USE OF SYSTEMS ANALYSIS TECHNIQUES IN THE EG&G IDAHO WASTE MANAGEMENT ENVIRONMENTAL SURVEILLANCE PROGRAM*

M. J. Case and P. D. Ritter
Idaho National Engineering Laboratory
EG&G Idaho, Inc.
Idaho Falls, Idaho 83415

ABSTRACT

The Environmental Surveillance Program of EG&G Idaho, Inc., has successfully implemented a systems analysis approach, using simulation models to supplement its monitoring program at the Radioactive Waste Management Complex (RWMC) at the Idaho National Engineering Laboratory. Systems analysis has been used to attain several program objectives including environmental and performance assessments of buried radioactive waste, design and modification of the monitoring program, and support to operations personnel in revising operations to reduce RWMC impacts and in formulating closure designs. This endeavor has also provided an avenue for cooperative interaction between modeling, monitoring, and waste management operations. A description of the approach and models used are presented in this paper.

INTRODUCTION

The Radioactive Waste Management Complex (RWMC) was established in 1952 near the southwestern corner of the Idaho National Engineering Laboratory (INEL) as a controlled area for the management of solid radioactive waste. In recognition of potential hazards associated with waste at the RWMC, an environmental monitoring program was instituted. The EG&G Idaho, Inc., Environmental Surveillance Program provides independent assurance that the RWMC isolates radioactive wastes from the biosphere in a safe and environmentally acceptable manner.

The use of mathematical models to simulate radionuclide transport from buried waste at the RWMC through the environment has proved to be a useful adjunct to the Environmental Surveillance Program. Analysis of radionuclide migration pathways has allowed the program to systematically evaluate the RWMC and therefore to effectively address the following specific program goals:

OBJECTIVE 1: Assess the environmental impact of radioactive waste buried at the RWMC in support of environmental assessment documents.

OBJECTIVE 2: Identify radionuclides and pathways which are relatively important and should therefore be monitored.

OBJECTIVE 3: Design or modify individual sampling activities and special studies that will provide sufficient data for predictive models and trend analysis.

OBJECTIVE 4: Provide to operations personnel data that will aid them in designing engineered barriers and implementing practices which will minimize the impact of radioactive waste management on the environment.

OBJECTIVE 5: Assess the impacts of proposed strategies for RWMC closure and aid in selection of an optimum design.

OBJECTIVE 6: Assess the performance of the RWMC, currently and in the long term, in relation to regulatory standards and guidelines.

The purpose of this paper is to provide an overview of the systems analysis approach used by Environmental Surveillance Program. The models in current use or development are described primarily in terms of their applications in support of the objectives presented above. The paper also illustrates the development of a valuable cooperative interaction between performance assessment modeling, environmental monitoring, and disposal operations--three activities which often are conducted independently.

SIMPLIFIED COMPARTMENTAL PATHWAYS MODEL

The core of the modeling effort for the RWMC facility has been the development of a simple pathways model of radionuclide movement from radioactive waste buried at the RWMC to the surrounding environment. The current version of the model is entitled "Simplified Compartmental Pathways Environmental Transport Model" or "SCoPE". The model was or is currently being used to address all of the objectives presented earlier in this report. The development, continuing evolution, and relationship of the SCoPE model to the Environmental Surveillance Program is illustrated in Fig. 1 and is discussed below.

Early Development and Applications

Shallow-land burial of radioactive waste can result in contamination of surrounding surface and subsurface soils. Many radiological models are available that will project the transport of radionuclides and resulting potential doses to humans, subsequent to

*Work supported by the U.S. Department of Energy under DOE Contract No. DE-AC07-76ID01570.

