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LOW LEVEL WASTE MANAGEMENT:
A COMPILATION OF
MODELS & MONITORING
TECHNIQUES VOLUME 1-3

Report Prepared by
SCIENCE APPLICATIONS, INC.
Oak Ridge, Tennessee 37830

for

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Oak Ridge, Tennessee 37830

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LOW LEVEL WASTE MANAGEMENT:
A COMPILATION OF
MODELS AND MONITORING TECHNIQUES

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ABSTRACT

In support of the National Low-Level Waste (LLW) Management Research and Development Program being carried out at Oak Ridge National Laboratory, Science Applications, Inc. conducted a survey of models and monitoring techniques associated with the transport of radionuclides and other chemical species from LLW burial sites. As a result of this survey, approximately 350 models were identified. For each model the purpose and a brief description are presented. To the extent possible, a point of contact and reference material are identified. The models are organized into six technical categories: atmospheric transport, dosimetry, food chain, groundwater transport, soil transport, and surface water transport. About 4% of the models identified covered other aspects of LLW management and are placed in a miscellaneous category. A preliminary assessment of all these models was performed to determine their ability to analyze the transport of other chemical species. The models that appeared to be applicable are identified. A brief survey of the state-of-the-art techniques employed to monitor LLW burial sites is also presented, along with a very brief discussion of up-to-date burial techniques.

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1.0 OVERVIEW

1.1 Introduction

The purpose of this document is to present the results of a survey of models, computer codes, and monitoring techniques that may be used in the National Low Level Waste Management Program. This survey covers the following general topics:

- o Radionuclide release from storage.
- o Radionuclide transport mechanisms.
- o Radionuclide uptake.
- o Dose-to-man resulting from exposure to radionuclides.
- o Monitoring techniques and instrumentation potentially useful for LLW management.
- o Handling and storage procedures and techniques.
- o The release, transport and uptake of other hazardous materials that might be associated with a LLW isolation site.

It should be clearly understood that the results presented in this document are neither complete nor comprehensive. Important data, such as key assumptions or algorithms, could not be obtained for some of the models and codes presented. The same is true for the survey of monitoring techniques and instrumentation. Moreover, not all models, codes, monitoring techniques, or instrumentation could be identified. This lack of completeness and comprehensiveness is due to the very limited schedule (eight weeks) and budget under which the project was performed, as well as to revisions in procedure and scope that were required or developed during the performance of the project.

Nevertheless, The authors feel that the data gathered and presented represent a significant sample of the information available about modeling, code development, and monitoring techniques relevant to LLW management.

From these data, preliminary guidance can be obtained and decisions can be made concerning the direction and priorities of the National Low Level Waste Management Program.

1.2 Organization of the Document

This document is divided into four main sections; this overview is the first section; the second section deals with models applicable to LLW management, and the third one deals with LLW monitoring techniques and instrumentation. The fourth and least extensive section of this document deals with non-radioactive hazardous materials and their behavior in the environment. Although relating to the same general subject, LLW management, sections 2 and 3 of this document were prepared independently and can be treated as standing alone.

The second section contains the models and codes identified during this project. Each page in that section, with the exception of the last few pages, contains information on only one model or code. The information is given in the following format:

A category locator is placed in the upper right-hand corner of the page. The text begins with the acronym for the model or code (when available), and the title of the model or code. Then, there is a section labeled "Purpose," which briefly states the purpose of the model or code. This is followed by a "Description" section which summarizes the information that could be assimilated about the model or code within the time and budgetary constraints of the project. In many cases these descriptions were quoted verbatim from the sources referenced at the bottom of the page. Separating the "Description" section from the remainder of the page is a dividing line. Beneath this line is a name, and, when known, an address, of a person familiar with the model or code described. It may be the name of the person(s) who developed the model or code, or it may be the name of a contact person through which the model

or code may be obtained; or it may be the name of the researcher who has used the model as indicated by his citation of it in articles or books. The intention of this section is to provide the reader with some indication of how or from whom the model or code may be obtained. Finally, there is a "Source" section which indicates the reference number(s) and page number(s) for the reference(s) from which the data on the model were obtained. References are listed by number at the end of Section 2. Following the listing of numbered references is a bibliography of all the literature reviewed.

It should be noted that this format was chosen because it is simple yet flexible enough to permit updating of the survey from a large number of sources. The one code/model per page convention was selected for the same reason. In addition, this convention promotes succinct presentation without unduly limiting information.

Section 2 divides the models and codes into seven categories: 1) atmospheric transport;* 2) dosimetry;** 3) food chain;† 4) groundwater transport;* 5) soil transport;* 6) surface water transport;* and 7) other LLW models. The categories are indicated by tabs, and within each category, the models and codes are arranged alphabetically by acronym (when possible) or by title.

*Including chemical reactions as well as physical movement of the nuclides.

**"Dosimetry" is meant to include all models that deal with actual or potential doses to man, regardless of the pathway of the dose source.

†"Food Chain" deals with the biotic uptake of radionuclides.

It was found that only about four percent of the models or codes identified did not obviously fit into the first six categories and had to be placed in "other LLW models" category. As will be noted again later, this fact is taken to indicate that the categorization scheme developed is a satisfactory framework for the initial assessment of LLW management codes and models.

It should be noted that many of the models and codes identified fit into more than one of the first six categories mentioned above. For the convenience of the reader with specialized interests, the one-page data sheet on such a code or model was duplicated and located in the appropriate place in each of the relevant categories. The full listing of categories was maintained in the upper right-hand corner in order to provide an easy cross-reference, as well as to suggest interfaces with other codes or models.

Section 3 of this document deals primarily with monitoring techniques and instrumentation. In addition, prevalent and experimental procedures and techniques of LLW handling and storage are addressed. Because of the fundamental difference in subject matter, and because Section 3 was developed independently from Section 2, Section 3 is organized differently than Section 2. The organization of Section 3 is much like a literature review, as opposed to the very discrete, modular organization of Section 2. Monitoring techniques and instrumentation are treated in a more generic fashion, with only a few specific examples.

Section 4 deals with non-radioactive hazardous materials and their behavior in the environment. A great number of the models or codes identified as relevant to the behavior of radionuclides in the environment are also relevant to the behavior of non-radioactive nuclides. This is particularly true of many of the transport models and codes of all the various types. These relevant models and codes are identified in this section, and a reference to the page number on which each model or code appears in Section 2 is provided.

It should be recalled that the major effort in this project was devoted to identifying models and codes relating to the behavior of LLW radionuclides in storage and in the environment, so the data on monitoring techniques, equipment, and non-radioactive hazardous materials can reasonably be expected to be less complete and less comprehensive.

1.3 Investigative Procedures

The procedures used by SAI personnel to identify and gather data for models, codes or monitoring techniques for this project were varied. Initially, a phone call and follow-up mail survey was attempted. Roughly one hundred individuals were contacted by phone,* informed of the purpose and scope of the survey,* and asked if they would fill out a form (or forms) detailing their knowledge of codes, models or monitoring techniques. Those responding affirmatively were sent forms and a stamped return envelope. Even with the initial phone calls the phone-letter survey response rates fell below the response rate expected of straight mail surveys; i.e., surveys that were not preceeded by phone calls.

When it became apparent that the phone-call, mail-out survey technique was not succeeding as expected, two other options were adopted. The first and most important option was an exhaustive literature search of all material that could be gathered and assimilated within the time and

*It should be noted that some of these individuals were contacted because they were known to be experts in matters with which the Battelle office of Nuclear Waste Isolation (ONWI) was concerned. Thus, not all phone contacts were relevant to the National Low Level Waste Management Program.

funding constraints of the project. The second option was personal visits with selected experts in various facets of LLW management. The two options together were, of course, synergistic. SAI personnel would show the contracted experts what had been gathered; the experts would respond with codes, models or monitoring techniques that had been missed; and the response of the experts would lead SAI personnel to further codes, models or monitoring techniques. Altogether, such a synergistic interaction appears to be the most effective and productive approach to such broadly-scoped problems as gathering preliminary information for the LLW management program.

1.4 General Results

In Section 2, a total of over 350 distinct codes or models are identified. It should be noted that, upon the basis of the data available, codes were often not distinguishable from mathematical or physical models. In many of the individual descriptions of a code/model, the distinction is made clear, but in some pages of data on codes or models, the information that could be gathered was so scarce as to make the code-model distinction meaningless. These data pages were included only to notify the reader that such codes or models (or both) exist and may be located.

The frequency distribution of codes and/or models identified in Section 2 was as follows:

Atmospheric Transport	~28%	(142)
Dosimetry	~23%	(115)
Food Chain	~6%	(28)
Groundwater Transport	~20%	(102)
Soil Transport	~6%	(29)
Surface Water Transport	~13%	(65)
Other LLW Models	~4%	(22)
	100%	503*

*This includes models which were placed into more than one category.

Certain general statements can be made concerning the compilation of LLW models presented in Section 2. These statements follow:

- o It is noticeably easier to locate models dealing with groundwater transport, dosimetry, and atmospheric transport than it is to locate models dealing with food chain analyses or soil transport. The paucity of models on soil transport and food chain transport can most likely be taken to indicate areas where further research is needed.
- o Many atmospheric transport models use the Gaussian plume model and some variant of the Pasquill (or Pasquill-Gifford) model for dispersion. These models still seem to be accepted and in fact dominate the analysis of atmospheric transport although finite elements or finite diffusion models seem to be gathering popularity.
- o Much like the models dealing with atmospheric transport, many of the models in other categories of this report are also derivatives or variations of a small number of basic models. Determining the degree to which there are basic models in other categories is an obvious research effort which is suggested in the "Recommendations and Suggested Directions for Future Work" section, which follows this one.
- o This compilation is not considered to be complete nor comprehensive, but the format and organization of this document was designed to allow for continual updating and additions by adopting the loose-leaf form and single model per page conventions.

- o To perform a proper assessment of the adequacy and validity of these LLW models one must first develop the necessary evaluation methodology. This methodology must consist of several basic tasks: 1) model identification, 2) model and algorithm examination, 3) data evaluation, 4) model and algorithm verification, 5) sensitivity analysis, 6) validation studies, and 7) code comparison studies. A similar approach has been discussed in considerable detail by Schaeffer in Reference 6. Section 2 of this report accomplishes the first task. If a proper assessment is desired the remaining tasks should be accomplished.
- o A general monitoring problem exists in experimental design, the uncertainty being where to take measurements more so than how or what to monitor. Although this is a site-specific problem, general guidelines could be established to assist in these decisions.
- o Further advances are possible in shallow land burial of low-level waste handling and storage procedures, techniques, and equipment.

1.5 Recommendations for Future Work

The experience with this project and the contents of the resulting document suggest a number of areas in which time and effort might profitably be spent.

As indicated throughout this overview, the present effort is probably not a complete and comprehensive compilation. Although it is felt that a substantial sample of models and monitoring techniques is represented, the completeness of the existing document should be improved through further investigation of potential resources. In several cases, model descriptions and contacts need to be identified and incorporated into

the document. A more comprehensive listing of reference documentation on most of the models is needed. Also, it is felt that particular emphasis should be placed on determining if additional models exist in the areas of groundwater transport, soil transport, and food chain transport.

It should be recognized that once substantial completeness of the compilation has been assured, a small but periodic effort should be expended to maintain the document. This would consist of identifying any new modeling efforts, updating references to available documentation, describing improvements to any existing models already listed, and describing new developments in monitoring technology.

An analysis of the information contained in this data book should be performed to determine if it can provide guidelines for focusing the modeling and analytical efforts within the National Low-Level Waste Management Program. In addition to identifying general areas of strengths and weaknesses, specific model development requirements and data gathering requirements may be identified. Furthermore, ancillary program information could be developed, such as, a set of criteria by which proposals dealing with modeling or monitoring techniques and instrumentation could be evaluated. Similarly, general guidelines could be established to plan and assess monitoring programs. Through these types of efforts, the research program can be better focused and research projects structured more efficiently.

Section 2 of this compilation can form the basis for a complete assessment of the models most appropriate to the National Low-Level Waste Program. The first step in this assessment would be an examination of the models within the compilation to determine: (1) the degree to which there are basic models and algorithms within each category, (2) the historical and technical relationships among the models within a given category, and (3) operational or data relationships among the models from the various categories. These latter relationships would identify consistent sets of models that could

effectively represent a low-level waste management system in its totality.

In the assessment process, model or code verification should be performed during which it may be determined whether the model or code properly represents the analytical or empirical algorithm or process that it intends to model. Strengths, weaknesses, and limitations of the various models/codes can be clearly delineated. The availability, validity and accuracy of required input data can be assessed and the sensitivity of the models results to data uncertainties can be determined. The device dependency and source language of each code can be determined in order to ascertain whether a given code can be used at a particular installation. Finally, if experimental, test, or monitoring data are available, model validation can be accomplished by comparing computation results with such data.

During the accomplishment of some of the above recommended projects, or as a separate and distinct project, a library of the codes and their users' manuals could be compiled. This may allow more efficient dissemination of information on the codes and distribution of the codes themselves, thus reducing duplication of effort.

Obviously, there is a multitude of other projects that can be undertaken; the projects suggested above are intended to indicate in a tentative way some of the more apparent possibilities. The most important thing to note is that all of the projects suggested depend on the information contained in this initial compilation and additional information that may be gathered to supplement these data. Without adequate, comprehensive, and timely data, both managers and researchers may be hampered by needless delays, sub-optimal allocation of resources, and needless duplication of effort.

1.6 Summary

While preliminary and admittedly incomplete, this compilation is still of considerable value to managers and researchers in the National Low Level Waste Management Program. The document identifies many of the existing models and monitoring techniques that can be of use in low level waste management. Thus, needless duplication of effort can be avoided. In the identification of each model, the purpose of the model is presented, it is briefly described, and one or more contacts for further information is provided.

The document provides some indication of the strong and weak points in important areas of low-level waste management giving the managers an indication of where resources might be allocated in the most cost-effective way.

Though the data presented are often both technical and limited, the document can be used as a part of a quick introduction to the problems, both analytical and physical, of low level waste management. Even reading the brief descriptions of codes and models can provide the educated newcomer with an overview of many of the facets of low level waste management.

An examination of the models and codes presented may give impetus to both the theoritician and the empiricist. Seeing the various ways in which models have attempted to depict aspects of physical reality may provide the stimulous necessary for the theoritician to develop wholly new ways of modeling physical reality, or to produce hybrid models that combine the strengths of their component models while eliminating their weaknesses. For the experimentalist, the data on models, as well as on monitoring techniques and instrumentation, may suggest directions for research efforts and even specific experiments.

If kept updated, and revised as more data become available, the document can become a standard reference in the field of low level waste management.

Other uses of the document will doubtless become apparent as the document reaches different hands.

While the document has many potential uses, it is only a beginning. As suggested in the previous section, "Recommendations for Future Work," there are many challenging directions in which further efforts can be made, given time and sufficient funding. It is hoped that this document provides a springboard for at least some of those efforts.

2.0 MODELS

This section contains the one page description of the models identified during the course of this work. As described in the Overview, the models are organized into 7 categories: Atmospheric Transport, Dosimetry, Food-Chain, Groundwater Transport, Soil Transport, Surface Water Transport, and Other LLW Models. Within each category, the models are arranged alphabetically in the following way: first, those models for which acronyms were identified are listed; following this, models without acronyms are listed alphabetically.

ATMOSPHERIC TRANSPORT DOSIMETRY

Model - ACRA, A Computer Program for the Estimation of Radiation Doses Caused by a Hypothetical Reactor Accident.

Purpose - A computer code to calculate atmospheric dispersion of radionuclides released from nuclear accidents.

Description The radioactive material released to the atmosphere on account of a hypothetical reactor accident is transported away by the wind and is dispersed in a 3-dimensional normal distribution. The fission product activity is described throughout the space domain as a function of time. Presently the code calculates two types of exposure from the passing cloud of finite size: internal exposure from inhalation of the radionuclides in the air, and external dose from gamma radiation. The cloud depletion terms by washout and dry deposition have not been incorporated. However, this option can be easily implemented. Up to 100 receptor locations and 20 time intervals can be handled in one run. The program accepts information for up to 300 isotopes. Computer time is about 3 seconds per receptor and time inversion layers are present.

Mathematical analysis is based on information in ORNL-4086. Density distribution of the disposed cloud is assumed to be Gaussian. Only linear nuclear decay sequences are handled. This code has been updated by ACRA II in which the effects of plume depletion resulting from wet and dry deposition are considered.

Stallmann, F.W.
Oak Ridge National Laboratory
Oak Ridge, TN 37830

Source - Reference #6: p. 117

ATMOSPHERIC TRANSPORT DOSIMETRY

Model - ACRA II

Purpose - ACRA II was developed for estimation of external and inhalation doses from atmospheric releases of radioactive material during hypothetical nuclear reactor accidents.

Description - The radioactive material is assumed to be uniformly mixed within the reactor containment system and released to the atmosphere at a uniform rate. Filtration upon release may be included. Dispersion of the material leaving the stack is described as three-dimensional normal distribution with symmetric horizontal distribution ($s_x = s_y$). Reflections off the ground plane and off an inversion layer^x are described by the virtual cloud image technique. The effective release height is calculated by the method of Holland, "Meteorology and Atomic Energy" (1955).

The inhalation dose is a function of the air concentration at the exposure point while the external dose depends on the distribution of material throughout the plume. The external gamma dose rate is calculated as the volume integral of the contributions from all photons for each nuclide as a function of time. The total dose is then calculated as the time integral of the dose rate. The amount of each nuclide is calculated as a function of time after the accident and transit time to the exposure point according to a linear decay sequence.

The volume integral is calculated as a function of gamma energy and cloud dimensions only and is, therefore, independent of time after the accident. The dimensions of the cloud are specified as a function of distance from the release point to the exposure point.

Numerical instabilities in the radioactive decay calculation are avoided by using a technique similar to that developed by H. H. Van Tuyl (1964). Radionuclide decay is handled as a linear sequence without branching. Branching may be included by splitting the decay sequence into a number of independent linear chains through manipulation of input.

The program does not depend on any particular internal dosimetry model. Dose conversion factors are supplied as input to convert to rem from μCi uptake. Breathing rate is also supplied. All nuclide and dosimetric data are supplied via data cards.

Considerable attention has been given to the external gamma dose space integration. The mathematical treatment is thorough and numerical approximations are employed where appropriate. ACRA II is written in FORTRAN IV for an IBM computer.

F. W. Stallman, and F.B.K. Kam (1973)
Union Carbide Corporation
Oak Ridge National Laboratory
Oak Ridge, TN.

Source - Reference #12: pp. B-33, 34.

ATMOSPHERIC TRANSPORT

Model - ADPIC: A Three-Dimensional Computer Code for the Study of Pollutant Dispersal and Deposition Under Complex Conditions.

Purpose - This code models 3D Cartesian particle diffusion calculating time dependent dispersion of pollutants under varied conditions.

Description - Atmospheric Diffusion Particle-In-Cell (ADPIC) is a three-dimensional, Cartesian, particle-diffusion code, capable of calculating the time-dependent dispersion of inert or radioactive air pollutants under many conditions, including stratified shear flow, calms, topography, and wet and dry deposition, for individual or multiple instantaneous or continuous sources and space- and time-variable diffusion parameters. The code solves the three-dimensional diffusion-advection equation by the pseudo-velocity technique for a given mass-consistent advection field. The method is based on the particle-in-cell technique with the pollutant concentration represented by Lagrangian particles in an Eulerian grid mesh. ADPIC has been verified for a number of selected advection-diffusion problems for which analytic solutions are available, and has been found to give results to within plus or minus 5% of the analytic solutions. ADPIC can be used for both routine and accidental atmospheric releases. The program requires most of the core of a CDL 7600 to run. It may be scaled to handle different size problems, 20 m to 20 km horizontal cell size. The output gives cloud center or surface air concentrations and cumulative surface deposition. The ADPIC code should also be applicable to water dispersion studies.

R. Lange
Lawrence Livermore Laboratory
Livermore, CA

Source - Reference #6: p. 151.

ATMOSPHERIC TRANSPORT

Model - AEOLUS: Atmospheric Dispersion and Finite-Cloud Doses During Normal, Sea-Breeze, and Accident Conditions

Description - None available.

J. N. Hamawi, J. Laznow
Yankee Atomic Electric Company
Westboro, MA
Transactions of the American Nuclear Society, 26, 33, 1977

Source - Reference #18: p.97

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - AERIN, A Code for Acute Aerosol Inhalation Exposure Calculations.

Purpose - AERIN is a code designed to compute organ and tissue burdens and doses resulting from acute exposure to inhaled radioactive aerosols.

Description - AERIN is a FORTRAN IV program written to simplify the application of equations for computing the organ and tissue burdens and doses resulting from an acute inhalation exposure to a radioactive aerosol. The models which form the basis for the calculations are (1) the deposition and clearance models of the International Commission on Radiological Protection (ICRP) Task Group on Lung Dynamics, (2) the gastrointestinal (GI) tract model of Eve (1966) and (3) a single exponential model for the "critical" organs and tissues. The fundamental data for the respiratory and GI tract models are written into the program. The user can select suitable dosimetric parameters for the respiratory and GI tract tissues, choose the appropriate metabolic and dosimetric quantities to be used in calculations for the "critical" organs and tissues, and specify the number of computations to be made and the time interval between them. The output consists of a complete listing of the assumed parameters as well as the organ and tissue burdens and doses as functions of time post exposure.

Voilleque, P.G.
Health Services Laboratory
U.S. Atomic Energy Commission
Idaho Falls, ID

Source - Reference #6: p. 133.

ATMOSPHERIC TRANSPORT
DOSIMETRY
FOOD CHAIN

Model - AIRDOS - EPA

Purpose - The AIRDOS-EPA computer code is a methodology, designed for use on IBM-360 computers, that estimates radionuclide concentrations in air; rates of deposition on ground surfaces; ground surface concentrations; intake rates via inhalation of air and ingestion of meat, milk, and fresh vegetables; and radiation doses to man from airborne releases of radionuclides.

Description - A modified Gaussian plume equation is used to estimate both horizontal and vertical dispersion of as many as 36 radionuclides released from one to six stacks or area sources. Radionuclide concentrations in meat, milk and fresh produce consumed by man are estimated by coupling the output of the atmospheric transport models with the U.S. Nuclear Regulatory Commission, Regulatory Guide 1.109 terrestrial food chain models. Dose conversion factors are input to the code, and doses to man at each distance and direction specified are estimated for total body, red marrow, lungs, endosteal cells, stomach wall, lower large intestine wall, thyroid, liver, kidneys, testes, and ovaries through the following exposure modes: (1) immersion in air containing radionuclides, (2) exposure to ground surfaces contaminated by deposited radionuclides, (3) immersion in contaminated water, (4) inhalation of radionuclides in air, and (5) ingestion of food produced in the area.

The code may be run to estimate highest annual individual dose in the area or annual population dose. For either option, output tables summarize doses by nuclide, exposure mode, and organ. Also, for either a square or circular grid option, ground concentrations of radionuclides and intake rates by man are tabulated for each environmental location. Working level exposures are also calculated and tabulated for inhalation of ^{222}Rn short-lived progeny. Run time is less than 5 min on the IBM 360/91, and the core requirement is 650 K (kilocore).

Robert E. Moore
Building 7509
Oak Ridge National Laboratory
Oak Ridge, TN 37830

Source - Reference #4

Model - AIREM

Purpose - The AIREM code was developed for analysis of emissions and effluents from nuclear fuel cycle facilities. The program may be used to estimate air concentration, ground deposition (both wet and dry) and doses from external gamma radiation and from inhalation.

Description - The dispersion calculation, based on the sector-averaged Gaussian diffusion model, produces results as a function of direction and distance for each nuclide. Contributions from the first daughter are included. The release is assumed to be at a constant rate over a specified release period. In-plant holdup time and decontamination factors may be supplied as input. Inhalation doses are calculated using conversion factors for each organ (four per run) and nuclide (twenty per run). For the external gamma dose, a table of dose integrals is to be supplied relating dose to release height, cloud size and gamma energy. A modified version of EGAD (Cooper, 1972) is given in the AIREM report (Martin, 1974) for calculation of the dose integrals.

The code requires dose conversion factors as input for each radionuclide, organ and population group. A table of dose conversion factors is also required for the finite cloud gamma dose calculation. Meteorological data are supplied as the frequency (percent of time) that the wind blows in a sector under a given stability class. An average wind speed must be supplied for each direction and stability combination. This procedure carries less information than supplying frequency data as a function of direction, stability and wind speed class. Air concentrations and wet and dry ground deposition are calculated and printed for each nuclide as a function of distance and direction, with effects of decay in transit included. The contribution to external body exposure from nuclides in adjacent sectors is included in the dose integrals calculated by the code EGAD. This is accomplished by integrating in the lateral direction over all distances contributing significantly to dose without respect to sector boundaries. Inherent in this procedure is the assumption that the wind blows uniformly in all sectors adjacent to the given sector. AIREM is written in FORTRAN IV for an IBM 370 system.

J.A. Martin, Jr., C.B. Nelson, and P.A. Cuny (1974)
U.S. Environmental Protection Agency
Washington, D.C.

Source - Reference #12: p. B37.

ATMOSPHERIC TRANSPORT
DOSIMETRY
FOOD CHAIN

Model - AIRWAY

Purpose - This is a model to estimate the local radiation doses to man from the atmospheric release of radionuclides.

Description - A model was developed to estimate the radiation dose commitments received by people in the vicinity of a facility that releases radionuclides into the atmosphere. This model considers dose commitments resulting from immersion in the plume, ingestion of contaminated food, inhalation of gaseous and suspended radioactivity, and exposure to ground deposits. The dose commitments from each of these pathways is explicitly considered for each radionuclide released into the atmosphere and for each daughter of each released nuclide. Using the release rate of only the parent radionuclide, the air and ground concentrations of each daughter are calculated for each position of interest. This is considered to be a significant improvement over other models in which the concentrations of daughter radionuclides must be approximated by separate releases.

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Bettis Atomic Power Laboratory
P. O. Box 79
West Mifflin, PA 15122
412-462-5000 EXT. 384; FTS 721-0384
National Technical Information Service WAPD-TM-1273, 34 pp.

Source - Reference #18: p.273

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - AISITE II: A Digital Computer Program for Investigation of Reactor Siting.

Purpose - This code is used to determine allowable sitings of nuclear reactors based on reactor parameters. It also can provide dose/distance data for existing reactors.

Description - AISITE II automatically varies any one of 46 parameters such as reactor power, building leak rate, iodine cleanup rate, halogen filter efficiency, etc. The siting criteria of 10CFR100 are used in AISITE II with computation of the exclusion area, low population boundary zone, and low-population-center distances as functions of any parameter. In addition, dose-versus-distance curves are obtained for inhalation, direct building, and direct cloud doses. The printed edit consists of the dose-versus-distance data, fractional contribution by isotope group to the inhalation dose, and critical distances for both a 2-hr and a 30-day release. Graphical displays can be obtained for critical distances as a function of the variable parameter and dose versus distance for any organ or the critical organ, for each value of the parameter. Three isotope release models with up to four levels of containment are provided.

Blaine, R.A.
Atomics International
Canoga Park, CA

Source - Reference #6: p. 129.

GENERAL TRANSPORT
RISK ASSESSMENT

Model - AMRAW: Risk Assessment Method for Radioactive Waste Management.

Purpose - This model provides calculational methods for risk assessment in radioactive waste management systems.

Description - A Radioactive Waste Management Systems Model was developed and implemented by the University of New Mexico under contract with the U.S. Environmental Protection Agency. The systems model and associated computer code called AMRAW (Assessment Method for Radioactive Waste), has two parts. The first part, AMRAW-A, consists of the Source Term (Radioactive inventory versus time), the Release Model, and the Environmental Model. The Release Model considers various geologic and man-caused events which are potential mechanisms for release of radioactive material beyond the immediate environs of a repository or other location; the risk analysis mode uses events distributed probabilistically over time, and the consequence analysis mode uses discrete events occurring at specified times. The Environmental Model includes: 1) the transport to and accumulations at various receptors in the biosphere, 2) pathways from these environmental concentrations, and 3) resulting radiation dose to man.

The second part of the system model, AMRAW-B, is the Economic Model which calculates health effects corresponding to the various organ dose rates from AMRAW-A, collects these health effects in terms of economic costs and attributes these costs to radionuclides, decay groups, and elements initially in the waste inventory. Implementation, with calculated results, of AMRAW for Terminal Storage in a Bedded Salt Reference Repository has been accomplished. Preliminary demonstrations for the repository operations phase of waste management and terminal storage in a shale formation have also been accomplished; possible applications to other radioactive and nonradioactive hazardous materials have been discussed. AMRAW uniquely links all analytic steps together in a continuous calculation sequence.

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University of New Mexico

Source - Reference #10: June 1978, p.v

ATMOSPHERIC TRANSPORT

Model - APORT/APOPLT

Purpose - APORT is a program for the area-based apportionment of county variables to cells of a polar grid.

Description - The APORT computer code was developed to apportion variables tabulated for polygon-structured civil districts onto cells of a polar grid. The apportionment is based on fractional overlap between the polygon and the grid cells. Centering the origin of the polar system at a pollutant source site yields results that are very useful for assessing and interpreting the effects of airborne pollutant dissemination. The APOPLT graphics code, which uses the same data set as APORT, provides a convenient visual display of the polygon structure and the extent of the polar grid. The APORT/APOPLT methodology was verified by Application to County Summaries of cattle population for counties surrounding the Oyster Creek, New Jersey, nuclear power plant. These numerical results, which were obtained using approximately 2-min computer time on an IBM system 360/91 computer, compare favorably to results of manual computations in both speed and accuracy.

D. E. Fields, and C. A. Little
Oak Ridge National Laboratory
Oak Ridge, TN 37830
ORNL/TM-6418, p. 62, Nov. 1978.

Source - Reference #25: p. 91.

ATMOSPHERIC TRANSPORT

Model - ARADS: Alternate Radiological Atmospheric Dispersion Study.

(For Description See RADS; ARADS)

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - ARCON: Areas Affected by Ground Deposition of Cs-137.

Purpose - This code is used in determining ground deposition of Cs-137 from an atmospheric release.

Description - The code deals with the combined probability analysis and parametric study of Cs-137 deposition after a postulated nuclear reactor accident. Study was performed for a 3000 MW(th) reactor at a site typical of the Oslo Fjord area. No efforts have been made to determine definite accidental sequences or amounts of release. It is simply postulated that an accident has taken place that will lead to release of a large amount of radioactivity to the atmosphere during a relatively short time period: on the order of one hour. The size of the area affected by a certain release of radioactive cesium depends upon the meteorological conditions during the release time period. Local weather data have been used to determine the probability of a certain magnitude of the area. The results are given in the form of conditional, cumulative probabilities. Conditional because they give the probability of a certain magnitude of the consequence if the release has taken place and the wind is blowing in the direction for which the weather data are valid. Cumulative because, e.g., the 5% probability means that the weather conditions may give these or worse consequences with a 5% probability or, expressed differently, they will give less severe consequences with a 95% probability. Since the calculations do not apply to a specific accident sequence, several pertinent release characteristics cannot be assigned a definite value. The most important are: amount of Cs-137 due to decay of radioactive materials; and deposition velocity. The last item is only partially a release characteristic. Besides depending upon particle size and chemical conditions, the deposition velocity depends upon characteristics of the land area over which deposition takes place. A parametric study is performed by varying each of these characteristics over a certain range while keeping the others fixed at what it is reasonable to assume are typical values under extreme accident conditions. A computer code ARCON has been developed for this analysis, adaptable to a large range of calculations connected to atmospheric releases during accident conditions as well as normal operation, e.g., calculation of reference levels for milk consumption, health effects on specified populations, and the area within any kind of concentration limit or dose limit (except external gamma dose). The program may be modified for longer release times, but not easily. While Cs-137 is the only isotope treated, other isotopes may be treated in a similar manner.

U. Tveten, Institute for Atomenergi, Kjeller, Norway, 1975. IAEA-SM-188/35; Siting of Nuclear Facilities, Proceedings of a Symposium held in Vienna, Austria December 9-13, 1974, pp. 497-515.

Source - Reference #26: Item 1225.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - AREAC: Area Source Radiological Emission Analysis Code.

Purpose - A computer code designed to calculate the potential radiological impact of atmospheric releases of radionuclides from area sources.

Description - The code is written in Fortran IV, requires 48K storage, and runs about 12 seconds on an IBM 370 system. The code can calculate radionuclide concentrations and individual inhalation doses at up to six specific receptor locations and at up to 192 general locations around an area source. Population doses can also be calculated. The code accounts for area source shape, cloud diffusion, ground and inversion-lid reflections, and radionuclide decay by time of flight. It is dose model-independent and requires a dose conversion factor as part of the input data to calculate doses proportional to radionuclide concentrations.

D. Michlewicz
Environmental Protection Agency
Office of Radiation Programs
Washington, D.C.
ORP/EAD-76/6, p. 63, Oct. 1976.

Source - Reference 25: p.90.

ATMOSPHERIC TRANSPORT

Model - AREAS: A Computer Code for Estimating Air Pollutant Concentrations from Dispersed Sources.

Purpose - This code is used for estimating air pollutant concentrations from dispersed sources.

Description - The AREAS area-source computer code estimates annual-average concentrations of an air pollutant at ground level in each of 400 grid squares in a 20 by 20 area reference grid. Areas can be used for multiple, dispersed sources located in each of the 400 grid squares by treating them as area sources. Required input includes 20 by 20 arrays of annual-average point-source X/Q values generated by use of a point-source model or computer code for specific grid sizes relative to the size of the area reference grid. AREAS can be applied to any size area for which a uniform meteorology can be assumed. It has been applied to dispersed emissions of fossil fuel combustion products and automobile emissions in Roane County, Tennessee, and to the atmospheric dispersion of radionuclides emitted from the tailings piles of uranium mills.

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Source - Reference #18: p.71

ATMOSPHERIC TRANSPORT DOSIMETRY

Model - ATM: A Comprehensive Atmospheric Transport and Diffusion Model.

Purpose - This code applies a detailed atmospheric transport model suitable for long-lived radionuclides dispersed in air.

Description - A comprehensive version of the Atmospheric Transport Model (ATM) has been developed that includes the effect of aerodynamic roughness on dispersion constants, clarifies the roles of the terminal velocity and deposition velocity, incorporates a tilting plume for heavy particulates, and includes an episodic calculation of exposure maxima. This model also limits the maximum value of the dispersion constants in order to retain the emitted material in the planetary boundary layer. The structure of the program has been modularized in order to clarify the flow of calculation and allow more flexibility. Values for atmospheric concentration as well as both wetfall and dryfall deposition are calculated. The model has been applied to three power plants. The dispersion calculation is based on the Gaussian plume model, corrected by the above considerations. The model allows the use of point sources, line sources, area sources, and windblown resuspension sources.

It should be noted that this program does not include corrections for radioactive decay or daughter product formation so care must be exercised if it is to be used for atmospheric transport of radionuclides. This, however, should not be significant for long-cooled waste material.

Culkowski, W.M.
Oak Ridge National Laboratory
Oak Ridge, TN 37830

Source - Reference: #6: p. 127.

ATMOSPHERIC TRANSPORT

Model - ATMAS: A Three-Dimensional Atmospheric Transport Model to Treat Multiple Area Sources.

Purpose - This code is used in estimating gaseous concentrations of pollutants from multiple sources.

Description - ATMAS, an atmospheric transport computer model, estimates the concentration of gaseous species emitted from multiple area sources. It can handle space- and time-varying wind fields, first-order chemical transformations, ground deposition, and inversion effects. The model presented here is based on the three-dimensional advection-diffusion equation to describe atmospheric transport. ATMAS solves this equation and calculates the concentration levels using the particle-in-cell method. The model calculates short-term (hourly) average concentrations over periods ranging from a month to a year; it can also calculate longer averages by varying the averaging time. Output from the code typically includes isopleth maps showing the calculated concentration levels and the probability with which given thresholds or standards are exceeded during the simulation period.

D. L. Ermak; R. A. Nyholm; R. Lange
California University
Livermore (USA)
Lawrence Livermore Lab.
November 27, 1978
UCRL--52603

Source - Reference #27: Item 11.

ATMOSPHERIC TRANSPORT

Model - ATR: Models of Radiation Transport in Air.

Purpose - Used to calculate radiation environment problems throughout the atmosphere.

Description - The ATR computer code is a user-oriented code for calculating quickly and simply radiation environment problems at all altitudes in the atmosphere. The ATR code is based on parametric models of a comprehensive data base of air base transport results which was generated using rigorous transport techniques for infinite homogeneous air. The effects of an air-ground interface and non-uniform air density are treated as perturbation corrections on homogeneous-air results. The data base has been generated for neutrons, secondary gamma-rays, high-energy photons and low energy photons as a function of space, energy and angle out to range of 550 gm/cm² of air. Parametric models have been developed for all of this data base except photon angular distribution and a version of ATR has been completed for neutron and secondary gamma-ray transport.

R. J. Harris, J. A. Lonergan, L. Huszar, Jr.
ATR
Science Applications, Inc.
La Jolla, CA
NTIS
AD--743 180,1971

Source - Reference #18: p.39

ATMOSPHERIC TRANSPORT
DOSIMETRY
FOOD CHAIN

Model - BELCH: TVA Gaseous Dispersion Code

Purpose - This code calculates doses to the public from routine gaseous releases at power reactors.

Description - The TVA gaseous dispersion code calculates individual and population doses to the public from routine gaseous radioactive release from TVA's power reactors; the methodology is that set forth in NRC Reg. Guides 1.109 and 1.111. The code uses site-specific meteorological data, agricultural data, and population information to estimate doses to individuals at site boundaries, nearest residences, and real milk cow locations. Populations doses to persons living within 50 miles of the site are also calculated. Dose pathways considered include beta and gamma air doses at the site boundary, skin and total body doses at nearest residences, and thyroid doses at milk cow locations. Thyroid doses include the following pathways: submersion, ground contamination, inhalation, and ingestion of beef, vegetables and milk. Estimated doses are considered conservative for average animal, routine radioactive releases.

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Source - Reference #18: p. 96

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - BURP: TVA Gaseous Effluent Licensing Code for Uranium Mining and milling.

Purpose - This code calculates individual doses due to environmental release of U-238 daughter radionuclides.

Description - BURP calculates atmospheric concentrations and individual doses due to the environmental release of U-238 decay chain radionuclides. Pathways to man include ingestion, inhalation and air submersion. Ingestion doses are calculated using methodology similar to NRC Regulatory Guide (NRC RG) 1.109 and the effect of the decay and build-up of subsequent decay chain products is fully accounted for. In addition, inhalation and air submersion doses are calculated using NRC RG 1.109 methodology. Organs for which doses are evaluated are total body, skin, liver, bone, lungs and bronchial epithelium, stomach, small intestines, ULI, and LLI. The code is capable of handling multiple sources of release.

Nicoll, Regis M.
Tennessee Valley Authority, Environmental
Planning, River Oaks Bldg.
Muscle Shoals, AL 35660

Source - Reference #18: p. 73.

ATMOSPHERIC TRANSPORT

Model - CDM: Climatological Dispersion Model

Purpose - This model is used for calculation of air pollutant concentrations from a given number of point sources.

Description - The model calculates concentrations of specified conservative pollutants at specified receptor locations from a given number of sources. The model uses Turner Dispersion Relationships and Briggs Plume Rise Formulas. The model can be used either for short term periods on the order of one hour, or for periods as long as one year. Also, it is a flat terrain model.

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Source - Reference #18: p. 51.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - CDR: Air Transport Calculations Using the LASL-NWEF Air Flux Tape and the NWEF Computer Program--CDR

Purpose - Calculates ranges of constant dose from a point source.

Description - The recent availability of coupled neutron-gamma, multi-group, cross-section sets has prompted the production of a neutron-gamma air flux tape similar to the neutron air flux tape reported previously. The air flux data consists of complete transport calculations in uniform, sea-level air for one source neutron in each of 30 energy groups and one source photon in each of 12 energy groups. The computer program CDR (constant dose range) uses the new air flux tape to produce ranges of constant dose from a point source in the atmosphere.

J. E. Campbell
253050 Naval Weapons Evaluation Facility
Albuquerque, NM
Report No. NWEF-1090

Source - Reference #18: p.13

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - COMO, Atmospheric Dispersion Model as used in the Reactor Safety Study, WASH-1400.

Purpose - This code is designed to aid in determining dose levels from reactor accidents.

Description - The Reactor Safety Study, WASH-1400, was published in final form in October, 1975, by the U.S. Nuclear Regulatory Commission. The objective of predicting consequences of a given radioactivity release was accomplished through construction and execution of a computerized model which accounted for the manner in which radioactivity is dispersed in the environment, the number of people and amount of property exposed, the effects of radiation exposure on people, and property contamination. The basic elements of the model, release characteristics, atmospheric dispersion, dosimetry, population, health effects, and property damage are documented. The code COMO (for consequence model) was used for dose calculations.

Church, H.W.
Sandia Laboratories
Albuquerque, NM

Source - Reference #18: p. 258.

Model - COMRADEX

Purpose - The COMRADEX code was developed to calculate radiation doses from postulated accidental release of radionuclides from nuclear reactors.

Description - The code considers up to four levels of containment with independent time varying leak rates. Filtration, particle coagulation and fallout, and special cleanup systems are also included in the containment model. Material reaching the atmosphere is dispersed according to the bivariate Gaussian model with dispersion parameters (s_y and s_z) defined by the Pasquill curves A-F (Pasquill, 1962; Hilsmeier^y and Gifford, 1962). Plume rise is considered by specifying an effective height of release.

Doses calculated by COMRADEX include direct dose from contained activity, external cloud gamma dose, and internal dose from inhalation of contaminated air. The external cloud gamma dose is calculated by a space integration over the active volume of the plume (finite cloud approach). The inhalation dose may be for as many as 14 organs of interest by specifying appropriate dose conversion factors.

The initial inventory is specified as disintegrations per second for each nuclide. Shielding between various containment shells is accounted for by an attenuation factor in calculating the direct dose from contained material. Air attenuation for this calculation is done for one photon energy. Volume sources are modeled by a virtual source technique. For the finite cloud integration, s_y and s_z are held constant about the exposure point. The space integration is performed by dividing the Y-Z plane into small rectangles and evaluating the dose kernel at the center of each rectangle. The finite cloud integration is performed for only one photon energy. COMRADEX is written in FORTRAN IV for an IBM 360.

G.E. Spangler, C.A. Willis and E.A. Rhoades (1968).
McDonnell Douglas Corporation
Santa Monica, CA

Source - Reference #12: p. B41.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - COMRADEX - IV The Containment and Meteorology of Environmental Radiation Exposure Code.

Purpose - This code is used in computing site dose from accidental radioactive releases.

Description - The COMRADEX-IV (containment and meteorology of environmental radiation exposure) code was developed for the calculation of radiological doses from hypothetical power reactor accidents. It permits the user to analyze as many as four levels of containment with time varying leakage and fallout rates in each level. Filtration in each containment region may be by isotopic class (noble gas, solids, or halogens). Shielding may be introduced between the various containment shells. The environmental doses calculated include the direct gamma dose from the containment building, the internal doses to as many as 12 body organs (such as the thyroid, bone, lung, etc.) due to inhaling the airborne radioactivity, and the external gamma and beta doses from the cloud. Leakage and fallout rates, and initial inventory must be given as input data. A direct numerical technique, designed especially for quasi-linear differential equations, is used to solve the leakage (as well as containment region fallout) and decay chains. Either the meteorology model of Pasquill, with Briggs' dispersion coefficients, or site-specific attenuation factors may be used. The cloud gamma dose is obtained by integrating over an anisotropic Gaussian cloud. The external beta dose calculation assumes a semi-infinite radioactive cloud. Plume tilt due to gravity and dry deposition may be calculated.

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Rockwell International
Atoms International Division
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Canoga Park, CA. 91305
203-341-1000 Ext. - 2722

Source - Reference #18: p. 108.

Model - CRAC

Purpose - This model is to calculate atmospheric dispersion and ground deposition of radionuclides released from a postulated nuclear power plant accident.

Description - A computer model (CRAC) was developed for the reactor safety study (WASH-1400) to estimate the consequences of postulated accidents at U.S. commercial nuclear power plants. One hundred reactors at 68 sites were included in the study. The 68 sites were divided into 6 classes according to their geographic location and meteorology. For each site class, a composite population distribution was constructed from the true population distributions at each of the sites comprising that class, and a reference site was chosen for which a full year of meteorological data (wind speed, atmospheric stability, occurrence of rain) was obtained, given data about a postulated accident (probability, amounts of the released radionuclides, etc.) and the reference reactor site (meteorology, composite population, land usage), CRAC was used to calculate the atmospheric dispersion and ground deposition of the released radionuclides (Gaussian Plume Submodel) and the health effects (dosimetric and dose response submodels) and costs (land interdiction and decontamination submodel) resulting from their release. The Gaussian Plume Model used in CRAC either did not treat or treated simplistically a number of meteorological phenomena. Simplified models were used to treat plume rise, inversion layers, and rainstorms, while wind shear, wind direction, and correlations between wind fields and population distributions were not treated at all. Some of the effects of all of these phenomena on predictions of accident consequences as calculated using CRAC have been or are being investigated.

J. L. Spring, et. al., "Investigations of the Adequacy of the Meteorological Transport Model Developed for the Reactor Safety Study," a paper presented at a conference on Probabilistic Analysis of Nuclear Reaction Safety, Los Angeles, CA, 8 May, 1978, SAND-77-1383C, p. 10.

Source - Reference #25: p. 196.

DOSIMETRY
ATMOSPHERIC TRANSPORT

Model - CUEX, AIRMOD, TERMOD

Purpose - These codes have been used to assess radiation exposure from environmental releases of radionuclides

Description - The CUEX (CUMulative EXposure Index) methodology has been developed to provide reasonable assessments of radiation exposures resulting from environmental releases of radioactivity. Incorporated in the CUEX methodology are an atmospheric dispersion model designated AIRMOD and a terrestrial transport model designated TERMOD. The atmospheric and terrestrial models were tested through use of radiological source terms and environmental data provided by a number of different organizations. AIRMOD was used to predict noble gas concentrations in the vicinity of the Haddam Neck pressurized water reactor and a boiling water reactor, tritium concentrations in the vicinity of the Argonne CP-5 Reactor, and I-131 gross alpha concentrations in the vicinity of Oak Ridge National Laboratory. The terrestrial model TERMOD was used to predict I-131 concentrations in milk samples collected in the vicinity of the Oak Ridge National Laboratory and in the vicinity of the Quad Cities Nuclear Power Station. The estimated concentrations and doses calculated through use of AIRMOD and TERMOD were frequently within a factor of two of measured monitoring data.

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Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

Source - Reference #20: ESD ORNL.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - CURIE-DOSE-THUNDERHEAD: A Digital Computer Program for External and Internal Radiation Dose Calculations

Purpose - This code calculates both external and internal radiation doses from air releases accounting for release-reactor parameters.

Description - The CURIE-DOSE-THUNDERHEAD program is a combination of three basic computer programs employed in succession. The first, CURIE, calculates the fission product buildup and decay as a function of reactor operating time, operating power, and decay time. The second, DOSE, uses the fission product inventory obtained from CURIE to calculate the dose to 14 internal body organs due to inhalation of fission products released to the atmosphere. The third, THUNDERHEAD, also uses fission product activity data from CURIE to calculate the external cloud gamma exposure from the released fission products. Cloud diffusion is calculated from Sutton's equation or the Convair modification. In calculating the internal dose it is assumed 62.5 percent of the inhaled isotopes are ultimately swallowed and pass through the entire G.I. tract.

Kenfield, G.P.; (1965)
Atomics International,
A Division of North American Aviation, Inc.

Source - Reference #6: p. 125.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - DACRIN - A Computer Program for Calculating Organ Dose from Acute or Chronic Radionuclide Inhalation.

Purpose - DACRIN calculates effective radiation dose to the human respiratory tract and other organs resulting from the inhalation of radioactive aerosols, using the ICRP Task Group Lung Model. Dispersion models for chronic or acute atmospheric release are included.

Description - The computer program, DACRIN, permits rapid and consistent estimates of the effective radiation dose to the human respiratory tract and other organs resulting from the inhalation of radioactive aerosols. The program is an outgrowth of the development of a mathematical model for the organ dose following the basic precepts of the ICRP Task exponential model for retention by an organ of interest. Mathematical models describing atmospheric dispersion have been included for the purpose of evaluating doses resulting from either accidental or chronic atmospheric releases of radionuclides. The program will calculate the effective radiation dose to any of 18 organs and tissues from inhalation of any one or combination of radionuclides considered by the ICRP. A maximum of 10 organs may be selected for each case. Organ doses from inhalation can be calculated by specifying either the quantity of a radionuclide inhaled or the quantity released to the atmosphere. In the latter case, the duration of release, the release height, wind speed, atmospheric dispersion parameters and downwind distance at which the dose is to be calculated must also be specified. As many as 10 distances may be specified for each use. Output of the code consists of the effective radiation dose to the selected organs at selected time intervals, for each radionuclide inhaled as indicated by the input.

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Source - Reference #6: p. 124, #8: p. 206

ATMOSPHERIC TRANSPORT

Model - DELFIC: A New Fallout Transport Code for the Delfic System:
The Diffusive Transport Module.

Purpose - This program is a supplement to DASA 2669.

Description - The diffusive transport module of the new DELFIC fallout prediction system has undergone additional development since publication of its description in DASA 2669. This supplement to DASA 2669 describes these developments and presents amendments and corrections to the code and its documentation. Complete FORTRAN statement listing of subroutines that have been substantially changed are included.

Norment, H.G.
Mount Auburn Research Associates, Inc.
Newton Upper Falls, MA

Source - Reference #18: p. 74.

ATMOSPHERIC TRANSPORT

Model - DIFFAL: Distribution of Fallout.

Purpose - This model is used to estimate radioactive fallout from peaceful use of nuclear explosions.

Description - A method has been developed for predicting radioactive fallout levels arising from peaceful cratering applications of nuclear explosives. The computer program used, which is titled DIFFAL, calculates deposited activity, airborne concentration and related parameters downwind of the large volume, quasi-instantaneous, cloud of particulate debris created by the explosion. The mechanisms of gravitational fall and diffusion included in transporting particles back to earth are provided for in DIFFAL. Equations for determination of diffusion, standard deviation, deposition velocity, mean direction wind speed, particle fall rates, finite land size, particle size distributions, and fission product decay are presented and described. As well as a program testing method for DIFFAL, cloud models, radiation from passing clouds, and methods of fallout prediction in the field are described. Comparisons are made with U.S. and Russian prediction methods.

A. Robson, United Kingdom Atomic Energy Authority, Atomic Weapons Research Establishment, Aldermaston, United Kingdom, 1974. AWER-0-11/74; Part of Lapage, R. (Ed.), Peaceful Uses of Nuclear Explosives, Review Paper No. 1, (p. 67-87), 114 p.

Source - Reference #26. Item 588.

ATMOSPHERIC TRANSPORT

Model - DIFOUT: Model for Computation of Aerosol Transport and Diffusion in the Atmosphere.

Purpose - This code is used for predicting atmospheric transport and diffusion of aerosols.

Description - In conjunction with Roller Coaster, a joint United States-United Kingdom project conducted at the Nevada Test Site in 1963, a computer-programmed model for prediction of the atmospheric transport and diffusion of aerosols was developed. The program was a melding of a U.S. code describing gravitational fallout of a log-normal size distribution of particles in a vertically varying wind field and a U.K. code describing the dispersion of a particle cloud by atmospheric turbulence. In the program, the aerosol cloud is approximated by a series of cylindrical layers in the vertical direction characterized by a source strength, lateral diameter and thickness, and a distribution of aerosol mass with particle diameter. In turn, each layer is represented by several superposed line source elements of equisize particles to conform to the aerosol mass-diameter distribution for the layer. Each element descends at its gravitational fall rate and is transported by its mean vector wind while expanding by the action of turbulent diffusion. Deposition and/or airborne dosage is calculated at ground level on a specified circular grid of ranges and azimuths whose origin is at the initial position of the cloud. Unique line source equations are used in the model, including an analytical method used to account for linearly changing transport direction over the length of the source. Expressions used to calculate turbulent spread, deposition, particle fall rates and transport vectors are included. There are various input and output options which permit great flexibility in program use, either in prediction of the dispersal from a given cloud or in the determination of the input necessary to produce a given result. The program may be used for both continuous and instantaneous releases.

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Source - Reference #6: p.125

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - DOSES: A Computer Technique for Calculating the Radiological Consequences of Pressurized Water Reactor Power Plant Hypothetical Accidents

Purpose - Used to predict radioactive releases from PWR's due to hypothetical accidents.

Description - A closed form analytical method of calculating the radiological consequences of ten pressurized water reactor (PWR) hypothetical accidents was developed. This methodology was used to develop a computer code, DOSES, to compute the gamma-whole body, beta-skin and iodine inhalation thyroid doses at the site boundary, at the low population zone outer boundary and for control room occupancy for the ten PWR hypothetical accidents. The computer code DOSES was developed to operate in the conversational remote terminal mode and to provide a mechanism for producing required information for chapter 15 of PWR nuclear power plant safety analysis reports. The identification of causes and accident descriptions, fission product release and dose analysis assumptions, dose calculation models, input parameters to the computer code DOSES, and the dose results and conclusions are presented for each of the ten hypothetical PWR accidents for a typical PWR nuclear power plant. The severity rank and the conservatism ratios of each accident were calculated. The loss of coolant accident was found to be the most severe. All doses calculated for the plant considered fell well within the limits of 10CFR100 and general design criterion 19 of appendix to 10CFR50.

C. F. Gill
University of Missouri-Rolla
Department of Mechanical Engineering
Rolla, MO
Ph.D. Thesis, Engineering Department, 1975

Source - Reference #18: p.34

ATMOSPHERIC TRANSPORT DOSIMETRY

Model - EERIE: Environmental Evaluation of Radioactive Isotopic Effluents - Assessment of Environmental Hazards Following Nuclear Reactor Accidents.

Purpose - This code is used in determining dose and ground deposition from an atmospheric release.

