of the RODOS system;

2) the second subgroup will develop new software modules for the three subsystems (ASY, CSY and ESY) of the RODOS system; this subgroup will also be responsible for the adding new software modules coming from the RODOS community;

3) the third subgroup will be responsible for both communications and interfacing the RODOS system with our national RMS networks.

All works related to the RODOS system will be done by IFIN- LAB following QA/QC procedures as stated in the Quality Assurance Manual of our Institute; if necessary, special QA/QC procedures will be elaborated in due time.

A domestic long lasting (from 1994 to 1999) R&D contract has been approved by the Ministry of Research and Technology for the RODOS Project; in accordance with this contract, IFIN-LAB will benefit from April 1994 up to June 1999 of the necessary funds, expressed in Romanian currency which will, mainly cover the expenditures with salaries of the research workers during this period, consummables and internal collaborations.

The buildings of the Institute of Atomic Physics are endowed with all necessary facilities required by the current R&D activities in the nuclear domain; all the three subgroups involved in the RODOS Project have their own working spaces and recently additional rooms have been assigned in close connection and above the Command Room of the Public Authority Headquarters for installation and operation of the RODOS HP configuration.

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APPENDIX

RODOS-Documentation

The registration numbers are to be interpreted according to the following coding:

RODOS(P)-DC(93)n

with

(P) subproject to which the document belongs (at present A, B, C, D).

DC Document-type; three different types are distinguished

- MN minutes of meetings
- TN technical notes
- RP reports, papers
- (93) year
- n consecutive number, starting each year with 01.

RODOS(B)-MN(93)01

final: 8 March 1993 — RODOS coordination meeting on the further development of ASY, CSY and ESY modules - Minutes of the contractors' meeting held at Kernforschingszentrum Karlsruhe, 10 -12 February 1993

RODOS(B)-MN(93)02

final: 29 March 1993 — Minutes of the RODOS Coordination Meeting on System Hardware and Software Structures, KfK, 18 February 1993

RODOS(B)-MN(93)03

final: 29 March 1993 — Minutes of the RODOS coordination meeting on meteorology and atmospherical dispersion, KfK, 24-25 February 1993

RODOS(B)-MN(93)04

final: 13 April 1993 — Minutes of the 1st RODOS coordination meeting with CYFRONET,KfK, 11 and 12 March 1993

RODOS(B)-MN(93)05

final: 30 April 1993 — Minutes of the 2nd contractors meeting, Electricité de France, Paris 6 and 7 April 1993

RODOS(B)-MN(93)06

draft: 22 Nov. 1993 — Minutes of the 3rd contractors meeting on RODOS subtask "Training" SCK/CEN Mol, November 15 and 16, 1993

RODOS(B)-MN(93)07 — Minutes of the RODOS Meeting on dose and Countermeasure Models at KfK, 16 -17 December 1993

RODOS(B)-MN(94)01 final: 13 January 1994	Minutes of the 2-nd RODOS coordination meeting with IAE Swierk, Poland, KfK, January 12-13,1994
RODOS(B)-MN(94)02	RODOS Uncertainty meeting 2nd/3rd February 1994, Leeds University
RODOS(B)-MN(94)03 Draft: 10 April	Minutes of the 4th contractors meeting on RODOS subtask "Training", NE Barnwood, 29 - 30 March 1994
RODOS(B)-MN(94)04 draft: 4 July 1994	Briefing on WG5 meeting in Interlaken, June 20 - 24 1994, C. Steinhauer
RODOS(B)-MN(95)01 Draft: 7 April 1995	Minutes of the WG5 meeting in Karlsruhe, March 28-30,1995, C. Steinhauer
RODOS(B)-TN(93)01	RODOS Subtask "Training": Potential implementation of RODOS in the MOL Training Courses, 26.11.1992/SCK/CEN
RODOS(B)-TN(93)02	RODOS Subtask "Training": Collection of materail dealing with 3 training courses held at EdF, 27.1.93
RODOS(B)-TN(93)03	RODOS Subtask "Training": Proposed RODOS Training Module Suite, 10.3.93, Nuclear Electric
RODOS(B)-TN(93)04	RODOS Phase 2: FRODO-Relocation Endpoints, 19.4.1993, NRPB
RODOS(B)-TN(93)05	Concepts for the Graphics System in Prototype Version 2 of the RODOS System, 11.5.93, KfK
RODOS(B)-TN(93)06	Endpoints of the Calculations in the Foodchain Transport Module and the Dose Module, August 1993, GSF
RODOS(B)-TN(93)07	The RODOS System Phase 2 Functional Specification of the Late Countermeasure Module FRODO, September 1993, NRPB
RODOS(B)-TN(93)08	Structure of the RODOS System - Documentation December 1993, KfK
RODOS(B)-TN(94)01 Draft 14/4/94	Quality Assurance in RODOS Simon French, Dave Ranyard

