Forschungszentrum Karlsruhe
Technik und Umwelt

Wissenschaftliche Berichte
FZKA 6069
RODOS R-3-1998

RODOS: Decision Support for Nuclear Emergencies

J. Ehrhardt, A. Weis (Eds.)

Institut für Neutronenphysik und Reaktortechnik
Projekt Nukleare Sicherheitsforschung

März 1998

Forschungszentrum Karlsruhe

Technik und Umwelt

Wissenschaftliche Berichte

FZKA 6069
RODOS R-3-1998

RODOS: decision support for nuclear emergencies

J. Ehrhardt, A. Weis (Eds.)

Institut für Neutronenphysik und Reaktortechnik
Projekt Nukleare Sicherheitsforschung

Forschungszentrum Karlsruhe GmbH, Karlsruhe
1998

Als Manuskript gedruckt

Forschungszentrum Karlsruhe GmbH
Postfach 3640, 76021 Karlsruhe

Mitglied der Hermann von Helmholtz-Gemeinschaft
Deutscher Forschungszentren (HGF)

ISSN 0947-8620

This work has been performed with the support of the
European Commission
Radiation Protection Research Action
(DGXII-F-6)
contracts FI4P-CT-95-0007, FI4C-CT96-0006, IC15-CT96-0318

RODOS: Entscheidungshilfe bei kerntechnischen Notfällen

Zusammenfassung

Das integrale und umfassende Echtzeit- und On-line Entscheidungshilfesystem RODOS (Real-Time On-line Decision Support) für den externen Notfallschutz nach kerntechnischen Unfällen wird u.a. mit Unterstützung der Europäischen Kommission durch ein Konsortium von etwa 40 Instituten in Ost- und Westeuropa entwickelt. Aufgrund seines Softwaredesigns wird es im Nahbereich bis hin zu großen Entfernungen und in der Frühphase bis zu den Spätphasen eines Unfalls einsetzbar sein. Es bietet Entscheidungshilfe auf mehreren Stufen, die ausgehend von den Informationen über die derzeitige und zukünftige radiologische Situation bis hin zur Ermittlung und Bewertung der Vor- und Nachteile verschiedener Maßnahmenstrategien reichen.

Der vorliegende Bericht enthält eine Reihe von Veröffentlichungen aus den Jahren 1997/1998, die das RODOS-Projekt, die wichtigsten Software-Komponenten des Systems, seinen Entwicklungsstand und sein Potential zur Verbesserung des Notfallschutzes in Europa beschreiben.

Abstract

RODOS (Real-Time On-line Decision Support) is an integrated and comprehensive real-time on-line decision support system for off-site emergency management of nuclear accidents. It is being developed by a consortium of some 40 institutes across Europe with support from, inter alia, the European Commission. Designed as a generic software tool, the RODOS system will be applicable from the very early stages until many years after an accident, and from the vicinity of a release to far distant areas. Decision support will be provided at various levels, ranging from the largely descriptive presenting information on the present and future radiological situation to an evaluation and ranking of the benefits and disadvantages of different countermeasures' options.

This report contains a number of papers written during 1996/1997, which describe the RODOS project, the main software components of the system, the status of its development and its potential role for improving emergency response in Europe.

I Off-site Emergency Preparedness Activities within the European Commission

G N Kelly
European Commission, DG XII/F/6,
Rue de la Loi 200, Brussels 1049, Belgium

Abstract

Increasing attention is being given by the European Commission to off-site emergency preparedness as part of its broader contribution to improving nuclear safety in Eastern Europe. The main initiatives being taken or planned by the Commission in this area are summarised. Particular attention is given to two topics: firstly, the development of the RODOS (**R**eal-time **O**n-line **D**ecisi**O**n **S**upport) system for supporting off-site emergency management in the event of a nuclear accident; and, secondly, the work of an Inter-Service Group on nuclear **O**ff-**S**ite **E**mergency **P**reparedness (OSEP) in Eastern Europe that has been established within the Commission. The contribution that each is making to improving emergency preparedness, both in Eastern Europe and in Europe more widely, is described.

I.1 Introduction

Over the past few years the Commission has taken a number of initiatives to improve nuclear safety in Eastern Europe[1]. While the main focus of these has been accident prevention and mitigation, increasing attention is now being given to off-site emergency preparedness as the third and final link in the nuclear safety chain. The main initiatives taken or planned by the Commission in this latter area are summarised in this paper. Particular attention is given to two topics: firstly, the development of the RODOS (**R**eal-time **O**n-line **D**ecisi**O**n **S**upport) system for supporting off-site emergency management in the event of a nuclear accident; and, secondly, the work of an Inter-Service Group on nuclear **O**ff-**S**ite **E**mergency **P**reparedness (OSEP) in Eastern Europe that has been established within the Commission. The contribution that each is making to improving emergency preparedness, both in Eastern Europe and in Europe more widely, is described.

I.2 The RODOS Decision Support System

Following the Chernobyl accident, increased resources were allocated in many countries to improve systems to aid the off-site management of any future nuclear accident. Much has since been achieved but much yet remains to be done to ensure an integrated, coherent and consistent response to any accident that might in future affect Europe. The need for and importance of a coherent and consistent response were amply demonstrated following the Chernobyl accident when differences in the countermeasures taken by national authorities contributed greatly to a loss of public confidence. The development of a Decision Support System (DSS) for off-site emergency management, that would be comprehensive and capable of finding broad application across Europe, was included as a major item in the Radiation Protection Research Action of the

---

1 Unless otherwise indicated, the use of Eastern Europe in this paper refers to all countries in East and Central Europe and to the European Countries of the Former Soviet Union.

European Commission's 3rd Framework Programme. The following considerations were central to the inclusion of this item in the programme:

- to make better use of resources in the European Union (EU) for further improving off-site emergency management (eg, minimise unnecessary duplication, integrate best features of systems developed at national levels, etc)
- to benefit from the development of a comprehensive (ie, applicable at all distances, all times and to all important countermeasures) and fully integrated decision support system that was generally applicable across the EU (eg, seamless transition between different stages of an accident, greater continuity and consistency in decision support, etc)
- to provide greater transparency in the decision process as one input to improving public understanding and acceptance of off-site emergency actions
- to provide a common platform or framework for incorporating the best features of existing and future DSS
- to provide a basis for improved communication between countries of monitoring data, predictions of consequences, etc, in the event of any future accident, and
- the overriding consideration, to promote, through the development and use of the system, a more coherent and harmonised response to any future accident that may affect the EU.

It is evident that these considerations, set out above in the context of the EU, are equally if not more pertinent to Europe as a whole.

Development of the RODOS system began in late 1990. For institutional reasons participation in the project was initially restricted to EU institutes. Forschungszentrum Karlsruhe (FZK) has co-ordinated the project throughout and, inter alia, has overall responsibility for developing the system and integrating the software products of other contractors. About 10 EU institutes were initially involved in the project increasing since to almost 20. Means were subsequently found to broaden the scope of participation beyond the EU with two main benefits: firstly, greater and more diverse resources were made available to the project leading to a better final product and, secondly, the opportunity to develop a system that would be applicable across the whole of Europe as opposed to the narrower confines of the EU. The latter is particularly important in terms of achieving effective and timely response to any future nuclear emergency. About 10 institutes from Belarus, Russia and the Ukraine were formally integrated within the project in 1992 under the auspices of a collaborative programme on the consequences of the Chernobyl accident between the EC and the State Committees on Chernobyl Affairs in the respective countries. Subsequently, institutes from Poland (in 1993), Hungary, Romania and the Slovak Republic (in 1994) and the Czech Republic (in 1996) have joined the project under the auspices of the Commission's International Collaboration Programmes (PECO (**P**ays d'**E**urope **C**entrale et **O**rientale - Scientific and Technical Cooperation with Central and East European Countries) and INCO (International Co-operation)). Currently about 40 institutes (from about 20 countries) are involved in the development of RODOS with about half from Eastern Europe. This wide and diverse participation in the development of the system augurs well both for its efficacy and future implementation.

I.2.1 Objectives of the system and potential users

The basic concept, design and software framework of the system were specified and agreed by participants at the outset of the project and its main conceptual features are indicated in Figure 1. Decision support can be provided at various levels ranging, in increasing sophistication, from the largely descriptive, to providing an evaluation of the benefits and disadvantages of different countermeasures' options, to ranking them according to the decisions makers' expressed preferences for different outcomes. Most decision support systems, developed to an operational state, are limited to providing analyses and predictions of the current and future radiological situation. Some extend to the simulation of countermeasures but are often limited in the range of countermeasures they address or in the completeness of the benefits and disadvantages that are considered. The few systems that have progressed to the evaluation and ranking of alternative countermeasures' options are limited in the range of countermeasures they address. RODOS is unique in that it will provide comprehensive support (ie, at all levels) for each potentially useful countermeasure at all times following an accident.

The system is being designed to fulfil a number of roles, the more important of which are:

- full or partial integration into emergency arrangements at local, regional, national or supra-national levels (ie, subject to interfacing with radiological monitoring and meteorological networks and with the decision making process)
- providing a more effective means for communication and exchange of monitoring data, prognoses of accident consequences, etc, between countries
- 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 a professional interest in and/or responsibility for off-site emergency management
- contributing to improvements in existing decision support systems through the development and dissemination of improved stand alone modules
- a research and development tool to explore the merits and limitations of new techniques or approaches prior to their integration into operational decision support systems
- providing greater transparency in the decision process as a contribution to better public understanding and acceptance of emergency actions
- a basis or framework for decision support systems for the management of non-nuclear emergencies with potential widespread off-site consequences.

Not all roles will be of interest or relevant to every potential user. Consequently, the system has been designed in a modular way so that it can be tailored to the user's particular needs.

The roles for which RODOS is being designed largely determine its potential users. These include those responsible at local, regional, national and supra-national levels for off-site emergency management and related training, for the operation of nuclear installations, for public information, or for communication and exchange of information (eg, in accord with bilateral or international agreements); the research and development community concerned with improving decision support for off-site emergency management; and developers of decision support systems for the off-site management of non-nuclear emergencies.

I.2.2 Status of the system and its future development

A first prototype of the RODOS system was completed in 1992 and installed in institutes in Belarus, Germany, Greece, Hungary, Russia, Poland, Romania, the Slovak Republic and the Ukraine. A second prototype was completed in the autumn of 1995, the end of the first phase of the project (ie, the Commission's 3rd RTD Framework Programme). A pre-operational version (Version 3.0), with functionality limited to the early and intermediate stages of an accident, was completed in mid-1997. This version has been developed specifically for on-line testing in emergency centres, where it will be interfaced with meteorological and radiation monitoring networks and the decision making process itself, albeit in a pre-operational mode. Descriptions of the overall design of the system, its software/hardware environment, the technical content of its modules, its current status and plans for its implementation can be found elsewhere in this volume and in other publications [1-12]. Current developments and progress with the system are reported in periodic issues of the RODOS Newsletter [13], copies of which can be obtained on request.

Further development of the system will focus on extending its applicability to encompass all stages of an accident (ie, to the late stage including the long term management of contaminated land and the subsequent return to "normality" after an accident) and making improvements in those areas where there is a demonstrable need. Two topics will receive particular attention in the latter context: firstly, the development of an integrated approach for the handling of uncertainties and their effective communication to decision makers (an important issue that has received insufficient attention in the past) and, secondly, the development of improved methods for assimilating and making better use of expert judgement, model predictions and monitoring data. Improvements will also be made in response to experience gained in the pre-operational use and testing of the system in several European countries, in particular its interface with meteorological and radiological monitoring networks and with the decision making process. Important feedback has already been obtained from using the prototype system in exercises with decision makers and this aspect will receive increasing attention in future. A fully operational and comprehensive version of RODOS, applicable throughout Europe, is scheduled for completion by mid-1999, the end of the second phase of the project.

With the completion of the pre-operational version of the system, potential users are increasingly recognising the many benefits which RODOS offers. In particular, its potential role as part of a wider European network has become evident. The existence of such a network would promote a more effective and coherent response to any future emergency in Europe. Four factors will largely determine how far and how quickly the RODOS system (or elements of it) finds operational use as part of emergency arrangements within Europe: firstly, the results of pre-operational testing of the pilot version in several countries; secondly, the extent to which the technical objectives of the second phase of the project are achieved; thirdly, a commitment by countries in Europe to take advantage of these new developments, a matter which will be influenced by broader and largely non-technical considerations; and, fourthly, the extent to which assistance can be made available to accelerate the implementation process in Eastern Europe. The interest currently being shown in the system by many EU and East European countries augurs well for its future use. Subject to the successful testing of the pre-operational version (applicable to the early and intermediate stages of an accident) and assistance to accelerate its implementation in Eastern Europe, the basis of a European network of RODOS centres could be in existence by the end of 1998.

I.3 The Commission's Inter-service OSEP Group

Considerable resources have been, and continue to be, committed by the European Commission and others to improve nuclear safety in Eastern Europe. These efforts have, quite properly, concentrated on the first two links in the nuclear safety chain, ie, the prevention of accidents and their mitigation should they occur. The G-24 mechanism has provided a means of overall co-ordination of the projects undertaken in these two areas, regardless of the particular national or international origin of support for specific initiatives. Lesser, but not insignificant, resources have also been committed to improve the third link in the nuclear safety chain, ie, off-site nuclear emergency preparedness and response; the G24 co-ordination mechanism does not, however, extend to projects in this area. The absence of effective co-ordination in this latter area has inevitably led to some duplication of assistance and a less than efficient use of limited resources; in extreme cases incompatible support may have even been provided to individual beneficiary countries.

With a view, *inter alia*, to improving future co-ordination in this area, both within and beyond the Commission, an inter-service working group was established within the Commission on nuclear Off Site Emergency Preparedness (OSEP). The Group was set up in mid-1995 with three main objectives:

- to contribute to improvements in local, regional, and national off-site emergency preparedness arrangements in Eastern Europe
- to establish and/or improve arrangements for information exchange within Eastern Europe and with the European Union (EU) in the event of any future nuclear emergency
- to contribute to better co-ordination, both within and beyond the Commission, of assistance in the area of off-site emergency preparedness and response.

and with the following terms of reference:

- to develop a coherent and integrated programme within the Commission to improve off-site emergency preparedness in Eastern Europe
- to formulate priorities within this integrated programme
- to advise the TACIS/PHARE Nuclear Safety Programme (which is the primary avenue for channelling Commission support to the beneficiary countries on nuclear safety matters) in developing a well balanced programme for improving nuclear safety (ie, balanced in terms of accident prevention, on-site mitigation and off-site emergency preparedness)
- to advise the TACIS/PHARE Nuclear Safety Programme on how and where resources could be most effectively allocated to improve off-site emergency preparedness in Eastern Europe
- to be consulted and to advise on the scope and content of all projects supported by the Commission concerned with off-site nuclear emergency preparedness in Eastern Europe and to evaluate their progress
- to establish appropriate means to co-ordinate/integrate the Commission's programme with other bi- and multi-lateral initiatives being taken in this area, in particular to minimise duplication and achieve a better utilisation of resources.

The following Directorate Generals (DG) of the Commission are currently formally represented on the OSEP Group: ECHO (European Community Humanitarian Office), DG IA (External Political Relations - TACIS/PHARE Nuclear Safety Programme), DG III (Industry), DG XI (Environment, Nuclear Safety and Civil Protection), DG XII (Science, Research and Development), DG XIII (Telecommunications, Information Market and Exploitation of Research), DG XVII (Energy) and the Secretariat-General; arrangements exist to involve others as need or interest dictates. The Secretariat and Chairman of the Group were initially provided by ECHO; these roles have subsequently been taken over by DGIA.

Following its creation the OSEP Group reviewed the Commission's existing and planned activities in this area as an input to establishing a coherent and integrated programme of assistance. Apart from the decision support system, RODOS (see Section 2), being developed within the Commission's RTD programme, the only other major project at that time was the implementation, with support from the TACIS programme, of the first stage of an early warning system, GAMMA-1 [14], for nuclear accidents in Belarus and Ukraine in the form, *inter alia*, of automatic environmental gamma monitoring facilities. Two immediate priorities were identified by the OSEP Group to enable it to meet its objectives. The first (in response to the first of the Group's objectives) was to commission an assessment of needs in each of the countries concerned; clearly these should largely determine the nature and content of any future assistance programme. The second (in response to the second of the Group's objectives) was to explore possible means for improving the exchange of radiological information across Europe as a whole in the event of any future accident.

I.3.1 Needs Assessment

The need for assistance in the area of off-site emergency preparedness, as part of a balanced approach to improving nuclear safety in Eastern Europe, is beyond question. However, it was judged essential for these needs to be prioritised, both within and between countries, in order to develop a well considered and directed assistance programme within the financial resources which might be available. Moreover, it was also essential to identify what assistance had been or was being provided through other bi- or multi-lateral assistance programmes, both to avoid duplication and to allocate future assistance more effectively.

The objectives of the needs assessment were:

- to determine the current status of off-site emergency preparedness in each potential beneficiary country
- to identify the nature and content of past, current and foreseen bi- or multi-lateral assistance projects
- to evaluate current and/or foreseen arrangements
- to identify where assistance is needed to bring off-site emergency preparedness to an adequate level
- to establish priorities for assistance within and between countries
- to prepare a data base to facilitate the implementation and monitoring of any future EC assistance programme.

The countries included in this initial "needs assessment" were Belarus, Bulgaria, the Czech Republic, Estonia, Hungary, Kazakhstan, Latvia, Lithuania, Romania, Poland, Slovakia, Slovenia, Russia, and the Ukraine; Armenia was subsequently included. The topics covered by the needs assessment included the following:

- legislative bases
- organisational arrangements and responsibilities
- on-site arrangements (in so far as they affect off-site emergency preparedness)
- off-site monitoring and early warning
- communications (local scale to international scale)
- arrangements for informing the public

- arrangements and criteria for countermeasures
- impact forecasting and decision support capabilities
- emergency response services capabilities
- exercises and training.

Consultants were appointed by the Commission to carry out this "needs assessment" which was completed in early 1996; the assessment in Armenia is ongoing and expected to be completed by the end of 1997. To ensure a systematic and structured approach to the collection and documentation of information from each country on the status of off-site emergency preparedness, a comprehensive questionnaire was developed covering each of the above topics. The responses to the questionnaire were used to identify and prioritise needs in each area by comparison with a "benchmark" set of requirements/performance standards. The latter was developed within the project to be representative of good practice in the EU as a whole and its use ensured a consistent approach to the identification of needs. Inevitably, some flexibility had to be incorporated in the use of this benchmark to accommodate differences in national practice.

The status of off-site emergency preparedness in each country has been compiled in a data base (which includes, *inter alia*, responses to the questionnaire) that can be readily interrogated to identify needs in each of the topic areas. In addition, a data-base has been compiled of past, current and foreseen bi- and multi-lateral assistance projects; this should enable a more integrated approach to future assistance and help minimise duplication.

I.3.2 Response to the Needs Assessment

Based on the Needs Assessment, a number of priority areas were identified as requiring early attention. Assistance projects were defined in order to respond to these more pressing needs. In each case, Terms of Reference (TOR) were developed for the purposes of competitive tendering. The scope, content and current status of these projects are tabulated below. In addition a number of other assistance projects, concerned mainly with the provision of equipment and protective clothing for off-site emergency personnel, are in the process of being developed for implementation in early 1998.

A multi-annual programme of technical assistance is also being prepared and will provide a more integrated and coherent response to the "needs assessment". This will be completed by mid 1998 and discussed with the beneficiaries and other potential donors (in particular with Member States of the EU). Account will be taken of developments in each country since the needs assessment was completed, in particular of any changes in priorities and assistance that may have since been provided. The various data bases of needs and assistance will be maintained and updated and, subject to the agreement of the beneficiaries, will be made more generally available; this will help minimise duplication and contribute to more effective assistance from potential donors in future.

Assistance Project	Beneficiaries	Status
Iodine tablets (approx 0.8 million packages) for population in emergency planning zones and emergency personnel	Belarus, Bulgaria, Hungary, Latvia and Romania	Completed early 1997
Protective clothing and dosimetric equipment for emergency teams	Hungary, Lithuania, Romania and Ukraine	Completed mid 1997
Improvement of communications with and between emergency teams	Bulgaria, Hungary, Kazakhstan, Latvia, Romania, Slovak Republic and Ukraine	Out to tender, late 1997
Early warning system around three NPPs in Russia	Russia	Tender evaluation, October 1997, Contract award, late 1997
Accelerated implementation of RODOS	Hungary, Ukraine	Tender, November 1997 Contract award, early 1998
Accelerated implementation of RODOS	Poland, Slovak Republic	Tender, November 1997 Contract award, early 1998
TRAINING **a) Preparation of training modules/material**	All	Completion, mid 1998
b) Training centre infra-structure and delivery of training courses	Lithuania and Slovak Republic (including all other CEE countries and Baltic States)	Tender, end 1997 Contract award, early 1998
c) Training centre infra-structure and delivery of training courses	Russia (including Belarus and Ukraine)	Tender, end 1997 Contract award, early 1998

I.3.3 International Data Exchange

In the event of a nuclear accident the rapid and reliable exchange of radiological information, both within and between potentially affected countries, is a pre-requisite for timely, effective and coherent emergency response. The timely and efficient exchange of information between countries is of particular importance within Europe given the widespread use and dispersal of nuclear installations and the potentially large number of countries which may be affected, directly or indirectly, by any future accident. The establishment and/or improvement of arrangements for information exchange within Eastern Europe and with the EU is the second of the two objectives of the OSEP Group.

Following the Chernobyl accident major improvements were made in the exchange of information following a nuclear accident. In particular, an international Convention was established by IAEA [15] and a decision taken by the Council of Ministers of the European Communities [16]; the latter was implemented through what is now known as the European Community Urgent Radiological Information Exchange (ECURIE) system [17]. In addition a large number of bi-lateral arrangements have been made between neighbouring countries. More recently a pilot project, European Union Radioactivity Data Exchange Platform (EURDEP) [18], was initiated to investigate improved means for data exchange, in particular in a continuous and automatic manner; a number of topics are being addressed, including common data formats and the possible establishment of a "European network" based initially on existing monitoring stations approximating to a 100 by 100 km grid. Notwithstanding the considerable progress that has been made since the Chernobyl accident, it is evident that much more could and needs to be done to make best use of the very large amounts of radiological monitoring and other data (eg, accident consequence prognoses, etc) that would be generated in the event of any future accident and to benefit from the major and continuing advances in informatics and communications.

The development of a system for the on-line exchange of radiological information between European countries would greatly improve the efficacy and timeliness of off-site response to any future nuclear accident that may occur in Europe. In this context, TOR have been prepared for the development and testing of a prototype of such a system and will be used as the basis of tendering in late 1997. Installation of the prototype system is expected to be completed in 1998 and a testing programme begun.

The system concept is based upon having a number of regional centres in Europe which will communicate with each other, with each regional centre also communicating with national centres within its region. Both measured (eg, monitoring data) and processed data (eg, prognoses of accident consequences, etc) are to be exchanged. The immediate priority is to demonstrate the functionality of the system, in particular the exchange between regional centres and between a regional centre and several national centres. For reasons of cost and simplicity, the scope of the project (see Figure 2) is initially being limited to the minimal number of centres necessary to demonstrate functionality of the system; the current plan is to establish two regional centres, one in Russia and the other in Hungary, with the former linked to national centres in Belarus, Russia and Ukraine and the latter solely to a national centre in Hungary.

In addition, data would be exchanged with a regional centre/s in Western Europe. Subject to demonstrating the success of the prototype, consideration would be given to the wider implementation of the system. At this stage, however, the objectives are limited to demonstrating system functionality and the benefits of timely data exchange for effective emergency response; the actual exchange of data in practice would be subject to political agreements between the countries concerned.

I.3.4 References

1. Ehrhardt, J, et al, RODOS - Decision Making Support for Off-site Emergency Management after Nuclear Accidents. Kerntechnik, 62 (2/3), 1997.
2. Ehrhardt, J, et al, RODOS: Real-time On-line Decision Support System for Off-site Emergency Management in Europe. IN Proc of Int Topical Meeting on Severe Accident Risk and Management (SARM), Piešt'any, Slovakia, June 1997 (in press)
3. Kelly, G N, Ehrhardt, J and Shershakov, V M, Decision support for off-site emergency preparedness in Europe, Radiat. Prot. Dosim. 64(1/2), 129-141 (1996).

4. Ehrhardt, J, Shershakov, V, Zheleznyak, M and Mikhalevitch, A, RODOS: Decision support system for off-site emergency management in Europe. IN First International Conference of the European Commission, Belarus, the Russian Federation and Ukraine on the Consequences of the Chernobyl Accident, Minsk, 18-22 March (1996), (Office for Official Publications, EC, Luxembourg), EUR 16544, 1075-1086, (1996).

5. Shershakov, V, Ehrhardt, J, Zheleznyak, M and Mikhalevitch, A, The implementation of RODOS in Belarus, Russia and Ukraine and future perspectives. EUR 16544 (see Ref. 4.) pp. 1097-1108.

6. Schüle, O, Rafat, M and Kossykh, V, The software environments of RODOS. EUR 16544 (see Ref. 4.) pp. 1109-1118.

7. Glushkova, V and Schichtel, T, Modelling of early countermeasures in RODOS. EUR 16544 (see Ref. 4.) pp. 1119-1128.

8. Brown, J, et al, Modelling of agricultural countermeasures in RODOS. EUR 16544 (see Ref. 4.) pp.1129-1138.

9. Zheleznyak, M, et al, Modelling of hydrological pathways in RODOS. EUR 16544 (see Ref. 4.) pp.1139-1148.

10. Borzenko, V and French, S, Decision analytic methods in RODOS. EUR 16544 (see Ref. 4.) pp.1149-1158.

11. Proceedings of the Sixth Topical Meeting on Emergency Preparedness and Response, American Nuclear Society, San Francisco, April 22-25, 1997, Sessions 2-5 and 2-6: RODOS Development and Application, pp397-430, 1997.

12. Proceedings of the Fourth International Workshop on Decision Support for Systems for Off-site Emergency Management, Aronsborg, Sweden, 6-11 October 1996, RODOS Session, to be published in Rad Prot Dosim (Nuclear Technology Publishing, UK), 1997.

13. RODOS Newsletter (J Ehrhardt, Ed), Forschungszentrum Karlsruhe GmbH, INR, Germany.

14. Jousten, N and Jeanes, P, The GAMMA-1 project. IN First International Conference of the European Commission, Belarus, the Russian Federation and Ukraine on the Consequences of the Chernobyl Accident, Minsk, 18-22 March (1996), (Office for Official Publications, EC, Luxembourg), EUR 16544, 1173-1176, (1996).

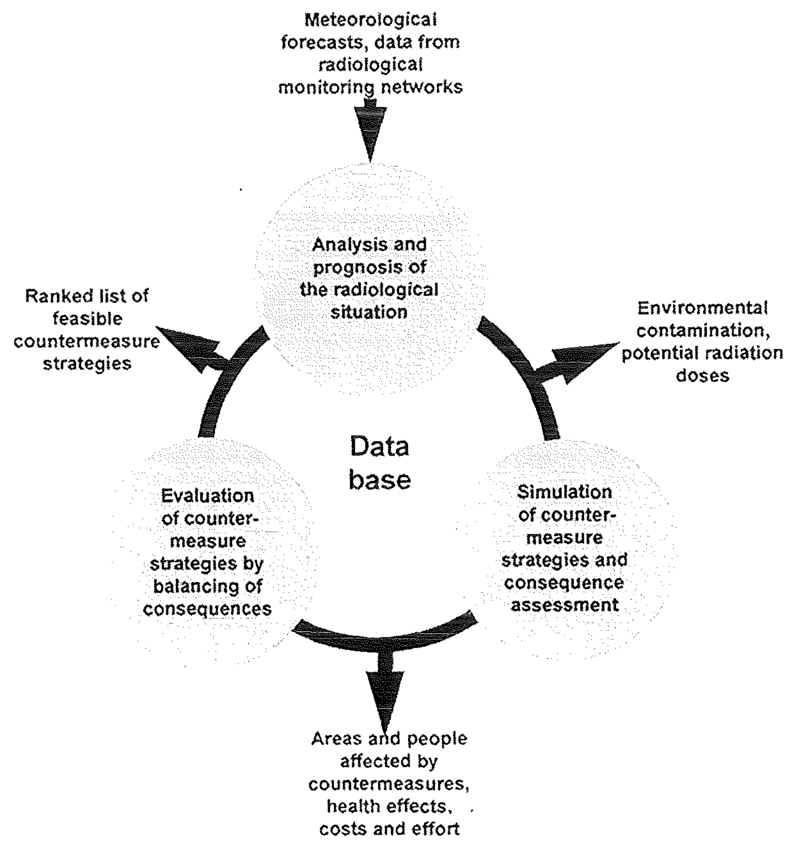
15. IAEA, Convention on early notification of a nuclear accident. Vienna, (1986).

[16] Council Decision, 87/600/EURATOM, on Community arrangements for the early notification of information in the event of a radiological emergency (OJ L371/76 of 30/12/87).

[17] Vadé, S, Die Europäische Union und der Strahlenschutz der Bevölkerung bei einer radiologischen Notstandssituation, FS-94-74-I, Stand des Notfallschutzes in Deutschland und der Schweiz, ISSN 1013-4506, 385-390, (1994).

[18] De Cort, M, Leeb, H, De Vries, G, Breitenbach, L and Weiss, W, International exchange of radiological information in the event of a nuclear accident - future perspectives. IN First International Conference of the European Commission, Belarus, the Russian Federation and Ukraine on the Consequences of the Chernobyl Accident, Minsk, 18-22 March (1996), (Office for Official Publications, EC, Luxembourg), EUR 16544, 1159-1169, (1996).

Figure 1 The main elements of the RODOS decision support system



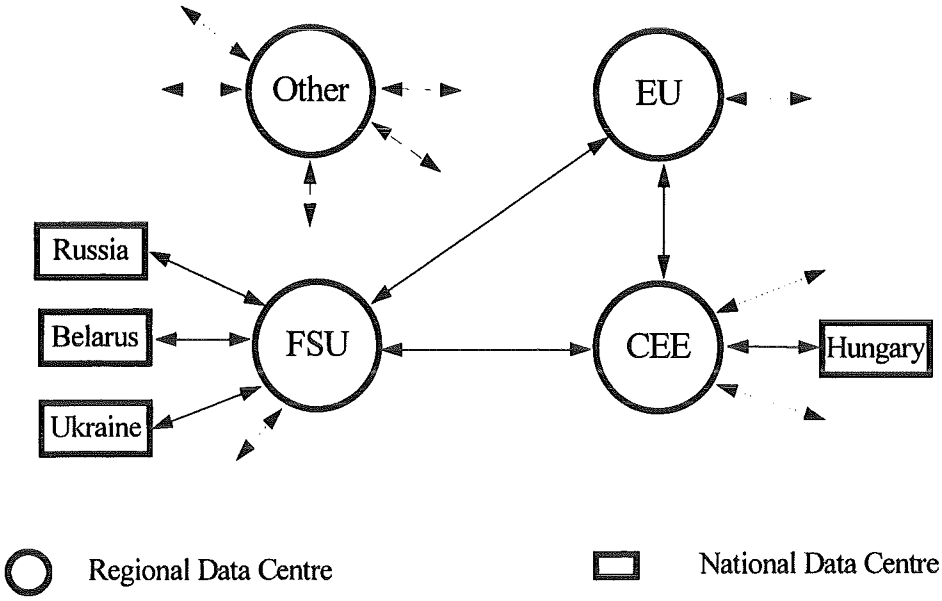


Figure 2: Prototype System for Data Exchange

II The RODOS System: Decision Support for Off-site Emergency Management in Europe

Joachim Ehrhardt
Forschungszentrum Karlsruhe, Institut für Neutronenphysik und Reaktortechnik,
Postfach 3640, D-76021 Karlsruhe

Abstract

The integrated and comprehensive Real-time On-line DecisiOn Support system, RODOS, for off-site emergency management of nuclear accidents is being developed with support of the European Commission and the German Ministry of Environment. Designed as a generic tool, the RODOS system will be applicable from the very early stages of an accident up to many years after the release and from the vicinity of a site to far distant areas. Decision support will be provided at various levels, ranging from the largely descriptive with information on the present and future radiological situation, to an evaluation of the benefits and disadvantages of different countermeasures' options. A large number of West and East European institutes are involved in its development to operational use. This paper gives an overview of the structure, the content, the main functions and the development status of the RODOS system and discusses its potential role for improving emergency response in Europe.

II.1 Background

Following the Chernobyl accident, increased resources were allocated to the development of decision support systems for off-site emergency management in a number of institutes world-wide. However, there is no generally accepted consensus about the structure, hardware and software configurations, access to monitoring data, measurements and databases, the extent of accident consequences to be estimated and the models applied, and the evaluation and graphic presentation of results. In the case of any future accident, the manifold systems will produce more or less different answers and thus will not ensure an integrated, coherent and consistent response.

Therefore, the European Commission began in late 1990 as a major item in the Radiation Protection Research Action of the 3rd R&D Framework Programme (1991-1994) the development of RODOS, a unique Real-time On-line DecisiOn Support system, that would provide consistent and comprehensive support for off-site emergency management on a local, regional and national level at all times following an accident and that would be capable of finding broad application across Europe unperturbed by national boundaries [1]. Besides the application in real emergencies, the use of RODOS for training and education in radiological protection and emergency management is one of the major objectives of the project. These applications will have a positive feedback on the further development for operational use of the user interface and of data and models.

The roles for which RODOS has been designed largely determine its potential users. These include those responsible at local, regional, national and supra-national levels for off-site emergency management and related training, for the operation of nuclear installations, for public information, or for communication and exchange of information (e.g., in accord with bi-lateral or international agreements); the research and development community concerned with improving decision support for off-site emergency management; and developers of decision support systems for the off-site management of non-nuclear emergencies.

II.2 Main Functions and Characteristics of RODOS

II.2.1 Capacity for Generic Use in Europe

RODOS is designed as a comprehensive system incorporating models and databases 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 it 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 to run on workstations with the UNIX operating system; in particular its software framework supports the integration of application software developed externally by many of the contractors[2,3,4]. The modular structure of RODOS allows the exchange of models and data, and thus facilitates the adaptation of the system to the local/regional and national conditions.

II.2.2 Levels of Information Processing

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: Analysis and prediction 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, including 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.

Most decision support systems that have been developed to an operational state are limited to levels 0 or 1. A few extend to level 2 or even level 3 but, in general, are limited in the range of countermeasures they address or in the completeness of benefits and disadvantages that are considered.

