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RODOS: Decision Support System for Off-Site Emergency Management in Europe

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Abstract. The integrated and comprehensive real-time on-line decision support system, RODOS, for off-site emergency management of nuclear accidents is being developed under the auspices of the European Commission's Radiation Protection Research Action. A large number of both West and East European institutes are involved in the further development of the existing prototype versions to operational use with significant contributions coming from the partner institutes in the CIS Republics. This paper summarises the structure, the main functions and the status of the RODOS system.

1. Introduction

1.1. Background

Following the Chernobyl accident, increasing resources were allocated in many countries to the improvement of arrangements for off-site emergency response in the event of a nuclear accident. Within the European Commission's Radiation Protection Research Action, a major project was initiated in 1990 to develop a comprehensive Real-time On-line DecisiOn Support system, RODOS, for nuclear emergency management[1]. A large number of EC contractors are participating in this project and advantage is being taken of existing developments at national levels. Developments of a similar nature were being undertaken within the former Soviet Union and subsequently within individual Republics, taking account of the practical experience gained in responding to the Chernobyl accident. The working programme of the Joint Study Project 1 (JSP1) reflects the common efforts and ideas of the joint undertaking to develop a decision support system that would be broadly applicable and accepted in West and East Europe.

1.2. Objectives

The main objectives of the RODOS project are to provide the methodological basis, develop models and data bases and install the hardware and software framework of a system which offers comprehensive decision support from the very early stages of an accident up to many years after the release and from the vicinity of the site to far distant areas unperturbed by national boundaries. In this way it will be possible to achieve estimates, analyses, and prognoses of accident consequences, protective actions and countermeasures which are consistent throughout all accident phases and distance ranges. All relevant environmental data, including radiological and meteorological information and readings, are to be processed, by means of models and mathematical procedures, into understandable, interpretable pictures of the current and predicted future radiological situations. Simulation models for any kind of protective actions and countermeasures are designed not only to permit their extension in terms of time and space to be estimated, but, together with dose, health effects and economic models, also to allow their benefits and disadvantages to be quantified. Feasibility rules and subjective arguments of decision makers implemented in rule-based expert systems and other decision analytic methods will help to evaluate alternative countermeasure strategies and to provide a ranked order of countermeasure options together with an explanation for that order.

Within the collaborative arrangements between the institutes involved in JSP1, the following objectives were of particular importance:

- further development of a comprehensive decision support system for operational use generally applicable in the EU and CIS, using the RODOS system as a common platform
- improvement and validation of models and completion of data bases included in the RODOS system using monitoring and other data obtained during and after nuclear accidents in the CIS, such as those at Chernobyl and Tomsk
- implementation and adaptation of the RODOS system in each of the three CIS Republics, its link with meteorological and radiological monitoring networks and demonstration of its on-line operation

1.3. Project Overview

During the 3rd Framework Programme of the European Commission, 1990 - 1995, the RODOS project evolved as as an ambrella for four individual subprojects, each with its own contractors and coordinator:

- Co-ordination of atmospheric dispersion activities for the real-time decision support system under development at FZK, with RISØ National Laboratory as coordinator
- Development of a comprehensive decision support system for nuclear emergencies in Europe following an accidental release to atmosphere, with Forschungszentrum Karlsruhe as coordinator
- Evaluation and management of post-accident situations, with CEA/IPSN as coordinator
  The Joint Study Project 1 (JSP1) of the EC/CIS Collaborative Agreement for International Collaboration on the Consequences of the Chernobyl Accident

The contractual arrangements and the work performed within the first three contracts is described elsewhere[2,3,4]. This paper emphasises on the JSP1 contract and the institutes involved are as follows:

- Forschungszentrum Karlsruhe GmbH (FZK), D (EU coordinator)
- National Radiological Protection Board (NRPB), UK
- V. KEMA, NL
- Studiecentrum voor Kernenergie/Centre d'Etude de l'Energie Nucleaire (SCK/CEN), B
- SPA TYPHOON, Russia (CIS coordinator)
- Institute of Control Science Problems (ICSP), Russia
- Russian Institute of Agricultural Radiology (RIAR), Russia
- Institute of Mathematical Machines and Systems, Cybernetics Centre (IMMS CC), Ukraine
- Ukrainian Institute of Agricultural Radiology (UIAR), Ukraine
- Institute of Power Engeneering Problems (IPEP), Belarus
- Belorussian Institute of Agricultural Radiology (BIAR), Belarus
- Committee for Hydrometeorology (HYDROMET), Belarus

From the beginning of JSP1, the work programme was split into four subprojects and the tasks of each of them can be summarised as follows:

Development of decision support systems: Improvement and extension of the functions and capabilities of RODOS by incorporation of software available from and/or developed by the project partners and based on the experience with the operation of the actual RODOS prototype version in CIS and EU institutes (FZK; SPA TYPHOON, ICSP, IMMS CC, IPEP, CRKM, ONIL, HYDROMET).

Modelling of hydrological pathways: Development of a model chain for short- and long-term prognoses of the consequences of a radioactive contamination of the aquatic part of the environment (KEMA, FZK; IMMS CC, SPA TYPHOON).

Agricultural countermeasures: Modelling the efficiacy and cost of agricultural countermeasures by evaluating radiological and countermeasure data bases existing or under development in CIS institutes (NRPB; BIAR, RIAR, UIAR).

Data assimilation and interpretation: Development of a generic methodology for assessing the source term and the dose distributions during and shortly after an accidental release of radioactive material by evaluating model predictions and early radiological monitoring data and meteorological measurements (SCK/CEN, JRC ISPRA; SPA TYPHOON).

Close cooperation has been achieved with project JSP2 consequent upon the common interest in decision support systems for longer term countermeasures and with project ECP3 on hydrological modelling.

2. Main Functions and Characteristics of RODOS

2.1. Capacity for Generic Use in Europe

RODOS is designed as a comprehensive system incorporating models and data bases for assessing, presenting and evaluating the accident consequences in the near, intermediate and far distance ranges under due consideration of the mitigating effect of countermeasure actions. Its flexible coding allows 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 UNIX operation system; in particular its software framework supports the integration of application software developed externally by many of the contractors[5]. The modular structure of RODOS allows an easy exchange of models and data, and thus facilitates the adaptation of the system to the local/regional and national conditions. Finally RODOS offers a variety of access tools to cope with the different capabilities, knowledge and aims of the future users.

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, incl. source term estimation.
- Level 2: Simulation of potential countermeasures (e.g. sheltering, evacuation , issue of iodine tablets, relocation, decontamination and food-bans), in particular, determination of their feasibility and quantification of their benefits and disadvantages.
- Level 3: Evaluation and ranking of alternative countermeasure strategies by balancing their respective benefits and disadvantages (e.g. costs, averted dose, stress reduction, social and political acceptability) taking account of societal preferences as perceived by decision makers.

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.

2.3. Structure and Endpoints of RODOS

In recognition of the need for a unique and integrated real-time on-line decission 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 subystems, which are denoted by ASY, CSY and ESY[1]. Each of the subsystems consists of a variety of modules developed for processing data and calculating endpoints belonging to the corresponding level of information processing. The modules are fed with data stored in four different data bases comprising real-time data with information coming from regional or national radiological and meteorological data networks, geographical data defining the environmental conditions, program data with results obtained and processed within the system, and facts and rules reflecting feasibility aspects and subjective arguments.

The content of the subsystems and the data bases will change with the 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 subsytems 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) 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 quantifyable 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 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, with an easy understandable but very limited interface for training courses on emergency management on the top and the full spectrum of interaction tools for system developers familiar with the system ingredients and structures on the bottom.

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. It has been developed following the Client-Server Model: each module requests a service from the system (typically this might be a request for data) and the system determines how this might be satisfied. If the data is already in the data base then it can be supplied directly. Alternatively, it may call another module which can calculate the required information[5].