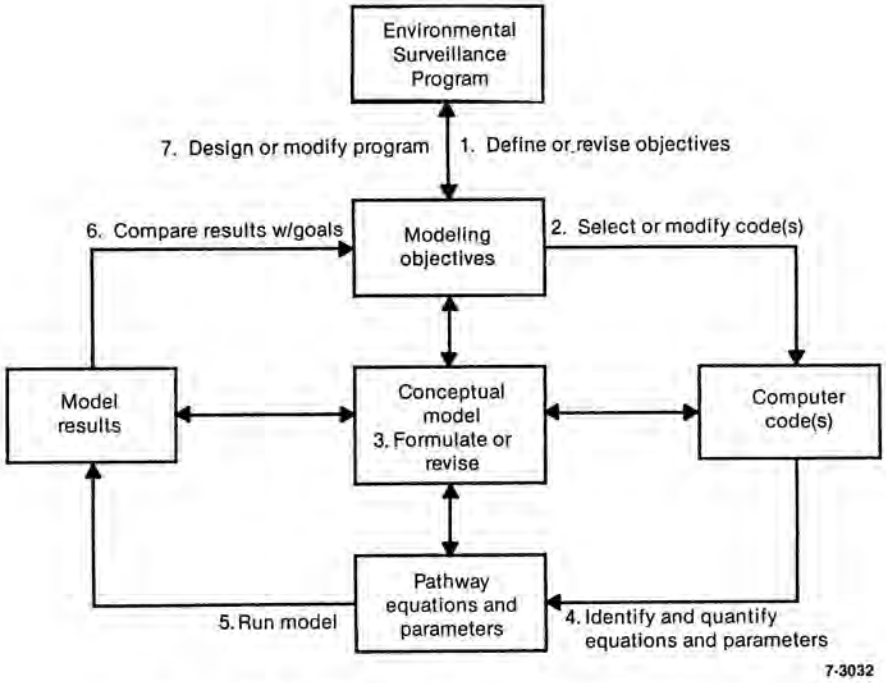

Fig. 1. Model development and revision process.

release from the disposal site. However, no generic models are available that will estimate the potential migration of subsurface contamination within a shallow land burial site such as the RWMC. Disposal sites are, in principle, difficult to model generically because of the importance of site-specific features. The RWMC, for example, is a complex environmental system that has been subjected to changing operational practices and unexpected natural events, such as flooding.

The development of a model which adequately addresses the unique nature of the RWMC began in 1982. First, the objectives of the modeling effort were defined (Step 1 in Fig. 1). The program goals at that time were essentially Objectives 1 through 3. A preliminary conceptual model was then formulated using site-specific information (Step 2). All major potential radionuclide transport pathways from buried waste to the environment and to humans were considered.

A comprehensive review of available computer codes was performed to select a code compatible with the conceptual model and adaptable to site-specific applications (Step 3). The codes were evaluated according to a set of criteria which included the specific objectives of the modeling effort as well as necessary and desirable characteristics of the code. The selection process is described in Shuman et al. (1). The Savannah River Laboratory (SRL) DOSTOMAN code (2) was chosen primarily because of its simplicity, its dynamic (versus equilibrium) nature, and its flexibility. The DOSTOMAN model could easily be modified for use at the INEL and could be applied to a variety of different modeling objectives. Moreover, the code had been verified, and some field validation had been accomplished by Savannah River Laboratory (SRL).

The immediate use of the model was for an environmental assessment of the low-level radioactive waste (LLW) buried at the RWMC (3). The modeling objective was to provide a source term for projection of long-term impacts of the facility. The preliminary conceptual model was streamlined to include only those major pathways which could result in the movement of radionuclides from buried waste to the surface soil. Critical radionuclides were selected for assessment through the use of screening calculations, which weighted the relative hazards of each radionuclide in the waste. A detailed description of the model may be found in Rope et al. (4). A brief description follows.