II.3 Structure and Content of RODOS

II.3.1 Conceptual Design

In recognition of the need for a unique and integrated real-time on-line decision support system that will provide consistent and comprehensive information from Level 0 to Level 3, the basic concept, content and design of RODOS were specified and agreed by participants at the outset of the project. The conceptual RODOS architecture is split into three distinct subsystems, which are denoted by ASY (Analysing Subsystem), CSY (Countermeasure

Subsystem) and ESY (Evaluating Subsystem) [1]. The interconnection of all program modules, the input, transfer and exchange of data, the display of results, and the interactive and automatic modes of operation are all controlled by the specially designed Operating System OSY. 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 databases comprising (i) real-time data with information coming from regional or national radiological and meteorological data networks, (ii) geographical data defining the environmental conditions, (iii) program data with results obtained and processed within the system, and (iv) facts and rules reflecting feasibility aspects and subjective arguments.

The content of the subsystems and the databases will change with the application 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. A Supervising Subsystem (SSY) of the OSY under development will manipulate the components of RODOS in order to respond to user requests.

RODOS can be run in two modes of operation. 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 time cycle (e.g. 10 minutes in the early phase of emergency protection). 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. Cyclic processing is carried out synchronous with the incoming monitoring data of automated radiological information networks. Interaction with the system is limited to a minimum of user input necessary to characterise the current situation and adapt models and data.

Either in parallel to the automatic mode or alone, RODOS can be operated in the interactive mode. In particular, in the later phases of an accident, when longer-term protective actions and countermeasures must be considered and no quick decisions are necessary, or for emergency planning, exercises and education under normal non-accident conditions, this mode is more important. Editors specially developed for the menu-driven user interaction 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 dialogue between RODOS and a user is performed via various user-interfaces tailored to the needs and qualification of the user. The access rights of different user groups determine the type of user-interface, which allows increasing access to models, data and system parameters in a hierarchical structure. Thus, easily understandable but very limited interface for training courses on emergency management is on the top of the hierarchy and the full spectrum of interaction tools for system developers familiar with the system ingredients and structures is on the bottom.

II.3.2 Diagnosis and Prognosis of the Radiological Situation

The main purpose of the subsystem **ASY** is the estimation of the present and future distributions of activity concentrations in the environment and the calculation of radiation doses and dose rates, irrespective of any protective actions or countermeasures taken. A nested atmospheric model chain applicable for all relevant scales (local, national and European wide) has been identified and the corresponding programs are now being interconnected for operational application in RODOS, where they will be connected on-line to local synoptic stations and forecasts of national weather services[2,4,6].

For near range flow and dispersion calculations, the model chain consists of the mass consistent flow model MCF[2,6] and the linearised flow model LINCOM[2,6], and either the puff-model RIMPUFF[2,6] or the simplified puff-model ATSTEP[2,6], which both have already been integrated. For applications in complex terrain, the prognostic flow model ADREA[2,6] and the Lagrangian dispersion model DIPCOT[2,6] have been made available for the RODOS system. For mesoscale and long-range applications, the Eulerian K-model MATCH[2,6] will be nested with the puff model RIMPUFF.

Main objective of the next project period will be the completion of the meteorological and atmospheric dispersion model chain for all distance ranges and its coupling to local synoptic stations and weather forecasts of the national weather services (e.g. HIRLAM[2,6]). Progress has already been made in this direction with support of SPA TYPHOON, who integrated in RODOS their long range atmospheric dispersion models together with software for accessing and evaluating weather forecasts for Europe from meteorological services (Washington, Moscow, Bracknell, Toulouse).

For the assessment of human radiation exposure, RODOS incorporates the module group ECOAMOR for calculating individual doses via all exposure pathways, in particular ingestion [7]. It has been developed on the basis of the dynamic radioecological model ECOSYS-87[8]. Inputs to ECOAMOR are the contamination of air and ground surface provided by the atmospheric dispersion models. Additionally, data on foodstuff production together with a large number of parameter values characterising the transfer processes in the radioecological scenario considered are required. Many of these parameters vary to a large extent over the different the regions in Europe; investigations are under way to identify radioecological regions in Europe and to compile for each a full set of model parameters and - if necessary - to adapt to each model characteristics.

In 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 [3,4,17] presently under development, 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. The pilot version 3.1 of RODOS will contain such methods for near range atmospheric dispersion, by mid 1999 they will be extended to far distance calculations.

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. Methodological investigations have already been started on how to assess and propagate uncertainty estimates through the various modules of the RODOS system [3]. The further development of these techniques for operational use will be a main objective of the 4th Framework Programme, and the planning foresees the quantification of uncertainties in the near range models of RODOS by mid 1999.

II.3.3 Countermeasures and Consequences

The countermeasure and consequence subsystem **CSY** mainly serves to quantify the benefits and drawbacks of various combinations of protective actions and countermeasures together with the technical equipment and manpower required. Currently, it incorporates

- the module group EMERSIM[9] for simulating sheltering, evacuation and distribution of stable iodine tablets,
- the module group FRODO[3,11] for simulating relocation, decontamination and agricultural countermeasures,
- the module HEALTH for quantifying stochastic and deterministic health effects[3]
- the module ECONOM for estimating the economic costs of emergency actions, countermeasures and health effects[3].

The early emergency actions considered in EMERSIM can be defined indirectly by dose intervention criteria or directly by graphical input of areas. Important endpoints are areas and number of people affected and individual doses with and without emergency actions. In the present version of EMERSIM, the assumption is made, that before and during evacuation the dose rate is constant and identical with the home location. In the next versions of EMERSIM, a more realistic modelling of exposure during evacuation will be possible by using the results of the evacuation simulation module EVSIM [9,10], which is capable of taking into account the most important factors that may influence the success and effectiveness of this measure, such as traffic network and conditions, availability of transportation means, population distribution, weather conditions and time of accidental release. It will be completed by the optimisation module STOP[4,10], which is able to optimise routes for evacuation with respect to route length, dose saved, starting time and costs.

The relocation model in FRODO[3,11] uses criteria for the imposition and relaxation of permanent and temporary relocation in the form of dose levels. The endpoints evaluated relate to the areas of land interdicted, the time periods over which this occurs, the number 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.

The impact of decontamination on relocation can be evaluated for decontamination occurring either before or after relocation is implemented. The agricultural countermeasures considered in FRODO are: banning and disposal, food storage, food processing, supplementing animal feedstuffs with uncontaminated, lesser contaminated or different feedstuff, use of sorbents in animal feeds or boli, changes in crop variety and species grown, amelioration of land, decontamination of agricultural areas and change in land use.

II.3.4 Hydrological Pathways

The evaluation of the radiological and environmental consequences of the Chernobyl accident demonstrated the significant contribution of contaminated water bodies. 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 exchange with sediments and the behaviour of radionuclides in lakes. The corresponding models RETRACE (run-off) [12], RIVTOX [12] and COASTOX (rivers) [12] and LAKECO (lakes) [12] have been coupled, implemented in RODOS and adapted to the Rhine river system. Other river systems can be readily implemented in RODOS using the same model chain subject to gathering appropriate data.

II.3.5 Evaluation of Countermeasure Combinations

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 ESY subsystem will become operational in the next project period [3].

II.4 Project status and future developments

The development of RODOS began in late 1990 as a major item in the Radiation Protection Research Action of the European Commission's 3rd R&D Framework Programme (1991-1994. For institutional reasons, participation in the project was initially restricted to EU institutes. Forschungszentrum Karlsruhe (FZK), Institut für Neutronenphysik und Reaktortechnik (INR), has co-ordinated the project throughout and, inter alia, has overall responsibility for developing the system and integrating the software products of other contractors. About 10 EU institutes were initially involved in the project increasing since to more than 20. Means were subsequently found to broaden the scope of participation beyond the EU with two main benefits: firstly, greater and more diverse resources were made available to the project leading to a better final product and, secondly, the opportunity to develop a system that would be applicable throughout Europe as opposed to the narrower confines of the EU. The latter is particularly important in terms of achieving effective and timely response to any future nuclear emergency. About 10 institutes from Belarus, Russia and the Ukraine were formally integrated within the project in 1992 under the auspices of a collaborative programme on the consequences of the Chernobyl accident between the EC and the State Committees on Chernobyl Affairs in the respective countries [4]. Institutes from Poland (in 1993), Hungary, Romania and the Slovak Republic (in 1994) have joined the project under the European Commission's PECO programme (pays d'Europe Centrale et Orientale - Scientific and Technical Cooperation with Central and East European Countries) [3]. By 1995 almost 40 institutes were involved in the development of RODOS with about half of them from Eastern Europe. This wide and diverse participation in the development of the system augurs well both for its efficacy and future implementation.

Under the auspices of the European Commission's R&D Programme, the basic hardware and software components of the RODOS system have been transferred to institutes in East European countries, namely, Belarus, Hungary, Poland, Romania, Russia, Slovak Republic and the Ukraine. Effective working arrangements between the project partners in the West and the East, in particular the institutes in the CIS Republics, have been established and a full integration in one co-ordinated working programme has been achieved [4]. Most of the countries mentioned above have committed themselves to actively cooperate in the further development of RODOS for operational use, the customisation of its databases and models to local, regional and national conditions, the establishment of interfaces with national meteorological and radiological monitoring networks, and its final integration and operation in the national emergency management arrangements. Moreover, the prospect of interconnected RODOS systems running in Western and Eastern European countries has been widely accepted as an important step forward to an improved emergency management in the case of any future nuclear accident.

The system will be further developed with support from each of the participating institutes and from the Commission's 4th Framework Programme (1995-1998). Currently two RODOS contracts are in place and 3 further proposals have been accepted by the European Commission with new partners in the Czech Republic, Finland, France, the Netherlands, Switzerland, and requests to participate have been received from others (Portugal, Spain). Besides the R&D areas already mentioned in this paper, key elements of these new contracts and proposals are

- the development of common methodologies and the corresponding software packages for estimating early the source term from in-plant information before measurable releases, and
- the enhancement and customisation of the RODOS system for operational use in Nordic and Eastern European countries.

Assuming successful contract negotiations, by the end of 1996 / beginning of 1997 altogether 36 EU and East European institutes will be involved in a fully integrated manner. The overall project control will be exercised vertically within each of the RODOS contracts on three levels of interaction: the RODOS Management Group (RMG), the Principal Contractors and the Co-ordinator. The more detailed technical work within the overall RODOS project will be managed horizontally by twelve Working Groups on special topics. 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 within the defined milestones and deliverables of the project, and to identify problems and issues which need broader discussion. Working Group Leaders (WGLs) have been appointed jointly by the co-ordinators of the RODOS contracts in agreement with the RODOS Management Group. The results of the WG meetings are reported to the RMG via the responsible co-ordinators. Information of common interest is exchanged through the RODOS Newsletters, issued by the Forschungszentrum Karlsruhe. A register of RODOS documents is also kept by Forschungszentrum Karlsruhe. It builds part of the WWW RODOS Homepage (http://rodos.fzk.de), which provides, inter alia, information on the RODOS project, its management structure, the institutes and the staff members involved.

The German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU) financially supports the development of RODOS/RESY [15], which builds an integrated component of RODOS. It is different only in its contents, i.e., in the selection of computer models and data sets, which limit its applicability to the immediate vicinity of a nuclear facility and the early phase of an accident. An overall concept for the central operation of the RODOS system with remote access by those organisations responsible for emergency management is currently being developed for Germany.

The prototype version PRTY 2.0 of RODOS has been released at the beginning of 1996 together with a first pilotversion PV 2.0 of RODOS/RESY for test-operational use in emergency centres. Coupling of RODOS/RESY to existing meteorological and radiological data networks, such as the nuclear reactor remote monitoring systems (KFÜs), and testing of the system under realistic conditions will be carried out in the next months and improvements will be made in response to experience gained. Important feedback has already been obtained from using the prototype system in exercises with decision makers [18] and this aspect will receive increasing attention in the future. This part of the system (i.e., application to the early and intermediate stages of an accident) will be brought to maturity in mid 1997 with the perspective of a full operational version of RODOS ready by mid 1999.

With the completion of the pilot version and a commitment from the Commission to support the further development of RODOS, potential users are increasingly recognising the many benefits which the system offers. In particular, its potential role as part of a wider European network has become evident. The existence of such a network would promote a more effective and coherent response to any future nuclear emergency in Europe. Four factors will largely determine how far and how quickly the RODOS system (or elements of it) finds operational use as part of emergency arrangements within Europe: firstly, the results of pre-operational testing of the pilot version in several countries in 1996/7; secondly, the extent to which the technical objectives of the second phase of the project are achieved; thirdly, a commitment by countries in Europe to take advantage of these new developments, a matter which will be influenced by broader and largely non-technical considerations; and, fourthly, the extent to which assistance can be made available to accelerate the implementation process in Eastern Europe. The interest currently being shown in the system by many EU and Eastern European countries augurs well for its future use. Subject to the successful pre-operational testing of the pilot version (applicable to the early and intermediate stages of an accident) and assistance to accelerate its implementation in Eastern Europe, the basis of a European network of RODOS centres could be in existence by 1997/8.

Acknowledgements

This work has been carried out with support from, *inter alia*, the European Commission under the auspices of its Nuclear Fission Safety Research Programme and from the German Ministry of Environment, Nature Conservation and Reactor Safety.

This paper was originally presented at the Fourth International Workshop, Aronsborg, Sweden, October 7 - 11, 1996 and was published in the Proceedings of that meeting published as Radiation Protection Dosimetry Vol. 73, Nos. 1-4 (1997), pp. 35-40. It is reproduced with permission of the publisher, Nuclear Technology Publishing.

II.5 References

1. Ehrhardt, J., Päsler-Sauer, J., Schüle, O., Benz, G., Rafat, M., Richter, J. Development of RODOS, a comprehensive decision support system for nuclear emergencies in Europe-an overview. Radiation Protection Dosimetry, Vol. 50, Nos 2-4, pp 195-203 (1993)
2. Final Report of contract FI3P-CT92-0044: Co-ordination of atmospheric dispersion activities for the real-time decision support system under development at FZK. in: European Commission, Radiation Protection Research Action, Final Report 1992-95, EUR Report, to be published
3. Final Report of contract FI3P-CT92-0036: Development of a comprehensive decision support system for nuclear emergencies in Europe following an accidental release to atmosphere. in: European Commission, Radiation Protection Research Action, Final Report 1992-95, EUR Report (to be published) and FZKA-Report 5772 (1996)
4. Ehrhardt, J., Shershakov, V. M. (Eds.). Real-time on-line decision support systems (RODOS) for off-site emergency management following a nuclear accident. European Commission, Report EUR 16533 (1996)

5. Schüle, O., Rafat, M. The software framework of RODOS. Proceedings of the "Fourth International Workshop on Real-Time Computing of the Environmental Consequences of an Accidental Release from a Nuclear Installation", Aronsborg, Sweden, 6 to 11 October 1996, Radiation Protection Dosimetry Vol 73 Nos.1-4,1997, pp. 41-44
6. Mikkelsen, T., Thykier-Nielsen, S., Meteorology and atmospheric dispersion, Proceedings of the "Fourth International Workshop on Real-Time Computing of the Environmental Consequences of an Accidental Release from a Nuclear Installation", Aronsborg, Sweden, 6 to 11 October 1996, Radiation Protection Dosimetry (this issue)
7. Müller, H. The modelling of exposure pathways. Proceedings of the "Fourth International Workshop on Real-Time Computing of the Environmental Consequences of an Accidental Release from a Nuclear Installation", Aronsborg, Sweden, 6 to 11 October 1996, Radiation Protection Dosimetry Vol 73 Nos.1-4,1997, pp.45-56
8. Müller, H., Pröhl, G., ECOSYS-87: a dynamic model for assessing radiological consequences of nuclear accidents, Health Physics 64, pp 232-252 (1993)
9. Päsler-Sauer, J., Schichtel, T. The simulation of early emergency actions in RODOS. Proceedings of the "Fourth International Workshop on Real-Time Computing of the Environmental Consequences of an Accidental Release from a Nuclear Installation", Aronsborg, Sweden, 6 to 11 October 1996, Radiation Protection Dosimetry Vol 73 Nos.1-4,1997, pp.71-74
10. Glushkova, V., Schichtel, T., Päsler-Sauer, J. Modelling of early countermeasures in RODOS. Proceedings of the First International Conference of the European Commission, Belarus, the Russian Federation and Ukraine on the Consequences of the Chernobyl Accident, Minsk, Belarus, 18-22 March 1996, Report EUR 16544 (1996), pp. 1119-1128
11. Brown, J., Smith, K. R., Mansfield, P., Smith, J. Models for decontamination, relocation and agricultural countermeasures in RODOS. Proceedings of the "Fourth International Workshop on Real-Time Computing of the Environmental Consequences of an Accidental Release from a Nuclear Installation", Aronsborg, Sweden, 6 to 11 October 1996, Radiation Protection Dosimetry Vol 73 Nos.1-4,1997, pp.75-80
12. Zheleznyak, M., Heling, R. Aquatic model chain. Proceedings of the "Fourth International Workshop on Real-Time Computing of the Environmental Consequences of an Accidental Release from a Nuclear Installation", Aronsborg, Sweden, 6 to 11 October 1996, Radiation Protection Dosimetry Vol 73 Nos.1-4,1997, pp. 67-70
13. Borzenko, V., French, S. Decision analytic methods in RODOS. Proceedings of the First International Conference of the European Commission, Belarus, the Russian Federation and Ukraine on the Consequences of the Chernobyl Accident, Minsk, Belarus, 18-22 March 1996, Report EUR 16544 (1996), pp.1149-1158
14. Kelly, G. N. European Commission's contribution to improving off-site emergency preparedness. Proceedings of the First International Conference of the European Commission, Belarus, the Russian Federation and Ukraine on the Consequences of the Chernobyl Accident, Minsk, Belarus, 18-22 March 1996, Report EUR 16544 (1996), pp. 1075-1086
15. Shershakov, V., Kossykh, V., Zheleznyak, M., Mikhalevich, A. The implementation of RODOS in Belarus, Russia and Ukraine, and future perspectives. Proceedings of the "Fourth International Workshop on Real-Time Computing of the Environmental Consequences of an Accidental Release from a Nuclear Installation", Aronsborg, Sweden, 6 to 11 October 1996, Radiation Protection Dosimetry Vol 73 Nos.1-4,1997, pp.85-90

16. De Cort, M. International exchange of radiological and meteorological information in the event of a nuclear accident-future possibilities. Proceedings of the First International Conference of the European Commission, Belarus, the Russian Federation and Ukraine on the Consequences of the Chernobyl Accident, Minsk, Belarus, 18-22 March 1996, Report EUR 16544 (1996), pp. 1097-1108
17. Smith, J. Q., Duranova, T., Dutton, M., French, S., Ranyard, D., Rojas, C., Sohier, A., Vlesshouwer, D. Data assimilation within RODOS. Proceedings of the "Fourth International Workshop on Real-Time Computing of the Environmental Consequences of an Accidental Release from a Nuclear Installation", Aronsborg, Sweden, 6 to 11 October 1996, Radiation Protection Dosimetry Vol 73 Nos.1-4,1997, pp. 57-60
18. Ahlbrecht, M., Borodin, R., Borzenko, V., Ehrhardt, J., French, S., Shershakov, V., Sohier, A., Trakhtengerts, E., Verbruggen, A. Decision support issues in RODOS: the needs of decision makers. Proceedings of the "Fourth International Workshop on Real-Time Computing of the Environmental Consequences of an Accidental Release from a Nuclear Installation", Aronsborg, Sweden, 6 to 11 October 1996, Radiation Protection Dosimetry Vol 73 Nos.1-4,1997, pp.81-84

III The Software Environment of RODOS

Oliver Schüle, Mamad Rafat,
Forschungszentrum Karlsruhe, Institut für Neutronenphysik und Reaktortechnik,
P. O. Box 3640, D-76021 Karlsruhe, Germany

Valery Kossykh
Scientific Production Association TYPHOON, Emergency Centre,
82, Lenin Street, Obninsk, Kaluga Region, 249020, Russia

Abstract

The Software Environment of RODOS provides tools for processing and managing a large variety of different types of information, including those which are categorised in terms of meteorology, radiology, economy, emergency actions and countermeasures, rules, preferences, facts, maps, statistics, catalogues, models and methods. The main tasks of the Operating Subsystem OSY, which is based on the Client-Server Model, 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 paper describes the software environment of RODOS, in particular, the individual modules of its Operating Subsystem OSY, its distributed database, the geographical information system RoGIS, the on-line connections to radiological and meteorological networks and the software environment for the integration of external programs into the RODOS system.

III.1 Introduction

The interconnection of all program modules, the input, transfer and exchange of data, the display of results and control of the interactive and automatic modes of operation of the system are all controlled by the Operating Subsystem OSY, which builds the central part of the Software Environment of RODOS. The main duties of OSY are the correct 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.

III.1.1 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 one of the key features 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. The task of the modules of the Analysing, Countermeasure and Evaluation Subsystems is just performing the model calculations for providing the required results.

III.1.2 Automatic and Interactive Mode

The dialogue between RODOS and a user can be organised in two different modes. In the so-called "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 emergency protection). For this purpose, all the data entered into the system in the preceding cycle (either on-line or entered by the user) are taken into account in the current cycle. Interaction with the system is limited to a minimum amount of user input necessary to characterise the current situation and adapt models and data.

Either in parallel to the automatic mode or alone, RODOS can be operated in the "interactive mode". In this dialogue mode, the user of the system and RODOS communicate via a menu interface. 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 (control system), SSY, supports users by generating a suitable flowchart by which subsystems and modules can be called, which is based on the inherent logic of the spatial and temporal sequence of physical processes and protective actions and countermeasures.

III.2 Brief Description of the Modules of OSY

III.2.1 The Message Interface and Communication Server

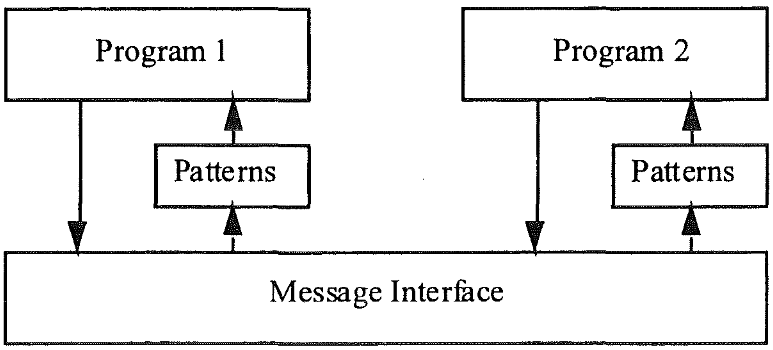


Figure 1: Message Interface of the RODOS System

The exchange of messages between the modules of the RODOS system is controlled by the Communication Interface. Each module can send messages to and receive messages from other modules. The messages contain fields which define the type, sender and recipient of the message. Three types of messages are considered by the Communication Interface:

- Requests are sent to other modules to ask for special services.
- Notification is sent back by the recipient if the request was successfully completed.
- Failures are sent back if some error occurred during the service.

On startup, each module sends a message to the Communication Interface, telling it the message patterns which should be sent to this module (c.f. figure 1).

The System Controller handles the program flow in the RODOS system. It uses information stored in the Database to decide which modules have to be called.

III.2.2 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 parts of 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 lead 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 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 independent 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 of function plots. A user interface gives the user the possibility of interacting 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 customized 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.

III.2.3 The Database Manager

A basic feature of the RODOS system is the centralized 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, sent to the programs on request and archived after calculations.

As the RODOS system will contain several different databases, only the Database Manager of RODOS is responsible for the exchange of data between the external programs and the different databases. A unique format for the transfer of data is used to facilitate the access to the data from the external programs.

III.3 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 of the RODOS operating system and will convert 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 (c.f. figure 2).

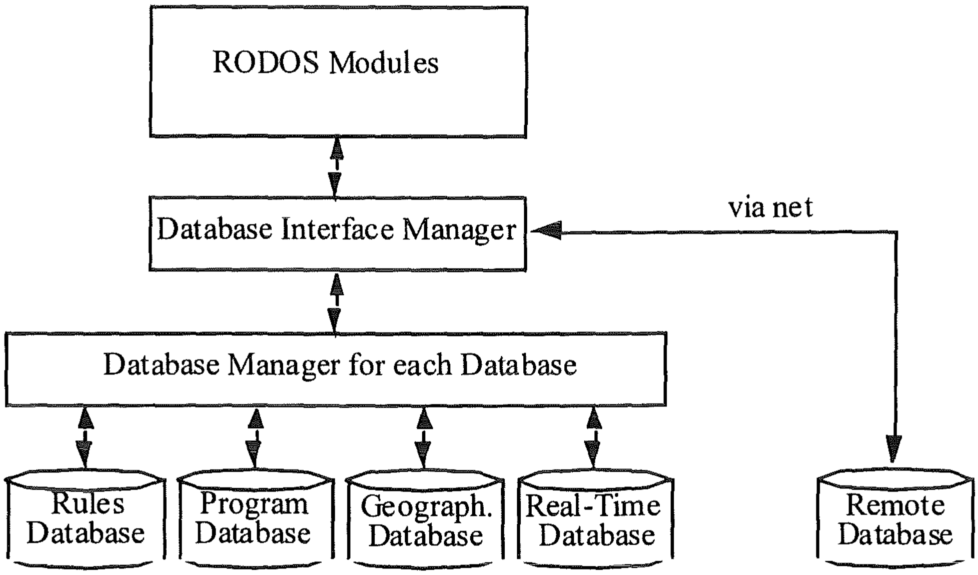


Figure 2: Structure of the RODOS Distributed Database

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 judgments, 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.

III.3.1 The Geographical Database

Geographical and statistical data are stored in the geographical database. These data are maintained by the geographical information system RoGIS, which is described in the next chapter.

III.4 The Geographical Information System 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 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 socalled 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. It will be available to other RODOS contractors with no license problems and no charge.

III.5 Remote Databases

The concept of distributed databases in the RODOS system allows the integration of remote databases, situated at different places. These remote databases can be either stand-alone databases (like ECURIE at ISPRA) or the databases of another RODOS system. An on-line connection to these databases is used to transfer the data.

As such remote databases can have different structures and contents, a tool has to be developed, which allows the easy exchange of data between the different database systems and handles the communication via the on-line network. The design of these tools uses the Client-Server approach to handle the data exchange and communication. The client part is responsible for the sending of the request, the server part handles the data exchange with the remote database. A well defined data format is used to send the requests and data via the on-line network.

In particular, the Client has to perform the following tasks:

- provide a user and program interface for the data access,
- create the message for the request and send it to the server,
- receive the data from the Server,
- provide the data to the user or the program.

The Server has to

- process the incoming requests for data,

- get the requested data from the remote database,
- send the data back to the Client via the on-line network.

Figure 3 shows the mechanism of processing requests to a database of a remote RODOS installation.

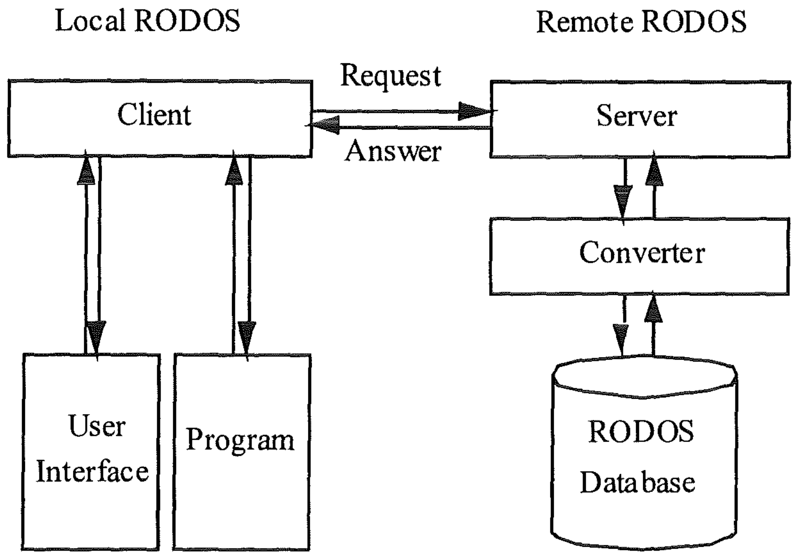


Figure 3: The Connection to Remote Databases

The Connection to the Databases at SPA TYPHOON was established as a first example of the remote database tools. This connection allows the exchange of weather forecasts (temperature, precipitation, wind).

A user interface was developed, which allows the user to define the data request. It allows the interactive input of the region, grid, type and other parameters, for the requested data. A second part of this user interface can display the requested data in form of fields on maps of different scale.

A server for processing the requests and sending the data back to the client via E-mail was developed. The data exchange is realised via the Internet data network. The request is sent using a mechanism of program interaction via Unix-Sockets, permitting a rather sophisticated interaction between the client and the server. E-mail was selected for the transfer of results as the most reliable tool available to pass large amounts of information.

The conducted trials with this software have shown good time characteristics, in particular, the request was sent from Karlsruhe (Germany) to Obninsk (Russia) in several seconds; the request was processed within one minute and the result (up to 50KB) was returned in about 3-5 minutes.

III.6 Integration of External Programs

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 of testing 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 above. In particular, the following steps have to be done:

- 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)

Acknowledgements

This paper was originally presented at the First International Conference, Minsk, Belarus, 18 to 22 March 1996, and was published in the Proceedings of that meeting published as EUR Report 16544 EN 73, pp. 1109-1118.

IV MET-RODOS: A Comprehensive Atmospheric Dispersion Module

Torben Mikkelsen, Soren Thykier-Nielsen, Poul Astrup, Josep Moreno Santabárbara
RISO National Laboratory, DK-4000 Roskilde, Denmark

Jens Havskov Sorensen, Alix Rasmussen
Danish Meteorological Institute, DK-2100 Copenhagen, Denmark

Lennert Robertson, Anders Ullerstig
Swedish Meteorological and Hydrological Institute, S-601 76 Norrköping, Sweden

Sandor Deme
Atomic Energy Research Institute, H-1525 Budapest, Hungary

Reinhard Martens
Gesellschaft für Reaktorsicherheit m.b.H., D-50667 Köln, Germany

John G. Bartzis
NCSR-Demokritos, Athens, Gr-15310, Greece

Jürgen Päsler-Sauer
FZK-Forschungszentrum Karlsruhe, P.O. Box 3640, D-76021 Karlsruhe, Germany

Abstract

A comprehensive meteorological dispersion module called MET-RODOS is being developed to serve the real-time RODOS (1, 2, 3) decision support system with an integrated prediction capability for airborne radioactive spread, deposition and gamma radiation exposure on all scales. Deposition, ground-level air concentrations, and ground level gamma dose rates from up to 15 simultaneous released nuclides are calculated using a nested system of local and long-range atmospheric dispersion models, driven by real-time available on-line meteorological information. The MET-RODOS module uses concurrently the available source term and weather information in the RODOS data base system, and returns, up to +36 hour forecasts of nuclei-specific air and deposited concentrations including gamma dose rate estimations for display and subsequent processing within the RODOS framework.

Weather and meteorology is available to the system via on-line connections to on-site local meteorological observations (met-towers and sodars) and via network (either public-domain Internet or user-owned point-to-point ISDN) connections to remote national or international meteorological forecasting services.

In its final form, scheduled for operational use in 1999, the MET-RODOS meteorological module is intended to service the RODOS system with actual and forecast (+36 hour) nuclei-specific air concentrations, deposition values, and gamma radiation estimates on the local, national, and European scale.

Provisions are furthermore being made for accommodating on-line available radiological monitoring data in the meteorological model chains in order for the module to assist with source term determination based on real-time data-assimilation and back-fitting procedures.

IV.1 Introduction

A set of atmospheric transport and dispersion models suitable for real-time atmospheric dispersion assessment on stand-alone workstations and large PC's have earlier been identified by Mikkelsen and Desiato(4). Now, with the aim of becoming fully operational within the rodos framework by year 1999, these models and their associated pre-processors are on-going being system-integrated in the rodos system on a UNIX-based workstation as a comprehensive meteorological sub-module named met-rodos. This work, involving many partners, is coordinated as a joint research and development project within the fourth framework of the European Union 1996-1999 Radiation Protection Program. The present paper summarizes the systems' features and shows that its model nesting and data integration is "state of the art".

IV.2 The MET-RODOS system

An overview of the atmospheric dispersion system is given in Figures 1a - 1c. The figures show that the processing "hardcores" of the system is centred about three sub-systems.

- The Local-Scale Preprocessor lsp,
- The Local-Scale Model Chain lsmc, and
- The Long-Range Model Chain lrmc

The system in addition integrates the following two data bases:

- The on-line met-TOWER Data Base towerdb,
- The real-time numerical weather ForeCAST Data Base fcastdb.

The local scale preprocessing program lsp maintains the local-scale system with actual and forecast local scale wind fields and corresponding micro-meteorological scaling parameters by intensive pre-processing and by use of local scale wind models.

lsmc contains a suite of local scale mean wind and dispersion models, from which case-specific models are selected depending on the actual topography and atmospheric stability features in question. It provides ground level air concentrations (in [Bq/m3]) and concentration of deposited isotopes (in [Bq/m2]), and ground level gamma dose rates (in Grays per second [Gy/s]) for subsequent use by the rodos system. When clouds are reaching the outer bounds for the local scale domain (20 km), diffusion specific parameters, such as cloud sizes, content and positions, are passed on to the long-range model chain lrmc.

The long-range model chain manages the trajectory and dose rate assessments on national and European scales in met-rodos. The tower data base maintains and updates the on-line meteorological met-tower measurements available to the system. The forecast data base contains the real-time numerical weather forecasts available to the system.

The system is equipped with pre-processors, flow and diffusion models previously selected for real-time applications within the rodos framework (4). Table 1 lists the many individual software packages and programs which are now being combined in the MET-RODOS system:

TABLE 1: MODULES ASSOCIATED THE MET-RODOS SYSTEM:	
Near-range flow and dispersion models, including pre-processors:	
·	Meteorological preprocessor **(PAD)**
·	Mass Consistent Flow model **(MCF)**
·	Linearized flow model **(LINCOM)**
·	Puff model with gamma dose **(RIMPUFF)**
·	Near-range segmented plume model **(ATSTEP)**
Complex terrain models (stand alone system):	
·	Prognostic flow model **(ADREA)** and Lagrangian dispersion model **(DIPCOT)**
Mesoscale and Long-range Models:	
·	Eulerian K-model **(MATCH)** nested with puff radiation dose models **(RIMPUFF)**
On-line Weather Forecast data:	
·	Numerical Weather Prediction models **(DMI-HIRLAM** and **SPA -TYPHOON)**

IV.2.1 Integration with RODOS

The modular structure of rodos allows **MET-RODOS** to become integral part of the **RODOS** system. The meteorological sub-systems control, data management, user input and graphical output will eventually be handled via the main **RODOS** system's Operating Subsystem **(OSY)**.

As Figure 1a indicates, met-rodos communicates with its host **(RODOS)** via shared memory and common real-time data bases.