3. Status and Future Planning

Since the end of 1995, the prototype version RODOS-PRTY-2.0 is available, which will be further developed in the next years with the first pre-operational version 3.1 ready by mid 1997 and the version 4.0 for full operational use by mid 1999. In the following the content of the current version will be briefly described together with selected key objectives for the 4th Framework Programme.

3.1. Diagnosis and Prognosis of the Radiological Situation

The analysing subsystem ASY can be operated with measured or historical meteorological data solely (diagnosis mode) or together with forecasted meteorological fields (prognosis mode). The meteorological data are converted in the meteorological preprocessor PAD into input data on the state of the atmospheric boundary layer for use by the subsequent meteorological model chain. It consists alternatively of the windfield models MCF or LINCOM and either the puff-model RIMPUFF or the simplified puff-model ATSTEP[6].

The mass consistent wind field model MCF allows a spatial wind vector field free of divergences to be set up over an area extending to a few tens of kilometres. The boundary layer and wind profile data are processed together with the site topography to get a wind vector field taking into consideration the influence of the underlying terrain over which material would be dispersed. The flow model LINCOM is a non-hydrostatic diagnostic model based on the solution of linearised continuity and momentum equations with a first order spectral turbulent diffusion closure. Both models can be operated in the prognosis mode with input from national forecast models to produce a wind field with higher resolution (e.g. 1 km), such as those from the German Weather Service with a resolution of 14 km or HIRLAM from Sweden[6].

Atmospheric dispersion and deposition as well as nuclide specific activity concentration and gamma radiation fields are calculated in RIMPUFF and ATSTEP. RIMPUFF is suitable for real-time simulation of puff and plume dispersion during time and space changing meteorology. Its modelling is consistent with the German-French atmospheric dispersion model now agreed by both countries for operational use in nuclear emergency situations. The ATSTEP code offers all features of RIMPUFF but calculates with a lower spatial and temporal resolution. It will mainly be applied as a fast atmospheric dispersion code for training and exercises with RODOS.

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. Progress has already been made in this direction with support of SPA TYPHOON, who integrated in RODOS their long range atmosphric dispersion models together with software for accessing and evaluating weather forecasts for Europe from meteorological services (Washington, Moscow, Bracknell).

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 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 throuh the various modules of the RODOS system. 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.

3.2. Countermeasures and Consequences

The countermeasure and consequence subsystem CSY incorporates

- the module group ECOAMOR for calculating individual doses via all exposure pathways, in particular ingestion pathways,
- the module group EMERSIM for simulating sheltering, evacuation and distribution of stable iodine tablets,
- the module group FRODO for simulating relocation, decontamination and agricultural countermeasures,
- the module HEALTH for quantifying stochastic and deterministic health effects[6]
- the module ECONOM for estimating the economic costs of emergency actions, countermeasures and health effects[6].

ECOAMOR[7] is a system of program modules which has been developed on the basis of the dynamic radioecological model ECOSYS-87[8]. Inputs to ECOAMOR are the contamination of air and precipitation provided by ASY. 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; the modules are designed to facilitate the adaptation to these regional variations.

In its present version, ECOAMOR consideres 31 basic food products, 22 feedstuffs and 35 processed foodstuffs. The models describe the dynamics of the different radioecological transfer processes, such as the seasonality in the growing cycle of plants, the feeding practices of domestic animals and human dietary habits. In the dose modules of ECOAMOR, the ingestion doses are calculated from the activity concentrations in foodstuffs, age and possibly season dependent intake rates and age dependent dose factors. Doses due to short term inhalation from the passing plume as well as long-term inhalation of resuspended material are also calculated. In addition, doses resulting from external exposure pathways are determined, such as irradiation from the passing plume and from deposited material on ground surface and the skin. Dose reductions from nuclide migration into deeper soil layers and by the shielding of houses are considered, as well as the influence of variable deposition patterns at different urban environments.