Description - Theoretical models have been developed describing the build-up of fission products in irradiated nuclear fuel and the behaviour of these in a reactor and subsequently in atmosphere under definable accident conditions. These models have been incorporated into a computer program EERIE (Environmental Evaluation of Radioactive Isotopic Effluents) which enables inhalation doses to body organs, gross beta and gamma doses, and the quantity of radioactivity deposited on the ground in the area surrounding the site of a release of activity to be evaluated. The data obtained in this study have been examined in order to provide guidance on the best methods of obtaining adequate monitoring results with sufficient speed to institute effective precautionary measures. The comprehensive nature of the calculations, which enables the complete history of the isotopic content of the damaged fuel to be followed continuously from the time of its release from the fuel through its dispersal in the atmosphere, makes it possible to identify those parameters which are important in determining sampling and monitoring techniques. In addition it makes it possible to evaluate the usefulness of different analytical methods at various stages during an incident. It is concluded that the assessment of inhalation hazards from measurements of isotopes deposited on the ground is considered difficult and unreliable, while measurements of exposed persons would impose too great a time delay. Finally in the extreme of high or low levels of released activity, where the major hazard results from external radiation and contamination of food chains respectively, simple exposure rate measurements are considered adequate for the initial determination of emergency control actions.

H. F. MacDonald, Central Electricity Generating Board, Berkeley Nuclear Laboratories, Berkeley, Gloucestershire, United Kingdom, 1971. IAEA-SM-148/38; CONF-710705; Rapid Methods for Measuring Radioactivity in the Environment, Proceedings of the International Symposium held in Munich, Germany, July 5-9, 1971, pp. 43-54.

Source - Reference #26: Item 1229.

ATMOSPHERIC TRANSPORT DOSIMETRY

Model - EGAD: A Computer Program to Compute Dose Integrals from External Gamma Emitters.

Purpose - EGAD is a code to estimate whole body dose resulting from radioactive material release.

Description - EGAD is an external gamma dose code programmed in FORTRAN IV for the IBM 360/65 that is intended to provide an estimate of whole body dose resulting from radioactive material released to the environs. The material is assumed to be bounded between the ground and an inversion lid on the vertical axis and bounded in the crosswind direction between fictitious sector boundaries or some real physical constraint such as mountains on both sides of a valley. To model average exposure over long time periods, the distribution of material is assumed to be Gaussian about a given release height in the vertical direction with a homogeneous distribution in the crosswind direction. The code provides output in the form of dose integrals that are a function of the vertical dispersion parameter, release height, inversion lid, and gamma energy. The calculated integrals are independent of the source, radioactive decay, wind speed, and sector width. It is therefore feasible to cover a large variety of possibilities by using a relatively small set of tabular values as a function of the vertical dispersion parameter and employing an interpolation procedure. The code is expected to be used primarily in the construction of these tabular values to be used in a more comprehensive program of computing radiation dose. The code is currently being used in this manner as a part of the overall man-rem evaluation program at Savannah River.

Cooper, R.E.
Savannah River Laboratory
Aiken, SC 29801

Source - Reference #6: p. 116

ATMOSPHERIC TRANSPORT

Model - ENTRY/RPM-1: Reactive Plume Model, Version 1.

Purpose - The program is used to simulate the effects of reactive pollutants from a point source.

Description - ENTRY is a reactive plume model developed to simulate the behavior of reactive pollutants in a plume from a single point source. This model is a moving parcel model based on simple mass balance for each pollutant species within a single well-mixed box. It treats chemical reactions using a detailed kinetic module (the carbon-bond mechanism). Provisions are made for the model to accommodate variations in meteorological conditions and ambient pollutant concentrations. Documentation is available

Mei-Kao Liu, Douglas Stewart
Systems Applications, Inc.
950 Northgate Drive
San Rafael, CA 94903
415-472-4011

Source - Reference #18: p.54

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - ESDORA: Estimate of the Radiation Dose in the Evaluation of Risks for Nuclear Power Plants and Radioactive Facilities.

Purpose - A code to estimate radiation doses from continuous or instantaneous escape of fission products into the atmosphere.

Description - The program ES.DO.RA. (Estimacion de DOsis Radiologicas [estimate of radiation doses]) estimates the damage produced by the continuous or instantaneous escape of fission products into the atmosphere. It was programmed in FORTRAN IV for the IBM 7090 computer and is divided into 4 subroutines: ESD 1. Generates an inventory of fission products according to the operating process (sic., burnup ?) of the fuel of the facility. ESD 2. Determines the quantity of fission products emitted to the atmosphere through the stack or the technical safety measures employed. ESD 3. Calculates the integrated doses of the radioactive cloud, as well as the ground-level contamination due to fallout of the fission products, with consideration of meteorological conditions. ESD 4. Estimates the external beta and gamma doses by submersion in the radioactive cloud as well as the internal doses received by the various organs of the human body by inhalation. The program was developed to evaluate the risks resulting from an explosive type of accident in a nuclear facility, but in special cases it can be used with routine releases.

F. D. Cruz
Juanta De Energia Nuclear, Spain
1971, March
SS/01/71; ORNL-tr-2628; 4 pp.

Source - Reference #6: p. 122.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - EXDOSE: A Computer Program for Calculating the External Gamma Dose from Airborne Fission Products.

Purpose - This model calculates external gamma doses to the human body.

Description - The EXDOSE program calculates the external gamma radiation dose to the total body from a half-infinite cloud of fission products. It is designed primarily for estimating accident consequences. The code calculates a fission product inventory according to specified input parameters using an adaptation of the program RIBD. Any fraction of these fission products may then be released to the atmosphere at a desired rate. The subsequent downwind dispersion and resulting dose to individuals is then calculated. The dispersion of the plume is based on the bivariate normal mode and Simpson and Fuquay's equation or Sutton's equation. Cloud depletion by ground deposition is an available option. Correction for radioactive decay and daughter product growth is included.

M. M. Hendrickson
Battelle, Pacific Northwest Laboratories
Richland, WA

Source - Reference #6: p.126

ATMOSPHERIC TRANSPORT

Model - EXGAM: A Code to Calculate Gamma Photon Dose from an Airborne Radioactive Release

Purpose - This code is used in predicting gamma dose from an airborne release.

Description - A FORTRAN IV code - EXGAM - for use on a CDC-3600 digital computer has been written to predict the integrated photon dose at a receptor exposed to an airborne release of radioactivity. The code assumes the source spatial distribution to be Gaussian. Input options allow the user to choose source decay mode, cloud thickness, cloud wind speed, cloud stability class, cloud drift direction, air attenuation and build-up coefficients and source photon energies. The code has been optimized with respect to computer execution time.

J. J. Steyn, Y. S. Kim
NUS Corporation
1730 M Street, N.W.
Washington, DC 2036
NUS-329, 1966

Source - Reference #18: p.110

ATMOSPHERIC TRANSPORT DOSIMETRY

Model - FISSP/CLOUD

Purpose - The linked computer programs FISSP and CLOUD perform a reactor excursion analysis involving: 1) the fission product inventory immediately preceding the release, 2) the release from the containment structure to the atmosphere, 3) the transport of the released fission products to the exposure point, and 4) the resulting external and internal dose.

Description - FISSP performs the fission product inventory and release calculation while CLOUD performs the fission product transport and dose calculation.

CLOUD models transport by a three-dimensional Gaussian dispersion equation with Sutton's dispersion parameter representation. The time-integrated air concentration is calculated numerically for use in determining external dose and inhalation dose. The external dose from gamma radiation is calculated using the semi-infinite cloud assumption. Contributions to external dose from both beta and gamma radiations are included. The dose to organs from inhaled material is calculated using MPC values. The doses calculated are the 50-year dose commitments from uptake over a specified uptake period. A puff release to the atmosphere of the inventory at the end of the operating history is assumed. Fractional releases may be assigned to the nuclide groups - noble gases, halogens, high temperature volatiles and the remainder. One neutron energy group is allowed.

FISSP performs a double precision calculation. CLOUD applies a factor of 0.64 to the external beta dose to account for perturbation of the average energy of the beta field by preferential absorption of the high energy particles. Inhalation doses for nuclides not listed in ICRP Publications 2 (1959) or 6 (1964) are calculated using "artificial" MPC values.

This code is written in FORTRAN IV for a CDC 6600 and requires 60k (octal) to run.

L.L. Bonzon and J.B Rivard (1970)
Albuquerque, NM

Source - Reference #12: p. B-46.

ATMOSPHERIC TRANSPORT

Model - FOG1: Plume Simulation Model Fog

Purpose - This code is used in calculating atmospheric dispersion of plumes.

Description - The mathematical plume simulation model fog is suitable for the calculation of plumes with or without lift, emitted by cooling towers of any given construction or by chimneys, into the atmosphere boundary layer. The program was developed, starting in 1973, at the request of the confederation office for energy economy (Waste Heat Commission, Cooling Tower Commission) and later in the framework of the IIHT Project (Microclimate Project). Since then, it has been used for diverse studies on the influencing of the environment by cooling tower plumes and is presently used in the project CLIMOD (climate study for the Rhine Valley between Basel and Koblenz) for prediction of plume lengths in weather conditions which are especially critical in this connection. The version of FOG described here is the basic version FOG1.

F. Gassman
Eidgenoessisches Inst.
Fuer Reaktorforschung, Wuerenlingen (Switzerland)
November 8, 1978.

Source - Reference #27: Item 13.

ATMOSPHERIC TRANSPORT

Model - FROTAR: Fast Response Model of Toxic Aerosol Resuspension by Wind.

Purpose - This model concerns itself with resuspension of toxic particulates.

Description - This model is still in the initial stages of development (as of 1974) to incorporate data of dust suspension by wind into an advection and diffusion particle in cell predictive model to estimate the down wind hazard of toxic aerosol suspended or resuspended by wind. This model will be regional in scale and oriented toward fast response hazards due to toxic aerosol accidents.

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415-422-1831; FTS 532-1831

Source - Reference #18: p. 137

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - GADOSE and DOSET: Programs to Calculate Environmental Consequences of Radioactivity Release.

Purpose - The codes calculate dose to man from an accidental release by a nuclear power plant.

Description - GADOSE is a FORTRAN program which calculates the radioactivity in various reactor plant locations and the doses to the public resulting from instantaneous accidental release of activity into any of the plant spaces. The calculations can be performed for any combination of isotopes and include consideration of decay, buildup, filtration, atmospheric dilution, fallout, and rainout. The companion program DOSET is also available to include the effects of a time dependent accidental fission product release into the various plant spaces. A typical calculation of the activities and doses at five times and five distances from the plant with 134 isotopes requires approximately 4 centihours of IBM 7044 machine time for the basic GADOSE program. The program was written specifically for the High-Temperature Gas-cooled Reactor (HTGR) type of plant.

Lee, E.
General Atomic
San Diego, CA 92112

Source - Reference #6: pg. 138.

ATMOSPHERIC TRANSPORT

Model - GALP: Aerosol Analytical Model

Purpose - Used to determine aerosol attenuation in leakage paths of reactor containments.

Description - A preliminary model and associated computer code (GALP) were developed to assess the attenuation of aerosols in leakage paths. The GALP code is able to determine the leakage path size, the bulk gas velocity, and the flow regime for three postulated leakage geometries, i.e., circular pipe, parallel plates and annulus. Brownian diffusion and sedimentation are considered for laminar flow: turbulent diffusivity, inertial effects and sedimentation are taken into account for turbulent flow. Input instructions, sample problems and program listing for the GALP code are documented.

T. C. Huang
General Electric Company
Advanced Reactor Systems Department
M/C S-54
P. O. Box 5020
Sunnyvale, CA 94086
408-738-7278
National Technical Information Service
GEAP-14147, 84 pp., 1976

Source - Reference #18: p.41

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - GAMMA: Model for Radiation Exposure from a Boiling Water Reactor Plume

Purpose - Evaluates noble gas plume exposure from boiling water power reactors.

Description - Field measurements of exposure rates for noble gases were compared with model predictions to determine the sensitivity to approximations for build-up of gamma radiation, plume rise and cloud size. The model used was based on May and Stuart (1970), i.e., a crosswind averaged Gaussian plume. The vertical dispersion coefficient is that due to Watson and Gammertsfelder. Holland's formula with Moses' correction for stack diameter is used to calculate plume rise. Growth and decay of daughter radionuclides is considered. Deposition and inhalation are not taken into account. For the buildup factor, Capo's formula is used for gamma energies greater than 0.5 mev, and Berger's formula is used for gamma energies less than 0.5 mev. Exposure rate is averaged over 4 atmospheric stability classes, 16 wind directions and 6 wind speed ranges weighted by their frequency of occurrence. Gamma ray measurements were made for two months near a boiling water reactor with ionization chambers and thermoluminescence dosimeters. Measured and calculated exposure rates agree within a factor of 2. The model predictions were compared with those obtained with EGAD, the Gammertsfelder model and calculations made as part of the safety analysis for the plant. The linear buildup factor approximation is a sensitive function of meteorology and gamma ray energy. Calculations of dose rates for the different models differed by more than 100% at large distances from the stack under unstable conditions. Models treating off-sector exposures separately match the data more accurately than those that do not.

C. V. Gogolak
Environmental Measurements Laboratory
U.S. Department of Energy
376 Hudson St.
New York, NY 10014
212-620-3635

Source - Reference #18: p.34

DOSIMETRY
ATMOSPHERIC TRANSPORT

Model - GASPAR: A Program for Population Dose Evaluation

Purpose - To calculate population and individual doses through gaseous pathways for the implementation of Regulatory Guide 1.109.

Description - None available at the time of presentation of this document.

K. Eckerman.
Health and Safety Research Division
Bldg. 4500-S
Oak Ridge National Laboratory
P. O. Box X
Oak Ridge, TN 37830
(Work performed at NRC, System Dynamics and Reliability Group)

Source - Reference #31

ATMOSPHERIC TRANSPORT

Model - GDEP: A Code to Estimate Strontium-90 Global Deposition from Atmospheric Nuclear Detonations.

Purpose - The code is used to predict the world-wide strontium-90 deposition from nuclear atmospheric testing.

Description - An empirical model is presented for estimating the surface deposition of "world-wide" radioactivity from atmospheric nuclear detonations given the yield, latitude, season and type of each burst. The procedure is readily adaptable to computer calculation. The model is based primarily on injection-deposition experience gained from the U.S. and U.S.S.R. nuclear tests in 1958. Use of the technique to estimate Sr-90 deposition from the 1961-62 tests shows the predictions are usually within a factor or two of the observed deposition.

Peterson, K.
Lawrence Livermore Laboratory, L-262,
G Division, P.O. Box 808
Livermore, CA 94550

Source - Reference #18: p. 80.

ATMOSPHERIC TRANSPORT

Model - GENKIN-1: A General Kinetics Code with Atmospheric Applications.

Purpose - This code is used to model atmospheric conditions of well mixed chemical systems.

Description - A multi-purpose, semi-automatic code for setting up and solving large coupled sets of stiff, non-linear kinetic equations, interfaced with a library of chemical reactions and rate coefficients important in atmospheric modeling. It uses advanced variants of the gear method to solve the differential equations.

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415-422-1807; FTS 532-1807
Developed at LLL
R. J. Gelinas, and R. P. Dickinson
Genkin-1, UCID-16577, August 1974

Source - Reference #18: p. 27.

ATMOSPHERIC TRANSPORT
DOSIMETRY
FOOD CHAIN

Model - GRONK

Purpose - GRONK calculates annual dose resulting from radionuclides released with gaseous effluents. It is part of the HERMES computer program.

Description - Skin and total body dose to an individual and total body dose to the population are calculated for a standard matrix of points made up by 16 sectors and up to 10 annular rings out to 50 miles from release point. Options permit calculation of dose at other specified distances. An optional calculation for thyroid dose from radioiodine via inhalation, milk and leafy vegetables may be made.

Terminal input to GRONK includes: facility name, a string of code letters signifying what σ_z model to use (Pasquill or Hanford) and the various options selected and up to 10 ranges, if ranges other than the internally set standard ranges are required. Other inputs are required depending on the options selected, such as release height for elevated release, plume rise constant for plume rise consideration, building height for wake effect correction and sensor level for translating meteorological data from actual height of wind sensor to height selected for dose estimate. For the thyroid dose calculation, the child and adult vegetable consumptions, the cow grazing period and the leafy vegetable consumption period are entered for the milk and leafy vegetable pathways. GRONK is operational with 136 radionuclides available; however, only 52 may be used at any one time because of core allocation limitations.

J. K. Soldat, N. M. Robinson, D. A. Baker (1974)
Battelle, Pacific Northwest Laboratories
Richland, WA

Source - Reference #12: p.B-39,40

GENERAL TRANSPORT

Model - HERMES: A Digital Computer Code for Estimating Regional Radiological Effects from the Nuclear Power Industry

Purpose - This model is used in estimating regional radiological effects resulting from operation of nuclear facilities.

Description - The HERMES model is designed to calculate radionuclide release and radiation dose occurring within a study area in a given year. While cumulative radionuclide release as such is not considered, the accumulated buildup and deposition of key radionuclides is "back-calculated" for a five-to-ten year period for use in dose calculations. The initial development of the HERMES model was based on a study of the region comprising the upper Mississippi and lower Missouri River basins, excluding the Chicago metropolitan area. To estimate the effects on dose in the study area caused by air transport of radionuclides from adjacent regions, an "air envelope" some 200 miles in width was included around the study area. Considerations in the study included the operation of 400,000 MW generating capacity power plants (nuclear and fossil) at 186 separate sites. The air transport code (ARTRAN) utilizes monthly climatological data applied to standard mathematical models for diffusion, deposition, and transport. The water transport code (WTRAN) calculates diffusion from emission points, concentrations in sediments and surface water at each location requested, and ground water transport. The code (DOSE) considers exposure to the whole body and six specific organs in (1) direct submersion in air or water, (2) inhalation, (3) external exposure from surface contamination, and (4) ingestion of food and water over numerous food-chain pathways. Life habits and dietary differences are also considered in the code (LPM). Present structure allows calculations for up to 50 radionuclides; 200 release points; and 300 receptor locations. More recent applications have been for the Tennessee Valley region and Southwest Environmental Study.

J. F. Fletcher, W. L. Dotson
Hanford Engineering Development Laboratory
Richland, WA 99352
509-942-6523; FTS 444-6523
HEDL-TME-71-168; 759 pp., 1971

Source - Reference #18: p.305

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - HERMES; ARTRAN: An Atmospheric Radionuclide Transport Model.

Purpose - The purpose of this code is to determine dose to individuals and groups from activities such as waste storage or reprocessing.

Description - A computer code, HERMES, was developed for calculations from which a reasonable estimate may be derived of the potential radiation dose and dose commitment to individuals and population groups residing in regions where nuclear power reactors, and ancillary activities such as fuel reprocessing plants and waste storage facilities, are located in the year 2000. ARTRAN is the radionuclide air transport model. The three types of data used include: source to receptor travel distance; effluent source rate and constituent characteristics; and meteorological variables including wind speed and direction, atmospheric stability, mixing depth, and precipitation characteristics.

Dotson, W.L.
Hanford Engineering Development Laboratory
Richland, WA

Source - Reference #18: p. 260.

ATMOSPHERIC TRANSPORT DOSIMETRY

Model - INHEC: Computation of Radiological Consequence Using INHEC Computer Program.

Purpose - This code is designed to perform parametric analysis of radiological consequences of an accidental radioactivity release at a nuclear power plant. Accidental releases from LLW management sites may be similarly analyzed.

Description - INHEC is a computer code specifically prepared for parametric investigation of radiological consequences involved in the accidental release of radioactivity from a nuclear power plant. The computer code is designed to calculate off-site doses from time-varying releases of radioactivity to the environment with an option to calculate the resulting activity buildup in a secondary volume (e.g., a nuclear power plant control room). The code has wide applicability since it can be used in the analysis of both single and double containment systems with varying purge and/or leak rates from either containment. Also, the code has the flexibility of computing either instantaneous or time-varying activity releases to the innermost level of containment and activity reduction from internal cleanup systems such as containment sprays and filtering units. The meteorology contained in Regulatory Guides 1.3 and 1.4 is available as an internal data table; however, other meteorology may be used as desired. The printed computer output includes the off-site inhalation doses, the off-site cloud center and ground level gamma doses, the off-site cloud center and surface body beta doses, and activity inventories in the containments and on filters. The printed computer output resulting from the secondary volume option includes inhalation and surface body beta doses, integrated activity exposure inside the secondary volume, and activity inventories in the secondary volume and on related filters. Also, a gamma source sort of each activity inventory is provided to facilitate shielding calculations. All activities and doses are calculated as a function of time and, where applicable, as a function of distance.

T. F. Mackay, R. F. Ely, Jr.
Gilbert Associates, Incorporated
525 Lancaster Avenue
Reading, PA 19603

Source - Reference #6: p.132

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - ISOLA II: A Fortran IV Code for the Calculation of the Long-Term Alpha- and Gamma-Dose Distributions in the Vicinity of Nuclear Installations.

Purpose - Model air doses caused by alpha and beta emitters emitted as off-gas products from the area of a nuclear reactor.

Description - The computer code ISOLA is used to calculate the annual radiation doses caused by alpha- and beta-active off-gases in the environment of the Karlsruhe Nuclear Research Center. In the revised version, ISOLA II, the double Gaussian distribution model is strictly observed. As a consequence, the contribution of activity from neighbour sectors is taken into account. Up to 15 emitters may be coped with simultaneously. The emission rates are considered to be constant during the given time interval. Optionally, either the isodoses chart of a specified area (for instance a square 20 by 20 km) or a list of doses calculated at up to 2000 locations (for instance the living areas) in the environment may be set up.

W. Hubschmann, D. Nagel
Gesellschaft für Kernforschung m.b.H.,
Karlsruhe, Germany

Source - Reference #6: p.123

ATMOSPHERIC TRANSPORT
DOSIMETRY

Name of Program - KRONIC

Purpose - KRONIC calculates annual external total body tissue dose from chronic release of radionuclides to the atmosphere.

Description - The external total body tissue dose is calculated as a function of the 1) radionuclides present, 2) climatology for the site, 3) time dependence of fission product concentrations, 4) photon and beta particles emitted from nuclides, and 5) physical properties describing interaction of photons and beta particles with air and tissue.

Atmospheric dispersion effects are estimated using data on joint frequency of occurrence of wind speed, wind direction and stability for a particular site. Each sector is considered to be a plume for which the center line ground-level dose is calculated for specified downwind distances. The result of the calculation is a table of annual dose rates as a function of direction and distance from the release point.

Both photons and beta particles contribute to the external total body dose. The beta dose contribution is calculated using a semi-infinite cloud model. The gamma dose calculation is performed by space integration over the plume volume. The gamma dose can be calculated at any specified tissue depth.

KRONIC uses extensive data bases to minimize input requirements. Radioactive chain decay with branching is calculated for chains with up to seven members. Multiple releases may be specified with results summed. KRONIC is written in FORTRAN IV for CDC CYBER computer.

Streng, Dennis L.
Battelle-Pacific Northwest Laboratories
Post Office Box 999
Richland, WA 99352
509-942-4323; FTS 444-7511 EXT 942-4323

Source - Reference #13: p. B-48, 8 p. 207.

ATMOSPHERIC TRANSPORT

Model - LIRAQ-1: Livermore Regional Air Quality Model.

Purpose - This code is designed to aid in pollution studies.

Description - The LIRAQ-1 model is a regional air quality model developed for use by an air pollution control district in studying regional land use, control strategy and air quality problems. The model treats temporally and spatially varying meteorology and source emissions, complex topography and simple physical sinks in a regional domain in the well mixed layer below the inversion. The model can be applied to variable size grids, to regions, subregions, or cities, and to various meteorological situations.

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415-422-1824; FTS 532-1824

Source - Reference #18: p. 135.

ATMOSPHERIC TRANSPORT

Model - LIRAQ-2 Livermore Regional Air Quality Model: Kinetics and Transport.

Purpose - This code is designed to aid in pollution studies.

Description - LIRAQ-2 is an Eulerian (fixed spatial grid) multicell regional air quality model, incorporating mass-consistent advection, diffusion and photochemical kinetics. Using as input data the topography, meteorology, and pollutant source inventory for the region of interest. LIRAQ-2 computes the time and spatial variations of both the ground level pollutant concentrations and the average vertical concentrations between ground level and the bottom of the inversion layer. The model is structured in a modular fashion, with a module (submodel) for each of the major calculational steps, such as pollutant transport, chemical kinetics, and generation of mass-consistent wind fields from meteorological and topographical data.

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415-422-1807; FTS 532-1807

Source - Reference #18: p. 129.

ATMOSPHERIC TRANSPORT

Model - MATHEW: A Mass-Consistent Wind Field Model

Purpose - This model is used in the study of three-dimensional pollutant transport.

Description - MATHEW, a regional three-dimensional time-independent wind field model, utilizes a variational analysis technique to determine a three-component non-divergent velocity field which can be used to provide the advection velocities in atmospheric pollutant transport and diffusion models. The regions of interest have horizontal distances of 10 to 200 km and extend less than 2 km above topography.

C. S. Sherman
California University
Livermore (USA)
Lawrence Livermore Lab.
May 1978.

Source - Reference #27: Item 27.

ATMOSPHERIC TRANSPORT

Model - MESODIF-II: A Variable Trajectory Plume Segment Model to Assess Ground-Level Air Concentrations and Deposition of Effluent Releases From Nuclear Power Facilities

Purpose - MESODIF-II was developed because of a need to assess the radiological effects of routine operations of commercial nuclear power plants.

Description - MESODIF-II is a variable trajectory plume segment atmospheric transport model designed to predict normalized air concentrations and deposition of radioactive, but otherwise non-reactive, effluents released from one or two levels over the same position in an xy-plane. In such a model, calculated particle trajectories vary as synoptic scale wind varies. At all sampling times the particles are connected to form a segmented plume centerline; the lateral and vertical dimensions of the plume are determined by a parameterization of turbulence scale diffusion. The model development arose from the need to assess the radiological effects of routine operations of commercial nuclear power reactors.

D. C. Powell, H. L. Wegley, T. D. Fox
Battelle Pacific Northwest Labs.
Richland, WA (USA)

Source - Reference #26: p. 2,3

ATMOSPHERIC TRANSPORT

Model - METEO: A Program for Calculations of Atmospheric Dispersion of Activities from Nuclear Power Reactors.

Purpose - These codes are used in determining dispersion of radionuclide activity in the atmosphere.

Description - METEO consists of the programs METEO-H (reactor-crash outflows) and METEO-N (operational outflow statistics). Both cases are based on the Pasquill-formulation of the problem. The following phenomena are enclosed: 1) reactor-crash outflow, 2) operational outflow statistics, 3) normal temperature gradient (decrease with height), inversion (increase with height), 4) lofting, 5) fumigation, 6) high stack (h is greater than or equal to $2.5h_b$), h = stack height, h_b = building height, 7) short stack (h_b is less than h is less than $2.3h_b$), 8) leakage from the reactor building, 9) two terms of decay chains for rare gases, one term for other isotopes (due to practical possibilities, but we are able to include general decay chains, 10) fall out and wash out deposition processes, and 11) statistical fluctuations of the wind direction for the case of reactor-crash outflow. For cases 6, 7, and 8 a uniform system of formula is used in contradiction to the American and German system. The wind direction and the mean wind speed are assumed to be constant. Supposing an effective containment system the plume rise during the atmospheric transport due to the radiation-induced heat is not included. The generalization of the programs including this effect is anticipated. The output of the programs are the surface concentrations and the total deposition intensities. The programs METEO-H and METEO-N are linked to a system of programs solving the transport of activities on a nuclear power establishment. The link of the METEO-programs are the programs DOSIS and INTERCORP.

O. Veverka; V. Valenta; K. Vlachovsky
Skoda Works, Plzen, Czechoslovakia
1975
ZJE-166; 30 pp.

Source - Reference #26: Item 1280.

ATMOSPHERIC TRANSPORT DOSIMETRY

Model - MO 142, A FORTRAN Program for the Calculation of the Potential Hazards from an Accidental Fission Product Release.

Purpose - This code was designed to determine individual nuclide doses from a gaseous release of fission products.

Description - A FORTRAN Program, MO 142, has been written to perform a detailed analysis of the space and time-dependent radiation doses resulting from a potential fission-product release incident from a nuclear reactor. The program permits the calculation of the hazards from any radioactive source of known concentration and isotopic distribution. The nuclides which form the radioactive cloud are specified as program input. For each nuclide, an initial concentration, release rate, radioactive decay constant, and average gamma and beta emission energy must be supplied. In addition, the exposure period, the distance from the source to the receptor point, and the appropriate meteorological conditions must be specified. For each nuclide in the calculation, the program computes the external gamma and beta dose and the inhalation dose to several critical organs. The total in each category is obtained by a straightforward summation of the individual nuclide doses. Atmospheric dispersion is calculated using Sutton's equation and the resulting air concentration is corrected for decay before the dose is calculated. The program allows for a time-dependent release rate to be used if desired.

Eckert, R.J.
Bettis Atomic Power Laboratory
Pittsburgh, PA
WAPD-TM-348, 22 pp. 1964.

Source - Reference #18: p. 260.

ATMOSPHERIC TRANSPORT

Model - MSDM: Multiple Source Dispersion Model

Purpose - This is a code used for calculating atmospheric pollutant concentrations and surface deposition rates.

Description - MSDM is a computer code for calculating pollutant concentrations and surface deposition rates from up to 100 point sources and within a spatial range of approximately 100 km. The model is based on the Gaussian Plume Concept with modifications to simulate the effects of plume rise, first order chemical transformations, gravitational settling, surface deposition, and an inversion layer. Two modes of operation can be employed: climatological or instantaneous. In the climatological mode, long-term (monthly to yearly) averages are calculated using a joint frequency distribution of wind speed, wind direction, and atmospheric stability for the time period over which the average is to be taken. Short-term (hourly) averages for a specific set of meteorological conditions are calculated in the instantaneous mode.

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Source - Reference #18: p. 28.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - MUNDO: A Digital Code for Computing Accident Dose Rates in Reactor Environs

Purpose - This code calculates dose received from a given reactor based on location, time, and reactor parameters.

Description - The MUNDO computer code calculates the dose equivalent received at the point F and time T in rem as a function of meteorological and internal physical and engineering properties of the reactor. The code considers fuel release factors, decontamination factors, filter factors, leak functions, multi-containment, ground release, stack release, weather conditions, external irradiation, internal irradiation, and direct irradiation from the reactor building. Approximately 80 nuclides can be included in the calculation. Atmospheric dispersion includes Sutton's diffusion parameters, and plume depletion via deposition and decay are accounted for. Exposures are calculated for inhalation, external exposure to the plume, and external exposure to the ground. Ingestion and wet deposition are not considered.

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Karlsruhe, Germany

Source - Reference #6: p.131

ATMOSPHERIC TRANSPORT DOSIMETRY

Model - NUBE: A Digital Code to Evaluate the Hazards of Different Types of Reactor Accidents.

Purpose - An analytical method to assess abnormal reactor behavior including air transport of radionuclides. Although dealing with reactors, this model may have general applicability in analyzing LLW management systems.

Description - The method determines the fission product inventory as a function of reactor power, fuel irradiation, and cooling time. It analyzes the fission product behavior within the containment system, when released from the core as a result of an accident. Finally, the method calculates the atmospheric diffusion of the escaping nuclides under a variety of conditions. External and inhalation doses to individuals within the radioactive plume may be assessed at different distances downwind from the reactor. The method has been used to evaluate the hazards caused by different types of reactor accidents such as reactivity accidents, loss-of-coolant accidents, reactor fires, and fuel handling accidents. Different types of containment systems are considered in the analysis. The systems analyzed include negative pressure containment, double containment, and high-pressure and pressure suppression containment systems. The effect of engineered safeguards such as building sprays, filters, condensation pools, etc. can be taken into account. Each nuclide can be considered individually, as the cleaning rates, condensation ratios, deposition velocities, etc. are nuclide dependent. The results are given in terms of the amounts of the most important nuclides retained within the containment barriers or by the engineered safeguards. The most relevant health hazards produced outside the containment system are also given for the accidents analyzed.

A. Alonso (1965) CONF-650407; "Fission Product Release and Transport Under Accident Conditions," Proceedings of the International Symposium held at Oak Ridge, Tennessee, April 5-7, 1965, pp. 1080-1090, 1249 pp. (Junta de Energia Nuclear, Madrid, Spain)

Source - Reference #6: p.116

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - PABLM

Purpose - This model calculates internal doses and dose commitments to man for either acute or chronic ingestion of radionuclides from the air pathway.

Description - PABLM calculates internal doses and dose commitments to man for either acute or chronic ingestion of radionuclides for population or maximum individual for the air pathway.

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Source - Reference #8: p.208

ATMOSPHERIC TRANSPORT

Model - PATRIC: A Three Dimensional Particle-in-Cell Sequential Puff Code for Modeling the Transport and Diffusion of Atmospheric Pollutants

Purpose - This code is designed to calculate the distribution of atmospheric pollutants.

Description - PATRIC is a transport and diffusion code designed to calculate the three-dimensional distribution of atmospheric pollutants in a given space and time varying flow field. It is based on the particle-in-cell model in which the pollutant mass or activity is represented by the spacial distribution of a large number marker particles. The temporal evolution of this particle distribution results from the transport of each individual marker particle due to advection by the mean wind and diffusion by the Gaussian formula. The code is capable of computing instantaneous or time-integrated air concentrations and deposition for a variety of instantaneous or continuous sources, including inert and radioactive materials. PATRIC was developed as a simplified and speeded-up version of the Lawrence Livermore Laboratory three-dimensional transport and diffusion code for complex terrain. PATRIC computer time is approximately one minute for every 24 hours modeled, which makes the code suitable for annual air quality assessments.

R. Lange
California Univ., Livermore (USA). Lawrence Livermore Lab.
January 1978

Source - Reference #27, Item 41

ATMOSPHERIC TRANSPORT

Model - PDIMLUST: Pollutant Distributions in the Mixed Layer, Using Similarity Theory.

Purpose - This code was developed to predict pollutant distribution in the mixed layer downstream of a near-surface source.

Description - PDIMLUST predicts pollutant distributions in the mixed layer downstream of a near-surface source. Further description not presently available.

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Source - Reference #18: p.24

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - PLUME: Estimation of Radiation Doses Following a Reactor Accident.

Purpose - This code calculates downwind radiation doses to be expected from a reactor accident.

Description - Based upon the "Gaussian Plume" formula, a model has been developed which permits calculation of the downwind radiation doses to be expected following a reactor accident. Although the calculations to date are concerned only with the thyroid dose due to iodines and the whole body dose due to iodines and noble gases, the code can easily be adapted to handle other radioisotopes. The basic assumptions include instantaneous release of a given quantity of radioactive material into a reactor building followed by emission at a constant (volume) rate from a point source. Radioactive decay both within the building and during passage downwind are accounted for as are the growth and decay of daughter products and the effects of physical separation such as filtration. A Fortran IV computer program PLUME has been written for the purpose of solving the equations developed. The code calculates dose due to inhalation and from submersion in the gamma emitting cloud.

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Source - Reference #6: pp.123-4

Model - PREDO: Estimating Radiation Doses

Purpose - This code is used in estimating statistical dose distribution.

Description - PREDO is a combination of the codes SITMET and WCLIM. SITMET uses hourly, onsite meteorological data to generate total body and/or skin doses for specified release inventories, release heights, and downwind distances. WCLIM generates a statistical distribution of doses with magnitude and direction.

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Source - Reference #18: p. 289.

ATMOSPHERIC TRANSPORT DOSIMETRY

Model - RACER

Purpose - RACER calculates tissue dose in rads at a downwind location, delivered over a specified time, from gamma radiation emitted by a cloud of airborne radionuclides.

Description - The distribution of radionuclides is described by a bivariate normal equation. The location can be any point downwind of the release on or off the centerline of the cloud at ground level. No restrictions have been placed on release height. The penetrating dose; i.e., dose at five centimeters, and the dose to organs of interest resulting from inhalation have not been incorporated in this computer code.

The program includes a fission product inventory calculation using the computer code RIBD (Gumprecht, 1968, 1969) as a subroutine. The fission product inventory, with additional activation products specified, is released to the atmosphere through a three barrier containment system with depletion and filtration in each barrier.

Nuclide decay is considered during production, release and transport using a chain decay scheme with branching to and from isomeric states. The dose is calculated as the space-time integral of air concentration. A data base is used to minimize input requirements. The space-time integration causes long typical running times. RACER is written in FORTRAN IV for a UNIVAC 1108 computer.

D.I. Streng, M.M. Henderson, and E.C. Watson (1971)
Battelle, Pacific Northwest Laboratories
Richland, WA

Source - Reference #12: p. B-50.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - RADOS, A code to estimate gamma dose from a cloud of radioactive gases.

Purpose - This code can be used to rapidly calculate whole body dose from a cloud of airborne radioactive material.

Description - RADOS is a computer code that represents the finite spatial distribution of airborne source material as an infinite number of line sources. The code provides a means of rapidly calculating whole body gamma dose from a finite cloud of radioactive material. The simplifying assumptions used to minimize computation time are: (1) the material release is instantaneous and results in a radioactive cloud of unit thickness in the x or downwind direction. (2) there is no change in the size and shape of the cloud during passage over the effective range of the receptor. (3) the gamma buildup factors can be expressed analytically with sufficient accuracy. These assumptions limit the applicability of RADOS as follows: the material release should occur over a relatively short time; the receptor distance should be more than 600 meters downwind from the release point; and the gamma energies should be in the specified range. A 4 group, 12 isotope, 1 receptor-point problem requires approximately 1.75 seconds on the IBM System/360-65. This is approximately 8 percent of the running time for the more detailed CLOUD code. Dispersion is essentially based on the Gaussian assumption.

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Source - Reference #6: p. 128.

ATMOSPHERIC TRANSPORT

Model - RADS; ARADS: Computer Model for the Prediction of the Dispersion of Airborne Radioactive Pollutants.

Purpose - This program was developed to predict the dispersion of radioactive effluents deposited into the atmosphere from a smoke stack.

Description - Two computer programs have been written for an IBM 1401/7040 digital computer in a FORTRAN IV computer language. The programs are called RADS and ARADS, acronyms for radiological atmospheric dispersion study and alternate rads, respectively. Both programs are designed to investigate the use of various equations formulated to predict the dispersion of radioactive effluents deposited into the atmosphere from a smoke stack. The release of the effluents may be of either an instantaneous or continuous nature. Predictions of atmospheric concentrations are made for approximately 600 points throughout an observation area surrounding the smoke source, allowing contour lines of equal concentrations to be drawn. The RADS program was designed for one particular effluent release. The program predicts the path of the smoke from the source to one of the boundaries of the observation area. Predictions are then made concerning the dispersion of the smoke. The ARADS program uses average meteorological conditions to predict the air concentrations resulting from long-term releases of a smokestack effluent. The output data for both programs contain a scaled map of the observation area showing the location of the predicted concentrations in order to simplify the drawing of the contour lines. While the authenticity of the prediction equations is not certain, a definite relationship between relative air concentrations with respect to the location of the source was established. The programs permit fast, accurate, and voluminous solutions to the complex equations, and provide a tool with which to examine the prediction equations themselves.

P. A. Plato, Menker, D. F., M. Dauer
University of Miami
School of Medicine
Miami, FL
Health Physics, 13, 1105-1115, 1967

Source - Reference #18: p.81

ATMOSPHERIC TRANSPORT

Model - RAR: A Computer Code for Analyzing Routine Atmospheric Releases of Short-lived Radioactive Nuclides.

Purpose - Measures amount of pollutants and effluents from energy processes and provides for environmental monitoring of the atmosphere.

Description - RAR calculates average annual ground level air concentrations, deposition rates, and ground concentrations for a decaying chain of radioactive nuclides. Members of this chain are assumed to have been emitted from a stack under routine nonaccidental operating conditions. Averages are performed relative to atmospheric stabilities, wind speeds, and wind directions.

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Source - Reference #18: p.21

ATMOSPHERIC TRANSPORT

Model - RELISH: Some Techniques for Estimating the Results of the
Emission of Radioactive Effluent from ORNL Stacks.

(For Description See STAREL; RELISH)

ATMOSPHERIC TRANSPORT

Model - RETADD: Regional Trajectory and Diffusion Deposition Model

Purpose - This model estimates the transport and long-range diffusion of material emitted by a point source.

Description - RETADD is based upon a version of the NOAA Air Resources Laboratories Regional-Continental Scale Transport, Diffusion, and Deposition Model (J. L. Heffter, et al., NOAA Technical Memorandum ERL-ARL-50, Air Resource Laboratories, Silver Springs, MD, 1975).

The Fortran IV computer model uses a trajectory analysis technique for estimating the transport and long-range diffusion of material emitted from a point source. The wind trajectory portion of the code uses observed upper winds to compute the transport of the material. Ground level concentrations and depositions are computed by using the Gaussian plume equation for wind trajectories projected forward in time. Options are included to specify an upper bound for the mixed layer and a chemical decomposition rate for the effluent. The limitations of the technique, the equations and model, and listings of the program, input, and output are documented.

C. L. Begovich, B. D. Murphy, C. J. Nappo, "RETADD: A Regional Trajectory and Diffusion Deposition Model," ORNL/TM-5859, (June, 1978).

Source - Reference: Document cited above.

ATMOSPHERE TRANSPORT
DOSIMETRY

Model - RISC: Radiological Inhalation Safety Code for IBM 7090

Purpose - This code is designed to evaluate internal doses following inhalation.

Description - Radiological inhalation safety code (RISC) is a digital machine program used to compute internal exposures (according to the methods of Morgan and Ford) to seven body organs or tissues (thyroid, bone, muscle, lungs, gastro-intestinal tract, soft body tissues, and testes), incurred over the first year following short-duration inhalation. Doses to these body organs are based on computations of up to 50 radionuclide sources. These computations include both radioactive and atmospheric sources, strength determination, and the dose contributions from any of the 50 radionuclides to any or all of the above-mentioned body organs. RISC may be used to estimate the environmental consequences from reactor operations and accidental power excursions at stationary power plants, vehicle launch or test facilities, and from in-flight vehicles. The basic diffusion theory of O.G. Sutton is utilized in developing specific atmospheric diffusion models with the appropriate initial-volume-source corrections. The initial cloud size and height of rise are input parameters, along with isotope-release fractions, and downwind-dose points. The effects of a capping temperature inversion are determined in the program from a subroutine applicable for low-altitude releases. Also, the reduction of the cloud source material due to washout and dry fallout may be taken into account by exercising a separate option. The radionuclide source terms for each of 20 specified positions downwind are also computed in a subroutine which considers specific fission and decay times. This part of the program also permits dose normalization so that the output is in terms of Rem/MW-sec or Rem/MW.

Anno, G.H.; Debois, P.J.; Wilcox, T.P.; Witthaus, J.K.

Source - Reference #18: p. 255.

ATMOSPHERIC TRANSPORT

Model - RPM-II: Reactive Plume Model, Version 2.

Purpose - This program supplements RPM-I.

Description - This model is an expanded form of RPM-I. The plume is visualized as an array of cells oriented across the plume moving downstream with wind velocity. Boundaries between cells are impermeable to inert species but permeable to reactant species. Diffusion between cells is parameterized by an equivalent K-theory. Chemical reactions are treated in the same fashion as the RPM-I (carbon-bond mechanism). Provisions are made for the accommodation of variable meteorological conditions and ambient pollutant concentrations.

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Source - Reference #18: p.55

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - RSAC-2: The Radiological Safety Analysis Computer Code.

Purpose - To provide a code to calculate the radiological consequences of accidental release of radionuclides to the atmosphere.

Description - RSAC-2 can be used to calculate 1) fission product inventory source terms, 2) lung doses using either the ICRP Task Group on Lung Dynamics Lung Model (TGLM) (ICRP, 1966) or the initial ICRP Lung Model (ILM) (ICRP 2, 1959), 3) gastrointestinal tract doses using either the model of Dolphin and Eve (1966) or the ICRP Publication 2 (1959) model, 4) dose to various internal organs using the ILM, 5) ground deposition gamma doses, and 6) cloud gamma doses using either a "finite" or "semi-infinite" cloud model. Cloud concentration is determined by the bivariate normal distribution model.

Containment features are modeled as a ten-term exponential function. Straight chain decay is considered. Branching is simulated by dividing the chain branches into two or more straight chains. Special attention is given to the finite cloud integration using Gaussian quadrature techniques applied to a variable interval. Buildup is modeled as a third-order polynomial. RSAC-2 is written in FORTRAN IV for an IBM computer.

R.L. Coates, N.R. Harton (1966)
L.C. Richardson (1968)
National Reactor Testing Station
Idaho Falls, ID.

Source - Reference #12: p. B-53

ATMOSPHERIC TRANSPORT
SOIL TRANSPORT

Model - SDIST: Wind Effectuated Redistribution of Surface Contamination

Purpose - This code is used in analyzing redistribution effects of wind over soil.

Description - A mathematical model was developed for use for computer calculations of the redistribution of surface soil contaminants as a function of downwind distribution and erosion or weathering variables. A computer program, SDIST, was developed for plotting the concentrations as a function of time for each space interval and steady state isopleths.

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Source - Reference #18: p. 5.

ATMOSPHERIC TRANSPORT

Model - SEP: A Program for Evaluating Atmospheric Dispersion from a Nuclear Power Station.

Purpose - This code is used in analyses of short-term and long-term releases at a nuclear plant.

Description - A computer code (SEP for site evaluation program) has been developed. The program uses a joint frequency distribution of winds and stability classes to evaluate the atmospheric dispersion potential near a nuclear power station. The code includes models for short-term and long-term effluent releases. A description of the input parameters is documented. The program is written in FORTRAN IV and uses 250 K memory on an IBM 360/75 computer. Plume rise may be calculated using formulas from Briggs, or it may be ignored.

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NOAA TM EPL ARL-42, 12 pp.

Source - Reference #18: p.102

ATMOSPHERIC TRANSPORT

Model - SPHERES: Diffusion-Controlled Fission Product Release and Absorption

Purpose - This program is used to determine diffusion coefficients of volatile solutes and to estimate diffusion profiles.

Description - Concern about fission product release from coated reactor fuel particles and fission product sorption by fallout particles has provided stimulus to understand diffusion. In a fallout program, mathematics of diffusion with simple boundary conditions have been used as a basis for (1) an experimental method of determining diffusion coefficients of volatile solutes and (2) a calculational method for estimating diffusion profiles with time-dependent sources and time-dependent diffusion coefficients. The latter method has been used to estimate the distribution of fission products in fallout. In a fission product release program, a numerical model which calculates diffusion profiles in multicoated spherical particles has been programmed, and a parametric study based on coating and kernel properties has provided an understanding of fission product release.

J. H. Norman; P. Winchel; J. M. Dixon; B. W. Roos; R. F. Korts, Gulf General Atomic Inc., San Diego, California 1970. Part of Freiling, E.C. (Chairman), Proceedings of the 155th Meeting of the American Chemical Society on Radionuclides in the Environment Held in San Francisco, California, April 1-3, 1968; Advances in Chemistry Series 93, (p. 13-34), 529 p.

Source - Reference #26: Item 300.

ATMOSPHERIC TRANSPORT

Model - STAREL; RELISH: Some Techniques for Estimating the Results of the Emission of Radioactive Effluent from ORNL Stacks

Purpose - These codes are used in analysis of release of radioactive gases from a series of stacks.

Description - There are at the Oak Ridge National Laboratory five stacks which from time to time emit small quantities of radioactive material to the atmosphere. These stacks are located at different points within the laboratory, have different emission characteristics, and serve a variety of equipment and processes. Because of this the task of predicting a safe upper limit to the permissible rate of release of activity from a given stack is quite complex; the limit depends not only upon the atmospheric concentrations generated by the stack under consideration but also upon the contributions from each of the other stacks. Moreover, the atmospheric concentration produced at a given point by a given release rate is a complicated function of the meteorological conditions which prevail at the time of the release. In most previous calculations aimed at the establishment of permissible release rates, each stack has been regarded as isolated from the others and the interrelationship between the several stacks has generally been neglected. To compensate for this, a maximum permissible release rate, or alternatively a total permitted annual release for all of the stacks taken together, has usually been imposed. One of the purposes of this study is to examine the cumulative effect of emissions from all the stacks and to develop a more realistic approach to the prediction of maximum permissible release rates for each of them. Program STAREL was written to compute centerline ground-level concentration. Program RELISH calculates the isopleth coordinates of stack releases in three coordinate systems: rectangular cartesian, logarithmic polar, and modified rectangular cartesian.

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Source - Reference #18: p.128

ATMOSPHERIC TRANSPORT

Model - STRAIGHTWINDS: A Model to Predict Radiological Environmental Impact Resulting from Straightline Wind Damage to a Plutonium Facility

Description - The model is designed to predict concentrations resulting from a straightline wind striking a facility housing particulate material. Once characteristic winds are determined and an applicable source term is generated, resultant ground-level concentrations are determined.

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FTS 972-3206
Turner, D. Bruce, Workshop of Atmospheric Dispersion Estimates,
PHS #999-AP-26, 1967

Source - Reference #18: p.47

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - SUBDOSA

Purpose - SUBDOSA calculates the external dose to humans for skin, eye, gonads, and total body resulting from accidental release of radionuclides to the atmosphere.

Description - The computer program SUBDOSA has been developed for the purpose of calculating the dose to humans following accidental atmospheric releases of radionuclides. SUBDOSA calculates the dose from airborne radionuclides external to the body and does not consider the dose resulting from radionuclides deposited in the body and its organs via inhalation. Doses are calculated as a function of: quantity released, duration of release, atmospheric conditions during the release, and horizontal distance from the release point.

The dose to organs of reference in adults from airborne radionuclides external to the human body is primarily dependent upon the type of radiation, the energy of the radiation and the spatial distribution of the airborne radionuclides surrounding the human receptor. The energy and type of radiation are characteristic of each radionuclide. Spatial distribution of airborne radionuclides is determined by the quantity released, the duration of release, the atmospheric conditions prevailing during the release and the distance between the dose receptor and the point of release.

The organs of reference most frequently considered in external dose calculations are the skin, lens of the eye and total body. Corresponding tissue depths for these organs used in SUBDOSA are 0.007, 0.1 and 5 cm respectively. The male gonads are less often considered in dose calculations but when such calculations are made with SUBDOSA, the tissue depth is 1 cm.

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Source - Reference #8: p. 208, #9 p. 2.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - SUBPOPA

Purpose - SUBPOPA calculates the population dose resulting from accidental releases of radionuclides to the atmosphere.

Description - Population doses are calculated by assuming that the cloud travel and dispersal to any point surrounding the release are represented by the joint frequency distribution of wind vector and atmospheric stability. A sector average concentration and a one-hour release are assumed.

Radioactive chain decay with branching is calculated for chains with up to seven members. Contributions to external dose from both beta and gamma radiations are calculated. Dose is calculated as a function of depth in tissue. Extensive data bases are used to minimize input requirements. Up to five release inventories may be specified with results from each release summed. A finite cloud approach is used for the external gamma dose calculation. SUBPOPA is written in FORTRAN IV for a CDC CYBER computer and requires 143k (octal) words of core to execute.

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Source - Reference #8: p.208; Reference #12: p.856

ATMOSPHERIC TRANSPORT

Model - TIRION: A Computer Program for the Calculation of the Consequences of Releasing Radioactive Material to the Atmosphere.

Purpose - The program calculates the consequences of releasing radioactive materials to the atmosphere.

Description - TIRION, is a computer program that has been written for use in calculations of the consequences of releasing radioactive material to the atmosphere.

KAISER, G.D. (1976)
United Kingdom Atomic Energy Authority
Safety and Reliability Directorate

Source - Reference #6: p. 148.

ATMOSPHERIC TRANSPORT

Model - TORNABENE: A Model for Radiological Dispersion from Tornadic Accidents .

Description - TORNABENE was designed to predict the ground-level concentrations resulting from a tornado striking an unhardened plutonium facility.

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Source - Reference #18: p.46

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - UDAD: Argonne Steady State Uranium Dispersion and Dosimetry Code.

Purpose - This code is used in the calculation of dose and transport of radionuclides from a uranium mine.

Description - The UDAD is a computer code to calculate airborne concentrations, ground deposited radioactivity, dose rates and doses from emissions from uranium mining & milling (Vol. 1) and induced health effects (Vol. 2). The annual average concentrations in air are computed from a sector averaged Gaussian diffusion equation. The concentrations in air, the radioactive cloud depletion and decay, the ingrowth radioactive daughter product concentrations and working levels, and the ground-deposited activities are computed for 16 wind directions and 15 distances up to a radius of 99 KM. Concentrations are also computed for specified receptor points. Dose rates and doses are computed for selected organs on the basis of the recommendations of the ICRP II and task groups. Dose rates from inhalation of radon daughters are computed from working-level. Health effects are predicted from competitive mortality from radiation induced, naturally included death, accidents and non-radiation forces of mortality.

Michael H. Momeni, Argonne National Laboratory, Environmental Impact Studies Division, 9700 S. Cass Ave. 60439. Momeni, Michael H. Yuchien Yuan, A. J. Zielen, and T. Beissel: The Argonne Steady-State Uranium Dispersion and Dosimetry Code, Vol. 1 (UDAD), ANL, 1978. Momeni, Michael H., S. A. Tyler, A. J. Zielen, and Y. Yuan: The Argonne Steady-State Uranium Dispersion and Dosimetry Code, Vol. 2, ANL, 1978.

Source - Reference #26: Item 1478.

ATMOSPHERIC TRANSPORT

Model - UNAMAP: Short Term Dispersion Models

Purpose - These models are used in calculating atmospheric dispersion of pollutants.

Description - UNAMAP is a Gaussian Dispersion Model which treats short term air dispersion as described in the Turner Workbook. Situations treated include inversion breakup, limited mixing, and coning. It also uses Briggs Plume Rise. It is designed for estimation of air dispersion from point sources.

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Source - Reference #18: p. 51.

Model - UTM (Unified Transport Model)*

Purpose - The Unified Transport Model (UTM) allows simulation of the transport, accumulation, and redistribution of trace contaminants in the environment.

Description - The air, land, and aquatic systems are represented by three major model components, designed to be run in sequence. The atmospheric component is based upon a Gaussian plume model and calculates deposition rates of aerosols for any point within a watershed. Concentrations of airborne aerosols at ground level are also calculated. The model includes consideration of point, area, line, and windblown sources for air pollutants. Deposition occurs by dry fallout and also by washout caused by rain falling through the plume. Air concentrations and depositions depend upon source strength, atmospheric stability, and wind speed and direction patterns. The spatial resolution of the atmospheric module now extends to a radius of 50 kilometers from any point source. One can use the model to simulate larger areas by constructing a mosaic of sub-area calculations. The deposition values calculated by the atmospheric model are used for input to the land component of the UTM.