Met-rodos is integrated in rodos based on shared memory. Met-rodos input its source terms directly from the rodos source term module while meteorological data are on-line accessed via network connections and stored in the rodos real-time environmental data base. Met-rodos produced outputs are automatically stored for each time step in the rodos data base system.

The met-rodos system setup and run time control is being implemented in the rodos main menu system.

IV.2.2 On-line Meteorological Input Data

Real-time application of an atmospheric-dispersion based nuclear emergency system requires on-line access to real-time measurements of the local dispersion meteorology. Such data are usually available from a network-connected met-tower located in the vicinity of the release point (on-site) and instrumented with wind and temperature sensors. For off-site assessments of releases beyond the local (10 to 20 km) scale, similar on-line estimates from the regional (100-km scale) wind and temperature conditions are also requested by met-rodos to work in real time. Such on-line regional scale meteorology is, in some European countries (such as Hungary), already available from real-time measurements based on a distributed network of on-line automatic meteorological stations.

IV.2.3 Real-time Numerical Weather Prediction Data

Real-time on-line numerical weather forecasts produced at remote meteorological institutes are also integrated part of the met-rodos system. For installations of rodos where no direct on-line access to a local meteorological weather station exists, met-rodos is able to run its local-scale model chain based on meteorology extracted from numerical weather prediction data alone. On the contrary, with local tower measurements available, numerical weather prediction data are primarily serving the system with forecast weather data (prognoses), to be used locally for dispersion and trajectory estimates on all ranges, including the local, the national and the European scale.

Numerical estimates of both actual and forecast (+36 Hr) regional wind and temperature conditions can in most part of Europe today be down loaded as high-resolution (~10-20 km grid resolution) Numerical Weather Prediction (NWP) data sets from the national operational meteorological institutes in Europe. After the establishment (in 1995) of the EU approved ECOMET organization of the European National Meteorological Services (NMS), customers in 7 EU countries can now purchase real-time NWP data from collaborating NMS's at EU approved price settings. During the rodos development and implementation phase 1996-1997, active collaborating NMS centres include the Danish Meteorological Institute (DMI), the Swedish Meteorological and Hydrological Institute (SMHI), and the SPA-Typhoon centre in Obninsk, Russia.

Section 5 describes the DMI-HIRLAM model and the on-line transfer and integration of DMI-HIRLAM produced numerical weather prediction data in MET-RODOS.

IV.3 MET-RODOS: BUILD-IN Model Chains and Modules

IV.3.1 The local scale model chain LSMC

Running the local scale dispersion models atstep and rimpuff in real-time requires real time measurements of the wind, turbulence and mixing height. Extensive pre-processing software is therefore included in the local scale model chain: On-line incoming meteorology (observed or forecast) are pre-processed real-time into gridded mean (wind) and turbulence quantities for all grid points on the local scale grid. A typical local-scale grid contains 81 x 81 grid points, covering an area of 20 x 20 km. This pre-processing is performed within the local scale pre-processing unit lsp, which invokes a set of nine pre-processing routines (the pad sub-routines) running in conjunction with a fast diagnostic local-scale and turbulence model (lincom). The local-scale model chain also handles the local scale the dispersion, deposition and gamma radiation models, in addition to producing "source-terms" for the long range model chain.

IV.3.1.1 Local Scale preprocessor LSP

Figures 1a - 1c shows the Local Scale Pre-processing unit lsp interfacing the on-line incoming meteorological data from both on-line met-tower measurements and national meteorological services to the local scale dispersion models atstep and rimpuff and to the long-range model match. The lsp provides the necessary input parameters to both local and the long range model chains: The starting point is parsing and binning of the on-line incoming meteorological data, which are automatically checked for consistency before stored in the met-rodos real-time databases towerdb and fcastdb.

Continuously running in background, lsp accesses the real-time databases every 10 min and processes all new meteorology available, including both met-tower based measurements and updated weather prediction data, into gridded wind fields, mixing heights, and scaling parameters on the local scale grid. Subsequently, they are stored as time-stamped grid files in shared memory.

IV.3.1.2 Preprocessor for Atmospheric Dispersion: PAD

Mikkelsen and Desiato (4) developed a micro-meteorological preprocessor which is now system-integrated into LSP for real-time operational use. It real-time processes basic meteorological observations into atmospheric stability measures and turbulence scaling parameters based on similarity theory as required by the model chains local-scale flow and dispersion models.

At the beginning of each local-scale time step (typically between 10-min and one 1-hr), the pad subroutines automatically processes available meteorological data from tower measurements and NWP data into requested atmospheric stability measures such as: stability category (Monin-Obukhov stability length scale), mixing heights (mechanical or convective) and turbulence (heat-fluxes, shear-stresses, and variances).

IV.3.1.3 Linearized wind model: LINCOM (-hill, -z_0, and thermal)

Across hilly terrain, and over mixed surfaces such as heterogeneous land-water-land interfaces, more detailed modelling of the local wind fields winds and turbulence fields is important for accurate prediction of the radioactive clouds trajectories such as their direction of travel, their time of arrival, and their potential impact.

The integrated lincom suite provides the local model chain with a fast diagnostic flow modelling system based on solutions of linearized conservation equations for momentum and continuity. Gridded fields of wind and turbulence are modelled in response to: 1) the local topography (hills), 2) the vertical thermal stratification of the atmosphere, and 3), to the local surface aero-dynamic roughnesses (z0).

Troen and de Baas (5) provided the basis for the neutrally stratified, pressure-gradient driven wind model for flow over hilly terrain (LINCOM-hill). Moreno et al.(6) extended the concept to include effects of thermally driven flows such as valley breezes and nocturnal drainage flows (LINCOM-thermal). Astrup et al.(7) recently extended the system to respond to the effects of changing surface roughness (LINCOM-z_0). This version also models the local turbulence levels (the surface sheer-stress) on the local scale grid.

The Lincom suite is integrated within lsp for providing wind-fields and turbulence to the dispersion models for advecting, depositing, and spreading the puffs and plumes.

Figure 2a-2c shows lincom-z0 generated mean and turbulence winds over Northern Zealand (from Astrup et al.(8)).

IV.3.1.4 The mass consistent wind model MCF

A Mass-Consistent-Flow (MCF-code) is added to the LSP module. It has complementary properties to the LINCOM system.: While the dynamic-equation based LINCOM system must be initialized with data from a single met-tower only (or alternatively by data from a single meteorological wind forecast grid point), the interpolating MCF code can handle simultaneous inputs from a network of several on-line met-towers. MCF generates mass-consistent interpolated wind fields over the entire local scale domain under the constraints of minimum flux diver gence[9]. A user's guide in the LSP module assists the user, depending on the available meteorology, in selecting the most suited model (LINCOM or MCF) for a given application.

IV.3.2 Diffusion, deposition, and gamma dose models

The local scale model chain integrates the puff dispersion model RIMPUFF and the segmented plume model ATSTEP. A separate (outside MET-RODOS) stand alone system for dealing with more severe **RIMPUFF** (10, 11, 12) is a fast and operational puff diffusion code, developed for real-time simulation of atmospheric dispersion during accidents. It accounts for changes in meteorological conditions (in both time and space)while the accident evolves. The dispersion model is provided with a puff-splitting feature for modelling of dispersion over hilly terrain, which involves channelling, slope winds and inversion layer effects). Recently, a Gaussian puff-based gamma dose module has been added (13).

The diffusion parameterization in **RIMPUFF** is formula-based and modular. The puff advection steps and diffusion growth rates are during each time step (typically 10 secs) determined by the puffs local wind and turbulence levels as provided by lsp.

RIMPUFF complex terrain and sea-breeze circulations is under development by Demokritos (cf. Section 4). The long range model chain is established by nesting the outputs from the local scale model chain to the Eulerian long-range model MATCH.

IV.3.2.1 The puff dispersion model RIMPUFF

can accommodate almost any user-specified formula-based parameterization scheme for its horizontal and the vertical dispersion parameters σ_y and σ_z. It has so far 6 optional sigma parameterization schemes included within the RODOS framework. They are, based on the co-called split horizontal and vertical σ-method, combinations of:

Mode 1-2: Karlsruhe-Jülich height dependent σy and σz (1-hr averaged plume sigmas)

Mode 3-4: RISO instantaneous (no averaging) true puff-diffusion sigmas σy and σz.

Mode 5: Similarity-theory based plume-sigmas (σy and σz) - averaging time 10-min to 1-hr.

Mode 6: German-French-Commission (GFC) proposed horizontal σy's, - for variable averaging-time ranging between zero (instantaneous puff) and 1-hr (plume sigmas).

RIMPUFF is equipped with standard (Briggs) plume rise formulas and has usual inversion-height and and ground-level reflection options.

A fast set of subroutines for the calculation of the ground-level gamma dose rates from both airborne and deposited radioactive isotopes have recently been added (14,15).This new feature plays an important role within rodos for data assimilation and back-fitting procedures in conjunction with real-time radiological (gamma radiation) monitoring data.

Deposited activity is also modelled with rimpuff. Dry deposition rates are treated differently for e.g. iodine vapour (elementary iodide) and iodine contaminated aerosols, and different deposition velocities can be specified depending on land use. Figure 3 shows a rimpuff calculated footprint of deposited radioactivity from a Cs137 plume traversing Northern Zealand. During the plume passage, the deposition rate is varied depending on the local surface characteristics (land, water, forrest, urban areas, etc).

For dry deposition of aerosols, the deposition velocity is under certain conditions limited by the atmospheric turbulence [15]. The next version of RIMPUFF [16] is planned to take this atmospheric turbulence-limited deposition velocity into account. It will be based on calculation of the atmospheric resistance (U/u_*^2) as provided by the model chains LINCOM-z_0 model.

IV.3.2.2 The segmented plume dispersion model ATSTEP

ATSTEP (17, 18) is a segmented Gaussian plume model with properties of a simplified puff model. It is capable of calculating the dispersion of a segmented plume during (steadily) changing meteorological conditions. It was the first atmospheric dispersion model fully integrated with the RODOS system. Because of its simplicity, it is extensively used in connection with demonstration and training of the RODOS system. It is also used as a tool for generating hypothetical data sets to be used with expert elicitation on local scale radiological accidents, and as a benchmark reference for RIMPUFF. ATSTEP requires fewer computation loops compared to RIMPUFF for simulation of a given accident due to its relative long advection time steps (10 to 30 minutes, as opposed to 10-30 secs for RIMPUFF), and to its correspondingly elongated plume-segment structure. Its shortcomings compared to RIMPUFF shows in connection with inhomogeneous or non-stationary conditions, - including non-uniform terrain, where high-resolution wind and turbulence structures are required from a wind and turbulence model (e.g. LINCOM or MCF).

ATSTEP also has a cloud gamma dose module but simpler than in RIMPUFF. ATSTEP calculates the gamma-dose rate as proportional to the local air concentrations by assuming submersion and by use of cloud-correction and dose-conversion factors, whereas RIMPUFF invokes a full cloud integration for each time step.

Tests have shown that the two dispersion models produces comparable results if the meteorology is "well-behaved" (i.e. quasi-stationary met-conditions and hilly or heterogeneous terrain is avoided). This is because they are both producing a meandering Gaussian plume in this limit.

CPU times on a HP 700 Series workstation takes for a simple local-scale plume typically less than 1-minute for atstep while rimpuff requires up to 5-min of CPU for the corresponding full gamma-cloud integrating simulation.

Although ATSTEP resides in RODOS-ASY, ATSTEP and RIMPUFF interfaces identically to "shared memory" in RODOS whereto they both provide ground-level air concentrations (in [Bq/m^3]), and concentration of wet and dry deposited isotopes (in [Bq/m^2]), and ground level gamma dose rates (in Grays per second [Gy/s]) for display and subsequent use by the other modules of the RODOS system.

IV.3.2.3 The Long Range Model Chain: LRMC

The European-scale long-range dispersion model selected for system integration in MET-RODOS is the operational MATCH code developed by the Swedish Meteorological and Hydrological Institute (SMHI). This particular code has previously demonstrated its potential with real-time back-fitting and data assimilation (19). MATCH (20) is a 3-dimensional Eulerian atmospheric transport model. It is based on a terrain following vertical coordinate and a mass conservative, positive definite advection scheme, with small phase and amplitude errors. The model has modules for nesting local scale outputs, vertical turbulent diffusion, and deposition processes. It has a submersion-based gamma dose module. It can handle an arbitrary number of radio-nuclides and their daughter products. MATCH runs on MET-RODOS on meteorological

NWP data down-loaded from DMI-HIRLAM and given its source terms by RIMPUFF on the border between the local and long-range scale (typically at the 20 km distance from the source). A seamless interfacing of Eulerian long-range models with the outputs from RIMPUFF have already been demonstrated (21).

MATCH is configured to work with a subset of the DMI-HIRLAM specific terrain following vertical layers. Vertical diffusion is for the convective case described from a determination of the turn-over-time for the boundary layer based on similarity theory, and for the neutral and stable case from ordinary eddy diffusivity (K-theory). This requires intensive integration with DMI-HIRLAM model outputs, cf. Section 4 on downloaded NWP data. MATCH is in operational state at SMHI, where it is nested with the Swedish version of HIRLAM.

IV.3.3 Real-time interactive visualisation: VIS5D

Outputs from the model chains (ground level concentrations and dose rates) are available to the shared memory data bases of the RODOS system and are as such displayable using the RODOS systems build-in graphics system. However, in order to provide the MET-RODOS user with full three-dimensional graphical access to the vast amount of weather information, including the local-scale and the long-range wind fields, turbulence fields and three-dimensional diffusion data available from the met-rodos module, MET-RODOS has been extended by the interactive visualization program VIS5D. This program gives the MET-RODOS user access to a real-time display and animation feature based on available weather forecasts, winds and dispersion predictions.

VIS5D is a system for interactive visualization of large 5-D gridded data sets such as those produced by e.g. DMI-HIRLAM. VIS5D provides instant images of vector plots, iso-surfaces, contour line slices, coloured slices, volume rendering etc of data in a 3-D grid, then rotate and animate the image in real time. VIS5D is set up in MET-RODOS to visualize the DMI-HIRLAM provided medium and long-range meteorological forecast data downloaded in the real-time numerical weather prediction data base FCASTDB. It can be set up to run immediately following a new set of NWP forecast data have been downloaded and archived in the data base. VIS5D features also a simplified real-time display and animation of long-range trajectories (forward and backward). Trajectories associated with any source point within the European Continent are in this way readily available in MET-RODOS by "a click on the mouse".

IV.4 Stand-alone Special Models for Complex Terrain

The Rodos framework allows for associating individual external software for the evaluation of dispersion of air pollutants in the surrounding area of nuclear sites. It is envisioned that rodos in its final (1999) version will be able to supply the user with a menu of codes covering even severe complex topography.

The Greek partners at NCSR "Demokritos" have engaged in flow and diffusion modelling over terrain more complex than the models directly integrated in the met-rodos module can handle. NCSR "Demokritos" are providing an (external to met-rodos) stand-alone system based on the particle diffusion model system ADREA-DIFF/DIPCOT. It is combined with the prognostic flow model ADREA-FLOW. This is a full prognostic, primitive-equation based non-hydrostatic flow model that accounts for self-generating thermally induced circulations caused by differential heat ing, such as local sea-breezes, valley slope and drainage winds etc. The Greek model system already co-exists as a RODOS implemented but directly integrated system. Its use will requires special training. It is intended for handling and studies of accidents over complex topography.

The modules **DELTA** (topography simulator), **FIL MAKER** (weather preprocessor), **ADREA**-diag (diagnosis) and **DIPCOT** (puff Lagrangial dispersion) have been implemented in **RODOS** Proto Type version 2.0.

IV.5 Numerical Weather Prediction and Data Transfer

This section gives a description of on-line transfer and use of **DMI-HIRLAM** produced numerical weather prediction (NWP) data in **MET-RODOS**. The **DMI-HIRLAM** project was initially started by the Nordic countries and the Netherlands [22, 23, 24]. The project has later been joined by Ireland, and partly by France and Spain.

The HIgh Resolution Limited Area Model **DMI-HIRLAM** [25] is a primitive-equation NWP facility in service at the Danish Meteorological Institute (DMI). It is running operationally around the clock on two different limited areas. The boundary fields for the large-area version (GRV) are obtained from the global model run by the European Centre for Medium-Range Weather Forecast (ECMWF). The small-area version (DKV) is nested in the GRV version which provides the boundary values. The horizontal resolution is 0.42 deg. (46 km) for GRV and 0.21 deg. (23 km) for DKV. The time steps are 4 and 3 minutes for GRV and DKV, respectively, and the forecast lengths are 48 and 36 hours, respectively. Both models outputs data each 3 hours. The GRV and DKV models have the same vertical resolution (31 hybrid levels). The models have nine model levels available for resolving a typical day-time boundary layer with a height of 1500 m. The **DMI-HIRLAM** forecasting system consists of pre--processing, analysis, initialisation, forecast, post-processing and verification. Both model versions are run with their own 6-hourly data- assimilation cycle.

Different versions of **DMI-HIRLAM** runs operationally around the clock at several European meteorological services from where e.g. local wind, precipitation and stability forecasts are available for on-line transfer to **RODOS** users via e.g. dedicated fast point-to-point digital telephone networks (ISDN), or via existing computer networks (Internet).

On-line transfer of **DMI-HIRLAM** data have been tested in Denmark between DMI (Copenhagen) and RISO (Roskilde), and between RISO and the University of Leads (UK) with the following set of data, cf. Table 2 and Table 3:

TABLE 2:	**ON-LINE TRANSFER OF** DMI-HIRLAM **DATA TO** MET-RODOS
<European scale grid>	(141 lat's x 136 long's) @ 13 (ground + 12 vertical layers).
<Time frames>	13 (0,+3,+6,... 36 Hrs) @ ~ 9 Mbyte each (uncompressed).
<Total amount to transfer>	13 time steps @ 9 MB ~117 Mbyte.
<Compression>	reduction factor ~½: ~ 60 Mbyte.
<On-line transfer time>	<point-to-point>,<Internet>
<Point-to point>	by standard ISDN telephone line @ 2x 64 Kbit/s: ~1 hour.
<Internet>	via FTP: ~2-3 hours, depending on load.

TABLE 3: DMI-HIRLAM **DATA TRANSFER TO** MET-RODOS **CONTAINS:**	
<ground level fields>	<precipitation intensity>, <boundary-layer height>, <latent plus sensible heat flux>, <momentum flux>.
<multi-level fields>	<geopotential heights>,<wind speeds>,<wind direction>, <virtual potential temperature>.

Figure 4a shows DMI-HIRLAM predicted boundary layer heights over Europe on August 20 1996 at 1300 UTZ as it appears downloaded to MET-RODOS using VIS5D graphics.

Figure 4b shows the corresponding predicted precipitation field over Europe at the same time.

Figure 4c shows a sub-set (40 x 40 grid points or ~1000 km x 1000 km) of the 10 metre surface winds over "greater" Denmark at the same time. The inserted "black box" over Northern Zealand and Copenhagen defines the outer bounds of the local-scale nested grid shown in Figures 2 a-c.

IV.6 Modes of Operation

This section discusses the envisioned strategy for daily operation of the MET-RODOS system. For the local scale, transfer of new +36 Hr forecast for a subset of a few NWP grid points (available every +6 hours) is operationally feasible in less than a minute. For the long range (European scale), a new +36 Hr forecast can be down-loaded to MET-RODOS in approximately 1-hr transmission time by use of a single-ended 64 Kbit point-to-point ISDN telephone line. This can easily be reduced to ~½ hr by use of a double-ended (2 x 64 Kbit/s) ISDN line.

It is envisioned that the local-scale atmospheric model chain will run "around the clock" in the emergency centre and automatically be updated with new meteorology from both tower networks and forecasts in the "Alert State: Normal" mode.

Display windows of dispersion from a potential local sources can in this way be visualized instantly (calculated on the basis of a "unit release"), so that the present "dispersion situation" is always at hand for the rodos operators and the decision makers. This continuous "Normal" mode of operation also ensures continuous exercising of the data transfer systems and some quality assurance of the meteorological measurements involved.

During "elevated alert states", or during exercises, special trained personnel will have to convene in the emergency room for manually taking control over the MET-RODOS system. Their tasks will be to start up the programs for the long-range dispersion and to assist with data- assimilation and back-fitting procedures on the local scale, and to provide realistic source terms, and to critically evaluate and update the MET-RODOS dispersion forecasts etc.

In proto-type version **RODOS-PV 3.0/3.1**, RIMPUFF is currently running in the following 3 modes:

Prognostic mode: This is a fast sequential forward-running mode, used for real-time predictions. Rimpuff runs sequentially on available meteorology. Time control is governed by the meteorology input file, e.g. from present time T0 to T+36 hr.

Diagnostic mode : This mode is used for off-line, non real-time, re-evaluation and interaction with e.g. land-use and food-chain sub-modules. Time control is again sequential governed by the meteorology available.

Automatic mode: This mode is not sequential, but rather it gives the user full step-by-step time control of the dispersion code. Rimpuff is re-start able from the beginning of any 10-min time period within the time frame of the real-time system, which pt. is [T -1 week to T+ 36 hrs].

IV.7 Model Evaluation Histories

Codes and modules selected for the atmospheric model chain have all previously been evaluated experimentally during full-scale field tests, in addition they are on-going being quality assured, integrated and documented according to the specifications set out by the overall RODOS concept [1, 18].

IV.7.1 Near Range model - evaluation records:

Near range, non-homogeneous terrain (Land-water-land):

RIMPUFF has been evaluated with data from several non-homogeneous terrain experiments - e.g., the Øresund Experiments during 1982-1984 [10].

Near range, hilly terrain:

A comprehensive field study "MADONA" (after: Meteorology And Diffusion Over Non-uniform Areas) were conducted over gently rolling hills near Porton Down in England in 1992. Several accident-simulations were recorded at High temporal resolution and with High spatial details using remote lidar sensing techniques for comparison of data with modelled diffusion patterns. A computerized near-range atmospheric dispersion model training module have especially been made for RODOS [26]. The MADONA data set is is available on CD-ROM [27].

Complex terrain:

A series of 14 full-scale dispersion experiments was carried out during the 1990 Guardo trials in Northern Spain [28]. They now form part of the experimental data base for evaluation of the near-range model chain over complex terrain. Actual wind and turbulence and smoke plume measurements (using lidar remote sensing) were recorded in real-time and used as input data for a series of simulations made with the combined local-scale model chain: PAD-LINCOM-RIMPUFF.

IV.7.2 Long-range model evaluation: ETEX

Two long-range "European Tracer EXperiments" by name ETEX were conducted in 1994 in continuation of the Chernobyl-triggered Atmospheric Transport Model Evaluation Study (AT MES). Sponsors were the EU, the World Meteorological Organisation (WMO) and the International Atomic Energy Agency (IAEA). ETEX was conducted to evaluate existing operational meteorological long-range models to forecast - in real time - air concentrations from a ground-based point source. A tracer gas cloud was monitored by 168 sampling stations as it dispersed over Europe in a four days course.

The MET-RODOS long-range transport model MATCH participated in both the ETEX (Figure 5), and the Nordic-1996 NKS-ECO4 [29] evaluation studies. Also the Danish Emergency Response Model of the Atmosphere DERMA[30] participated in these model evaluations based on DMI-HIRLAM data. In the real-time ETEX model evaluation study coordinated by JRC-Ispra and based on measurements from 86 sampling stations during the ETEX-1 exercise, the DERMA model obtained high scores compared to most others. This is indicative of high performance of also the DMI-HIRLAM European scale forecasting facility.

Acknowledgement

This paper was originally presented at the Fourth International Workshop, Aronsborg, Sweden, October 7 - 11, 1996 and was published in the Proceedings of that meeting published as Radiation Protection Dosimetry Vol. 73, Nos. 1-4 (1997), pp. 45 - 56. It is reproduced with permission of the publisher, Nuclear Technology Publishing.

IV.8 References

1. Ehrhardt, J. (1996): The RODOS System: Decision Support for Off-site Emergency Management in Europe. In Proceedings of the : Fourth International Workshop On Real-time Computing of the Environmental Consequences of an Accidental Release from a Nuclear Installation. Aronsborg, Sweden, October 7-11 1996. To appear in: Radiation Protection Dosimetry.
2. Kelly, G. N., J. Ehrhardt and V.M. Shershakov (1996): Decision support for off-site emergency preparedness in Europe. Radiation Protection Dosimetry, Vol. 64, No.1/2, pp 129-141.
3. Ehrhardt, J. Brown, S. French, G.N. Kelly, T. Mikkelsen and H. Müller (1997): RODOS: Decision-making support for off-site emergency management after nuclear accidents. Submitted to "Kerntechnik" February 1997.
4. Mikkelsen, T. and F. Desiato (1993). Atmospheric dispersion models and pre-processing of meteorological data for real-time application. Radiation Protection Dosimetry Vol. 50, Nos. 2-4, pp 205-218.
5. Troen, I. and de Baas, A.F. (1986): A spectral diagnostic model for wind flow simulation in complex terrain. In: Proceedings of the European Wind Energy Association Conference & Exhibition, pp.37-41, Rome, 1986.
6. Moreno, J., A.M. Sempreviva, T. Mikkelsen, G. Lai and R Kamada (1994). A spectral diagnostic model for wind flow simulation: extension to thermal forcing. In proceedings of the: Second International Conference on Air Pollution, 27-29 September 1994, Barcelona, Spain. Eds. J.M. Baldasano, C.A. Brebbia, H. Power and P. Zanetti, Computational Mechanics Publications, Southhamton, U.K., Vol II, pp 51-58.
7. Astrup P., N.O. Jensen and T. Mikkelsen (1996): Surface Roughness Model For Lincom. RISO report RISO-R-900(EN), ISBN 87-550-2187-5, ISSN 0106-2840; 30 pp. Available on request from: Information Service Department, RISO National Laboratory, e-mail: risoe@risoe.dk
8. Astrup P., N.O. Jensen and T. Mikkelsen (1997): A fast model for mean and turbulent wind characteristics over terrain with mixed surface roughness. Submitted to Radiation Protection Dosimetry, October 1996.
9. Massmeyer, K., and Martens, R. (1991): Regional Flow Fields in Northrhine Westfalia - A Case Study Comparing Flow Models of Different Complexity -.in: Air Pollution Modelling and ist Application VIII, ed. by H. van Dop and D.G. Steyn, Plenum Press, New York, pp. 301 - 309, 1991
10. Mikkelsen, T., S.E. Larsen and S. Thykier-Nielsen (1984). Description of the RISO Puff Diffusion Model. Nuclear Technology, Vol. 67, pp. 56-65.
11. Thykier-Nielsen, S, Mikkelsen, T., Larsen, S.E., Troen, I., de Baas, A.F., Kamada, R., Skupniewicz, C., and Schacher, G. (1989). A Model for Accidental Releases in Complex Terrain. Proceedings of the 17th NATO/CCMS International Meeting on Air

Pollution Modelling and its Application VII, Cambridge (UK), September 19-22, 1988. (Ed. H. van Dop), Plenum Publishing Corporation, 1989, 65-76.
12. Thykier-Nielsen, S., Mikkelsen T. and Moreno, J. (1993a): Experimental evaluation of a PC-based real-time dispersion modeling system for accidental releases in complex terrain. Proceedings from 20th International Technical Meeting on Air Pollution Modelling and its Application , Valencia, Spain, November 29 - December 3., 1993.
13. Thykier-Nielsen, S., S. Deme, and E. Láng (1995). Calculation method for gamma-dose rates from Gaussian puffs. RISO-R-775(EN).
14. Thykier-Nielsen, S., Deme, S. and Láng, E. (1993b): Calculation method for gamma dose rates from spherical puffs. RISO National Laboratory, RISO-R-692 (EN), July 1993.
15. Jensen, N.O. and P. Hummelshoj (1995): Derivation of canopy resistance for water vapour fluxes over a spruce forest, using a new technique for the viscous sublayer resistance. Agricultural and Forest Meteorology, Vol 73, pp 339-352.
16. Thykier-Nielsen S., S. Deme and T. Mikkelsen (1997). RODOS SYSTEM, ANALYSING SUBSYSTEM: Atmospheric Dispersion Module RIMPUFF - User's guide. Stand Alone Version: RIMDOS7. February, 1997. Available on request from: Wind Energy and Atmospheric Sciences Department, RISO National Laboratory, P.O. Box 49, DK-4000 Roskilde, Denmark.
17. Päsler-Sauer, J., T. Schichtel, T. Mikkelsen, S. Thykier-Nielsen (1995): Meteorology and atmospheric dispersion, simulation of emergency actions and consequence assessment in **RODOS**. IN: Proceedings for Oslo Conference on International Aspects of Emergency Management and Environmental Technology. June 18-21 1995. Edited by: K. Harald Drager, A/S Quasar Consultants, P.O. Box 388 Skoyen N-0212, Oslo.
18. Päsler-Sauer, J., O. Schüle, C. Steinhauer (1996): **RODOS** Prototype Version 2.0 User Guide. RODOS(WG1)-TN(96)09.
19. Robertson, L. and C. Persson (1993) Attempt to apply four dimensional data assimilation of radiological data using the adjoint technique. Radiation Protection Dosimetry, Vol. 15, Nos 2-4, 333-337.
20. Robertson, L., Langner, J. and M. Engardt (1996) MATCH - Meso-scale Atmospheric Transport and Chemistry Modelling system. Basic model description and control experiments with 222RN. SMHI Report No. 70, September 1996.
21. Brandt, J., T. Mikkelsen, S. Thykier-Nielsen and Z. Zlatev (1996): Using a combination of two models in tracer simulation. Mathl. Comput. Modelling Vol. 23, No. 10, pp 99-115.
22. Machenhauer B. (Ed.) (1988): HIRLAM final report. HIRLAM Technical Report 5.
23. Machenhauer B., U.B. Nielsen and A. Rasmussen (1991): Evaluation of the Quality Especially of Wind-forecasts by the Operational Meteorological HIRLAM-system. Procee dings of the OECD/NEADB Specialists' Meeting on Advanced Modelling and Computer Codes for Calculating Local Scale and Meso-Scale Atmospheric Dispersion of Radio nuclides and their Applications (AD-LMS'91), Saclay, France. OECD Publication No. 75907. pp 152-163.
24. Källén, E. (Ed.): (1996) HIRLAM documentation manual, System 2.5. Available from the Swedish Meteorological and Hydraulic Institute (SMHI), Nörköping, Sweden
25. Sass.B.H. (1994): The DMI Operational HIRLAM Forecasting System, Version 2.3. DMI Technical Report 94-8 (1994).
26. Jorgensen, H.E., J.M. Santabarbara and T. Mikkelsen (1993). A real-time uncertainty-knowledge and training data base. Radiation Protection Dosimetry Vol. 50, Nos 2-4, pp. 289-294.

27. Ride, D.J., T. Higgs, C. Biltoft, J.H. Byers, R.M. Cionco, C.G Collins, A.R.T. Hin, C.D. Jones,P.E. Johansson, H.E. Jorgensen, W. aufm Kampe, J.F, Kimber, T. Mikkelsen, M. Nordstrand, K. Nyrén, H. van Raden, R. Robson, J. M Santabarbara, R. Sterkenberg, J.M. Streicher, H. Weber.(1995): The High Resolution Data Set from Trial ***MADONA*** (Meteorology and Dispersion over Non-Uniform Areas) CD-ROM VERSION 2.0. Available on request from: Hans E. Jorgensen; (e-mail: hans.e.joergensen@risoe.dk). RISO National Laboratory, Wind Energy and Atmospheric Physics Department, P.O. Box 49, DK-4000 Roskilde.
28. Thykier-Nielsen, S., J.M. Santabarbara and T. Mikkelsen (1993c): Dispersion scenarios over complex terrain. Radiation Protection Dosimetry, Vol. 50, Nos 2-4, pp 249-255.
29. Tveten, U. and T. Mikkelsen, Eds. (1995) Report of the Nordic dispersion-/trajectory model comparison with the ETEX-1 full-scale experiment.NKS/EKO-4 inter-comparison-/valida-tion exercise held at RISO, Denmark, 6-7 June 1995. RISO-Report-847(EN)/NKS Report EKO-4(95)1. ISBN 87-550-2118-2, ISSN 0106-2840.
30. Sorensen, J.H. and A. Rasmussen (1996): Calculations Performed by the Danish Meteorological Institute. In: Report of the Nordic Dispersion/Trajectory Model Comparison with the ETEX-1 Full Scale Experiments, Eds: U. Tveten and T. Mikkelsen (1995) RISO-R-847(EN), NKS EKO-4(95), ISBN 87-550-2118-2, ISSN 0106-2840.