The early emergency actions considered in EMERSIM[7,9] 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], 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 transportattion means, population distribution, weather conditions and time of accidental release. It will be completed by the optimisation module STOP[9], which is able to optimise routes for evacuation with respect to route length, dose saved, starting time and costs.

The relocation model in FRODO[7,10] 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 decontamintion of agricultural land is included in so far as its impact on the need for or reduction in food restrictions is evaluated. The other 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 and change in land use.

The criteria for banning the consumption of food are defined in terms of the activity concentrations in foods. A database of information on the effectiveness of the agricultural countermeasures has been compiled. These data have come primarily from a database on the effectiveness of a range of agricultural countermeasures compiled for inclusion in RODOS under the JSP1. This database contains robust, representative data that can be applied to relatively large areas, potentially over long periods of time[10].

Important extensions of CSY in the next project period will be an improved treatment of the interaction between combined countermeasures, the inclusion of consequence and countermeasure models for natural and semi-natural environments and data assimilation in the models for deposition on soil and vegetation and foostuff and feedstuff contamination.

3.3. 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), RIVTOX and COASTOX (rivers) and LAKECO (lakes) have been coupled, implemented in RODOS and adapted to the Rhine river system[11]. Other river systems can be readily implemented in RODOS using the same model chain subject to gathering appropriate data.

3.4. 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; the sequence of calculations will be oriented at its internal structure:

First, a very simple expert system will be used to discard strategies which are incompatible with the principles of radiological protection, which do not five continuity of treatment, or which fail very coarse practicability rules. The remaining strategies will be passed to a multi-attribute value ranking module, which will identify the top 10 or 20 ranked strategies. The operator will be able to use interactive sensitivity analyses, such as that in the software packages HERESY[12] and M-CRIT[12], to confirm that these strategies are worth careful consideration. These strategies would then be passed to an expert system with a much finer and more sophisticated system or rules, each of which could be applied to each of the candidate strategies. The small number of strategies would allow a full set of explanations to be developed, which would give a critique of each of the strategies. Thus the output of RODOS will be a short list of strategies, each of which satisfies the constraints implied by intervention levels, practicability, etc. together with a detailed commentary on each strategy explaining its strength and weaknesses.

3.5. Customisation in Central and Eastern European Countries and CIS Republics

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 coordinated working programme has been achieved[13].

Within 4 years of the start of the RODOS project, EU, Eastern European and CIS countries have agreed: the hardware and software concepts, the modelling and operating features, and the various levels of information processing and presentation. 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.

Before the RODOS system can become fully operational in Europe, especially in the Central and Eastern European countries and the CIS Republics, a number of tasks need to be completed. These include

- customisation of data bases and models to local, regional and national conditions,
- establishing interfaces with national meteorological and radiological monitoring networks,
- integration of the system within national emergency management arrangements.

With support of the European Commission the process of bringing the RODOS system into operational use in the respective countries will be accelerated in the next months and years with attendant benefits for emergency preparedness both in the East and Europe more generally.

4. Benefits of RODOS

4.1. Potential Role for Improving Emergency Response in Europe

With the continuation of the R&D work by the institutes with a leading function already in the 3rd Framework Programme, existing skills, knowledge and co-operation will be carried forward into the Framework 4 programme to deliver a decision support system which provides benefits and functions unavailable elsewhere. These include:

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

Those institutes in Eastern and Western Europe, which already or in the near future will run the current version of RODOS, are directly or indirectly responsible for emergency management in their countries. In parallel to the ongoing R&D work during the period 1996-99, there are plans in at least some of these countries to integrate RODOS within national emergency response systems. In addition, the work on the realisation of a European wide network for the exchange of radiological information has started with the main partners of this proposal and the current RODOS users[14,15]. In this way, the RODOS system will facilitate communication and exchange of information and promote a more coherent and harmonised emergency response within Europe to any future nuclear accident.

4.2. Future Users

The roles for which RODOS is 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 bi-lateral or international agreements); the R&D 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.

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