The terrestrial component is structured to receive atmospheric wet and dryfall input to a watershed canopy and then simulate its movement until it is discharged in streamflow. The model simulates the amount of material washed from the canopy to the land surface during rainfall and allows for the exchange and uptake or adsorption of materials on surface soil. Surface runoff and scouring of soil particles are considered together with leaching of trace elements into the soil profile. An experimentally derived equilibrium distribution coefficient is used to estimate the concentrations of contaminants in subsurface soil water. This estimated concentration and the rate of soil water drainage are combined to estimate a subsurface input to the stream channel.

Finally, the outputs from the terrestrial component of the UTM enter the channel component, where flows are routed using a kinematic wave approximation. This portion of the program simulates transport of dissolved and particulate materials in streamflow. Suspended and bedload transport are considered by the model. Mixing and exchange between the aqueous and solid phases for the particular chemical species of concern are also simulated. If point-source discharges of known strength are released to the stream, the channel component is capable of simulating their introduction and subsequent transport.

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Source - Reference #3

*Program components of the UTM appear in the "Other LLW Models" category.

ATMOSPHERIC TRANSPORT
DOSIMETRY
FOOD CHAIN
SURFACE WATER TRANSPORT

Model - VADOSCA: A Simple Code for the Evaluation of Population Exposure Due to Radioactive Discharges.

Purpose - This is a combination liquid-gas isotopic distribution model, with doses calculated using varying environmental parameters.

Description The code consists of two parts, one for liquid discharges (VADOSCA-II) and one for gaseous discharges (VADOSCA-GAS). It incorporates the transfer parameters of twenty-four radioisotopes in the case of liquid discharges, and of twenty radioisotopes in the case of gaseous discharges. It allows the evaluation of the concentrations of the various isotopes in all the compartments of the critical paths outlined in the International Commission on Radiological Protection (ICRP) Publication No. 7, and the evaluation of the annual doses for five critical organs (whole body, G.I. tract, thyroid, bones, lung) for the various critical groups of population on the basis of environmental parameters such as the time of residence in a certain area, diet, type of activity, hydrological regimen, irrigation methods, and meteorological conditions. Although extremely simple, the code allows rapid performance of all the evaluations required to define the amount of radioactivity that can be released and the associated exposures. In its present form, the code VADOSCA-II covers twenty-four radionuclides including some fission products, some activation products, plus an alpha emitter. VADOSCA-II calculates the doses to four special groups, namely, fishermen, other workmen, local population, farmers. A separate calculation is made for the doses originated by drinking water. The doses are evaluated for five critical organs and they are expressed in mrem/year if the discharges are expressed in Ci/yr. In VADOSCA-GAS, twenty nuclides are considered, including eight noble gases (fission and activation products, various isotopes as particulates, and H-3, N-13, C-14 in the form of vapor. Atmospheric diffusion is evaluated with Pasquill's theory adapted to the meteorological data available. In its present form VADOSCA-GAS does not take into account particular effects such as the cloud depletion due to deposition, down draft and building effect; the particulate deposition rate is assumed constant at $3 \cdot 10^{-2}$.

Bramati, L.; Marzullo, T.; Rosa, I.; Zara, G.
Italian National Electric Energy Agency

Source - Reference #6: p. 131.

ATMOSPHERIC TRANSPORT DOSIMETRY

Model - WEERIE: A Program for Assessing the Radiological Consequences of Airborne Effluents from Nuclear Installation

Purpose - This code is used in determining safety and siting for reactors under operational or accident conditions. It may also be applicable to LLW management, although some modification may be required.

Description - A mathematical model has been devised for guidance in the safety and siting aspects of nuclear installations under operational or accident conditions. The model begins with the full fission product inventory applicable to the fuel at the time of interest generated for any reactor type and irradiation history. The amount of fuel involved in the incident may vary as a function of time, and either a time decaying or constant fission product inventory may be used to specify the release. The activity leaks from the circuit with allowances for time-dependent platecut, resuspension and filtration of each elemental species. By preserving the full nuclide decay schemes, nuclides leaking into the atmosphere depend not only upon their own release behavior but also on that of their precursors. The effluent in the atmosphere is dispersed from an effective stack height and allowance is made for building entrainment. Standard meteorological dispersion models are used and the effects of radioactive buildup and decay, ground and inversion reflections and ground deposition are taken into account. WEERIE then evaluates the inhalation and the cloud beta doses, while integration over the volume of the plume leads to estimates of the cloud gamma exposure. WEERIE is written in FORTRAN IV (H) and executes on the IBM 370/165 computer requiring 250 kbytes of fast core storage. Execution times vary with the degree of precision requested in the cloud gamma routine, but typically doses and exposures may be evaluated at the rate of 200 observation points per minute.

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Source - Reference #6: p.133

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - WRED: A Siting Code to Estimate Dose Probability Distribution from Measured Meteorology Data.

Purpose - WRED is a reactor siting code designed to estimate probability distributions of whole body gamma and thyroid doses using measured meteorological parameters as input data.

Description - Distribution analyses are performed as a function of downwind distance, activity release height, and wind direction. This statistical approach for gamma dose estimates, employing thousands of sets of meteorology data, is made economically feasible by using two-dimensional tables of space distribution-attenuation integrals and interpolation techniques. Measured meteorological parameters are converted to atmospheric dispersion parameters according to techniques developed at Brookhaven National Laboratory. Space distribution attenuation integrals are computed by techniques developed at the Savannah River Laboratory. When utilizing the full capacity of the code, approximately 2000 sets of data (involving 16,000 each gamma and thyroid dose calculations from raw meteorological data) are processed per minute on the IBM System 360/65. Concurrently, meteorological statistics are compiled, and all data are summarized for output. Provision is made for including compiled statistics from previous data processing to update the distribution analyses for each job. Code options allow minimum data input (wind speed, direction, temperature) or full input including measured standard deviations of the horizontal and vertical wind directions.

This code includes the dosimetric calculations computed by RADOS for gamma doses.

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Aiken, SC 29801

Source - Reference #6: p.121-2

ATMOSPHERIC TRANSPORT

Model - XOQDOQ: An Atmospheric Dispersion Code for Implementing Regulatory Guide 1.111

Purpose - To calculate average relative effluent concentrations and average deposition values at specified locations and distances from nuclear power reactors resulting from routine releases.

Description - XOQDOQ is a computer code used by the USNRC in its meteorological evaluation for routine releases from commercial nuclear power reactors. Using a "straight-line" airflow model, this code implements the assumptions outlined in Section C (excluding C1a and C1b) of Regulatory Guide 1.111, Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors. For routine plant releases, it calculates average relative effluent concentrations (X/Q 's) and average relative deposition values (D/Q 's) at locations specified by the user, and at standard radial distances and segments for downwind sectors. It also calculates these values at specified locations for intermittent releases.

John Goll
Nuclear Regulatory Commission Washington, D.C.

Source - Reference #29: p.77

ATMOSPHERIC TRANSPORT

Model - XPIC: Modelling of Pollutant Dispersion in the Atmosphere Under Varying Conditions in the Large Regions.

Purpose - This code is used in simulating turbulent dispersion in atmospheric releases.

Description - In Version A of the computer code XPIC for simulating the turbulent diffusion of a single cloud, the way in which the parameters of the computer code and of the diffusion model affect the calculations of the concentration time integral on the ground was tested experimentally and theoretically. As far as necessary, the code is fitted to the results of these tests. In some cases, these results and their consequences are valid in Version B also. Furthermore, attempts were made to optimize the code for a more convenient computation time. Version A as well as Version B should now be able to simulate a given dispersion model without uncertainties caused by computer or by model techniques. Therefore, it is now possible to investigate the meteorological influences on the turbulent diffusion and transport, in so far as these influences can be described by analytical forms.

H. Schultz; E. Voelz; C. D. Wueneker
Technische University
Hannover (Germany, F.R.)
Arbeitsgruppe Fuer Technischen Strahlenschutz
December 1977

Source - Reference #27: Item 16.

ATMOSPHERIC TRANSPORT
DOSIMETRY
FOOD CHAIN

Model - 2BPUFF: Lagrangian Transport and Diffusion Code to Calculate Concentrations and Deposition at Long Range of Particles Less than 10 Micro Meters Diameter.

Purpose - The code is used to calculate concentrations and deposition of small particles following atmospheric nuclear tests.

Description - The 2BPUFF code is the latest version of the original 2BPUFF code developed at LLL in 1966 by Todd V. Crawford (see UCRL-50179, Nov. 23, 1966). The code calculates the dispersion of pollutants in a cylindrical cloud with a vertical axis of symmetry using a coordinate system fixed to the cloud's center. Similarity theory of atmospheric turbulence is used to predict the horizontal diffusivity as a function of initial cloud size, turbulent atmospheric dissipation, and time. Vertical diffusivity is entered as a function of height and time, enabling entry of diurnal variations in the boundary layer and temperature inversions. The model calculates cloud center and surface air concentrations, exposure rate, dry deposition, washout, and the vertical integral of individual nuclides and doses to an individual for a variety of pathways, including inhalation, whole body external gamma, submersion, forage-cow-milk, and pasture-meat.

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Source - Reference #18: p. 79

ATMOSPHERIC TRANSPORT

Model - A Code for Calculating Atmospheric Transport Under Inhomogeneous and Instationary Conditions.

Purpose - This is a computer code for calculating the atmospheric transport of radioactive pollutants under inhomogeneous and instationary conditions.

Description - For calculations of atmospheric dispersion of radioactive releases from the nuclear industry, a numerical computer code was developed using the particle-in-cell method with the pollutant concentration represented by Lagrangian particles in an Eulerian grid mesh. Rules are presented for proportioning the cell-dimensions of the Eulerian grid system and the appropriate time-interval at the Lagrange step. An option is installed to get the fall-out-distributions on the ground due to a given surface adsorption-rate. To warrant a faultless pollutant dispersion of several radioactive sources in a limited area, special boundary conditions have to be considered by extrapolating the diffusion velocities at the boundaries. Introducing a particle-weight the code is capable of considering the radioactive decay of the pollutant, and of investigating potential synergistic effects. A very difficult case to handle with the particle-in-cell method is given when advection is omitted. For this case, calculations with constant, time or height-dependent diffusion coefficients beginning with small Gaussian distributed clouds from radioactive point sources were performed. Compared with pure Gaussian calculations the results show good agreement, if the above mentioned rules for cell-dimensions and time-steps are followed. Additionally the influence of various wind profiles and wind shears has been investigated. By means of some special cases the impact of meteorological or boundary conditions is shown.

C. D. Wuenneke, H. Schultz, and E. Voelz, Technische Univ., Hannover Germany, F.R., Proceedings of the 4th International Congress of the International Radiation Protection Association, Vol. 2, Conf-770409--, pp. 585-588, 24 April 1977.

Source - Reference #25: p. 146.

ATMOSPHERIC TRANSPORT

Model - A Computer Code for Analyzing Routine Atmospheric Releases of Short-Lived Radioactive Nuclides.

Purpose - This code calculates concentrations of radioactive nuclides at various points in the air to ground deposition of routine releases. For the purposes of LLW management, this model is useful for demonstrating techniques for the analysis of air deposition problems.

Description - A computer code is presented which calculates average annual ground level air concentrations, deposition rates, and ground concentrations for a decaying chain of radioactive nuclides. Members of this chain are assumed to have been emitted from a stack under routine nonaccidental operating conditions. Averages are performed relative to atmospheric stabilities, wind speeds, and wind directions.

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Oak Ridge National Laboratory
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Source - Reference #6: p: 129.

ATMOSPHERIC TRANSPORT DOSIMETRY

Model - A Diffusion-Type Model of the Global Carbon Cycle for the Estimation of Dose to the World Population from Releases of Carbon-14 to the Atmosphere.

Purpose - The model estimates dose to the world from release of Carbon-14 from the nuclear power industry.

Description - A nonlinear dynamic model of the exchange of carbon among the atmosphere, terrestrial biosphere, and ocean is described and applied to estimating the radiation dose to the world's population from the release of C-14 to the atmosphere from the nuclear power industry. A computer implementation of the model, written in the IBM Continuous System Modeling Program III (CSMP III) simulation language, is presented. The model treats the ocean as a diffusive medium with respect to vertical transport of carbon, and the nonlinear variation of CO₂ partial pressure with the total inorganic carbon concentration in surface waters is taken into account in calculating the transfer rate from ocean to atmosphere. Transfers between the atmosphere and terrestrial biosphere are represented by nonlinear equations which consider CO₂ fertilization and impose a constraint on the ultimate total carbon mass in the biosphere. Sensitivity of the model to variation of its environmental parameters and scenarios (such as future production of nonradioactive carbon from the combustion of fossil fuels) has been studied with respect to its population dose estimates; the results of these studies indicate that the uncertainties in the environmental parameters of the model are sufficiently contained to provide adequate estimates of the population dose if the population growth model is stipulated. Comparisons of the model's predictions with a selection of population dose estimates given by other investigators show reasonable agreement, notwithstanding the differences among the models on which the estimates are based.

The program is written in IBM-CSMB III simulation language for the IBM/360.

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Source - Reference #6: pg. 147.

ATMOSPHERIC TRANSPORT

Model - Air Transport Modeling for Regional Dose Studies.

Purpose - Used as a model to assess the radioactive dose attributable to nuclear power plants.

Description - A computer program designed to calculate the atmospheric transport, diffusion and deposition of radioactive effluent from the continuing operation of a number of nuclear facilities within a region has been written. Calculations in this program are made for the radionuclide contamination contribution from the several sources at a series of geographical receptors denoted as centroids. The sources are sites for nuclear reactors or reprocessing plants representative of a population group. The computer program was developed as part of a regional model to assess the radioactive dose attributable to a developing nuclear power industry. Other programs are available to calculate population doses resulting from the atmospheric radionuclide concentrations at each centroid. Doses due to deposition and uptake through food and water pathways are also calculated.

W. L. Dotson,
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Richland, WA

Source - Reference #18: p. 26.

ATMOSPHERIC TRANSPORT

Model - A Mathematical Model for the Transport of Environmental Plutonium.

Purpose - This model described the behavior of particulate Pu in the lower atmosphere.

Description - The model describes mathematically the behavior of particulate Pu in the lower atmosphere, which accounts for particle settling or impinging on the earth's surface as well as particle re-entrainment or resuspension. An equation is derived assuming that 1) the particle is spherical in shape, 2) the particle is small compared to the smallest wavelength of atmospheric motions, and 3) the particle concentration is characterized by a dilute gas-solid suspension.

J. R. Travis, Los Alamos Scientific Laboratory, Los Alamos, NM, 1973. LA-UR-73-954; 6 p.

Source - Reference #26: Item 621.

ATMOSPHERIC TRANSPORT

Model - A Model for Evaluation of Airborne Contamination.

Purpose - This model computes effect of airborne particulates.

Description - The level of airborne activity is considered to depend on two factors--the fraction of particles dispersed per unit time (given by a dispersion factor) and the residence time of the activity in the air. Calculations are made for the air activity for steady state resuspension and for transient distributions based on single dispersal processes. Expressions for the resuspension factor are also derived. It is shown that under the usual conditions of ventilation, the resuspension factor depends primarily on the dispersion factor and ventilation and not on the settling properties of the particles, except for very large particles that settle out rapidly. Laboratory tests for evaluation of the dispersion factor and the residence time were conducted by brushing with Ba35S04 crystals and by combustion. Field studies were made with slides of glass, stainless steel, lucite, lexran, and rubber that had been contaminated in a glove box used to process americium and plutonium. It is concluded that the most significant test from the viewpoint of routine operations determines the fraction of the surface contamination released to the air when a contaminated surface is repeatedly brought into contact with another surface and separated from it. The dispersion test must be combined with measurements of the residence time in a settling chamber to provide data applicable to hazard evaluation of contamination in field situations.

J. Shapiro, "Tests for the Evaluation of Airborne Hazards from Radioactive Surface Contamination," Health Physics, Vol. 19, pp. 501-510, 1970, Harvard School of Public Health, Boston, Massachusetts 02115.

Source - Reference #26: Item 211.

ATMOSPHERIC TRANSPORT
SOIL TRANSPORT

Model - A Model for Predicting the Redistribution of Particulate Contaminants from Soil Surfaces.

Purpose - The model predicts redistribution of soil-contaminant mixtures.

Description - A computerized model was developed to describe the redistribution of wind eroding soil-contaminant mixtures. Potentially mobile particulate contaminants can, in the first approximation, be assumed to be indistinguishable from the wind eroding soil in which they are distributed. A grid network characterized important soil and surface conditions, and mass conserving control volumes are constructed on each cell. Material is transported through the vertical and top surfaces of a control volume by a modified Bagnold-Chepil horizontal flux formulation and modified Gillette vertical flux formulation, respectively. The vertical emissions, considered as puffs from area sources, create at regular time intervals a contaminant cloud which is proportional to the suspendable ground concentration. These puffs diffuse downwind under time dependent wind velocity and atmospheric stability conditions, maintaining during the time interval a three-dimensional Gaussian distribution of concentration with cloud volume. Material from each puff is deposited in downwind cells, leading to the possibility of many different flights from these new sources. The usefulness of the predictive tool is demonstrated by calculations involving mixtures of particulate Pu-238/Pu-02 in highly erodeable soils under dust storm conditions. Time dependent surface concentration and breathing zone exposure isopleths, evolving from a small contaminated area, show the potential hazard from wind eroding toxic materials.

J. R. Travis, Los Alamos Scientific Laboratory, Los Alamos, NM, 1974. LA-UR-74-1340; CONF-740921; Part of Proceedings of the Atmospheric-Surface Exchange of Particulate and Gaseous Pollutants Symposium held in Richland, Washington, September 4-6, 1974, (58 p.).

Source - Reference #26: Item 509.

ATMOSPHERIC TRANSPORT
SOIL TRANSPORT

Model - A Model for Redistribution by Wind of Surface Contamination.

Purpose - A theoretical model has been formulated to predict the long range time and space redistribution by wind of surface contamination.

Description - In the case of long-lived isotopes, such as Pu239, this redistribution is of paramount importance. Creep, saltation, suspension (followed by diffusion and deposition), and weathering are considered to effect a one dimensional flow pattern spatially described by an unlimited number of continuous intervals. Within each interval the contamination concentration is described as a function of time by a first order differential equation. Possible applications and extensions are discussed.

A. J. Amato, "A Mathematical Analysis of the Effects of Wind on Redistribution of Surface Contamination," WASH-1187, 7p., Sept. 1971, Norfolk State College, Department of Mathematics, Division of Biology and Medicine, Washington, D.C. 20545.

Source - Reference #26: Item 198.

ATMOSPHERIC TRANSPORT
DOSIMETRY
FOOD CHAIN

Model - A model to estimate the local radiation doses to man from the Atmospheric Release of Radionuclides.

Purpose - The model estimates doses to man from the atmospheric release of radionuclides.

Description - A model was developed to estimate the radiation dose commitments received by people in the vicinity of a facility that releases radionuclides into the atmosphere. This model considers dose commitments resulting from immersion in the plume, ingestion of contaminated food, inhalation of gaseous and suspended radioactivity, and exposure to ground deposits. The dose commitments from each of these pathways is explicitly considered for each radionuclide released into the atmosphere and for each daughter of each released nuclide. Using the release rate of only the parent radionuclide, the air and ground concentrations of each daughter are calculated for each position of interest. This is considered to be a significant improvement over other models in which the concentrations of daughter radionuclides must be approximated by separate releases.

Rider, J.L.; Beal, S.K.
Bettis Atomic Power Laboratory,
Westinghouse, West Mifflin, PA).

Source - Reference #6: p. 152.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model A Model to Estimate Radiation Dose Commitments to the World Population from the Atmospheric Release of Radionuclides.

Purpose This code is used in modeling dose commitments in a global scenario.

Description A model to estimate the radiation dose commitments received by the population of the world beyond the immediate vicinity of a facility which releases radionuclides into the atmosphere is described. This model considers the dose commitments arising from immersion in the atmosphere containing the released material, ingestion of contaminated food, inhalation of gaseous and suspended radioactivity and exposure to ground deposits. The dose commitments from each of these pathways is explicitly considered for each radionuclide released into the atmosphere and for each daughter of each released nuclide. This is accomplished via the calculation of the specific air and ground concentrations in the world regions directly affected by each released nuclide and its daughter using the release rate of only the parent. This is considered to be a significant improvement over other models in which the effect of daughter radionuclides must be approximated by separate releases.

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Source Reference #18, p. 98

ATMOSPHERIC TRANSPORT

Model - Analytical Model for Air Pollutant Transport and Deposition From a Point Source.

Purpose - This model is used to simulate atmospheric transport and deposition of pollutants from an elevated point source.

Description - An atmospheric transport and deposition model is presented for pollutants emitted from an elevated point source over flat terrain. The model is obtained from the analytic solution of the atmospheric diffusion equation with the coefficients of eddy diffusion taken to be functions of downwind distance and the average wind velocity taken to be constant. Ground deposition of the pollutants is accounted for by (1) including a gravitational settling term in the atmospheric diffusion equation and by (2) applying an absorptive boundary condition at the ground surface. In order to facilitate application of the model, the results for the general situation that includes settling and deposition (and where the distribution is no longer Gaussian) are expressed in terms of the Gaussian plume parameters, and specifically the crosswind and vertical standard deviation functions $\sigma_y(X)$ and $\sigma_z(X)$. Graphs of the pollutant air concentration and ground deposition flux are presented for a number of deposition conditions.

Donald L. Ermak
University of California
Livermore, CA
Atmospheric Environment, 11, 231-237, 1977

Source - Reference #18: p.28

ATMOSPHERIC TRANSPORT

Model - A Numerical Model for the Study of Dispersion of Radioactive Pollutants in Air.

Purpose - The model calculates the dispersion of radioactive pollutants in air for both instantaneous and continuous emissions.

Description - The model provides a numerical solution of the diffusion equation for dispersion in air of radioactive pollutants from an elevated source. Instantaneous and continuous emissions are considered. In the case of instantaneous emission, the model calculates the pollutant concentration for any point as a function of time; in the case of continuous emission, the average yearly concentration for any point is calculated. Input data are: height and temperature of the released material, discharge rate, together with climatological frequency data relating to wind speed, wind direction, atmospheric stability and morphological features in the area examined. The model makes it possible to study the particular cases of maximum concentration and to determine, on the basis of the maximum permissible concentration in air, the maximum dischargeable amount of each radionuclide. The model was applied to evaluate the ground-level concentrations due to the potential emission of radioactive effluents from the reprocessing plant EUFEX of the Comitato Nazionale per l'Energia Nucleare, Saluggia, Italy. In particular, the maximum dischargeable amounts for Pu-239, H-3 and Kr 85 were evaluated. The model is also provided with a multiple inversion subroutine to take into account the effect of the presence of an inversion layer on the ground-level concentration. The model was written in FORTRAN IV and tested on an IBM 360/44 computer.

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Source - Reference #6: pg. 148.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - A Procedure to Determine the Relative Extent of Reactor Fission Product Releases Under Various Meteorological Conditions.

Purpose - This code simulates fission product releases accounting for meteorological variations.

Description - Several versions of Sutton's equations expressing the atmospheric concentrations, doses, etc. due to a fission product release have been programmed for solution by an IBM 1620 computer, as an aid in evaluating the effects of postulated reactor accidents. In addition, each of these equations has been solved over a wide range of meteorological parameters, and the results graphed, providing an illustration of the effects of changes in one parameter or a combination of them on the solutions. The code handles both instantaneous and continuous point sources. Cloud depletion by both wet and dry processes are included using Chamberlain's procedure. The only dose calculated is the inhalation dose to the thyroid.

It should be noted that this is an early code and there is some question on the use of the terms rainout and dose, and on the derivation of the thyroid dose equation.

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Source - Reference #67: p.123

ATMOSPHERIC TRANSPORT

Model - A Model to Predict Radiological Environmental Impact Resulting from Straightline Wind Damage to a Facility Housing Particulate Material.

Purpose - To analyze effects of straightline wind on particulates released from a nuclear facility such as a temporary storage shed for LLW.

Description - The model is designed to predict concentrations resulting from a straightline wind striking a facility housing particulate material. Once characteristic winds are determined and an applicable source term is generated, resultant ground-level concentrations are determined.

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Source - Reference #8: p. 141.

ATMOSPHERIC TRANSPORT

Model - A Regional-Continental Scale Transport, Diffusion, and Deposition Model.

Purpose - The code calculates transport, diffusion and deposition of effluents on regional and continental scales.

Description - The Air Resources Laboratories has developed a computerized post-facto trajectory model intended primarily for calculating the transport, diffusion, and deposition of effluents on regional and continental scales. A month, season, or year of trajectories at 6-hourly time intervals may be calculated forward or backward in time from any origin in the Northern Hemisphere for durations up to 10 days. Trajectory computations use winds at any altitude above sea level or winds averaged through any desired layer above average terrain. Computer output includes a listing of individual trajectory and points after selected durations, plotted trajectories for any desired map scale of either Mercator or Polar Stereographic projections, and plotted maps showing percent frequency of trajectory traverses over grid squares. A Gaussian plume model is combined with the trajectory model to calculate long-term (monthly, seasonal, annual) mean ground-level air concentrations and deposition amounts. Both wet and dry deposition are incorporated in the model. Another model calculates short-term (once or twice a day) mean ground-level air concentrations for selected sampling stations. Computer output includes plotted maps showing long-term concentrations and deposition amounts, and tables of short-term concentrations where the contributions from individual plumes are identified.

Heffter, J.L.; Taylor, A.D.; Ferber, G.J.
Air Resources Laboratories
Silver Spring, MD

Source - Reference #6: pg. 139.

ATMOSPHERIC TRANSPORT

Model - A Semi-Empirical Box Model of Atmospheric Transport

Purpose - This is a semi-empirical box model of atmospheric transport that permits the calculation of stratospheric inventories, surface air concentrations, and deposition of debris injected into the stratosphere, mesosphere, or higher levels.

Description - The model divides the atmosphere of each hemisphere into three compartments: the atmosphere above 21 km, the stratosphere below 21 km, and the troposphere. The transfer between compartments follows first-order kinetics, although the season and height of injection regulate the onset of the injections of Rh 102, Cd 109, Pu 238, and Sr 90 from the 1961-1962 tests, and Sr 90 from the sixth Chinese nuclear test in June 1967. It was calculated that the French thermocuclear tests in the Southern Hemisphere on August 24 and September 9, 1968, injected a total Sr 90 input of 130 kc into the stratosphere. The model also predicted the 1969 fallout from the recent atmospheric tests.

P. W. Krey, and B. Krajewski, "Comparison of Atmospheric Transport Model Calculations with Observations of Radioactive Debris," International Symposium on Atmospheric Trace Constituents and Atmospheric Circulation Held in Heidelberg, Germany, September 8-13, 1969 and Organized by the Commission on Atmospheric Chemistry and Radioactivity of the International Association of Meteorology and Atmospheric Physics; Journal of Geophysical Research, Vol. 75 (15), pp. 2901-2908.

Source - Reference #26: Item 260.

ATMOSPHERIC TRANSPORT

Model - A simple dispersion model for the analysis of chemically reactive pollutants.

Purpose - This code is used to calculate concentrations of chemically reactive pollutants.

Description - The simple ATDL dispersion model, in which the surface concentration is proportional to area source strength divided by wind speed, has been used successfully in the past to estimate concentrations of chemically inert pollutants. In the analysis of chemically reactive pollutants, the concentration predicted by the simple ATDL model can be used as a scaling parameter to put the governing equations into the dimensionless form. The resulting set of differential equations for the time rate of change of concentration in a region contains a few dimensionless governing parameters per equation. By analyzing the governing parameters, the relative importance of chemical and meteorological variables and source strengths can be assessed. As expected, the wind speed and source strength are seen to be the major factors determining the seriousness of the pollution problem in any region. Using a simple kinetic mechanism for photochemical smog as an example of the application of the model, it is shown that the model is capable of simulating observed NCON-TIME concentrations of NO, NO₂, and hydrocarbons of relatively high reactivity (RH) averaged over the Los Angeles basin on 29 September 1969. It is also shown that the predicted hourly concentrations of NO, NO₂, and RH averaged over the Los Angeles basin on 30 September 1969 are as well correlated with observed concentrations as the predictions of the more complex pick model, developed by Sklarew et al. (1972).

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Source - Reference #18: p. 38.

ATMOSPHERIC TRANSPORT

Model - A Surface Flux Model for Diffusion, Deposition and Resuspension.

Purpose - This model predicts the diffusion deposition, resuspension transport of airborne particles.

Description - A model of the diffusion-deposition-resuspension transport process is developed and programmed for use on the CDC 6000 computer. The model accounts for the effect of deposition and resuspension on the airborne concentrations by representing the net vertical flux of material at the surface due to these processes as an areal source of material for further downwind diffusion. The diffusion process is modeled by the standard Gaussian plume. This model is used to show that the assumptions of the source depletion model of deposition overestimate surface air concentrations and, hence, the deposition flux by factors of 2 to 4 for moderately strong deposition, $vd/u = 10^{-2}$ where vd is deposition velocity ($m \cdot sec^{-1}$) and (u) is the mean wind speed ($m \cdot sec^{-1}$). These results can be used to define the limits within which the source depletion model may be used with acceptable accuracy.

T. W. Horst, Battelle Memorial Institute, Pacific Northwest Laboratories, Richland, April 1974. BNWL-1850 (Part 3); Part of Simpson, C. L., et al (Eds.), Annual Report for 1973, (p. 63-67), 284 p.

Source - Reference #26: Item 445.

ATMOSPHERIC TRANSPORT

Model - ATDL Computer Model for Dispersion from Multiple Sources

Purpose - This code predicts pollution dispersion from multiple sources.

Description - The simple ATDL model for area source and multiple point source diffusion is programmed in FORTRAN IV. This model has been applied to specific problems.

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Moll, K. and J. Duncan
Industrial Air Pollution Control
Ann Arbor Science Publishers, Inc.
(P. 23-32), 1973.

Source - Reference #18: p.38.

ATMOSPHERIC TRANSPORT

Model - A Time-Dependant Atmospheric Dispersion Model.

Purpose - This code provides a time-dependent atmospheric dispersion model of airborne releases of radioactive material.

Description - Over the past several years, the manner in which assessments have been made of the consequences of large airborne releases of radioactive material has not changed much conceptually. The models to describe the atmospheric dispersion of the radioactive material have generally been time-invariant, i.e., the meteorological conditions (thermal stability, wind speed, and precipitation) are invariant during release and the subsequent period of radiation exposure of the population to the airborne material. The frequency distribution of the meteorological conditions are determined by analyzing several years of weather data from the appropriate geographical location. In reality, weather is continuously changing over short time periods (hours) following the release. It is to be expected that the changing meteorological conditions would have important effects on the potential consequences of the release. A time-dependent atmospheric dispersion model was developed and implemented. Results from this implementation were compared with those obtained using time-invariant models. Emphasis is given to an explanation of how, and why, these results differ from those estimated with time-invariant models.

P. E. McGrath; R. M. Blond
Sandia Laboratories
Albuquerque, NM
SAND--76-56, 1976; Proceedings Ans Winter Meeting, Held in Washington, D.C., November 15, 1976; Transactions of the American Nuclear Society, 24:76.

Source - Reference # 18: p. 66.

ATMOSPHERIC TRANSPORT

Model - Atmospheric Diffusion and Deposition of Particulate Matter.

Purpose - This code is developed to model air pollution diffusion and deposition of particulate matter.

Description - The physical situation considered is described by a non-homogeneous, gravity modified, dimensional, time varying, convective diffusive transport equation. This partial differential equation, subject to a nonhomogeneous boundary condition and source term, was solved analytically by integral transforms for a third type (Monin) boundary condition which describes the total flux of particles at the earth boundary. By applying the transform kernels provided, the analytical solutions to the cases of first (Dirichlet) or second (Neumann) type boundary conditions may be obtained directly from the general, modular solution presented. The inclusion of the particle flux boundary condition is a significant improvement over previous three dimensional studies which either assumed infinite geometry in all three dimensions thus avoiding complicating boundary conditions or used tilting plume techniques (corrections applied to gaseous no deposit solutions) which do not properly represent the concurrent processes of diffusive spread and settling.

R. W. Cleary, D. D. Adrian, R. J. Kinch
Princeton University
Department of Civil Engineering
Princeton, NJ 08540
609-452-4600

Journal of the Environmental Engineering Division, Proceedings American Society Civil Engineers, 100/EET, 187-200, 1974

Source - Reference #18: p.18

Model - Atmospheric Dispersal of Radioactive Pollutants Over Long Distances and the Calculation of Collective Dose

Purpose - This model describes various factors influencing dispersal of radionuclides in the atmosphere.

Description - The important factors influencing dispersal of atmospheric releases of radioactive nuclides over various distances ranges are considered. Appropriate modelling techniques after the first few hours of travel show that spatial and temporal changes in the boundary layer are important in assessing contributions to the collective dose beyond 30 or 40 km. A model has been developed which is designed to study the effects of routine releases from European nuclear installations. This model considers releases of a few hours duration at a time from any selected site and uses pressure fields at 6 hour intervals and quasi-geostrophic forecasting methods to track the meandering paths taken by a series of discrete puffs of radioactive material up to one or two thousand kilometres across a prescribed map area. The development and dispersion of each puff in different synoptic weather situations is simulated using local meteorological data at the time of passage to estimate population dose. The model has been used to analyze the behavior of representative nuclides.

H. M. Apsimon, A. J. H. Goddard
Congress of the International Radiation Protection Agency
Paris, France
April 24, 1977

Source - Reference #27, Item 37

ATMOSPHERIC TRANSPORT

Model - Atmospheric Transport and Diffusion in the Planetary Boundary Layer.

Purpose - The purpose of this code is to calculate effects of reactor accidents.

Description - A computerized model has been programmed to calculate the effects of simulated reactor accident and annual average atmospheric dilution factors on contamination of the environment by nuclear power stations. This program makes it possible to rapidly evaluate potential nuclear power station sites in a consistent manner. For input to the program the applicant must provide a joint frequency distribution of wind speed and stability classes for each directional section from a representative 12-month period. In most cases, periods of calm are included separately as the number of calms occurring for each stability class. The program assigns the calms to the various sectors in the same ratio as the lowest wind speed class and adds them to that category. Also included as input to the program are the distances to the site boundary for each sector, the cross-sectional area and height of the reactor building, and the distance to the nearest population center. If the reactor has a stack, the applicant also includes the height and diameter of the stack and the exit velocity of effluent, the distance and bearing of the stack from the reactor, the distances from the stack to the site boundaries for each sector, and information on terrain. Terrain heights and distances are read into the program for each sector and the program performs a linear interpolation to obtain the terrain height at any needed location. Plume rise is determined by the formulas developed by Briggs (1969). Methods used for the measurement of the meteorological parameters required are described. Results are included from a study on the effect of a city on the low-level windfield, carried out at Oklahoma City and in Colorado. Data are also included from studies on the effects of sampling interval on turbulent energy spectra, directional wind shear under low wind speed conditions, the applicability of geostrophic winds to mesoscale transport, the use of mesoscale windfield data in the preparation of prognostic weather charts, diagnostic applications of wind speed and component spectra, and methods for the prediction of long-term trajectories of radioactive gaseous effluents using single and multi-station models and long distance transport and diffusion of gaseous wastes.

Van Le Hoven, I
National Oceanic and Atmospheric Administration
Air Resources Laboratories
Silver Spring, MD
NCAA-TM-ERL-ARL--39, pp. 84, JUN 1973

Source - Reference #18: p. 117.

ATMOSPHERIC TRANSPORT

Model - A Two-Dimensional Transport Model of the Atmosphere.

Purpose - The model estimates atmospheric dispersion.

Description - A two-dimensional transport model of the atmosphere from 0 to 50 km is developed. The transport includes advection by the mean meridional circulation and the diffusion by the large scale eddies. The mean winds and the diffusion coefficients (components of a second order diffusion tensor) vary with latitude, height and season. The contributions of the mean circulation and the diffusion to the transport of tracers are equally important. In many cases they oppose each other. Observed mean winds are used below 15 Km. Above this level the mean winds are computed by solving the thermodynamic and continuity equations. Use is made of the observed distribution of ozone and of its observed vertical flux at the ground to deduce the diffusion coefficients consistent with the mean circulation. The model is capable of simulating the transport of tracers with both low and high latitude sources. It has been tested by simulating the behavior of W-185 from low latitude United States nuclear tests, and Zr-95 from high latitude Chinese nuclear tests. The overall distribution of the tracers, their rate of spreading, the rate of decrease of the maximum concentration, the residence time of the stratospheric burden and the deposition by wet fall-out are all well simulated and agree qualitatively and quantitatively with observations. In order to obtain quantitative agreement with observations, the mean winds and diffusion coefficients had to be decreased by a factor of two. The implications of this reduction are discussed. This work demonstrates that a first order closure using a diffusion coefficient tensor (K theory) approximates well the effect of the eddies. It also shows that the diffusion cannot be treated independently of the mean circulation. As an example of the use of the model, the distributions of nitrous and nitric oxides are computed in the stratosphere. The model has been computerized using a CDC 7600 computer. Partial documentation is available.

Louis, J.F.
University of Colorado
Boulder, CO. 80302

Source - Reference #6: pg. 146.

DOSIMETRY
ATMOSPHERIC TRANSPORT

Model - Calculation of the Gamma-Dose Rate from A Continuously Emitted Plume.

Purpose - This code is used in calculating long-term gamma dose from airborne releases of radionuclides.

Description - This computer model calculates the long term gamma dose rate cause by the radioactive off-gas continuously emitted from a stack. The statistical distribution of the wind direction and velocity and of the stability categories is taken into account. The emitted activity, distributed in the atmosphere according to this statistic, is assumed to be concentrated at the mesh points of a three-dimensional grid. The grid spacing and the intergration limits determine the accuracy as well as the computer time needed. When calculating the dose rate in a given wind direction, the contribution of the activity emitted into the neighboring sectors is evaluated. This influence is demonstrated in the results, which are calculated with an error below 3% and compared to the dose rate distribution curves of the submersion model and the model developed by K. J. Vogt.

W. Hubschmann; D. Papadopolous, Gesellschaft fur Kernforschung M.B.H., KFK-2172, (1975).

Source - Reference #26: Item 1060.

ATMOSPHERIC TRANSPORT

Model - Comparative model theory of atmospheric contaminant loading by power stations.

Purpose - Program used to compare pollutants from nuclear and fossil fueled power plants.

Description - On the basis of maximum permissible concentrations, simplified box models are developed to compare air pollution from nuclear and fossil fueled power plants. Assuming exponential decay of the pollutants, body-burden functions for the main pollutants from different types of power plants are calculated and compared. The calculations are based on an extensive acquisition of emission data, vertical profiles and basic standards of the pollutants. Results for the German power plants show, within the scope of the model, that the pollutant body-burden of nuclear power plants is much smaller than those from power plants fueled with hard coal, brown coal and oil, but larger than those from other nuclear facilities, such as reprocessing plants. Krypton-85 released from reprocessing plants is the main pollutant of nuclear power systems. With coal and lignite, the contribution of fluorine to air pollution was surprisingly large, especially under inversion conditions, and deserves further study.

Jansen, P.; Jordan, S.; Schikarski, W.

Source - Reference 18: p. 43

ATMOSPHERIC TRANSPORT

Model - Computed-Aided Air Quality Control

Purpose - This code is used in calculating dispersion of airborne pollutants.

Description - A FORTRAN IV computer program has been developed for predicting the dispersion of airborne effluents. More specifically, the program computes the wind speed, wind direction standard deviations, plume standard deviations, plume rise, maximum ground-level pollutant concentrations, center line pollutant concentrations, crosswind pollutant concentrations, short-term pollutant concentrations, long-term pollutant concentrations, and downwind pollutant concentrations for an angular sector. An example run using hypothetical environmental conditions is available.

L. K. Wang; J. Bergenthal; M. H. Wang
Rensselaer Polytechnic Inst.
Troy, N
Environmental Technology
April 24, 1977

Source - Reference #27: Item 21.

ATMOSPHERIC TRANSPORT

Model - Computer Code for Calculating the Atmospheric Transport of Radioactive Pollutants under Inhomogeneous and Instationary Conditions.

Purpose - This code is used in determining dispersion of radionuclides.

Description - For calculations of atmospheric dispersion of radioactive releases from the nuclear industry a numerical computer code was developed using the particle-in-cell method with the pollutant concentration represented by lagrangian particles in an eulerian grid mesh. Rules are presented for proportioning the cell-dimensions of the Eulerian grid system and the appropriate time-interval at the Lagrange step. An option is installed to get the fallout-distributions on the ground due to a given surface adsorption-rate. To warrant a faultless pollutant dispersion of several radioactive sources in a limited area, special boundary conditions have to be considered by extrapolating the diffusion velocities at the boundaries. Introducing a particle-weight the code is capable of dealing with the radioactive decay of the pollutant, and of investigating potential synergistic effects. A very difficult case to handle with the particle-in-cell method is given when advection is omitted. For this case, calculations with constant, time or height-dependent diffusion coefficients beginning with small Gaussian distributed clouds from radioactive point sources were performed. Compared with pure Gaussian calculations the results show good agreement, if the above mentioned rules for cell-dimensions and time-steps are followed. Additionally the influence of various wind profiles and wind shears has been investigated. By means of some special cases the impact of meteorological or boundary conditions is shown.

C. D. Wueneker; H. Schultz; E. Voelz
Technische Univ.
Hannover (Germany, F.R.)
Proceedings of the 4. International Congress
of the International Radiation Protection Association
Vol. 2
April 24, 1977

Source - Reference #27: Item 29

ATMOSPHERIC TRANSPORT

Model - Development of Atmospheric Models and Modeling Capacity.

Purpose - This code is used to model atmospheric transport processes.

Description - Parameterized meteorological functions for modeling atmospheric transport processes are presented. Attention is given to the fundamental chemical transformation process. Several chemical mechanisms are available for consideration. A box model approach has been developed, evaluation studies have been developed and evaluation studies have begun using the St. Louis Raps data base.

K. L. Demerjian, K. L. Schere
U.S. Environmental Protection Agency
Environmental Sciences Research Laboratory
Research Triangle Park, NC 27711

Source - Reference #18: p.25

ATMOSPHERIC TRANSPORT

Model - Development of Vertical Dispersion Coefficients for Rolling Terrain Environments.

Purpose - The program develops dispersion coefficients for a atmospheric dispersion model. The relevance for LLW management is in terms of controlling air releases.

Description- Data from U.S. Army Dugway Proving Ground tracer experiments are used to develop vertical, dispersion coefficient values for a Pasquill-Gifford atmospheric dispersion model. The data selected from 300 field tests provide information about the vertical component of dispersion and have been applied to rural, rolling terrain, observed instantaneous puff diffusion and calculated puff meander are combined to compose total dispersion. Derived coefficients are representative of 10 minute sampling time, and are compared with Pasquill-Gifford dispersion coefficients for flat terrain. The program is written in FORTRAN IV (G) compiler for the IBM and Basic Fortran for the Univac 90/30 OS 3.5.

D. I. Shearer; D. H. Minott; G. R. Hilst
The Research Corporation of New England
Wethersfield, CT 06109

Source - Reference #6: p. 143.

GENERAL TRANSPORT

Model - General Model for Evaluating Transport of Radioactive Products Released to Environment and its Consequences.

Purpose - The model describes transport of radionuclides released from normal operation of nuclear power plant.

Description - A mathematical model is described for the evaluation of the transport and behavior of radioactive products released into the environment during the operation of nuclear power plants. It is based on the behavior of the products on the main protective barriers of nuclear power plants. A block diagram is presented of the model and the respective main programs are characterized.

Hladky, E.; Kubik, I.; Moraveck, J.
Vyskumny Ustav Energeticky,
Jaslcuske Bohunice, Czechoslovakia.

Source - Reference #6: pg. 138.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - Integrated Environmental Modeling System for Noble Gas Releases at the Savannah River Plant.

Purpose - This code computes doses from radioactive gas releases at the Savannah River Plant at distances up to 100 kilometers.

Description - Of the releases of radioactive gases at the Savannah River Plant (SRP), the noble gases constitute about 11% of the total man-rem exposure to the population out to a distance of 100 km. Although SRP has an extensive radiological monitoring program, an environmental modeling system is necessary for adequately estimating effects on the environment. The integrated environmental modeling system in use at SRP consists of a series of computer programs that generate and use a library of environmental effects data as a function of azimuth and distance. Annual average atmospheric dispersion and azimuthal distribution of material assumed to be released as unit sources is estimated from a 2-year meteorological data base, assuming an arbitrary point of origin. The basic library of data consists of: (1) ground-level concentrations according to isotope, and (2) whole body gamma dose calculations that account for the total spatial distribution at discrete energy levels. These data are normalized to tritium measurements, and are subsequently used to generate similar library data that pertain to specific source locations, but always with respect to the same population grid. Thus, the total additive effects from all source points, both on- and off-site, can be estimated. The final program uses the library data to estimate population exposures for specified releases and source points for the nuclides of interest (including noble gases). Multiple source points are considered within a single pass to obtain the integrated effects from all sources.

Cooper, R.E.
Savannah River Laboratory
Aiken, SC 29801

Source - Reference #6: p. 142.

Model - Land Requirement for a Radioactive Waste Disposal Yard

Purpose - This model estimates the intake by humans of radionuclides through food and air.

Description - A model and the rationale were presented with respect to land use requirements for a hypothetical waste burial site. The thrust of the study was to minimize the intake by humans, of radionuclides through the food and air. A to-space transportation diffusion equation was used to describe the migration of the radionuclides in groundwater. The numerical solution was obtained by solving the equation by Crank-Nicolson type differential approximation and successive over relaxation. A sample run was made for a power plant with a total output of 2000 MWe. Numerous environmental land requirements and socio-political factors were considered. With this model it is possible to locate a burial site which ensures the greatest radiological safety. To locate burial site it is necessary to include a zone where ground water use is prohibited; a zone where use is restricted and a buffer zone. The necessary land area will increase with increasing permeability coefficient, decreasing distribution factor and increasing stratum porosity. Variations in the diffusion coefficient do not change the land requirement greatly.

Inoue, Y. and S. Morisawa
Kyoto University
Department of Sanitary Engineering
Kyoto, Japan
ORNL-TM-4444; 13 pp.
1976

Source - Reference #11: p. 149.

ATMOSPHERIC TRANSPORT

Model - Long Range Transport Modeling

Purpose - The model calculates atmospheric transport of pollutants.

Description - The winds, temperature, eddy diffusion coefficients and other meteorological parameters will be furnished by a boundary layer model being developed by NOAA. Emissions will be calculated from the NEDS Data Base and will include plume rise. The model will calculate transport of pollutants using a flux-corrected advection scheme (SHAS-TA), while diffusion will be calculated using an implicit approximation. The model will also include deposition at the surface via boundary conditions. The program has been tested using fictitious data to test the advection and diffusion schemes used. It is expected that testing of sulfur chemistry using fictitious meteorology and real emissions will be completed by June 1977.

Robert E. Eskridge
U.S. Environmental Protection Agency
Environmental Sciences Research Laboratory
Research Triangle Park, NC 27711

Source - Reference #18: p. 29.

ATMOSPHERIC TRANSPORT

Model - Low-level Isentropic Trajectories and the MIDAS Computer Program for the Montgomery Stream Function.

Purpose - This program calculates long distance three-dimensional trajectories for particles or gases in the air of any type.

Description - The optimum trajectory for releases of materials at low elevations in the atmosphere is constructed with isotropic charts.

Isentropic analysis reveals vertical motions of the material and predicts where the material will appear in the air near the ground. These trajectories can be calculated using teletyped weather data, and precipitation scavenging may be included if desired. The solutions are found using the Modified Integral Digital Analog Simulator (MIDAS) technique.

R. J. Englemann; W. E. Davis
Battelle, Pacific Northwest Laboratories
Richland, WA

Source - Reference #6: p.12.

ATMOSPHERIC TRANSPORT

Model - Modeling Atmospheric Effects - An Assessment of the Problems.

Purpose - This computer code is designed to simulate atmospheric processes that affect the pollution life cycle.

Description - An approximate transport model has been developed which is used to calculate the ambient concentration of SO_2 throughout the United States. Associated calculations include dry deposition and the ratio of dry to wet removal for each state of the contiguous United States.

Douglas G. Fox
U.S. Department of Agriculture,
Forest Service
Rocky Mountain Forest and Range Experiment Station
240 W. Prospect Street
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303-221-4390; FT 323-1254

Source - Reference #18: p. 30.

Model - Modeling of Environmental Pathways and Radiation Doses from Nuclear Facilities

Purpose - A computer model was developed which calculates total annual radiation doses and 50-year dose commitments to several categories of persons at population centers and continues these calculated doses into integrated (man-rem) annual and 50-year doses for large populations. The application to LLW management is general.

Description - The dose model was designed as one portion of an overall computer program developed to delineate the nuclear facilities expected in the year 2000, the radionuclides released to air and water, their diffusion, dispersion, and reconcentration in the environment, and the resulting radiation doses to people. Equations for calculating dose factors were derived from those given by the International Commission on Radiological Protection (ICRP). Effective decay energies for various radionuclides were calculated from the ICRP model, which assumes that all the radionuclide is in the center of a spherical organ with an appropriate effective radius. Where data were lacking, metabolic parameters for the Standard Man were used for other ages as well. The model includes a sub-routine which calculates radionuclide concentrations in a wide variety of foods at time of harvest from concentrations in air, irrigation water, and soil. The latter concentrations are output from previous portions of the overall computer program. The tremendous variety of data required for proper dose assessment is not always available in the literature. Such data has been extrapolated from environmental studies of fallout nuclides and from planned laboratory and field studies of a limited number of nuclides.

J. K. Soldat
Battelle, Pacific Northwest Laboratories
Richland, WA 99352

Source - Reference #6: p.116

Model - Numerical Models for Precipitation Scavenging

Purpose - The purpose of this code is to approximate the collection and formation of droplet size in clouds.

Description - Two models are developed. The first is designed for precipitation scavenging in stratiform clouds. This model incorporates heuristic approximations of diffusive attachment, impact collection and accretion, and includes consideration of particle and cloud droplet size spectra. An overriding, independently generated steady rain removes contaminated cloud droplets and contaminant particles. The conservation of contaminant mass is expressed by a set of three ordinary differential equations for which analytic solutions are derived. Rainout ratios and efficiencies are computed, and the results compare favorably with available field measurements. It is shown that the fraction of the air concentration of contaminant that is attached to the cloud droplets is affected by processes of particle attachment and rainfall removal. The second model addresses the problem of air cleansing by a convective rain-generating system. In this model, raindrop growth and motion in spatial contaminant concentration gradients are of major concern. Numerical solutions for raindrops growing by coalescence with cloud droplets and moving in a cylindrically symmetric motion field within a steady-state cloud are provided. The drop breakup process is formally accounted for, and, in the sub-cloud region, evaporation is considered. The contaminant concentrations of individual raindrops are computed. Drops of different sizes can have the same concentration, and under the assumed conditions a particular drop-size is identified with the minimum concentration.

Y. Lee
Michigan State University
Ann Arbor, MI
M.S. Thesis; C00--1407-52; pp. 96, 1974.

Source - Reference #18: p. 138.

ATMOSPHERIC TRANSPORT

Model - Pressure Effects on Radon 222 Transport

Purpose - This model describes radon flux variations due to atmospheric pressure.

Description - A mathematical model to describe the effect of large-scale atmospheric pressure changes on the Rn flux across the soil-air interface has been developed. Field data collected during 1972 and 1973 show that pressure changes of 1-2% associated with the passage of frontal systems produce changes in the Rn-222 flux from 20 to 60%, depending upon the rate of change of pressure and its duration. A simple model of molecular diffusion combined with pressure-induced transport in the soil has been confirmed by laboratory experiments using a vertical column of Ra-226-bearing sand. On the basis of this model, pressure changes of 10-20 mbar occurring over a period of 1-2 days produce Darcy velocities of the order of $10(E-1)$ cm/s near the surface of a soil having a permeability of $10(E-8)$ sq cm. The corresponding variations in the Rn-222 flux predicted by the model are in agreement with those observed from valley alluvium in central New Mexico.

Clements, W. E. and M. H. Wilkening
New Mexico Institute of Mining and Technology
Department of Physics
Socorro, NM
Journal of Geophysical Research
79(33), 5025-5029
November, 1974

Source - Reference #11: p. 118.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - Program for Computing External Dose Rate from a Radioactive Cloud and Numerical Examples for Nuclear Ships.

Purpose - The program calculates external dose to man from immersion and radioactive cloud.

Description - A program for calculating the external dose rate from a radioactive cloud was written in 06 NARC language (analogous to FORT-RAN). The basic equation used for the atmospheric dispersion is equivalent to the so-called generalized Gaussian plume formula with the stack and the inversion lid modifications. The numerical integration was performed using the Legendre-Gauss quadrature technique together with the polar coordinate system developed by D.S. Duncan. The time required for the integration was found to be around forty minutes on the NEAC-2206 computer.

Sato, K.; Ito, Y.; Iyori, I; Yamaji, A.

Source - Reference #6: 137.

ATMOSPHERIC TRANSPORT

Model - Source Assessment: Severity of Stationary Air Pollution Sources--A Simulation Approach

Purpose - The code simulates the effects of stationary air pollution sources.

Description - The effort gives results of a study simulating the establishment of the severity of stationary air pollution sources. The potential environmental impact of an emission source can be determined from the source severity (the ground level concentration contribution of pollutants relative to some potentially hazardous concentration of the same species). The frequency distribution of the severity of well-documented source types can be examined deterministically. A statistical approach is required to simulate the frequency distribution of the severity of source types that are complex or involve a large number of emission points in order to ultimately assess such sources. A Monte Carlo simulation technique is described, together with efficient algorithms for fitting the inverse weibull, gamma, normal, and log-normal cumulative density functions. Significant correlation is demonstrated between deterministic and simulated severity results using coal-fired steam/electric utilities as an example.