IV.9 Figures

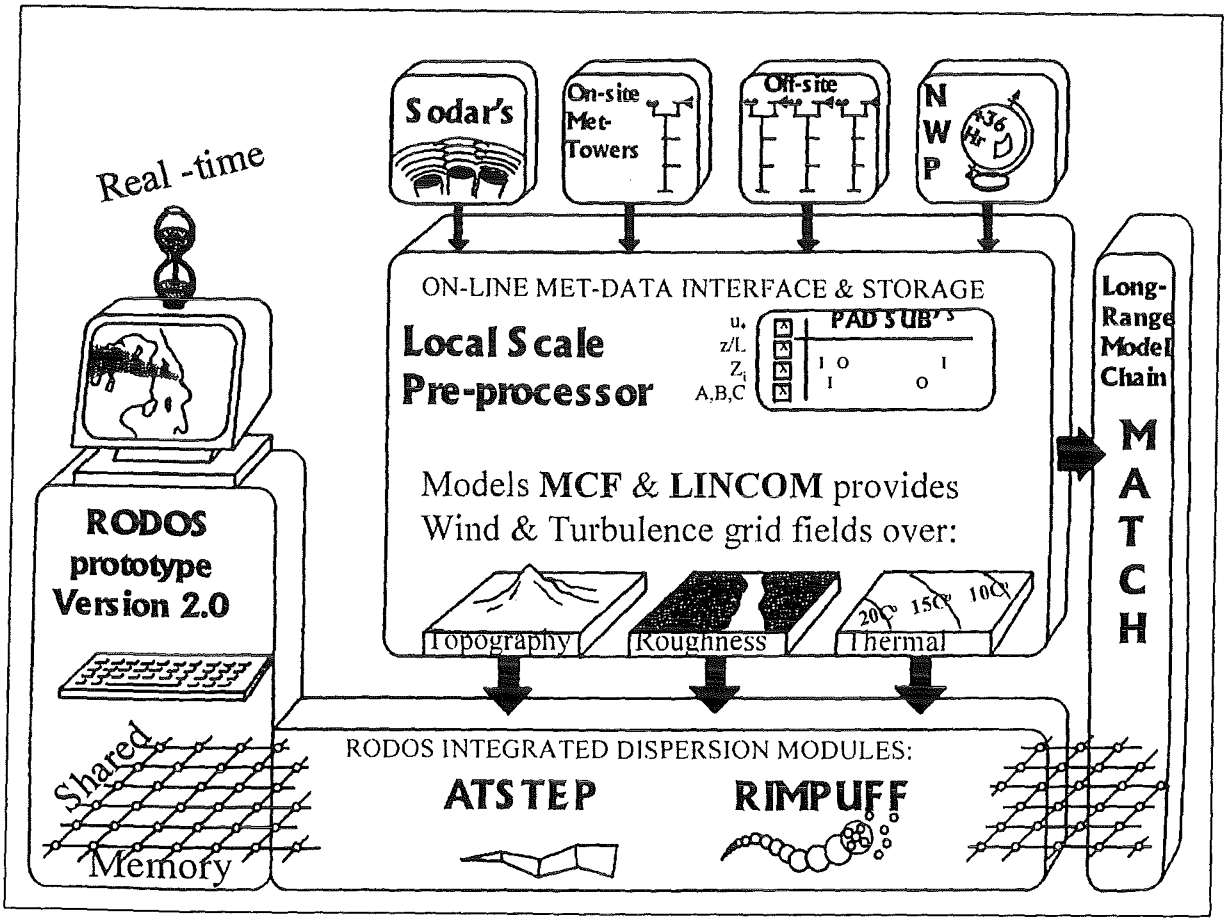


Figure 1a: The MET-RODOS system integrated with RODOS on a Unix based workstation

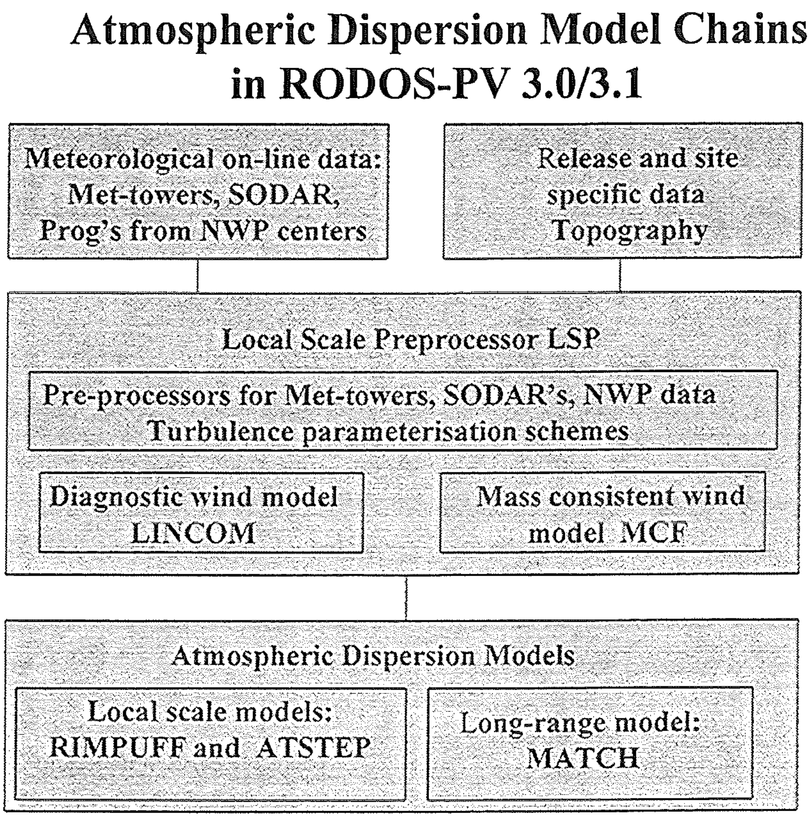


Figure 1b: MET-RODOS Atmospheric Dispersion Model Chain

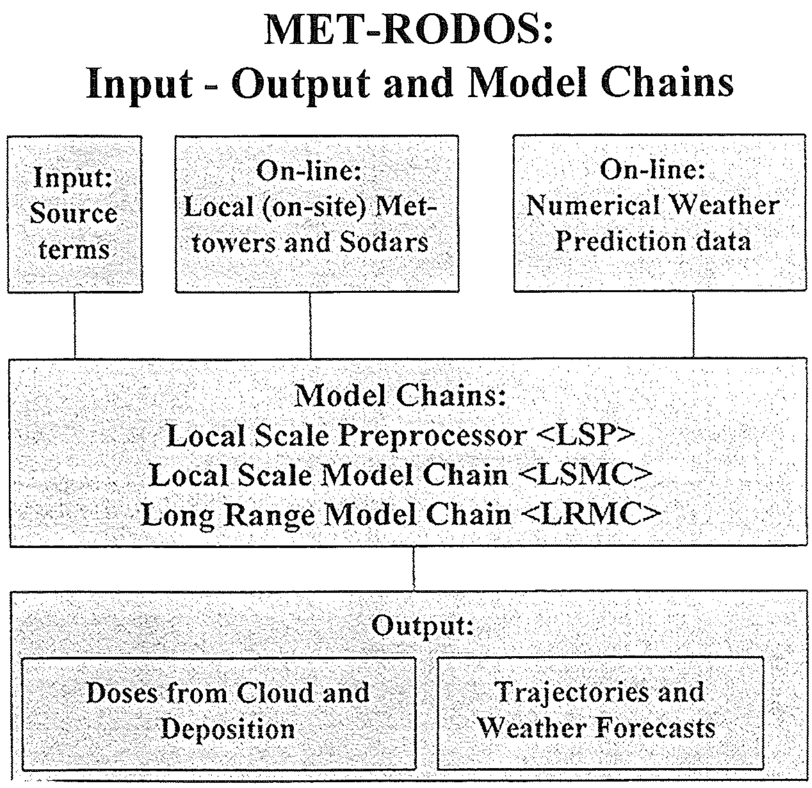


Figure 1c: MET-RODOS Input/Output and Model Chain Structure

Figure 2a:
Roughness (Z_0) distribution over Northern Zealand

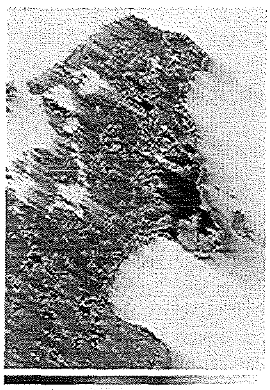


Figure 2b:
LINCOM generated mean wind field (U) over Northern Zealand

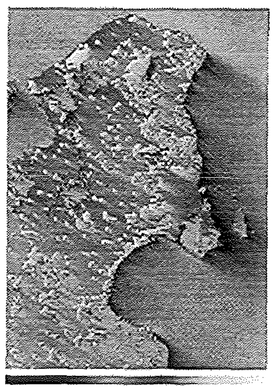


Figure 2c:
LINCOM generated turbulence wind field (u.) over Northern Zealand

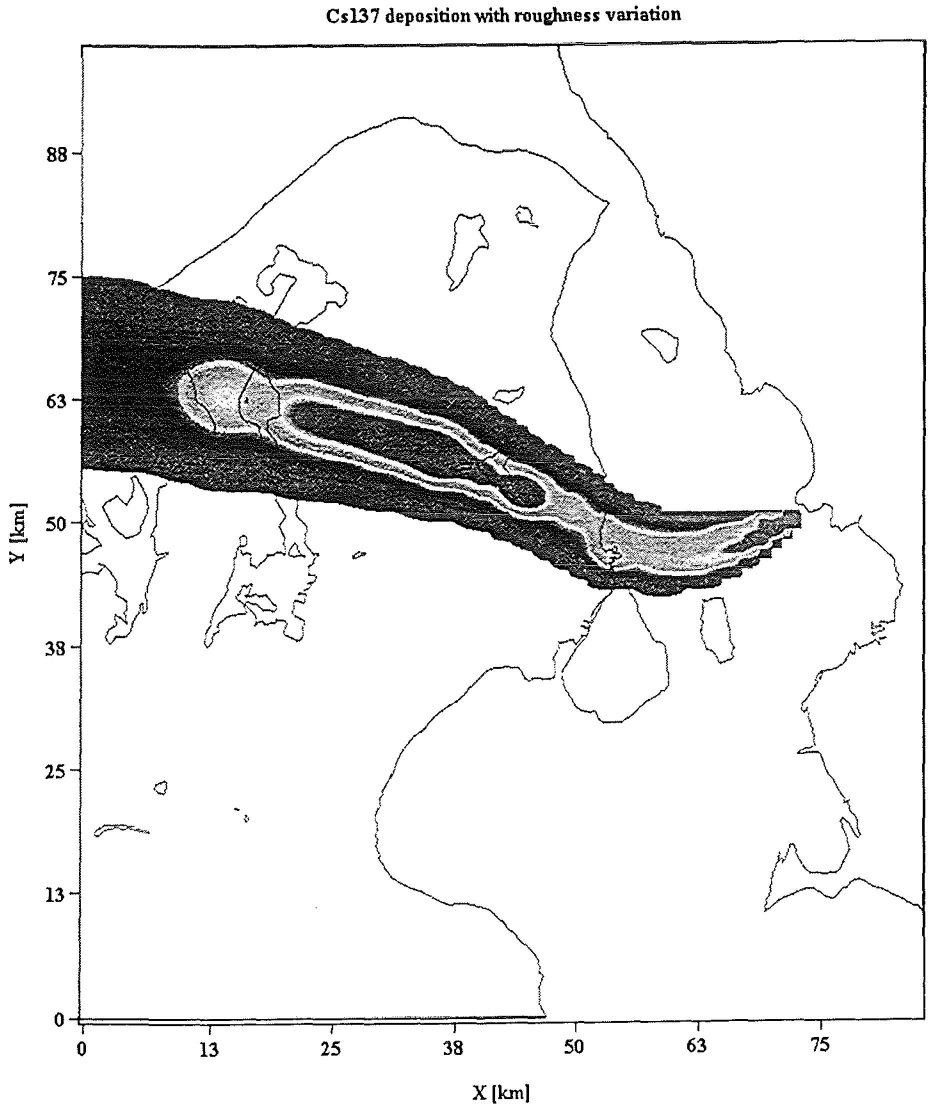


Figure 3: Footprint of a depositing Cs 137 plume (RIMPUFF over Northern Zealand)

Figure 4a: DMI-HIRLAM predicted boundary layer heights over Europe on August 20. 1996 at 1300 UTC as it appears in MET-RODOS using VIS5D graphics

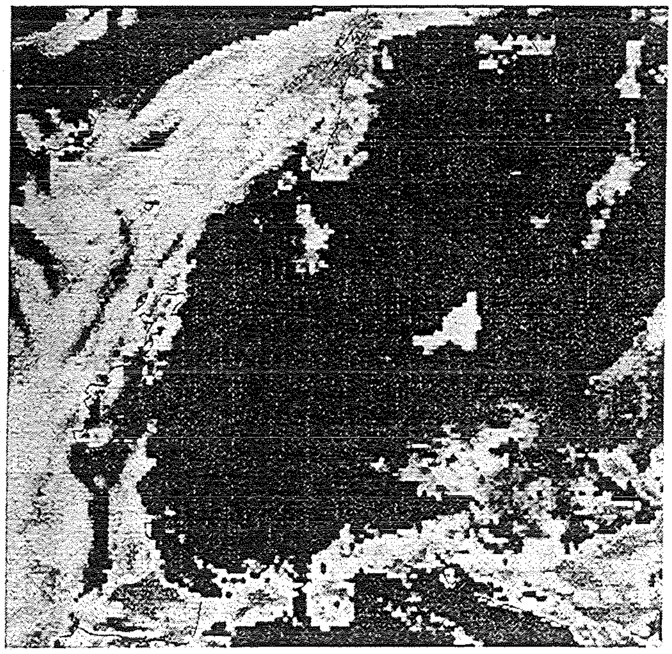


Figure 4b: DMI-HIRLAM precipitation field over Europe on August 20. 1996 at 1300 UTC

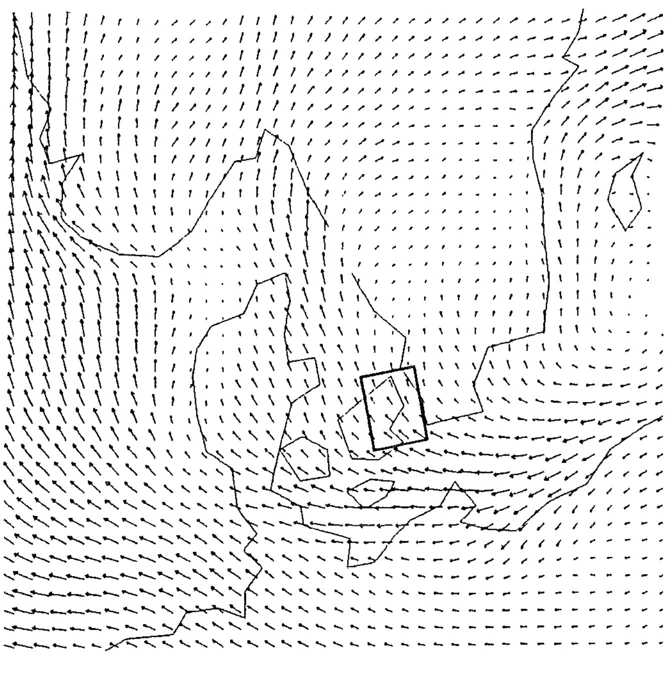


Figure 4c: Subset (40x40 grid poins or ~ 1000 kmx 1000 km) of surface (10m) winds over Northern Europe on August 20. 1996 1300 UTC. The insert "box" over Northern Zealand, Øresund and Copenhagen defines the bounds of the local scale model chain (i.e. the LSMC) nested grid.

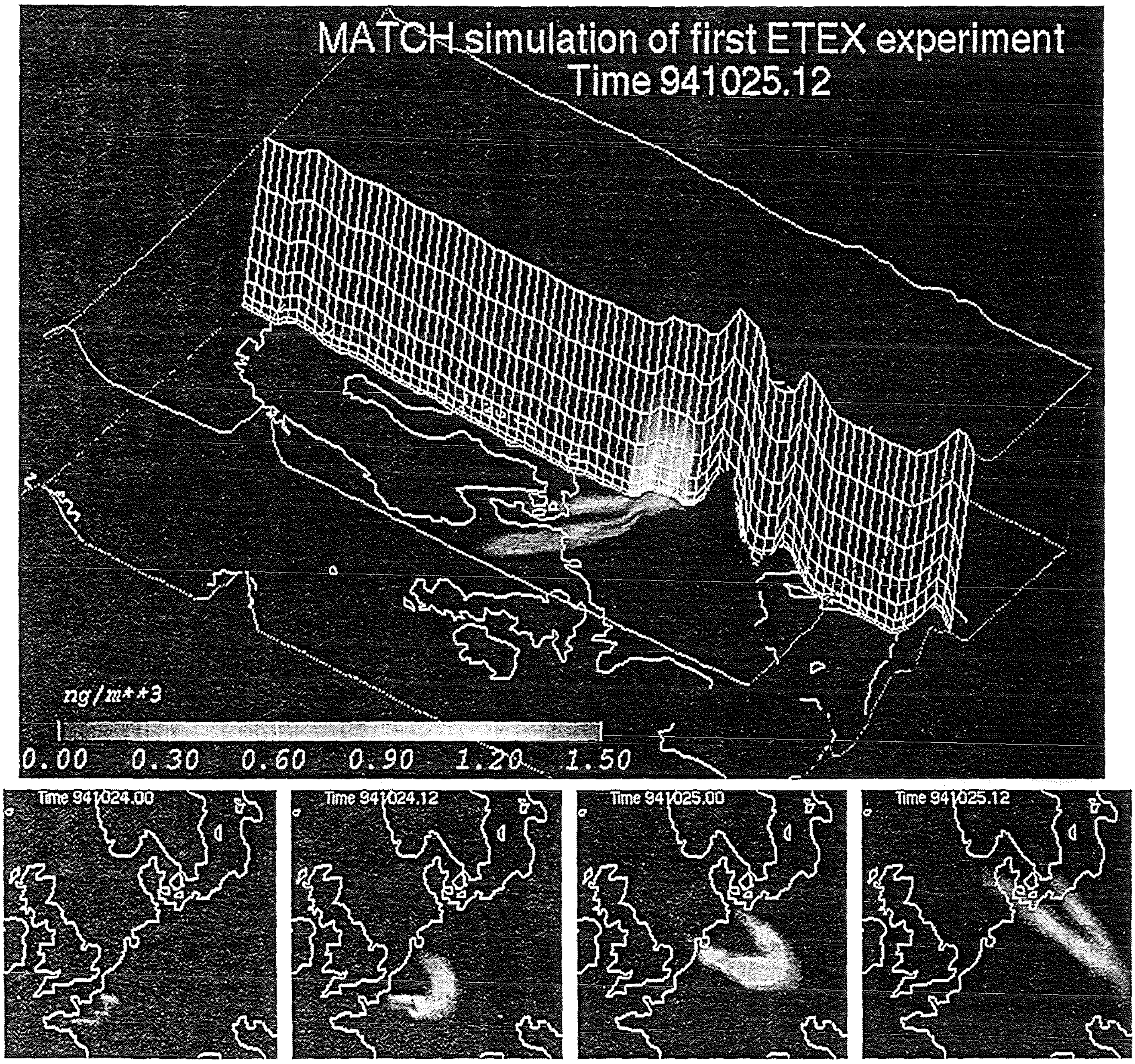


Figure 5: The upper large figure shows the horizontal and vertical distribution of the ETEX tracer cloud at 12 UTV on October 25. 1994 [941025.12] - 44 hours after ist start of release near Rennes in France. The ETEX clouds vertical distribution is shown in a North-South vertical cross-section which also shows the vertical grid of the MATCH model. Concentration are in [ng/m^3], see legend. The four smaller figures inserted below show the position of the cloud at four consecutive 12-hour intervals: [941024.00; 941024.12; 941925.00 and 941025.12].

V Modelling of Hydrological Pathways in RODOS

Zheleznyak, M., Gofman,D., Lyashenko,G., Marinets, A., Shepeleva, T., Tkalich, P.
Cybernetics Centre of the Ukrainian Academy of Sciences, Institute of Mathematical Machines and Systems, Prospect Glushkova 42, Kiev, 252207, Ukraine

Heling, R.
NV KEMA, P.O. Box 9035, Arnhem, Netherlands

Raskob, W.
Forschungszentrum Karlsruhe GmbH, INR, P.O. Box 3640, D-76021, Karlsruhe,
Popov, A.· Borodin, R. Pokhil, A.
Scientific Production Association TYPHOON, Lenin str 82, Obninsk, Kaluga Region, 249020, Russia

Abstract

In 1992, a joint EC-CIS team of experts started to develop a hydrological module for the decision support system RODOS. A model chain was outlined covering the processes such as run-off of radionuclides from watersheds following deposition from the atmosphere, transport of radionuclides in river systems and the radionuclide behaviour in lakes and reservoirs. The output from the hydrological transport chain is used to calculate the main exposure pathways such as the doses derived from the consumption of drinking water, of fish, of irrigated foodstuffs and the external irradiation. Test and validation studies of the whole chain as well as for individual models were performed on the basis of experimental data from the basins of Dnieper and Rhine. A user friendly graphical interface was developed to operate the individual models inside the hydrological module.

V.1 Introduction

Within its Radiation Protection Research Programme, the Commission of the European Communities has embarked on a major project aiming at the development of an integrated and comprehensive real-time on-line decision support system (RODOS) for nuclear emergencies in Europe[1]. The Chernobyl accident demonstrated the importance of the aquatic pathways in the radiological assessment of environmental consequences of an accidental release of radionuclides from a nuclear installation. After the Chernobyl accident, the CIS countries gained a lot of experience in supporting decision makers by modeling the radionuclide contamination of large water systems [2,3].

In 1992, a joint EC-CIS team of experts started to develop a hydrological module for RODOS in the frame of the Joint Study Project (JSP-1) [4,5]. A model chain was outlined covering the processes such as run-off of radionuclides from watersheds following deposition from the atmosphere (RETRACE-1 for small watersheds and RETRACE-2 for large watersheds), transport of radionuclides in river systems (RIVTOX) and the radionuclide behaviour in lakes and reservoirs (LAKECO and COASTOX). The near range transport and dispersion of radionuclides following direct releases into the river are described by the COASTOX model. The aquatic versions of the foodchain-, dose- and countermeasure modules of RODOS use subsequently the output from the hydrological model chain to calculate the main exposure pathways such as the doses from the consumption of drinking water, fish, irrigated foodstuffs, and from external irradiation as well as potential countermeasures. Validation studies of the whole chain and of the individual models were performed on the basis of experimental data from the basins of the rivers Dnieper and Rhine. A user friendly graphical interface was developed to operate the individual models inside the hydrological module. This publication summarizes these collaborative activities.

V.2 Modelling of Radionuclide Transport via the Hydrological Pathways

The evaluation of the radiological consequences of accidental releases of radionuclides from various specific sites demonstrated a significant contribution from the contaminated waterbodies to the dose of the population. This was e.g. clearly shown for the Clinch River-Tennessee River basin (releases from Oak Ridge), for the Techa River-Ob River watershed (releases from "Mayak"), for the Dnieper river basin, and for the dose to the population in the vicinity of Scandinavian lakes (Chernobyl accident). The re-mobilisation of dry and wet deposited material by long term floods and heavy rain events, and the resuspension of sediments during storm events resulted in the migration of radionuclides and affected also uncontaminated agricultural areas together with drinking water supplies downstream from the source of the initial contamination. Additionally, the remobilisation of radionuclides stored in the bottom sediments of lakes and reservoirs caused a delayed transfer of activity to the aquatic environment.

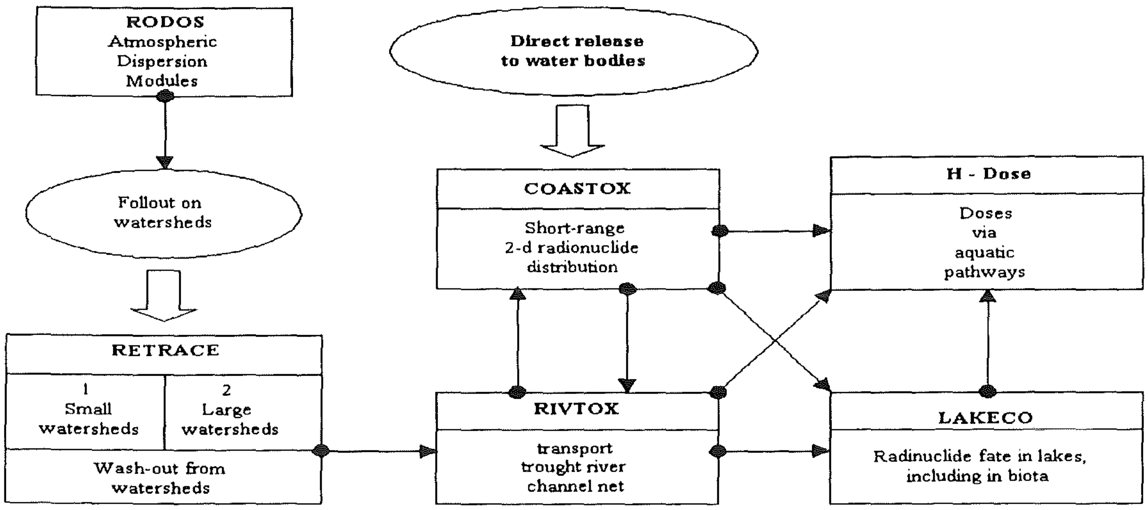


Fig.1

To facilitate and enhance the quality of emergency actions, the mathematical description of the processes involved is required. RODOS will therefore contain a chain of models, which cover 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 exchange with sediments and the behaviour of radionuclides in lakes and reservoirs. The hydrological model chain will be part of the analyzing subsystem of RODOS (ASY) to predict activity concentrations in waterbodies. These models will also operate in the consequence subsystem of RODOS - CSY, for identifying strategies of possible countermeasures. Starting points for the early phase can be a direct release into a river or lake and/or the predicted contamination of a land area following an atmospheric release of radionuclides. On later stages after the accident, the estimated deposition data will be corrected by monitoring data. As RODOS is designed to predict the short-term and long-term consequences of the accidental releases, the aquatic module contains models of different temporal and spatial scales.

V.2.1 Run-off models RETRACE-1 and RETRACE-2

The RETRACE code, simulating radionuclide transport by runoff from watersheds, is under development at SPA Typhoon, Obninsk, Russia [6]. RETRACE-1 describes the radionuclide wash-off at a local scale, i.e. small watersheds which sizes of less than 1000 km2 and with a temporal resolution of hours, while RETRACE-2 covers the regional scale up to large watersheds (larger than 1000 km2 and with a temporal resolution varying from days to years). Both models consist of a hydrological and a radionuclide transport submodel.

In RETRACE-1, the water dynamics of the soil surface following rain events is simulated on the basis of the two-dimensional kinematic wave equation including source/sink terms describing precipitation rate, infiltration rate, canopy interception rate, rate of losses in surface depression and evaporation rate. The two dimensional kinematic wave approach is also used for the description of the subsurface runoff.

The approach applied in the hydrological submodel of RETRACE-2 is situated between a lumped-parameter model and a distributed-parameter model. It operates with ordinary differential conceptual equations but for spatially distributed parts of the catchment.

The sediment concentration (from erosion) in the runoff water is calculated in both models on the base of empirical relationships. It is assumed, that the radionuclides in the upper soil layer with a thickness of 1 mm can contribute to the run-off process by water wash-off and by erosion processes. Additionally, it is assumed, that the concentration of the solved radionuclides in the surface and the subsurface water are in equilibrium (Kd approach). The transport equations of the radionuclides in the RETRACE are based on the conservation equation for the total activity of dissolved and sorbed components. RETRACE-2 uses ordinary differential equations for the radiological modules whereas RETRACE-1 is based on partial differential equations.

The required input data includes among others cartographic data (e.g. relief, soil, vegetation, rivers and lake location), parameters of the soil (e.g. infiltration capacity, moisture), weather (e.g. the probability of precipitation), vegetation (e.g. interception parameters of canopy for different seasons), and parameters of the radionuclide transport (e.g. distribution coefficient, transformation rates).

V.2.2 RIVTOX, a one dimensional river model

The one-dimensional model RIVTOX, developed at IMMS, Cybernetics Centre, Kiev[7,8], simulates the radionuclide transport in networks of river channels. Sources can be a direct release into a river or the runoff from a catchment. In the latter case, the output from RETRACE is used as the input of RIVTOX. The stream function, the transport of suspended sediments and the radionuclide dynamics are averaged over the cross-section of the river. A 'diffusion wave' model, derived from the one-dimensional Saint-Venant's equation, describes the water discharge. An advection-diffusion equation calculates the transport of the suspended sediments in the river channel. Its sink/source terms describe the rate of sedimentation and resuspension as a function of the difference between the actual and the equilibrium concentration of suspended matter with respect to the transport capacity of the flow. The latter is calculated on the base of semi-empirical relations. The dynamics of the upper contaminated river bed is driven by an equation for the erosion of the bottom layer.

The radionuclide transport submodel of RIVTOX describes the dynamics of the cross-sectionally averaged concentrations of activity in solution, in suspended sediments and in bottom depositions. The adsorption/desorption and diffusion transfer in the systems "solution - suspended sediments" and "solution - bottom deposition" is treated via the Kd approach assuming equilibrium. However, the exchange rates between solution and particles are taken into account too, for a more realistic simulation of the kinetics of the processes. It is assumed that the adsorption and desorption rates are not equal.

The most important input data are:

- parameters of the river channel network, e.g. length of branches and junction positions, dependence of the crossection on the water surface elevation, bottom roughness and typical scenarios of floods for the simulation of a direct release of radionuclides into the river.
- typical distribution of the grain size of suspended sediments and of bottom depositions.

V.2.3 COASTOX, a two-dimensional model calculating the lateral-longitudinal distribution of radionuclides in water bodies

The two-dimensional model COASTOX [7, 9] uses the depth averaged Navier Stokes equations to calculate the velocity field in rivers, lakes and reservoirs generated from the combined influence of discharge, wind and bottom friction. The steady state approximation without advection terms and the system of the unsteady shallow water equation are used. The same approach as in RIVTOX is applied to simulate the radionuclide exchange in the system: solution - suspended sediments - bottom depositions. The 2-D advection-diffusion equations and the equations of flow dynamics are solved numerically by using the finite difference methods. Necessary input to COASTOX is the geometrical data of the river/lake bed in a sufficient fine spatial resolution.

V.2.4 Lake model LAKECO

The box-type model LAKECO, developed by the KEMA, Arnhem, The Netherlands [10], is used for predicting the behaviour of radionuclides in lakes and reservoirs. It calculates the concentration of the activity in the water column, in sediments and in the biota dynamically. It is divided into an abiotic part, describing the change of the activity concentrations in the water/soil column by means of linear differential equations of first order and a biotic part predicting the transfer throughout the aquatic food chain.

The processes which are taken into account are: particle scavenging/sedimentation, molecular diffusion, enhanced migration of radionuclides in solution due to physical and biological mixing processes, particle reworking - also by physical and biological means - and the downward transfer of radionuclides in the seabed as a result of sedimentation. In sediments both the fractions of solved and dissolved radionuclides are modelled., A complex dynamic model, taking into account the position of the different species in the food web, has been developed to predict the transfer throughout the aquatic food chains. This dynamic uptake-model is based upon studies on mercury in fish [11].

Sensitivity analysis showed that the distribution coefficient water suspended matter, and the concentration factor water phytoplankton are the most sensitive parameters. Less sensitive were the reworking rate, and the biological half life of the aquatic organisms. To improve the predictive power and the flexibility of LAKECO, new submodels to assess these sensitive parameters were implemented. As a result, the modified model LAKECO-B has more environmental parameters, like the potassium concentration in the lake water, as input, but less model specific parameters. Thus, LAKECO-B has become an aquatic model where tuning is nearly impossible as environmental input parameters control the model.

V.3 Software Framework of RODOS Hydrological Chain

The hydrological chain consists of an self-reliant user friendly graphical interface to operate the individual models inside the RODOS system. The interface provides the possibility to access easily all the information necessary to run the individual models as well as displaying the results in a way decision makers can handle them (e.g., Fig. 2). The interface allows:

- to integrate codes on the base of a RODOS-like technology with the possibility to allocate only as much shared memory as the program really uses for the simulation
- to input and edit data and parameters through a system of users-configured dialogs and input windows
- to run models separately or simultaneously with the possibility to exchange data between individual models via shared memory
- to manage the data base and to create predefined scenarios
- to present data base information and on-line results of the simulations in graphs and maps (e.g. contamination)
- to support different modes with different user services: 2 automatic modes- "whole chain"(whole chain starting from data of the atmospheric dispersion) ,"direct release" (RIVTOX, COASTOX, LAKECO) and 2 manual modes -"decision maker" (with loading of predefined scenarios) and "scenario maker" (creating scenarios, data base updating)

New ideas realized in the RODOS hydrological interface are

- creation of predefined scenarios
- different automatic and manual modes for different categories of RODOS users
- a user configured system of input windows and dialogs
- new techniques of integration of external programs.

At present, there are 4 models (RETRACE, RIVTOX, COASTOX and LAKECO) integrated in the RODOS Hydrological module. For each of these models the interface provides the same basic set of the user interfaces and data base tools ,however great effort was made to consider all the specific needs of input and output of individual models. For example the operation of RETRACE in the interactive test and expert modes was realized by a specially developed interface - the RETRACE monitor. For the automatic and the "decision maker" mode however, RETRACE is under the complete control of the 'normal' tools of the hydrological interface.

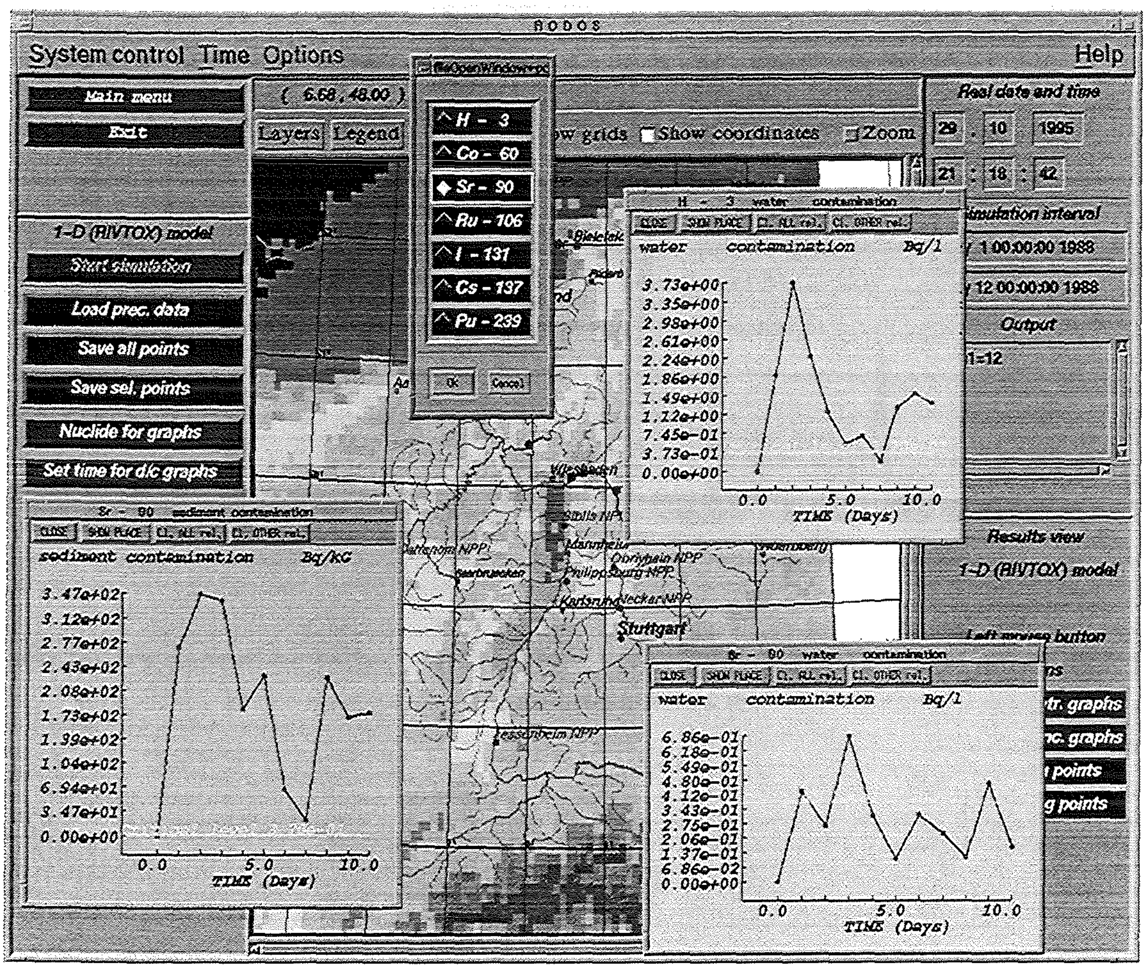


Fig. 2: **Interface of RODOS Hydrological Model Chain. RIVTOX application for Rhine basin**

V.4 Model Chain Validation Studies

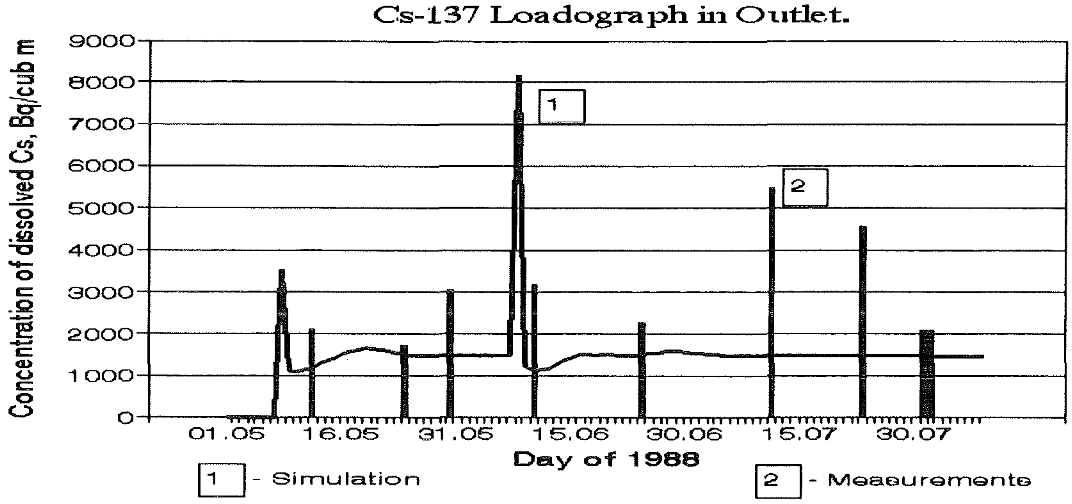
To prove the reliability of the various aquatic models, validation and intercomparison studies were performed, among others, within the frame of the IAEA/CEC VAMP program and the BIOMOVS II program, as well as within other special validation studies [12]. The knowledge gained herein has lead to further model improvements.