An abridged version of the pathways diagram is shown in Fig. 2. Pathway "a" represents the burial of waste. The rate of burial of each radionuclide in each of four categories of waste (activated metals, wooden boxes, cardboard boxes, and steel drums) was estimated from waste management records. Pathway "b" represents release of the waste radionuclides, via leaching or corrosion of metals, to burial soil. Container degradation was accounted for by use of a delay time period prior to release of radionuclides. Radionuclides in upper burial soil were assumed to be available for upward migration by physical and biological transport processes. These include excavation of soil from lower soil layers to the surface by burrowing animals (Pathway "c"). Subsidence of soil into abandoned burrows was assumed (Pathway "d"). Plant uptake by shallow-rooted and deep-rooted plants also contributes to upward movement of waste radionuclides. The death of plant roots and subsequent deposition of radionuclides in a more shallow soil layer is represented by Pathway "g". Deposition of aboveground plant material, following death, is represented by Pathway "h". Other pathways, such as the transport of radionuclides to the surface via soil water (Pathway "e") and downward migration via percolating water, were not included in the computer simulations. The upward migration pathway was eliminated after screening calculations demonstrated it to be insignificant compared to other pathways. The downward migration pathway was excluded because the limited rainfall and depth to ground water (180 m) would probably result in a very small dose to offsite receptors, compared to that from surface migration pathways. This conclusion was supported by monitoring results from observation wells drilled in and around the RWMC.

The conceptual model was then quantitatively described (Step 4 of Fig. 1). The rates of change in

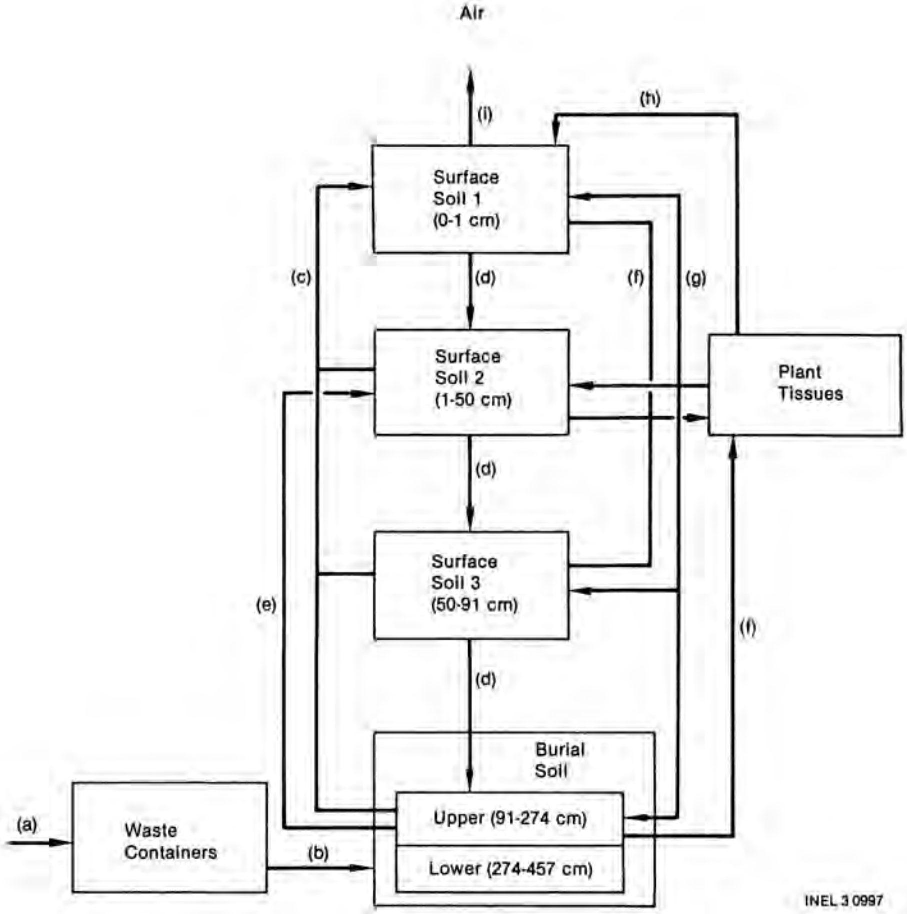

Fig. 2. Simplified pathways diagram showing transport of radionuclides from buried waste to surface soil. (See text for explanation transfer processes indicated by letters.)

compartments were represented by a series of first-order differential equations. Rate constants were used to specify the fraction of total inventory that leaves a compartment per unit time. Rate constants were calculated using site-specific information, if available. If not available, parameters were estimated from references pertaining to similar arid environments.