E. C. Eimutis, B. J. Holmes, L. B. Mote
Monsanto Research Corporation
Dayton, OH
PB--256310, 1976

Source - Reference #18: p.28

ATMOSPHERIC TRANSPORT

Model - The Air Pollution Component of an Ecosystem Simulation Model.

Purpose - This model is used to simulate the effects of air pollution on the environment.

Description - The air diffusion component of a total model to simulate effects of air pollution on environment and provide optimal control strategies has been developed.

Edmonds, R. L. and W. S. Benninghoff (eds), Ecological Approaches to Demonstration and Evaluation of Models. International Biological Program, Aerobiology Program, Handbook No. 3, University of Michigan, Ann Arbor.

Source - Reference #18: p.28

ATMOSPHERIC TRANSPORT

Model - The effect of ground level absorption on the dispersion of pollutants in the atmosphere.

Purpose - This code measures the effect of ground level absorption on the dispersion of pollutants in the atmosphere.

Description - The emission of an air pollutant species from a point or line source has been studied analytically for a case in which the pollutant may be absorbed or desorbed at ground level. The solution of the mass conservation equation leads to expressions which describe the concentrations downstream from the emission source. The ground level concentrations are presented in the form of dimensionless plots. Typical numerical values for the parameters in the equations were used to show that the concentration profiles over water in the vicinity of the emissions source would be appreciably affected only for very soluble gases, such as SO_2 , NH_3 and HCl .

Heines, T.S.; Peters, L.K.
Cleveland State University
Department of Computer and Information Science
Department of Chemical Engineering
Cleveland, OH
Atmospheric Environment, 8, 1143-1153, 1974.

Source - Reference #18: p. 40.

ATMOSPHERIC TRANSPORT

Model - Urban Air Pollution

Purpose - The code is used to calculate pollution levels for urban areas.

Description - For the usual case of receptors within a city, the area source component of urban air pollution is strongly dominated by the source strength pattern and by transport by the mean wind. Urban area source patterns tend to be fairly uniform and atmospheric diffusion conditions in cities tend to be of the near-neutral type, without the strong diurnal variations found elsewhere. For these reasons a simple area source formula $X=cQ/u$ where X is air pollution concentration, Q is source strength per unit area, and u is average wind speed, is studied. The parameter c is, according to the authors' urban diffusion model, a weak function of city size and should be approximately constant. This formula is compared with means derived from a large quantity of air pollution data, average annual emissions and concentrations of particles for 44 U.S. cities and SO_2 data for 20 cities, in order to calibrate the constant, c . The constant c is found to equal about 225 for particles, and 50 for SO_2 . Standard deviations of c are roughly half their magnitude. The value $c=225$ for particles is most representative of the purely meteorological processes governing urban diffusion, since c is low for SO_2 because of the greater influence of strong elevated point sources and of SO_2 decay. It is suggested that this simple formula has wide applicability in air pollution investigations.

F. A. Gifford, Jr.
National Oceanic and Atmospheric Administration
Atmospheric Turbulence and Diffusion Laboratory
Oak Ridge, TN 37830
615-483-8611 Ext-3481; FTS 850-4081

Source - Reference #18: p. 32.

ATMOSPHERIC TRANSPORT

Model - Vertical transport and removal of radioactive aerosols in the atmosphere: quantitative models of aerosol washout by precipitation and dry deposition on the underlying surface.

Purpose - Used to predict the vertical transport of fallout radioisotopes.

Description - On the basis of a review of quantitative models of the vertical transport of fallout radioisotopes and the removal of radioactive aerosols in the troposphere, estimates are given for the rates of removal of radioisotopes from the ground level layer of the atmosphere by dry deposition and seasonal variations in precipitation washout at various geographical locations. Equations are presented for the vertical dissipation of contaminant concentration in the boundary layer of the atmosphere.

Karol, I.L.

Source - Reference #18: p. 44.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - ACRA, A Computer Program for the Estimation of Radiation Doses Caused by a Hypothetical Reactor Accident.

Purpose - A computer code to calculate atmospheric dispersion of radionuclides released from nuclear accidents.

Description The radioactive material released to the atmosphere on account of a hypothetical reactor accident is transported away by the wind and is dispersed in a 3-dimensional normal distribution. The fission product activity is described throughout the space domain as a function of time. Presently the code calculates two types of exposure from the passing cloud of finite size: internal exposure from inhalation of the radionuclides in the air, and external dose from gamma radiation. The cloud depletion terms by washout and dry deposition have not been incorporated. However, this option can be easily implemented. Up to 100 receptor locations and 20 time intervals can be handled in one run. The program accepts information for up to 300 isotopes. Computer time is about 3 seconds per receptor and time inversion layers are present.

Mathematical analysis is based on information in ORNL-4086. Density distribution of the dispersed cloud is assumed to be Gaussian. Only linear nuclear decay sequences are handled. This code has been updated by ACRA II in which the effects of plume depletion resulting from wet and dry deposition are considered.

Stallmann, F.W.
Oak Ridge National Laboratory
Oak Ridge, TN 37830

Source - Reference #6: p. 117

Model - ACRA II

Purpose - ACRA II was developed for estimation of external and inhalation doses from atmospheric releases of radioactive material during hypothetical nuclear reactor accidents.

Description - The radioactive material is assumed to be uniformly mixed within the reactor containment system and released to the atmosphere at a uniform rate. Filtration upon release may be included. Dispersion of the material leaving the stack is described as three-dimensional normal distribution with symmetric horizontal distribution ($s_x = s_y$). Reflections off the ground plane and off an inversion layer^x are described by the virtual cloud image technique. The effective release height is calculated by the method of Holland, "Meteorology and Atomic Energy" (1955).

The inhalation dose is a function of the air concentration at the exposure point while the external dose depends on the distribution of material throughout the plume. The external gamma dose rate is calculated as the volume integral of the contributions from all photons for each nuclide as a function of time. The total dose is then calculated as the time integral of the dose rate. The amount of each nuclide is calculated as a function of time after the accident and transit time to the exposure point according to a linear decay sequence.

The volume integral is calculated as a function of gamma energy and cloud dimensions only and is, therefore, independent of time after the accident. The dimensions of the cloud are specified as a function of distance from the release point to the exposure point.

Numerical instabilities in the radioactive decay calculation are avoided by using a technique similar to that developed by H. H. Van Tuyl (1964). Radionuclide decay is handled as a linear sequence without branching. Branching may be included by splitting the decay sequence into a number of independent linear chains through manipulation of input.

The program does not depend on any particular internal dosimetry model. Dose conversion factors are supplied as input to convert to rem from μCi uptake. Breathing rate is also supplied. All nuclide and dosimetric data are supplied via data cards.

Considerable attention has been given to the external gamma dose space integration. The mathematical treatment is thorough and numerical approximations are employed where appropriate. ACRA II is written in FORTRAN IV for an IBM computer.

F. W. Stallman, and F.B.K. Kam (1973)
Union Carbide Corporation
Oak Ridge National Laboratory
Oak Ridge, TN.

Source - Reference #12: pp. B-33, 34.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - AERIN, A Code for Acute Aerosol Inhalation Exposure Calculations.

Purpose - AERIN is a code designed to compute organ and tissue burdens and doses resulting from acute exposure to inhaled radioactive aerosols.

Description - AERIN is a FORTRAN IV program written to simplify the application of equations for computing the organ and tissue burdens and doses resulting from an acute inhalation exposure to a radioactive aerosol. The models which form the basis for the calculations are (1) the deposition and clearance models of the International Commission on Radiological Protection (ICRP) Task Group on Lung Dynamics, (2) the gastrointestinal (GI) tract model of Eve (1966) and (3) a single exponential model for the "critical" organs and tissues. The fundamental data for the respiratory and GI tract models are written into the program. The user can select suitable dosimetric parameters for the respiratory and GI tract tissues, choose the appropriate metabolic and dosimetric quantities to be used in calculations for the "critical" organs and tissues, and specify the number of computations to be made and the time interval between them. The output consists of a complete listing of the assumed parameters as well as the organ and tissue burdens and doses as functions of time post exposure.

Voilleque, P.G.
Health Services Laboratory
U.S. Atomic Energy Commission
Idaho Falls, ID

Source - Reference #6: p. 133.

ATMOSPHERIC TRANSPORT
DOSIMETRY
FOOD CHAIN

Model - AIRDOS - EPA

Purpose - The AIRDOS-EPA computer code is a methodology, designed for use on IBM-360 computers, that estimates radionuclide concentrations in air; rates of deposition on ground surfaces; ground surface concentrations; intake rates via inhalation of air and ingestion of meat, milk, and fresh vegetables; and radiation doses to man from airborne releases of radionuclides.

Description - A modified Gaussian plume equation is used to estimate both horizontal and vertical dispersion of as many as 36 radionuclides released from one to six stacks or area sources. Radionuclide concentrations in meat, milk and fresh produce consumed by man are estimated by coupling the output of the atmospheric transport models with the U.S. Nuclear Regulatory Commission, Regulatory Guide 1.109 terrestrial food chain models. Dose conversion factors are input to the code, and doses to man at each distance and direction specified are estimated for total body, red marrow, lungs, endosteal cells, stomach wall, lower large intestine wall, thyroid, liver, kidneys, testes, and ovaries through the following exposure modes: (1) immersion in air containing radionuclides, (2) exposure to ground surfaces contaminated by deposited radionuclides, (3) immersion in contaminated water, (4) inhalation of radionuclides in air, and (5) ingestion of food produced in the area.

The code may be run to estimate highest annual individual dose in the area or annual population dose. For either option, output tables summarize doses by nuclide, exposure mode, and organ. Also, for either a square or circular grid option, ground concentrations of radionuclides and intake rates by man are tabulated for each environmental location. Working level exposures are also calculated and tabulated for inhalation of ^{222}Rn short-lived progeny. Run time is less than 5 min on the IBM 360/91, and the core requirement is 650 K (kilocore).

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Building 7509
Oak Ridge National Laboratory
Oak Ridge, TN 37830

Source - Reference #4

Model - AIREM

Purpose - The AIREM code was developed for analysis of emissions and effluents from nuclear fuel cycle facilities. The program may be used to estimate air concentration, ground deposition (both wet and dry) and doses from external gamma radiation and from inhalation.

Description - The dispersion calculation, based on the sector-averaged Gaussian diffusion model, produces results as a function of direction and distance for each nuclide. Contributions from the first daughter are included. The release is assumed to be at a constant rate over a specified release period. In-plant holdup time and decontamination factors may be supplied as input. Inhalation doses are calculated using conversion factors for each organ (four per run) and nuclide (twenty per run). For the external gamma dose, a table of dose integrals is to be supplied relating dose to release height, cloud size and gamma energy. A modified version of EGAD (Cooper, 1972) is given in the AIREM report (Martin, 1974) for calculation of the dose integrals.

The code requires dose conversion factors as input for each radionuclide, organ and population group. A table of dose conversion factors is also required for the finite cloud gamma dose calculation. Meteorological data are supplied as the frequency (percent of time) that the wind blows in a sector under a given stability class. An average wind speed must be supplied for each direction and stability combination. This procedure carries less information than supplying frequency data as a function of direction, stability and wind speed class. Air concentrations and wet and dry ground deposition are calculated and printed for each nuclide as a function of distance and direction, with effects of decay in transit included. The contribution to external body exposure from nuclides in adjacent sectors is included in the dose integrals calculated by the code EGAD. This is accomplished by integrating in the lateral direction over all distances contributing significantly to dose without respect to sector boundaries. Inherent in this procedure is the assumption that the wind blows uniformly in all sectors adjacent to the given sector. AIREM is written in FORTRAN IV for an IBM 370 system.

J.A. Martin, Jr., C.B. Nelson, and P.A. Cuny (1974)
U.S. Environmental Protection Agency
Washington, D.C.

Source - Reference #12: p. B37.

ATMOSPHERIC TRANSPORT
DOSIMETRY
FOOD CHAIN

Model - AIRWAY

Purpose - This is a model to estimate the local radiation doses to man from the atmospheric release of radionuclides.

Description - A model was developed to estimate the radiation dose commitments received by people in the vicinity of a facility that releases radionuclides into the atmosphere. This model considers dose commitments resulting from immersion in the plume, ingestion of contaminated food, inhalation of gaseous and suspended radioactivity, and exposure to ground deposits. The dose commitments from each of these pathways is explicitly considered for each radionuclide released into the atmosphere and for each daughter of each released nuclide. Using the release rate of only the parent radionuclide, the air and ground concentrations of each daughter are calculated for each position of interest. This is considered to be a significant improvement over other models in which the concentrations of daughter radionuclides must be approximated by separate releases.

J. L. Rider, S. K. Beal
Bettis Atomic Power Laboratory
P. O. Box 79
West Mifflin, PA 15122
412-462-5000 EXT. 384; FTS 721-0384
National Technical Information Service WAPD-TM-1273, 34 pp.

Source - Reference #18: p.273

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - AISITE II: A Digital Computer Program for Investigation of Reactor Siting.

Purpose - This code is used to determine allowable sitings of nuclear reactors based on reactor parameters. It also can provide dose/distance data for existing reactors.

Description - AISITE II automatically varies any one of 46 parameters such as reactor power, building leak rate, iodine cleanup rate, halogen filter efficiency, etc. The siting criteria of 10CFR100 are used in AISITE II with computation of the exclusion area, low population boundary zone, and low-population-center distances as functions of any parameter. In addition, dose-versus-distance curves are obtained for inhalation, direct building, and direct cloud doses. The printed edit consists of the dose-versus-distance data, fractional contribution by isotope group to the inhalation dose, and critical distances for both a 2-hr and a 30-day release. Graphical displays can be obtained for critical distances as a function of the variable parameter and dose versus distance for any organ or the critical organ, for each value of the parameter. Three isotope release models with up to four levels of containment are provided.

Blaine, R.A.
Atomics International
Canoga Park, CA

Source - Reference #6: p. 129.

GENERAL TRANSPORT
RISK ASSESSMENT

Model - AMRAW: Risk Assessment Method for Radioactive Waste Management.

Purpose - This model provides calculational methods for risk assessment in radioactive waste management systems.

Description - A Radioactive Waste Management Systems Model was developed and implemented by the University of New Mexico under contract with the U.S. Environmental Protection Agency. The systems model and associated computer code called AMRAW (Assessment Method for Radioactive Waste), has two parts. The first part, AMRAW-A, consists of the Source Term (Radioactive inventory versus time), the Release Model, and the Environmental Model. The Release Model considers various geologic and man-caused events which are potential mechanisms for release of radioactive material beyond the immediate environs of a repository or other location; the risk analysis mode uses events distributed probabilistically over time, and the consequence analysis mode uses discrete events occurring at specified times. The Environmental Model includes: 1) the transport to and accumulations at various receptors in the biosphere, 2) pathways from these environmental concentrations, and 3) resulting radiation dose to man.

The second part of the system model, AMRAW-B, is the Economic Model which calculates health effects corresponding to the various organ dose rates from AMRAW-A, collects these health effects in terms of economic costs and attributes these costs to radionuclides, decay groups, and elements initially in the waste inventory. Implementation, with calculated results, of AMRAW for Terminal Storage in a Bedded Salt Reference Repository has been accomplished. Preliminary demonstrations for the repository operations phase of waste management and terminal storage in a shale formation have also been accomplished; possible applications to other radioactive and nonradioactive hazardous materials have been discussed. AMRAW uniquely links all analytic steps together in a continuous calculation sequence.

S. E. Logan
Chemical and Nuclear Engineering Department
College of Engineering
University of New Mexico

Source - Reference #10: June 1978, p.v

DOSIMETRY
FOOD CHAIN
SURFACE WATER TRANSPORT

Model - AQUAMAN

Purpose - AQUAMAN is a computer code for calculating dose commitment to man from aqueous releases of radionuclides.

Description - AQUAMAN is an interactive computer code for calculating values of dose (50-year dose commitment) to man from aqueous releases of radionuclides from nuclear facilities. The data base contains values of internal and external dose conversion factors, and bioaccumulation (freshwater and marine) factors for 56 radionuclides. A maximum of 20 radionuclides may be selected for any one calculation. Dose and cumulative exposure index (CUEx) values are calculated for total body, GI tract, bone, thyroid, lungs, liver, kidneys, testes, and ovaries for each of three exposure pathways: water ingestion, fish ingestion, and submersion. The user is provided the option at the time of execution to change the default values of most of the variables, with the exception of the dose conversion factor values. AQUAMAN is written in FORTRAN for the PDP-10 computer.

D. L. Shaeffer, and E. L. Etnier
Oak Ridge National Laboratory
Oak Ridge, TN 37830
ORNL/TM-6618, p. 27, Feb. 1979.

Source - Reference #25: p. 36.

DOSIMETRY
SURFACE WATER TRANSPORT

Model - AQUAMOD: A Systems Analysis Model for Calculating Radionuclide Transport Between Receiving Waters and Bottom Sediments.

Purpose - This code is used in analyzing radionuclide transport between receiving waters and bottom sediments and the resulting doses to man.

Description - Equilibrium radionuclide concentrations in waters receiving radioactive effluents and in bottom sediments associated with the receiving waters were calculated so that potential doses to man and biota and radionuclide buildup in the environment could be determined realistically. A four-compartment systems analysis model was developed to predict dynamic radionuclide transfer. The dependent variables of the model are the receiving water, interstitial water intermingled with the bottom sediments, bottom sediment particles that undergo sorption-desorption reactions with the interstitial water, and bottom sediment particles that undergo only sorption reactions with the interstitial water. The model was used to generate two tables. The first table gives equilibrium radionuclide concentrations in the receiving water when radionuclide transfer to bottom sediments are possible, divided by the receiving water concentrations when transfers to bottom sediments are ignored. These factors are always less than unity, since radioactivity must be conserved, and adding sediments to the system adds another compartment where radionuclide concentrations will equilibrate. The other table lists ratios of equilibrium radionuclide concentrations in sediments, divided by their corresponding receiving water concentrations. These concentrations in the sediments can be used to calculate external doses to a person sunbathing or fishing. Preliminary results indicate that the usual effect of a neglect of sediment interactions is an overestimation of the total potential dose to man from the radionuclides. This neglect of sediment interactions overestimates receiving water concentrations which, in turn, overestimates potential doses from important pathways (drinking water or eating fish) directly related to the receiving water concentration. This would not be the case, however, for a situation where exposure to radionuclides in sediments is the critical pathway. The results for Cs-137 are particularly interesting since it often causes a major fraction of the calculated dose for a typical release. For environmental parameters appropriate to freshwater lakes in the northeastern states, neglecting sediment interactions could result in potential doses approximately 4 times too high from Cs-137 contained in potable water and edible fish. Further, increasing only the Kd value of a sample of sediment from 27,000 to 270,000 (which reflects various freshwater environments) increases this factor from approximately 4 to approximately 25.

Booth, R.S.
Oak Ridge National Laboratory
P. O. Box X, Oak Ridge, TN 37830

Source - Reference #18: p. 151.

ATMOSPHERIC TRANSPORT DOSIMETRY

Model - ARCON: Areas Affected by Ground Deposition of Cs-137.

Purpose - This code is used in determining ground deposition of Cs-137 from an atmospheric release.

Description - The code deals with the combined probability analysis and parametric study of Cs-137 deposition after a postulated nuclear reactor accident. Study was performed for a 3000 MW(th) reactor at a site typical of the Oslo Fjord area. No efforts have been made to determine definite accidental sequences or amounts of release. It is simply postulated that an accident has taken place that will lead to release of a large amount of radioactivity to the atmosphere during a relatively short time period: on the order of one hour. The size of the area affected by a certain release of radioactive cesium depends upon the meteorological conditions during the release time period. Local weather data have been used to determine the probability of a certain magnitude of the area. The results are given in the form of conditional, cumulative probabilities. Conditional because they give the probability of a certain magnitude of the consequence if the release has taken place and the wind is blowing in the direction for which the weather data are valid. Cumulative because, e.g., the 5% probability means that the weather conditions may give these or worse consequences with a 5% probability or, expressed differently, they will give less severe consequences with a 95% probability. Since the calculations do not apply to a specific accident sequence, several pertinent release characteristics cannot be assigned a definite value. The most important are: amount of Cs-137 due to decay of radioactive materials; and deposition velocity. The last item is only partially a release characteristic. Besides depending upon particle size and chemical conditions, the deposition velocity depends upon characteristics of the land area over which deposition takes place. A parametric study is performed by varying each of these characteristics over a certain range while keeping the others fixed at what it is reasonable to assume are typical values under extreme accident conditions. A computer code ARCON has been developed for this analysis, adaptable to a large range of calculations connected to atmospheric releases during accident conditions as well as normal operation, e.g., calculation of reference levels for milk consumption, health effects on specified populations, and the area within any kind of concentration limit or dose limit (except external gamma dose). The program may be modified for longer release times, but not easily. While Cs-137 is the only isotope treated, other isotopes may be treated in a similar manner.

U. Tveten, Institute for Atomenergi, Kjeller, Norway, 1975. IAEA-SM-188/35; Siting of Nuclear Facilities, Proceedings of a Symposium held in Vienna, Austria December 9-13, 1974, pp. 497-515.

Source - Reference #26: Item 1225.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - AREAC: Area Source Radiological Emission Analysis Code.

Purpose - A computer code designed to calculate the potential radiological impact of atmospheric releases of radionuclides from area sources.

Description - The code is written in Fortran IV, requires 48K storage, and runs about 12 seconds on an IBM 370 system. The code can calculate radionuclide concentrations and individual inhalation doses at up to six specific receptor locations and at up to 192 general locations around an area source. Population doses can also be calculated. The code accounts for area source shape, cloud diffusion, ground and inversion-lid reflections, and radionuclide decay by time of flight. It is dose model-independent and requires a dose conversion factor as part of the input data to calculate doses proportional to radionuclide concentrations.

D. Michlewicz
Environmental Protection Agency
Office of Radiation Programs
Washington, D.C.
ORP/EAD-76/6, p. 63, Oct. 1976.

Source - Reference 25: p.90.

DOSIMETRY
FOOD CHAIN
SURFACE WATER TRANSPORT

Model - ARRRG, Aqueous Release of Radionuclides Report Generator.

Purpose - ARRRG calculates annual individual and population doses resulting from radionuclides released with liquid effluents. It is part of the HERMES computer program.

Description - ARRRG calculates annual individual and population doses resulting from radionuclides released to surface-water bodies. Eight environmental pathways are modeled: eating fish, crustacea, molluscs, and algae; drinking surface water; direct external radiation from shoreline; water immersion (swimming), and direct external radiation from boating. Doses are calculated for skin, total body, gastrointestinal-lower large intestinal tract, thyroid, bone, liver, lung, and kidney. The output format specifies contributions to the dose by nuclide and by pathway.

Currently ARRRG is operational with the capability of calculating doses for 6 organs and 200 radionuclides. The user inputs the following variables from an interactive terminal: the name of the facility under investigation; decay between release and point of exposure (holdup), usages, and mixing ratios by pathway; reactor coolant flow, shoreline width factor and reconcentration factor parameters.

J.K. Soldat, N.M. Robinson, and D.A. Baker (1974)
Battelle, Pacific Northwest Laboratories
Richland, WA

Hoenes, Glenn R.
Battelle, Pacific Northwest Laboratories
Post Office Box 999
Richland, WA 99352
509-942-3754; FTS 444-7511 EXT 942-3754

Source - Reference #8: p. 207-208, #12 p. 2-27, B-39.

ATMOSPHERIC TRANSPORT DOSIMETRY

Model - ATM: A Comprehensive Atmospheric Transport and Diffusion Model.

Purpose - This code applies a detailed atmospheric transport model suitable for long-lived radionuclides dispersed in air.

Description - A comprehensive version of the Atmospheric Transport Model (ATM) has been developed that includes the effect of aerodynamic roughness on dispersion constants, clarifies the roles of the terminal velocity and deposition velocity, incorporates a tilting plume for heavy particulates, and includes an episodic calculation of exposure maxima. This model also limits the maximum value of the dispersion constants in order to retain the emitted material in the planetary boundary layer. The structure of the program has been modularized in order to clarify the flow of calculation and allow more flexibility. Values for atmospheric concentration as well as both wetfall and dryfall deposition are calculated. The model has been applied to three power plants. The dispersion calculation is based on the Gaussian plume model, corrected by the above considerations. The model allows the use of point sources, line sources, area sources, and windblown resuspension sources.

It should be noted that this program does not include corrections for radioactive decay or daughter product formation so care must be exercised if it is to be used for atmospheric transport of radionuclides. This, however, should not be significant for long-cooled waste material.

Culkowski, W.M.
Oak Ridge National Laboratory
Oak Ridge, TN 37830

Source - Reference: #6: p. 127.

Model - BELCH: TVA Gaseous Dispersion Code

Purpose - This code calculates doses to the public from routine gaseous releases at power reactors.

Description - The TVA gaseous dispersion code calculates individual and population doses to the public from routine gaseous radioactive release from TVA's power reactors; the methodology is that set forth in NRC Reg. Guides 1.109 and 1.111. The code uses site-specific meteorological data, agricultural data, and population information to estimate doses to individuals at site boundaries, nearest residences, and real milk cow locations. Populations doses to persons living within 50 miles of the site are also calculated. Dose pathways considered include beta and gamma air doses at the site boundary, skin and total body doses at nearest residences, and thyroid doses at milk cow locations. Thyroid doses include the following pathways: submersion, ground contamination, inhalation, and ingestion of beef, vegetables and milk. Estimated doses are considered conservative for average animal, routine radioactive releases.

Rodican P. Reed
Tennessee Valley Authority
Environmental Planning
River Oaks Bldg.
Muscle Shoals, AL 35660
205-383-4631 EXT 2767; FTS 872-8767

Source - Reference #18: p. 96

Model - BETA: A Computer Program for Calculating Beta-Dose Rates From Point and Plane Sources

Purpose - A computer program to calculate BETA dose rates.

Description - A computer program has been written to calculate the beta dose-rate at various distances from a point source, or along the axis of a disc source, containing a mixture of beta-emitters. Data for 75 radionuclides published recently by Berger are used, and the dose-rates may be evaluated in any isotropic homogeneous medium of low atomic number and arbitrary density. The program has been used to produce tables of beta dose-rate distributions in unit density tissue near point and plane sources of each of the 75 radionuclides. Extensive Documentation is available. The program is written in O/S 370, FORTRAN IV (H).

M. R. Bailey
Central Electricity Generating Board
Berkeley Nuclear Laboratories
United Kingdom

Source - Reference #6: p.143

Model - BIM130

Purpose - This code is applicable to any problem involving neutron and/or photon transport, especially in real space, e.g., shielding, dosimetry, therapy, spectrometry.

Description - BIM130 is a computer analogue Monte Carlo program for the detailed computation of neutron-proton interactions with matter to at least 15 mev. 45 regions, of any composition chosen from 15 elements, may be specified, of any size, interrelation and shape expressible as algebraic functions. Similarly, a variety of sources may be included. The program uses available data for the calculations, and with storage and output facilities gives neutron, photon, and let spectra as well as N/gamma dose spectra for each region, and doses deposited in 19360N and 19360gamma histograms. Two geometric descriptions of a standard man are proposed. The results differ markedly, in many regions, from those previously obtained with the simple, symmetric, homogeneous solids used as human phantoms. BIM has lost the expertise in using and supporting this code due to staff termination. Code and listings are retained but any effort to use it would involve prolonged study.

Frank S. Williamson
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Biological and Medical Research Division
9700 S. Cass Ave.
Argonne, IL 60439
FTS 972-3864

Source - Reference #18: p.278

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - BURP: TVA Gaseous Effluent Licensing Code for Uranium Mining and milling.

Purpose - This code calculates individual doses due to environmental release of U-238 daughter radionuclides.

Description - BURP calculates atmospheric concentrations and individual doses due to the environmental release of U-238 decay chain radionuclides. Pathways to man include ingestion, inhalation and air submersion. Ingestion doses are calculated using methodology similar to NRC Regulatory Guide (NRC RG) 1.109 and the effect of the decay and build-up of subsequent decay chain products is fully accounted for. In addition, inhalation and air submersion doses are calculated using NRC RG 1.109 methodology. Organs for which doses are evaluated are total body, skin, liver, bone, lungs and bronchial epithelium, stomach, small intestines, ULI, and LLI. The code is capable of handling multiple sources of release.

Nicoll, Regis M.
Tennessee Valley Authority, Environmental
Planning, River Oaks Bldg.
Muscle Shoals, AL 35660

Source - Reference #18: p. 73.

Model - CARDOCC: Modeling of Radiation Doses from Chronic Aqueous Releases.

Purpose - A general model and corresponding computer code, called CARDOCC, were developed to calculate personnel dose estimates from chronic releases via aqueous pathways.

Description - Cardocc uses the internal dose portion of the ARRRG code, increases its generality and scope, and simplifies the input requirements. Potential internal dose pathways are consumption of water, fish, crustacean, and mollusk. Dose prediction from consumption of fish, crustacean, or mollusk is based on the calculated radionuclide content of the water and applicable bioaccumulation factor. 70-year dose commitments are calculated for whole body, bone, lower large intestine of the gastrointestinal tract, and six internal organs. In addition, the code identifies the largest dose contributor and the dose percentages for each organ-radionuclide combination in the source term. The 1974 radionuclide release data from the Savannah River Plant were used to evaluate the dose models. The dose predicted from the model was compared to the dose calculated from radiometric analysis of water and fish samples. The whole body dose from water consumption was 0.45 mrem calculated from monitoring data and 0.61 mrem predicted from the model. Tritium contributed 99% of this dose. The whole body dose from fish consumption was 0.20 mrem calculated from monitoring data and 0.14 mrem from the model. Cesium 134,137 was the principal contributor to the 70-year whole body dose from fish consumption.

J. R. Watts
Savannah River Laboratory
Aiken, SC 29801

Source - Reference #6: p.120

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - CDR: Air Transport Calculations Using the LASL-NWEF Air Flux Tape and the NWEF Computer Program--CDR

Purpose - Calculates ranges of constant dose from a point source.

Description - The recent availability of coupled neutron-gamma, multi-group, cross-section sets has prompted the production of a neutron-gamma air flux tape similar to the neutron air flux tape reported previously. The air flux data consists of complete transport calculations in uniform, sea-level air for one source neutron in each of 30 energy groups and one source photon in each of 12 energy groups. The computer program CDR (constant dose range) uses the new air flux tape to produce ranges of constant dose from a point source in the atmosphere.

J. E. Campbell
253050 Naval Weapons Evaluation Facility
Albuquerque, NM
Report No. NWEF-1090

Source - Reference #18: p.13

DOSIMETRY

Model - CEDRIC: A Multi-Compartment Model for Studying the Dose-Intake Relationship for Radioactive Isotopes.

Purpose - A code provided to estimate dose to internal organs of man from radionuclides received by ingestion, inhalation, or through the skin.

Description - A model (CEDRIC) has been developed in which the various organs of the body are represented by single or multiple compartments, coupled to provide a simplified metabolism. The method of entry of radioactive material may be by inhalation, ingestion, through contaminated skin or a wound, using standard models for the respiratory and gastrointestinal tracts. The distribution of a parent nuclide and all its daughter products throughout the compartments is followed as a function of time by the solution of the set of first order differential equations which represent transport within the body. Either acute or chronic exposures are treated and facilities exist for varying metabolic parameters with time. Special attention has been given to dealing with multi-exponential retention functions, both for individual organs and for the whole body, and methods of treating power function retention data are given. Examples of the use of the compartment model under these conditions have been included and the results compared with published results given by the International Commission on Radiological Protection in ICRP-10 (1968) and by Voilleque (1971), who has published details of a simplified compartment model which he developed (Voilleque, 1970). CEDRIC (Computer Evaluation of Doses from Radioactive Isotopes by Compartments) is written in FORTRAN IV. Typical running times vary from a few seconds to approaching 60 seconds for a complex case. Documentation is available.

The compartment model CEDRIC is a FORTRAN IV code which improves upon the SAURON (1970) code which was based upon the metabolic retention data and lung models adopted by ICRP II (1959). These models have been developed as part of the WEERIE program.

Clarke, R.H.
Central Electricity Generating Board
Berkeley Nuclear Laboratories
United Kingdom

Source - Reference #6: p. 122.

Model - CHIM: Composite Hazard Index Methodology

Purpose - To provide methodology for limiting human exposure to environmental pollutants.

Description - A calculational hazard index methodology is developed for limiting human exposure to environmental pollutants. Hazard index is defined as Q/Q_1 , where Q is a measure of exposure, such as an organ's burden of a pollutant from all environmental pathways, and Q_1 is a corresponding limit that should not be exceeded because of health risk to human beings. Mathematical formulations relating hazard indices to environmental pollutant concentration are developed for each sampling medium corresponding to each effluent mode. These formulations are used to derive limiting pollutant concentrations such that the resultant measure of exposure will not exceed the health risk limit. Mathematical formulations for composite hazard indices for multiple pollutants are presented in the reference below.

Phillip Walsh, George G. Killoug, Paul S. Rohwer
Health and Safety Research Division
Oak Ridge National Laboratory
P. O. Box X
Oak Ridge, TN 37830
July 1978

Source - Environmental Science and Technology, July 1978.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - COMO, Atmospheric Dispersion Model as used in the Reactor Safety Study, WASH-1400.

Purpose - This code is designed to aid in determining dose levels from reactor accidents.

Description - The Reactor Safety Study, WASH-1400, was published in final form in October, 1975, by the U.S. Nuclear Regulatory Commission. The objective of predicting consequences of a given radioactivity release was accomplished through construction and execution of a computerized model which accounted for the manner in which radioactivity is dispersed in the environment, the number of people and amount of property exposed, the effects of radiation exposure on people, and property contamination. The basic elements of the model, release characteristics, atmospheric dispersion, dosimetry, population, health effects, and property damage are documented. The code COMO (for consequence model) was used for dose calculations.

Church, H.W.
Sandia Laboratories
Albuquerque, NM

Source - Reference #18: p. 258.

ATMOSPHERIC TRANSPORT DOSIMETRY

Model - COMRADEX

Purpose - The COMRADEX code was developed to calculate radiation doses from postulated accidental release of radionuclides from nuclear reactors.

Description - The code considers up to four levels of containment with independent time varying leak rates. Filtration, particle coagulation and fallout, and special cleanup systems are also included in the containment model. Material reaching the atmosphere is dispersed according to the bivariate Gaussian model with dispersion parameters (s_y and s_z) defined by the Pasquill curves A-F (Pasquill, 1962; Hilsmeier and Gifford, 1962). Plume rise is considered by specifying an effective height of release.

Doses calculated by COMRADEX include direct dose from contained activity, external cloud gamma dose, and internal dose from inhalation of contaminated air. The external cloud gamma dose is calculated by a space integration over the active volume of the plume (finite cloud approach). The inhalation dose may be for as many as 14 organs of interest by specifying appropriate dose conversion factors.

The initial inventory is specified as disintegrations per second for each nuclide. Shielding between various containment shells is accounted for by an attenuation factor in calculating the direct dose from contained material. Air attenuation for this calculation is done for one photon energy. Volume sources are modeled by a virtual source technique. For the finite cloud integration, s_y and s_z are held constant about the exposure point. The space integration is performed by dividing the Y-Z plane into small rectangles and evaluating the dose kernel at the center of each rectangle. The finite cloud integration is performed for only one photon energy. COMRADEX is written in FORTRAN IV for an IBM 360.

G.E. Spangler, C.A. Willis and E.A. Rhoades (1968).
McDonnell Douglas Corporation
Santa Monica, CA

Source - Reference #12: p. B41.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - COMRADEX - IV The Containment and Meteorology of Environmental Radiation Exposure Code.

Purpose - This code is used in computing site dose from accidental radioactive releases.

Description - The COMRADEX-IV (containment and meteorology of environmental radiation exposure) code was developed for the calculation of radiological doses from hypothetical power reactor accidents. It permits the user to analyze as many as four levels of containment with time varying leakage and fallout rates in each level. Filtration in each containment region may be by isotopic class (noble gas, solids, or halogens). Shielding may be introduced between the various containment shells. The environmental doses calculated include the direct gamma dose from the containment building, the internal doses to as many as 12 body organs (such as the thyroid, bone, lung, etc.) due to inhaling the airborne radioactivity, and the external gamma and beta doses from the cloud. Leakage and fallout rates, and initial inventory must be given as input data. A direct numerical technique, designed especially for quasi-linear differential equations, is used to solve the leakage (as well as containment region fallout) and decay chains. Either the meteorology model of Pasquill, with Briggs' dispersion coefficients, or site-specific attenuation factors may be used. The cloud gamma dose is obtained by integrating over an anisotropic Gaussian cloud. The external beta dose calculation assumes a semi-infinite radioactive cloud. Plume tilt due to gravity and dry deposition may be calculated.

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Atomics International Division
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Source - Reference #18: p. 108.

DOSIMETRY

Model - CONDOS: A Model and Computer Code to Estimate Population and Individual Radiation Doses to Man from the Distribution, Use, and Disposal of Consumer Products that Contain Radioactive Materials.

Purpose - This code is used to estimate radiation doses to man from various consumer products.

Description - A model and computer code (CONDOS) are described that estimate radiation doses to man from distribution, use, and disposal of a variety of consumer products that contain radioactive materials. CONDOS utilizes a generalized format in which the life span of a consumer product is divided into five main stages (distribution, transport, use, disposal, and emergencies) that require descriptions of the activities by which man may be exposed to the product (events) during each stage. These descriptions identify homogeneous groups of exposed persons and, thus, facilitate the selection of individuals who represent the exposed groups. The radiation doses associated with one year of product use to the total body and to selected reference organs and tissues of representative individuals can be estimated for each mode of exposure that is applicable to each event. Summation of the doses to representative individuals yields group and total population doses. An example of the use of CONDOS is given; the radiation doses associated with a hypothetical product are estimated for assumed conditions of exposure.

F. R. O'Donnel; L. R. McKay; O. W. Burke; F. H. Clark, Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN, May 1975. ORNL-TM-4663; Environmental Sciences Division No. 638; 99 p.

Source - Reference #26: Item 645.

ATMOSPHERIC TRANSPORT DOSIMETRY

Model - CRAC

Purpose - This model is to calculate atmospheric dispersion and ground deposition of radionuclides released from a postulated nuclear power plant accident.

Description - A computer model (CRAC) was developed for the reactor safety study (WASH-1400) to estimate the consequences of postulated accidents at U.S. commercial nuclear power plants. One hundred reactors at 68 sites were included in the study. The 68 sites were divided into 6 classes according to their geographic location and meteorology. For each site class, a composite population distribution was constructed from the true population distributions at each of the sites comprising that class, and a reference site was chosen for which a full year of meteorological data (wind speed, atmospheric stability, occurrence of rain) was obtained, given data about a postulated accident (probability, amounts of the released radionuclides, etc.) and the reference reactor site (meteorology, composite population, land usage), CRAC was used to calculate the atmospheric dispersion and ground deposition of the released radionuclides (Gaussian Plume Submodel) and the health effects (dosimetric and dose response submodels) and costs (land interdiction and decontamination submodel) resulting from their release. The Gaussian Plume Model used in CRAC either did not treat or treated simplistically a number of meteorological phenomena. Simplified models were used to treat plume rise, inversion layers, and rainstorms, while wind shear, wind direction, and correlations between wind fields and population distributions were not treated at all. Some of the effects of all of these phenomena on predictions of accident consequences as calculated using CRAC have been or are being investigated.

J. L. Spring, et. al., "Investigations of the Adequacy of the Meteorological Transport Model Developed for the Reactor Safety Study," a paper presented at a conference on Probabilistic Analysis of Nuclear Reaction Safety, Los Angeles, CA, 8 May, 1978, SAND-77-1383C, p. 10.

Source - Reference #25: p. 196.

Model - CRITR

Purpose - Calculates internal radiation dose to four common classes of aquatic organisms and to organisms which consume them.

Description - CRITR calculates annual internal total-body dose to organisms resulting from radionuclides ingested with their food. CRITR always calculates the internal dose to four primary organisms which are directly exposed to radionuclides in the water: fish, crustacea, molluscs and algae. At the user's option, internal dose can also be calculated for up to six secondary organisms which feed upon one of the primary organisms.

Program output at the user's terminal consists of internal dose to all four primary organisms of the selected organ radius, internal dose to the selected secondary organisms, optional percentage contribution to internal dose by nuclide for each selected primary and secondary organism, and an optional table of release rates and concentrations of radionuclides in the liquid effluent by isotope. CRITR produces no high-speed printer output.

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Source - Reference #24: p. 1-1, p. 7-19, p. 7-28, p. 10-23.

DOSIMETRY
ATMOSPHERIC TRANSPORT

Model - CUEX, AIRMOD, TERMOD

Purpose - These codes have been used to assess radiation exposure from environmental releases of radionuclides

Description - The CUEX (CUMulative EXposure Index) methodology has been developed to provide reasonable assessments of radiation exposures resulting from environmental releases of radioactivity. Incorporated in the CUEX methodology are an atmospheric dispersion model designated AIRMOD and a terrestrial transport model designated TERMOD. The atmospheric and terrestrial models were tested through use of radiological source terms and environmental data provided by a number of different organizations. AIRMOD was used to predict noble gas concentrations in the vicinity of the Haddam Neck pressurized water reactor and a boiling water reactor, tritium concentrations in the vicinity of the Argonne CP-5 Reactor, and I-131 gross alpha concentrations in the vicinity of Oak Ridge National Laboratory. The terrestrial model TERMOD was used to predict I-131 concentrations in milk samples collected in the vicinity of the Oak Ridge National Laboratory and in the vicinity of the Quad Cities Nuclear Power Station. The estimated concentrations and doses calculated through use of AIRMOD and TERMOD were frequently within a factor of two of measured monitoring data.

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Source - Reference #20: ESD ORNL.

DOSIMETRY

Model - CUMEX, A Cumulative Hazard Index for Assessing Limiting Exposures to Environmental Pollutants.

Purpose - This code is designed to calculate potential health impact based on received dose of various pollutants including radionuclides.

Description - A hazard index methodology called CUMEX has been developed for limiting human exposure to environmental pollutants. Hazard index is defined as Q/Q_L where Q is exposure and Q_L is a limit which should not be exceeded because of health risk.

Mathematical formulations for hazard indices are developed for each sampling medium corresponding to each effluent type. These hazard indices are accumulated into composite indices such that total human intake overdose would not exceed the health risk limit. Mathematical formulation for composite hazard indices or CUMEX indices for multiple pollutants are presented.

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Source - Reference #21

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - CURIE-DOSE-THUNDERHEAD: A Digital Computer Program for External and Internal Radiation Dose Calculations

Purpose - This code calculates both external and internal radiation doses from air releases accounting for release-reactor parameters.

Description - The CURIE-DOSE-THUNDERHEAD program is a combination of three basic computer programs employed in succession. The first, CURIE, calculates the fission product buildup and decay as a function of reactor operating time, operating power, and decay time. The second, DOSE, uses the fission product inventory obtained from CURIE to calculate the dose to 14 internal body organs due to inhalation of fission products released to the atmosphere. The third, THUNDERHEAD, also uses fission product activity data from CURIE to calculate the external cloud gamma exposure from the released fission products. Cloud diffusion is calculated from Sutton's equation or the Convair modification. In calculating the internal dose it is assumed 62.5 percent of the inhaled isotopes are ultimately swallowed and pass through the entire G.I. tract.

Kenfield, G.P.; (1965)
Atomics International,
A Division of North American Aviation, Inc.

Source - Reference #6: p. 125.

DOSIMETRY

Model - CWMS: Commercial Waste Management Report Generator.

Purpose - This model calculates doses from releases of radionuclides from nuclear fuel cycle facilities. Although the model is general, it may be adapted to LLW management problems.

Description - The program CWMS generates result tables for doses from releases of radionuclides from nuclear fuel cycle facilities. Input includes source inventory, release fractions and dispersion parameters. The program INPREP is an interactive program to generate input for CWMS.

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Source - Reference #8: p.209

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - DACRIN - A Computer Program for Calculating Organ Dose from Acute or Chronic Radionuclide Inhalation.

Purpose - DACRIN calculates effective radiation dose to the human respiratory tract and other organs resulting from the inhalation of radioactive aerosols, using the ICRP Task Group Lung Model. Dispersion models for chronic or acute atmospheric release are included.

Description - The computer program, DACRIN, permits rapid and consistent estimates of the effective radiation dose to the human respiratory tract and other organs resulting from the inhalation of radioactive aerosols. The program is an outgrowth of the development of a mathematical model for the organ dose following the basic precepts of the ICRP Task exponential model for retention by an organ of interest. Mathematical models describing atmospheric dispersion have been included for the purpose of evaluating doses resulting from either accidental or chronic atmospheric releases of radionuclides. The program will calculate the effective radiation dose to any of 18 organs and tissues from inhalation of any one or combination of radionuclides considered by the ICRP. A maximum of 10 organs may be selected for each case. Organ doses from inhalation can be calculated by specifying either the quantity of a radionuclide inhaled or the quantity released to the atmosphere. In the latter case, the duration of release, the release height, wind speed, atmospheric dispersion parameters and downwind distance at which the dose is to be calculated must also be specified. As many as 10 distances may be specified for each use. Output of the code consists of the effective radiation dose to the selected organs at selected time intervals, for each radionuclide inhaled as indicated by the input.

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Source - Reference #6: p. 124, #8: p. 206

DOSIMETRY

Model - DISDOS: Absorbed Dose Rates in Humans from Exposure to Environmental Gamma-Rays

Purpose - The code calculates the propagation of environmental gamma rays incident on the human body.

Description - The propagation of environmental gamma rays through the human body is accounted for by using the 3-D Monte-Carlo computer code DISDOS which is based on the MIRD phantom. The radiation field was assumed to be isotropically incident. The calculation was performed with the aim of determining the dose to the body organs with a statistical accuracy of better than 10%. Of the 32 organs and groups of organs treated by DISDOS, the poorest statistics are associated with the calculation of dose to the ovaries. The mean annual absorbed dose to the gonads in the United States was calculated to be about 32 mrad/yr, and to the red marrow to be about 29 mrad/yr.

K. O'Brien
U.S. Atomic Energy Commission
New York, NY

Source - Reference #6: p.140

DOSIMETRY

Model - DOSCON: Dose Conversion Constant Code Used to Compute Radiological Dose Through Various Pathways.

Purpose - This model performs radiological dose computation in a general way.

Description - DOSCON will be a combination of dose conversion models assimilated to provide dose estimates for various pathway drives calculated by three dimensional regional transport and diffusion models. DOSCON will not be the development of the individual dose models; rather, these models will be tailored to a regional model output.

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Source - Reference #8: p.191-192

DOSIMETRY

Model - DOSEB: A CDC 6600 Program for Calculation of Inhalation and External Dose for Establishing Reactor Siting Distance Requirements.

Purpose - This program is used in determining allowable reactor sites and in the calculation of thyroid and direct gamma dose. There may be relevance in the analytic techniques to the siting of LLW management facilities.

Description - The DOSEB Program has been written to facilitate the calculation of distance factors for nuclear reactor sites as described in the USAEC Document "Calculation of Distance Factors for Power and Test Reactor Sites", TID-14844. The calculations are essentially as described in this document except that the dose code allows for arbitrary operating power histories and variable containment leak rates. The program calculates the thyroid and direct gamma doses received by an individual standing at a distance D from the point of fission product release for a time tau subsequent to the time of release and based upon a given reactor operating history.

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Knolls Atomic Power Laboratory
Schenectady, NY

Source - Reference #6: p.130

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - DOSES: A Computer Technique for Calculating the Radiological Consequences of Pressurized Water Reactor Power Plant Hypothetical Accidents

Purpose - Used to predict radioactive releases from PWR's due to hypothetical accidents.

Description - A closed form analytical method of calculating the radiological consequences of ten pressurized water reactor (PWR) hypothetical accidents was developed. This methodology was used to develop a computer code, DOSES, to compute the gamma-whole body, beta-skin and iodine inhalation thyroid doses at the site boundary, at the low population zone outer boundary and for control room occupancy for the ten PWR hypothetical accidents. The computer code DOSES was developed to operate in the conversational remote terminal mode and to provide a mechanism for producing required information for chapter 15 of PWR nuclear power plant safety analysis reports. The identification of causes and accident descriptions, fission product release and dose analysis assumptions, dose calculation models, input parameters to the computer code DOSES, and the dose results and conclusions are presented for each of the ten hypothetical PWR accidents for a typical PWR nuclear power plant. The severity rank and the conservatism ratios of each accident were calculated. The loss of coolant accident was found to be the most severe. All doses calculated for the plant considered fell well within the limits of 10CFR100 and general design criterion 19 of appendix to 10CFR50.

C. F. Gill
University of Missouri-Rolla
Department of Mechanical Engineering
Rolla, MO
Ph.D. Thesis, Engineering Department, 1975

Source - Reference #18: p.34

DOSIMETRY

Model - EERIE: Environmental Evaluation of Radioactive Isotopic Effluents.

Purpose - This is a set of theoretical models describing the build-up of fission products in irradiated nuclear fuel and the behavior of these in a reactor and subsequently in atmosphere under definable accident conditions.

Description - EERIE enables inhalation doses to body organs, cloud beta and gamma doses, and the quantity of radioactivity deposited on the ground in the area surrounding the site of a release of activity to be evaluated. The results of a computer study of a representative range of reactor accidents are described. The accidents chosen as examples are specific to gas-cooled reactors, but the methods used can in principle be applied to any reactor type. The effects of factors which influence the nature or magnitude of the releases, such as isotopic release fractions from the damaged fuel and plate-out within the reactor coolant circuit, and the associated hazards are outlined. In addition compilations of the gamma spectra of fission product elements are used to make theoretical estimates of the gamma spectra which would be obtained from air sample filters taken downwind of the site of a reactor accident. The data obtained in this study are critically examined in order to provide guidance on the best methods of obtaining adequate monitoring results with sufficient speed to institute effective precautionary measures. The comprehensive nature of the calculations, which enables the complete history of the isotopic content of the damaged fuel to be followed continuously from the time of its release from the fuel through its dispersal in the atmosphere, makes it possible to identify those parameters which are important in determining sampling and monitoring techniques. In addition it makes it possible to evaluate the usefulness of different analytical methods at various stages during an incident.

H. F. MacDonald, "Assessment of Environmental Hazards Following Nuclear Reactor Accidents," CONF-710705; IAEA-SM-148/38, Proceedings of the International Symposium on Rapid Methods for Measurement of Radioactivity in the Environment, Neuherberg Bei Munchen, July 5-9, 1971, (p. 43-54), C.E.G.B., Berkely Nuclear Laboratories, Berkeley, Glos., United Kingdom.

Source - Reference #26: Item 212.

ATMOSPHERIC TRANSPORT DOSIMETRY

Model - EGAD: A Computer Program to Compute Dose Integrals from External Gamma Emitters.

Purpose - EGAD is a code to estimate whole body dose resulting from radioactive material release.

Description - EGAD is an external gamma dose code programmed in FORTRAN IV for the IBM 360/65 that is intended to provide an estimate of whole body dose resulting from radioactive material released to the environs. The material is assumed to be bounded between the ground and an inversion lid on the vertical axis and bounded in the crosswind direction between fictitious sector boundaries or some real physical constraint such as mountains on both sides of a valley. To model average exposure over long time periods, the distribution of material is assumed to be Gaussian about a given release height in the vertical direction with a homogeneous distribution in the crosswind direction. The code provides output in the form of dose integrals that are a function of the vertical dispersion parameter, release height, inversion lid, and gamma energy. The calculated integrals are independent of the source, radioactive decay, wind speed, and sector width. It is therefore feasible to cover a large variety of possibilities by using a relatively small set of tabular values as a function of the vertical dispersion parameter and employing an interpolation procedure. The code is expected to be used primarily in the construction of these tabular values to be used in a more comprehensive program of computing radiation dose. The code is currently being used in this manner as a part of the overall man-rem evaluation program at Savannah River.

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Savannah River Laboratory
Aiken, SC 29801

Source - Reference #6: p. 116

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - ESDORA: Estimate of the Radiation Dose in the Evaluation of Risks for Nuclear Power Plants and Radioactive Facilities.

Purpose - A code to estimate radiation doses from continuous or instantaneous escape of fission products into the atmosphere.

Description - The program ES.DO.RA. (Estimacion de DOsis Radiologicas [estimate of radiation doses]) estimates the damage produced by the continuous or instantaneous escape of fission products into the atmosphere. It was programmed in FORTRAN IV for the IBM 7090 computer and is divided into 4 subroutines: ESD 1. Generates an inventory of fission products according to the operating process (sic., burnup ?) of the fuel of the facility. ESD 2. Determines the quantity of fission products emitted to the atmosphere through the stack or the technical safety measures employed. ESD 3. Calculates the integrated doses of the radioactive cloud, as well as the ground-level contamination due to fallout of the fission products, with consideration of meteorological conditions. ESD 4. Estimates the external beta and gamma doses by submersion in the radioactive cloud as well as the internal doses received by the various organs of the human body by inhalation. The program was developed to evaluate the risks resulting from an explosive type of accident in a nuclear facility, but in special cases it can be used with routine releases.

F. D. Cruz
Juanta De Energia Nuclear, Spain
1971, March
SS/01/71; ORNL-tr-2628; 4 pp.

Source - Reference #6: p. 122.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - EXDOSE: A Computer Program for Calculating the External Gamma Dose from Airborne Fission Products.

Purpose - This model calculates external gamma doses to the human body.

Description - The EXDOSE program calculates the external gamma radiation dose to the total body from a half-infinite cloud of fission products. It is designed primarily for estimating accident consequences. The code calculates a fission product inventory according to specified input parameters using an adaptation of the program RIBD. Any fraction of these fission products may then be released to the atmosphere at a desired rate. The subsequent downwind dispersion and resulting dose to individuals is then calculated. The dispersion of the plume is based on the bivariate normal mode and Simpson and Fuquay's equation or Sutton's equation. Cloud depletion by ground deposition is an available option. Correction for radioactive decay and daughter product growth is included.

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Richland, WA

Source - Reference #6: p.126

Model - EXREM III

Purpose - EXREM III is the third in a series of computer programs for estimating external radiation exposure from submersion in contaminated water and air and from exposure to contaminated surfaces.

Description - The initial program EXREM was improved to include contributions from daughter products (EXREM III). The codes were developed for estimating radiation dose rates and doses from construction of a sea-level canal with nuclear explosive. As such, the codes calculate doses for accidental releases rather than chronic releases.