V.4.1 RETRACE - RIVTOX chain validation on the base of Ilya River case study

The RETRACE - RIVTOX chain validation study was performed for the catchment of Ilya River, a tributary of the Uzh River, flowing into the Kiev Reservoir. The watershed, situated mainly in the 30-km Chernobyl zone, has a size of about 20 km in longitudinal direction and about 15 km in lateral direction. The following data, measured in 1988 by the SPA Typhoon (Obninsk, Russia) and the Ukrainian Hydrometeorological Institute (Kiev, Ukraine) were used in the validation study:

- soil contamination
- meteorological data (daily precipitation);
- water discharge at the outlet;
- concentration of soluble and sorbed forms of 90Sr and 137Cs at the outlet;

- contamination of bottom sediments.



-

Fig. 3. Simulation by RETRACE of ^{137}Cs day averaged concentration in runoff from the Ilya River catchment

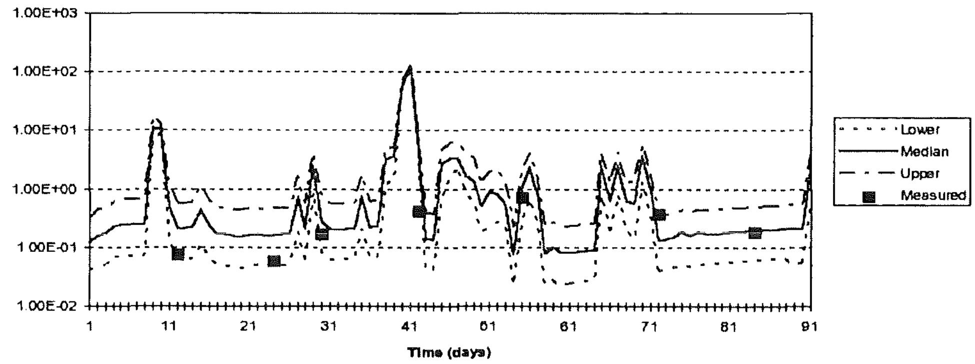


Fig. 4. Simulation by RIVTOX of ^{137}Cs concentration on suspended sediment at outflow from the Ilya River

The lateral inflow into the river net simulated by the RETRACE (Fig. 3) was used by the RIVTOX to calculate the transport in the river channels taking into account the interaction between radionuclides in dilution and bound on suspended sediments (Fig. 4). The incomplete set of the measurements at the river outlet did not cover the exact times of the short rainstorm events. Therefore, the measured and calculated concentrations should be compared rather for averaged than for peak values. The uncertainties for the water-sediments exchange parameters of RIVTOX were evaluated by using the Monte-Carlo technique. The measured data lay inside a 90% confidential interval of simulated ^{137}Cs concentration bound on sediments (Fig. 4).

RETRACE was tested within the BIOMOVS-II program with a scenario covering the run-off of cesium and strontium from small experimental plots located in the 30 kilometer Chernobyl zone. The agreement between the results of RETRACE and the experimental data was one of the best among the contributing models [6]

V.4.2 RIVTOX and COASTOX validation studies

The hydrological part of RIVTOX was tested with data of the Tvertsa river (Russia) and the Dniester rivers (Moldova-Ukraine) [8]. RIVTOX was successfully applied to simulate the fate of chemicals in the Rhine river which resulted of an accidental release at Sandoz, Basel, Switzerland [4]. In the frame of IAEA\CEC VAMP programme RIVTOX was validated on the scenario of the Clinch river -Tennessee river which were contaminated by radionuclide releases from Oak Ridge[12]. The VAMP scenario of the contamination of the Dnieper following the Chernobyl accident was used to calibrate 137Cs and 90Sr transfer parameters inside the RIVTOX code.

A special study was performed within the JSP-1 project to test RIVTOX on the basis of post-Chernobyl data of the Rhine basin. A reasonable good agreement was obtained with data measured in the two rivers Neckar and Mosel. The validation study for the combined RETRACE-RIVTOX chain on the basis of contamination data from the whole Rhine basin is still under way.

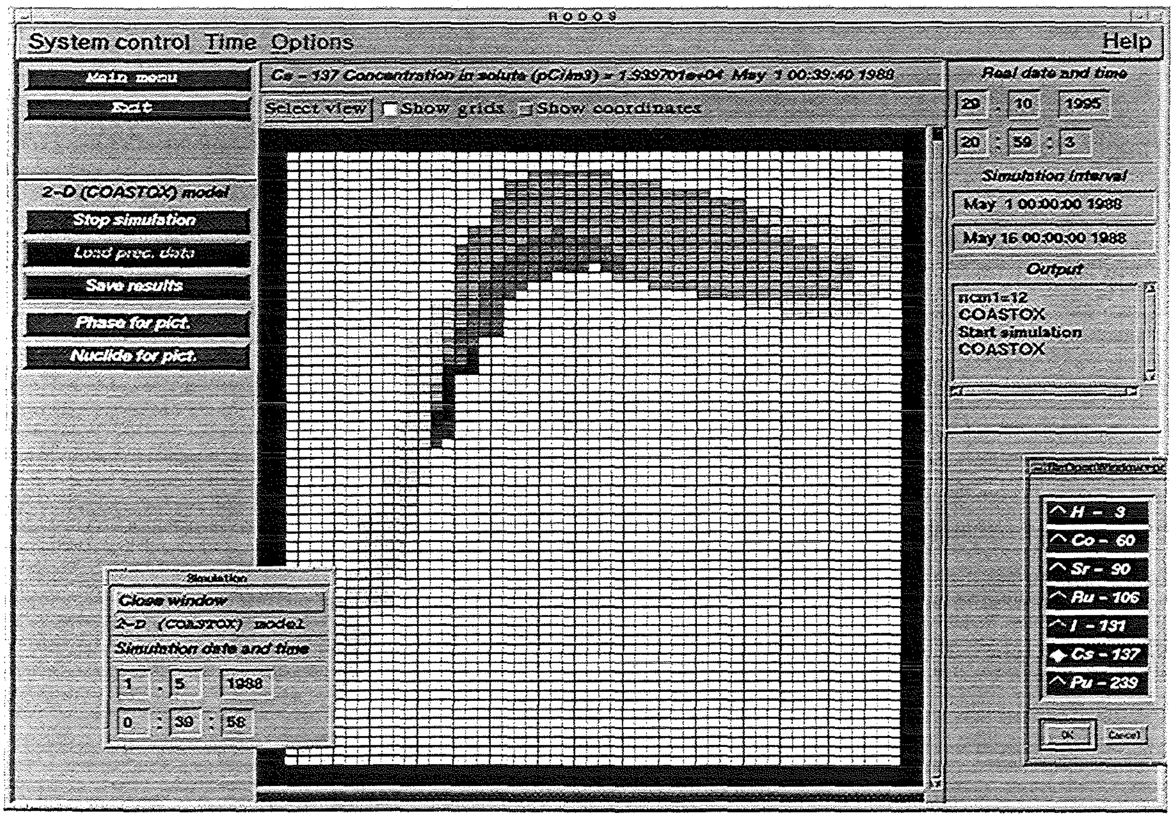


Fig. 5. Interface of COASTOX. Simulation of direct release into the Rhine River.

COASTOX (Fig. 5) was widely used by IMMS CC to simulate the radionuclide transport in the Kiev Reservoir and the Pripyat River floodplain close to the Chernobyl Nuclear Power Plant [3,4,7,9]. Measurements for a ^{90}Sr release from the floodplain after ice jams, January 1991 and February 1994, confirmed the results of predictions based on simulations with COASTOX [9]. Within JSP-1, COASTOX was tested and verified on the basis of measured ^{137}Cs and ^{90}Sr distributions during the 1987 spring flood in the Kiev reservoir. These results demonstrate the importance of application of different adsorption and desorption rates to describe the transfer of ^{137}Cs between solute and bottom deposition.

V.4.3 LAKECO validation

LAKECO was tested and validated within various international working groups. Within the IAEA/CEC VAMP-project the lake model was successfully applied to a wide range of lake ecosystems in Europe, different in terms of trophic status, climatology, deposition of radionuclides, and morphology. LAKECO participated in a blind test within BIOMOVS II, where a Cooling Pond Scenario was outlined. As tuning of the model was impossible, this study could be considered as a quality test. It showed that the original LAKECO model, with a relatively great number of parameters, most of them assessed on the basis of expert judgment, was not able to predict the concentration in the aquatic system with the required accuracy. The enhanced model LAKECO-B showed better results, which proved the increase of predictive power after the implementation of the new submodels. Fig. 6 shows in the left part the concentration in water, averaged over the entire cooling pond (Bq./l), and presents in the right part the activity in predatory fish (Bq/kg wet weight) for both model variants. Furthermore a fuel leaching submodel was added to the code, to govern the fact that in the vicinity of a reactor a high fraction of undissolvable particles can be expected.

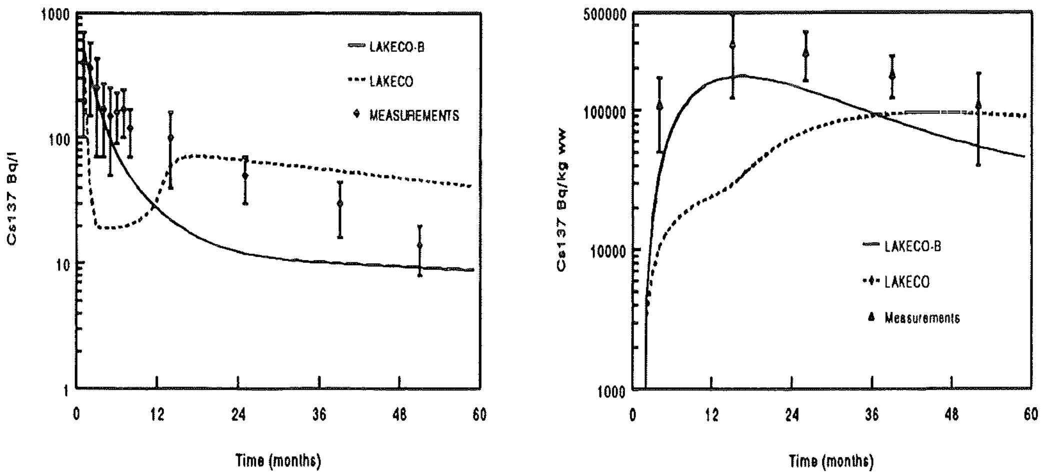


Fig . 6. LAKECO model results for Chernobyl NPP Cooling Pond

V.5 Conclusions

The hydrological model chain for the nuclear emergency decision support system RODOS was developed by the joint efforts of EC and CIS scientists in the frame of the JSP-1 project. Test and validation studies of the whole chain as well as of individual models were performed on the basis of post-Chernobyl data. The software framework for the hydrological model chain was developed and tested. The hydrological module is an integrated part of the RODOS system starting from the PRTY-version 3.01.

Acknowledegement

This paper was originally presented at the First International Conference, Minsk, Belarus, 18 to 22 March 1996, and was published in the Proceedings of that meeting published as EUR Report 16544 EN 73, pp. 1139-1148.

V.6 References

1. J.Ehrhardt, V. Shershakov, M. Zheleznyak, A. Mikhalevich, RODOS: decision support system for off-site emergency management in Europe. -Proceedings of Minsk Conference. First International Conference of the European Commission, Belarus, the Russian Federation and Ukraine on the Consequences of the Chernobyl Accident, Minsk, Belarus, 18-22 March 1996, EUR 16544, pp. 1087-1096
2. V. Borzilev *et al.*, Forecasting of secondary radioactive contamination of the rivers in the 30-th kilometers zone of the Chernobyl NPP, *Meteorologica i Gidrologia*, No. 2 (1989), pp. 5-13, (in Russian)
3. M. Zheleznyak *et al.*, Simulating the effectiveness of measures to reduce the transport of radionuclides in the Pripyat-Dnieper aquatic system - Proc. International Seminar on Intervention Levels and Countermeasures for Nuclear Accidents. Cadarache, France, 7-11 October 1991.-Commission of the European Communities, Radiation Protection-54, EUR 14469, 1992, p.336-362.
4. M. Zheleznyak, P. Tkalich, G. Lyashenko, A. Marinets, Radionuclide aquatic dispersion model-first approach to integration into the EC decision support system on a basis of Post-Chernobyl experience. - *Radiation Protection Dosimetry*, N6 (1993), 37-43.
5. W. Raskob, R. Heling, A. Popov , P. Tkalich, The modelling concept for the radioactive contamination of waterbodies in RODOS, the decision support system for nuclear emergencies in Europe, *The Science of the Total Environment,* (in press).
6. A. Popov, R. Borodin, A. Pokhil. Description of a Physically Based Distributed RETRACE Model to Simulate Radionuclide Transport in Runoff Water, In: Hydrological Model Chain in RODOS, JCP-1 Final Report, EUR 16533 (1995).
7. M. Zheleznyak *et al.,* Mathematical modeling of radionuclide dispersion in the Pripyat-Dnieper aquatic system after the Chernobyl accident, *The Science of the Total Environment* **112** (1992), 89-114.
8. P. Tkalich, M. Zheleznyak, G. Lyashenko, A. Marinets, RIVTOX - Computer Code to Simulate Radionuclides Transport in Rivers, In: A. Peters et al.(Eds.) , Computational Methods in Water Resources X, vol. 2, Kluwer Academic Publishers, Dordrecht, The Netherlands, 1994, pp. 1173-1180.
9. M. Zheleznyak *et al.* Modeling of Radionuclides Transport in the Set of River Reservoirs, In: A. Peters et al.(Eds.), Computational Methods in Water Resources X, vol. 2, Kluwer Academic Publishers, Dordrecht, The Netherlands, 1994, pp. 1189 - 1196
10. R. Heling, LAKECO - the model for predicting the behaviour of radionuclides in lakes and reservoirs, In: Hydrological Model Chain in RODOS, JCP-1 Final Report, EUR 16533 (1995).
11. M.B. De Vries, H. Pieters, Bioaccumulation in pike perch, data analysis on data of Lake IJsselmeer, Lake Ketelmeer, and Lake Markmeer. in: Accumulation of heavy metals in organics. Delft Hydraulics and National Institute of Fishery Investigations, 1989
12. M. Zheleznyak *et al.,* Modeling of radionuclide transfer in rivers and reservoirs: Validation study within the IAEA\CEC VAMP Program. International Symp. on Environmental Impact of Radioactive Releases, IAEA, Vienna, 8-12 May 1995, Extended Synopses IAEA-SM-339, IAEA, 1995, p.330-331

VI Food Chain Modelling and Dose Assessment in RODOS

Heinz Müller and Stephan Hübner
GSF -Institute of Radiation Protection
Ingolstädter Landstr. 1, D-85764 Neuherberg, Germany

Abstract

All radiation exposure pathways which are considered in the RODOS food chain and dose modules are described. For each of them, the principal processes controlling the exposure are discussed, showing up the input data requirements. Emphasis is put on those data which vary from region to region and thus require the adaptation of model parameters if RODOS is to be applied for regions with different conditions. Calculation of individual doses as well as estimation of collective doses are reflected. Possibilities for improving the dose estimations by consideration of measured data are discussed. The deposition onto different kinds of surfaces (e.g., soil, plant canopies, urban areas) can be improved by means of gamma dose rate measurements, vegetation samples, in situ gamma spectrometry etc. Measurements of concentrations of activity in feed and foodstuffs, whole body burdens, personal dosemeters etc. can help to improve the predicted internal and external doses.

VI.1 Introduction

A major task of a decision support system like RODOS[1] is to provide informations about the present and future radiation exposure of the population. This requires the application of models describing the behaviour of radionuclides in the environment and assessing the resulting radiation exposure.

For this purpose RODOS comprises a terrestrial Food Chain Module (FMT) for the assessment of the radioactive contamination of foodstuffs following the deposition of radionuclides from atmosphere onto agricultural production areas, and an aquatic Food Chain Module (FMA) which estimates the activity concentration in foodstuffs following a radioactive contamination of animal feeding water and water for irrigation of agricultural crops. Input to FMT comes mainly from the Atmospheric Dispersion Module while FMA starts from the results of the Hydrological Module which models the transfer of radionuclides after radioactive contamination of water bodies.

The assessment of present and future doses is performed in the terrestrial and aquatic dose modules (DMT and DMA) which get input from the Atmospheric Dispersion Module and from the Food Chain Module (Figure 1). The radiation exposure via all pathways which might be of importance during and after passage of the radioactive plume is estimated for persons of different age:

- 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.

The basic modelling asumptions of the FCM and the DM are described in this paper, and some problems in defining the endpoints of calculation, as well as in adapting the models to different regions are discussed.

All model predictions in a decision support system will lose part of their initial importance as soon as radiological measurements are available after an accidental release of radioactive material. The system users would no longer use a system which is based on models only, and which ignores available measurements. Especially in areas where the activity and dose predictions are close to existing intervention limits, the confirmation of predicted values by measurements is of importance. Therefore, the decision support system has to combine model predictions and measured data in a multi stage process in which the measurements get more and more important as time elapses. The approaches of assimilation of measured data which are being integrated in the RODOS system, are discussed in the second part of this paper.

VI.2 Food Chain Modelling

The Food Chain Module of RODOS is based on the dynamic radioecological model ECOSYS-87(2). Starting from the activity concentration in air and the wet deposited activty, the assessment of the activity in foodstuffs after deposition of activity from the atmosphere onto agricultural production areas is performed in several steps (see Fig. 2):

(1) Activity deposition onto plant canopies and onto ground: Dry and wet deposition is considered separately. The dry deposition velocity is dependent on the seasonal stage of development of the different plant species, expressed by their leaf area index. Interception of wet deposited activity by the foliage also depends on the plants' leaf area index, and also on the amount of precipitation. While the applied model seems to work quite well for short term deposition events, problems might arise with long term inhomogeneous deposition processes, e.g. removal of initially dry deposited activty by subsequent precipitation.

(2) Calculation of the time dependent activities in edible parts of plants (raw products): 15 plant species are considered using 5 different modelling approaches to take into account different processes after initial deposition of radionuclides to the leaves (see Table 1).

(3) Calculation of time dependent activities in feedstuffs: dilution or enrichment of the concentration of activity during processing is taking into account, as well as radioactive decay during processing and storage of the products.

(4) Estimation of the time dependent activities in animal products: Activity intake by the animals is considered by season dependent feeding practices. The kinetics of activity transfer to the animal products (milk from cows, sheep and goats; beef from cows and bulls; veal; pork; lamb; roe deer; chicken; eggs) is approximated by applying biological halflives in addition to transfer factors.

(5) The time dependent concentrations of activity in foodstuffs are also estimated taking into account processing, storage and culinary preparation of vegetable and animal products.

Presently, the products considered in the RODOS Food Chain Module comprise 22 feedstuffs (17 based on plants, 4 based on animal products, and feeding water) and 35 foodstuffs (17 plant products, 17 animal products, and drinking water). This relatively large number of products results on the one hand from the diversification of plant species which is necessary to reflect properly radioecological conditions in various regions. 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. To allow the adaptation of the model to agricultural conditions of different countries, the model allows to define additional plant species, animal products, feed and foodstuffs. For consideration of products from natural or semi-natural environments a simple approach of radionuclide transfer to roe deer meat (the most important product of this category in Germany) is included. While this is appropriate for application in Central Europe, it seems insufficient for application of RODOS in several regions of Eastern and Northern Europe; therefore, an additional module for food contamination and doses from natural environments is under development by some other institutes.

The model for food chain transfer has been initially developped for Central European conditions. Since it uses many parameters which vary to a high degree over the area of Europe, these parameters need adaptation to local conditions if the model is to be applied to other regions. Data with highest need for adaptation are

- selection of relevant feed and food species,
- seasonal development of the leaf area index and harvesting periods for all plant species considered in the model,
- feeding practices for animals.

In addition - for long-term predictions - the soil-plant transfer factors, mainly determined by the soil type, are important. Normally, information on many of the required data is available in the literature of agricultural sciences. But a special problem arises with the adaptation to several Eastern European countries: due to the tremendeous changes of economy and agriculture since the beginning of this decade, much of the available literature does no longer reflect the present and future conditions. Here the model adaptation might face severe problems, and it will need large resources.

VI.3 Calculation of individual doses

In RODOS two types of individual doses are calculated:

- Potential doses which give an upper limit of individual doses.
- Expected doses which give a best estimate of the average exposure of the population.

Ingestion doses are estimated from the time dependent concentrations of activity in foodstuffs, applying age and season dependent consumption rates, and age dependent dose conversion factors. A special problem with ingestion doses is that many foodstuffs are produced at a location different from that where they are consumed. Quantitative consideration of food transport from the producer to the cumsumer is hardly possible in „normal" situations, and it is absolutely impossible after a severe accidental release of radioactivity due to unpredictable changes of such transports. In addition, spontaneous changes of the peoples' consumption rates after the accident are unpredictable. Therefore, only potential ingestion doses (i.e. assuming full local production of all foodstuffs, and long term average consumption rates) are calculated in RODOS.

Inhalation doses are estimated from the concentration of activity in air, and age dependent inhalation rates. Long term inhalation of resuspended material is also considered, but due to the large variability of this pathway the results can only give an estimation of the order of magnitude. Potential inhalation doses assume that people stay outdoors, while expected doses consider lower concentrations of activity inside buildings and the fractions of time when people stay in- and outdoors.

The assessment of external exposure from radionuclides in the plume is based, where applicable, on the time-integrated activity concentration in air assuming a semi-infinite homogeneous cloud. For locations in the vicinity of the emission source, a three-dimensional integration over the contribution of all parts of the plume is performed in the atmospheric dispersion module of RODOS; the resulting kerma in air is passed to the Dose Module which estimates the organ doses and/or effective dose from it. The external exposure from nuclides deposited on the ground is calculated on the basis of the total deposited activity onto vegetated soil. Long term dose reductions from nuclide migration into deeper soil layers are considered. For both these external exposure pathways, age dependent dose conversion factors are used based on Monte Carlo calculations using human phantoms[3,4].

As an additional pathway of external exposure, irradiation from radionuclides deposited onto skin and clothes is considered. The applied model is considered to have rather big uncertainties, but the contribution of this pathway is of minor importance.

For all external exposure pathways, potential doses are estimated assuming that the persons stay in the open air over a lawn all the time, i.e. no shielding or filtering effects by buildings are assumed. For estimations of expected doses, shielding effects due to staying at different environments outside and inside houses are considered as well as the influence of variable deposition patterns[5]. Due to large uncertainty of the actual residual habits of the population (depending on time, weather conditions etc.) the estimated doses using default parameters can only be average doses for the average population. But if appropriate data are available for specific population groups, they can be considered by the user.

The most relevant model parameters which need adaptation to local conditions if the Dose Module is to be applied to other regions are food consumption habits, residual habits, and shielding properties of buildings.

VI.4 Calculation of Collective Doses

The collective dose of a certain population is commonly thought of the sum of individual doses of all people belonging to the population. For large populations it is not possible to take this definition as a basis for calculating the collective dose, since it is not possible to consider the living conditions of all individuals for estimating their individual doses. Instead of this, individual doses for representatives of certain population groups are calculated and then multiplied by the number of people belonging to these population groups.

In RODOS, collective doses are estimated in order to quantify the effectiveness of different possible countermeasures for mitigating the radiological consequences. For this purpose, the absolute values of collective doses are of less concern than the relative changes due to application such countermeasures. Therefore, the collective doses are estimated by simply multiplying the individual doses for average adults with the total number of inhabitants living in a certain area. Of course, such kind of collective dose is not appropriate for application e.g. in an epidemiological study.

In the case of ingestion doses the calculation of a collective dose by summing up individual doses is complicated by the fact that foodstuffs are normally not totally produced in the area where they are consumed, or, vice versa, they are not totally consumed in the production area. Therefore, for reasonably estimating a collective ingestion dose for a population, it would be necessary to know where all the foods have been produced, and what the level of their contamination is. This knowledge is not available in general. But it is possible to take another definition of collective ingestion dose of a certain area: it is the dose resulting from consumption of all foodstuffs produced in this area, irrespective of where they are consumed.

This type of collective ingestion dose is more appropriate for the evaluation of the effectiveness of countermeasures in food production, and therefore this approach is used in RODOS.

VI.5 Assimilation of Measured Data for Dose Assessment

The data basis on which the present and future radiation exposure is estimated will change continuously before, during and after passage of a radioactive plume[(6)]. In the very early phase any assessment of radiation exposure can only be based on assumptions about the released radioactivity, and on model calculations of atmospheric dispersion, of radionuclide transfer in the environment and of the resulting doses to the population. But very soon after the start of the emission, an increasing number of measurements will be available which can and must be used to improve the intial predictions of radionuclide transfer and of doses. This is a multistage process in which first the atmospheric dispersion calculations are more and more modified or even replaced by measurements of air concentration, gamma dose rate etc. The next step is an improvement of predicted activity deposition to different kinds of surface (soil, urban areas, different plant species) using measured data on contamination of these surfaces. Then the model predictions of the radionuclides' food chain transfer have to be improved more and more by measurements in animal feed and human food. But even after the release has been stopped the models will not be fully replaced by measurements since measurements can only supply information about the past and present situation, but not about future radiation exposure, and measurements will never be complete enough with respect to time and space to supply all information needed. Therefore, also on the long term, the question will not be 'models *or* measurements ?' but we have to combine models *and* measurements in order to provide assessments of the radiological situation which are as reliable as possible. For this purpose, two modules for the RODOS system are under development which allow to assimilate the available measurements for a step by step improvement of the predictions:

- A Deposition Monitoring Module which uses available measurements to improve the knowledge about radionuclide activities deposited onto different types of surface (e.g. plants' foilage, urban areas) which cause long term radiation exposures.
- A Dose Monitoring Module which assimilates measurements for making the dose predictions as reliable as possible.

The data flow to and from these two modules for data assimilation in RODOS can be seen from Figure 1.

Integration of model predictions and measured data can only be performed in a reasonable way if both quantities are comparable (e.g. personal dosemeter data can only be compared with expected exposure), and if both agree in their representativeness of time and space. This means, it makes no sense to compare model predictions which represent an average over a big grid cell (which is from 1 km x 1 km up to about 100 km x 100 km in RODOS) with measurements at a single location, especially if the deposition pattern or other conditions are rather inhomogeneous. Therefore, single measurements can not be directly used in the Deposition and Dose Monitoring Modules, but the measured data have to be processed first to get representative means for comparison with model calculations. Another presupposition is that the measured data are quality assured before being integrated in RODOS.

VI.5.1 Improvement of estimated deposition

The Deposition Monitoring Module integrates the following kinds of measured data:

- Gamma dose rate over different kinds of surface (e.g. lawn),

- Measurements of in-situ gamma spectrometry over different kinds of surface,
- Activity concentrations in samples of soil and plants.

The interpretation of these measurements can be very difficult (and is sometimes even impossible) if the measurements have been performed before the end of the passage of the contaminated plume. In this case the dose rate and in-situ measurements may include contributions both from airborne and from deposited nuclides. Without having further information, these two contributions can not be distinguished; this prevents an unambiguous interpretation of the data. This problem will arise especially if an emission of radionuclides occurs over a long time period. It can be solved by processing measured data of dose rate and activity concentration in air taken simultaneously at the same location, as it is done in the German Program System for the Assessment an Mitigation of Radiological Consequences PARK(7). A further source of uncertainty may be the unknown depth profile of radionuclides in the soil, though procedures have been developed which deduce information on the depth profile from in-situ measurements(8).

VI.5.2 Improvement of dose estimations

In the Dose Monitoring Module, measurements of activity concentrations in feed and foodstuffs as well as whole body measurements can be processed to improve the predictions of ingestion doses. The reliability of external exposure assessments can be checked/improved by results of personal dosemeters and stationary dose rate measurements.

For the assimilation of measurements of activity in feed and foodstuffs it is necessary that the samples have been taken from locally produced products in order to be comparable with the model predictions.

It can be anticipated that measurements will be available only for some part of the locations (grid cells) where predictions have been made, and only for limited points of time. This brings up the problem of interpolation of existing measurements in space and time. In an ideal case, the model parameters can be tuned to fit the existing measurements; after that, the model can be applied for all locations and times. But in reality, such an automatic adaptation of model parameters to meet the measured food concentrations is very risky because the discrepancies of predictions and measurements are often caused by wrong assumptions in the scenario (e.g. wrong type of animal feed). In such a case parameter fitting can reduce the discrepancy in certain situations (i.e. at certain times and/or locations where measurements exist), but this does not mean that the model has become more realistic: in other situations the model might give even worse results than before the parameter fitting. Of course, if there are consistent data sets (i.e. measurements of activity in different media at the same location) available which allow to improve the knowledge about certain processes, (e.g. deposition, interception, translocation) then the adaptation of one or more model parameters can be reasonable and can improve the overall behaviour of the model. This is also the case in situations for which measurements do not exist. This kind of model improvement should not be done purely automatically, but the last decision about parameter adaptation should be taken by an experienced scientist who is familiar with the whole model and with the circumstances under which the measurements were taken. Therefore, the data assimilation modules of RODOS will not perform model adaptations automatically, but they will give advice to the user about possible sources of disagreement and they will suggest to him improvements of certain model parameters if the measurements allow such conclusions to be drawn.

Acknowledgement

This paper is an extended version of a paper which was originally presented at the Fourth International Workshop, Aronsborg, Sweden, October 7 - 11, 1996 and was published in the Proceedings of that meeting published as Radiation Protection Dosimetry Vol. 73, Nos. 1-4 (1997), pp. 61 - 66. It is reproduced with permission of the publisher, Nuclear Technology Publishing.