RODOS(B)-TN(94)02 draft: April 1994	The RODOS System Phase 2 Definition of Shared Common Blocks for the Late Countermeasures Module FRODO/Version 1 Justin Smith and Phil Mansfield
RODOS(B)-TN(94)03 draft: June 1994	Quality Assurance for RODOS S. Vade
RODOS(B)-TN(94)04 draft: 4 July 1994	Computer Based Training Course on Off-site Emergency Response to Nuclear Accidents, C. Steinhauer
RODOS(B)-TN(94)05 final: 7 July 1994	Agenda, list of participants and collection of material presented at the 4th RODOS contractors meeting, Interlaken
RODOS(B)-TN(94)06 draft:29. Sept. 1994	Interfaces between ECOAMOR and OSY concerning aquatic pathways H. Müller, GSF
RODOS(B)-TN(94)07 draft: December 8 1994	The RODOS System Phase 2:Documentation of theFoodchain and dose module ECOAMOR, Part V: Model Description, GSF
RODOS(B)-TN(95)01 final	Proceedings of the Special Warsaw RODOS Seminar Institut of Atomic Energy, Poland
RODOS(B)-TN(95)02	Technical Specification of the late countermeasre module FRODO/Version 1 Ph. Mansfield, J. Smith. R. Smith, J. Brown
RODOS(B)-TN(95)03	Databases of FRODO
RODOS(B)-RP(93)01	Progress Report FI3P-CT92-0036, August 1993
RODOS(B)-RP(93)02 final: April 1993	Models, Data and Expert Judgement in Decision Support Systems
RODOS(B)-RP(94)01 draft: January 1994	Multi-Attribute Decision Analysis after a Nuclear Accident Simon FRENCH

RODOS(B)-RP(94)02 final	The real-time on-line decision support system RODOS for off-site emergency management G.Benz, J. Ehrhardt et al., Kerntechnik 59 (1994), pp. 215-219
RODOS(B)-RP(94)03 final: October 1994	Progress Report Cooperation in Science and Technology with Central and Eastern European Countries/Suppl. Agr. No. ERBCIPDCT930419 to Contract No. ERBCI3PCT920036
RODOS(B)-RP(94)04 final: December 1994	Data Assimilation During the Early Phase of an Accident. Release SCK/CEN Mol
RODOS(B)-RP(94)05 final: December 1994	Uncertainty in RODOS S. French, D. Ranyard, J. Smith
RODOS(B)-RP(94)06	The Modelling Concept for the Radioactive Contamination of Waterbodies in RODOS, the Decision Support System for Nuclear Emergencies in Europe Proceedings of the "International Seminar on Freshwater and Estuarine Radioecology, Lisbon, March 1995 W. Raskob, R. Heling, A. Popov, P. Tkalich
RODOS(B)-RP(95)01 final	RODOS Database Adapter Gang Xie, M. Rafat, Report FZKA 5649 (1995)
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RODOS(B)-RP(95)03 final: May 1995	Equity and MCDA in the event of a Nuclear Accident S. French, E. Halls, D. Ranyard
RODOS(B)-RP(95)04	Event conditional attribute modelling in decision making on a threatening nuclear accident S. French, M.T. Harrison, D. Ranyard
RODOS(B)-RP(95)05	Design of a decision support system for use in the event of a radiation accident S. French, N. Papamichail, D. Ranyard, J. Smith

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Proceedings of the "Fifth Topical Meeting on Emergency Preparedness and Response, April 1995, pp. 8 - 11

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J. Brown, K. Smith, P. Mansfield, J. Smith, H. Müller
Proceeding for Oslo Conference on "International Aspects of Emergency Management and Environmental Technology, June 1995,pp 207-213

RODOS(B)-RP(95)08 Meteorology and Atmospheric Dispersion, Simulation of Emergency Actions and Consequence Assessment in RODOS
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RODOS(B)-RP(95)09 RODOS, a Real-Time On-line Decision Support System for Nuclear Emergency Management in Europe
J. Ehrhardt, F. Fischer, I. Hasemann, A. Lorenz, J. Päsler-Sauer, O. Schüle, T. Schichtel, C. Steinhauer, M. Rafat, G. Benz
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