The air concentration is defined via input by specifying "location correction factors" as a function of distance, nuclide and exposure mode (beta, gamma position or electron). The submersion doses are estimated as semi-infinite cloud calculations proportional to the air concentration at the exposure point.

The code includes contributions from gamma rays, x-rays, position, electron and beta radiations. Radioactive decay is calculated in a detailed manner with branching to and from isomeric states included. A nuclear data base is available with the code which includes data for 189 nuclides. The codes is written in FORTRAN for an IBM computer.

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Source - Reference #12: p. B-45.

ATMOSPHERIC TRANSPORT DOSIMETRY

Model - FISSP/CLOUD

Purpose - The linked computer programs FISSP and CLOUD perform a reactor excursion analysis involving: 1) the fission product inventory immediately preceding the release, 2) the release from the containment structure to the atmosphere, 3) the transport of the released fission products to the exposure point, and 4) the resulting external and internal dose.

Description - FISSP performs the fission product inventory and release calculation while CLOUD performs the fission product transport and dose calculation.

CLOUD models transport by a three-dimensional Gaussian dispersion equation with Sutton's dispersion parameter representation. The time-integrated air concentration is calculated numerically for use in determining external dose and inhalation dose. The external dose from gamma radiation is calculated using the semi-infinite cloud assumption. Contributions to external dose from both beta and gamma radiations are included. The dose to organs from inhaled material is calculated using MPC values. The doses calculated are the 50-year dose commitments from uptake over a specified uptake period. A puff release to the atmosphere of the inventory at the end of the operating history is assumed. Fractional releases may be assigned to the nuclide groups - noble gases, halogens, high temperature volatiles and the remainder. One neutron energy group is allowed.

FISSP performs a double precision calculation. CLOUD applies a factor of 0.64 to the external beta dose to account for perturbation of the average energy of the beta field by preferential absorption of the high energy particles. Inhalation doses for nuclides not listed in ICRP Publications 2 (1959) or 6 (1964) are calculated using "artificial" MPC values.

This code is written in FORTRAN IV for a CDC 6600 and requires 60k (octal) to run.

L.L. Bonzon and J.B. Rivard (1970) -
Albuquerque, NM

Source - Reference #12: p. B-46.

Model - FOOD

Purpose - FOOD calculates annual individual doses from the consumption of garden foods and animal products contaminated from air deposition or water (sprinkler irrigated). It is part of the HERMES computer program.

Description - FOOD is a companion code to ARRRG and calculates annual individual and population doses from eating garden foods and animal products contaminated by air deposition or water irrigation. Doses are calculated for 14 foods. A key assumption in the code is that the accumulation and dispersion processes in the biosphere are such that the local soils used for farming contain the accumulated radionuclides from a specified number of years of irrigation previous to the time of interest.

Terminal input for FOOD includes: facility name, holdups, usages, irrigation rates, air concentration, crop yields and growing periods for 14 food types (for animal products the parameters refer to animal's feed); coolant flow and mixing ration, and reconcentration factor parameters in the case of liquid release. FOOD is operational with 136 nuclides.

D.H. Denham, D.A. Baker, J.K. Soldat, and J.P. Corley
Battelle, Pacific Northwest Laboratories
Richland, WA.

Source - Reference #62: pp. 2-28, B-39, 40.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - GADOSE and DOSET: Programs to Calculate Environmental Consequences of Radioactivity Release.

Purpose - The codes calculate dose to man from an accidental release by a nuclear power plant.

Description - GADOSE is a FORTRAN program which calculates the radioactivity in various reactor plant locations and the doses to the public resulting from instantaneous accidental release of activity into any of the plant spaces. The calculations can be performed for any combination of isotopes and include consideration of decay, buildup, filtration, atmospheric dilution, fallout, and rainout. The companion program DOSET is also available to include the effects of a time dependent accidental fission product release into the various plant spaces. A typical calculation of the activities and doses at five times and five distances from the plant with 134 isotopes requires approximately 4 centihours of IBM 7044 machine time for the basic GADOSE program. The program was written specifically for the High-Temperature Gas-cooled Reactor (HTGR) type of plant.

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Source - Reference #6: pg. 138.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - GAMMA: Model for Radiation Exposure from a Boiling Water Reactor Plume

Purpose - Evaluates noble gas plume exposure from boiling water power reactors.

Description - Field measurements of exposure rates for noble gases were compared with model predictions to determine the sensitivity to approximations for build-up of gamma radiation, plume rise and cloud size. The model used was based on May and Stuart (1970), i.e., a crosswind averaged Gaussian plume. The vertical dispersion coefficient is that due to Watson and Gammertsfelder. Holland's formula with Moses' correction for stack diameter is used to calculate plume rise. Growth and decay of daughter radionuclides is considered. Deposition and inhalation are not taken into account. For the buildup factor, Capo's formula is used for gamma energies greater than 0.5 mev, and Berger's formula is used for gamma energies less than 0.5 mev. Exposure rate is averaged over 4 atmospheric stability classes, 16 wind directions and 6 wind speed ranges weighted by their frequency of occurrence. Gamma ray measurements were made for two months near a boiling water reactor with ionization chambers and thermoluminescence dosimeters. Measured and calculated exposure rates agree within a factor of 2. The model predictions were compared with those obtained with EGAD, the Gammertsfelder model and calculations made as part of the safety analysis for the plant. The linear buildup factor approximation is a sensitive function of meteorology and gamma ray energy. Calculations of dose rates for the different models differed by more than 100% at large distances from the stack under unstable conditions. Models treating off-sector exposures separately match the data more accurately than those that do not.

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Environmental Measurements Laboratory
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New York, NY 10014
212-620-3635

Source - Reference #18: p.34

DOSIMETRY
ATMOSPHERIC TRANSPORT

Model - GASPAR: A Program for Population Dose Evaluation

Purpose - To calculate population and individual doses through gaseous pathways for the implementation of Regulatory Guide 1.109.

Description - None available at the time of presentation of this document.

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(Work performed at NRC, System Dynamics and Reliability Group)

Source - Reference #31

Model - GAUCHE

Purpose - The purpose of this code is to calculate annual dose and in some cases dose commitments from exposure to radionuclides in the atmosphere as deposited in such a way as to enter the food chain through ingestion of milk or leafy vegetables.

Description - GAUCHE computes individual doses from three sources: 1) air submersion at a specified location; 2) inhalation and tritium transpiration at a specified location; and 3) inhalation and consumption of milk and leafy vegetables at any specified X/Q'. For the first source, annual dose and dose commitments to skin and total body are computed; for the second source, annual dose and dose commitments to total body, GI-UI, thyroid, bone liver and kidney are computed; for the third source, only annual dose to thyroid is computed.

D. L. Brenchley, J.K. Soldat, J.A. McNeese, and E.C. Watson
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Source - Reference #19: p. 6

ATMOSPHERIC TRANSPORT
DOSIMETRY
FOOD CHAIN

Model - GRONK

Purpose - GRONK calculates annual dose resulting from radionuclides released with gaseous effluents. It is part of the HERMES computer program.

Description - Skin and total body dose to an individual and total body dose to the population are calculated for a standard matrix of points made up by 16 sectors and up to 10 annular rings out to 50 miles from release point. Options permit calculation of dose at other specified distances. An optional calculation for thyroid dose from radioiodine via inhalation, milk and leafy vegetables may be made.

Terminal input to GRONK includes: facility name, a string of code letters signifying what σ_z model to use (Pasquill or Hanford) and the various options selected and up to 10 ranges, if ranges other than the internally set standard ranges are required. Other inputs are required depending on the options selected, such as release height for elevated release, plume rise constant for plume rise consideration, building height for wake effect correction and sensor level for translating meteorological data from actual height of wind sensor to height selected for dose estimate. For the thyroid dose calculation, the child and adult vegetable consumptions, the cow grazing period and the leafy vegetable consumption period are entered for the milk and leafy vegetable pathways. GRONK is operational with 136 radionuclides available; however, only 52 may be used at any one time because of core allocation limitations.

J. K. Soldat, N. M. Robinson, D. A. Baker (1974)
Battelle, Pacific Northwest Laboratories
Richland, WA

Source - Reference #12: p.B-39,40

GENERAL TRANSPORT

Model - HERMES: A Digital Computer Code for Estimating Regional Radiological Effects from the Nuclear Power Industry

Purpose - This model is used in estimating regional radiological effects resulting from operation of nuclear facilities.

Description - The HERMES model is designed to calculate radionuclide release and radiation dose occurring within a study area in a given year. While cumulative radionuclide release as such is not considered, the accumulated buildup and deposition of key radionuclides is "back-calculated" for a five-to-ten year period for use in dose calculations. The initial development of the HERMES model was based on a study of the region comprising the upper Mississippi and lower Missouri River basins, excluding the Chicago metropolitan area. To estimate the effects on dose in the study area caused by air transport of radionuclides from adjacent regions, an "air envelope" some 200 miles in width was included around the study area. Considerations in the study included the operation of 400,000 MW generating capacity power plants (nuclear and fossil) at 186 separate sites. The air transport code (ARTRAN) utilizes monthly climatological data applied to standard mathematical models for diffusion, deposition, and transport. The water transport code (WTRAN) calculates diffusion from emission points, concentrations in sediments and surface water at each location requested, and ground water transport. The code (DOSE) considers exposure to the whole body and six specific organs in (1) direct submersion in air or water, (2) inhalation, (3) external exposure from surface contamination, and (4) ingestion of food and water over numerous food-chain pathways. Life habits and dietary differences are also considered in the code (LPM). Present structure allows calculations for up to 50 radionuclides; 200 release points; and 300 receptor locations. More recent applications have been for the Tennessee Valley region and Southwest Environmental Study.

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509-942-6523; FTS 444-6523
HEDL-TME-71-168; 759 pp., 1971

Source - Reference #18: p.305

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - HERMES; ARTRAN: An Atmospheric Radionuclide Transport Model.

Purpose - The purpose of this code is to determine dose to individuals and groups from activities such as waste storage or reprocessing.

Description - A computer code, HERMES, was developed for calculations from which a reasonable estimate may be derived of the potential radiation dose and dose commitment to individuals and population groups residing in regions where nuclear power reactors, and ancillary activities such as fuel reprocessing plants and waste storage facilities, are located in the year 2000. ARTRAN is the radionuclide air transport model. The three types of data used include: source to receptor travel distance; effluent source rate and constituent characteristics; and meteorological variables including wind speed and direction, atmospheric stability, mixing depth, and precipitation characteristics.

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Source - Reference #18: p. 260.

Model - ICRP

Purpose - This is a computer model which calculates total annual radiation doses and 50-year dose commitments to several categories of persons at population centers and combines these calculated doses into integrated (man-rem) annual and 50-year doses for large populations.

Description - The dose model was designed as one portion of an overall computer program developed to delineate the nuclear facilities expected in the year 2000, the radionuclides released to air and water, their diffusion, dispersion, and reconcentration in the environment, and the resulting radiation doses to people. Equations for calculating dose factors were derived from those given by the ICRP. Effective decay energies for various radionuclides were calculated from the ICRP model, which assumes that all the radionuclide is in the center of a spherical organ with an appropriate effective radius. Where data were lacking, metabolic parameters for the Standard Man were used for other ages as well. The model includes a subroutine which calculates radionuclide concentrations in a wide variety of foods at time of harvest from concentrations in air, irrigation water, and soil. The later concentrations are output from previous portions of the overall computer program. The tremendous variety of data required for proper dose assessment was not always available in the literature. Such data must be extrapolated from environmental studies of fallout nuclides and from planned laboratory and field studies of a limited number of nuclides.

J. K. Soldat, "Modeling of Environmental Pathways and Radiation Doses from Nuclear Facilities," BNWL-SA-3939; 33p. Oct. 1971, Battelle Memorial Institute, Pacific Northwest Laboratories, Richland, Washington 99352.

Source - Reference #26: Item 237.

Model - ICRP Lung Model

Purpose - The model computes the burden and dose to the respiratory tract from continuous inhalation of a radioactive aerosol.

Description - The ICRP Lung Model can be used to calculate the burden and dose to the respiratory tract from the inhalation of a known radioactive aerosol. Snyder has given analytical expressions and curves to compute such quantities for a single intake. This code gives expressions and curves for the case of continuous intake. The use of these curves is illustrated by an example in which burdens and doses to various compartments of the respiratory tract are computed for the chronic inhalation of plutonium oxide aerosol making use of the aerosol data available from Hanford Laboratories.

P. Kotrappa, "Calculation of the Burden and Dose to the Respiratory Tract from Continuous Inhalation of a Radioactive Aerosol," Health Physics, Vol. 17, pp. 429-432, 1969. University of Rochester, Department of Radiation Biology and Biophysics, Rochester, New York.

Source - Reference #26: Item 190.

DOSIMETRY
MANAGEMENT AND PLANNING
COSTING/PRICING

Model - IMPACT

Purpose - IMPACT calculates annual and cumulative health impacts and operating costs associated with a given waste management system.

Description - IMPACT calculates isotopic releases and 70-year population radiation doses for each waste type, and waste management step. The waste curies are obtained from the waste processing logistics calculation (WASTRAC). The isotope release fraction is dependent on isotope, fuel cycle process, waste type, and waste management step. IMPACT calculates regional dose commitment to whole body, bone, lungs, and thyroid. IMPACT also calculates worldwide dose commitment for release of ^3H , ^{14}C , and ^{85}Kr . Four types of waste management costs are computed: treatment costs, interim waste storage costs, transportation costs, and repository costs. The IMPACT program also organizes the results of the calculations, sums up annual and cumulative totals at five-year intervals and prepares a series of tables to display the results. Both undiscounted and present worth costs are calculated. Levelized unit power costs and levelized unit fuel costs of waste management are also calculated.

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Source - Reference: U.S. Department of Energy, "Technology of Commercial Radioactive Waste Management."

Model - INDOS: Conversational Computer Codes to Implement ICRP-10-10A Models for Estimation of Internal Radiation Dose to Man (INDOS-1, INDOS-2, INDOS-3).

Purpose - Codes to estimate radiation doses to organs of the body.

Description - The INDOS codes are special purpose conversational programs written to function in a time-sharing environment. They have been implemented on the ORNL PDP 10. These codes use ICRP-10-10A models to estimate the radiation dose to an organ of the body of reference man from accidental or routine releases. They compute dose and dose rate to an organ as functions of time. INDOS 1 computes dose rate and dose resulting from deposition of a specified quantity of a radionuclide in the organ. The user must specify all parameters related to radionuclide and organ, his choice of mathematical model (exponential or power function), and intake information as these items are requested by the code. The term 'intake' in messages output by INDOS 1 refers to quantity of material deposited in the organ, not total quantity introduced into the body. The output of INDOS 1 is a tabulation of time (days), dose rates (rems/day), and doses (rems). INDOS 2 computes dose rate and dose resulting from deposition of a specified quantity of any one of several radionuclides in the organ, and the organ is the one which is regarded as critical for the radionuclide selected. Once the user designates his choice of radionuclide, INDOS 2 secures parameter values associated with the material and its critical organ from a direct-access file stores in the user's disk area. This stored data base is one feature which distinguishes the capabilities of INDOS 2 from those of INDOS 1. A second distinction is the meaning of the term 'intake.' For INDOS 2, this term refers to the quantity of material inhaled or ingested into the body (the user chooses the route of intake). INDOS 2 converts the intake into a proportionate deposition in the critical organ for the calculations. The output of INDOS 2 is capable of an optional typewritten graph of dose vs. time. Computationally, INDOS 3 is identical to INDOS 2, and these codes access the same direct-access files. The codes differ only in the form of output. INDOS 3 provides punched-card output which can serve as input to other codes such as graphical programs.

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Source - Reference #6: p.118

DOSIMETRY
FOOD CHAIN

Model - INGDOS, A conversational code to implement models for estimation of annual doses from ingestion of radionuclides.

Purpose - The purpose of this code is to compute dose to internal organs from ingestion of food contaminated by atmospherically released radionuclides.

Description - INGDOS is a conversational FORTRAN IV program utilizing models described in U.S. Nuclear Regulatory Commission Regulatory Guide 1.109 for calculating:

- 1) concentrations of airborne radionuclides in food;
- 2) annual doses to various organs of man from ingestion of foods contaminated by radionuclides released to the atmosphere.

The code has been implemented on the ORNL PDP-10 system for use in time sharing mode. An on-line data base provides default values for most of the parameters required in the calculation of these quantities. The calculation of nuclide concentrations in and on vegetation at a given location is based on the rate of deposition at that location--a product of ground-level concentration and deposition velocity. As output the user may specify any (or all) of 11 tables which specify nuclide concentration and annual doses via various pathways.

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Source - Reference #23.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - INHEC: Computation of Radiological Consequence Using INHEC Computer Program.

Purpose - This code is designed to perform parametric analysis of radiological consequences of an accidental radioactivity release at a nuclear power plant. Accidental releases from LLW management sites may be similarly analyzed.

Description - INHEC is a computer code specifically prepared for parametric investigation of radiological consequences involved in the accidental release of radioactivity from a nuclear power plant. The computer code is designed to calculate off-site doses from time-varying releases of radioactivity to the environment with an option to calculate the resulting activity buildup in a secondary volume (e.g., a nuclear power plant control room). The code has wide applicability since it can be used in the analysis of both single and double containment systems with varying purge and/or leak rates from either containment. Also, the code has the flexibility of computing either instantaneous or time-varying activity releases to the innermost level of containment and activity reduction from internal cleanup systems such as containment sprays and filtering units. The meteorology contained in Regulatory Guides 1.3 and 1.4 is available as an internal data table; however, other meteorology may be used as desired. The printed computer output includes the off-site inhalation doses, the off-site cloud center and ground level gamma doses, the off-site cloud center and surface body beta doses, and activity inventories in the containments and on filters. The printed computer output resulting from the secondary volume option includes inhalation and surface body beta doses, integrated activity exposure inside the secondary volume, and activity inventories in the secondary volume and on related filters. Also, a gamma source sort of each activity inventory is provided to facilitate shielding calculations. All activities and doses are calculated as a function of time and, where applicable, as a function of distance.

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Source - Reference #6: p.132

DOSIMETRY

Model. - INREM, A FORTRAN Code Which Implements ICRP 2 Models of Internal Radiation to Man.

Purpose - The code estimates cumulative dose equivalents to body organs from a continuous intake of radionuclides.

Description - INREM is a FORTRAN IV Computer Code to estimate the cumulative dose equivalents to body organs of man following a continuous intake, through inhalation or ingestion, of one or more radionuclides. Dosimetry parameters for the organs are dependent on the age of the individual, and the intake rate is a function of time and the individual's age. The method of estimation is based on adaptations of models presented in publication 2 of the International Commission on Radiological Protection. The equations for the models are derived, and information about the code and its use is provided.

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Source - Reference #8: p. 204.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - ISOLA II: A Fortran IV Code for the Calculation of the Long-Term Alpha- and Gamma-Dose Distributions in the Vicinity of Nuclear Installations.

Purpose - Model air doses caused by alpha and beta emitters emitted as off-gas products from the area of a nuclear reactor.

Description - The computer code ISOLA is used to calculate the annual radiation doses caused by alpha- and beta-active off-gases in the environment of the Karlsruhe Nuclear Research Center. In the revised version, ISOLA II, the double Gaussian distribution model is strictly observed. As a consequence, the contribution of activity from neighbour sectors is taken into account. Up to 15 emitters may be coped with simultaneously. The emission rates are considered to be constant during the given time interval. Optionally, either the isodoses chart of a specified area (for instance a square 20 by 20 km) or a list of doses calculated at up to 2000 locations (for instance the living areas) in the environment may be set up.

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Karlsruhe, Germany

Source - Reference #6: p.123

ATMOSPHERIC TRANSPORT
DOSIMETRY

Name of Program - KRONIC

Purpose - KRONIC calculates annual external total body tissue dose from chronic release of radionuclides to the atmosphere.

Description - The external total body tissue dose is calculated as a function of the 1) radionuclides present, 2) climatology for the site, 3) time dependence of fission product concentrations, 4) photon and beta particles emitted from nuclides, and 5) physical properties describing interaction of photons and beta particles with air and tissue.

Atmospheric dispersion effects are estimated using data on joint frequency of occurrence of wind speed, wind direction and stability for a particular site. Each sector is considered to be a plume for which the center line ground-level dose is calculated for specified downwind distances. The result of the calculation is a table of annual dose rates as a function of direction and distance from the release point.

Both photons and beta particles contribute to the external total body dose. The beta dose contribution is calculated using a semi-infinite cloud model. The gamma dose calculation is performed by space integration over the plume volume. The gamma dose can be calculated at any specified tissue depth.

KRONIC uses extensive data bases to minimize input requirements. Radioactive chain decay with branching is calculated for chains with up to seven members. Multiple releases may be specified with results summed. KRONIC is written in FORTRAN IV for CDC CYBER computer.

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Source - Reference #13: p. B-48, 8 p. 207.

DOSIMETRY
GROUNDWATER TRANSPORT
SURFACE WATER TRANSPORT

Model - LADTAP: Liquid Annual Doses to All Persons

Purpose - To calculate doses received by individuals and populations through liquid pathways for the implementation of NRC Regulatory Guide 1.109.

Description - None available at the time of presentation of this document. See Regulatory Guide 1.109 for a description of the calculational model and parameters that this code implements.

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System Dynamics and Reliability Group
Washington, D.C.

Source - Reference #30

ATMOSPHERIC TRANSPORT DOSIMETRY

Model - MO 142, A FORTRAN Program for the Calculation of the Potential Hazards from an Accidental Fission Product Release.

Purpose - This code was designed to determine individual nuclide doses from a gaseous release of fission products.

Description - A FORTRAN Program, MO 142, has been written to perform a detailed analysis of the space and time-dependent radiation doses resulting from a potential fission-product release incident from a nuclear reactor. The program permits the calculation of the hazards from any radioactive source of known concentration and isotopic distribution. The nuclides which form the radioactive cloud are specified as program input. For each nuclide, an initial concentration, release rate, radioactive decay constant, and average gamma and beta emission energy must be supplied. In addition, the exposure period, the distance from the source to the receptor point, and the appropriate meteorological conditions must be specified. For each nuclide in the calculation, the program computes the external gamma and beta dose and the inhalation dose to several critical organs. The total in each category is obtained by a straightforward summation of the individual nuclide doses. Atmospheric dispersion is calculated using Sutton's equation and the resulting air concentration is corrected for decay before the dose is calculated. The program allows for a time-dependent release rate to be used if desired.

Eckert, R.J.
Bettis Atomic Power Laboratory
Pittsburgh, PA
WAPD-TM-348, 22 pp. 1964.

Source - Reference #18: p. 260.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - MUNDO: A Digital Code for Computing Accident Dose Rates in Reactor Environs

Purpose - This code calculates dose received from a given reactor based on location, time, and reactor parameters.

Description - The MUNDO computer code calculates the dose equivalent received at the point F and time T in rem as a function of meteorological and internal physical and engineering properties of the reactor. The code considers fuel release factors, decontamination factors, filter factors, leak functions, multi-containment, ground release, stack release, weather conditions, external irradiation, internal irradiation, and direct irradiation from the reactor building. Approximately 80 nuclides can be included in the calculation. Atmospheric dispersion includes Sutton's diffusion parameters, and plume depletion via deposition and decay are accounted for. Exposures are calculated for inhalation, external exposure to the plume, and external exposure to the ground. Ingestion and wet deposition are not considered.

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Source - Reference #6: p.131

ATMOSPHERIC TRANSPORT DOSIMETRY

Model - NUBE: A Digital Code to Evaluate the Hazards of Different Types of Reactor Accidents.

Purpose - An analytical method to assess abnormal reactor behavior including air transport of radionuclides. Although dealing with reactors, this model may have general applicability in analyzing LLW management systems.

Description - The method determines the fission product inventory as a function of reactor power, fuel irradiation, and cooling time. It analyzes the fission product behavior within the containment system, when released from the core as a result of an accident. Finally, the method calculates the atmospheric diffusion of the escaping nuclides under a variety of conditions. External and inhalation doses to individuals within the radioactive plume may be assessed at different distances downwind from the reactor. The method has been used to evaluate the hazards caused by different types of reactor accidents such as reactivity accidents, loss-of-coolant accidents, reactor fires, and fuel handling accidents. Different types of containment systems are considered in the analysis. The systems analyzed include negative pressure containment, double containment, and high-pressure and pressure suppression containment systems. The effect of engineered safeguards such as building sprays, filters, condensation pools, etc. can be taken into account. Each nuclide can be considered individually, as the cleaning rates, condensation ratios, deposition velocities, etc. are nuclide dependent. The results are given in terms of the amounts of the most important nuclides retained within the containment barriers or by the engineered safeguards. The most relevant health hazards produced outside the containment system are also given for the accidents analyzed.

A. Alonso (1965) CONF-650407; "Fission Product Release and Transport Under Accident Conditions," Proceedings of the International Symposium held at Oak Ridge, Tennessee, April 5-7, 1965, pp. 1080-1090, 1249 pp. (Junta de Energia Nuclear, Madrid, Spain)

Source - Reference #6: p.116

Model - NUS: Effective Energy Program

Purpose - The NUS Program for Effective Energy is an IBM-7090 Computer program written for the purpose of obtaining the effective energies absorbed by internal body organs due to disintegration of radioactive fission products inhaled and ingested by a human being.

Description - The internal body organs considered in the program are thyroid, bone, gastrointestinal (G.I.) tract, and lung. The results are presented in units of Mev per disintegration of the parent nuclide in a given chain. The program considers a fission product decay chain, examines whether the chain elements have affinity with a particular body organ, and computes effective energies. The average beta and total gamma energies, the radioactive decay constant, and the biological decay constants for each of the elements of a given chain must be provided as the input to the program.

Y. S. Kim
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Source - Reference #6: p.139

Model - ORDEAL

Purpose - A computer code was designed to use the entire record of an employee's urinary excretion of plutonium to produce an estimate of his intakes as well as of the plutonium present in his body at any time during or after exposure.

Description - ORDEAL was used to fit the logarithms of the excretion of data by the least-squares method because it is believed that the data fit a power function of the form $F(a, \alpha, t) = at E - \alpha$. Studies have been made and are continuing to enable one to determine, in the light of daily fluctuation in the data, whether a given fluctuation is the result of a patient's excretion variability or is actually the result of a new intake.

D. E. Anurius; A. M. Craig, Jr.; S. H. Merriman; C. L. Thompson; G. G. Warner, "Health Physics Estimation of Plutonium Body Burden", ORNL-4385, Part of Feliciano, M., Nestor, C.W. (Eds.) Mathematics Division Annual Progress Report for Period Ending December 31, 1968, (p. 23), Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830.

Source - Reference #26: Item 194.

Model - ORIGEN: The ORNL isotope generation and depletion code.

Purpose - ORIGEN is used to compute the compositions and radioactivity of fission products, cladding materials, and fuel materials as a function of cooling time.

Description - ORIGEN is a versatile point depletion code which solves the equations of radioactive growth and decay for large numbers of isotopes with arbitrary coupling. The code uses the matrix exponential method to solve a large system of coupled, linear, first-order ordinary differential equations with constant coefficients. The general nature of the matrix exponential method permits the treatment of complex decay and transmutation schemes. An extensive library of nuclear data has been compiled, including half-lives and decay schemes, neutron absorption cross sections, fission yields, disintegration energies, and multi-group photon release data.

The ORIGEN code has been designed to be extremely versatile in its applications. It is capable of computing isotopic compositions of fuel, fission products, and cladding in both fixed and fluid fuel reactors. The library of nuclear data that has been compiled for use with the code is sufficiently extensive to treat U-235 and Pu-239 fuels in both fast thermal spectra, and fission of U-233 in thermal spectra. The library also contains multigroup photon release rates for the fission products and the heavy metals, which permits the calculation of gamma-ray spectra in spent and refabricated fuels. One other important feature of the code is that the matrix exponential technique has been developed to solve a nonhomogeneous system of equations. This feature makes it possible for ORIGEN to be employed in calculating the accumulation of activity in processing plants, in waste disposal operations, and in the environment.

A.G. Croft and C.W. Kee (ORNL)

Source - ORNL-4628, ORIGEN - The ORNL Isotope Generation and Depletion Code, M.J. Bell (May 1973). See also ORNL/TM 6055 and CCC-217.

Model - ORIGEN-S: ORNL Isotope Generation and Depletion Code (Version for SCALE-System)

Purpose - Calculates isotopic depletion, activity, and burnup of fuel cycle materials at any part of fuel cycle or during storage.

Description - This code predicts isotopic composition, activity, heat-generation rates, and spectra and hazard units of material during any part of fuel cycle. Can be used in the analysis of various reactor irradiation schemes; fuel processing and spent fuel studies; γ and neutron source shielding; shipping cask and proliferation fuel-resistant studies.

ORIGEN-S uses the matrix exponential method for most nuclides, Bateman Equations and Secular Equilibrium for others as necessary, and assumes a linear matrix equation or non-time-variant cross sections, though this code can be interfaced to NITAWL and XSDRNPM codes to circumvent this. As input, nuclide compositions, flux or power, reactor time history, decay history or option triggers may be required. The code uses library data bases. Input can be supplied in either a condensed or detailed version. The code is written in FORTRAN for the IBM 360/91, 370/195, and 3033 systems. Also CDC 7600.

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Source - Reference #17: p. 208

Model - ORIGEN2: Oak Ridge Isotope Generation and Depletion Code

Purpose - Calculates the characteristics of fuel cycle materials undergoing or having undergone neutron irradiation.

Description - This code predicts the composition, activity of various kinds, and heat generation as tabulated functions of time. These results can be used in off-gas studies, waste management, reprocessing, and transportation application. Method of solution is matrix exponential to buildup and decay equations, disallowing for spatial or self-shielding effects. Assumes zero dimensional, one-group irradiation methods. Uses self-contained data libraries which minimizes user input. Output is considered more than adequate, but can be voluminous. This program is written in FORTRAN for IBM 360 batch processing, requires 180-700K and times vary depending on material complexity.

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Source - Reference #15, 16

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - PABLM

Purpose - This model calculates internal doses and dose commitments to man for either acute or chronic ingestion of radionuclides from the air pathway.

Description - PABLM calculates internal doses and dose commitments to man for either acute or chronic ingestion of radionuclides for population or maximum individual for the air pathway.

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Source - Reference #8: p.208

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - PLUME: Estimation of Radiation Doses Following a Reactor Accident.

Purpose - This code calculates downwind radiation doses to be expected from a reactor accident.

Description - Based upon the "Gaussian Plume" formula, a model has been developed which permits calculation of the downwind radiation doses to be expected following a reactor accident. Although the calculations to date are concerned only with the thyroid dose due to iodines and the whole body dose due to iodines and noble gases, the code can easily be adapted to handle other radioisotopes. The basic assumptions include instantaneous release of a given quantity of radioactive material into a reactor building followed by emission at a constant (volume) rate from a point source. Radioactive decay both within the building and during passage downwind are accounted for as are the growth and decay of daughter products and the effects of physical separation such as filtration. A Fortran IV computer program PLUME has been written for the purpose of solving the equations developed. The code calculates dose due to inhalation and from submersion in the gamma emitting cloud.

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Source - Reference #6: pp.123-4

Model - PREDO: Estimating Radiation Doses

Purpose - This code is used in estimating statistical dose distribution.

Description - PREDO is a combination of the codes SITMET and WCLIM. SITMET uses hourly, onsite meteorological data to generate total body and/or skin doses for specified release inventories, release heights, and downwind distances. WCLIM generates a statistical distribution of doses with magnitude and direction.

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Source - Reference #18: p. 289.

Model - PUQFUA

Purpose - PUQFUA is an IBM 704 Code for Computing Plutonium Body Burdens.

Description - PUQFUA is an IBM 704 Fortran program, written primarily for Pu 239 which calculates from urinalyses the plutonium body burden in microcuries and the percentage of the maximum permissible body burden. It is based on a set of power-function elimination equations developed by Wright H. Langham for the excretion of plutonium over a five-year period. Results with PUQFUA compare favorably with those of other easy methods. In general, it is easy to apply for a large number of individual samples, and the validation method is objective and requires no past experience with plutonium body-burden calculations on the part of the evaluator.

A letter from the author written September 12, 1972, states that this version of PUQFUA is no longer available. A new version, PUQFUA 1 for operations on a CEC 6600 is in the process of evaluation, and no publication is available at this time describing the changes.

J.N.P. Lawrence, "PUQFUA: An IBM 704 Code for Computing Plutonium Body Burdens," Health Physics, Vol. 8, pp. 61-66, 1962, University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico.

Source - Reference #26: Item 240.

ATMOSPHERIC TRANSPORT DOSIMETRY

Model - RACER

Purpose - RACER calculates tissue dose in rads at a downwind location, delivered over a specified time, from gamma radiation emitted by a cloud of airborne radionuclides.

Description - The distribution of radionuclides is described by a bivariate normal equation. The location can be any point downwind of the release on or off the centerline of the cloud at ground level. No restrictions have been placed on release height. The penetrating dose; i.e., dose at five centimeters, and the dose to organs of interest resulting from inhalation have not been incorporated in this computer code.

The program includes a fission product inventory calculation using the computer code RIBD (Gumprecht, 1968, 1969) as a subroutine. The fission product inventory, with additional activation products specified, is released to the atmosphere through a three barrier containment system with depletion and filtration in each barrier.

Nuclide decay is considered during production, release and transport using a chain decay scheme with branching to and from isomeric states. The dose is calculated as the space-time integral of air concentration. A data base is used to minimize input requirements. The space-time integration causes long typical running times. RACER is written in FORTRAN IV for a UNIVAC 1108 computer.

D.I. Streng, M.M. Henderson, and E.C. Watson (1971)
Battelle, Pacific Northwest Laboratories
Richland, WA

Source - Reference #12: p. B-50.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - RADOS, A code to estimate gamma dose from a cloud of radioactive gases.

Purpose - This code can be used to rapidly calculate whole body dose from a cloud of airborne radioactive material.

Description - RADOS is a computer code that represents the finite spatial distribution of airborne source material as an infinite number of line sources. The code provides a means of rapidly calculating whole body gamma dose from a finite cloud of radioactive material. The simplifying assumptions used to minimize computation time are: (1) the material release is instantaneous and results in a radioactive cloud of unit thickness in the x or downwind direction. (2) there is no change in the size and shape of the cloud during passage over the effective range of the receptor. (3) the gamma buildup factors can be expressed analytically with sufficient accuracy. These assumptions limit the applicability of RADOS as follows: the material release should occur over a relatively short time; the receptor distance should be more than 600 meters downwind from the release point; and the gamma energies should be in the specified range. A 4 group, 12 isotope, 1 receptor-point problem requires approximately 1.75 seconds on the IBM System/360-65. This is approximately 8 percent of the running time for the more detailed CLOUD code. Dispersion is essentially based on the Gaussian assumption.

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Source - Reference #6: p. 128.

Model - RAMM: A System of Computer Programs for Radionuclide Pathway Analysis Calculations

Purpose - A generalized system of computer programs to analyze the movement of radionuclides through the environment to man.

Description - A generalized system of computer programs, designated RAMM (Radioactive Materials Management) system, has been developed to assist in the analysis of the movement of radionuclides through the environment to man. RAMM incorporates the GASP IV continuous/discrete simulation system. A nodal approach is used whereby the system to be analyzed is split up into parts small enough that the distribution of nuclides within the node may be taken to be homogenous. Pathways are defined between nodes, and appropriate transfer coefficients are input or generated. Nodes are general "containers of nuclides" and may be volumes, such as a volume of water or a body organ, or surfaces such as a square meter of land surface. Nodes may be defined as belonging to streams within which movement may be by transportation as well as by diffusion. Output includes the time dependent contents of the nodes and dose rates, integrated doses and dose commitments of selected nodes.

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Source - Reference #6: p.149

DOSIMETRY
RISK ASSESSMENT

Model - REDIQ

Purpose - This model calculates risk equivalence of dosage from internal and external irradiation.

Description - The computer program REDIQ calculates the risk equivalence of dosage from internally deposited radionuclides to dosage from external whole-body irradiation. The calculation gives an estimate of the microcurie intake per nuclide that would result in a risk equivalent to receiving one rem of external whole-body irradiation. The program allows for internal deposition resulting from either inhalation of radioactive aerosols or ingestion of contaminated food. The inhalation portion of REDIQ was taken from the computer program DACRIN, which uses the models of the respiratory tract adopted by the Task Group on Lung Dynamics. REDIQ also uses a simple exponential model for retention by an organ of interest, and the gastrointestinal tract model of the International Commission on Radiological Protection (ICRP).

For each nuclide specified, the program first calculates the radiation dose per microcurie intake by inhalation or ingestion to any of 23 organs and tissues. A maximum of ten organs may be specified for any one case. The values for dose per microcurie intake are then coupled with relative risk values for each organ being considered, to arrive at the estimated intake equivalent to one rem of external whole-body irradiation.

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Source - Reference #8: p.208

ATMOSPHERE TRANSPORT
DOSIMETRY

Model - RISC: Radiological Inhalation Safety Code for IBM 7090

Purpose - This code is designed to evaluate internal doses following inhalation.

Description - Radiological inhalation safety code (RISC) is a digital machine program used to compute internal exposures (according to the methods of Morgan and Ford) to seven body organs or tissues (thyroid, bone, muscle, lungs, gastro-intestinal tract, soft body tissues, and testes), incurred over the first year following short-duration inhalation. Doses to these body organs are based on computations of up to 50 radionuclide sources. These computations include both radioactive and atmospheric sources, strength determination, and the dose contributions from any of the 50 radionuclides to any or all of the above-mentioned body organs. RISC may be used to estimate the environmental consequences from reactor operations and accidental power excursions at stationary power plants, vehicle launch or test facilities, and from in-flight vehicles. The basic diffusion theory of O.G. Sutton is utilized in developing specific atmospheric diffusion models with the appropriate initial-volume-source corrections. The initial cloud size and height of rise are input parameters, along with isotope-release fractions, and downwind-dose points. The effects of a capping temperature inversion are determined in the program from a subroutine applicable for low-altitude releases. Also, the reduction of the cloud source material due to washout and dry fallout may be taken into account by exercising a separate option. The radionuclide source terms for each of 20 specified positions downwind are also computed in a subroutine which considers specific fission and decay times. This part of the program also permits dose normalization so that the output is in terms of Rem/MW-sec or Rem/MW.

Anno, G.H.; Debois, P.J.; Wilcox, T.P.; Witthaus, J.K.

Source - Reference #18: p. 255.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - RSAC-2: The Radiological Safety Analysis Computer Code.

Purpose - To provide a code to calculate the radiological consequences of accidental release of radionuclides to the atmosphere.

Description - RSAC-2 can be used to calculate 1) fission product inventory source terms, 2) lung doses using either the ICRP Task Group on Lung Dynamics Lung Model (TGLM) (ICRP, 1966) or the initial ICRP Lung Model (ILM) (ICRP 2, 1959), 3) gastrointestinal tract doses using either the model of Dolphin and Eve (1966) or the ICRP Publication 2 (1959) model, 4) dose to various internal organs using the ILM, 5) ground deposition gamma doses, and 6) cloud gamma doses using either a "finite" or "semi-infinite" cloud model. Cloud concentration is determined by the bivariate normal distribution model.

Containment features are modeled as a ten-term exponential function. Straight chain decay is considered. Branching is simulated by dividing the chain branches into two or more straight chains. Special attention is given to the finite cloud integration using Gaussian quadrature techniques applied to a variable interval. Buildup is modeled as a third-order polynomial. RSAC-2 is written in FORTRAN IV for an IBM computer.

R.L. Coates, N.R. Harton (1966)
L.C. Richardson (1968)
National Reactor Testing Station
Idaho Falls, ID.

Source - Reference #12: p. B-53

DOSIMETRY

Model - RUBY: A Program for the Calculation of Activity Releases and Potential Doses from a Pressurized Water Reactor Plant.

Purpose - This code calculates radiation releases and doses from normal reactor operation.

Description - The RUBY program is designed for the calculation of radiation releases and doses resulting from the operation of a large pressurized water reactor. The approach used in RUBY is similar to an analog simulation of a real system. Each major component or volume in the plant containing radioactive material is represented by a subroutine which keeps track of the production, transfer, decay, and removal of radioactivity in that volume. During the course of the analysis, activity is transferred from subroutine to subroutine in the program as it would be transferred from place to place in the plant. The necessary rates of production, transfer, cleanup, leakage, and release are read in as input to the program. Subroutines are also included which calculate the off-site radiation exposures at various distances, for individual nuclides and sums of nuclides. The program contains a library of physical data for the fifty-five nuclides of most interest in licensing calculations, and other nuclides can be added or substituted. These calculations can be performed for any or all time periods during the lifetime of the plant. Both external and thyroid internal doses can be calculated on an individual and a population basis. Values for atmospheric dilution at desired downwind distances and dose conversion factors for the thyroid doses are input by the user.

Boone, J.S.
Carolina Power and Light Company
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Source - Reference #6: p. 126-7.

DOSIMETRY
SURFACE WATER TRANSPORT

Model - RVRDOS: A Computer Code (RVRDOS) to Calculate Population Doses from Radioactive Liquid Effluents.

Purpose - A computer program RVRDOS has been developed to calculate population doses due to releases of radionuclides into flowing streams.

Description - Concentrations of the radionuclides downstream take into account dilution, decay, and the ingrowth of a daughter product. Population doses to four organs are calculated for drinking water and fish ingestion pathways. Individual doses due to swimming may also be estimated. RVRDOS has been used to calculate population doses due to releases from nuclear power reactors on the Mississippi River Basin during 1973. The data base for these calculations and a summary of the calculations are available.

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Office of Radiation Programs
Environmental Analysis Division
Washington, DC 20460

Source - Reference #6: p.140

DOSIMETRY

Model - SAURON: Initial Estimates of Doses in Human Body Organs Following Acute Exposure to Radioactive Fission Products

Purpose - A method has been developed which evaluates the dose commitment to human body organs following a single acute exposure to radioactive fission products.

Description - In this model all the fission products from Zn-72 to Tb-161 have been considered and their effective decay energies and effective half-lives in 17 human body organs have been calculated. The dose commitment to these organs following acute exposure to 1 Curie of each fission product is presented for both soluble and insoluble forms of each nuclide. The model has been programmed in FORTRAN IV (H) for the IBM 360/75 and is called SAURON. Preliminary calculations have been performed with SAURON for use in conjunction with reactor safety assessment programs. Although the results are for adult human beings, the program can be used for all age groups. It is intended that the model should be improved when better biological information becomes available.

Clarke, R.H.; Utting, R.P.
Central Electricity Generating Board, Research and Development
Department,
Berkeley Nuclear Laboratories, United Kingdom
1970, August. ED/B/N1762; 122 pp.

Source - Reference #6: p. 141.

DOSIMETRY

Model - SEBEACH: A Digital Computer Program for the Estimation of Body Content of Plutonium from Urine Data.

Purpose - A model which predicts the amount of plutonium retained in the body.

Description - The digital computer program SEBEACH allows estimation of the retained body content of plutonium from urine data. A function is given which relates the amount of plutonium found in a 24 hour urine sample at a time after intake, to the amount retained in the body. The method is based upon the trend of urine values. Two types of computation are carried out: first, as an upper bound, the calculated trend value is assumed to result from a single intake during the earliest possible period indicated by the urine record; second, the trend value is assumed to result from a constant and continuous intake over the whole exposed period. Two different clearance rates from the lung or wound to the blood are considered. The difficulties encountered in estimating the body content of plutonium are discussed in the light of the method of estimation programmed in SEBEACH. Comparison is made with other digital programs undertaking the same type of computation. A flow chart of the program is included.

S. A. Beach, National Radiological Protection Board, Research Division, Harwell, Didcot, Berkshire, England. January 1973, Health Physics, 24, 9-16.

Source - Reference #26: Item 357.

Model - STRAP II: Risk Evaluation for Stack Releases.

Purpose - A method of calculating the risk to the population distribution around a reactor site is presented for both ground level and elevated releases.

Description - The reactor is assumed to satisfy a control curve of the Farmer type for accidental releases of radioactivity, and the dose-risk relationship is assumed to be simple power law. Results are presented in which iodine is imagined to be released, on a number of typical sites. The resulting frequency distributions of thyroid cancer have been calculated and are given in the form of frequency-casualty curves (f-N curves).

The program depends on having input the number of rem per curie air concentration for a given radionuclide and the number of casualties of a given type per rem for that radionuclide.

G. D. Bell, J. Houghton
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Source - Reference #6: p.121

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - SUBDOSA

Purpose - SUBDOSA calculates the external dose to humans for skin, eye, gonads, and total body resulting from accidental release of radionuclides to the atmosphere.

Description - The computer program SUBDOSA has been developed for the purpose of calculating the dose to humans following accidental atmospheric releases of radionuclides. SUBDOSA calculates the dose from airborne radionuclides external to the body and does not consider the dose resulting from radionuclides deposited in the body and its organs via inhalation. Doses are calculated as a function of: quantity released, duration of release, atmospheric conditions during the release, and horizontal distance from the release point.

The dose to organs of reference in adults from airborne radionuclides external to the human body is primarily dependent upon the type of radiation, the energy of the radiation and the spatial distribution of the airborne radionuclides surrounding the human receptor. The energy and type of radiation are characteristic of each radionuclide. Spatial distribution of airborne radionuclides is determined by the quantity released, the duration of release, the atmospheric conditions prevailing during the release and the distance between the dose receptor and the point of release.

The organs of reference most frequently considered in external dose calculations are the skin, lens of the eye and total body. Corresponding tissue depths for these organs used in SUBDOSA are 0.007, 0.1 and 5 cm respectively. The male gonads are less often considered in dose calculations but when such calculations are made with SUBDOSA, the tissue depth is 1 cm.

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Source - Reference #8: p. 208, #9 p. 2.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - SUBPOPA

Purpose - SUBPOPA calculates the population dose resulting from accidental releases of radionuclides to the atmosphere.

Description - Population doses are calculated by assuming that the cloud travel and dispersal to any point surrounding the release are represented by the joint frequency distribution of wind vector and atmospheric stability. A sector average concentration and a one-hour release are assumed.

Radioactive chain decay with branching is calculated for chains with up to seven members. Contributions to external dose from both beta and gamma radiations are calculated. Dose is calculated as a function of depth in tissue. Extensive data bases are used to minimize input requirements. Up to five release inventories may be specified with results from each release summed. A finite cloud approach is used for the external gamma dose calculation. SUBPOPA is written in FORTRAN IV for a CDC CYBER computer and requires 143k (octal) words of core to execute.

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Source - Reference #8: p.208; Reference #12: p.856

Model - TERMOD

Purpose - TERMOD is a systems analysis methodology for predicting dose to man from a radioactively contaminated terrestrial environment.

Description - A systems analysis methodology has been developed to predict intakes by man, estimate dose commitments, and identify "critical" exposure pathways resulting from radioactivity releases to a terrestrial environment. A mathematical model was constructed simulating selected terrestrial pathways by which fallout radioactivity can be transferred ultimately to man. This model is intended for preliminary predictions of radionuclide intakes by man through consumption of milk, beef, and plant parts contaminated directly by fallout as well as by uptake from the soil. Differential equations were written describing the radionuclide transfers, and the parameters required to implement these equations were derived. In verification tests, model predictions of cesium 137 concentrations in environmental compartments agreed within a factor of 2 with experimental data. More extensive verification studies involving other radionuclides are needed. The intake rates and total intakes of seven sample radionuclides were predicted for a "reference" man based on a hypothetical fallout of 1 pCi/CM² of each radionuclide. These predicted intakes were used as input to an internal dosimetry model which calculated dose commitments for each radionuclide and pathway. This generalized food-chain model is sufficiently versatile that it can be applied to many terrestrial environments and to all radionuclides. The first version of the model is expected to undergo future refinements.

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Source - Reference #18: p.279

Model - TIMED: A Computer Program for Calculating Cumulated Activity of a Radionuclide in the Organs of the Human Body at a Given Time, t , After Deposition.

Purpose - The program calculates dose in body organs

Description - TIMED is a computer program designed to calculate cumulated activity in the various source organs at some time t after deposition. TIMED embodies a system of differential equations which describes activity transfer in the lungs, gastrointestinal tract, and other organs of the body. This system accounts for delay of transfer of activity between compartments of the body and radioactive daughters. The computer program contains routines which are written in either IBM System/360 or System/370 FORTRAN or IBM System/360 Assembler language. The code is executable on the IBM System/360 or System/370 machines and requires a minimum of 310 K core storage for execution.

S. B. Watson, W. S. Snyder, E. R. Ford
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Source - Reference #6: p.146

DOSIMETRY

Model - TTD: Beta Transmission, Degradation, and Dissipation Model.

Purpose - Absorbed beta-radiation dose expected from fallout particles deposited on the skin was estimated by use of the Beta Transmission, Degradation, and Dissipation (TTD) model.

Description - Comparison of computed doses with the most recent experimental data relative to skin response to beta-energy deposition leads to the conclusion that, even for fallout arrival times as early as 10^3 sec (16.7 min postdetonation), no skin ulceration is expected from single particles 500 μ or less in diameter. Doses from arrays of fallout particles of different size distributions were computed also for several fallout-mass deposition densities; time intervals required to accumulate doses sufficient to initiate skin lesions were calculated.

S. Z. Mikhail, "Beta-Radiation Doses from Fallout Particles Deposited on the Skin," CONF-700909, Proceedings of a Symposium held at Brookhaven National Laboratory, Long Island, New York, Sept. 15-18, 1970, (p. 31-50).

Source - Reference #26: Item 209.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - UDAD: Argonne Steady State Uranium Dispersion and Dosimetry Code.

Purpose - This code is used in the calculation of dose and transport of radionuclides from a uranium mine.

Description - The UDAD is a computer code to calculate airborne concentrations, ground deposited radioactivity, dose rates and doses from emissions from uranium mining & milling (Vol. 1) and induced health effects (Vol. 2). The annual average concentrations in air are computed from a sector averaged Gaussian diffusion equation. The concentrations in air, the radioactive cloud depletion and decay, the ingrowth radioactive daughter product concentrations and working levels, and the ground-deposited activities are computed for 16 wind directions and 15 distances up to a radius of 99 KM. Concentrations are also computed for specified receptor points. Dose rates and doses are computed for selected organs on the basis of the recommendations of the ICRP II and task groups. Dose rates from inhalation of radon daughters are computed from working-level. Health effects are predicted from competitive mortality from radiation induced, naturally included death, accidents and non-radiation forces of mortality.

Michael H. Momeni, Argonne National Laboratory, Environmental Impact Studies Division, 9700 S. Cass Ave. 60439. Momeni, Michael H. Yuchien Yuan, A. J. Zielen, and T. Beissel: The Argonne Steady-State Uranium Dispersion and Dosimetry Code, Vol. 1 (UDAD), ANL, 1978. Momeni, Michael H., S. A. Tyler, A. J. Zielen, and Y. Yuan: The Argonne Steady-State Uranium Dispersion and Dosimetry Code, Vol. 2, ANL, 1978.

Source - Reference #26: Item 1478.

ATMOSPHERIC TRANSPORT
DOSIMETRY
FOOD CHAIN
SURFACE WATER TRANSPORT

Model - VADOSCA: A Simple Code for the Evaluation of Population Exposure Due to Radioactive Discharges.

Purpose - This is a combination liquid-gas isotopic distribution model, with doses calculated using varying environmental parameters.

Description The code consists of two parts, one for liquid discharges (VADOSCA-II) and one for gaseous discharges (VADOSCA-GAS). It incorporates the transfer parameters of twenty-four radioisotopes in the case of liquid discharges, and of twenty radioisotopes in the case of gaseous discharges. It allows the evaluation of the concentrations of the various isotopes in all the compartments of the critical paths outlined in the International Commission on Radiological Protection (ICRP) Publication No. 7, and the evaluation of the annual doses for five critical organs (whole body, G.I. tract, thyroid, bones, lung) for the various critical groups of population on the basis of environmental parameters such as the time of residence in a certain area, diet, type of activity, hydrological regimen, irrigation methods, and meteorological conditions. Although extremely simple, the code allows rapid performance of all the evaluations required to define the amount of radioactivity that can be released and the associated exposures. In its present form, the code VADOSCA-II covers twenty-four radionuclides including some fission products, some activation products, plus an alpha emitter. VADOSCA-II calculates the doses to four special groups, namely, fishermen, other workmen, local population, farmers. A separate calculation is made for the doses originated by drinking water. The doses are evaluated for five critical organs and they are expressed in mrem/year if the discharges are expressed in Ci/yr. In VADOSCA-GAS, twenty nuclides are considered, including eight noble gases (fission and activation products, various isotopes as particulates, and H-3, N-13, C-14 in the form of vapor. Atmospheric diffusion is evaluated with Pasquill's theory adapted to the meteorological data available. In its present form VADOSCA-GAS does not take into account particular effects such as the cloud depletion due to deposition, down draft and building effect; the particulate deposition rate is assumed constant at $3 \cdot 10^{-2}$.

Bramati, L.; Marzullo, T.; Rosa, I.; Zara, G.
Italian National Electric Energy Agency

Source - Reference #6: p. 131.

Model - VITTLS

Purpose - VITTLS calculates annual dose and in some instances, dose commitments from radionuclides transported through various pathway.

Description - VITTLS calculates radionuclide concentrations on soil from aerial deposition or irrigation. The calculations are site-specific. From these calculation, individual annual dose and dose commitments to skin and total body are computed. Also calclated are radionuclide concentrations in produce, milk, eggs, and meat from aerial deposition or irrigation at a specific site. From these calculations, individual doses from the ingestion of farm products are computed in terms of the annual dose to total body, GI-LLI, Thyroid, bone, liver, lung, and kidney.

D. L. Brenchly, J.K. Soldat, J.A. McNeese, and E.C. Watson
Battelle Pacific Northwest Laboratories, Richland, WA 99352

Source - Reference #19: p. 6

DOSIMETRY
SURFACE WATER TRANSPORT

Model - WATER: Water Code.

Purpose - This code concerns itself with the environmental impact of radionuclides in liquid effluents.

Description - A FORTRAN IV code that models radionuclide releases into a flowing river and the subsequent dose to individuals and the population via various pathways. The code uses RG 1.109-dose factors, river flow data, and release data for the source. The doses are calculated at public water supplies and for swimmers at the nearest public use area.