VI.6 References

1. Ehrhardt, J., Päsler-Sauer, J., Schüle, O., Benz, G., Rafat, M. and Richter, J. Development of RODOS, a Comprehensive Decision Support System for Nuclear Emergencies in Europe - an Overview Radiat. Prot. Dosimetry 50, 195-203 (1993)
2. Müller, H. and Pröhl, G. ECOSYS-87: A Dynamic Model for Assessing Radiological Consequences of Nuclear Accidents Health Phys. 64(3), 232-252 (1993)
3. Jacob, P., Rosenbaum, H., Petoussi, N. and Zankl, M. Calculation of organ doses from environmental gamma rays using human phantoms and Monte Carlo methods, Part II: Radionuclides distributed in the air or deposited on the ground GSF-Forschungszentrum, Neuherberg, Germany, GSF-Report 12/90 (1990)
4. Henrichs, K., Eiberweiser, C. and Paretzke, H.G. Dosisfaktoren für die Kontamination der Haut und der Kleidung GSF-Forschungszentrum, Neuherberg, Germany, GSF-Report 7/85 (1985)
5. Meckbach, R. and Jacob, P. Gamma Exposures due to Radionuclides Deposited in Urban Environments. Part II: Location Factors for Different Deposition Patterns Rad. Prot. Dosim. **25**(3), 181-190 (1988)
6. Müller, H., Bleher, M., Jacob, P. and Luczak-Urlik, D. Consequence Assessment and Improvement of Model Predictions by Environmental Measurement Data Proc. NEA-Workshop "Emergency Data Management", Zurich, Switzerland, 12-14 September 1995
7. Bleher, M. and Jacob, P. Real-time assessment of radionuclide deposition by PARK Rad. Prot. Dosim. **50**(2-4), 343-348 (1993)
8. Jacob, P., Golikov, V. and Gering, F. Gamma-ray spectrometry in the environment and modelling of external exposures In: Proc. Int. Congr. on Radiation Protection, IRPA 9, Vienna (1996)

Figure 1. Data flow in the food chain, dose, and according data assimilation modules in RODOS

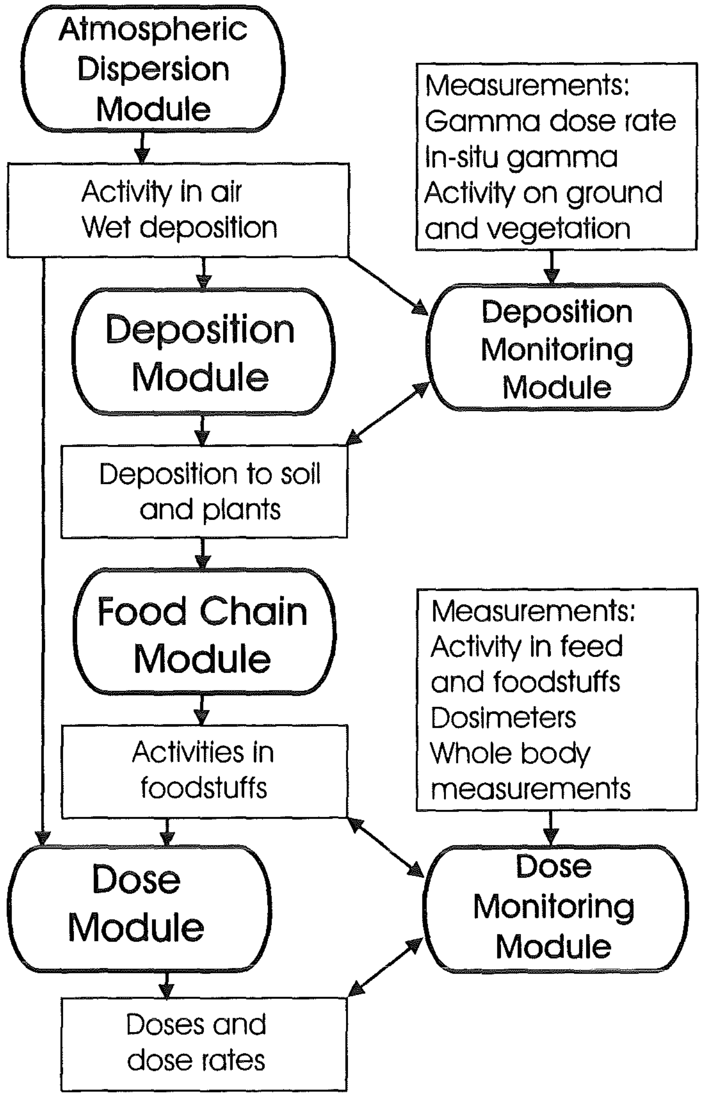


Figure 2. Calculation steps in the assessment of foodstuff contamination

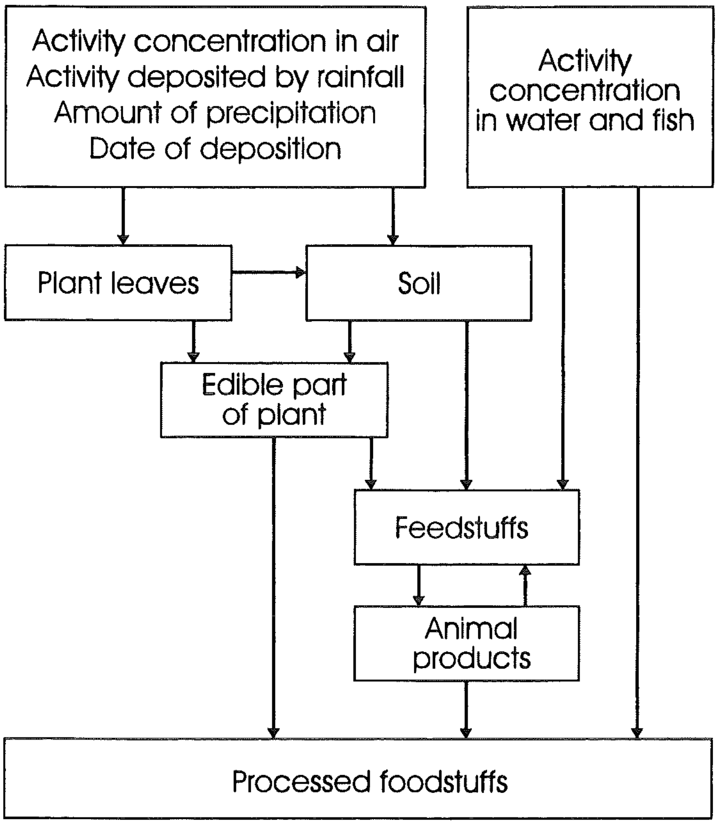


Table 1. Plant types used in modelling the contamination of crops

Plant type	I	II	III	IV	V
Applied for	grass/hay #	maize, beet leaves	leavy vegetables	barley*, wheat*, rye, oats, beet, maize bulbs, potatoes	root and fruit vegetables, fruit, berries
Eaten/fed part:					
whole plant	•	•	•		
fruit or root only				•	•
Harvest:					
continuously during vegetation period	•		•		•
short harvest period		•		•	
Considered processes:					
Weathering	•	•	•		
Growth dilution	•	•	•		
Translocation				•	•
Root uptake	•	•	•	•	•
Resuspension	•	•	•	•	•
Storage for winter period	•	•		•	•

Grass from intensive and from extensive cultivation is considered.

* Winter and spring species are considered.

VII The Simulation of Early Emergency Actions in RODOS

J.Päsler-Sauer, T.Schichtel
Forschungszentrum Karlsruhe G.m.b.H.
Institut für Neutronenphysik und Reaktortechnik P.O.Box 3640, D-76021 Karlsruhe

Abstract

Based on the diagnosis and prognosis of the radiological situation performed in the analysing sub- system ASY of RODOS countermeasure scenarios are simulated and their radiological and eco- nomic consequences are quantified in the countermeasures subsystem CSY. In the automatic mode the user gets information about the temporal and spatial distribution of organ doses with and without the effects of single emergency actions like sheltering, evacuation, and administration of iodine tab- lets. The areas for these actions are defined by the corresponding dose intervention levels. Addition- ally, consequences like the size of the areas and the number of people affected by the actions, deterministic and stochastic somatic health effects, and the costs of evacuation and medical treat- ment of health effects are calculated and presented to the user. In the interactive mode the user can modify intervention levels and areas for the actions and generate her/his own countermeasure sce- narios by input of time and duration parameter values. In this way she/he can assess the effect of a countermeasure scenario consisting of the spatial and temporal course of sheltering, evacuation, and distribution of iodine tablets of her/his own choice. Again all the resulting consequences like in the automatic mode are calculated and presented.

A special module has been developed for simulating evacuation in the affected areas, taking into account the existing road network, the capacity of the streets and the population distribution around nuclear power plants. It allows to calculate the time dependent location of the population during evacuation, the duration to leave the area and - in connection with the dose modules - to assess the doses received. An optimisation module for identifying the best-suited traffic routes for selectable criteria, such as route length, doses received or costs is being developed.

VII.1 Emergency Actions and Consequence Assessment

The aim of the Countermeasure Subsystem CSY(1) of RODOS is to inform the deci- sion maker about the consequences in the population resulting from a present and/or future radiological situation and to present the potential effects of countermeasures. The simulation of early emergency actions and the assessment of consequences are the main objectives of the program group EMERSIM, HEALTH and ECONOM in 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 some up to a few ten kilo- metres 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 passage of the radioactive cloud. Decisions on emergency actions are in general based on dose intervention lev- els. 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 personnel support. These questions have to be answered by the emergency man- agement. EMERSIM allows the user for choosing different temporal and spatial pat- terns of combinations of early emergency action and quantifies the resulting individual doses.

VII.2 Radiological Situation and Simulation of Early Emergency Actions

In the case of a threatening or already ongoing radioactive release decisions about countermeasures must be oriented at the prognosis of the radiological situation. Therefore, the starting point of all countermeasure simulations in RODOS is a prognostic calculation of the radiological situation. This is carried out in the Analysing Subsystem ASY(2). Since countermeasures generally depend on the spatial and temporal development of the radiological situation during the time interval from the release to the end of the prognosis period it is neccessary to calculate and store a time series of data representing this development. It has turned out to be useful to calculate these data in terms of the corresponding doses, i. e. in the form of ‚potential dose histories'. These histories contain for each point on a calculation grid all information about the development of individual doses for different pathways, organs, and locations during the release and dispersion time interval of 24 hours. The effect of time dependent countermeasures is quantified by multiplying the potential dose histories with dose reduction factors representing the effects of the actions for population groups of the same behaviour.

VII.2.1 Calculation 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. Location specific quantities on the grid are assigned to or calculated for the cen- tral point of the cells; for area specific quantities the number contained in the cell is assigned.

VII.3 Modelling of emergency actions and dose calculations in EMERSIM

For the calculation of doses with protective actions a scenario has to be defined. On the one hand, it consists of the prognosis of the radiological situation including its temporal development from the beginning of the release, and - on the other hand - of an action scenario during the prognosis time interval. As outlined above the temporal development of the radiological situation is archived in the form of potential dose his- tories in each grid cell during a PROGNOSIS run in the subsystem ASY. The potential dose histories are calculated in the form of series of half hour dose segments on all cells of the calculation grid. All histories begin with the start of the release which is identical with the begin of the prognosis interval.

VII.3.1 Action areas and action timing

The definition of an action scenario includes the action areas and the action time inter- vals. In the interactive version of EMERSIM the user can either define action areas indirectly by setting dose intervention levels or directly by graphical input of these areas on the screen. The action areas are stored as sets of grid cells marked with action specific tags. The action time intervals define when a certain action starts and ends in relation to the beginning of the prognosis time interval. The action times are user input to EMERSIM.

VII.3.2 Calculation of doses with emergency actions

With given potential dose histories, action areas and action time intervals, 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 without an action tag the potential dose segments are summed up, i. e. the resulting potential dose remains unchanged. The cells with an action tag are treated in a different way: the potential dose segments are summed up only at times before an action has started. During or after the action the value of each dose segment is modified by a specific factor describing the effect of the action on dose. Then all cell segments are added to get the cell dose. In the upper parts of Fig.1 a, b, c examples of time series of potential dose segments are shown, in the lower parts the corresponding time series modified by different actions are given. The timing of the actions is drawn between both diagrams. In Fig. 1 a the effect of sheltering against external gamma radiation is shown. The dose reduction during sheltering is simulated in EMERSIM by using building type specific location factors for external cloud and ground gamma radiation. The location factors are defined as average values for each grid cell and are derived from the building types in that cell. In Fig. 1 b the effect of evacuation on dose is exemplarily shown. In the present version of EMERSIM the simplifying assumption is made that before the start of and during the evacuation people receive 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 possi- ble by using the results of the evacuation simulation module EVSIM described below. In Fig.1 c the

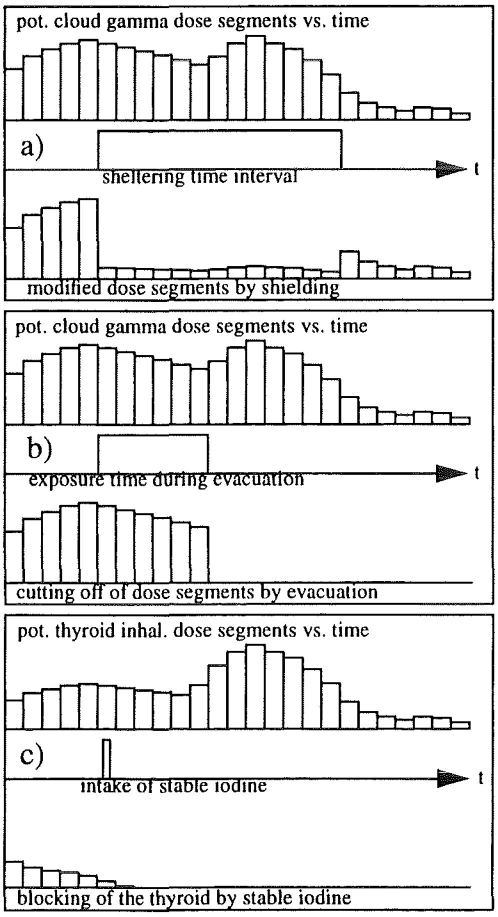


Fig. 1: Modelling of the effect of emergency actions on dose; a) sheltering, B) evacuation, c) intake of stable iodine

effect of the administration of iodine tablets is indicated. The intake of the tablets leads to an attenuation of the thyroid doses resulting from inhalation, also influencing the calculated committed dose histories several hours before the intake: the efficiency of thyroid blocking decreases exponentially with the time difference between intake of tablets and inhalation. A short time after the intake of the tablets the blocking of the thyroid amounts to 100% .

VII.3.3 Patterns of action scenarios

In order not to focus the decision maker's attention to the more simple cases, where the evacuation area is part of the sheltering area and all actions begin at the same time, the user can define several more or less overlapping action areas, starting times, and durations in the interactive mode of EMERSIM. Fig. 2 gives an example. The capital letters denote the action tags of the areas: Sheltering, Evacuation, intake of stable Iodine, the combination ShEvIo means that Sheltering, Evacuation, and intake of sta- ble Iodine take place in the area tagged with it. ‚No action' denotes areas without emergency actions with normal living conditions.:

The starting times and durations of the actions can be chosen independently in differ- ent areas. An evacuation starting before the end of sheltering terminates sheltering. The intake of stable iodine is assumed to occur synchronously in all Io tag areas. It is not carried out in Ev areas if evacuation starts before the time of iodine intake.

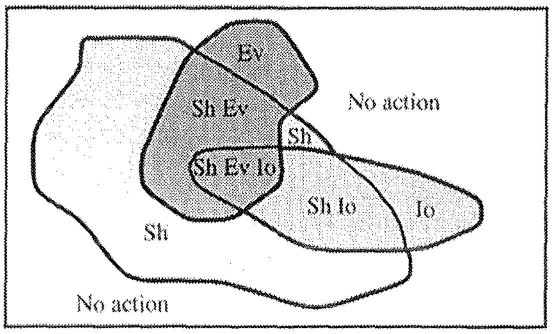


Fig. 2: Example action areas: Sh=sheltering,Ev= Evacuation, Io= iodine tablets intake

VII.3.4 Dose results of EMERSIM

Each dose is estimated for 5 different integration times: 1, 7, and 30 days, 1, and 50 years (except the external cloud gamma dose). The doses are calculated separately for the three exposure pathways cloudshine, groundshine, inhalation, and as the sum of these pathways. All doses are field values defined on the 41 x 41 cells grid. Besides the effective dose organ doses are calculated for: lung, bone marrow, thyroid, and uterus.

VII.4 The health effects module HEALTH

The health effects module HEALTH estimates the numbers of people with determinis- tic and stochastic somatic health effects. The models used are the same as those imple- mented in the program package COSYMA(3). Input to the health effects models are the organ dose fields calculated in the modules NOACDOS and ACDOS of EMER- SIM and the population distribution (see Fig. 3). From the dose fields the following individual risk fields are calculated:

A) individual risk of deterministic health effects;

- morbidity: lung function impairment, hypothyroidism, and mental retardation

- mortality: pulmonary syndrome, hematopoietic syndrome, pre- and neo-natal death

B) risk of stochastic somatic health effects;

- cancer mortality

The numbers of people with different health effects are determined from the risk fields and the population distribution.

VII.5 The economic module ECONOM

In the economic module ECONOM various off-site economic consequences of the accident are assessed in the form of monetary costs. The different kinds of costs are calculated in several submodels for

- costs of medical treatment of persons with health effects
- costs of evacuation and accommodation of people
- productivity losses to society due to illness or death of people

The models contain realistic economic parameters and data describing the economic structure of the areas affected by the accident. Input data to ECONOM are population data, the health effects data, regional economic data, and the numbers of persons affected by evacuation. The modelling of economic consequences is oriented at the methodology used in COSYMA(4).

VII.6 Program structure of EMERSIM

The program structure of EMERSIM is shown in Fig.3 together with the modules HEALTH and ECONOM. In NOACDOS a situation without protective actions is assumed; in ACDOS the emergency action scenario is simulated. The doses without and with actions are calculated in these programs. A more detailed simulation of 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.

VII.7 The evacuation simulation module EVSIM

VII.7.1 Model description

The task of the evacuation simulation module EVSIM is, to estimate the time evolution of the spatial population distribution in the early countermeasure phase. In real evacu- ations performed in the past and in evacuation plans (e.g. in Germany) the self evacu- ation by private cars plays a predominant role. Therefore the modelling of self evacuation plays the most important role in EVSIM: it is assumed that the evacuation takes place on certain evacuation routes predefined in emergency plans.

Because of the need of a fast evacuation simulation the traffic net in EVSIM is mod- elled on a grid. The temporal changes in the population distribution are calculated using constant time steps. In the present version of EVSIM the length of a grid element is 1 kilometer and a time step of a typical run is one minute of evacuation time. The model takes into consideration that the velocities on the road segments depend on the type of road. During an evacuation heavy traffic flows are expected. Therefore a macroscopic description by traffic variables as flow, speed and density can be expected to be rela- tively accurate. Fundamental diagrams represent the relation between density and ve- locity. EVSIM estimates the density of a car chain of certain speed from such fundamental diagrams. 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.

VII.7.2 User Interface

The success of an evacuation strongly depends on a lot of factors which may change during daytime (e.g. actual number of people in settlements, availability of private cars, ...) and even during the evacuation (e.g. possible traffic blocks, availability of technical and personnel support). To handle all these actual conditions and to use the knowledge of experts about evacuation management (e.g. by exercises and in the plan- ning phase) EVSIM has its own user interface. It includes a graphics package designed for the special needs of EVSIM. This graphics package is based on the graphics library used in RODOS.

Due to the modelling in EVSIM decisions on evacuation have to be based on settle- ments (villages, cities, districts of cities, ...). An evacuation scenario in EVSIM defines which settlements will be evacuated at which time. The user can either use predefined scenarios or define his/her own scenarios via the user interface. The user can interrupt and resume the evacuation simulation by control buttons and can make changes if the simulation is interrupted. The chosen scenario and the simulation status are depicted by special symbols. 'Information Windows' of EVSIM give the symbol explanation. The user can specify the simulation time intervals between updates of the screen. So it is possible to follow the simulation in 'slow motion'. EVSIM detects when the evacu- ation is finished.

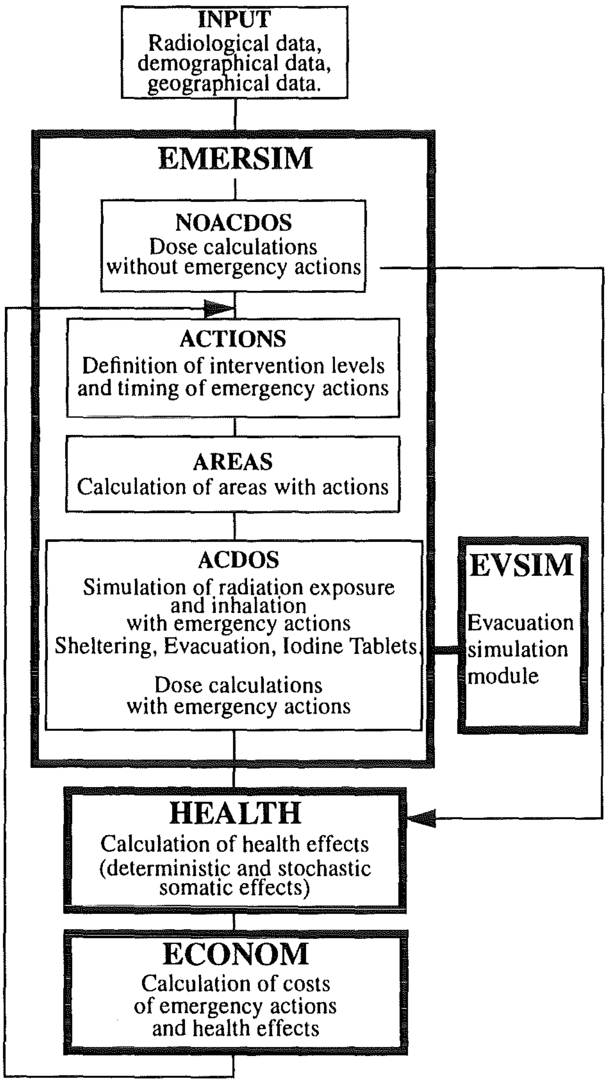


Fig. 3: Program flow of EMERSIM, EVSIM

VII.7.3 Analysing Tool

EVSIM has its own analysing module. It is a module that evaluates the efficency of the simulated evacuation. While the EVSIM graphics tool serves to identify traffic bottle- necks during the evacuation process, the analysing module presents the resulting driv- ing times and individual doses. To optimise the evacuation with respect to traffic jams and with respect to dose exposure it is important to know the starting time and the end of the evacuations for each settlement. Therefore these data are graphically presented in one diagram. The connection of these data with the information about the movement of the radioactive cloud is necessary to optimise the evacuation with respect to dose. The analysing module builds the driving time distributions for settlements and for the complete evacuated population from the simulation data. The distributions are present- ed as data files and as diagrams.

Acknowledgement

This paper was originally presented at the Fourth International Workshop, Aronsborg, Sweden, October 7 - 11, 1996 and was published in the Proceedings of that meeting published as Radiation Protection Dosimetry Vol. 73, Nos. 1-4 (1997), pp. 67-70. It is reproduced with permission of the publisher, Nuclear Technology Publishing

VII.8 References

1. Ehrhardt, J. The RODOS system: Decision support for off-site emergency management in Europe. Proceedings of the "Fourth International Workshop on Real- Time Computing of the Environmental Consequences of an Accidental Release from a Nuclear Installation", Aronsborg, Sweden, 6 to 11 October 1996, Radiation Protection Dosimetry Vol73 Nos.1-4, 1997 pp.35-40

2. Päsler-Sauer, J., Schichtel, T.; Mikkelsen, T., Thyckier-Nielsen Meteorology and atmospheric dispersion, Simulation of emergency actions and consequence assessment in RODOS, Proceedings of the Oslo Conference on Intern. Aspects of Emergency Management and Env. Technology, June 18-21,1995, Oslo, edited by: H. Drager, A/S Quasar Consultants.

3. COSYMA- A New Programme Package for Accident Consequence Assessment. Report EUR 13028 EN. (Brussels: CEC)(1990).

4. Faude, D. COSYMA- Modelling of Economic Consequences. KfK Report 4336 Forschungszentrum Karlsruhe (1992). The Simulation of Early Emergency Actions in RODOS

VIII Models for Decontamination, Relocation and Agricultural Countermeasures in RODOS

J Brown, K R Smith, P Mansfield and J Smith
National Radiological Protection Board
Chilton, Didcot, UK-Leeds, LS2, 9JT

Abstract

Predictions of the effects of decontamination, relocation and agricultural countermeasures are an important part of the decision making process following an accidental release of radioactive material into the environment. Models and supporting databases have been developed for this purpose and integrated into the EU decision support system, RODOS. A wide range of potentially practicable countermeasures are considered on timescales from a day to many years, and endpoints related to their imposition are calculated such that the economic and health impacts can be evaluated. This paper outlines the countermeasures methodology adopted and the databases used and discusses their applicability on different spatial scales.

VIII.1 Introduction

Relocation, decontamination and agricultural countermeasures are countermeasures applicable in the intermediate and later phases following an accident. Predictions of the effects of these countermeasures are an important part of the decision making process following an accidental release of radioactive material into the environment. Models have been developed for these countermeasures by the National Radiological Protection Board, UK, within the RODOS project(1) and have been integrated into the RODOS system as the late countermeasures module, LCM:FRODO (Late Countermeasures Module: Food, Relocation and Decontamination Options).

LCM:FRODO links closely with other modules of RODOS and, in particular, the FDM (Food and Dose Module) which provide information on activity of countermeasures in reducing activity concentrations in foods and doses, and gridded information on agricultural production and population habits are required as input.

This paper gives an overview of the modelling approach adopted and the databases used, and discusses their applicability within the framework of the RODOS project and the wider requirements of decision support systems. In particular, the use of the current database for agricultural countermeasures effectiveness for general application and its use at the different levels of detail required by a decision support system are discussed. concentrations in foods and animal feedstuffs as a function of location, nuclide and time, and models and data to calculate doses from the relevant exposure pathways without countermeasures(2). In addition, information on the countermeasures criteria to be considered, databases on the effectiveness

VIII.2 The late countermeasure module

The general approach to the modelling of countermeasures within LCM:FRODO is illustrated in the Figure. The initial aim of the module is to determine if there is a need for intervention, ie whether, on the basis of user supplied criteria, there is a need for the implementation of relocation or food restrictions. If intervention is required, the objective is to provide the information that underpins an assessment of possible courses of action to determine if intervention can be avoided or, if this can not be achieved, whether its duration and extent can be reduced. The interaction between countermeasures can be considered to varying extents. For example, the effect of decontamination on the extent and duration of relocation and the need and duration of food restrictions can be considered. Within RODOS, the user can also consider the implication of earlier countermeasures, eg evacuation, on the implementation of relocation.

LCM:FRODO provides information to allow early screening of possible strategies, identifying those which may be effective in the short term and those which may be effective in the long term, and therefore worthy of further investigation. This screening process also allows the dismissal of options which are clearly not worthy of further investigation. Early screening is a valuable part of any decision support system in that it allows the more detailed consideration of options to be focussed on those most likely to be of benefit.

The principal endpoints evaluated within LCM:FRODO include, for each countermeasure, the extent (area, quantities of food, population numbers) and duration of restrictions, doses received and saved and additional data required for evaluating the costs of countermeasure implementation. A decision maker will, in general, require additional information, such as the economic costs and numbers of health effects arising or prevented by countermeasure implementation, before making a decision on the most appropriate course of action. Within RODOS the output from LCM:FRODO is used in an Evaluating subsystem (ESY) which will evaluate countermeasure strategies using a wide range of information including effectiveness, costs, health effects and feasibility considerations.

The modelling approach adopted in FRODO can be applied outside the RODOS system and used to provide support on the effectiveness of countermeasures on a level of detail consistent with the underlying databases available. The approach taken to modelling the countermeasure options is described below.

VIII.3 Relocation

Within FRODO, endpoints related to the imposition of relocation in the presence or absence of land decontamination are modelled. Two types of relocation are considered, temporary and permanent.

Permanent relocation is 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 is 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 defined in terms of dose or ground contamination levels. 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 either the sum of the effective doses from external irradiation from deposited activity and the inhalation of resuspended material, or ground contamination level against the appropriate relocation criteria. If the dose or ground contamination level at a location is less than the criterion for the imposition of relocation then no relocation occurs. If it is greater than the criterion for the imposition of relocation, the duration of land interdiction is determined by comparing doses (or ground contamination) with the criterion 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.

VIII.4 Decontamination

Decontamination 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 on reducing external doses from deposited material is modelled using a dose reduction factor 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 RODOS, and the dose reduction factors used enable the reduction in the lifetime dose that could be expected from the implementation of decontamination to be assessed. No account is currently taken of the time dependence in dose reduction following decontamination and of the different behaviour of individuals. The impact of decontamination on relocation can be evaluated for decontamination occurring either before or after relocation is implemented.

The effect of the decontamination of agricultural land on the need for, or reduction in, food restrictions is evaluated. In the current version, decontamination of agricultural land by ploughing and soil removal is considered and the effectiveness of the two techniques is assessed in terms of the reduction in activity concentrations found in food following decontamination. A robust approach is taken such that a single reduction factor is used for all crops. The removal of soil would implicitly include any vegetation remaining on the land prior to decontamination. The removal of vegetation as a decontamination option could be addressed by considering the agricultural countermeasure of food disposal. Any subsequent reduction in activity concentrations in food can be studied by applying an appropriate reduction factor, although the effect is unlikely to be significant. An area for future development is the extension of the models and databases in this respect, particularly with regard to the effectiveness of different techniques over a range of timescales.

VIII.5 Agricultural Countermeasures

Within LCM:FRODO, endpoints related to the imposition of countermeasures on food are evaluated. The criteria for banning the consumption of food are defined in terms of the activity concentrations in foods. As a default, the EC maximum permitted levels in food following a nuclear emergency are used although the user of the system can change these criteria. The predicted activity concentrations in foods are compared with the criteria as a function of time, nuclide and spatial grid point, to determine whether a restriction is required. If a restriction is not required for a food then no further measures are considered. If restrictions are required, a number of countermeasure options are considered for each food. If following the implementation of a countermeasure option restrictions are still required, the user of the system will be informed of this requirement, together with the length of the restriction that would still be required before activity concentrations fell to below the chosen criteria. In the current version of RODOS, agricultural countermeasures are not combined other than with a food ban. However, practicable combinations of agricultural countermeasures using experience gained after the Chernobyl accident are being implemented.

A brief description of the countermeasure options included is given below. Factors such as the timing of the implementation of an option or the duration of a given husbandry or farming practice can be changed by the user so that a range of possible scenarios can be considered.

The **banning of foods** is linked with food disposal or the stopping of food production depending on the duration of the ban. The user can chose at what time following the accident he wishes to consider that a particular crop is no longer grown if the activity concentrations in the harvested crop are still above the intervention criteria.

Food processing and the storage of food are closely linked. For fresh foods such as milk, processing 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. However, a constraint is placed on the storage period such that these are practicable in terms of the 'shelf life' of processed or fresh foods. In practice, this means that storage is only considered when intervention is required because of the short-lived radionuclide content of the food.

Changes in ***the dietary composition of grazing animals*** are also considered. Factors that can be evaluated include the effect of administering clean feed for a chosen period at various times following deposition, changes in the proportion of contaminated feedstuffs in the diet and use of different feedstuffs. Endpoints are evaluated for the shortest period, out of those provided by the user, during which the revised feeding regime is effective in reducing activity concentrations to below the intervention criteria, if this is achievable. The effect of the *administration of sorbents* 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.

Soil treatment such as the addition of fertilisers can be evaluated together with subsequent effects on the uptake of radionuclides by plants. Data for a range of techniques are utilised and are represented as a factor by which the activity concentrations in crops are reduced or enhanced. The effect of repeated applications on the long term activity concentrations in crops can be considered by the use of appropriate data. Soil treatments tend to be effective for a finite time following applciation and any reduction in uptake by plants from subsequent applications can be considered by applying a reduction factor to the activity concentrations in the crop that would be observed in the absence of countermeares.

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 existing crop could not be grown on the land over a specific period (chosen by the user) and that by growing another crop the activity concentrations could be reduced to below the chosen criteria. The change of crop variety is more practicable than a change in crop species and is chosen in preference by the system if activity concentrations can be reduced sufficiently.

The ***change of land use from agricultural production to forestry*** can be assessed. The criteria for this option is that food at activity concentrations below the banning criteria cannot be produced on the land over a specific period (chosen by the user). If this is the case the land is not used for agricultural production over the period.

VIII.6 Databases

For use in a decision support system, data on countermeasure effectiveness are required at two main levels, one to aid those with responsibility for advising persons who make broad, policy decisions, and the other to aid people at a more local level such as advisors to the farming community. A default database has been compiled for use in RODOS on a scale appropriate for policy level decisions. This contains robust, representative data that can be applied generally to relatively large areas. To achieve this, cautious values have been chosen where necessary so that the radiological impact would not be significantly underestimated.

VIII.7 Default decontamination database in RODOS

The dose reduction factors for decontamination in urban areas have been determined using the EXPURT urban dose model(3). The effectiveness of a range of feasible decontamination techniques have been considered using current sources of data(4,5). The following techniques are included in the database: grass cutting and collection; ploughing (tractor pulled ploughs for large areas), rotovating (hand held motorised ploughs for small areas) or digging; soil removal to a depth of 5 cm; fire hosing, vacuum sweeping and planing (removal of surface layer) of metalled surfaces, eg. roads and pavements, and the combined strategy of grass cutting and fire hosing or vacuum sweeping metalled surfaces. The information in the database assumes an optimum implementation time that is consistent with the data chosen for the evaluation of the dose reduction.

VIII.8 Default agricultural countermeasures database in RODOS

A database on the effectiveness of the decontamination of agricultural land and of other agricultural countermeasures in reducing activity concentrations in crops has been compiled from a review of available data, primarily from the Ukraine, Russia, Belarus following the Chernobyl accident [(6,7)], and the use of a dynamic foodchain model, FARMLAND[(8)].

Soils were broadly classified into mineral or organic for the purposes of the default database. This is a simplified approach to soil classification but it is relatively easy to identify soils which fall into these categories. The database primarily contains data on mineral soils and includes data on organic soils where these are available.

The applicability in the UK of the countermeasures effectiveness factors compiled in the default database has been addressed[(9)]. The effectiveness of the addition of sorbents to animal feeds or the administration of boli in reducing concentrations in milk and meat are generally applicable to conditions in Western Europe. Others measures, however, such as those implemented to improve soil fertility and reduce radiocaesium uptake by plants, will be ineffective on the high fertility soils prevalent in the Western Europe. The practicability in the UK of countermeasures implemented, or considered, in the former Soviet Union (FSU) after the Chernobyl accident has also been addressed[(9)] ; practicability aspects need to be taken into account within the evaluation of optimum countermeasures strategies.

VIII.9 Use of the models and databases at a local level

The structure of the RODOS system is appropriate for application of LCM:FRODO on a local, regional, national or international level provided that data are available on the spatial scale being considered.

The robust default data for agricultural countermeasure effectiveness have been compared with data collected from four settlements in the FSU(10) for both the collective farm and the associated private farms within these settlements. The comparison of the observed countermeasure effectiveness factors for caesium at the four settlements with the default values and ranges showed that, in general, the differences were less than a factor of 3. Given the scope of the database, these differences are considered acceptable. The overall conclusion of the study was that modifications to the robust values in the default database would not be warranted, but more specific information would be required before decisions could be taken on a local level.

In the long term, the use of models such as FRODO would contribute to the development of practical, site-specific advice on countermeasure strategies alongside measurement programmes and experimental research. Systems that deal specifically with agricultural countermeasures have been developed in the FSU for use after a few years following an accident(11,12). These contain simple empirical relationships to calculate activity concentrations in foods and have databases for radiocaesium that are more detailed than those currently in RODOS. Systems such as these may be more practicable for local advisors who may not have access to RODOS or the required computer hardware. Provided that the same databases are used, assessment of countermeasure effectiveness in RODOS would be compatible with those made with these local systems and they may therefore be regarded as complementary. The transfer and sharing of data between systems is a key factor in accessing the strengths of each type of system and consequently, obtaining the best picture of the radiological situation.

VIII.10 Conclusion

This paper has provided an outline of the methodology used for the development of models for relocation, decontamination and agricultural countermeasures and the supporting databases which have been implemented in the RODOS decision support system. Default databases have been developed for RODOS with the objective of providing information on a scale appropriate for policy level decisions. These data have been compared with site-specific data and their adequacy addressed. Work is in progress to provide advice on data applicability and also data requirements for using RODOS on different spatial scales. Care is required in the use of the database compiled for the FSU for wider application as some of the measures that were radioecologically effective in these countries would not be so in Western Europe, while others would not be practicable. Further work on the applicability of countermeasures applied in the FSU to Western Europe is planned.

Acknowledgement

This paper was originally presented at the Fourth International Workshop, Aronsborg, Sweden, October 7 - 11, 1996 and was published in the Proceedings of that meeting published as Radiation Protection Dosimetry Vol. 73, Nos. 1-4 (1997), pp. 75-80. It is reproduced with permission of the publisher, Nuclear Technology Publishing

VIII.11 References

1. Ehrhardt, J., The RODOS system: decision support for off-site emergency management in Europe, Proceedings of the "Fourth International Workshop on Real- Time Computing of the Environmental Consequences of an Accidental Release from a Nuclear Installation", Aronsborg, Sweden, 6 to 11 October 1996, Radiation Protection Dosimetry Vol73 Nos.1-4, 1997 pp.35-40

2. Müller, H. And Bleher, M., Exposure pathways and dose calculations in RODOS: improvement of predictions by measured data, Radiation Protection Dosimetry Vol73 Nos.1-4, 1997 pp. 61-66 (see Ref. 1)

3. Crick, M.J. and Brown, J. EXPURT-Exposure from urban radionuclide transfer. A model for evaluating exposure from radioactive material deposited in the urban environment. Chilton, NRPB-R235, London HMSO, 1990.