The model was run for a length of time corresponding to the period from beginning of burial to 1000 years following site closure (Step 5 of Fig. 1). Figure 3 is an example of output from the model in which inventories of Cs-137 in the top three soil compartments are plotted with time. The projected radionuclide inventory in surface soil was used as a source term for calculations of resuspension and subsequent inhalation doses to members of the public.

Sensitivity Analyses

Although the first version of the SCoPE model satisfied the initial modeling objective, additional revisions were recognized as necessary to satisfy the other program goals identified at that time (Objectives 2 and 3). These objectives were translated into the modeling objective of determining critical pathways and key input parameters through the use of sensitivity analyses. The first version of the model was insufficient for accomplishment of this task for several reasons. First, the environmental assessment only considered the LLW buried at the RWMC. It did not include the transuranic (TRU) waste buried prior to 1970, before the Transuranic Storage Area was established. This portion of the burial ground was assessed in an earlier environmental assessment (5). Second, variations in cover soil depths and times of additional cover soil applications were not considered. Third, the potential export of radionuclides from the RWMC to the environment outside the facility via pathways such as subsurface migration in the unsaturated zone, surface water runoff, and small mammals was not examined. Although none of these pathways was considered to be important in terms of potential dose

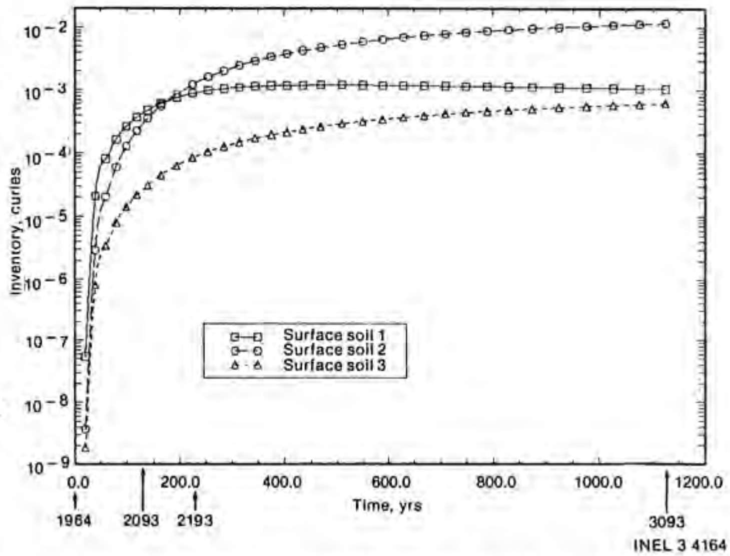

Fig. 3. Projected inventories of Cs-137 in surface soil compartments.

received by the public, they were perceived to be important indicators of the ability to confine waste radionuclides at the RWMC and to be directly relevant to environmental monitoring activities. Finally, the effects of past occurrences of localized flooding on release of radionuclides from open pits were not accounted for in the model. Monitoring results indicate that the largest potential radionuclide inventory currently available for potential offsite transport to the public is contained in the surface soil contaminated by past flooding of open pits in 1962 and in 1969. These deficiencies were considered to be important omissions in the evaluation of the effectiveness of the monitoring program.

The reformulation of the conceptual model to account for each deficiency discussed above resulted initially in a cumbersome and unwieldy pathways diagram. The quantitative interpretation of this model likewise appeared to be an overwhelming task. The problem was resolved by developing two separate models to describe two hypothetical burial grounds, separated by time, space, and different operational activities at the RWMC. One submodel, called the Early Disposal Site (EDS) model, addressed that part of the RWMC in which a mixture of TRU and non-TRU wastes was buried between 1952 and 1964. Burial of TRU waste continued in this part of the RWMC until 1970. Flooding of pits containing TRU waste occurred in 1962 and in 1969 and contaminated surface soil in the near vicinity. The contaminants (Pu-239 and Am-241) were assumed to be localized within the area defined for the EDS model (including offsite soil) and were input into the model as initial inventories in the upper surface soil compartments. Additional soil cover was added to this section of the RWMC in the latter part of the 1970s. Transport of radionuclides in the unsaturated zone beneath the RWMC was modeled. The model also simulated TRU waste retrieval activities from 1976 through 1978. The final EDS pathways diagram is shown in Fig. 4.