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Source - Reference #18: p.197

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - WEERIE: A Program for Assessing the Radiological Consequences of Airborne Effluents from Nuclear Installation

Purpose - This code is used in determining safety and siting for reactors under operational or accident conditions. It may also be applicable to LLW management, although some modification may be required.

Description - A mathematical model has been devised for guidance in the safety and siting aspects of nuclear installations under operational or accident conditions. The model begins with the full fission product inventory applicable to the fuel at the time of interest generated for any reactor type and irradiation history. The amount of fuel involved in the incident may vary as a function of time, and either a time decaying or constant fission product inventory may be used to specify the release. The activity leaks from the circuit with allowances for time-dependent plateout, resuspension and filtration of each elemental species. By preserving the full nuclide decay schemes, nuclides leaking into the atmosphere depend not only upon their own release behavior but also on that of their precursors. The effluent in the atmosphere is dispersed from an effective stack height and allowance is made for building entrainment. Standard meteorological dispersion models are used and the effects of radioactive buildup and decay, ground and inversion reflections and ground deposition are taken into account. WEERIE then evaluates the inhalation and the cloud beta doses, while integration over the volume of the plume leads to estimates of the cloud gamma exposure. WEERIE is written in FORTRAN IV (H) and executes on the IBM 370/165 computer requiring 250 kbytes of fast core storage. Execution times vary with the degree of precision requested in the cloud gamma routine, but typically doses and exposures may be evaluated at the rate of 200 observation points per minute.

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Source - Reference #6: p.133

DOSIMETRY

Model - WOLGA-1: A Fortran IV Program for Calculation of Gamma-Dose Rate

Purpose - The program calculates gamma dose rate from radioactive effluent air released by one or several continuously emitting sources.

Description - The program WOLGA 1 serves for the calculation of the gamma dose rate in the surroundings of one or more emitters which emit gamma-active waste gases continuously. Frequently distributions in the directions of expansion, the wind velocities and the expansion categories must be available. The program is used in the calculation of the annual load on the environment because of the gamma-active emissions from the reactors at the Karlsruhe Nuclear Research Center (KFZK), among other things. Because of the occasional arrival of new emitters and the changes in the intensities of the sources, the nuclide mixture and the meteorological situation, this problem has to be solved anew annually. The computer program should take into account changes of this type, without difficulty. The program calculates the gamma dose rate from the effluent cloud of one or more emitters for any desired field point. There is a possibility of producing a list of the dose rates at the desired field points (e.g., villages) and an isodose map for given dose limits. The input and output of the program are explained on the basis of an example.

The program is written in Fortran IV for the IBM/370-168. Extensive documentation is available.

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Source - Reference #6: p.145

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - WRED: A Siting Code to Estimate Dose Probability Distribution from Measured Meteorology Data.

Purpose - WRED is a reactor siting code designed to estimate probability distributions of whole body gamma and thyroid doses using measured meteorological parameters as input data.

Description - Distribution analyses are performed as a function of downwind distance, activity release height, and wind direction. This statistical approach for gamma dose estimates, employing thousands of sets of meteorology data, is made economically feasible by using two-dimensional tables of space distribution-attenuation integrals and interpolation techniques. Measured meteorological parameters are converted to atmospheric dispersion parameters according to techniques developed at Brookhaven National Laboratory. Space distribution attenuation integrals are computed by techniques developed at the Savannah River Laboratory. When utilizing the full capacity of the code, approximately 2000 sets of data (involving 16,000 each gamma and thyroid dose calculations from raw meteorological data) are processed per minute on the IBM System 360/65. Concurrently, meteorological statistics are compiled, and all data are summarized for output. Provision is made for including compiled statistics from previous data processing to update the distribution analyses for each job. Code options allow minimum data input (wind speed, direction, temperature) or full input including measured standard deviations of the horizontal and vertical wind directions.

This code includes the dosimetric calculations computed by RADOS for gamma doses.

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Source - Reference #6: p.121-2

DOSIMETRY

Model - YIELDS: A Biological Dose and Radiological Activity from Nuclear Reactor or Nuclear Weapon Fission Products

Purpose - A code to calculate dose and activity from the fission products in a nuclear reactor core or from a nuclear weapon.

Description - If a dispersal model is assumed, calculations can be made of contaminated area, dose from inhaled or ingested fission products to each part of a biological system, or dose from external fission products, from a dispersed reactor core, or nuclear weapon fallout. Individual beta and gamma ray energies for each isotope are included, permitting detailed calculation of biological dose or other functions of these energies vs. time. The calculation method facilitates the handling of complicated radiological decay chains coupled with multisection biological systems. The option of sorting the output by isotopes or chemical species is available. The model may be modified to account for routine releases. The code is basically an internal dosimetry calculation based on inhalation. Ingestion apparently can be taken into account by modifying the appropriate input parameters. The radionuclide inventory can be specified as input. The code assumes that an atmospheric dispersion model is already available.

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1974, Dec. ORNL-4996

Source - Reference #6: p.117

ATMOSPHERIC TRANSPORT
DOSIMETRY
FOOD CHAIN

Model - 2BPUFF: Lagrangian Transport and Diffusion Code to Calculate Concentrations and Deposition at Long Range of Particles Less than 10 Micro Meters Diameter.

Purpose - The code is used to calculate concentrations and deposition of small particles following atmospheric nuclear tests.

Description - The 2BPUFF code is the latest version of the original 2BPUFF code developed at LLL in 1966 by Todd V. Crawford (see UCRL-50179, Nov. 23, 1966). The code calculates the dispersion of pollutants in a cylindrical cloud with a vertical axis of symmetry using a coordinate system fixed to the cloud's center. Similarity theory of atmospheric turbulence is used to predict the horizontal diffusivity as a function of initial cloud size, turbulent atmospheric dissipation, and time. Vertical diffusivity is entered as a function of height and time, enabling entry of diurnal variations in the boundary layer and temperature inversions. The model calculates cloud center and surface air concentrations, exposure rate, dry deposition, washout, and the vertical integral of individual nuclides and doses to an individual for a variety of pathways, including inhalation, whole body external gamma, submersion, forage-cow-milk, and pasture-meat.

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Source - Reference #18: p. 79

Model - A Computer Code for Environmental Calculations.

Purpose - The model is to calculate the dose to man resulting from releases of radionuclides to the environment.

Description - A major computer code for environmental calculations is under development at the Savannah River Laboratory. The primary aim is to develop a flexible, efficient capability to calculate the Dose to Man potential radioactive sources in the southeastern United States. It is being developed as a modular data-based system within the framework of the larger JOSHUA computer system, which provides data management, terminal, and job execution facilities.

T. B. Crawford, and C. E. Bailey "Environmental Science Computations: A Modular Data-Based Approach," a paper presented at an ERDA-Wide Conference on Computer Support of Environmental Science and Analysis, Albuquerque, NM, 9 July 1975. CONF-750706, pp. 199-222.

Source - Reference #25: p. 330.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - A Diffusion-Type Model of the Global Carbon Cycle for the Estimation of Dose to the World Population from Releases of Carbon-14 to the Atmosphere.

Purpose - The model estimates dose to the world from release of Carbon-14 from the nuclear power industry.

Description - A nonlinear dynamic model of the exchange of carbon among the atmosphere, terrestrial biosphere, and ocean is described and applied to estimating the radiation dose to the world's population from the release of C-14 to the atmosphere from the nuclear power industry. A computer implementation of the model, written in the IBM Continuous System Modeling Program III (CSMP III) simulation language, is presented. The model treats the ocean as a diffusive medium with respect to vertical transport of carbon, and the nonlinear variation of CO₂ partial pressure with the total inorganic carbon concentration in surface waters is taken into account in calculating the transfer rate from ocean to atmosphere. Transfers between the atmosphere and terrestrial biosphere are represented by nonlinear equations which consider CO₂ fertilization and impose a constraint on the ultimate total carbon mass in the biosphere. Sensitivity of the model to variation of its environmental parameters and scenarios (such as future production of nonradioactive carbon from the combustion of fossil fuels) has been studied with respect to its population dose estimates; the results of these studies indicate that the uncertainties in the environmental parameters of the model are sufficiently contained to provide adequate estimates of the population dose if the population growth model is stipulated. Comparisons of the model's predictions with a selection of population dose estimates given by other investigators show reasonable agreement, notwithstanding the differences among the models on which the estimates are based.

The program is written in IBM-CSMB III simulation language for the IBM/360.

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Source - Reference #6: pg. 147.

DOSIMETRY

Model - A FORTRAN Program to Determine Absorbed Organ Dose Due to Inhalation of Radionuclides.

Purpose - This code is used in determining maximum organ dose resulting from a given radiological inhalation. The relevance to LLW management is that the model gives a "worst case" analysis. A possible deficiency is that the model may be dated.

Description - A FORTRAN computer program has been developed to determine the maximum internal dose received by a given body organ as a result of inhalation of specific radionuclides. The program, based upon equations reported in the literature, determines the effective energy absorbed by the body organ per disintegration of the radionuclide, and computes the absorbed organ dose for various periods of intake for single or continuous release and for various periods of internal exposure. The organ dose includes effects from all descendants of the nuclide originally considered to have entered the body organ. Tabulated results for 133 radionuclides and their contributions to the dose to seven body organs and the whole body are presented. Input to the FORTRAN computer program may be modified to yield results for other radionuclides or body organs. The computer program may also be used to determine (by summing) the total absorbed organ dose for a mixture of fission products if the concentration in air of each major contributor at initial intake time is known.

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Source - Reference #6: p. 133

DOSIMETRY

Model - A Methodology for Calculating the Radiation Doses from Radioactivity Released to the Environment.

Purpose - This series of models were developed to predict amounts of radiation doses received by man and biota from nuclear facilities.

Description - The Radiological Analyses and Applications Group of the Environmental Sciences Division has developed a methodology for making estimates of radiation doses to man and biota following the release of liquid, gaseous, and particulate matter from nuclear facilities. The transport of released radioactivity through the environment is divided into four conceptual sections: atmospheric dispersion, (AIRDOS computer code), resuspension of material by wind action, terrestrial transport, (TERMOD computer code), and movement of material in underground water (SOGMOD computer code). Computation of dose to man and biota is divided into internal (INREM, and INDOS computer codes) and external exposure sections (EXREM 3 computer code). And finally, a development model (CONDOS) which estimates the dose to a population resulting from the manufacture, storage, distribution, use and disposal of consumer products which contain radioactivity was developed.

G. G. Killough (Comp.); L. R. McKay (Comp.), Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN, March 1976. ORNL-4992; Environmental Sciences Division Publication No. 660, 550 p.

Source - Reference #26: Item 597.

Model - A Model for Predicting the Transport of Radionuclides in the Marine Environment.

Purpose - This is a mathematical model to describe the transport of radionuclides in the marine environment, their accumulation in marine organisms, and their consequent dose to man.

Description - Expressions for the internal radiation dose to Standard Man are then derived on the basis of this model. These expressions give conservatively high estimates of the potential internal radiation dose, which can be compared with radiation-protection guides to determine the necessity, if any, of radiological safety measures. The model derivation starts with an instantaneous point-source solution to a partial differential equation that has been shown to be an adequate description of the physical dispersion process in the ocean. An expression for the radionuclide concentration in the ocean resulting from a fallout input is developed from this point-source solution. This expression indicates that vertical diffusion is the controlling mechanism for dispersion soon after the fallout deposition, and that convection controls dispersion later. From this observation, two simpler expressions are derived, one for early and one for later times. The simpler expressions for describing dispersion of a fallout input are used to define a mixing volume which then is considered to be the receptor of both the fallout and the terrestrial radionuclide inputs. The terrestrial input is due to direct groundwater contamination and terrestrial fallout. From these concepts, an expression is derived for the radionuclide concentration in the mixing volume. This expression is then combined with a seawater-seafood-man food-chain model to arrive at expressions for the infinite internal radiation dose to man.

S. G. Bloom, and G. E. Raines. Battelle Memorial Institute, Columbus Laboratories, 505 King Avenue, Columbus, Ohio 43201, BMI-171-123, 16 p., 1969.

Source - Reference #26: Item 201.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model A Model to Estimate Radiation Dose Commitments to the World Population from the Atmospheric Release of Radionuclides.

Purpose This code is used in modeling dose commitments in a global scenario.

Description A model to estimate the radiation dose commitments received by the population of the world beyond the immediate vicinity of a facility which releases radionuclides into the atmosphere is described. This model considers the dose commitments arising from immersion in the atmosphere containing the released material, ingestion of contaminated food, inhalation of gaseous and suspended radioactivity and exposure to ground deposits. The dose commitments from each of these pathways is explicitly considered for each radionuclide released into the atmosphere and for each daughter of each released nuclide. This is accomplished via the calculation of the specific air and ground concentrations in the world regions directly affected by each released nuclide and its daughter using the release rate of only the parent. This is considered to be a significant improvement over other models in which the effect of daughter radionuclides must be approximated by separate releases.

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WAPD-TM-1274

Source Reference #18, p. 98

ATMOSPHERIC TRANSPORT
DOSIMÉTRY
FOOD CHAIN

Model - A model to estimate the local radiation doses to man from the Atmospheric Release of Radionuclides.

Purpose - The model estimates doses to man from the atmospheric release of radionuclides.

Description - A model was developed to estimate the radiation dose commitments received by people in the vicinity of a facility that releases radionuclides into the atmosphere. This model considers dose commitments resulting from immersion in the plume, ingestion of contaminated food, inhalation of gaseous and suspended radioactivity, and exposure to ground deposits. The dose commitments from each of these pathways is explicitly considered for each radionuclide released into the atmosphere and for each daughter of each released nuclide. Using the release rate of only the parent radionuclide, the air and ground concentrations of each daughter are calculated for each position of interest. This is considered to be a significant improvement over other models in which the concentrations of daughter radionuclides must be approximated by separate releases.

Rider, J.L.; Beal, S.K.
Bettis Atomic Power Laboratory,
Westinghouse, West Mifflin, PA).

Source - Reference #6: p. 152.

Model - An Interspecies Model for Retention of Inhaled Particles.

Purpose - This code is used in determining movement of inhaled particles in various animals.

Description - A model has been developed which may be applied to mouse, rat, and dog, to describe the kinetics of clearance of inhaled particles from the respiratory tract, and the uptake and excretion kinetics of this cleared material. Emphasis has been placed on the tracheobronchial lymph nodes as a storage site for cleared particles, with uptake being described as a constant fraction of the amount of the deposited substance remaining in the respiratory tract at any time. First-order kinetics have been used to describe most of the translocation processes, and a very long life of retention (several thousand days) has been used for lymph nodes and one compartment of the lung. The rate constants have been described in terms of speculative physiological processes, as they may be affected by particle size and solubility. One advantage of this model is the ability to readily alter one or two constants and be able to obtain rather precisely a reasonable fit to experimental data points. Close agreement with results calculated from the model was attained with data from several sources, comparing lung and lymph node content of dogs with time after inhalation of various substances including PuO₂, (Pu(HO₃)₄, UO₂, and ThO₂.

R. G. Thomas, Loveland Foundation for Medical Education and Research, Albuquerque, NM, 1970. Assessment of Airborne Particles, T.T. Mercer, P. E. Morrow and W. Stohr (Eds.). Charles C. Thomas, Publisher, Springfield, Illinois, (pp. 405-420).

Source - Reference #26: Item 1131.

Model - A Pathology and Risk Assessment Model.

Purpose - This model is related to the health hazards of energy-related chemical and radioactive environmental pollutants.

Description - A computer program was developed that takes the existing mortality and fertility data on a given population and applies dose-response coefficients and estimated increments of exposure to chemical or radioactive effluents and derives the excess deaths by age and sex for 5-year intervals. The program was used in an analysis of the health effects of airborne coal combustion effluents.

M. W. Rosenthal, (Ed), "Pathology and Risk Assessment", Division of Biological and Medical Research Annual Report, 1976, Argonne National Laboratory, ANL-77-55, pp. 75-97.

Source - Reference #25: p. 172.

DOSIMETRY
FOOD CHAIN

Model - Applications of a General Computational Model for Composite Environmental Radiation Doses.

Purpose - This code is designed to aid in the calculation of radiation doses to man and aquatic biota resulting from large-scale commercial use of nuclear power.

Description - A mathematical model for calculation on a large general-purpose digital computer of regional radiation doses resulting from large-scale use of nuclear energy was previously developed and reported. This general model has now been sub-divided to permit rapid calculations for the several exposure pathway groupings in an interactive mode using the BASIC computer language. The sub-programs are completely flexible as to the nuclides, body organs, and pathways from which radiation doses are to be calculated. They include at the present time: approximately 150 radionuclides, including transuranics; doses to whole body, skin, bone, lungs, thyroid, and gastrointestinal tract; sub-programs for cloud submersion, inhalation of nuclides other than radioiodines (resuspension of deposited nuclides is not included), ingestion of water and aquatic foodstuffs along with external dose from water and sediments, ingestion of irrigated crops, and thyroid dose from inhalation. Ingestion and dose to aquatic biota can also be calculated. Dose factors in the programs for the various media-nuclide-organ combinations have been calculated using ICRP methods. For radionuclides with long effective half-lives, the sub-programs calculate either total dose commitment for a single year's intake or the dose-rate at the end of a specified period of years at constant annual intake. Transfer factors between trophic levels have been taken in most part from summaries published by others, and are updated as newer data becomes available. The major application to date of the compartmented model has been the calculation of doses for U.S. Atomic Energy Commission environmental impact statements. Use is also being made of the same model for evaluation of potential radiological impacts associated with the ultimate fate of radioactive wastes for various long-term disposal concepts.

Soldat, J.K.; Baker, D.A.; Corley, J.P.
Battelle, Pacific Northwest Laboratories
Richland, WA

Source - Reference #6: p. 135.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - A Procedure to Determine the Relative Extent of Reactor Fission Product Releases Under Various Meteorological Conditions.

Purpose - This code simulates fission product releases accounting for meteorological variations.

Description - Several versions of Sutton's equations expressing the atmospheric concentrations, doses, etc. due to a fission product release have been programmed for solution by an IBM 1620 computer, as an aid in evaluating the effects of postulated reactor accidents. In addition, each of these equations has been solved over a wide range of meteorological parameters, and the results graphed, providing an illustration of the effects of changes in one parameter or a combination of them on the solutions. The code handles both instantaneous and continuous point sources. Cloud depletion by both wet and dry processes are included using Chamberlain's procedure. The only dose calculated is the inhalation dose to the thyroid.

It should be noted that this is an early code and there is some question on the use of the terms rainout and dose, and on the derivation of the thyroid dose equation.

S. J. Lanes
Health and Safety Laboratory
New York Operations Office
New York, NY

Source - Reference #67: p.123

DOSIMETRY
ATMOSPHERIC TRANSPORT

Model - Calculation of the Gamma-Dose Rate from A Continuously Emitted Plume.

Purpose - This code is used in calculating long-term gamma dose from airborne releases of radionuclides.

Description - This computer model calculates the long term gamma dose rate cause by the radioactive off-gas continuously emitted from a stack. The statistical distribution of the wind direction and velocity and of the stability categories is taken into account. The emitted activity, distributed in the atmosphere according to this statistic, is assumed to be concentrated at the mesh points of a three-dimensional grid. The grid spacing and the intergration limits determine the accuracy as well as the computer time needed. When calculating the dose rate in a given wind direction, the contribution of the activity emitted into the neighboring sectors is evaluated. This influence is demonstrated in the results, which are calculated with an error below 3% and compared to the dose rate distribution curves of the submersion model and the model developed by K. J. Vogt.

W. Hubschmann; D. Papadopolous, Gesellschaft fur Kernforschung M.B.H., KFK-2172, (1975).

Source - Reference #26: Item 1060.

Model - Comparison of Mathematical Models for Calculation of External Gamma Doses Originating from Releases of Radioactivity to the Atmosphere

Purpose - This discussion deals with models that predict gamma doses from nuclear power plants. The same techniques for analyses may be relevant to LLW management.

Description - A brief description is given of different mathematical models for estimating external gamma doses from a continuous plume of radioactive gases (iodines and noble gases) released to the atmosphere from a nuclear plant, and the uncertainties of such estimates are discussed. Gamma doses from unit releases of fourteen noble gases and iodines were calculated from these models and compared with the doses calculated from the computer program GDOS, which is an implementation of a gamma dose model developed at Riso. Good agreement was found between GDOS and seven other models, one of which was experimentally verified within a downwind distance of a few kilometres. Estimated gamma doses from unit releases of fourteen noble gases and iodines for two weather categories (Pasquill types D and F), and with three different release heights (0.24 and 100 meters) calculated with four the models (including GDOS), are given tabularly and graphically for values of downwind distances from 0.1 to 5.0 kilometres.

J. P. Hedemann
Danish Atomic Energy Commission
Risoe Research Establishment

Source - Reference #6: p.136

Model - Computer Modelling of Terrestrial Gamma-Radiation Fields.

Purpose - The program solves the one-dimensional photon transport equation. The applicability is general to the LLW management program.

Description - The plane, one-dimensional photon transport equation is considered in the case of two adjacent media, where one medium contains the gamma-ray sources and the other is inactive. Assuming that the sources have a composite line spectrum, and that they are uniformly distributed, an explicit solution is given for the uncollided flux component. The scattered component is evaluated on the basis of the double-P₁ approximation, involving separate treatments of the upstreaming and the downstreaming flux, and a corresponding equation is presented. The computational method permits determination of the differential and angular energy flux throughout the inactive medium. Formulas for obtaining integral field quantities (scalar energy flux, scalar number flux, and absorbed dose rate) are given. The flux calculation method is used in conjunction with a data processing system for evaluation of terrestrial gamma-radiation fields. A detailed description is given of both the data files and the programs of which the system consists. To illustrate the performance of the system, results obtained for the radiation field in water above sand are presented. The program is written in FORTRAN for the B 6700 (Danish Computer Installation at Riso). Extensive documentation is available.

Kirkegaard, P.; Lovborg, L.
Danish Atomic Energy Commission Research Establishment
Riso, Denmark

Source - Reference #6: p. 144.

Model - Computer Simulation of Iodine-131 Transfer from Fallout to Man.

Purpose - The model depicts the principle routes of I-131 transfer from fallout to man. The relevance of the model is that it can indicate I-131 paths from LLW disposal.

Description - A computer model has been constructed to depict the principal routes of I-131 transfer from fallout to man. Thyroid accumulation and excretion have been modelled for cow and for man. A simulation is carried out of the major fallout during the fall of 1962, following tests of nuclear weapons, and the results are compared with experimental data for southern Scandinavia.

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Niels Bohr Institute
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Source - Reference #6: pg. 149.

DOSIMETRY

Model - Digital Simulation of Two Models of the Biological Disposition of Inhaled Plutonium

Purpose - The model describes retention and transportation of inhaled plutonium.

Description - Two mathematical models which describe the retention and translocation of inhaled plutonium were simulated on BNW's minicomputer system MINERVA. Equation parameters are obtained by matching the simulation to data gathered by several studies at BNW. Interactive graphics techniques are described which facilitate the data fitting process. It is felt that additional model development will probably be required to best fit the data.

Bionne, P.J.; Harrington, T.P.
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Richland, WA 99352

Source - Reference #6: p. 140.

SURFACE WATER TRANSPORT
DOSIMETRY

Model - Effects of Rainstorms and Runoff on Consequences of Nuclear Reactor Accidents.

Purpose - The model describes the transportation of radionuclides from rain and the resulting runoff. The code also computes health consequences of reactor accidents.

Description - A preliminary model describing the effects of washout and runoff on the consequences of a nuclear reactor accident is presented. The most important new feature of this stratified model relative to the model in WASH-1400 is the spatial structure of rainstorms and runoff consisting of four levels of rain activity that are normalized by rain gage data. The predicted concentrations of radioactivity and resultant health consequences of the stratified model are compared with those of the model in WASH-1400 for simplified rainstorms with fixed meteorological conditions, an actual rainstorm, and a stratified sample run consisting of 91 separate reactor accidents. In the case of individual storms and runoff, the spatial structure of the rain in the new model can result in health consequences that are significantly different from those of the WASH-1400 model. The differences between the predictions of the two models are small for the stratified sample run.

Ritchie, L.T.; Brown, W.D.; Wayland, J.R.
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Albuquerque, NM 87115

Source - Reference #6: pg. 150.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - Integrated Environmental Modeling System for Noble Gas Releases at the Savannah River Plant.

Purpose - This code computes doses from radioactive gas releases at the Savannah River Plant at distances up to 100 kilometers.

Description - Of the releases of radioactive gases at the Savannah River Plant (SRP), the noble gases constitute about 11% of the total man-rem exposure to the population out to a distance of 100 km. Although SRP has an extensive radiological monitoring program, an environmental modeling system is necessary for adequately estimating effects on the environment. The integrated environmental modeling system in use at SRP consists of a series of computer programs that generate and use a library of environmental effects data as a function of azimuth and distance. Annual average atmospheric dispersion and azimuthal distribution of material assumed to be released as unit sources is estimated from a 2-year meteorological data base, assuming an arbitrary point of origin. The basic library of data consists of: (1) ground-level concentrations according to isotope, and (2) whole body gamma dose calculations that account for the total spatial distribution at discrete energy levels. These data are normalized to tritium measurements, and are subsequently used to generate similar library data that pertain to specific source locations, but always with respect to the same population grid. Thus, the total additive effects from all source points, both on- and off-site, can be estimated. The final program uses the library data to estimate population exposures for specified releases and source points for the nuclides of interest (including noble gases). Multiple source points are considered within a single pass to obtain the integrated effects from all sources.

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Source - Reference #6: p. 142.

Model - Long-Term Burdens of the Deep Lung and Systemic Organs.

Purpose - This model is used to predict long-term buildup and elimination of plutonium in critical organs.

Description - The dynamic simulation of plutonium buildup and elimination from the major organs of the body after plutonium dioxide inhalation was developed from tissue radioanalyses and excretion data from beagle dogs, which were sacrificed from two months to six and one-half years after inhaling Plutonium 239 PuO₂ aerosols. The model's description of individual tissue levels as functions of time after exposure were fitted to the analyzed plutonium burdens obtained from over fifty dogs, providing insights into several problems connected with inhaled insoluble plutonium. The use of a model based on the slow pulmonary compartment appears to be justified in the study of effects upon systemic organs and the lymphatic system as additional lung radioanalyses and whole body retention data become available. In addition, the model has been programmed for a UNIVAC 1108 digital computer using a digital simulation language. The model appears to give sufficiently accurate dynamic levels in all major organs to permit its use with individual animal retention and excretion data. Predictions of long-term buildup and elimination of plutonium in critical organs are used in establishing maximum permissible air concentrations of plutonium dioxide, and known excretion patterns may be used to determine initial burdens following possible accidental exposure.

P. J. Dionne,; B. O. Stuart, Battelle Memorial Institute, Pacific Northwest Laboratories, Applied Physics and Electronics Department, Richland, WA; Battelle Memorial Institute, Pacific Northwest Laboratories, Biology Department, Richland, WA. March 1, 1968, BNWL-SA-1540; CONF-680502-1; Part of Proceedings of the 6th IEEE Region Symposium held in Portland, Oregon, May 22, 1968, (23 p.), 206 p.

Source - Reference #26: Item 336.

Model - Methods and Techniques Relevant to Marine Disposal of LLW or Marine Contamination by LLW.

Purpose - Models covered include marine pathways for radionuclides, aquatic and terrestrial food chains, and dosimetry. The discussion thus has relevance for many aspects of LLW management, particularly marine disposal.

Description - A number of studies on circulation models and dose rate models are briefly discussed. Marine pathways are evaluated for intermittent releases of low-level wastes. The radionuclides of interest are Zn-65, Cs-137, Co-60, Mn-54. It is their concentration in edible marine organisms that are of concern. Also the concentrations of the above radionuclides are discussed with respect to bottom sediments. Various methods of treating wastes with strontium, plutonium, and ruthenium are briefly considered. Also, leach rates were compared by three methods of mathematical analysis. The present and past land burial and storage techniques have been adequate. However, such practices may not be sufficient in the future. Computer analysis of a one-dimensional transient response of a soil column to infiltrating water is mentioned. Assessments of power plant impacts are now including one- and two-dimensional mathematical models for the transport of dissolved radionuclides. Effects of sediment-radionuclide interaction, routine and accidental discharges, and aquatic and atmospheric dispersion, deposition, and resuspension are included. The aquatic and terrestrial food chain transport and the calculation of doses resulting from internal and external modes of exposure are considered as well. When comparing the behavior of plutonium and americium in marine and freshwater environments, there is no preference of uptake between the two transuranics. The major reservoirs of plutonium and americium are the sediments in both environments.

Blaylock, B.G. 1978, June.
Journal of the Water Pollution Control
Federation 50(6), 16 pp.
Oak Ridge National Laboratory
Environmental Sciences Division
Oak Ridge, TN 37830

Source - Reference #11: p. 46.

Model - Modeling of Environmental Pathways and Radiation Doses from Nuclear Facilities

Purpose - A computer model was developed which calculates total annual radiation doses and 50-year dose commitments to several categories of persons at population centers and continues these calculated doses into integrated (man-rem) annual and 50-year doses for large populations. The application to LLW management is general.

Description - The dose model was designed as one portion of an overall computer program developed to delineate the nuclear facilities expected in the year 2000, the radionuclides released to air and water, their diffusion, dispersion, and reconcentration in the environment, and the resulting radiation doses to people. Equations for calculating dose factors were derived from those given by the International Commission on Radiological Protection (ICRP). Effective decay energies for various radionuclides were calculated from the ICRP model, which assumes that all the radionuclide is in the center of a spherical organ with an appropriate effective radius. Where data were lacking, metabolic parameters for the Standard Man were used for other ages as well. The model includes a sub-routine which calculates radionuclide concentrations in a wide variety of foods at time of harvest from concentrations in air, irrigation water, and soil. The latter concentrations are output from previous portions of the overall computer program. The tremendous variety of data required for proper dose assessment is not always available in the literature. Such data has been extrapolated from environmental studies of fallout nuclides and from planned laboratory and field studies of a limited number of nuclides.

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Source - Reference #6: p.116

GENERAL TRANSPORT
DOSIMETRY

Model - Nevada Applied Ecology Group Plutonium Study Modeling Program: Plutonium Transport and Dose Estimation Model.

Purpose - This model predicts Pu-239 transport and radiation dose.

Description - A computer program based on a matrix exponential method was used to solve a system of ordinary differential equations which simulate the behavior of Pu-239 in desert ecosystems such as those found at and near the Nevada Test Site. The model was used to estimate the rates of Pu-239 transport, via several environmental pathways, to Standard Man, who was assumed to live in a contaminated area. These estimates were then used to calculate radiation doses and dose commitments, as a function of time, to different organs. The model provides a method for evaluating the potential radiological hazard to man due to the presence of Pu-239 in a given area. However, the studies designed to implement the model, by providing accurate estimates of critical parameters, are still in progress. Therefore, the results to date are incomplete and inconclusive. On the basis of present assumptions and parameter values, the model indicates a 70-year dose commitment to the pulmonary lymph nodes of 13.6 rem per pCi (Pu-239)/g (soil).

W. E. Martin; S. G. Bloom; R. J. Yorde, Jr., Battelle Columbus Laboratories, Columbus, OH, July 1974. CONF-731048; NVO-142; Part of Dunaway, P. B. and White, M.G. (Eds.), The Dynamics of Plutonium in Desert Environments, Proceedings of the NAEG Plutonium Environmental Studies Program Symposium held in Las Vegas, Nevada, October 2-3, 1973, (p. 331-360), 369 p.

Source - Reference #26: Item 412.

DOSIMETRY

Model - On the Selection of a Ground Disposal Site for Radioactive Wastes by Means of a Computer.

Purpose - This computer program calculates the best site for radioactive waste disposal and also predicts the dose of radioactivity to humans due to that site.

Description - A program for site selection is based on some reasonable assumptions and includes the data required to estimate the dose of radioactivity in the human body due to the disposed wastes of a nuclear facility along a coast. The calculations were made for a model nuclear facility that was chosen to show the general method of selecting a ground disposal site. An optimum location for a ground disposal site is defined as a location with minimum internal dose caused by the disposed wastes. Four locations were selected using a computer, each location having a minimum internal dose based on the assumption of 0.1 Ci/yr leakage of Sr-90. The minimum internal dose for the four locations was estimated to be lower than 10(E-80) mrem/yr. The method of selecting optimum locations is reasonably promising for solving current problems of site selection for disposal. A chart to compare the safety of sites by evaluating each with reference to eighteen environmental factors is included.

S. Morisawa; Y. Inoue, Kyoto University, Department of Sanitary engineering, Kyoto City, Japan. November 1974. Health Physics, 27, 447-457.

Source - Reference #26: Item 792.

Model - Plutonium

Purpose - The migration of plutonium in the human body is dealt with by this model.

Description - A computer model predicting the excretion, translocation, and retention of plutonium in the human body following intravenous injection of plutonium nitrate was developed. Recognizing the possible limitations of the model due to differences in pH, chemical composition, and amounts of injected material, prediction factors were estimated relating results of the human and dog models for injected plutonium citrate. These prediction factors along with the dog model for Pu injected in nitrate form were used to develop predictions of initial whole body, bone and liver burdens given the daily amount of Pu excreted in urine for injections of plutonium nitrate in humans.

P. J. Dionne; I. C. Nelson, Battelle-Pacific Northwest Laboratories, Systems Engineering Department, Richland, WA 99352. May 1972. BNWL-1651 (Part 2); Part of J. M. Nielsen (Mgr.), et al, Pacific Northwest Laboratory Annual Report for 1971 to the USAEC Division of Biology and Medicine, Vol. 2: Physical Sciences, Part 2. Radiological Sciences, (p. 82).

Source - Reference #26: Item 315.

DOSIMETRY

Model - Plutonium Transport and Dose Estimation Model.

Purpose - This model is used to predict amounts of Pu239 inhalation and ingestion from a Pu contaminated area.

Description - A Standard Man was assumed to live in and obtain most of his food from a Pu-contaminated area at the Nevada Test Site (NTS). A Pu-transport model, based on the results of other studies at NTS, provided a basis for estimating rates of Pu239 inhalation and ingestion as functions of the average concentration of Pu239 (C_s equals pCi/g) in the surface soil of the reference area. Assuming the transport system to be in equilibrium, the estimated inhalation and ingestion rates (pCi/day) are $0.002 C_s$ and $0.269 C_s$, respectively. A dose estimation model, based on parameters recommended in ICRP publications, is used to estimate organ burdens, accumulated doses, and dose commitments as functions of exposure time. Estimated doses (rems) due to inhalation and ingestion of Pu 239 for 50 years at the rates indicated above are: thoracic lymph nodes, $0.6 C_s$; lung, $0.025 C_s$; bone, $0.015 C_s$; liver, $0.01 C_s$; kidneys, $0.003 C_s$; total body, $0.0007 C_s$; and gastrointestinal tract (lower large intestine), $0.0003 C_s$. Inhalation accounts for 100% of the predicted dose to thoracic lymph nodes and lungs and for about 94% of the predicted dose to bone, liver, kidneys, and total body.

W. E. Martin; S. G. Bloom, Battelle Columbus Laboratories, Ecology and Ecosystems Analysis Division, Columbus, OH, 1975. CONF-751105; IAEA-SM-199/78; STI/PUB/410; Part of Proceedings of a Symposium on Transuranium Nuclides in the Environment held in San Francisco, California, November 17-21, 1975, (p. 385-400), 724 p.

Source - Reference #26: Item 556.

Model - Population Dose Caused by Low Level Radioactive Waste.

Purpose - This model evaluates the radioactive dose received by a population from waste dumped in a coastal area.

Description - A mathematical model for estimating the population dose caused by low-level radioactive waste discharged to a coastal area from a nuclear fuel reprocessing plant is presented. The population intake is a summation function which is summed over seawater position and season. Data required for the estimation are: catches of fishes, the fishing field distribution, the fishing season, the fishing layer, the fishing method, the concentration factor of radionuclides for each kind of fish and oceanic diffusion models for radionuclides. The population dose can be estimated by dividing the population intake by the value of intake of radionuclides which corresponds to the dose equivalent of 1 rem.

Fukuda, M.
Japan Atomic Energy Research Institute
Tokai-mura, Sbaraki-ken, Japan
Health Physics, 31(S), 476
November 1976

Source - Reference #11: p. 146.

ATMOSPHERIC TRANSPORT
DOSIMETRY

Model - Program for Computing External Dose Rate from a Radioactive Cloud and Numerical Examples for Nuclear Ships.

Purpose - The program calculates external dose to man from immersion and radioactive cloud.

Description - A program for calculating the external dose rate from a radioactive cloud was written in 06 NARC language (analogous to FORTRAN). The basic equation used for the atmospheric dispersion is equivalent to the so-called generalized Gaussian plume formula with the stack and the inversion lid modifications. The numerical integration was performed using the Legendre-Gauss quadrature technique together with the polar coordinate system developed by D.S. Duncan. The time required for the integration was found to be around forty minutes on the NEAC-2206 computer.

Sato, K.; Ito, Y.; Iyori, I; Yamaji, A.

Source - Reference #6: 137.

Model - Use of Computers to Calculate Radiation Dose from Metabolic Models.

Purpose - The technique was developed to calculate a factor called absorbed fraction which can be used to calculate gamma ray dose.

Description - Computers have played an increasing role in the calculation of radiation dose as greater precision has been required. This is particularly true for the dosimetry of gamma rays since their transport and absorption are complex. A technique was developed using Monte Carlo simulation to yield a factor called "absorbed fraction" which can be used to obtain rigorous values of the gamma ray dose under specified geometrical conditions. The absorbed fractions obtained from the Monte Carlo calculations are exact and do not have the approximations inherent in other point source kernels. The use of biological models permits more precise activity distributions to be obtained which, when combined with improved methods of physical dosimetry, yield improved estimates of radiation dose.

Brownell, G.S.; Alpert, N.M.
Physics Research Laboratory
Massachusetts General Hospital
Boston, MA

Source - Reference #6: p. 143.

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ATMOSPHERIC TRANSPORT
DOSIMETRY
FOOD CHAIN

Model - AIRDOS - EPA

Purpose - The AIRDOS-EPA computer code is a methodology, designed for use on IBM-360 computers, that estimates radionuclide concentrations in air; rates of deposition on ground surfaces; ground surface concentrations; intake rates via inhalation of air and ingestion of meat, milk, and fresh vegetables; and radiation doses to man from airborne releases of radionuclides.

Description - A modified Gaussian plume equation is used to estimate both horizontal and vertical dispersion of as many as 36 radionuclides released from one to six stacks or area sources. Radionuclide concentrations in meat, milk and fresh produce consumed by man are estimated by coupling the output of the atmospheric transport models with the U.S. Nuclear Regulatory Commission, Regulatory Guide 1.109 terrestrial food chain models. Dose conversion factors are input to the code, and doses to man at each distance and direction specified are estimated for total body, red marrow, lungs, endosteal cells, stomach wall, lower large intestine wall, thyroid, liver, kidneys, testes, and ovaries through the following exposure modes: (1) immersion in air containing radionuclides, (2) exposure to ground surfaces contaminated by deposited radionuclides, (3) immersion in contaminated water, (4) inhalation of radionuclides in air, and (5) ingestion of food produced in the area.

The code may be run to estimate highest annual individual dose in the area or annual population dose. For either option, output tables summarize doses by nuclide, exposure mode, and organ. Also, for either a square or circular grid option, ground concentrations of radionuclides and intake rates by man are tabulated for each environmental location. Working level exposures are also calculated and tabulated for inhalation of ^{222}Rn short-lived progeny. Run time is less than 5 min on the IBM 360/91, and the core requirement is 650 K (kilocore).

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Source - Reference #4

ATMOSPHERIC TRANSPORT
DOSIMETRY
FOOD CHAIN

Model - AIRWAY

Purpose - This is a model to estimate the local radiation doses to man from the atmospheric release of radionuclides.

Description - A model was developed to estimate the radiation dose commitments received by people in the vicinity of a facility that releases radionuclides into the atmosphere. This model considers dose commitments resulting from immersion in the plume, ingestion of contaminated food, inhalation of gaseous and suspended radioactivity, and exposure to ground deposits. The dose commitments from each of these pathways is explicitly considered for each radionuclide released into the atmosphere and for each daughter of each released nuclide. Using the release rate of only the parent radionuclide, the air and ground concentrations of each daughter are calculated for each position of interest. This is considered to be a significant improvement over other models in which the concentrations of daughter radionuclides must be approximated by separate releases.

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412-462-5000 EXT. 384; FTS 721-0384
National Technical Information Service WAPD-TM-1273, 34 pp.

Source - Reference #18: p.273

DOSIMETRY
FOOD CHAIN
SURFACE WATER TRANSPORT

Model - AQUAMAN

Purpose - AQUAMAN is a computer code for calculating dose commitment to man from aqueous releases of radionuclides.

Description - AQUAMAN is an interactive computer code for calculating values of dose (50-year dose commitment) to man from aqueous releases of radionuclides from nuclear facilities. The data base contains values of internal and external dose conversion factors, and bioaccumulation (freshwater and marine) factors for 56 radionuclides. A maximum of 20 radionuclides may be selected for any one calculation. Dose and cumulative exposure index (CUEX) values are calculated for total body, GI tract, bone, thyroid, lungs, liver, kidneys, testes, and ovaries for each of three exposure pathways: water ingestion, fish ingestion, and submersion. The user is provided the option at the time of execution to change the default values of most of the variables, with the exception of the dose conversion factor values. AQUAMAN is written in FORTRAN for the PDP-10 computer.

D. L. Shaeffer, and E. L. Etnier
Oak Ridge National Laboratory
Oak Ridge, TN 37830
ORNL/TM-6618, p. 27, Feb. 1979.

Source - Reference #25: p. 36.

DOSIMETRY
FOOD CHAIN
SURFACE WATER TRANSPORT

Model - ARRRG, Aqueous Release of Radionuclides Report Generator.

Purpose - ARRRG calculates annual individual and population doses resulting from radionuclides released with liquid effluents. It is part of the HERMES computer program.

Description - ARRRG calculates annual individual and population doses resulting from radionuclides released to surface-water bodies. Eight environmental pathways are modeled: eating fish, crustacea, molluscs, and algae; drinking surface water; direct external radiation from shoreline; water immersion (swimming), and direct external radiation from boating. Doses are calculated for skin, total body, gastrointestinal-lower large intestinal tract, thyroid, bone, liver, lung, and kidney. The output format specifies contributions to the dose by nuclide and by pathway.

Currently ARRRG is operational with the capability of calculating doses for 6 organs and 200 radionuclides. The user inputs the following variables from an interactive terminal: the name of the facility under investigation; decay between release and point of exposure (holdup), usages, and mixing ratios by pathway; reactor coolant flow, shoreline width factor and reconcentration factor parameters.

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Source - Reference #8: p. 207-208, #12 p. 2-27, B-39.

ATMOSPHERIC TRANSPORT
DOSIMETRY
FOOD CHAIN

Model - BELCH: TVA Gaseous Dispersion Code

Purpose - This code calculates doses to the public from routine gaseous releases at power reactors.

Description - The TVA gaseous dispersion code calculates individual and population doses to the public from routine gaseous radioactive release from TVA's power reactors; the methodology is that set forth in NRC Reg. Guides 1.109 and 1.111. The code uses site-specific meteorological data, agricultural data, and population information to estimate doses to individuals at site boundaries, nearest residences, and real milk cow locations. Populations doses to persons living within 50 miles of the site are also calculated. Dose pathways considered include beta and gamma air doses at the site boundary, skin and total body doses at nearest residences, and thyroid doses at milk cow locations. Thyroid doses include the following pathways: submersion, ground contamination, inhalation, and ingestion of beef, vegetables and milk. Estimated doses are considered conservative for average animal, routine radioactive releases.

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Source - Reference #18: p. 96

FOOD CHAIN

Model - BIOTRAN: Transuranic Biological Transport Model.

Purpose - This code is used in simulating the transport of radionuclides through an ecosystem.

Description - BIOTRAN simulates ecosystems, biomass density, and the cycling of transuranics of ruminant herds. The model uses biomass as a vector for predicting radionuclide uptake and surface deposition of plutonium in plants and animals.

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Source - Reference #18: p.247

Model - CARDOCC: Modeling of Radiation Doses from Chronic Aqueous Releases.

Purpose - A general model and corresponding computer code, called CARDOCC, were developed to calculate personnel dose estimates from chronic releases via aqueous pathways.

Description - Cardocc uses the internal dose portion of the ARRRG code, increases its generality and scope, and simplifies the input requirements. Potential internal dose pathways are consumption of water, fish, crustacean, and mollusk. Dose prediction from consumption of fish, crustacean, or mollusk is based on the calculated radionuclide content of the water and applicable bioaccumulation factor. 70-year dose commitments are calculated for whole body, bone, lower large intestine of the gastrointestinal tract, and six internal organs. In addition, the code identifies the largest dose contributor and the dose percentages for each organ-radionuclide combination in the source term. The 1974 radionuclide release data from the Savannah River Plant were used to evaluate the dose models. The dose predicted from the model was compared to the dose calculated from radiometric analysis of water and fish samples. The whole body dose from water consumption was 0.45 mrem calculated from monitoring data and 0.61 mrem predicted from the model. Tritium contributed 99% of this dose. The whole body dose from fish consumption was 0.20 mrem calculated from monitoring data and 0.14 mrem from the model. Cesium 134,137 was the principal contributor to the 70-year whole body dose from fish consumption.

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Source - Reference #6: p.120

Model - CRITR

Purpose - Calculates internal radiation dose to four common classes of aquatic organisms and to organisms which consume them.

Description - CRITR calculates annual internal total-body dose to organisms resulting from radionuclides ingested with their food. CRITR always calculates the internal dose to four primary organisms which are directly exposed to radionuclides in the water: fish, crustacea, molluscs and algae. At the user's option, internal dose can also be calculated for up to six secondary organisms which feed upon one of the primary organisms.

Program output at the user's terminal consists of internal dose to all four primary organisms of the selected organ radius, internal dose to the selected secondary organisms, optional percentage contribution to internal dose by nuclide for each selected primary and secondary organism, and an optional table of release rates and concentrations of radionuclides in the liquid effluent by isotope. CRITR produces no high-speed printer output.

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Source - Reference #24: p. 1-1, p. 7-19, p. 7-28, p. 10-23.

Model - FOOD

Purpose - FOOD calculates annual individual doses from the consumption of garden foods and animal products contaminated from air deposition or water (sprinkler irrigated). It is part of the HERMES computer program.

Description - FOOD is a companion code to ARRRG and calculates annual individual and population doses from eating garden foods and animal products contaminated by air deposition or water irrigation. Doses are calculated for 14 foods. A key assumption in the code is that the accumulation and dispersion processes in the biosphere are such that the local soils used for farming contain the accumulated radionuclides from a specified number of years of irrigation previous to the time of interest.

Terminal input for FOOD includes: facility name, holdups, usages, irrigation rates, air concentration, crop yields and growing periods for 14 food types (for animal products the parameters refer to animal's feed); coolant flow and mixing ration, and reconcentration factor parameters in the case of liquid release. FOOD is operational with 136 nuclides.

D.H. Denham, D.A. Baker, J.K. Soldat, and J.P. Corley
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Source - Reference #62: pp. 2-28, B-39, 40.

Model - GAUCHE

Purpose - The purpose of this code is to calculate annual dose and in some cases dose commitments from exposure to radionuclides in the atmosphere as deposited in such a way as to enter the food chain through ingestion of milk or leafy vegetables.

Description - GAUCHE computes individual doses from three sources: 1) air submersion at a specified location; 2) inhalation and tritium transpiration at a specified location; and 3) inhalation and consumption of milk and leafy vegetables at any specified X/Q'. For the first source, annual dose and dose commitments to skin and total body are computed; for the second source, annual dose and dose commitments to total body, GI-UI, thyroid, bone liver and kidney are computed; for the third source, only annual dose to thyroid is computed.

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Source - Reference #19: p. 6

ATMOSPHERIC TRANSPORT
DOSIMETRY
FOOD CHAIN

Model - GRONK

Purpose - GRONK calculates annual dose resulting from radionuclides released with gaseous effluents. It is part of the HERMES computer program.

Description - Skin and total body dose to an individual and total body dose to the population are calculated for a standard matrix of points made up by 16 sectors and up to 10 annular rings out to 50 miles from release point. Options permit calculation of dose at other specified distances. An optional calculation for thyroid dose from radioiodine via inhalation, milk and leafy vegetables may be made.

Terminal input to GRONK includes: facility name, a string of code letters signifying what σ_z model to use (Pasquill or Hanford) and the various options selected and up to 10 ranges, if ranges other than the internally set standard ranges are required. Other inputs are required depending on the options selected, such as release height for elevated release, plume rise constant for plume rise consideration, building height for wake effect correction and sensor level for translating meteorological data from actual height of wind sensor to height selected for dose estimate. For the thyroid dose calculation, the child and adult vegetable consumptions, the cow grazing period and the leafy vegetable consumption period are entered for the milk and leafy vegetable pathways. GRONK is operational with 136 radionuclides available; however, only 52 may be used at any one time because of core allocation limitations.

J. K. Soldat, N. M. Robinson, D. A. Baker (1974)
Battelle, Pacific Northwest Laboratories
Richland, WA

Source - Reference #12: p.B-39,40

Model - INGDOS, A conversational code to implement models for estimation of annual doses from ingestion of radionuclides.

Purpose - The purpose of this code is to compute dose to internal organs from ingestion of food contaminated by atmospherically released radionuclides.

Description - INGDOS is a conversational FORTRAN IV program utilizing models described in U.S. Nuclear Regulatory Commission Regulatory Guide 1.109 for calculating:

- 1) concentrations of airborne radionuclides in food;
- 2) annual doses to various organs of man from ingestion of foods contaminated by radionuclides released to the atmosphere.

The code has been implemented on the ORNL PDP-10 system for use in time sharing mode. An on-line data base provides default values for most of the parameters required in the calculation of these quantities. The calculation of nuclide concentrations in and on vegetation at a given location is based on the rate of deposition at that location--a product of ground-level concentration and deposition velocity. As output the user may specify any (or all) of 11 tables which specify nuclide concentration and annual doses via various pathways.

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Source - Reference #23.

Model - TERMOD

Purpose - TERMOD is a systems analysis methodology for predicting dose to man from a radioactively contaminated terrestrial environment.

Description - A systems analysis methodology has been developed to predict intakes by man, estimate dose commitments, and identify "critical" exposure pathways resulting from radioactivity releases to a terrestrial environment. A mathematical model was constructed simulating selected terrestrial pathways by which fallout radioactivity can be transferred ultimately to man. This model is intended for preliminary predictions of radionuclide intakes by man through consumption of milk, beef, and plant parts contaminated directly by fallout as well as by uptake from the soil. Differential equations were written describing the radionuclide transfers, and the parameters required to implement these equations were derived. In verification tests, model predictions of cesium 137 concentrations in environmental compartments agreed within a factor of 2 with experimental data. More extensive verification studies involving other radionuclides are needed. The intake rates and total intakes of seven sample radionuclides were predicted for a "reference" man based on a hypothetical fallout of 1 pCi/CM² of each radionuclide. These predicted intakes were used as input to an internal dosimetry model which calculated dose commitments for each radionuclide and pathway. This generalized food-chain model is sufficiently versatile that it can be applied to many terrestrial environments and to all radionuclides. The first version of the model is expected to undergo future refinements.

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Source - Reference #18: p.279

Model - TERMOD II: An Interactive Code for Analyzing Intake of Radionuclides by Man Through Terrestrial Pathways.

Purpose - This is an interactive code which was written to run on a DEC System 10 (PDP10) and use the TERMOD code to calculate daily intake rates of radioactivity.

Description - An interactive code, TERMOD II, has been written in FORTRAN IV for the PDP 10. This code allows calculation of the time-dependent input of radionuclides through terrestrial pathways to man following an acute or accidental release. TERMOD II calculates daily input rates of radioactivity and the total intake rate over specified periods. To calculate these rates, TERMOD II uses the TERMOD model developed at Oak Ridge National Laboratory. This model includes three food types which can be contaminated by fallout radionuclides. Food crops and grass can be contaminated by direct foliar deposition and by root uptake. Milk and beef can be contaminated via ingestion of contaminated grass. The user of TERMOD II can choose from 78 different radionuclides. Additional radionuclides can be added as more data become available. Summaries of intake rates can be displayed at a local terminal or at an auxiliary high-speed printer.

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Source - Reference #26: p. 1,2

ATMOSPHERIC TRANSPORT
DOSIMETRY
FOOD CHAIN
SURFACE WATER TRANSPORT

Model - VADOSCA: A Simple Code for the Evaluation of Population Exposure Due to Radioactive Discharges:

Purpose - This is a combination liquid-gas isotopic distribution model, with doses calculated using varying environmental parameters.

Description The code consists of two parts, one for liquid discharges (VADOSCA-II) and one for gaseous discharges (VADOSCA-GAS). It incorporates the transfer parameters of twenty-four radioisotopes in the case of liquid discharges, and of twenty radioisotopes in the case of gaseous discharges. It allows the evaluation of the concentrations of the various isotopes in all the compartments of the critical paths outlined in the International Commission on Radiological Protection (ICRP) Publication No. 7, and the evaluation of the annual doses for five critical organs (whole body, G.I. tract, thyroid, bones, lung) for the various critical groups of population on the basis of environmental parameters such as the time of residence in a certain area, diet, type of activity, hydrological regimen, irrigation methods, and meteorological conditions. Although extremely simple, the code allows rapid performance of all the evaluations required to define the amount of radioactivity that can be released and the associated exposures. In its present form, the code VADOSCA-II covers twenty-four radionuclides including some fission products, some activation products, plus an alpha emitter. VADOSCA-II calculates the doses to four special groups, namely, fishermen, other workmen, local population, farmers. A separate calculation is made for the doses originated by drinking water. The doses are evaluated for five critical organs and they are expressed in mrem/year if the discharges are expressed in Ci/yr. In VADOSCA-GAS, twenty nuclides are considered, including eight noble gases (fission and activation products, various isotopes as particulates, and H-3, N-13, C-14 in the form of vapor. Atmospheric diffusion is evaluated with Pasquill's theory adapted to the meteorological data available. In its present form VADOSCA-GAS does not take into account particular effects such as the cloud depletion due to deposition, down draft and building effect; the particulate deposition rate is assumed constant at $3 \cdot 10^{-2}$.