4. European Commission, Belarus, the Russian Federation, Ukraine. Experimental collaboration project No 4: Strategies of decontamination. EC Luxembourg, EUR 16530, 1996.

5. Brown, J., Cooper, J.R., Jones, J.A., Flaws, L., McGeary, R. and Spooner, J.A. Review of decontamination and clean-up techniques for use in the UK following accidental releases of radioactivity to the environment, Chilton, NRPB-R288 (DOE/RAS96.009), London HMSO, 1996.

6. Brown, J., Ivanov, Y., Perepelyatnikova, L., Prister, B., Fessenko, S., Sanzharova, N., Spiridonov, S., Alexakhin, R., Bouzdalkin, C. And Firsakova, S. Comparison of data from the Ukraine, Russia and Belarus on the effectiveness of agricultural countermeasures. Chilton, NRPB-M597, 1995.

7. Brown, J., Wilkins, B.T., Fesenko, S.V., Sanzharova, N.I., Perepelyatnikova, L., Perepelyatnikov, G. And Bouzdalkin, C. A compilation of data from the Ukraine, Russia and Belarus on the effectiveness of agricultural countermeasures for strontium-90. Chilton, NRPB-M709, 1996.

8. Brown, J., and Simmonds, J.R. FARMLAND: A dynamic model for the transfer of radionuclides through terrestrial foodchains, Chilton, NRPB-R273, London HMSO, 1995.

9. Nisbet, A.F. Evaluation of the applicability of agricultural countermeasures for use in the UK. Chilton, NRPB-M551, 1995.

10. Wilkins, B.T., Nisbet, A.F., Paul, M. et al, Comparison of data on agricultural countermeasures at four farms in the former Soviet Union. Chilton, NRPB-R285, London HMSO, 1996.

11. Fesenko, S.V., Sanzharova, N.I., Kulagin, B., Lissiansky, K., Nisbet, A.F. and Wilkins, B.T. FORCON: A decision support system for the provision of advice on intervention in agricultural systems at the local level in the former Soviet Union. Chilton, NRPB-M680, 1996.

12. European Commission, Belarus, the Russian Federation, Ukraine. Joint Study Project 2: Decision aiding system for the management of post-accidental situations. EC Luxembourg, EUR 16534, 1996.

Table 1: Approach to modelling late countermeasures in RODOS

Prediction of need for imposition: extent and duration

Prediction of effectiveness of decontamination and agricultural countermeasures: days - years

Real-time identification of countermeasures that may be effective in short - medium term (< 1 year)

Identification of countermeasures that may be effective in long term and worth further investigation

Dismissal of options not worth further investigation

IX Uncertainty Modelling, Data Assimilation and Decision Support for Management of Off-site Nuclear Emergencies

Simon French
School of Informatics
University of Manchester
Coupland 1
Oxford Road, Manchester, M13 9PL

Abstract

Decision support systems for off-site nuclear emergency management must address the inherent uncertainty in a evolving and effectively unique accident sequence. From the earliest moments when an accidental release threatens through any release to the long term consequences arising from the resulting contamination, there are many uncertainties to be weighed in selecting countermeasure strategies. Many of these uncertainties can be reduced through the careful collection and analysis of a variety of data. This paper discusses the ways in which data can and should be analysed to achieve this. It argues that there is no place for ad hoc approaches in designing a complex decision support system to underpin emergency management. The analyses must fit together so that data and assessments of uncertainty can be passed from module to module in a seamless fashion.

IX.1 Introduction

To many people, bringing together uncertainty modelling, data assimilation and decision support into one discussion may seem unnecessarily ambitious. Surely each can be addressed separately? I believe not. Emergency response, particularly nuclear emergency response, takes place in a very uncertain, changing environment. Decision makers need support in understanding and facing up to the uncertainties. The purpose of gathering and analysing data is to reduce these uncertainties. Thus uncertainty handling and data assimilation are two sides of the same coin, and they must be examined and discussed with the purposes and context of decision making in mind.

My purpose here is to raise a number of issues that I believe are central to such a discussion of uncertainty handling and data assimilation with decision support systems (DSS) for emergency response. I do so by taking a very partial view of the subject: I believe that the Bayesian approach to decision support provides a natural framework in which to resolve these issues. Notwithstanding this, the general questions raised here are as pertinent for other non-Bayesian approaches.

In any accident or potential accident scenario, there is likely to be uncertainty in some or all of the following.

- Will there be an accident, i.e. can a release be averted?
- The source term to include a specification of its composition, its time behaviour, and its release co-ordinates and height(s)?
- The weather conditions: e.g. stability class, local windfields and precipitation?
- Observation errors in the monitoring data, including human as well as physical measurement errors.

- The quality of the models such as those for atmospheric dispersion, deposition and re-suspension, hydrological spread, exposure pathways, food-chains, health effects, countermeasures and economic effects.
- The public compliance with any countermeasure. More generally, the level of success in implementing any countermeasure.
- The demography of the population affected.
- The accuracy of approximations used in calculations.

These uncertainties relate to the decision makers' and their advisors' lack of knowledge of the context and evolving situation. In addition, they are often uncertain about their objectives and how to evaluate the consequences. How should they deal with matters such as 'equity of treatment' or 'acceptability to the public'. These uncertainties relate to value judgements. Elsewhere I argue that such uncertainties can only be reduced by discussion and clear thought. One cannot derive ones values from data analysis(1). In this paper I focus entirely on uncertainties relating to lack of knowledge: such uncertainty can and should be reduced by the acquisition and analysis of data.

As an accident progresses, many types of data will become available, including:

- Plant and engineering data – including expert judgement – suggesting the strength and composition of the source term.
- Meteorological data and forecasts, again incorporating expert judgement.
- On-site stack and periphery monitoring data: off-site fixed and mobile monitoring data.
- Hydrological data concerning both flow rates, depths, etc. and contamination.
- Population data concerning the groups liable to be exposed.
- Agricultural, economic and land use data.
- Data on compliance with and effectiveness of countermeasures.

Note that some of these data arise from physical measurements, the characteristics of which are reasonably well understood, but others are derived from expert judgement, the characteristics of which are less clear, but very different.

A word on terminology: within the literature of statistics and decision support one is more likely to talk of 'inference' than 'uncertainty handling and data assimilation' – inference being a process of reducing prior uncertainties through the analysis of data. A consistent terminology has yet to permeate the emergency management literature: terms such as back-fitting, source term reconstruction and data assimilation are used along with more statistical ones such as estimation.

IX.2 Principles for Designing DSS for Emergency Management

IX.2.1 A need for coherence in decision support

To provide support from the moment that an accident threatens through any release and into the long term future, it is necessary that the output of any single analysis at one decision point not only supports the decision to be made then but also feeds as prior information into analyses designed to support subsequent decisions. Moreover, the principles underpinning choice at one time should be compatible with those used at other times. To do otherwise invites inconsistency, risks confusing the decision makers, and certainly requires extra calculations to convert the output of previous analyses into formats acceptable to subsequent ones. Thus we should not focus myopically on analyses to support particular inferences and decisions without first taking a larger view.

For example, we must ensure that not only do we analyse plant and engineering data to predict the source term in the very early stages of the threat, but if the release occurs we also use those data (and subsequent plant data) to combine with sparse monitoring data collected in order to predict the contamination spread by the plume. Later after the plume has passed, we should find a way of moving smoothly from the predictions of ground contamination coming from atmospheric dispersion-deposition models to interpolations in the growing set of ground monitoring measurements. We must continually balance that we have learnt from past data with the information inherent in incoming data. And at all times, we should ensure that the current estimates and descriptions of the uncertainty fit with and support the decisions to be made.

IX.2.2 Prediction not estimation

Many of us have come to the problem of providing decision support for off-site emergency management from backgrounds in Science. As such we have been trained to explain the past, to estimate parameters, and to develop and test models. Decision support requires that we deploy those models to predict the future and that requires a different emphasis and viewpoint. For instance, many talk of back-fitting or reconstructing the source term. In a sense this is reasonable: to predict the spread of the contamination we need to have some knowledge of the source term. But the 'best' estimate of the source term may not give the 'best' prediction of the spread of health effects arising from the plume. It is not what goes up that matters so much as what comes down! Thinking of the plume: suppose that we use a puff model. Scientific estimation would require that we use sufficient puffs to capture the evolving shape of the plume. But decision making on evacuation simply requires that we know its path, approximate time of arrival and strength. We may obtain sufficiently good assessments of these from a model using fewer puffs. Moreover, using fewer puffs allows quicker calculation and hence many more 'what-if' analyses.

IX.2.3 Experts are not always right

Some of the incoming data will arise from expert judgement. Meteorological forecasts are a prime example: they are based upon a mix of empirical data and experienced meteorologist's judgement. Some aspects of the plant's state may be judged rather than observed. Public compliance will also be forecast by experts rather than an empirical data-driven model. Expert judgement is to the decision maker essentially another form of data[(2), (3), (4)] and, like all forms of data, it can be in error. Where it differs from empirical data is that expert judgement has very different error characteristics. There are two distinct aspects to the quality of an expert's judgements. His or her substantive knowledge, i.e. that which makes him or her and expert; and his or her ability to encode that knowledge in a useful way with a reasonable assessment on the associated uncertainty. Many studies have shown that these two aspects are not very well correlated: sometimes the person who knows the most cannot express it usefully.

Given this we should not take expert judgement simply as parameter inputs. It should be balanced with the other data; and its inherent uncertainty should be included in the overall assessment of uncertainty at any stage.

IX.2.4 Neither are models always right

No model is perfect; few would argue otherwise. Yet history is littered with examples in which decision makers ignored the uncertainty in the model and took poor, if not disastrous decisions[(5), (6)]. It is worth pondering, for instance, that each time the speed of light is measured, the new estimate lies beyond three standard deviations from the previous estimate. Yet scientists do not learn from this and inflate their current estimate to allow for their previous, and presumably continuing, repeated underestimation of their uncertainty. The EC/NRC project on expert judgement and uncertainty analysis in accident consequence codes provides a more relevant example[(3)]. We must not perpetuate this mistake. The methodology employed in any DSS must have ways of representing the true uncertainty which will include components arising from uncertainty in the models themselves. Methods are available for doing this – or, rather, making a first approximation to what is conceptually an infinite regress. Models which predict modelling error are themselves models and hence have modelling errors[(6), (7)].

IX.2.5 Validation and Quality Assurance

Most DSS in industry are used repetitively in a relatively stable context. Thus if there are any imperfections in their design, they can be tuned through continual use and modification until they perform well. Such is not the case in decision support for emergency response. The ideal is that they are never used: and their success and validity will be judged upon their first real use. This brings all manner of difficulties in quality assuring the decision support, which is very different from simply assuring the software. Quality assured software can perform the wrong calculations perfectly or be implemented in the wrong process. We must be very sure of the methodologies underpinning a DSS for emergency response. We must test them on as near real a set of data with simulated arrival patterns as possible, and we must stretch them in exercises and subject them to detailed peer review, both of the physical models and of the decision support methodology.

IX.3 The Bayesian Approach

Data assimilation is the traditional province of statistics. However, lest it be thought that we can simply call upon statistical techniques without need for methodological considerations, note that, generalising very broadly, statistical inference is divided into two schools: the frequentist and the Bayesian[(8), (9), (10)]. The physical sciences have, by and large, used the frequentist approach because it either is or has a persuasive appearance of objectivity. However, frequentist statistics have a major disadvantage when it comes to decision support. The frequentist concept of probability is *only* applicable to the modelling of uncertainty in repeatable circumstances. Conceptually, it must be possible to embed the uncertainty or variability of interest into a sequence of repeated trials under essentially identical circumstances. Think of tossing a coin or repeatedly measuring a gamma dose rate. Most decisions are made in the face of unique circumstances and it is usually conceptually impossible to imagine embedding them in a sequence of essentially identical repetitions[(10)]. More importantly still, frequentist statistics are designed to provide estimates and to perform hypothesis tests. They do not lead in a straightforward way to methods of providing predictions and to ways of modelling the uncertainty of forecasts. Bayesian methods do[(8 -20)].

Figure 1 provides an overview of the Bayesian approach to decision analysis. Central to the approach is the following conception of a decision. The decision maker must choose an action a (countermeasure, in our case) and as a result a consequence c will arise. But the action does not depend solely on the chosen a. It also depends on the unknown future state of the world θ.

The decision is made by balancing value judgements expressing (society's) preferences and the uncertainty about θ. Thus the analysis separates value judgements from uncertainties. The value judgements are encoded with multi-attribute utilities[1]. We shall not explore that part of the analysis further here: but note that this separates the input of political decision makers from the scientific judgements of their advisors about what might happen: *viz.* the uncertainties in the model. These uncertainties are encoded through prior probabilities: $P(\theta)$.

The name 'Bayesian' arises because data is assimilated via an application of Bayes' Theorem. Suppose some data $X = x$ is observed and that before the observation the distribution of X is $P(X|\theta)$. Then after the observation the posterior distribution on θ is given by:

$$P(\theta|x) \underset{\theta}{\propto} P(x|\theta)P(\theta)$$

$$\textit{posterior} \underset{\theta}{\propto} \textit{likelihood} \times \textit{prior}$$

where the proportionality is as a function of θ with X fixed at the observed value x. Since the posterior from one analysis can serve as the prior for the next, Bayesian analysis naturally fits a decision support process with streams of incoming data and a sequence of decision points. There is a significant advantage over other data assimilation methods: namely, Bayesian methods provide a consistent approach to dealing with the combination of information from all sources. For instance, consider the information provided by expert judgement. To a Bayesian an expert is just a another source of data for the decision maker(s)[4].

There is a conceptual difficulty in that Bayesian methods are explicitly subjective and, moreover, are apparently focused on the needs of individuals. Most inferences and decisions involve groups. However, through the use of sensitivity analysis and robust methods, Bayesian methods allow the exploration of consensus and discovery of points of agreement and disagreement between the decision makers. It becomes possible to identify those issues for which there are sufficient data to enable a resolution and those issues which the data leave unresolved and which must be settled on the basis of judgement[21].

IX.4 Other Approaches

The above, not surprising, simplifies a complex situation and, moreover, presents a strongly held personal opinion, but one supported by an extensive literature in mathematics, statistics, operational research, economics, philosophy, psychology, and many other disciplines. This extensive literature is part of the peer review process of validation referred to as necessary to quality assure any DSS. There are other approaches to data assimilation, particularly ones currently being developed in areas related to expert systems and artificial intelligence. Among these belief functions, fuzzy set, interval measures, many valued logics and possibility theory must be noted[22], [23], [24]. While these may in time become as rounded and as tested in both theory and practice as the frequentist and Bayesian, they are at present in many respects untested in significant ways. Full quality assurance of methods based upon these approaches may not be possible until after many more years of testing and development

IX.5 Challenges for the Future

In a paper which raises more questions than it answers, it is difficult to provide a closing summary or set of conclusions. So I will simply close with two challenges: the first specifically for the RODOS project and the second for all of us.

The design of the RODOS DSS takes a Bayesian path. The methodology indicated above will be used to address the issues raised in this paper. But, of course, deciding upon a methodology and achieving its implementation are very different things. So the challenge to the RODOS team is to deliver a working system in which data are assimilated and the uncertainty in predictions is communicated to decision makers.

The challenge for all of us is to remember that, whatever methodology we use to address the issues described above, our task is to support the decision makers. We must stop thinking as scientists with a curiosity as to what is happening and focus on providing information that truly supports and helps decision makers. What they need to understand and the detail in which they need to do so may be very different from that which we might wish to advance our science.

Acknowledgements and Apologies

I have discussed these issues with many colleagues over the years. Few, if any, of the ideas are mine. I am particularly grateful to many within the RODOS project, especially Martin Bleher, Marc van Camp, Roger Cooke, Volker Herrnberger, Peter Jacob, Ian Lownes, David Ranyard, Jim Smith and Alain Sohier.

This paper was originally presented at the Fourth International Workshop, Aronsborg, Sweden, October 7 - 11, 1996 and was published in the Proceedings of that meeting published as Radiation Protection Dosimetry Vol. 73, Nos. 1-4 (1997), pp. 11-16. It is reproduced with permission of the publisher, Nuclear Technology Publishing.

IX.6 Figures

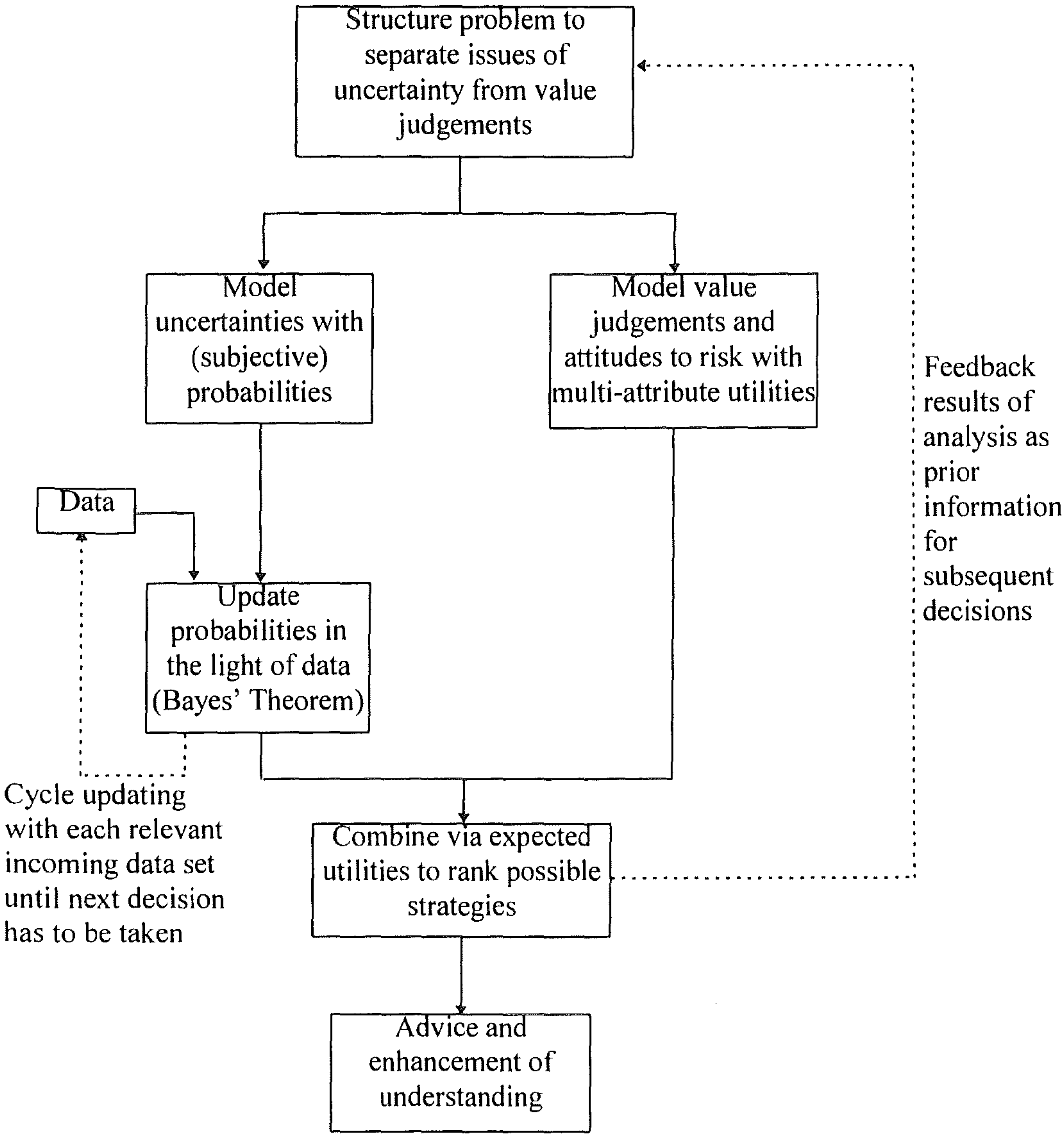


Figure 1: Bayesian Decision Analysis

IX.7 References

1. French, S. "Multi-Attribute Decision Support in the Event of a Nuclear Accident" Journal of Multi-Criteria Decision Analysis. 5, 39-57. (1996)
2. Cooke, R.M. Experts in Uncertainty: Opinion and Subjective Probability in Science. Oxford University Press. (1991)
3. Cooke, R.M., Goossens, L.H.J. and Kraan, B.C.P. Methods for CEC/USNRC accident consequence uncertainty analysis of dispersion and deposition. EUR 15856 EN, DG13, European Commission, L-2920, Luxembourg. (1994)
4. French, S. 'Group consensus probability distributions: a critical survey' in Bernardo, J.M. DeGroot, M.H. Lindley, D.V. and Smith, A.F.M. (Eds) Bayesian Statistics 2, 182-202. (1985)
5. Chatfield, C. "Model Uncertainty, Data Mining and Statistical Inference", J. R. Statist. Soc. A158, 419-466. (1995).
6. Draper, D. 'Assessment and propagation of model uncertainty (with discussion)' J. Royal. Statistical. Soc. B 57, 45-97. (1995)
7. French, S. Acta Crystallographica A34, 728-738. (1978)
8. Barnett, V. Comparative Statistical Inference. Second Edition. John Wiley & Sons, Chichester. (1982)
9. French, S. Decision Theory: an Introduction to the Mathematics of Rationality. Ellis Horwood, Chichester. (1986)
10. Granger Morgan, M. and Herrion, M. Uncertainty: a guide to dealing with uncertainty in quantitative risk and policy analysis. Cambridge University Press. (1990)
11. Aitcheson, J. and Dunsmore, I.R. Statistical Prediction Analysis. Cambridge University Press. (1975)
12. Barlow, R.E, Clarotti, C.A. and Spizzichino, F. (Eds) Reliability and Decision Making. Chapman and Hall, London. (1993)
13. Berger, J.O. Statistical Decision Theory and Bayesian Analysis. Second Edition, Springer-Verlag, New York. (1985)
14. Bernardo, J.M. and Smith, A.F.M. Bayesian Theory. John Wiley & Sons, Chichester. (1994)
15. DeGroot, M.H. Optimal Statistical Decisions. Mc-Graw-Hill, New York. (1970)
16. Gelman, A. Carlin, J.B. Stern, H.S. and Rubin, D.B. Bayesian Data Analysis. Chapman and Hall, London. (1995)
17. Geisser, S. Predictive Inference: an introduction. Chapman and Hall, London. (1993)
18. O'Hagan, A. Kendall's Advance Theory of Statistics: Vol. 2B. Bayesian Inference. Edward Arnold, London. (1994)

19. Smith, J.Q. Decision Analysis: a Bayesian approach. Chapman and Hall, London. (1987)

20. West, M. and Harrison, P.J. Bayesian Forecasting and Dynamic Models. Springer Verlag, New York. (1989)

21. French, S. "Uncertainty and Imprecision: Modelling and Analysis" Journal of the Operational Research Society. 46, 70-79. (1995)

22. Dubois, D. and Prade, H. 'Fuzzy sets and probability: misunderstandings, bridges and gaps' Second IEEE International Conference on Fuzzy Systems, San Francisco. (Dubois, D. Institute de Recherché et Informative de Toulouse (IRIT), CNRS, Université Paul Sabatier, 118 route de Narbonne, 31062 Toulouse Cedex, France) (1993)

23. Scozzafava, R. (Ed) Probabilistic Methods in Expert Systems. Società Italiana di Statistica, Rome. (1993)

24. Walley, P. Statistical Reasoning with Imprecise Probabilities. Chapman and Hall, London. (1992)

X Decision Support Issues in RODOS: the needs of decision makers

M. Ahlbrecht (University of Mannheim), R. Borodin (SPA Typhoon, Obninsk),
V. Borzenko (Institute of Control Sciences, Moscow),
J. Ehrhardt (Forschungszentrum, Karlsruhe), S. French[1] (Univerisity of Leeds),
V. Shershakov (SPA Typhoon, Obninsk), A. Sohier (SCK•CEN, Mol),
E. Trkhtengerts (Institute of Control Sciences, Moscow)
and
A. Verbruggen (University of Antwerp)

Abstract

Rodos will be used by a great variety of different decision makers from different backgrounds and with different skills and knowledge bases. In the early hours the users will be the plant management and local emergency planners, later regional and national politicians and government officials will become involved. In addition, a great number of technical experts and advisors will interact with rodos. In recent years, the cec has sponsored a number of investigations and exercises to identify the support that the decision makers perceive that they need. The results of these are reported.

X.1.1 Decision Support for Off-Site Nuclear Emergencies

The design of RODOS as a decision support system (DSS) for off-site nuclear emergencies requires that it be comprehensive in its applicability to all ranges and phases of an accident. This implies that RODOS must support a wide variety of decision makers, each with different skills, expertise, responsibilities and accountabilities. The urgency of the decisions faced will vary, generally decreasing as the accident progresses: decisions on evacuation are needed in tens of minutes; decisions on permanent resettlement may be made on more moderate timescales. Thus RODOS cannot be a simple DSS with single interface. It needs to have a chameleon-like ability to provide the support needed by the current decision maker(s).

The form of support offered at any time may be at one of several levels: see Table. At the lowest level, a DSS merely organises incoming data and presents it to the decision makers. Level 1 support provides predictions of how the environmental spread of contamination may evolve; level 2 simulates the costs and benefits of potential protective actions. At the highest level the DSS is designed to interact with the decision makers, helping them explore and evolve their judgements and evaluations. In some senses, only at level 3 does a DSS support *decision making*; at the lower levels, it organises and presents information to help the user understand the external world better but does not help them decide *per se* [1].

In our view a DSS is more than the computer hardware and software. It is the entire environment and process which support the decision makers. Thus, while the RODOS project may seem to be focused entirely upon software development, there is a strand to our R&D which considers and reflects upon the value of different forms of support and the circumstances in which they are appropriate. Similarly, we have a very 'soft' view of the interface to a DSS. In some circumstances, it may be a computer screen or perhaps a print-out; in others the output may be mediated through interactions with experts or facilitators [2].

---

1 Current address and address for correspondence: School of Informatics, University of Manchester, Coupland 1, Oxford Road, Manchester M13 9PL, UK. Email: simon.french@man.ac.uk

Level 0:	Acquisition and checking of radiological data and their presentation, directly or with minimal analysis, to decision makers, along with geographic and demographic information available in a geographic information system.
Level 1:	Analysis and prediction of the current and future radiological situation (i.e. the distribution over space and time in the absence of protective actions) based upon monitoring and meteorological data and models.
Level 2:	Simulation of potential protective actions (e.g. sheltering, evacuation, issue of iodine tablets, food bans, and relocation), in particular determination of their feasibility and quantification of their benefits and disadvantages.
Level 3:	Evaluation and ranking of alternative protective action strategies in the face of uncertainty by balancing their respective benefits and disadvantages (e.g. costs, averted dose, stress reduction, social and political acceptability) taking account of societal value judgements as perceived by decision makers.

Table1: Decision support can be provided at various levels, here categorised into four levels. The functions provided at any level include those at lower levels. RODOS will provide support at all levels, including level 3 for all potentially useful protective actions at all times following an accident.

General decision support issues in relation to nuclear emergencies in general and RODOS in particular may be found in [2,3].

X.2 Design of the ESY Modules of RODOS

Figure shows the conceptual structure of the modules with RODOS which provide level 3 support. Strictly, some level 3 support in the form of uncertainty modelling is provided by all modules. Here we focus on the support in terms of value judgement modelling; i.e. the modelling and balancing of the many conflicting objectives facing decision makers. Essentially we foresee three components: a coarse expert system to filter infeasible protective action strategies from consideration; a multi-attribute value or utility ranking module to help identify the strategies which provide the best balance – in the sense of justification and optimisation – of cost and protection; and a fine expert system to document and provide reports of the reasoning behind the recommendation. The objective throughout is to provide the decision makers with a better understanding so that they may make a more informed decision and communicate their thinking between themselves and to others.

Prototypes of the coarse expert system and MAV/UT modules have already been produced [3, 5]. Moreover, the structure of the support that these can provide for medium and long term decision making have been well explored in the International Chernobyl Project and other workshops [2,6]. On the other hand, the needs of decision makers for support during the earlier phases, particularly any threat phase, has been little explored. The RODOS project has recently run five workshops with the objective of exploring the needs of decision makers during these phases.

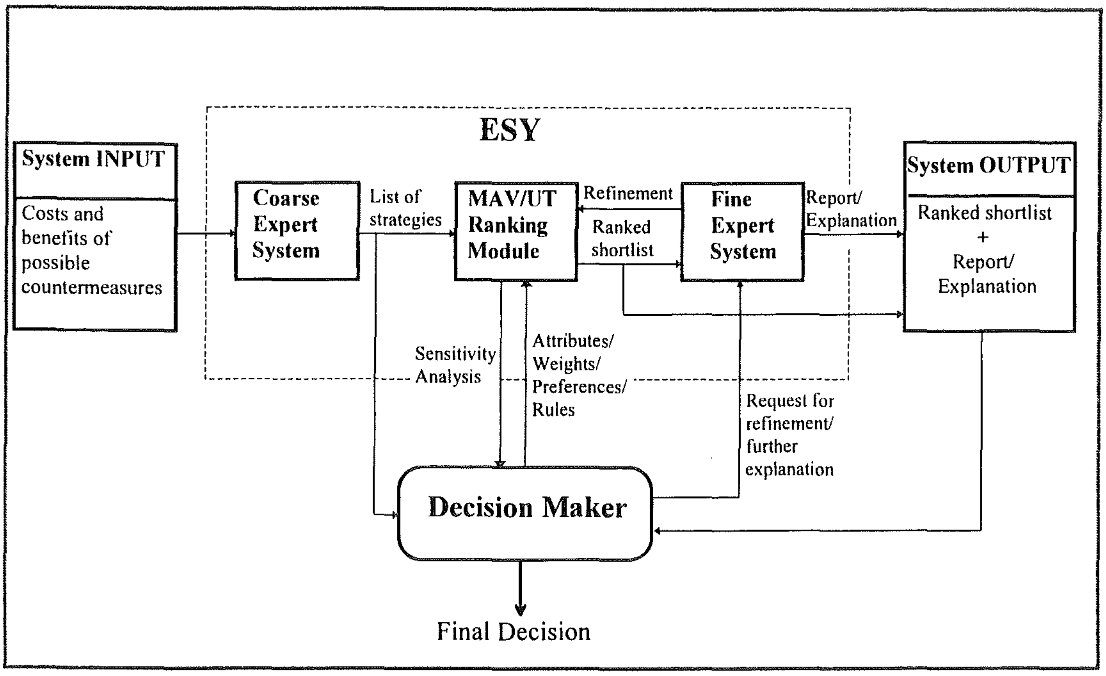


Figure 1: Outline of the proposed structure of the Evaluation Subsystem (ESY) of RODOS.

X.3 RODOS Elicitation Workshops

Two workshops were run in Germany, and one each in Belgium, France and the UK. In each we presented the emergency managers who would be responsible for the actions taken in the first few hours of an accident with the scenario of a threatened release. Uncertainty on the timing of any release and shifting wind direction meant that there was considerable uncertainty as to the size of the population at risk. We used RODOS to simulate the accident and outcomes, with and without possible protective actions. Thus we provided level 0, 1 and 2 support. Our intention was to interrupt the exercises at appropriate points and reflect upon the level 3 support required and the attributes that would concern them in evaluating the different strategies.

At present, reports are being finalised and agreed with the decision makers and are not publicly available. However, several observations may already be drawn, although it is, of course, a moot point whether the observations should be attributed to the use of RODOS or the workshop format which did not parallel faithfully the current emergency management procedures in any of the countries.

- The decision makers generally found level 0,1 and 2 support very useful. Indeed, simply the interactive level 0 support of using a geographic information system was novel and thought to be valuable in itself. 'What-if' analyses which are possible with level 1 and 2 support were used extensively.
- The advent of decision support systems such as RODOS with their potential to support more detailed analyses and 'what-if' simulations than before mean that the emergency management structures in some countries or organisations might need revision to allow more interaction between technical experts and decision makers.
- The introduction of uncertainty into an exercise was very discomforting to the decision makers. None found the expression of this uncertainty in terms of probabilities useful.

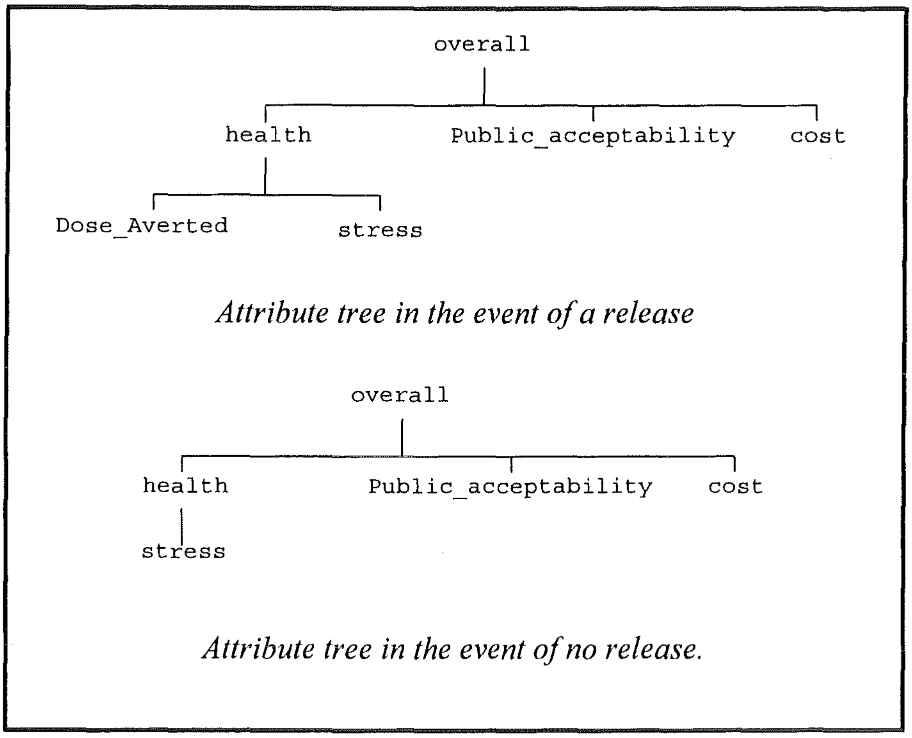
Generally, they adopted the heuristic of assuming that all the area at risk would be exposed: i.e. they effectively assumed a much larger and broader plume than formed by any release.