The second submodel, named the Current Disposal Site (CDS) model, simulated that portion of the RWMC receiving mostly nontransuranic waste since 1964. Additional soil cover was added to this section of the RWMC in 1985. Hydrologic transport of radionuclides in the unsaturated zone was simulated. TRU nuclides were omitted in the CDS model input because the inventory in this portion of the RWMC represents a minor fraction of the RWMC TRU waste inventory. The pathways diagram for the CDS model is similar to, although somewhat less complex than, that for the EDS model (Fig. 4). It was assumed that lateral migration of radionuclides between the EDS and CDS is minimal; therefore, the models were not linked.

Simulation runs were performed for Co-60, Sr-90, Cs-137, Pu-239, and Am-241 for the duration of the RWMC's operational period, assumed to extend to the year 2093. Sensitivity analyses, in which the relative importance of biotic and abiotic transport processes in radionuclide migration was evaluated, were conducted for the EDS and CDS models. The methodology used and results are described in Ref. 1. Briefly, the processes examined were waste release, hydrologic transport in the unsaturated zone, surface water runoff, resuspension, plant uptake, plant death, surface litter decay, small mammal ingestion, small mammal death and elimination, and small mammal burrowing. Interactive effects between transport processes were examined, as were time-dependent changes in process sensitivities. Transport processes were ranked in