Bramati, L.; Marzullo, T.; Rosa, I.; Zara, G.
Italian National Electric Energy Agency

Source - Reference #6: p. 131.

Model - VITTLS

Purpose - VITTLS calculates annual dose and in some instances, dose commitments from radionuclides transported through various pathway.

Description - VITTLS calculates radionuclide concentrations on soil from aerial deposition or irrigation. The calculations are site-specific. From these calculation, individual annual dose and dose commitments to skin and total body are computed. Also calculated are radionuclide concentrations in produce, milk, eggs, and meat from aerial deposition or irrigation at a specific site. From these calculations, individual doses from the ingestion of farm products are computed in terms of the annual dose to total body, GI-LLI, Thyroid, bone, liver, lung, and kidney.

D. L. Brenchly, J.K. Soldat, J.A. McNeese, and E.C. Watson
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Source - Reference #19: p. 6

ATMOSPHERIC TRANSPORT
DOSIMETRY
FOOD CHAIN

Model - 2BPUFF: Lagrangian Transport and Diffusion Code to Calculate Concentrations and Deposition at Long Range of Particles Less than 10 Micro Meters Diameter.

Purpose - The code is used to calculate concentrations and deposition of small particles following atmospheric nuclear tests.

Description - The 2BPUFF code is the latest version of the original 2BPUFF code developed at LLL in 1966 by Todd V. Crawford (see UCRL-50179, Nov. 23, 1966). The code calculates the dispersion of pollutants in a cylindrical cloud with a vertical axis of symmetry using a coordinate system fixed to the cloud's center. Similarity theory of atmospheric turbulence is used to predict the horizontal diffusivity as a function of initial cloud size, turbulent atmospheric dissipation, and time. Vertical diffusivity is entered as a function of height and time, enabling entry of diurnal variations in the boundary layer and temperature inversions. The model calculates cloud center and surface air concentrations, exposure rate, dry deposition, washout, and the vertical integral of individual nuclides and doses to an individual for a variety of pathways, including inhalation, whole body external gamma, submersion, forage-cow-milk, and pasture-meat.

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Source - Reference #18: p. 79

Model - A Model for Predicting the Transport of Radionuclides in the Marine Environment.

Purpose - This is a mathematical model to describe the transport of radionuclides in the marine environment, their accumulation in marine organisms, and their consequent dose to man.

Description - Expressions for the internal radiation dose to Standard Man are then derived on the basis of this model. These expressions give conservatively high estimates of the potential internal radiation dose, which can be compared with radiation-protection guides to determine the necessity, if any, of radiological safety measures. The model derivation starts with an instantaneous point-source solution to a partial differential equation that has been shown to be an adequate description of the physical dispersion process in the ocean. An expression for the radionuclide concentration in the ocean resulting from a fallout input is developed from this point-source solution. This expression indicates that vertical diffusion is the controlling mechanism for dispersion soon after the fallout deposition, and that convection controls dispersion later. From this observation, two simpler expressions are derived, one for early and one for later times. The simpler expressions for describing dispersion of a fallout input are used to define a mixing volume which then is considered to be the receptor of both the fallout and the terrestrial radionuclide inputs. The terrestrial input is due to direct groundwater contamination and terrestrial fallout. From these concepts, an expression is derived for the radionuclide concentration in the mixing volume. This expression is then combined with a seawater-seafood-man food-chain model to arrive at expressions for the infinite internal radiation dose to man.

S. G. Bloom, and G. E. Raines. Battelle Memorial Institute, Columbus Laboratories, 505 King Avenue, Columbus, Ohio 43201, DMI-171-123, 16 p., 1969.

Source - Reference #26: Item 201.

ATMOSPHERIC TRANSPORT
DOSIMETRY
FOOD CHAIN

Model - A model to estimate the local radiation doses to man from the Atmospheric Release of Radionuclides.

Purpose - The model estimates doses to man from the atmospheric release of radionuclides.

Description - A model was developed to estimate the radiation dose commitments received by people in the vicinity of a facility that releases radionuclides into the atmosphere. This model considers dose commitments resulting from immersion in the plume, ingestion of contaminated food, inhalation of gaseous and suspended radioactivity, and exposure to ground deposits. The dose commitments from each of these pathways is explicitly considered for each radionuclide released into the atmosphere and for each daughter of each released nuclide. Using the release rate of only the parent radionuclide, the air and ground concentrations of each daughter are calculated for each position of interest. This is considered to be a significant improvement over other models in which the concentrations of daughter radionuclides must be approximated by separate releases.

Rider, J.L.; Beal, S.K.
Bettis Atomic Power Laboratory,
Westinghouse, West Mifflin, PA).

Source - Reference #6: p. 152.

Model - An Interspecies Model for Retention of Inhaled Particles.

Purpose - This code is used in determining movement of inhaled particles in various animals.

Description - A model has been developed which may be applied to mouse, rat, and dog, to describe the kinetics of clearance of inhaled particles from the respiratory tract, and the uptake and excretion kinetics of this cleared material. Emphasis has been placed on the tracheobronchial lymph nodes as a storage site for cleared particles, with uptake being described as a constant fraction of the amount of the deposited substance remaining in the respiratory tract at any time. First-order kinetics have been used to describe most of the translocation processes, and a very long life of retention (several thousand days) has been used for lymph nodes and one compartment of the lung. The rate constants have been described in terms of speculative physiological processes, as they may be affected by particle size and solubility. One advantage of this model is the ability to readily alter one or two constants and be able to obtain rather precisely a reasonable fit to experimental data points. Close agreement with results calculated from the model was attained with data from several sources, comparing lung and lymph node content of dogs with time after inhalation of various substances including PuO₂, (Pu(HO₃)₄), UO₂, and ThO₂.

R. G. Thomas, Loveland Foundation for Medical Education and Research, Albuquerque, NM, 1970. Assessment of Airborne Particles, T.T. Mercer, P. E. Morrow and W. Stohr (Eds.). Charles C. Thomas, Publisher, Springfield, Illinois, (pp. 405-420).

Source - Reference #26: Item 1131.

DOSIMETRY
FOOD CHAIN

Model - Applications of a General Computational Model for Composite Environmental Radiation Doses.

Purpose - This code is designed to aid in the calculation of radiation doses to man and aquatic biota resulting from large-scale commercial use of nuclear power.

Description - A mathematical model for calculation on a large general-purpose digital computer of regional radiation doses resulting from large-scale use of nuclear energy was previously developed and reported. This general model has now been sub-divided to permit rapid calculations for the several exposure pathway groupings in an interactive mode using the BASIC computer language. The sub-programs are completely flexible as to the nuclides, body organs, and pathways from which radiation doses are to be calculated. They include at the present time: approximately 150 radionuclides, including transuranics; doses to whole body, skin, bone, lungs, thyroid, and gastrointestinal tract; sub-programs for cloud submersion, inhalation of nuclides other than radioiodines (resuspension of deposited nuclides is not included), ingestion of water and aquatic foodstuffs along with external dose from water and sediments, ingestion of irrigated crops, and thyroid dose from inhalation. Ingestion and dose to aquatic biota can also be calculated. Dose factors in the programs for the various media-nuclide-organ combinations have been calculated using ICRP methods. For radionuclides with long effective half-lives, the sub-programs calculate either total dose commitment for a single year's intake or the dose-rate at the end of a specified period of years at constant annual intake. Transfer factors between trophic levels have been taken in most part from summaries published by others, and are updated as newer data becomes available. The major application to date of the compartmented model has been the calculation of doses for U.S. Atomic Energy Commission environmental impact statements. Use is also being made of the same model for evaluation of potential radiological impacts associated with the ultimate fate of radioactive wastes for various long-term disposal concepts.

Soldat, J.K.; Baker, D.A.; Corley, J.P.
Battelle, Pacific Northwest Laboratories
Richland, WA

Source - Reference #6: p. 135.

Model - Computer Simulation of Iodine-131 Transfer from Fallout to Man.

Purpose - The model depicts the principle routes of I-131 transfer from fallout to man. The relevance of the model is that it can indicate I-131 paths from LLW disposal.

Description - A computer model has been constructed to depict the principal routes of I-131 transfer from fallout to man. Thyroid accumulation and excretion have been modelled for cow and for man. A simulation is carried out of the major fallout during the fall of 1962, following tests of nuclear weapons, and the results are compared with experimental data for southern Scandinavia.

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Source - Reference #6: pg. 149.

Model - Land Requirement for a Radioactive Waste Disposal Yard

Purpose - This model estimates the intake by humans of radionuclides through food and air.

Description - A model and the rationale were presented with respect to land use requirements for a hypothetical waste burial site. The thrust of the study was to minimize the intake by humans, of radionuclides through the food and air. A to-space transportation diffusion equation was used to describe the migration of the radionuclides in groundwater. The numerical solution was obtained by solving the equation by Crank-Nicolson type differential approximation and successive over relaxation. A sample run was made for a power plant with a total output of 2000 MWe. Numerous environmental land requirements and socio-political factors were considered. With this model it is possible to locate a burial site which ensures the greatest radiological safety. To locate burial site it is necessary to include a zone where ground water use is prohibited; a zone where use is restricted and a buffer zone. The necessary land area will increase with increasing permeability coefficient, decreasing distribution factor and increasing stratum porosity. Variations in the diffusion coefficient do not change the land requirement greatly.

Inoue, Y. and S. Morisawa
Kyoto University
Department of Sanitary Engineering
Kyoto, Japan
ORNL-TM-4444; 13 pp.
1976

Source - Reference #11: p. 149.

Model - Marine Transport of Radionuclides

Purpose - This is a preliminary mathematical model for predicting the transport of radionuclides in the marine environment.

Description - A diffusion model is given for fallout onto ocean surface, groundwater and surface runoff from the land and the internal dose to man resulting from consumption of marine organisms.

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Source - Reference #18: p. 302.

Model - Methods and Techniques Relevant to Marine Disposal of LLW or Marine Contamination by LLW.

Purpose - Models covered include marine pathways for radionuclides, aquatic and terrestrial food chains, and dosimetry. The discussion thus has relevance for many aspects of LLW management, particularly marine disposal.

Description - A number of studies on circulation models and dose rate models are briefly discussed. Marine pathways are evaluated for intermittent releases of low-level wastes. The radionuclides of interest are Zn-65, Cs-137, Co-60, Mn-54. It is their concentration in edible marine organisms that are of concern. Also the concentrations of the above radionuclides are discussed with respect to bottom sediments. Various methods of treating wastes with strontium, plutonium, and ruthenium are briefly considered. Also, leach rates were compared by three methods of mathematical analysis. The present and past land burial and storage techniques have been adequate. However, such practices may not be sufficient in the future. Computer analysis of a one-dimensional transient response of a soil column to infiltrating water is mentioned. Assessments of power plant impacts are now including one- and two-dimensional mathematical models for the transport of dissolved radionuclides. Effects of sediment-radionuclide interaction, routine and accidental discharges, and aquatic and atmospheric dispersion, deposition, and resuspension are included. The aquatic and terrestrial food chain transport and the calculation of doses resulting from internal and external modes of exposure are considered as well. When comparing the behavior of plutonium and americium in marine and freshwater environments, there is no preference of uptake between the two transuranics. The major reservoirs of plutonium and americium are the sediments in both environments.

Blaylock, B.G. 1978, June.
Journal of the Water Pollution Control
Federation 50(6), 16 pp.
Oak Ridge National Laboratory
Environmental Sciences Division
Oak Ridge, TN 37830

Source - Reference #11: p. 46.

Model - Modeling of Environmental Pathways and Radiation Doses from Nuclear Facilities

Purpose - A computer model was developed which calculates total annual radiation doses and 50-year dose commitments to several categories of persons at population centers and continues these calculated doses into integrated (man-rem) annual and 50-year doses for large populations. The application to LLW management is general.

Description - The dose model was designed as one portion of an overall computer program developed to delineate the nuclear facilities expected in the year 2000, the radionuclides released to air and water, their diffusion, dispersion, and reconcentration in the environment, and the resulting radiation doses to people. Equations for calculating dose factors were derived from those given by the International Commission on Radiological Protection (ICRP). Effective decay energies for various radionuclides were calculated from the ICRP model, which assumes that all the radionuclide is in the center of a spherical organ with an appropriate effective radius. Where data were lacking, metabolic parameters for the Standard Man were used for other ages as well. The model includes a sub-routine which calculates radionuclide concentrations in a wide variety of foods at time of harvest from concentrations in air, irrigation water, and soil. The latter concentrations are output from previous portions of the overall computer program. The tremendous variety of data required for proper dose assessment is not always available in the literature. Such data has been extrapolated from environmental studies of fallout nuclides and from planned laboratory and field studies of a limited number of nuclides.

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Source - Reference #6: p.116

FOOD CHAIN

Model - Prediction Models for Strontium-90 and Cesium-137 Levels in the Human Food Chain.

Purpose - These models are used in tracing several isotopes through the food chain.

Description - Mathematical models have been developed for the prediction of fallout CS-137 and SR-90 levels on the basis of measurements of fallout deposition on vegetation, in air samples, in samples of precipitation, and in samples of the total diet, milk, cereals, potatoes and other vegetables, in meat (beef, pork, and seafood), and in samples of adult and infant bones collected during a five-year period (1962 to 1967). During this time the predominant source of long-lived fission products in the environment was the 1961 and 1962 weapons test series. For the total diet and for the most important components in the food chain it was possible to predict the SR-90 and CS-137 levels mathematically on the basis of fallout rate and accumulated deposit as independent variables. The CS-137 and SR-90 levels in human tissues and whole-body counting data followed equations similar to those calculated for the diet. Estimates of the soil factors in the equations used received special attention. It was concluded that the soil factors for SR-90 were reliable but that more reliable determinations are needed for soil factors for CS-137 to determine the long-term fate of CS-137 in the human food chain.

A. Aabkrog
Chemical and Radionuclide Food Contamination, New York, MSS Information Corp., pp. 77-107, 1973

Source - Reference #18: p.255

FOOD CHAIN

Model - The Behavior of CS-137 and Other Fallout Radionuclides on a Michigan Dairy Farm.

Purpose - Movement of fallout radionuclides in the milk-food chain.

Description - The behavior of the fallout radionuclides Cs-137, Mn-54, Ce-144, Pr-144 and Sr-90 in the milk-food chain was studied at a commercial dairy farm near Tecumseh, Michigan during 1964 and 1965. The main purpose of the study was to develop mathematical models to describe the movement of radionuclides from air to milk. Three models were developed: the first predicts the total deposition on precipitation collectors given the air concentration and rainfall rate; the second predicts the concentration in forage from air concentration, rainfall rate, and the rates at which the forage grows and is consumed by the dairy herd; the third predicts the milk concentration from the concentration in each type of feed and the rate at which each feed type is consumed by the dairy herd. The first two models are applicable to all four radionuclides but the milk model is valid only for CS-137. Milk concentrations for the other three radionuclides are treated individually. The model for deposition on precipitation collectors was developed independently and is shown to predict weekly deposition rates to within a factor of three (95% of the time). This uncertainty is reduced as the time span for the prediction is increased. Development of the other two models was based in part on data from the Tecumseh study; both still require independent verification. The forage model fits the weekly experimental data to within a factor of 2.2. The milk model fits the weekly measurements of CS-137 concentrations to within a factor of 1.5. The error of the latter two models also decreases as the time span for the prediction is increased.

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Health Physics, 21, 772-792, 1971

Source - Reference #18: p.251

Model - Transfer of Radiocesium from Lichen to Reindeer.

Purpose - The purpose of this code is to aid in tracing the path of Cesium in an ecosystem.

Description - An empirical two compartment model that describes the transfer of radiocesium from fallout contaminated lichen to reindeer has been developed. Kinetic parameters were calculated from data derived from retention studies following a single dose of Cs 134 to reindeer maintained on a natural mountain tundra pasture at Cantwell, Alaska. Cesium retention values were statistically indistinguishable for the autumn and winter period. However, Cesium retention half-times were reduced 2 to 4 fold during the summer months as compared to the autumn-winter studies. Cesium kinetics in the reindeer were not influenced significantly by animal sex although a significant increase in Cesium retention with animal weight was observed. Results obtained from controlled lichen feeding experiments indicated that about 20 to 30% of the radiocesium contaminating lichen is available for absorption by the reindeer. The model was tested by comparing predicted values with results obtained with a single reindeer maintained on a constant Cs 134 intake. Predicted values are compared to observed radiocesium concentrations in the lichen-caribou segment of the arctic food chain.

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Health Physics, 21(5), 657-666

Source - Reference #18: p.248

FOOD CHAIN

Model - Turnover and Concentration of Radionuclides in Food Chains.

Purpose - This code is used in evaluating consequences of activity release in the environment; uptake and turnover of radionuclides by means of the biological processes occurring in organisms.

Description - Proliferation of nuclear technology and concern for radioactivity in the biosphere demand more sophisticated evaluations of future nuclear installations and procedures. Adequate analyses of radionuclide dispersion in the environment will require more substantial bioenvironmental information than is presently available. Frequently information known for one ecological system (e.g., arctic tundra) will not be applicable to other ecosystems (e.g., temperate or tropical forests). Only with sufficient ecological data can predictive models be developed that will enable assessment of the environmental consequences of radioactive contamination. A simple source-pathway-receptor model, analogous to the ecological food chain, requires pathway identification, data on assimilation by each link (organism) in the pathway, and determination of the biological turnover of each radionuclide. For acute releases of radioactivity to the environment, evaluation of these variables is needed to predict time-dependent concentrations of radioactivity in organisms. For chronic releases, concentration factors alone will often suffice.

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Source - Reference #18: p.250

FOOD CHAIN

Model - Uptake of Fallout Radionuclides by Mammals and a Stochastic Simulation of the Process

Purpose - This code is used in simulating intake of fallout radionuclides by mammals.

Description - The model was used to predict amounts of fallout radionuclides in consumers and evaluate the relationship between high extremes and mean values.

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Source - Reference #18: p.250

GENERAL TRANSPORT
RISK ASSESSMENT

Model - AMRAW: Risk Assessment Method for Radioactive Waste Management.

Purpose - This model provides calculational methods for risk assessment in radioactive waste management systems.

Description - A Radioactive Waste Management Systems Model was developed and implemented by the University of New Mexico under contract with the U.S. Environmental Protection Agency. The systems model and associated computer code called AMRAW (Assessment Method for Radioactive Waste), has two parts. The first part, AMRAW-A, consists of the Source Term (Radioactive inventory versus time), the Release Model, and the Environmental Model. The Release Model considers various geologic and man-caused events which are potential mechanisms for release of radioactive material beyond the immediate environs of a repository or other location; the risk analysis mode uses events distributed probabilistically over time, and the consequence analysis mode uses discrete events occurring at specified times. The Environmental Model includes: 1) the transport to and accumulations at various receptors in the biosphere, 2) pathways from these environmental concentrations, and 3) resulting radiation dose to man.

The second part of the system model, AMRAW-B, is the Economic Model which calculates health effects corresponding to the various organ dose rates from AMRAW-A, collects these health effects in terms of economic costs and attributes these costs to radionuclides, decay groups, and elements initially in the waste inventory. Implementation, with calculated results, of AMRAW for Terminal Storage in a Bedded Salt Reference Repository has been accomplished. Preliminary demonstrations for the repository operations phase of waste management and terminal storage in a shale formation have also been accomplished; possible applications to other radioactive and nonradioactive hazardous materials have been discussed. AMRAW uniquely links all analytic steps together in a continuous calculation sequence.

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Source - Reference #10: June 1978, p.v

GROUNDWATER TRANSPORT

Model - ARDISC

Purpose - This model solves nuclide migration in fractured or porous rock.

Description - In the ARDISC model, absorption and desorption are treated independently. An experimental study of the application of the ARDISC model to laboratory studies of nuclide migration in geologic media has been performed. Americium and strontium were used in the experiments. Results show that the migration can be treated in at least a semi-quantitative fashion, that the ARDISC model is a useful aid, although it is limited to first-order sorption kinetics, and that kinetic parameters may be as important in migration as equilibrium-sorption.

P. G. Rickert, R. G. Strickert, and M.G. Seitz, Argonne National Laboratory, "Nuclide Migration in Fractured or Porous Rock," NTIS, PC A03/MF A01. p. 28.

Source - Reference # 25: p. 53.

GROUNDWATER TRANSPORT

Model - AT123D, Analytical Transient, One-, Two- or three-dimensional code

Purpose - To provide a generalized computer code for estimating the transport of wastes in an aquifer.

Description - A generalized analytical transient, one-, two-, or three-dimensional (AT123D) computer code is developed for estimating the transport of wastes in the aquifer system. It contains 450 options: 288 for the three-dimensional case, 72 for the two-dimensional case in the x-y plane, 72 for the two-dimensional case in the x-z plane, and 18 for the one-dimensional case in the longitudinal direction. These are the combinations of three types of wastes, eight sets of source configurations, three kinds of source releases, and four variations of the aquifer dimensions. Three types of the wastes are the radioactive waste, chemicals, and heat. Eight types of source configurations are the point source, line source parallel to the x-axis, line source parallel to the y-axis, line source parallel to the z-axis, area source perpendicular to the x-axis, area source perpendicular to the y-axis, area source perpendicular to the z-axis, and the volume source. Three kinds of source releases are the instantaneous, continuous, and finite duration releases. Four variations of the aquifer dimensions are finite depth and finite width, finite depth and infinite width, infinite depth and finite width, and infinite depth and infinite width. The mechanisms of transport included in the analysis are advection, hydrodynamic dispersion, absorption, decay/degeneration, and the waste losses to the atmosphere. Boundary conditions included Dirichlet, Neumann, mixed type, and/or radiation boundaries.

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Source - Author

Model - BEWTA: Boussinesq Equation for Water Table Aquifer

Purpose - The model simulates the Boussinesq Equation for a Two-Dimensional Water Table Aquifer.

Description - The aquifer is given by a 2-D discrete representation in the horizontal plane. The aquifer boundary is irregular and mixed. The aquifer is superimposed by a meandering stream. Aquifer parameters are assigned to each nodal point and can be slightly anisotropic and nonhomogeneous. Transient ground-water flow through a water table aquifer is described by the Boussinesq equation which assumes the Dupuit-Forchheimer assumptions are valid. The principal conductivity components are colinear with the coordinate systems x and y . The water is released from storage mainly by gravity drainage with an instantaneous decline in head. The stream bed is semi-confined and the leakage obeys Darcy's law. The flow from the unsaturated zone and the change in fluid density over time is negligible. The replenishment to the aquifer system occurs through gravity drainage and stream bed leakage.

The model simulates the transient ground-water flow through a two-dimensional water table aquifer, described by the Boussinesq equation, using the alternating direction implicit method. The Boussinesq equation is approximated by a two-dimensional finite difference equation of linearized form, employing the noniterative alternating direction implicit method. The linearized finite difference equation is written for two half time steps, and is done for each node along either a row or column. The resulting simultaneous equations are solved by the Thomas algorithm. The calculation is carried on successively row by row for the first half time step and a similar calculation is carried on column by column for the second half time step. The results of the second half time step are the approximations to the transient solution of the problem under discussion.

The model was initially developed to simulate the two-dimensional nonsteady Boussinesq Equation for an outwash aquifer located at Elmsvale, Musquodoboit River Valley, Nova Scotia, Canada. It is one of two groundwater models developed during that study.

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Source - Reference #12: pp. B-20, 21.

GROUNDWATER TRANSPORT

Model - CCC: Conduction, Convection and Consolidation

Purpose - To compute the transport of heat and fluid through a porous reservoir and to compute the one-dimensional consolidation of the simulated systems.

Description - A major problem facing geothermal operations is the disposal of large quantities of relatively cool waste geothermal waters. Environmental regulations may require reinjection into the reservoir. Since the reservoir is thus cooled around the injection wells, there is some reluctance to reinject into wells that might be used for future production.

In this paper the response of a liquid-dominated geothermal reservoir to injection and production from a single well is studied. Different injection-production schemes are analyzed to explore how to minimize temporary cooling around the injection well and to optimize thermal recovery. The pressure response is also calculated, and found to be affected significantly by temperature-dependent viscosity variations. This will have implications on well-test methods for geothermal reservoirs. Vertical consolidation of the geothermal system during fluid withdrawal is also discussed, showing the need to establish previous stress history before attempting to predict the reservoir deformation.

The transport of heat and fluid through a porous reservoir is computed using a numerical model developed at the Lawrence Berkeley Laboratory. The one-dimensional consolidation theory of Terzaghi has been coupled to the heat and fluid flow to calculate reservoir compaction. No attempt is made to model chemical reactions or precipitation that might occur when waters of a different temperature and salinity are injected into the reservoir.

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Source - M. J. Kippman; D. Mangold
"Preparation of Input Data for Program CCC".
Lawrence Berkeley Laboratory
April, 1977.

GROUNDWATER TRANSPORT

Model - CERBERUS: One-Dimensional Transient Nonisothermal Two-Phase, Two Component Flow of Fluids and Gases Through Layered Porous Media

Purpose - This code is used in analyzing the flow of fluids through porous media.

Description - This model treats the transient low Reynolds number flow of multiple phase, multiple component fluids thru layered porous material in one dimension. The governing relationship is given by Darcy's Law, which applies for all constituents of flow and is coupled to relevant constitutive relationships. The variables: U is the velocity, K is the permeability of the layer, M is the fluid viscosity, P the pressure, and X the spatial coordinate. The source may be constant or variable with time. Permeability may be layered axially and radially.

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Source - Reference #18: p.233.

Model - COLORADO-FD

Purpose - The model is a three dimensional, partially saturated flow model.

Description - The model has evolved to handle three-dimensional problems, though originally restricted to two-dimensional systems. It is a finite difference model which uses a Newton iteration method in preference to the less stable forms examined by Brutsaert in some detail. The use of upstream weighting of the capillary conductivity is utilized with the Newton iteration to provide a stable solution method. The model was applied in a three-dimensional simulation of the partially saturated zone of a 40 mile reach of the Arkansas River of southeastern Colorado. The saturated zone was treated by applying a two-dimensional Boussinesq type model. The model as adapted for use in this stream-aquifer system model provided water table elevations that agreed reasonably well with observed data. This combination of models from the information now available, has been applied to the largest region and to the most complicated set of field conditions of any of the partially saturated flow models located.

W. Brutsaert, "Immiscible Multiphase Flow in Groundwater Hydrology: A Computer Analysis of the Well Flow Problem," Ph.D. thesis, Colorado State University, Fort Collins, Colorado, 1970.

W. Brutsaert, and C. Way, "A Conjunctive Use Surface Water-Groundwater Simulator," New Mexico Water Resources Research Institute Partial Technical Completion Report No. 033, November 1973.

W.F. Brutsaert, "A Functional Iteration Technique for Solving the Richards Equation Applied to Two-Dimensional Infiltration Problems," Water Resources Research, December 1971, Vol. 7, no. 6, p. 1583-1595.

Source - Reference #13: p. 84.

Model - COOLEY

Purpose - The model predicts transient or steady-state hydraulic head distribution in confined, semiconfined, or unconfined aquifer.

Description - The aquifer may be given an areal (plan view) description or may be cross-sectional. Aquifer parameters may be distributed or zoned and the system may be anisotropic with the principal components aligned with the global coordinate axes. In the areal description if used, leakage from confining beds (or river bottoms, etc.) is vertical and storage in the confining beds is neglected. The Dupuit-Forchheimer assumptions and delayed (or no delayed) yield concept are used for the water-table case in plan view.

The basic discretization method is the subdomain finite element method with the time discretized by a weighted average technique. The matrix equation is solved by the strongly implicit procedure; the iterative alternating direction implicit procedure; or line successive over-relaxation, with or without single line correction. Each method is incorporated into a separate computer program.

The program is on line at Dames and Moore and is used routinely by them. It is also distributed by the University of Colorado Computing Center. It has been used at the Desert Research Institute for the following projects: management of ground-water in ash meadows, Nevada (R.L. Bateman); analysis of the effects of waste-water discharge on the shallow groundwater flow system, Las Vegas Valley, Nevada (J.A. Westphal); hydrogeologic effects of a gravel-pit operation in Reno, Nevada (R.L. Cooley); ground-water and river-water interchange, Winnemucca reach of Humboldt River, Nevada (R.L. Cooley and J.A. Westphal) (program modified to interface with river-stage predictive model); and effects of energy losses in a pumping well on draw down around well (R.L. Cooley and A. Cunningham) (program modified to interface with model for flow in the well bore).

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Source - Reference #12: pp. 8-13, 14.

GROUNDWATER TRANSPORT

Model - DAVIS/FE3D

Purpose - This model predicts transient piezometric heads and salt transport in large natural multiaquifer basins.

Description - The model considers saturated confined flow in three dimensions with both the fluid porous material considered compressible. The time dependence arising from compressibilities is considered through a backward difference and the spatial discretization is through finite elements.

Three-dimensional isoparametric elements are used that can be deformed in any of the three coordinate directions. The spatial basis functions for the isoparametric shapes along any element edge may be either linear, quadratic, or cubic in functional form. Such functional forms are incorporated by inserting additional node points along the element edge, i.e., the two end points are used for the linear form, adding a node at the center provides the quadratic variation, and the cubic is obtained through adding internal nodes at the one-third points along the element side. This procedure allows flexibility, particularly in satisfying irregular boundary conditions, yet maintains the advantages of using the simpler Chapue basis functions for the potential or head representation.

The model was designed for use on a small to intermediate size computer, so the potential determination aspects utilize four of the five subprograms. The first subprogram, FE/PREP, is a preparation routine for setting up the problem, getting all the soils, boundary, and initial condition input and organized for use by the FE/HEAD subprogram. This second subprogram actually sets up the equations requiring solution and very efficiently organizes the resulting matrices through optimal ordering for efficient solution in the subprogram FE/GAUSIN. The small subprogram FE/FLUX complements the HEAD program by providing flux results as required most extensively in transient problems. The last subprogram solves the transport equations using finite elements.

Applications of the model have been with the Sutter Basin in California and to Long Island, New York. More recent applications have been by a private Consulting Engineering Firm.

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Land, Air and Water Resources
Water Science and Engineering Section
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Source - Reference #12: p. B-28; Reference #13: p. 77.

GROUNDWATER TRANSPORT
SURFACE WATER

Model - DPRWGW and DPRWCR, Transport Modeling in the Environment Using the Discrete-Parcel-Random-Walk Approach.

Purpose - The codes describe the transport of radionuclides by ground water and surface water.

Description When formulating a mathematical model for simulating transport processes in the environment, the system of interest can be viewed as a continuum of matter and energy or as a large set of small discrete parcels of mass and energy. The latter approach is used in the formulation of the Discrete-Parcel-Random-Walk (DPRW) Transport Model. Each parcel has associated with it a set of spatial coordinates as well as a set of discrete quantities of mass and energy. A parcel's movement is assumed to be independent of any other parcel in the system. A Lagrangian scheme is used for computing the parcel advection and a Markov random walk concept is used to simulating the parcel diffusion and dispersion. The DPRW technique is not subject to numerical dispersion and it can be applied to three-dimensional cases with only a linear increase in computation time. A wide variety of complex source/sink terms can be included in the model with relative ease. Examples of the model's application in the areas of oil spill drift forecasting, coastal power plant effluent analysis, and solute transport in groundwater systems are presented. DPRWGN is used for analyzing groundwater transport and DPRWCR is used for analyzing surface water transport.

Ahlstrom, S.W.; Foote, H.P.
Battelle, Pacific Northwest Laboratories
Richland, WA

Source - Reference #6: pg. 136.

Model - EQ3/EQ6

Purpose - EQ3/6 computes equilibrium models of aqueous geochemical systems.

Description - EQ3 performs distribution-of-species calculations for natural water compositions; EQ6 uses the results of EQ3 to predict the consequences of heating and cooling aqueous solutions and of irreversible reaction in rock-water systems.

The Newton-Raphson method is used to solve the governing equations of chemical equilibrium for a system of specified elemental composition at fixed temperature and pressure. Convergence is aided by optimizing starting estimates and by under-relaxation techniques. The minerals present in the stable phase assemblage are found by several empirical methods. Reaction path models may be generated by using this approach in conjunction with finite-differences. This method is analogous to applying high-order predictor-corrector methods to integrate a corresponding set of ordinary differential equations, but avoids propagation of error.

EQ3 computes from input analytical data the distribution of chemical species (ions, neutral species, ion-pairs, and complexes) in an aqueous solution. This calculation produces a model of the fluid, which specifies the concentration and thermodynamic activity of each chemical species occurring in the chemical system and included in the data base. The program then calculates the saturation state of the fluid with respect to all relevant mineral phases in the data base. The aqueous solution model calculated by EQ3 is used as a starting point for mass transfer computations by EQ6. Mass transfer and the effects of heating and cooling aqueous solutions and of irreversible reaction in rock-water systems are modeled.

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Source - Reference: T. J. Wolery, "Calculation of Chemical Equilibrium Between Aqueous Solution and Minerals: The EQ3/6 Software Package" (UCRL-52658), 1979.

Model - FASTPATH

Purpose - FASTPATH models the chemical evolution of a complex chemical system with water present as a function of reaction progress.

Description - FASTPATH is an improved, faster version of PATH by Helgeson, et al. It predicts aqueous species produced, the solid phases in thermodynamic equilibrium and the quantities of reactants destroyed, all as a function of time. The model operates only at discrete temperatures, i.e., 0, 25, 60, 100, 150, 100, 150 & 300 degrees C. The initial composition of the starting aqueous phase and a list of reactant phases is required for data. The user must have a good knowledge of physical chemistry.

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Source - Reference: Helgeson, et al., Geochem. Cosmochim. Acta, 34, pp. 569-592, 1972.

GROUNDWATER TRANSPORT

Model - FEMWASTE: A Finite Element Model of Waste Transport Through Saturated-Unsaturated Porous Media.

Purpose - To compute waste transport through porous media under dynamic groundwater conditions.

Description - A new finite-element model of waste transport through porous media simulates the spatio-temporal distribution of both the waste concentration and flux under dynamic groundwater conditions. The transport mechanisms include advection, hydrodynamic dispersion, chemical sorption, and first-order decay. The new model is developed based on a previous model completed at ORNL. This includes the implementation of quadrilateral isoparametric finite-elements, bilinear interpolation functions, asymmetric upstream weighting functions, and several time-marching schemes in the numerical formulation.

The new model differs from the previous one in the following aspects: 1) reformulation of the distribution coefficient and retardation factor, 2) computation of the waste flux field, 3) method of evaluation mass balance over the whole region, 4) implementation of upstream weighting functions, and 5) application of boundary conditions. Also, ten additional alternative numerical schemes are provided, which are more appropriate for any situations.

With the new model, the overprediction of concentration distribution in the unsaturated zone is eliminated, the continuous waste flux field is obtained, and the mass balance over the whole region is preserved.

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Source - ORNL-5601, 1979.

GROUNDWATER TRANSPORT

Model - FEMWATER: A Finite-Element Model of Water Flow Through Saturated-Unsaturated Porous Media.

Purpose - To simulate groundwater dynamics in and saturated-unsaturated subsurface systems.

Description - A revised finite-element model of water flow through porous media is presented to simulate the groundwater dynamics in saturated-unsaturated subsurface system. The response of the groundwater basin to the rainfall, artificial withdrawal, and other recharge or discharge sources (such as lakes, reservoirs, and streams) may be included in the simulation. This model is a modified and expanded version of a previous model developed at ORNL.

The modification includes: 1) computing the flow field in a manner consistent with the finite-element approach; 2) evaluating the moisture-content increasing rate within the region of interest with a new method consistent with the way of solving for the moisture-content and pressure fields; 3) treating the nonlinear terms in an appropriate way to ensure that a unique relationship between any nonlinear variable and pressure is preserved. The expansion is made to provide four additional alternative numerical schemes which would be more appropriate for many situations. Also, to save computer storage, all arrays pertaining to boundary condition information are compressed into smaller dimensions. This results in a saving of about one-fourth of the computer storage for the sample problem. To ease the treatment of different problems, all arrays are variably dimensioned in all subroutines.

With the above modifications and expansion, the Darcian velocity field is continuous everywhere in the flow regime, including element boundaries and nodal points, and the overall mass balance is preserved. Two sample problems are simulated to show the difference between the old and the revised models. Unique velocity fields are obtained by the revised model, while the discontinuous velocity fields at all nodal points appear by the old model. The discontinuity ranges from several hundred percent to negligible. The overall mass loss through boundaries for the transient problem is much reduced from 23.8 to 2.2% for one case and from 29.7 to -3.6% for another case.

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Source - ORNL-5567, 1979.

Model - FLOP 1

Purpose - Calculation of pathlines or streamlines in a confined, homogeneous aquifer without storage, and the residence times of a number of water particles. (Very similar to FRONT-N except no storage term is involved in the analytical well solutions used in this model.)

Description - The analytical closed form expression for a uniform flow in an infinite horizontal permeable slab containing pumping or injection wells is used in the velocity component equations. These two simultaneous differential equations are solved using the Runge-Kutta Method to obtain the pathlines and flow time for fluid particles.

If analytical potential functions are available, they may be readily incorporated into the programs. However, tabular potential data from measured or numerical solutions from flow models can also be used. The models appear to have been used by more than one technical group in the Netherlands.

C. van den Akker (1974)
Municipal Waterworks of Amsterdam
Condensatorweg 54
Amsterdam-Sloterdijk

Source - Reference #12: p. B-5; Reference #13: p. 89.

Model - FLOP 2

Purpose - Calculation of pathlines in a semi-confined, homogeneous aquifer without storage, and the residence times of a number of water particles in the aquifer. (Very similar to FLOP - except that the aquifer is semi-confined.)

Description - The analytical closed form expression for a uniform flow in an infinite horizontal permeable slab containing pumping or injection wells is used in the velocity component equations. These two simultaneous differential equations are solved using the Runge-Kutta Method to obtain the pathlines and flow time for fluid particles.

If analytical potential functions are available, they may be readily incorporated into the programs. However, tabular potential data from measured or numerical solutions from flow models can also be used. The models appear to have been used by more than one technical group in the Netherlands.

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Municipal Waterworks of Amsterdam (1975)
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Amsterdam-Sloterdijk

Source - Reference #12: p. B-6; Reference #13: p. 89.

Model - FRESURF 1 & 2

Purpose - This is a finite element model used to solve both two-dimensional and axisymmetric flow problems.

Description - In this model, the specifics of the free boundary as described by Neuman are incorporated into the finite element solution scheme used in this two-dimensional model. The free boundary is handled by the finite element network, expanding or contracting to accommodate the movement of the free surface with time. The total derivative of the potential, with respect to time, is combined with the specific free boundary conditions which are substituted into the generalized variational principle for the saturated flow problem to give the expression for the free surface. This expression is a set of nonlinear ordinary differential equations. A Crank-Nicholson time centered scheme is used to solve the non-steady flow with the free surface. The regular finite element approach, based upon the variational principle, provides the potential distribution below the free surface.

The above features for handling the free surface and potential distribution are used in the model to solve both two-dimensional and axisymmetric flow problems. The program also solves for the seepage face, if one occurs, through a two step iterative procedure. It would appear that considerable additional development would be required to extend the procedure to a three-dimensional situation. Since it is two-dimensional, the predictions are restricted to only vertical sections when the free surface feature is utilized.

S.P. Neuman, and P.A. Witherspoon, "Analysis of Nonsteady Flow with a Free Surface Using the Finite Element Method," Water Resources Research, June 1971, Vol. 7, no. 3, p. 611-623.

Source - Reference #13: p. 80.

Model - FRONT

Purpose - The FRONT model performs a two-dimensional simulation of a moving intrusion front in a thin horizontal confined aquifer by predicting the position of a moving interface between contaminated and uncontaminated water.

Description - The position of the interface is simulated by following the movements of a finite number of points on the interface for which the initial locations are given on input. This program was designed to run in conjunction with SOPH, but system flow characteristics could likely be provided by some other flow program with appropriate format adjustments. This model predicts a moving front rather than a series of pathlines. The results available from FRONT could be provided by several of the more sophisticated moving particle type transport codes by suppressing the dispersion related features.

A. Vandenberg
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Source - Reference #13: p. 90.

GROUNDWATER TRANSPORT

Model - GARD: A Computer Program for the Geochemical Assessment of Radionuclide Disposal

Purpose - Used to calculate the rate of movement of radionuclides from a proposed deep underground vault to the surface or near surface environment.

Description - The computer program GARD is being used to calculate the rate of movement of radionuclides from a proposed deep underground vault to the surface or near surface environment. The conceptual model represents a deep underground vault in igneous rock and a system of fissures which connect the vault with the surface of the geologic formation. After a certain initial period (container integrity time), during which there is assumed to be no release, the radionuclides are assumed to be released from a vault within a certain time (leach time) and transported as dissolved species by groundwater. Important phenomena influencing their transport are convection, radioactive decay and physicochemical processes such as sorption, ion exchange and precipitation. From the material balance, a set of partial differential equations has been formulated. Simultaneous solution of these equations by the Laplace transform technique leads to expressions for the discharge rates of radionuclide chains as a function of time and distance.

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Atomic Energy of Canada Ltd.
Pinawa, Manitoba

Source - Reference #26: p. 3

GROUNDWATER TRANSPORT

Model - GEOSPHERE

Purpose - The GEOSPHERE computer model was developed to compute the amount of radioactivity released per year (the release rate) to a receiver from a repository in a geologic formation through which ground water is flowing.

Description - The release rate is computed as a function of time, so that a chromatographic spectrum is obtained. In its present state, the program evaluates 56 radionuclides that may be present in reactor effluents or naturally occurring in rocks. The output, in the form of chromatographic spectra, obtained from the GEOSPHERE model is stored in a data file in such a way that the file can be used directly as input for the biosphere model.

B. Grundfelt
Kemakta Konsult AB (Sweden)
September 30, 1977

Source - Reference #26: p. 11

GROUNDWATER TRANSPORT

Model - GETOUT

Purpose - This model predicts the long-term migration of radionuclides through the geosphere from nuclear waste disposal sites.

Description - The model interfaces directly with the water-dose models, ARRRG and FOOD, and together they are used to predict the dose consequences to man from radionuclide releases.

The model analyzes the transport of radionuclides by flowing ground water following a leach incident at an underground nuclear waste disposal site. This model assumes that at some arbitrary time after the waste is deposited, the contents of the site are dissolved at a specified constant rate by ground water. The ground water flows at constant velocity through a homogeneous one-dimensional column of the geologic medium and discharges to a surface water body. The dissolved radionuclides are assumed to be in sorption equilibrium at all points in the geologic medium. Radioactive decay (including chain decay of the actinides) is modeled both at the disposal site and during migration through the geologic medium. Trace concentration of the dissolved nuclides are assumed, and as a result the adsorption equilibrium constants are independent of concentration. A constant axial dispersion coefficient is also assumed. This model is applicable to particulate and fractured media provided the necessary input data are obtained properly and can be applied to heterogeneous media if a weighted averaging technique is properly applied to the relevant input parameters.

The equations describing the one-dimensional nuclide transport of radionuclide decay chains are solved (by the Laplace transform technique) for both impulse and decaying band releases.

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Source - Reference #12: p. B-2.

GROUNDWATER TRANSPORT

Model - GWHEAD: A Computer Code for Determining the Ground Water Head with Three-Dimensional Flow.

Purpose - This program is used in the study of contaminants in groundwater.

Description - GWHEAD is a groundwater head computer code developed at the Savannah River Laboratory (SRL). For the cases of pumping from leaky aquifers, unconfined aquifers, and for the case of spherical flow to a continuous point source, GWHEAD calculates values of hydraulic head that compare favorably with exact analytical solutions applicable to these cases.

R. W. Root; R. R. Beckmeyer
Savannah River Laboratory
Environmental Transport and Effects Research
Annual Report, 1977
Savannah River Ecology Lab.
Aiken, SC (USA), Oct, 1978.

Source - Reference #27: Item 6.

GROUNDWATER TRANSPORT

Model - HANFORD PCP: Pathline Calculation Program

Purpose - This calculation program provides a two-dimensional pathline generation capability for use on grided tabular output data from water flow models.

Description - It is presently restricted to saturated flow systems with input potential data provided on rectangular grid points for up to 650 data time sets. The spatial potential gradients are obtained using special interpolation expressions that are differentiated and then evaluated. The hydraulic conductivity, effective porosity, and gradient changes with time use direct weighting to obtain the values at the points needed. Though the equal step in time feature is often the more useful mode for following contaminants, the program also can operate in a controlled distance mode along each path line.

The program was completed in 1976 and has been extensively tested against severe analytical results. Good agreement was found, suggesting the PCP model will be a useful evaluation tool for conservative contaminants in two-dimensional flow systems.

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Richland, WA

Source - Reference #13: p. 89.

GROUNDWATER TRANSPORT

Model - INTERA DWDM: Deep Well Disposal Model

Purpose - This model solves pressure as well as temperature and contaminant transport and dispersion in a three-dimensional heterogeneous aquifer.

Description - This model allows for the description of a three-dimensional heterogeneous aquifer. Source-sink terms allow handling a well field or connection with surface water. Single solute transport and diffusion at concentrations sufficiently high to affect fluid density and viscosity are included. The energy equation is solved to provide temperature distribution. A recently added option would allow N trace constituents, such as a decay chain, to be solved with the above equations.

Solution methods include finite difference approximations to water, solute and energy balance equations. Each of the above equations are solved simultaneously and can be solved by a Line Successive Over-relaxation (LSOR) technique with optimum parameter selection or a direct matrix inversion method.

The model was developed by INTERA for the U.S.G.S. who has applied the model. Sandia Laboratories also is using the program.

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INTERCOMP Resource Development and Engineering Inc.
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Source - Reference #12: p. B-29.

GROUNDWATER TRANSPORT

Model - INTERA HCTM: Hydrologic Contaminant Transport Model.

Purpose - This model predicts head pressures and contaminant transport with dispersion in a three-dimensional heterogeneous aquifer.

Description - The commercial proprietary INTERA-Hydrology Contaminant Transport Model is a coupled model with both conservative contaminant transport capability and ground-water flow predictive capability combined into a single computer program. The model provides two- and three-dimensional predictive capability for conservative contaminants. The method of characteristics is used so advection is considered directly through pathlines. The point tracking scheme with dispersion is very effectively utilized in the program. The dispersion characteristics used are a longitudinal and lateral input characteristic length which is automatically combined with the magnitude of effective groundwater pore velocity.

The flow portion of the model utilizes finite differences with emphasis on a block type formulation, as contrasted to a nodal emphasis or representation. Accordingly, the representation is more in the setting and has the advantages of the "Integrated Finite Difference Method" (IFDM). The actual solution of the once integrated difference equations is accomplished either by standard line successive over-relaxation (LSOR) techniques for larger problems, or through using a special equation ordering scheme followed by Gaussian elimination.

The model has been rather widely applied to a variety of practical problems, including the following: Transport and Diffusion of Groundwater Contaminants Downstream from Surface Mining, Utah; Investigation of Three-Dimensional Effects in Tritium Transport at Hanford Reservation, Atlantic Richfield Hanford Company, Washington; Interaction Between Industrial Aquifer Withdrawals for Water Flooding and City Use, Alberta; Design of Well Field for In Situ Leaching Project, Arizona; Mine Dewatering Needs, Wisconsin. The above applications illustrate the range of problems for which the model has been used. The use of the model for ARHCO above is the only one available in open literature.

INTERA Environmental Consultants Inc.
11511 Katy Freeway, Suite 630
Houston, TX 77079
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Source - Reference #12: p. B-9, 10. Reference #13: pp. 75, 76, 91.

Model - INTERCOMP-GWM: Gas Water Model

Purpose - The INTERCOMP-GWM model is a three-dimensional model describing the simultaneous immiscible flow of water and air.

Description - Any combination of reduced conditions can be treated, i.e., it may consider completely saturated flow in parts of the flow system, or conversely, if essentially no water is present, then the gas flow is evaluated.

The Gas-Water Model uses finite differences for numerical reduction of the partial differential equations and the resulting algebraic equations are solved, using either a line successive over-relaxation (LSOR) or a special ordering scheme followed by direct Gaussian elimination. Though either solution may be used the special ordering with Gaussian elimination is preferred for most systems. In very large systems, the LSOR method may be required.

There are two versions of the model: One is the IMPES version which is an Implicit in Pressures and Explicit in Saturation scheme which saves from 1/2 to 1/3 in computer running time to provide a solution. The second, more costly version involves completely simultaneous solution. The INTERCOMP oil-gas-water model, from which this gas-water model evolved as a special case, has been used extensively in evaluation of a variety of petroleum reservoirs. The present gas-water model is also being applied to an ever greater number of subsurface gas-water problems.

K.H. Coats
INTERCOMP Resource Development and Engineering, Inc.
Houston, TX

Source - Reference #13: p. 87.

Model - ISOQUAD

Purpose - The ISOQUAD model for contaminant transport is a version of ISOQUAD2 where flow and conservative transport are considered together.

Description - This model utilizes a Galerkin approximation with various basis functions, with a finite element integration scheme to solve the conservative transport equation. The time integration is performed through a backward difference time scheme. The major computer models of this type are presently restricted to considering two-dimensional flow systems. Accordingly, the SEGOL model with potential three-dimensional and combined saturated - partially saturated flow may be a more judicious model to consider.

George Pinder, Princeton University
Emil Frind, Waterloo University

Source - Reference #12: p. B-24; Reference #13: pp. 92, 93.

GROUNDWATER TRANSPORT

Model - KANSAS-GREEN

Purpose - The KANSAS-GREEN model is one of the very few water resource oriented models which considers both water and air flow in porous materials.

Description - The multiphase models have been associated almost exclusively with the petroleum industry. The KANSAS model is a two-dimensional, finite difference approach which uses the alternating direction implicit procedure (ADI) for solution of the equations.

D.W. Green,
Kansas Water Resources Research Institute
Manhattan, Kansas

Source - Reference #13: p. 88.

DOSIMETRY
GROUNDWATER TRANSPORT
SURFACE WATER TRANSPORT

Model - LADTAP: Liquid Annual Doses to All Persons

Purpose - To calculate doses received by individuals and populations through liquid pathways for the implementation of NRC Regulatory Guide 1.109.

Description - None available at the time of presentation of this document. See Regulatory Guide 1.109 for a description of the calculational model and parameters that this code implements.

Mike Bell
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Washington, D.C.

Source - Reference #30

Model - LEVINE

Purpose - LEVINE computes the thermodynamic equilibrium for large chemical and geochemical systems.

Description - LEVINE uses the free energy minimization and equilibrium constant approaches to model a system. A large number of solids can be included. This advantage is facilitated by a fast, efficient method of solution for the equilibrium equations which uses a combination of the relaxation method and univariate analysis. More than one liquid phase and possibly more than one gas phase may be treated. Material can be added to the system and water can be evaporated from it. Two data bases are utilized--a variation of Wolery's (EQ3/6) and a portion of the Janaff tapes.

Howard Levine and Don Miller
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Livermore, CA 94550 (Miller)

Source - Reference: Personal Communication with Miller; no documentation available yet.

GROUNDWATER TRANSPORT

Model - MAIN: A Model for Calculating Effects of Liquid Waste Disposal in Deep Saline Aquifers.

Purpose - This code has been developed to aid in the design and testing of waste disposal systems, concentrating on liquid transport.

Description - A transient, three-dimensional subsurface waste-disposal model has been developed to provide methodology to design and test waste-disposal systems. The model is a finite-difference solution to the pressure, energy, and mass-transport equations. Equation parameters such as viscosity and density are allowed to be functions of the equations' dependent variables. Multiple user options allow the choice of X, Y, and Z cartesian or R and Z radial coordinates, various finite-difference methods, iterative and direct matrix solution techniques, restart options, and various provisions for output display. Well-bore heat and pressure-loss calculations have been added to the model making available to the ground-water hydrologist the most recent advances from the oil and gas reservoir engineering field. The program is written in the FORTRAN programming language for implementation on an IBM 370/155 computer using the OS version 21.8, HASP-MVT level operating system. 172K bytes of core storage are required to operate the model.

D. B. Grove
Geological Survey
Water Resources Division
Denver, CO
PB--256902 1976

Source - Reference #18: p.231

GROUNDWATER TRANSPORT

Model - MESA, Dynamic Model of Water Movement in Soil Under Various Climatological Conditions.

Purpose - This code is used to trace groundwater movement under varied conditions.

Description - A study was conducted to ascertain if a previously developed kinetic equation ecosystem model (MESA) was sufficiently general to simulate and predict the movement of water (both stable and tritiated) in soil under diverse climatological conditions and, if so, to apply this model to water movement in the soil of a tropical rain forest, an Illinois grassland and a Nevada desert site. Basic agreement was obtained as to the location of the bulk of tritium between the observed data and the prediction. For example, the peak concentration after 76 days was predicted to be at 28 cm in depth and to have a value of 5×10^3 (E+3) dpm/ml. This compares well with an observed peak of between 25 cm and 30 cm and a concentration of 10^4 (E+4) dpm/ml. Tritium concentration predictions were made until at least 99.9% of the tritium had passed through the Puerto Rico and Illinois ecosystems and at least 99% through the desert ecosystems. Using these criteria, the Puerto Rico rain forest predictions were made for one-half of a year, the Illinois grassland for one year and the Nevada desert for five years. It was concluded that in the Puerto Rico rain forest, the most significant parameter controlling water (stable and tritiated) movement through the ecosystem is the rainfall, while in the Illinois grasslands, both the rainfall and transpiration rate are primary factors controlling water movement through the ecosystem. In the Nevada desert, the half-residence-time is primarily influenced by the transpiration and diffusion rates. When predicting long-term concentrations of tritium in the soil (other than possibly a tropical rain forest soil), it may prove an advantage to consider the tritium movement in the ecosystem as characterized by two separate half-residence-times. The initial value is determined primarily by the rate of transpiration and the final value, about an order of magnitude greater, is determined by the soil-water diffusion rate. The ecosystem model, MESA, appears to be sufficiently general to give satisfactory predictions of water movement in a tropical rain forest, grasslands and desert soil.

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Source - Reference #6: p. 136.

GROUNDWATER TRANSPORT

Model - MINUTE: Calculations of Nuclide Migration in Rock and Porous Media, Penetrated by Water

Purpose - A model was developed to calculate the migration of radionuclides in rock and porous media.