- Issues relating to the equity of treatment of different sub-populations were of considerable concern. Was it right to evacuate rural regions when it was quite infeasible to evacuate a highly populated urban region which was equally at risk in terms of individual dose?
- No group were able to articulate an explicit set of criteria upon which they based their decision making. This is not to imply irrationality or lack of careful consideration upon their part; just that they did not find it natural to think in terms of the multi-attribute models currently planned within RODOS and which have seemed of considerable value in medium and longer term decision making.
- Generally, no group felt in need of level 3 support. They felt able to make the decisions required of them without detailed modelling and exploration of their value judgements.

The last two points suggest perhaps that either the provision of level 3 support in the early phase is unnecessary or that the design of such support within RODOS is inappropriate. We are currently evaluating the evidence in this respect. However, we would point to two further possibilities.

Firstly, the provision of a DSS to help them was so novel in itself that the decision makers were not sufficiently 'acclimatised' to realise the benefits of level 3 support. There is a considerable body of evidence that *consistency* in decision making is of vital importance if public confidence is to be maintained. Within DSS's it is level 3 support which 'polices' consistency. Thus there may be reasons for national authorities to 'impose' level 3 support on the local emergency managers.

Secondly, some of the difficulty may lie in conventional approaches to multi-attribute modelling. Essentially standard methodology holds that *all* outcomes should be described against the *same* attributes or dimensions. Only then, it is argued, is it possible to compare outcomes consistently. When decisions are made under the threat of a major release, however, it is difficult to model the decision makers' judgements in this manner. The context after an accident is so different from the context after one has threatened but been averted that different sets of attributes are needed to represent the decision makers' judgements. The decision makers are aware that their decisions will be discussed with hindsight very differently in the event that there is no release to the event that there is one. We are exploring event conditional attribute modelling to represent this *anticipated regret* phenomenon [7]. Figure 1 gives an indication of our thinking.



Attribute tree in the event of a release

Attribute tree in the event of no release.

Figure 1: Possible event conditional attribute trees for decisions on precautionary measures. Note that the attributes `stress` may have different interpretations (and importance) in the two parts of this decomposition. In the event an accident happens, stress will be very long-lived, with many members of the public fearing for their health for the rest of their and their children's lives. In the event that an accident is averted, stress will be more short-lived, although those living close to the plant may feel more vulnerable in the future. It should be emphasised that the hierarchies here are offered as examples only.

The next stage in the RODOS project is to implement fully the level 3 support for medium term and longer term decision making and to reflect upon our findings in the workshops to build appropriate support for the early phases.

Acknowledgement

This paper was originally presented at the Fourth International Workshop, Aronsborg, Sweden, October 7 - 11, 1996 and was published in the Proceedings of that meeting published as Radiation Protection Dosimetry Vol. 73, Nos. 1-4 (1997), pp. 81-84. It is reproduced with permission of the publisher, Nuclear Technology Publishing.

X.4 References

1. S. French and Y. Liang (1993) "Decision Support Systems: a decision analytic view" In J. Norman (Ed) *OR Society Tutorial Papers 1993*. Operational Research Society, Seymour House, 12 Edward Street, Birmingham, B1 2RX, UK.

2. S. French (1996) "Multi-attribute decision support in the event of a nuclear accident" *J. Multi-Criteria Decision Analysis* **5**, 39-57.

3. V.Borzenko and S.French (1995) "Decision analytic methods in RODOS" In A Karaoglou, G.Desmet, G.N.Kelly and H.G. Menzel (Eds) *The Radiological Consequences of the Chernobyl Accident*. EUR 16544 EN. CEC, Luxembourg.

4. J.Lochard and S.Belyaev (1996) "Decision aiding system for the management of post-accidental situations" European Commission, DGXII, B1049 Brussels, EUR 16534 EN.

5. S. French, K.N. Papamichail, D.C. Ranyard and J.Q. Smith (1997) "Design of a decision support system for use in the event of a radiation accident" School of Informatics, University of Manchester, Manchester, M13 9PL. To be presented at an International Workshop on Decision Analysis Applications, Real Academia de Ciencias, Madrid, July 1997 and published in the proceedings.

6. S. French, R. Finck, R.P. Hamalainen, E Naadland, J Roed, A. Salo and K Sinkko (1996) 'Nordic Decision Conference: An exercise on clean-up actions in an urban environment after a nuclear accident." **STUK-A132**, Finnish Centre for Radiation and Nuclear Safety, PO Box 14, Fin-00881 Helsinki, Finland.

7. S. French, D.C. Ranyard and M.T. Harrison (1997) 'Event conditional attribute modelling in decision making when there is a threat of a nuclear accident'. RODOS(B)-RP(95)04. School of Informatics, University of Manchester, Manchester, M13 9PL. In S. French and J.Q. Smith (Eds) (1997) *Bayesian Analysis in Practice*. Edward Arnold, London. (in press).

XI The Implementation of RODOS in Belarus, Russia and Ukraine, and Future Perspectives

Shershakov, V., Kossykh, V., Zheleznyak, M.[1], Mikhalevich, A.[2]
Scientific Production Association TYPHOON, Emergency Response Centre,
Lenin St. 82, Obninsk, Kaluga Region, 249020, Russia
[1] Cybernetics Centre of the Ukrainian Academy of Sciences,
Institute of Mathematical Machines and Systems,
Prospect Glushkova 42, Kiev, 252207 Ukraine
[2] Belarus Academy of Sciences, Institute of Power Engineering Problems,
Sosny, Minsk 220109, Republic of Belarus

Abstract

Broad agreement has been achieved between institutes and institutions in the European Union, Belarus, Russia and the Ukraine to cooperate in the development of the Real-time On-line DecisiOn Support System (RODOS), a decision support system for general application in Eastern and Western European countries. The ultimate goal of this joint venture is the integration of an operational RODOS system into the national emergency management arrangements. To provide a standard platform for the common R&D work, the hardware and software components of RODOS have been implemented at SPA TYPHOON, Obninsk, Russia, the Cybernetics Center, Institute of Mathematical Machines and Systems (IMMS CC), Kiev, Ukraine and the Centre for Radiological and Environmental Monitoring (CREM) of the Committee on Hydrometeorology, Minsk, Belarus.

The activities of the CIS institutes in generating their RODOS teams, educating and training the personnel involved and organasing cooperation with other institutes for securing access to meteorological and radiological monitoring data, national geographical information and specific expertise necessary to adapt models and data of the RODOS system to local, regional and national conditions are presented. Examples are given of RODOS case studies and the application of RODOS to analyses of real emergency situations.

XI.1 Introduction

It is largely recognized that, at present, no alternative to nuclear energy exists and, this being so, not only the probability of potential harmful effects from nuclear installations needs to be reduced, but also the preparedness for emergency response should be enhanced. By scale and severity, nuclear accidents have the potential of being comparable to natural catastrophes. They are no longer "national assets" and pooled efforts are required to ensure radiation protection of the general public and the environment in emergency.

The proper selection and timely application of countermeasures can help to significantly reduce the consequences of an accident. For selecting effective countermeasures, a decision - maker should take into account specific features of a given facility and the conditions under which the accident developed. The characteristics can change as a result of application of radiation protection measures, which makes the task of a decision-maker even more difficult. Considering all this, it is impossible to make rational decisions without (1) a monitoring system operating on a constant basis, (2) facility specific information and (3) decision supporting tools. Moreover, this being an international problem, a common monitoring system and a common computer technology for decision making information support is required.

The RODOS system (Real - time On-line Decision Support system) [1] being developed with support of the European Commission is meant to be a base for creating a unified computer system environment to support collective decisions in the event of a nuclear accident. The RODOS system is being developed on the UNIX platform using workstations such as HP-9000/735. The implementation of the RODOS components in CIS countries aimed at determining whether the RODOS system can be used as a common platform. The main efforts were concentrated on a series of issues related to emergency response:

- interaction between the RODOS and national radiation monitoring systems with a view to collect and process on-line data ;
- organization of a distributed system for collection and processing of on-line data on the basis of territorial, departmental and off-site systems of radiation monitoring ;
- using the RODOS software for analysis of real accidents and their consequences (the Chernobyl accident, first of all) ;
- studies of the RODOS applicability and its acceptability by the potential RODOS users, i.e. national institutions that are responsible for the arrangements for off-site emergency response in the event of a nuclear accident; and
- adaptation of the RODOS system in each of three CIS countries for the needs of the specific RODOS users;
- preparing and providing data to specialized international organizations under the Convention on Early Notification of Nuclear Accidents and by other international agreements.

XI.2 Directions in implementation of RODOS and its supporting infrastructure

XI.2.1 Belarus

In Belarus the development of RODOS is carried out in the structure of the Ministry for Emergency Situations and Population's Protection from the Consequences of the Chernobyl NPP Catastrophe (Fig.1) . A workstation (HP-9000/735) has been installed in the Center for Radiological and Environmental Monitoring (CREM) of the Committee on Hydrometeorology, which is in the structure of the Ministry for Emergency Situation. The group of RODOS operators has been formed in CREM. The installation of software has been initiated; the linking of RODOS with the systems of radiation monitoring and meteorological observations is being developed.

The preparedness of RODOS software (adaptation of program modules developed within the RODOS project, compilation and assimilation of databases, verification of models and programs, etc.) is being carried out at the Institute of Power Engineering Problems and the Institute of Radioecological Problems/Academy of Science of Belarus, CREM, Branch Research Laboratory of the Management Academy, etc.

XI.2.2 Ukraine

In Ukraine the Cybernetics Center, Institute of Mathematical Machines and Systems (IMMS CC), since 1986 has acquired important experience in developing and executing decision support systems for off-site emergency management after the Chernobyl accident. The Institute was responsible on the national level for the development of the decision support system for the Dnieper River basin management after the Chernobyl accident. To that purpose, the models and methods for treating releases of radioactive material into hydrological systems were developed and applied[2]. The Institute experience in developing efficient procedures for the problems of discrete and combinatorial optimization was also used for developing decision making modules for different kinds of decision support systems.

Since 1991 IMMS CC has been involved in research and development activities for RODOS in the fields of hydrological modeling, system development and optimization of early emergency actions. The hardware and software system of RODOS PRTY 1.0 was installed in IMMS CC in spring 1994. The system is used for the R&D work, including RODOS adaptation and customization, as well as for the wide scale RODOS presentation for Ukrainian emergency management institutions.

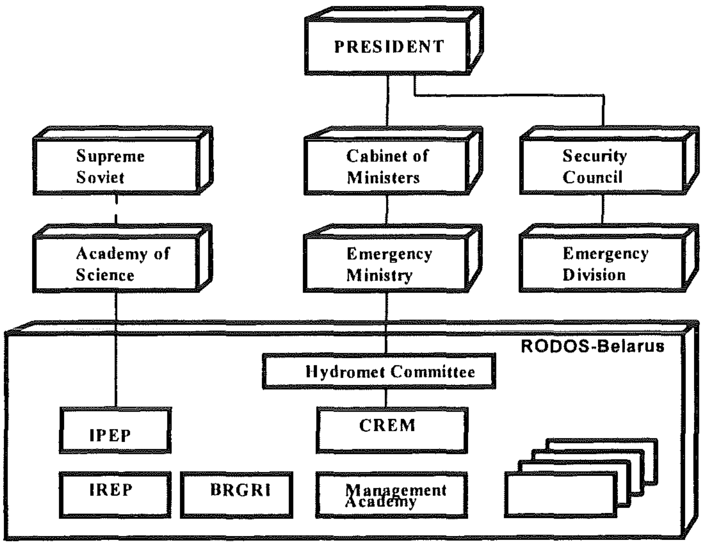


Figure 1: Organisational scheme for RODOS in Belarus

The following governmental institutions are responsible for off-site emergency management in Ukraine:

- State Emergency Commission, chaired by the Vice-Prime-Minister on Emergency Situations;
- Headquarters of the Civil Defense (HCD);
- Ministry of Environmental Protection and Nuclear Safety (MEPNS);
- Committee of Nuclear Power Production (GOSATOM);
- Administration of the Chernobyl Exclusive Zone (ACEZ) of the Ministry of Chernobyl Problems (Min Chernobyl);

All above mentioned governmental institutions have determined they will implement RODOS for decision support at the upper level of data processing and monitoring systems. As a first step, organizational conditions for the RODOS implementation were completed at ACEZ. The joint program of ACEZ and IMMS CC was started in October 1995 to ensure the test-operation of RODOS in late 1996 and its operational use in late 1997 to support the off-site emergency response in the event of a nuclear accident in the Chernobyl Exclusive Zone. The system will be adapted for two kinds of releases - from the working Chernobyl NPP units and from the SHELTER (destroyed Unit 4). A second step was the signingof an agreement in October 1995 between GOSATOM and IMMS CC to develop with some other Ukrainian institutions the decision support systems for the Emergency Centers of the NPPs and National Crisis Center of GOSATOM based on the RODOS design.

XI.2.3 Russia

The Russian Federal Service on Hydrometeorology and Environmental Monitoring (Roshydromet) carries out the development and implementation of RODOS in Russia. In the Russian Federation, a series of regulations are in force as to announcing a radiological emergency, real-time information transmission, special assistance to affected facilities, and population protection measures in the event of a radiation accident at a nuclear power plant. By these regulations, Roshydromet is to play an active role in emergency management on a national level.

In this context, Roshydromet has established a special Emergency Response Centre (ERC) for providing real-time and prognostic information about the radiological situation on the territory of Russia. The Centre has been based in SPA "Typhoon", Obninsk, and its primary responsibility is to provide information and decision support for mitigating the consequences of a nuclear accident. Among other services, information on atmospheric transport and dispersion of contamination in the environment are provided. The Centre works in close collaboration with organizations which are involved in emergency management by Russian regulations.

Roshydromet suggested that the ERC should be designated as a regional specialized meteorological Centre (RSMC) of WMO with the responsibilities to provide results of modeling radioactivity dispersion in the environment. The activities of the ERC as RSMC will be supported by the Russian Hydrometeorological Centre and Institute of Experimental Meteorology of SPA "Typhoon" which have the resources required for the purpose: computer capabilities, telecommunication networks and qualified personnel.

XI.3 Results: experience gained and problems arising on the way to implementation

XI.3.1 Organization of RODOS interconnection with national radiation monitoring systems

As part of the RODOS development, the ERC has concentrated its efforts on

- collection of measurement data from the radiation monitoring network of Roshydromet, managing the system of distributed databases on environmental contamination located in Roshydromet divisions, providing data on the radiological situation on the territory of Russia and predicting its changes with migration and transformation of radionuclides;
- preparing prognostic data about dispersion of radioactivity in the environment in the case of a nuclear accident and estimation of possible transboundary transport of radioactivity.

For accomplishing this, a tool has been developed as part of RODOS to process and present real-time meteorological and radiological data. The basic meteorological data (objective analysis data) and numerical predictions are transferred to the Centre in GRID and GRIB codes for the area lying between 25 N to 74 N : and 45 W to 180 E. The data include surface pressure, geopotential, temperature, wind speed and direction.

The information from Roshydromet stationary network of radiological monitoring is largely transmitted through the meteorological telecommunication system of Roshydromet. The Roshydromet system of collecting and processing real-time contamination data is being developed as a distributed system drawing on the regional and provincial divisions of Roshydromet which are constantly in touch with the Emergency Response Centre. The basic software used in the system is the Radioecological analysis support system (RECASS) [3] (Fig.2).

Since the RECASS system is oriented at PC type computers with the MS DOS operating system, the Emergency Response Centre had the task of making consistent the RODOS and RECASS systems, both in terms, of system management and data types.

As a result of this work, it has become possible to realize some of the RODOS objectives at the level of the Emergency Response Centre, namely:

- management of data transmission lines;
- management of the real-time meteorological and radiological data bank;
- modelling processes of transboundary transport of contaminated air masses from the affected area. (This function has enabled the efficiency of the entire system to be enhanced).

In the radiological monitoring network, information is transmitted in two modes: routine passing and request - answer mode. In the first mode real time data are transmitted including measured daily dose rates in the 100 km zone around a nuclear facility, measured total beta-activity in the ambient air and in atmospheric deposition (if available), and a monthly summary of average values for all types of performed measurements. If an established threshold for any type of measurements is exceeded, a special alarm message is sent. In the same mode all meteorological information is passed.

The "request-answer" mode is used to transmit data between information centres of different levels, both within Roshydromet and between Roshydromet and Rosenergoatom. In this mode, information can be accessed from the databases in the Centres including real-time data and more precise data of surveys around nuclear facilities.

In Belarus monitoring for the radiation situation is mainly carried out in the network of synoptic stations of Hydromet (54 such stations are located on the territory of the republic), which transmit the information daily to regional meteorological centres by telex and then from regional (district) centres to CREM over the allocated communication links. In case of necessity the information can be transmitted every three hours. At present, in the framework of the project "Gamma-1" in the framework of the EC cooperation program, an automated system of radiation monitoring is being created in the region adjacent to Ignalina NPP in the territory of the Lithuania Republic. It is expected that, namely in this region the first version of RODOS will be developed and introduced in Belarus. Then the system will be consistently extended in other regions linked with nuclear power plants surrounding the Republic of Belarus, such as: Chernobyl NPP, Rivno NPP and Smolensk NPP. The interaction with national RODOS system of neighboring states is supposed to be developed in each region.

The meteorological and radiological monitoring over Ukraine is provided by the State Committee on Hydrometeorology (UkrHYDROMET). The radiological monitoring around the NPP's will also be provided by the Automatic System of Radiation Situation Monitoring (ASKRO) that is under development by the GOSATOM. The radiation monitoring system GAMMA-1 is working now in the Ukraine, supported by the European Commission's Tacis programme. The first stage of GAMMA-1 includes the installation of the monitoring networks around Zaporoshe NPP and Rivno NPP. The information from these networks, as also from the UkrHYDROMET, would come to the Data Processing Centers in the MEPNS and Emergency Response Center in the HCD. The GAMMA monitoring network would be expanded later to other Ukrainian NPP's. GOSATOM has started the program that includes the development of the Emergency Response Centers at each NPP and National Crises Center, based on the ASKRO network and UkrHYDROMET data.

The future of the real time data collection and processing system lies in concentrating primary data processing in local centres and improving the "request - answer" mode to enable the Centres to interact on-line, within the system of distributed databases, using the client-server technology. The system should also be extended to allow for new types of data. It may be helpful in the future to use satellite data in the form of images and remote sounding data.

XI.3.2 International data exchange

The RODOS concept is intended to create a distributed decision-making support system. To this end, tools have been developed to get access to the real-time meteorological and radiological data banks through INTERNET. Data can be accessed in the "request-answer" mode (as in the national system) and on-line. The developed tools can be used as basis for interrelating the RODOS local centres within the RODOS international network in the exchange of monitoring data and results of determinations and predictions of radioactive contamination of the environment.

Another important direction is organizing links with specialized international systems which may be helpful in solving the RODOS tasks. With this aim in view, the Emergency Response Centre, "Typhoon" is working out tools for interconnection with WMO regional specialized meteorological centres assigned to provide prognostic data on transport of contaminated air masses. Users can get this kind of information through national meteorological organizations. Similar activities are being developed by Hydromet of Belarus. This institution maintains contacts through the regional WMO center in Moscow with international meteorological centers in Toulouse (France) and Bracknell (UK).

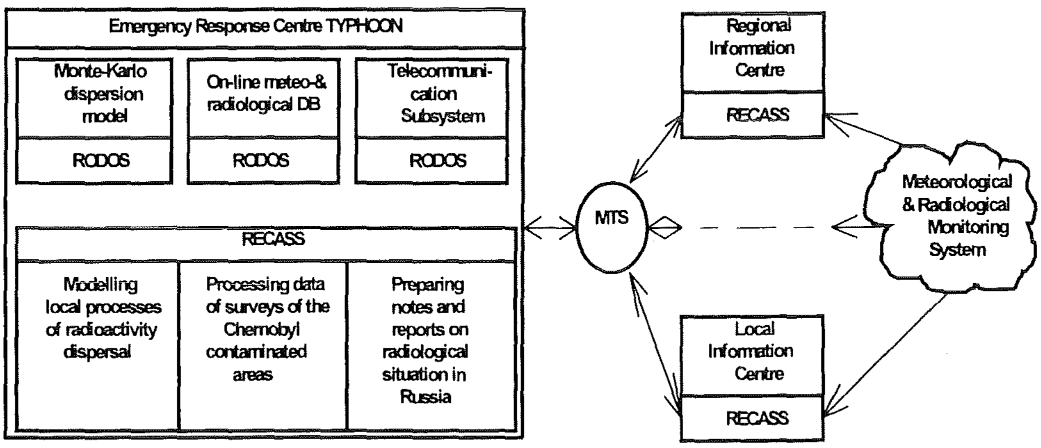


Figure 2: RECASS/RODOS coupling to ROSHYDROMET

XI.3.3 Practical application of the RODOS for solving accident-related problems

In Russia during the last several years a large body of data obtained in the surveys of the Russian territory contaminated after the Chernobyl and other accidents have been entered into the RODOS/RECASS databases. Drawing on these data, the Centre prepares maps of contamination of the environmental media and provides them to users. The continuous inflow of real-time data from the monitoring the 100 km monitoring zones around nuclear installations (such as gamma dose rate measurements) makes it possible to prepare information on the current radiation situation around nuclear installations.

The models incorporated in the system were actively used for analysis of the radiological situation after the Chernobyl accident and, in particular, for reconstruction of the dynamics of environmental contamination with short-lived and long-lived radionuclides. These data were used for the estimation of doses received by the population on the first day of the accident. The potential of the system was also tested during the accident at the Siberian chemical plant (Tomsk-7) [4] when the Centre engaged in modeling and processing measurement data. The results, obtained by modeling with the RIMPUFF program and presented in a short time, included the fields of 95Nb and 239Pu environment contamination and estimates of the projected individual effective equivalent dose received by the population during the accident.

In the future, the structure of the RODOS system, its software and databases will enable decision making support in a variety of emergencies, both related to accidents at nuclear installations and other types of disasters. One of the cases when the system was applied to such problems was a fire at the oil storage facilities near Grozny.

The hydrological module of RODOS was used in the Ukraine in the summer 1995 to evaluate the consequences of the accidental release of the Kharkov municipal waste water to the rivers. As the result of the heavy rainstorm at 29 June 1995 the pumps of the Dikanki Sewer Water Treatment Station that processed municipal waste water collected from the whole Kharkov City (population > 2,000,000) was flooded by a 43-meter layer of water. During the following month while repair works proceeded, the direct release of the waste water took place to the Kharkov region's small rivers- Udy River and its tributaries Lopan River and Kharkov River. The Udy River transported the contaminated water to the Siversky Donets River, that crosses whole territory of the Donbass Region of Ukraine and then transported contaminated water to the Russian Rostov Region. Under the impact of the heavy bio-organic pollution, the dissolved oxygen concentrations lowered practically to zero in the small Kharkov Region Rivers. Heavy bacteriological contamination of the Siversky Donets water was measured.

XI.4 Conclusion

Completion of the projects described above will lead to the installation of an operational version of the comprehensive RODOS system for off-site emergency management - in Russia, Belarus and Ukraine. The system will be adapted to the special conditions and integrated into the national infrastructure, including coupling to local/regional/national meteorological and radiological monitoring networks.

The Chernobyl accident clearly demonstrates how dangerous major nuclear power plant accidents are. Increasing the efficiency of post-accidental off-site management in the Ukraine, Belarus and Russia, though not Community member states, would be important to the whole Community and neighboring East European and Central European Countries. The simulation of an accident situation by national RODOS systems coupled with the national meteorological and radiological monitoring networks and date bases would be more valuable than simulations provided in regional RODOS centers, which would have lack national information in the first accident stage. The system of on-line connections of the European RODOS centers would help to disseminate the modeling information concerning an emergency though out wholeof the Europe.

Experience received by Ukranian, Belarusian and Russian specialist during joint work with EC institutions training with the RODOS system, has increased the scientific and technical level of numerous people. The skilled specialists can have a direct influence on the level of the nuclear safety in their countries. The RODOS system implementation promotes increased scientific application on the national level for off-site emergency management decision support.

Russian, Ukrainian and Belarusian scientists, engineers and programmers have the experience of on-line support for decision making after the Chernobyl and other accidents. They continue to collect and build comprehensive databases of environmental contamination, countermeasures' efficiency and dose assessment after the accidents. These data provide unique possibilities for RODOS validation studies. Therefore the Russian, Belarusian and Ukrainian involvement in the project brings potential benefits for further development of the whole RODOS system.

Acknowledgement

This paper was originally presented at the Fourth International Workshop, Aronsborg, Sweden, October 7 - 11, 1996 and was published in the Proceedings of that meeting published as Radiation Protection Dosimetry Vol. 73, Nos. 1-4 (1997), pp. 85-90. It is reproduced with permission of the publisher, Nuclear Technology Publishing

XI.5 References

1. Ehrhardt, J. et. al. Development of RODOS, a Comprehensive Decision Support System for Nuclear Emergencies in Europe - an Overview, Radiation Protection Dosimetry, Vol.50, Nos 2-4, pp. 195-205 (1993).
2. Zheleznyak, M.J. et. al. Aquatic Dispersion Models - First Approach to Integration into the CEC Decision Support System based on Post-Chernobyl Experience, Radiation Protection Dosimetry, Vol.50, Nos 2-4, pp. 235-243 (1993).
3. Shershakov, V.M. et. al. Radioecological Analysis Support System (RECASS), Radiation Protection Dosimetry, Vol.50, Nos 2-4, pp. 181-185 (1993)
4. Shershakov, V.M. et.al. Analysis and prognosis of radiation exposure following the accident at the Siberian chemical combine Tomsk-7, Radiation Protection Dosimetry, V.59, pp.93-126 (1995).

XII Adaptation of the generic RODOS system for operational use in Poland

M. Borysiewicz, S. Potempski, R. Zelazny

Institute of Atomic Energy, 05-400 Otwock-Swierk, Poland

Abstract

In Poland the intention is to use RODOS as the software framework for Integrated Emergency Data Management and Decision Support System (EDMDSS), whose structure will account for existence of specialised centres, with responsibilities relating to: meteorological fields diagnoses and predictions, measured radiological data collection and examining feasibility of countermeasures to work out rational decisions. The system will be distributed and functionally integrated in order to take best advantage of current organisational arrangements in Poland. A parallel workstation platform and dedicated package will be used for downscaling coarse data from national meteorological services and special emergency mode operation for weather predictions.

XII.1 Introduction.

A decision support system RODOS [1,2], for the off-site emergency management of nuclear accidents has been developed within the framework of the Commission's R&D programme. The system has been designed to be comprehensive generally applicable across Europe and capable of providing the basis of an integrated and coherent response to any future accident. Bringing the RODOS into operational use is clearly the responsibility of the respective countries. Poland is committed to integrating the RODOS decision support system into its emergency arrangements. The operational use of RODOS requires the adaptation of some models and data to local/national conditions and habits. Areas which need special attention in Poland include:

- the structure and format of on-line meteorological and radiological monitoring data
- emergency meteorological forecasts using down-scaling of regional/national weather predictions
- geographical, demographic, agricultural and economic data
- parameterisation of food-chain and ingestion models
- emergency plans and criteria for the introduction of countermeasures
- user interface and its translation to national language.

In Poland the intention is to use RODOS as the software framework for Integrated Emergency Data Management and Decision Support System (EDMDSS), which is being developed by the Institute of Atomic Energy (IAE) under supervision of the National Atomic Energy Agency (NAEA).

XII.2 Key components of EDMDSS.

The majority of functional modules of EDMDSS will be based on RODOS, being developed in frame of the European Union programme. Transforming RODOS into EDMDSS, which will operate in real time and on-line coupled with meteorological and radiological monitoring networks requires modification of 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 EDMDSS. 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.

Therefore, the structure of EDMDSS will account for existence of specialised centres, such as Institute of Meteorology and Water Management (IMWM) with responsibilities relating to meteorological fields diagnoses and prediction, Central Laboratory of Radiological Protection (CLRP) dealing with measured data collection, their consistency revision and maintenance of central bases of such data, and Radiological Emergency Centre (REC) of NAEA, where projections of radiological situations, and feasibility of countermeasures will be examined to work out ranked list of rational decisions.

To accomplish project tasks several key software components will be used:

- The RODOS will provide majority of required computational modules 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 accident.
- A software for collecting automatically monitored radiological data and transmitting to REC of NAEA. A part of the monitoring stations operate under ARGOS-NT system developed at the Danish Emergency Management Agency. The ultimate goal of all efforts is to approach gradually the technical standards and organisation structure of the system IMIS implementation in Germany. The CLRP is cooperating in this subject with the Institute of Atmospheric Radioactivity, Freiburg. Both meteorological and radiological data are to be available in METPAK network operated by IMWM.
- Regional Atmospheric Modelling System (RAMS) acquired from the Colorado State University to provide meteorological forecasting for emergency purposes. The RAMS is designed so that the code contains a variety of structures and physical options. This allows for an easy selection of the appropriate options for different spatial resolution and domains from few kilometres to entire hemisphere. A particular feature of RAMS that makes it attractive for mesoscale and microscale application is interactive nesting procedure allowing any number of nested grids. This unique nesting facilitates use of the model over relatively small regions employing a very fine innermost grid while at the same time treating the influences of inhomogeneous and time variable synoptic fields.
- Hybrid Particle and Concentration Transport (HYPACT) model under development in MRC*ASTER linked to RAMS representing a state-of-art methodology for predicting dispersion of air pollutants.
- Primary version of Heterogeneous Distributed Computer Environment (HEDICE) [3,4] for integration of emergency data management and decision support systems, already developed by IAE for EDMDSS. The HEDICE is not only as a system for data exchange using some more or less standard data formats, but serves as a main tool for interoperability of two or more tasks running on different nodes of network.

XII.3 Software tools for heterogeneous distributed computer environment

For ensuring high operational performance of EDMDSS and effective use of resources and technical capabilities of all the relevant institutions the system will be both distributed and functionally integrated, i.e.:

- operational system of EDMDSS will account for a network of the EDMDSS software kernels implemented along with a dedicated modules in specialised centres, with the software kernel providing basic function of communication, process and data management and graphic user interface,
- adequate tasks scheduling among the centres of the network will be designed to avoid intercentre transmissions of huge amount of data produced by intermediate steps of analysis phase, e.g. meteorological parameters for dispersion calculations,
- it will 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 will be reliable and fast enough,

  individual module can be executed and maintained on different machines under the supervision of teams of dedicated specialists.

To achieve these goals the basic tool for such integration HEDICE is being developed. 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 is be able to operate in different circumstances during dynamically changing situations. The well-defined interfaces, hiding internal operations clarify all possible operations of any element of the system.

The implementation of HEDICE is partially based on freely distributed software, such like Parallel Virtual Machine (PVM) package, based on message passing concept, which allows for easy integration with generic RODOS software.

At first, HEDICE shall be implemented in a heterogeneous-computer environment at the Institute of Atomic Energy on a coupled HP-735 and Convex C3220 machines which constitute also the parallel computer platform for numerical weather prediction and radionuclide atmospheric transport calculations.

In the next step the software of distributed EDMDSS will be developed for a computer network configuration with Convex C3220 and HP 735 computers located at IAE and other computers of relevant institutions in Warsaw providing services for IMWM, CLRP and SIEP, with all of them being connected to Metropolitan Area Network of Warsaw (WARMAN) allowing the data transfer with the speed of 155 Mbits/sec. The development of HEDICE will account for capabilities for parallel processing of some of the those computers.

XII.4 Dedicated software package for numerical weather prediction and radionuclide transport for emergency decision support

Atmospheric dispersion phenomena can be naturally divided according to time and space scales. To cover all scales of interest for EDMDSS two approaches are possible:

- integration of different programmes developed for different scales
- application of a programme with built-in features of multi-scale handling with interactive nesting procedure allowing to specify any number of telescoping grids or even moving

while calculating transport of dispersion and accounting for phenomena such as the propagation of thunderstorms.

For EDMDSS in Poland it is planned to implement the latter approach basing on capabilities of RAMS and HYPACT models. The RAMS model shall constitute a basis for downscaling and special emergency mode operations for weather predictions. The RAMS package has been already installed on HP-735 and Convex C3220 computers of 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 REC prepared for the emergency actions. For initialisation the RAMS package shall use coarse mesh numerical weather forecasting provided by the IMWM and observational data from public, military, mobile and Doppler radar stations. It is assumed that the parallel RAMS model shall be used for stand-by purposes, allowing to start on demand necessary data assimilation, initialisation and emergency calculation of numerical forecasts connected with the atmospheric dispersion simulations of EDMDSS system. A parallel computer platform for RAMS will be a cluster of machines consisting of Convex C3220 mainframe and HP735 workstation managed by PVM and supported by NCAR and AVS packages for graphics and visualisation.

This approach will in particular enhance 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 and national meteorological centres, to the purpose of an emergency situation development tracking). The regional atmospheric system RAMS 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. A relatively low cost solution would be an implementation of a paralleled version of RAMS in a heterogeneous cluster of workstations and/or mainframes.

Since the potential nuclear power plants accidents may happen relatively far from Polish territory, it was decided to adapt and further tune the software of HYPACT code for long distance transport of radionuclides, taking advantage of hybrid Lagrange and Euler characteristics of the code. The HYPACT model linked to RAMS allows assessment of the impact of one or multiple sources emitting into highly complex local weather regimes, including mountain/valley and complex terrain flows, land/sea breezes, urban areas, and other situations in which the traditional simplified based models are known to fail.

XII.5 Conclusions

It is expected that developing a software framework capable to integrate new advanced technologies in atmospheric modelling, radioactive impact assessment countermeasures ranking and software engineering into a real time operational EDMDSS will improve existing capabilities of the country to respond operationally to radioactive accidents of different spatial and time scales and harmonise national efforts with EU sponsored activities on RODOS development for real time assessment of consequences and emergency response related to nuclear accidents in Europe.

Acknowledgement

This paper was originally presented at the Fourth International Workshop, Aronsborg, Sweden, October 7 - 11, 1996 and was published in the Proceedings of that meeting published as Radiation Protection Dosimetry Vol. 73, Nos. 1-4 (1997), pp. 91-94. It is reproduced with permission of the publisher, Nuclear Technology Publishing

XII.6 References

1. Ehrhardt J., Päsler-Sauer J., Schüle O., Benz G., Rafat M., Richter J., "Development of RODOS a Comprehensive Decision Support System for Nuclear Emergencies in Europe - an Overwiev", Radiat. Prot. Dosim. 50, 195-203 (1993).

2. Benz G., Ehrhardt J., Faude D., Fischer F., Päsler-Sauer J., Rafat M., Schichtel M., Schüle O., Steinhauer C., "The real-time on-line decision support system RODOS for off-site emergency management", Kerntechnik 59 No. 4-5, 215-219 (1994).

3. Borysiewicz M., Potempski S., "Heterogeneous Distributed Computer Environment for National Decision Support System for Nuclear Emergencies", Proc. of Fifth Topical Meeting on Emergency Preparedness and Response, Savannah USA, ANS 366-370, (1995).