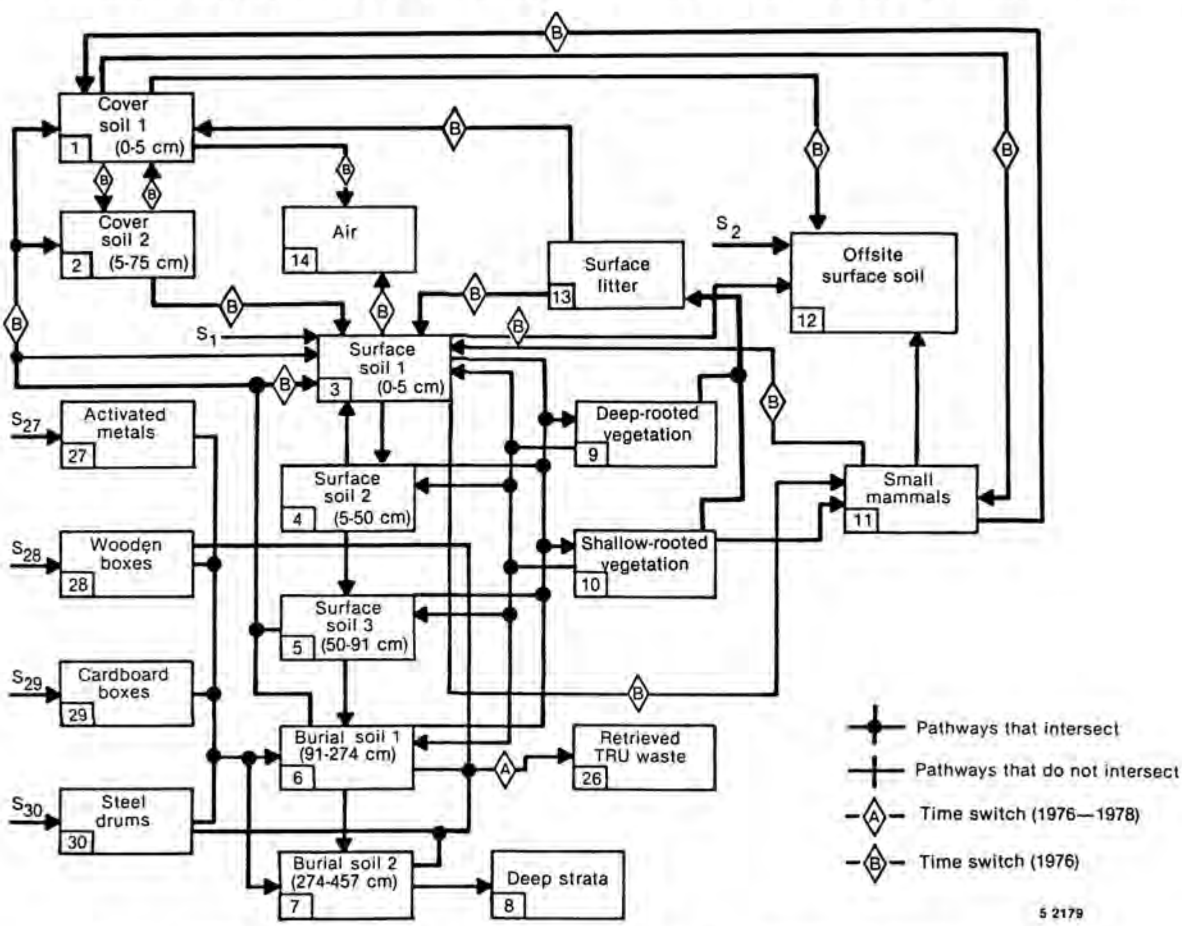

Fig. 4. Conceptual diagram of the EDS model of the RWMC during the operational period.

terms of relative sensitivity. Rankings were found to differ between radionuclides and over time. It was apparent that while the monitoring program addressed all pertinent environmental media, the level of comprehensiveness did not reflect the relative differences in importance of various transport processes. Based on the results, several changes were proposed in the design of the Environmental Surveillance Program (Step 7 of Fig. 1). The more notable recommendations included the expansion of routing sampling activities to include continuous surface water runoff monitoring, the initiation of special studies to better define resuspension of contaminated particles at the RWMC, and the development or acquisition of more complex models to simulate subsurface and airborne transport of radionuclides from the RWMC. These recommendations have been or are currently being implemented.

Present and Future Development and Applications

In 1986, preliminary calculations were done to assess the near-term and long-term performance of the RWMC as currently operated, in terms of compliance with regulatory guidelines. As a result, additional program goals were identified (Objectives 4, 5, and 6). The current modeling objective is to evaluate the effects of different proposed engineering and operational designs using corresponding model permutations. In support of Objective 4, the model will be changed to include planned modifications in operations. Variations of the model will also be developed to screen proposed operational alternatives for selection of the optimum approach in reducing the impact of operations on the environment. Completion of Objective 5 will likewise require the development of alternative models reflecting different closure designs for screening and selection. Finally, assessment of future performance of the RWMC (Objective 6) will involve refinement of the model to include the optimum operational activities and closure design, as determined in the first two tasks. In addition, an intruder scenario will be constructed to assess postclosure impacts on the maximally exposed member of the public. Completion of the objectives will also require coupling the SCoPE model outputs with more complex transport and dosimetric models for dose assessment purposes.

COMPLEX MODELS

The need for a more complex transport model to simulate airborne transport of resuspended contaminated soil was identified as a result of the sensitivity analysis of the SCoPE model. In addition, recently proposed changes in DOE Order 5480.1 incorporate specific guidelines for airborne emissions. By memorandum, the Department of Energy has directed DOE facilities to evaluate the airborne transport pathway, for radiological assessment, using AIRDOS-EPA (Fig. 6) or other EPA-approved model. AIRDOS-EPA was thus installed to satisfy program recommendations and DOE directives. Current soil monitoring data are used to estimate the airborne particulate source term for input into AIRDOS-EPA in the assessment of current performance of the RWMC (Objective 6). Projections of future surface soil contamination, using the SCoPE transport model, will be input into AIRDOS-EPA for assessment of the long-term performance of the RWMC.

To assess the external irradiation pathway at and near the RWMC, an external exposure code, QAD-FN (7), has been linked to SCoPE. The code was selected because it is extremely versatile in assessing a variety of geometries and detector locations. It was thus readily adaptable to simulating pit and burial ground configurations at the RWMC. The code will be used to evaluate proposed engineering designs and practices for reducing external irradiation (Objectives 4 and 5).

Although there is no evidence that subsurface migration of radionuclides has occurred below the buried waste, there is some question regarding the long-term migration potential of long-lived radionuclides. Moreover, the sensitivity analyses performed on the SCoPE model indicated that it could be a relatively important migration pathway, with respect to confinement, not dose, concerns. In a continuing effort to define the subsurface migration pathway, a subsurface investigation program was initiated in 1985 and will continue through 1992. The two major objectives of the study are to: (1) measure what, if any, migration of radionuclides has occurred to date, and (2) field-calibrate a model to predict long-term migration of radionuclides beneath the RWMC. TRACR-30 (8) is currently being investigated for adaptation by EG&G Idaho to accomplish the second objective.

DISCUSSION

Figure 1 summarizes the systems analyses approach used by the Environmental Surveillance Program. As illustrated in this paper, the process is a continually evolving one. As technical objectives change, the conceptual model is modified to accommodate those changes. An important aspect of the approach is the continual feedback between the conceptual model and the other aspects of the approach (i.e., the outer components in Fig. 1). During the development or revision of the model, these components may require repeated revisions to produce a technically sound unit. For example, updated or improved parameter values will be incorporated into the quantitative model. Field observations which indicate the need to modify system equations will likewise be incorporated. New or improved versions of computer codes that are more appropriate for solution of specific problems may be adapted. Also, model results may be used to indicate new directions in model development.

The systems analysis approach has proved to be a successful means of implementing several Environmental Surveillance Program goals. In general, the overall benefits can be summarized as follows:

1) The models developed have successfully met the needs for radiological performance assessment tasks.
2) The monitoring and modeling programs can be designed in concert, so that modeling and monitoring results can be correlated and used for the benefit of both programs.
3) The approach provides a means for cooperative interaction between modeling efforts, the monitoring program, and waste management operations.

REFERENCES

1. R. D. SHUMAN, M. J. CASE, and S. K. ROPE, Documentation of a Simple Environmental Pathways Model of the Radioactive Waste Management Complex at the Idaho National Engineering Laboratory, EGG-WM-6916, EG&G Idaho, Inc., 1985.

2. R. W. ROOT, JR., Documentation of User's Guide for 'DOSTOMAN' - A Pathways Computer Model of Radionuclide Movement, DPST-81-549, Savannah River Laboratory, 1981.

3. EG&G IDAHO, INC., Environmental and Other Evaluations of Low-Level Waste at the Radioactive Waste Management Complex, EGG-WM-6523, 1984.

4. S. K. ROPE, M. J. CASE, and P. G. VOLLEQUE', "A Compartmental Pathways Approach to Long-Term

Migration of Buried Contaminants in Soil," Proc. Eighteenth Midyear Topical Symposium of the Health Physics Society, Colorado Springs, Colorado, January 6-10, 1985, Health Physics Society, p. 543, 1985.

5. IDAHO OPERATIONS OFFICE, U.S. DEPARTMENT OF ENERGY, Environmental and Other Evaluations of Alternatives for Management of Defense Transuranic Waste at the Idaho National Engineering Laboratory, IDO-10103, U.S. Department of Energy, 1982.

6. R. E. MOORE, C. F. BAYES, III, L. M. MCDOWELL-BOYER, A. P. WATSON, F. O. HOFFMAN, J. C. PLEASANT, and C. W. MILLER, AIRDOS-EPA: A Computerized Methodology for Estimating Environmental Concentrations and Dose to Man from Airborne Releases of Radionuclides, ORNL-5532, Oak Ridge National Laboratory, 1979.

7. C. W. NIELSEN and E. E. HOCHHALTER, QAD-FN, A General Purpose Shielding Design Code with Simplified Input, ENI-157, Exxon Nuclear Company, Inc., 1981.

8. B. J. TRAVIS, TRACR3D: A Model of Flow and Transport in Porous/Fractured Media, LA-9667-MS, Los Alamos National Laboratory, 1984.