Description - Some physical and mathematical models are given for migration of nuclides in rock and porous media penetrated by water. The cases considered are thermal convection due to the decay heat from radioactive sources and transport due to the hydraulic gradient connected with the geographic structure. The model for thermal convection is highly simplified but is conservative compared with the often made adiabatic assumption which limits convection effects to a region characterized by a high ratio between buoyant and viscous forces. The piezometric head and corresponding gradients are calculated by analytic methods. It is shown that the solutions are strongly dependent upon the variation of the permeability with depth. The special features of migration in cracks are studied. A computer program, MINUTE, was developed for numerical calculations. Times for transport of some important nuclides to the ground surface were calculated using appropriate input data for representative Swedish deposition sites. Error margins are discussed.

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September 1977

Source - Reference #26: p. 9

Model - MMT: Multicomponent Mass Transport

Purpose - This model predicts the movement of radionuclides and other contaminants in ground water and in the vadose zone.

Description - The saturated or partially saturated flow vectors are defined at the center of each rectangle circumscribed by four nodes. Boundary types which are also defined at the center of the rectangles are either reflecting or flow boundaries. At inflow boundaries the concentration of the incoming fluid can be a continuous function of time at each node. Concentrations entering an aquifer from above are assumed to impact a specific size circular or trapezoidal area of the aquifer and mass is added to all coincident rectangles (cells). Specifically the processes involved are: 1) Mass transport of components of phases - chemical, physical and radioactive species (advection, hydrodynamic dispersion), 2) Reactions - chemical, radioactive (instant equilibria constraint), and 3) Processes at Interfaces - adsorption, ion exchange, precipitation and dissolution (instant equilibria constraint).

The model solves the problem of transport to multicomponent species in ground water using a technique referred to as the Discrete-Parcel-Random-Walk (DPRW) approach. This is a Lagrangian, particle-of-mass based approach that simulates dispersion using a random walk analogy. The soil-waste reaction submodel has a rapid equilibrium assumption as its basis, and the resulting system of non-linear equations is solved using a simultaneous Newton-Raphson algorithm.

Although the program is generic, to date it has only been applied to various portions of the Hanford Reservation in Southeast Washington State on behalf of DOE. It has been used for a variety of problems concerned with predicting the movement of radiocontaminants in the Hanford subsurface.

S.W. Ahlstrom, H.P. Foote, R.J. Serne (1976)
Pacific Northwest Laboratory
Water and Land Resources Department
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Source - Reference #12: p. B-31.

GROUNDWATER TRANSPORT
SURFACE WATER TRANSPORT

Model - MOC

Purpose - This model computes potentiometric heads and solute transport in flowing water.

Description - The model predicts the flow of water according to Darcy's Law and continuity equation. Capabilities include solute transport by convection and hydrodynamic dispersion, with the dispersion coefficient treated as second-order tensor. The code solves for both transient or steady-state flow. It can readily incorporate simple chemical reactions, radioactive decay, or adsorption.

The model solves a finite difference form of the flow equation using an iterative ADI procedure. The solute-transport equation is solved using the method of characteristics. Applications include the following: Transient position of interface between fresh water and salt water; cross-sectional model; flow is density dependent--Pinder and Cooper (1970); Movement of salt water in confined limestone aquifer; vertical leakage through confining bed; area in Georgia--Bredehoeft and Pinder (1973); Salinity increases in alluvial stream-aquifer system were related to irrigation practice; coupled streamflow routing model; applied to management problems; area in Colorado--Konikow and Bredehoeft (1974); Movement of industrial and low-level radioactive liquid wastes in interbedded basalt flows and unconsolidated sediments; effects of radioactive decay and adsorption included in model; area in Idaho--Robertson (1974); Contamination of shallow alluvial aquifer by seepage from sewage-treatment ponds; area in California--Robertson (1974); High chloride industrial wastes seeped out of unlined disposal ponds and spread through underlying alluvial aquifer; area in Colorado--Konikow (1976).

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Source - Reference #12: pp. B-18, 19.

Model - MTMVMC

Purpose - The model predicts piezometric heads in a multilayered aquifer.

Description - Each aquifer layer is given a 2-D discrete representation in the horizontal plane. Leakage between two layers is assumed to be vertical. The aquifer can be phreatic or confined. Replenishment of the first layer can be natural, either through rainfall or from lakes, rivers, etc. Replenishment of the lower layers occurs through leakage from the overlying or underlying horizons. Outlets for the various layers can be springs, lakes, rivers, wells, artificial drains, evaporation, etc. Boundary conditions are discretized along the sides of the meshes by prescribed heads or fluxes. The model solves flow of water according to Darcy's law and the continuity equation, with Dupuit approximation and variation of the transmissibility with the saturated thickness of the aquifer. Permeability varies according to the X and Y coordinates and is constant in each mesh representing an average value of the different permeabilities encountered along the vertical.

Integration of the flow equation in a porous medium is done by the method of finite differences. In a steady-state, the system of linear equations is solved by an over-relaxation method with an optimized relaxation factor. In a transient state, implicit or explicit methods can be used.

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Source - Reference #12: p. B-22.

Model - NEWSAM

Purpose - The model predicts piezometric heads and salt transport in a multi-layered aquifer.

Description - The model solves the flow of water according to Darcy's law and the continuity equation in each layer (aquifer and semi-pervious). It uses Dupuit approximation in the layers (horizontal flow), and variation of the transmissivities with the saturated thickness of the phreatic aquifer. The principal direction of anisotropy of permeability is assumed constant and parallel to the x and y coordinates. For semi-pervious layers, flow is given by Darcy's law in steady state; in transient state, flow is approximated by a few terms of the development of the complete analytical solution. The model computes the transport of salt with the water with only the convective term (neglecting dispersion) and assumes instantaneous mixing in each mesh of the flux over one time step. Adsorption of salt by the immobile phase can be represented assuming an instantaneous linear and reversible adsorption isotherm (relation between concentration in the mobile and immobile phases).

Integrated finite differences yield, in steady state, a set of linear equations which is solved by a point successive over-relaxation method (PSOR) with an optimised relaxation factor. In transient state, two methods are available: implicit (solved by PSOR) and integrated polynomial approximation. Leakage in semi-pervious layers is given by an analytical expression convoluted with the previous drawdown in each overlying the underlying meshes. These convolution integrals are approximated by a few terms of their development, making it unnecessary to store in the core the values of drawdown for previous time-steps. For salt transport, a fully implicit backward differences scheme is solved by PSOR.

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Source - Reference #12: p. B-25-27.

Model - OAK RIDGE FE

Purpose - The OAK RIDGE FE model handles combined partially saturated and saturated flow in two-dimensional transient situations.

Description - The model development effort appears to have grown out of the developers' experience using the partially saturated flow model of R.A. Freeze of IBM. Like most of the Freeze applications, the OAK RIDGE FE model has been applied to either drainage cases or those with rather moist initial conditions. Such cases are much less likely to experience instabilities in numerical solution.

The program is a finite element Galerkin model with isoparametric elements for the spatial integration and performs the time integration using a modified Crank-Nicholson type method with a moving location between 0 and Δt for calculating the time derivatives. In fact, the variable location along Δt can be selected to get greater stability if needed. The nonlinear capillary conductivity and saturation dependence upon the pressure head is handled by repeated cyclic solution. The dependent properties are updated compatible with the last calculated pressure heads followed by recycling through the efficient matrix solution steps to get new pressure heads with which to revise capillary conductivities and saturation again. Such a cyclic process could get into stability difficulties on imbibition problems with very low initial moisture contents. Unfortunately, it is this more difficult class of problems upon which the model apparently has not been tried.

M. Reeves, and J.O. Duguid, "Water Movement Through Saturated-Unsaturated Porous Media: A Finite-Element Galerkin Model," ORNL-4927, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Source - Reference #13: pp. 85, 86.

GROUNDWATER TRANSPORT

Model - OAK RIDGE FET: OAK RIDGE Finite Element Transport

Purpose - The OAK RIDGE Finite Element Transport model was developed as a two-dimensional companion transport model for use on the results provided by the OAK RIDGE FE flow model.

Description - The model considers advection, dispersion, and exchange of one chemical constituent which may involve radioactive decay under partially saturated flow conditions. The single chemical component exchange reaction is handled through an equilibrium exchange coefficient modified by the moisture content when partially saturated conditions exist. The spatial integration is accomplished through the Galerkin Finite Element approach using linear basis functions. The time integration uses a modified Crank-Nicholson finite difference form, where the usual differencing location at $\Delta t/2$ is variable in the range from zero to Δt , which the model user may select.

A special, rather standard numbering scheme for element nodes is utilized to reduce the matrix band width that must be stored and operated upon for solution. Special treatment of various boundary conditions are also utilized to maintain the desired matrix forms. The actual solution is standard Gaussian elimination by decomposition into the product of an upper and lower triangular matrices. The lower triangular matrix is used to modify the right hand side for back-substitution into the upper triangular matrix to obtain the solution.

The model is moderately well documented mathematically and very well described as a computer program, including test cases.

J.O. Duguid, and M. Reeves, "Material Transport Through Porous Media: A Finite Element Galerkin Model," ORNL-49280, March 1976, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Source - Reference #13: p. 96.

GROUNDWATER TRANSPORT

Model - PATHS

Purpose - The original purpose of the model was to provide an easily used two-dimensional analysis tool to determine the movement of water transported contaminants accidentally released from a waste storage facility.

Description - The model was purposely designed to provide a balance between modeling sophistication and the limited data usually available for initial evaluations of subsurface contamination problems. Accordingly, the basis of the code is an idealized two-dimensional analytical solution for the ground-water potential distribution. From the potential distributions the pathline differential equations are written and then numerically solved by the code to give the paths of the fluid particles and their advance with time toward the outflow boundary.

After finishing the original version of the code, it became apparent that the combination of moderately short running times to get results, the moderate field data requirements, and the ease of running the code, made it useful in a wider variety of situations. In fact, its main strength lies in providing initial "first cut" evaluations inexpensively and quickly.

The model was developed in original form (without wells) as an initial model for movement from deep underground caverns. Additional applications include the following: Initial Model of Accidental Release from a Fuels Reprocessing Facility in South Carolina; Initial Evaluation of Accidental Failure of Earthen Sewage Holding Ponds, Kennewick, Washington; Initial Evaluation of Seepage from a Copper Tailings Reservoir; Used during short course in "Groundwater Engineering Short Source," sponsored by Agricultural Research Service, Chickasha, Oklahoma; Example evaluation for State of Idaho Department of Water Administration; Evaluation of a numerical generation scheme for pathlines for ARHCO in cooperation with PNL for the U.S. Energy Research and Development Administration; Evaluation of potential hazard from subsurface reactor accidental releases for Sandia Laboratories, Albuquerque, New Mexico.

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Source - Reference #12: pp. B-3, 4.

GROUNDWATER TRANSPORT

Model - PERCOL: One-Dimensional Model of the Movement of Trace Radioactive Solute Through Soil Columns.

Purpose - This code models the movement of a solute through a soil column.

Description - This model, developed by the U.S. Geological Survey, will simulate groundwater flow in an Artesian Aquifer, a Water-Table Aquifer, or a combined Artesian and Water-Table Aquifer. The aquifer may be heterogeneous and anisotropic and have irregular boundaries. The source term in the flow equation may include well discharge, constant recharge, leakage from confining beds in which the effects of storage are considered, and evapotranspiration as a linear function of depth to water. The theoretical development includes presentation of the appropriate flow equations and derivation of the finite-difference approximations (written for a variable grid). The documentation emphasizes the numerical techniques that can be used for solving the simultaneous equations and describes the results of numerical experiments using these techniques. Of the three numerical techniques available in the model, the strongly implicit procedure, in general, requires less computer time and has fewer numerical difficulties than do the iterative alternating direction implicit procedure and line successive overrelaxation (which includes a two-dimensional correction procedure to accelerate convergence).

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Source - Reference #18: p. 236

GROUNDWATER TRANSPORT

Model - PST: Partially Saturated Transient Flow Model.

Purpose - The model is used to simulate isothermal, unsaturated, liquid flow in heterogeneous porous media.

Description - A computer model, the partially-saturated transient flow model (PST), is used to test the formulation for simulating isothermal, unsaturated, liquid flow in heterogeneous porous media. Because of the nonlinearities of the descriptive equations, finite difference approximation and an iterative technique were used to obtain solutions. The model, when tested, was computationally slow and impractical as a management tool but did demonstrate that the equation could be solved for flow entering relatively dry soils. Several methods of dealing with the sediment hydraulic characteristics were tested.

A. E. Reisenauer, D. B. Cearlock, and C. A. Bryan
Battelle Pacific Northwest Laboratories
Richland, WA
BNWL-1713, 1975.

Source - Reference #25: p. 382.

Model - RAMM: A System of Computer Programs for Radionuclide Pathway Analysis Calculations

Purpose - A generalized system of computer programs to analyze the movement of radionuclides through the environment to man.

Description - A generalized system of computer programs, designated RAMM (Radioactive Materials Management) system, has been developed to assist in the analysis of the movement of radionuclides through the environment to man. RAMM incorporates the GASP IV continuous/discrete simulation system. A nodal approach is used whereby the system to be analyzed is split up into parts small enough that the distribution of nuclides within the node may be taken to be homogenous. Pathways are defined between nodes, and appropriate transfer coefficients are input or generated. Nodes are general "containers of nuclides" and may be volumes, such as a volume of water or a body organ, or surfaces such as a square meter of land surface. Nodes may be defined as belonging to streams within which movement may be by transportation as well as by diffusion. Output includes the time dependent contents of the nodes and dose rates, integrated doses and dose commitments of selected nodes.

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Source - Reference #6: p.149

GROUNDWATER TRANSPORT

Model - RCPGW

Purpose - The model computes potentiometric heads in a two-dimensional aquifer using the Error Function, Well Function and the exponential integral function.

Description - The model describes a saturated, homogeneous, isotropic aquifer, and homogeneous, incompressible fluid. Model includes arrays to define areally a) recharge, b) discharge. Boundary condition options include specified head and impermeable boundaries.

The model solves analytic expressions for the flow equations. Previous applications include water allocation problems in Colorado.

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Source - Reference #12: pp. B-7, 8.

GROUNDWATER TRANSPORT

Model - REFQS: Return Flow Quality Simulation

Purpose - The REFQS, Return Flow Quality Simulation Model, was designed to enable evaluating field scale and project-wide consequences of irrigation upon project drainage water quality. However, the chemical interactions and exchange approach used could be of significant benefit.

Description - The model uses a complicated sequence of flow through linear partially saturated columns to the water table, then through the saturated region to a grid drainage network to finally arrive at the fluid outflow.

The chemical part of the model simulates many important chemical processes which have been identified and quantified over the years. The particular chemical constituents included in the model are:

Ca^{++} , Mg^{++} , Na^{++} , NH_4^+ , NO_3^- , HCO_3^- , CO_3^{--} , Cl^- , SO_4^{--} , urea, organic-N, exchangeable Ca^{++} , Mg^+ , Na^+ , and NH_4^+ and the ion pairs CaSO_4 and MgSO_4 .

Equilibrium reactions are predominantly used for most of the inorganic (salt) reactions, but the nitrogen transformations are simulated using kinetic approaches. The approach for handling chemical and exchange reactions, in principle, is the same as used in MMT-DPRW. That is, the constituents are first convected and dispersed, then sequentially chemically reacted at many small time increments, rather than attempting simultaneous solution of convection, dispersion, and chemical actions on all the constituents when many species must be considered.

Marvin J. Shaffer, and Richard W. Ribbens, "Generalized Description of Return Flow Quality Simulation Model," Engineering and Research Center, Bureau of Reclamation, October 1974, U.S. Department of Interior, Denver, Colorado.

Source - Reference #13: p. 95.

GROUNDWATER TRANSPORT

Model - SCHWARTZ

Purpose - To model groundwater transport, taking into consideration chemical reactions.

Description - This model uses the method of characteristics to solve the two-dimensional transport system. The exchange reactions involved binary exchange reactions with the porous material and include radioactive decay in the solution process. The chemical insight and detailed understanding of chemical exchange reactions with porous materials is most likely of greatest importance in this model. This is probably more important than potential actual use of the individual model.

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Source - Reference #13: pp. 94, 95.

GROUNDWATER TRANSPORT
SURFACE WATER TRANSPORT

Model - SEGOL

Purpose - The SEGOL model is a coupled model for contaminant transport and flow. The flow system is for combined saturated and partially saturated flow.

Description - The transport equations are solved using a Galerkin Finite Element approach. The model solves for three-dimensional combined partially saturated and saturated flow. Since solution for both saturated and partially saturated flow is possible, the free surface is very nicely handled. At the same time, a more realistic representation of flow from ponds or lakes is provided by the model, rather than requiring the assumptions involved when only saturated models are used. The SEGOL model utilizes finite elements for the numerical reduction with isoparametric elements. It is an operational model and has been tested, but has not yet been extensively used with field problems. A severe test case involving imbibition led the author to indicate that a spatial discretization of a few centimeters may be necessary for such problems.

G.A. Segol, "A Three-Dimensional Galerkin Finite Element Model for the Analysis of Contaminant Transport in Variably Saturated Porous Media User's Guide," June 1976, Department of Earth Sciences, University of Waterloo, Waterloo, Ontario, Canada.

Source - Reference #13: p. 91.

GROUNDWATER TRANSPORT

Model - STM: Solute Transport Model

Purpose - STM models the transport of waste in groundwater and the reaction between the waste and its environment. The applicability of STM is in its capacity to predict radionuclide migration in a given subsurface environment.

Description - Assessment of the environmental impact of disposal of waste in the subsurface environment requires that the reactions between the two be determined. This is most frequently determined by use of mathematical models such as the solute transport model (STM). The STM usually consists of two submodels. The first submodel, the waterflow submodel, computes water seepage velocities. The second part, the solute-transport model, uses the velocities to determine concentration. The solute transport model requires data on convection, hydrodynamic dispersion, ion-exchange reaction rates, rate controlled chemical reactions and radioactive decay (where applicable). These equations are most frequently solved by numerical techniques. Models are currently available for assessment of one or two dimensional transport equations. Techniques currently used are either finite differences or finite element methods.

D. B. Grove, J. Rubin.

Disposal of Residues on Land, Proceeding of a National Conference held in St. Louis, Missouri, September 13-15, 1976, (pp. 174-178), 1-216 pp. (CONF-760968)

U.S. Geological Survey, Denver, CO

U.S. Geological Survey, Menlo Park, CA

Source - Reference #11: pp.84,f.

GROUNDWATER TRANSPORT
SURFACE WATER TRANSPORT

Model - TEHM: A Terrestrial Ecosystem Hydrology Model

Purpose - The model can describe movement of radionuclides through the ground.

Description - The terrestrial ecosystem hydrology model (TEHM) combined mechanistic models for climatic and hydrologic processes with vegetation properties to explicitly simulate interception and through fall; infiltration; root zone evaporation, transpiration, and drainage; plant and soil water potential; unsaturated and saturated subsurface flow; surface runoff; and open channel flow. It is also possible to use the TEHM with models for forest stand biomass dynamics and chemistry and exchange of heavy metals to study the transport and fate of trace contaminants at a watershed scale. Walker Branch Watershed has been used as an example to illustrate development of the required input parameters and variables that are necessary to execute the TEHM. In all cases, emphasis has been placed on objective, physically based methods. When simulations of interception loss, soil moisture content, and base flow and storm flow are compared with observation, the overall adequacy of the model may be assessed. For user convenience, the documentation includes a complete discussion of input formats, example data input sets, output summaries, and a microfiche listing of the complete source deck and program output.

As presented, the TEHM provides an operational tool and a model structure and data management capabilities that will be useful for future hydrologic simulation work. From that viewpoint, the TEHM represents an important step forward in establishment of an objective framework for the study of terrestrial ecosystems.

FORTRAN IV is the language and IBM 360 the computer used in TEHM. WHTM is a part of TEHM.

Huff, D.D.; Luxmoore, R.J.; Rankin, J.B.; Begovich, C.L.
Oak Ridge National Laboratory, Oak Ridge, TN 37830

Source - Reference #6: p. 152.

GROUNDWATER TRANSPORT

Model - TRA-POND

Purpose - This model simulates transport of radionuclide solutes from a seepage pond through perched water zones to a regional aquifer.

Description - Aqueous chemical and low-level radioactive effluents have been disposed to seepage ponds since 1952 at the Idaho National Engineering Laboratory. The solutions percolate toward the Snake River Plain Aquifer (135 M below) through interlayered basalts and unconsolidated sediments and an extensive zone of ground water perched on a sedimentary layer about 40 M beneath the ponds. A three-segment numerical model was developed to simulate the system, including effects of convection, hydrodynamic dispersion, radioactive decay, and adsorption. The first segment uses an analytical solution to simulate transport from the ponds to the 25-M thick perched-water lens, assuming steady vertical flow through a 15-M long saturated homogeneous column. The second segment simulates two-dimensional horizontal transport in the perched-water body using finite-difference methods, assuming complete vertical mixing with vertical leakage from the bottom. The third segment of the model simulates vertical solute transport from the leakage from the bottom. The third segment of the model simulates vertical solute transport from the perched-water body toward the aquifer, by assuming unsaturated but steady water flow in a series of contiguous, nonhomogeneous independent vertical columns. The transport equation is solved by a "Hopscotch" finite-difference scheme for each column. Simulated hydraulics and solute migration patterns for all segments agree adequately with the available field data. The model can be used to project subsurface distributions of waste solutes under a variety of assumed conditions for the future.

J. B. Robertson, Numerical Modeling of Subsurface Radioactive Solute Transport from Waste-Seepage Ponds at the Idaho National Engineering Laboratory. IDO-22057, p. 76, Jan. 1977.

Source - Reference #25: p. 328.

Model - TRENCH

Purpose - Relates amount of radionuclides leaving bottom of burial trench per unit time to the current of radionuclides crossing a hypothetical boundary per unit time.

Descriptions - Model computes transport of dissolved radionuclides in water through a porous medium. Medium is homogeneous and isotropic, fluid is incompressible and has constant viscosity. Convection, longitudinal and transverse dispersion, reversible ion-exchange and radioactive decay are all included. Semianalytic approach is utilized to describe discharge surface represented by a "river bank" and a "well."

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White Plains, NY

Source - Reference: "Generic Methodology for Assessment of Radiation Doses from Groundwater Migration of Radionuclides in LWR Wastes in Shallow Land Burial Trenches," AIF/NESP-013, American Information Forum, January 1979.

GROUNDWATER TRANSPORT

Model - TRIGAT - HS 1, or XYZ - HS 5

Purpose - The model predicts piezometric heads in three-dimensional underground unsteady flow in confined aquifers or unconfined aquifers.

Description - In each point of the model, the flow is three-dimensional. Possible connection of the aquifer with surface water (rivers, lakes, oceans) is considered. Each cell of the model can be assigned a value of specific yield or storage coefficient. All the cells are not necessarily of the same size. Boundary conditions can vary.

The solution method is by finite difference implicit discretization with the linear equation solved by the Gauss-Seidel method with over-relaxation.

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Source - Reference #12: pp. B-11, 12.

GROUNDWATER TRANSPORT

Model - USFLW: Unsaturated Flow

Purpose - The USFLW model is an Israeli transport model for use with Unsaturated Flow in materials with contaminants that are sorbed. It uses a method of characteristics solution for the transport equations.

Description - NOT PRESENTLY AVAILABLE.

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Source - Reference #13: pp. 93, 97.

GROUNDWATER TRANSPORT

Model - USGS MC

Purpose - Though this model has usually been coupled to a flow model, it is so simply separated that it could be utilized along or directly coupled to another flow model with a minimum of effort. The model considers two-dimensional transport through use of the method of characteristics.

Description - A somewhat unique method is employed in generating the velocity field from groundwater potential data. Central spatial differences are used to estimate gradients at all nodes and at points of contact between node blocks. Values of hydraulic conductivity or transmissivity and porosity at nodes are used directly, while harmonic interpolation provides the hydraulic conductivity values at points between grid node blocks. With the velocities calculated, bilinear interpolation on half grid blocks is used to define the advection components at any point in that half grid space.

Several moving particles are next placed in each cell of the finite difference grid and are moved a distance proportional to the time increment and the velocity at the particle location. The concentration at each node is then temporarily assigned the average concentration of all particles located within that cell. The change in concentration due to dispersion is calculated explicitly for each node, and the average concentration at the node is adjusted for this change. The concentration associated with each particle located in the cell is then adjusted for the node change.

J.D. Bredehoeft, and G.F. Pinder, "Mass Transport in Flowing Groundwater," Water Resources Research, 1973, Vol. 9, no. 1, p. 194-209.

Leonard F. Konikow, and John D. Bredehoeft, "Modeling Flow and Chemical Quality Changes in an Irrigated Stream-Aquifer System," Water Resources Research, June 1974, Vol. 10, no. 3, p. 546-562.

Source - Reference #13: p. 92.

Model - UTM (Unified Transport Model)*

Purpose - The Unified Transport Model (UTM) allows simulation of the transport, accumulation, and redistribution of trace contaminants in the environment.

Description - The air, land, and aquatic systems are represented by three major model components, designed to be run in sequence. The atmospheric component is based upon a Gaussian plume model and calculates deposition rates of aerosols for any point within a watershed. Concentrations of airborne aerosols at ground level are also calculated. The model includes consideration of point, area, line, and windblown sources for air pollutants. Deposition occurs by dry fallout and also by washout caused by rain falling through the plume. Air concentrations and depositions depend upon source strength, atmospheric stability, and wind speed and direction patterns. The spatial resolution of the atmospheric module now extends to a radius of 50 kilometers from any point source. One can use the model to simulate larger areas by constructing a mosaic of sub-area calculations. The deposition values calculated by the atmospheric model are used for input to the land component of the UTM.

The terrestrial component is structured to receive atmospheric wet and dryfall input to a watershed canopy and then simulate its movement until it is discharged in streamflow. The model simulates the amount of material washed from the canopy to the land surface during rainfall and allows for the exchange and uptake or adsorption of materials on surface soil. Surface runoff and scouring of soil particles are considered together with leaching of trace elements into the soil profile. An experimentally derived equilibrium distribution coefficient is used to estimate the concentrations of contaminants in subsurface soil water. This estimated concentration and the rate of soil water drainage are combined to estimate a subsurface input to the stream channel.

Finally, the outputs from the terrestrial component of the UTM enter the channel component, where flows are routed using a kinematic wave approximation. This portion of the program simulates transport of dissolved and particulate materials in streamflow. Suspended and bedload transport are considered by the model. Mixing and exchange between the aqueous and solid phases for the particular chemical species of concern are also simulated. If point-source discharges of known strength are released to the stream, the channel component is capable of simulating their introduction and subsequent transport.

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Oak Ridge, TN 37830

Source - Reference #3

*Program components of the UTM appear in the "Other LLW Models" category.

Model - VCHFLD

Purpose - This model describes the movement of from two to six chemical species in a porous medium by solving the coupled transport equation using Galerkin methods. When needed for resolution, a separate locally refined grid can be employed for each dependent variable.

Description - Primary design of the program is for two-dimensional simulation, either areally or as a two-dimensional cross section. Local grid refinement may be employed in these two principle dimensions. A limited capability is provided for a third dimension when necessary. This dimension should be chosen as the one in which the minimum changes occur and the least resolution is required. The reservoir is confined and all boundaries are no flow. Injection and production is from point (line) sources and sinks. The carrier fluid (water) convects up to five different chemical species. Chemical species may sorb and desorb on the reservoir rock according to user specified sorption isotherms, with possible complex interactions between the species.

Spatial discretization in the two principle dimensions is achieved using Galerkin methods with a bilinear basis (Chapeau functions). In the accumulation and transmissibility terms, coefficients which are functions of the dependent variables are dated explicitly. Time discretization is at the user's option either (a) backward differencing or (b) Crank-Nicholson. The resulting linear equations are solved by Gaussian Elimination or, for large problems when storage is critical, by SOR.

INTERCOMP Resource Development and Engineering, Inc. (1977)
1201 Dairy Ashford, Suite 200
Houston, TX 77079

Source - Reference #12: p. B-30.

Model - VTT: Hanford Variable Thickness Transient Flow Model

Purpose - This model forecasts the piezometric head in a multiaquifer ground-water system.

Description - VTT is a Multiaquifer-Two-Dimensional Boussinesq Model with provisions for interaquifer transfer between aquifers and transfer to a water body through a semipervious layer. The system can handle heterogenous isotropic parameters and confined as well as unconfined aquifers. Water is treated as incompressible. The model can handle a variety of boundary conditions and boundary configurations. The model is part of a flexible interaction subsurface evaluation capability. Part of this interactive flexibility centers upon extensive input assistance and checking features to assure the problem is free of input inconsistencies. The extensive output capabilities are most useful in effectively demonstrating the solution process for complex problems.

When a steady-state is requested, the model utilizes a finite-difference formulation involving Newton's Method and a disk based direct Gaussian elimination procedure. This allows a converged solution of the non-linear unconfined problem to be computed in four-five iterations. When the system is confined or the starting point is far from the steady-state, another faster version is available which uses direct disk based on Cholesky decomposition. This method is approximately two times faster but for a nonlinear-unconfined problem, 10-12 iterations are sometimes required.

When the Transient Model is requested, a finite difference SLOR (Successive Line Over Relaxation) is used. For reasonable sized time steps, only seven-ten iterations per time step are required.

Significant applications include the following: Eastern third of Long Island for Brookhaven National Laboratory: travel times and direction of waste in ground water determined. Southport Region of Brunswick County, North Carolina for Nuclear Regulatory Commission; the investigation of brackish water infiltrations from sea level power plant canal. Hanford Reservation: model forecasts ground-water levels under different operating conditions and provides series of transient potential distributions from which pathlines and travel times can be determined.

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Pacific Northwest Laboratory
Water and Land Resources Department
Richland, Washington 99352

Source - Reference #12: pp. B-15, 16; Reference #13: p. 82.

Model - WALES (ENG)

Purpose - The WALES (ENG) model is a three-dimensional finite element formulation for saturated flow of an incompressible fluid in nondeformable porous material.

Description - The model yields the elliptic type partial differential equation valid for both steady and transient flow problems. In the transient flow systems, the time dependence enters through time varying boundary conditions, one of which may be the free surface. Accordingly, the transient free boundary is treated as a discrete number of steady flow problems to affect the time varying free surface. A carefully devised elemental formulation approach is used to calculate the normal velocity of the free surface and to adjust the free surface to the new location during the time increment. The revised locations of the finite element nodes lying on the new free surface are next calculated using a Newton-Raphson iterative method. With the new locations of the boundary finite element nodes known, the standard three-dimensional Galerkin finite element solution method is used to obtain the groundwater potential distribution throughout the region. Cubic isoparametric elements are used to permit accurate representation of irregular and curved boundaries.

This approach is the most direct analytical combined approach to the solution of free boundary problems in three dimensions. The approach was validated by the developer, utilizing analytical radial symmetrical solutions before adapting the method for general use.

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Wales, England

Source - Reference #13: p. 79.

GROUNDWATER TRANSPORT
SURFACE WATER TRANSPORT

Model - WHTM: Wisconsin Hydrologic Transport Model

Purpose - The model describes radionuclide transport by movement through the ground.

Description - A user's guide for the Wisconsin Hydrologic Transport Model (WHTM) is presented to enable the simulation of trace contaminant transport by the hydrologic cycle. This hydrologic transport model is based on the Stanford Watershed Model and forms a major component of the Unified Transport Model being developed at ORNL. WHTM includes the hydrologic transport of a trace contaminant by entrainment in overland flow, infiltration, impervious area runoff, and base flow. Chemical exchange reactions are simulated with a simple ion-exchange submodel for interaction with the soil and a sheet erosion submodel for transport of the trace contaminant that is sorbed on the surface of eroded soil particles. Detailed instructions for the application of the WHTM are given, and lists of the FORTRAN IV source decks and sample input data are provided. Simulation of the hourly flow in seven reaches of a stream channel system for a period of one year can be done on the IBM System 360/91 computer in about four minutes.

Since the publication of the WHTM user's manual in 1974, several useful adjustments to the program have been implemented. They include corrections to syntax, incorporation of effects of forest litter on contaminant transport, corrections to syntax, corrections to include conservation of mass on the theoretical plate ion-exchange algorithms, reintroduction of ion-exchange processes in subsurface soils, and the inclusion of some diagnostic print options. A description of each change is available, together with a comprehensive example of the results obtained when the revised WHTM is used.

Patterson, M.R.; Munro, J.K.; Fields, D.C.; Ellison, R.D.; Bronks, A.A.; Huff, D.D. Oak Ridge National Laboratory, Oak Ridge, TN 37830

Munro, J.K.; Huff, D.D., Corrections and Revisions to the FORTRAN IV Version of Wisconsin Hydrologic Transport Model 1977, May, ORNL/NSF/EATC-29; 40 pp. (Oak Ridge National Laboratory, Oak Ridge, TN 37830)

Source - Reference #6: p. 151.

GROUNDWATER TRANSPORT

Model - A Finite-Element Model for 3-D Modeling of Real Groundwater Systems.

Purpose - The model described is finite-element, three-dimensional for solving saturated or unsaturated real groundwater systems.

Description - A Galerkin Finite Element Model is designed with a view to providing flexibility, user convenience, and a high degree of efficiency, qualities which are critical to the success of 3-D modeling of real systems. The model is based on the general saturated-unsaturated continuity equation. Several integration schemes and matrix solvers have been compared, and relative costs are expressed as functions of grid size. A hypothetical system and a real system have been modeled. Simulation costs are generally found to be reasonable for grids of the size encountered with real systems.

E. O. Frind, and M. J. Verge, "Three-Dimensional Modeling of Groundwater Flow Systems," Water Resources Research, Oct. 1978, Vol. 14, No. 5., pp. 844-856.

Source - Reference #25: p. 10.

GROUNDWATER TRANSPORT

Model - A Galerkin-Finite Element Simulation of Groundwater Contamination on Long Island, New York

Purpose - This code is used in modeling groundwater contamination.

Description - The Galerkin method of approximation in conjunction with the finite element method of analysis may be used to simulate the movement of groundwater contaminants. In solving the groundwater flow and mass transport equations this approach allows a functional representation of the dispersion tensor, transmissivity tensor, and fluid velocity, as well as an accurate representation of boundaries of irregular geometry. A field application of the method to chromium contamination on Long Island, New York, shows that accurate simulations can be obtained by using the Galerkin-finite element approach.

G. F. Pinder

Source - Reference #18: p.194

Model - A Mathematical Model for Phosphorous Movement in Soils.

Purpose - This model simulates the transport of phosphorous in soils.

Description - Land application of municipal and industrial wastes is increasingly being looked upon as an alternative for treatment of effluent. Since phosphorous compounds constitute a major potential source of ground water contamination, a model for the movement of P was developed. Phosphorous moves through the soil in the form of soluble orthophosphates which can undergo precipitation, crystallization, and/or adsorption-desorption reactions in the soils. In order to predict the concentration profiles of phosphorus as functions of depth and time, some experimental data are needed. Hydraulic conductivity and capillary potential should be known over the whole range of saturation values. Also needed are the P equilibrium relationship between the solid phase and the liquid phase and the value of the overall volumetric mass transfer coefficient. The comprehensive model describing the quantitative behavior of water and P shows that the water saturation profile travels much faster than the P profile and that water redistribution between irrigations in the Barriered Landscape Water Renovation System (BLWRS) treatment system had a negligible effect on P movement. Under these conditions, the velocity of water through the bed in the zone of interest can be considered constant. Calculations are reduced by this assumption and predicted results agree very well with field data. Such a model is very useful in designing waste water irrigation sites. To get the most out of an irrigation system, it must be designed and operated so as to minimize P leakage to ground water. This type of model with predictive capability can be very well used for such a purpose.

D. B. Shah, G. A. Coulman, L. T. Novak, and B.S. Ellis
Michigan State University
Department of Chemical Engineering
East Lansing, Mich.

Journal of Environmental Quality 4(1), p. 87, 92.

Source - Reference #11: p. 118.

GROUNDWATER TRANSPORT

Model - A model of radionuclide migration from a low-level radioactive waste burial site.

Purpose - This is a simplified mathematical model for analyzing the migration of leachate and radioactive material contained in radioactive waste burial trenches.

Description - A differential equation describing the distribution and movements of radioisotopes is analytically solved, assuming a constant flux of trench water infiltrating into a saturated porous medium which is not an aquifer. The calculated lateral migration for tritium as tritiated water agrees well with the field measurements, using a realistic value of the water velocity and an adjusted dispersion coefficient. For strontium, however, the fit results in an inordinately small distribution coefficient. Migration in silty till appears to be insignificant relative to the projected 1000-year storage time primarily due to low permeability and radioactive decay.

A. H. Lu, New York State Department of Health, Albany, "Modeling of Radionuclide Migration from a Low-Level Radioactive Waste Burial Site" Health Physics, Vol, 34, No. 1, pp. 39-44, Jan. 1978.

Source - Reference #25: p. 172.

GROUNDWATER TRANSPORT

Model - A Model of Radionuclide Migration in Clay Formations.

Purpose - Modeling radionuclide migration in a homogeneous clay formation.

Description - Radioactive waste disposal into a clay formation at MOL is studied and the contamination risk of the biosphere is analyzed. The geological and geochemical barriers are investigated and the geological, seismic and tectonic data of this area are analyzed. This study enables an evaluation of the failure of the barrier by fault tree analysis. A simple tridimensional model is computed in order to evaluate the migration velocity of actinides and fission products in the considered clay formation. Results of measurements carried out on the field, analyses and laboratory experiments are introduced into the model. It is possible to investigate the migration of the most important radionuclides in function of time. It is shown that the geochemical barrier has an excellent behavior for intermediate half-life fission products and a good behavior for long half-life actinides.

M. Put, and R. Heremans, "Mathematical Modeling of Radionuclide Migration in a Homogeneous Formation," a paper presented at a Workshop on Risk Analysis and Geologic Modeling, Ispra, Italy, 23 May 1977.

Source - Reference #25: p. 79.

GROUNDWATER TRANSPORT

Model - Analysis of a Proposed Site.

Purpose - This model describes the transport of low-level radioactive waste at a proposed site.

Description - The application of a contaminant transport model to a hydrogeologic evaluation of a proposed low-level radioactive waste management site has been achieved. The proposed site is at the Defence Research Establishment, Suffield, Canada and solid low-level wastes with a half-life of less than 3,000 years would be stored there. The model is deterministic and incorporates most of the physical, chemical and nuclear processes required for a good assessment of subsurface transport and attenuation of radioactive contaminants. Suffield is an arid to semi-arid climate with temperatures fluctuating from less than -37° C to greater than 38° C. There is no permanent body of water and as result of the hummock topography small ponds form after spring melts. All this suggests that the quantity of recharge to the groundwater system will be small and of short duration. Five units are recognized in the near-surface rock and they are: gray silt, upper till, middle sand, lower till, gbrown silt, and Cretaceous shale. The model assumed that the groundwater flow is steady and the density does not change. This allows for the described velocity field to remain unchanged. To create a contaminant transport model from a mass transport model effective porosity, porous medium dispersivity, and cation exchange parameters are the major ones used. After 2,975 years, according to the model, the contaminants would spread over a small fraction of the entire system.

F. W. Schwartz
University of Alberta
Edmonton, Alberta, Canada
Journal of Hydrology, 32,
257-277. 1977

Source - Reference #11: p.156

GROUNDWATER TRANSPORT

Model - Application of Digital Computer for Aquifer Evaluation

Purpose - This program simulates groundwater flow and aquifer evaluation.

Description - The unsteady-state flow of a fluid in a confined aquifer can be approximated by linear, parabolic partial differential equations. A digital-computer program was written to solve these equations based upon an implicit finite-difference technique. Calculated values compared favorably with analytical solutions for homogeneous isotropic aquifers of simple geometry.

Pinder, G. F., J. D. Bredehoeft
Nova Scotia Dept. of Mines
Halifax, Nova Scotia
Canada
Water Resources Research, 4(S), -1069-1093
October, 1968

Source - Reference #11: p.152

GROUNDWATER TRANSPORT

Model - Application of Digital Modeling to the Prediction of Radioisotope Migration in Groundwater.

Purpose - This model was developed to predict ground water transport of radioisotopes.

Description - A digital model has been developed and verified for the prediction of radioisotope migration at the National Reactor Testing Station. The influence include space and time variations in ground-water flow, hydraulic dispersion, radioactive decay, ion exchange and other chemical reactions. These processes are included in problems of movement of radioactive wastes in ground water; design and analysis of tracer tests in ground water systems; and analysis of natural isotope distributions in ground water. The model is composed of two coupled phases--the first simulates the hydraulics and the second simulates solute transport. The hydraulic phase solves the transient, two-dimensional partial differential equation of ground water flow for a bounded, two-dimensional, one-layer aquifer, using finite difference techniques (iterative, alternating-direction implicit scheme). This method is described by Bredehoeft and Pinder. Ground water velocity vectors are computed, by this equation, for every grid point at any finite time step. The velocities are transferred to the solute transport phase of the model that solves the transient partial differential equation of transport, using the method of characteristics. This method characterizes the dissolved nuclides by characteristic imaginary particles. Considered terms in the solute transport phase are: hydraulic dispersion, convective transport, aquifer compression factors, sources and sinks, radioactive decay and sorption. Input for the model includes transmissivity, storage coefficient, boundaries, hydraulic dispersion coefficients (transverse and longitudinal), initial concentration distributions, ion exchange, distribution coefficient, radioactive decay constant, and source-sink inputs.

J. B. Robertson, U.S. Geological Survey, National Reactor Testing Station, Idaho Falls, ID, 1974.

Source - Reference #26: Item 743.

GROUNDWATER TRANSPORT SOIL TRANSPORT

Model - A Radionuclide Transport Model for Shallow Land Burial Sites.

Purpose - The model describes the movement of radionuclides through soil. Its applicability is general to LLW management.

Description - A state-of-the-art computer code has been developed that calculates the transport of pollutants through soils. The computer code calculates the one-dimensional transient response of a soil column to infiltrating water carrying a pollutant that interacts with the soil. The soil can initially contain a specified amount of water (0-100% of pore volume), and the surface boundary conditions can reflect either a variable rainfall or a variable pond height. The interaction includes both absorption and diffusion. These are the dominant interaction mechanisms for most heavy metals. However, the structure of the code is such that other mechanisms can be easily incorporated. Because of these capabilities the code is applicable to the evaluation of shallow land burial sites typically utilized for disposal of low-level radioactive wastes.

Among the major factors governing the movement of pollutants from residuals down through the soil profile are the characteristics of the residuals and the soils. Among the former are hydraulic conductivity (the ability of the material, sludge, etc., to transport fluid), leachability (the parting of soluble constituents under the effects of the percolating liquid), the extent of release of particulates (the washing out of suspended solids), the chemical behavior of interstitial fluids, and the presence of complexing agents. Important soil characteristics are hydraulic conductivity, the chemical environment, and the microbial environment.

The utilization of such a computer code requires that available data be examined and field investigations initiated as necessary to establish the physical properties that comprise the input to the code. Then, the leachate characteristics of the soil would be experimentally determined in order to precisely establish the conductivity of the soil and to quantify the interaction mechanisms between the radionuclides and the soil. Finally, a calculational parametric survey of the soil response would be performed.

The product of this assessment would be concentration-time and flux-time curves at depths corresponding to aquifers. These results would be used to determine the bottom-line impact, that is, the concentration of radionuclides in the aquifers surrounding an actual or proposed burial site.

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Berkeley, California 94704

Source - Reference #14: p. 1161

GROUNDWATER TRANSPORT

Model - A Sequence for Predicting Waste Transport by Ground Water

Purpose - Groundwater flow is analyzed with possibly general applicability to waste transport; however the early date of the work may indicate limited usefulness.

Description - A sequence of steps for analyzing ground water flow and predicting rates and paths of movement is described. Three computer programs are used to yield data in forms useful for subsequent steps and definition of the groundwater behavior with respect to outflow paths and rates. Input data required for the computations include the distribution of potentials (fluid heads) throughout the region of interest, boundary permeability data, representative data on relative capillary conductivity versus capillary pressure head of the soils, and the configuration of flow system boundaries. Independent fitting functions are also required to supplement the derived mathematical computation and program.

Nelson, R.W. 1965, January. BNWL-36 (Part 4); Hanford Radiological Sciences Research and Development Annual Report for 1964, D.W. Pearce and J.K. Green (Eds.), (pp. 4.16-4.26), 571 pp. (BNWL-36, Part 4).

Source - Reference ORNL 11: p. 11.

GROUNDWATER TRANSPORT

Model - A 3-Dimensional Finite Element Model for the Migration of Contaminants in Confined and Unconfined Aquifers

Purpose - Prediction of the movement of radioactive waste or other pollutant in a confined or unconfined aquifer.

Description - The model is capable of predicting the three dimensional movement of a solute in a confined or unconfined aquifer under transient saturated flow conditions. The finite element method using isoparametric elements, based on the Galerkin Formulation and on weighting functions of nonsymmetric form, was used to formulate the numerical description of the convective dispersive mass transport equation. A comparison of several solution schemes with new analytical solutions permitted a thorough check of the numerical model. The matrix equation was solved by the Crank-Nicholson Method using a mass lumping procedure for the time derivative. Field data collected at the site of the Babylon Landfill (New York) were used to calibrate and verify the parameters controlling the movement of the leachate.

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FTS 972-7791

Source - Reference #8, p. 139.

GROUNDWATER TRANSPORT

Model - A 2-Dimensional Finite Element Model for the Migration of Contaminants in Confined and Unconfined Aquifers

Purpose - Prediction of the movement of radioactive waste or other pollutant in a confined or unconfined aquifer.

Description - The model is capable of predicting the two dimensional movement of a solute in a confined or unconfined aquifer under transient saturated flow conditions. The finite element method using isoparametric elements, based on the Galerkin Formulation and on weighting functions of non-symmetric form, was used to formulate the numerical description of the corrective dispersive mass transport equation. A comparison of several solution schemes with new analytical solutions permitted a thorough check of the numerical model. The matrix equation was solved by the Crank-Nicholson Method using a mass lumping procedure for the time derivative. Field data collected at the site of the Babylon Land Fill (New York) were used to calibrate and verify the parameters controlling the movement of the leachate.

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Source - Reference #8: p. 139.

Model - Computer Model of Two-Dimensional Solute Transport and Dispersion in Ground Water.

Purpose - The purpose of the simulation model is to compute the concentration of a dissolved chemical species in an aquifer at any specified place and time.

Description - The model is both general and flexible in that it can be applied to a wide range of problem types. It is applicable to one- or two-dimensional problems involving steady-state or transient flow. The model computes changes in concentration over time caused by the processes of convective transport, hydrodynamic dispersion, and mixing (or dilution) from fluid sources. The model assumes that the solute is non-reactive and that gradients of fluid density, viscosity, and temperature do not affect the velocity distribution. However, the aquifer may be heterogeneous and (or) anisotropic.

The model couples the ground-water flow equation with the solute-transport equation. The digital computer program uses an alternating-direction implicit procedure to solve a finite-difference approximation to the ground-water flow equation, and it uses the method of characteristics to solve the solute-transport equation. The latter uses a particle-tracking procedure to represent convective transport and a two-step explicit procedure to solve a finite-difference equation that describes the effects of hydrodynamic dispersion, fluid sources and sinks, and divergence of velocity. This explicit procedure has several stability criteria, but the consequent time-step limitations are automatically determined by the program.

The model is written in FORTRAN IV and contains about 2000 lines. The model is based on a rectangular, block-centered, finite-difference grid. It allows the specification of any number of injection or withdrawal wells and of spatially varying diffuse recharge or discharge, saturated thickness, transmissivity, boundary conditions, and initial heads and concentrations. The program also permits the designation of up to five nodes as observation points, for which a summary table of head and concentration versus time is printed at the end of the calculations. The data input formats for the model require three data cards and from seven to nine data sets to describe the aquifer properties, boundaries, and stresses.

The accuracy of the model has been evaluated for two idealized problems for which analytical solutions could be obtained. In the case of one-dimensional flow the agreement was nearly exact, but in the case of plane radial flow a small amount of numerical dispersion occurred. An analysis of several test problems indicates that the error in the mass balance will be generally less than 10 percent. The test problems demonstrated that the accuracy and precision of the numerical solution is sensitive to the initial number of particles placed in each cell and to the size of the time increment, as determined by the stability criteria. Mass balance errors are commonly the greatest during the first several time increments, but tend to decrease and stabilize with time.

Source - Reference #22.

GROUNDWATER TRANSPORT

Model - Conceptual and Mathematical Modeling of the Hanford Groundwater Flow Regime.

Purpose - This model was developed to predict groundwater flow and contaminant movement.

Description - Disposal of radioactive wastes to surface disposal sites at the Hanford Atomic Reservation has resulted in some radioactive and chemical contamination of the underlying groundwater flow systems. In support of the Hanford groundwater management effort a preliminary conceptual model of the groundwater system has been formulated as a first step in understanding possible contaminant movement. The mathematical modeling capabilities needed for better understanding and prediction of such contaminant movement are discussed in this paper and the state-of-the-art in groundwater modeling as related to Hanford is summarized with emphasis upon computer solution methods. A set of operational flow and transport codes which models the unconfined aquifer in two-dimensional, horizontal space has been developed. A two-dimensional parameter identification code for calculating a hydraulic conductivity distribution throughout the Hanford Reservation is also available. These models have been tested using synthetic cases and verified as far as possible using actual Hanford field data. An inventory of potentially applicable codes available both at Hanford and elsewhere is included. The areas where groundwater modeling capability is lacking are outlined and the steps needed to overcome such deficiencies discussed in the documentation.

R. C. Arnett; R. A. Deju; R. W. Nelson; C. R. Cole; R. E. Gephart, Atlantic Richfield Hanford Company, Research and Engineering Division, Research Department, Richland, WA; Boeing Computer Services Richland, Inc., Scientific Systems Department, Richland, WA; Battelle-Pacific Northwest Laboratories, Water and Land Resources Department, Richland, WA. October 1976, ARH-ST-140; 103 pp.

Source - Reference #26: Item 754.

GROUNDWATER TRANSPORT

Model - Digital Modeling of Radioactive and Chemical Waste Transport in the Snake River Plain Aquifer at the National Reactor Testing Station, Idaho.

Purpose - This code deals with migration of radioactive wastes in ground water.

Description - Digital modeling techniques have been applied successfully to the analysis of the complex waste-transport system at the National Reactor Testing Station in Idaho, by utilizing numerical solution of the coupled equations of groundwater motion and mass transport. The model includes the effects of convective transport, flow divergence, two-dimensional hydraulic dispersion, radioactive decay (Sr-90 and Cs-137), and reversible linear sorption. The hydraulic phase of the model uses the interactive, alternating-direction, implicit finite-difference scheme to solve the groundwater flow equations, while the waste-transport phase uses a modified method of characteristics to solve the solute transport equations simulated by the model. The modeling results indicate that hydraulic dispersion (especially transverse) is a much more significant influence than suggested by earlier studies. The model has been used to estimate future waste migration patterns for varied assumed hydrological and waste conditions up through the year 2000. The hydraulic effects or recharge from the Big Lost River have an important (but not predominant) influence on the simulated future migration patterns. For the assumed conditions, the model indicates that detectable concentrations of waste chloride and tritium could move as much as 15 miles (24 kilometers) downgradient from the original discharge points by the year 2000. However, the model shows Sr-90 moving only 2 to 3 miles (3 to 5 kilometers) downgradient in the same time. The model may also be used to estimate the effects of the various future waste disposal, practices, and hydrologic conditions on subsequent migration of waste products.

Robertson, J.B.
U.S. Geological Survey
National Center
12201 Sunrise Valley Drive
Reston, VA 22092
703-860-6976
U.S. Geological Survey Openfile Report,
AEC NO. IDO-22054, 41 pp., 1974.

Source - Reference #18: p. 197.

GROUNDWATER TRANSPORT

Model - Distribution of Pu and Am with Depth of Soil

Purpose - This quasi-empirical model predicts downward transport of the elements after deposition. Aside from the obvious applications to Pu migration (percolation), the same techniques might be helpful in the analysis of percolation of other nuclides.

Description - The distribution of plutonium in the soil at Rocky Flats, Colorado is discussed and a model is proposed to describe the penetration of the plutonium with depth. Plutonium was accidentally released into the environment. By natural wind disturbance and recovery operations some of the contaminated soil particles were suspended in the atmosphere and transported to the east-southeast. Plutonium leaching from soil samples was inferred by the Health and Safety Laboratory (HASL)'s ratios of direct measurements of Am 241 to LFE's (Environmental Analysis Laboratories) measurements of the leachates. It was found at all three sample sites that 90% of the total deposit resides in the first 10 cm. However, plutonium was found at 40 cm depth with a concentration of $10(E-2)\%$. In all sites after a maximum was reached the percent of the total deposit per cm decreased at a fixed rate per unit depth to between 20 and 30 cm and then remained constant. The decrease defined an exponential function which had an average slope of 0.33. Due to the similarities of the observations at the sites it was apparent the downward transport mechanism was the same. From the data a semiempirical model was derived. The plutonium gets into the soil by the evaporative process and moves down through the soil by percolation. The percolation is assumed to follow first kinetics. As a result of this assumption a diffusion regime is imposed. The percent of the total plutonium deposit per cm is calculated. From the data the diffusion coefficient was selected as being 2 cm/year. The model sufficiently predicts that 50%/cm/year plutonium percolates downward. If the plutonium is percolating downward then less is available for resuspension in the atmosphere. A test was also done in North Eastham, Massachusetts, although the soil was a moist sandy loam with heavy vegetation (radically different from that at Rocky Flats) the diffusion coefficient was found to be the same.

Krey, P. W., E. P. Hardy, and L. E. Toonkel. April, 1977. HASL-318; Health and Safety Laboratory, New York, NY

Source - Reference #11: p.29

Model - Flow in Porous Media

Purpose - This is basically a literature review of relatively early (pre 1961) models for the analysis of groundwater flow. The applicability of the models discussed to groundwater transport may be limited by their age.

Description - A coverage of formulation and solution methods for saturated and unsaturated flow systems is presented, as well as flow of fluids with different densities. Basic equations and components are listed. Models formulated allow for heterogeneous soils (up to 15 soils can be included in any one flow pattern). The computer program can handle 1, 2 and 3 dimensional and axi-symmetrical problems with up to 8,000 grid points. Graphs showing flow pattern and moisture distribution are included. Also included is a schematic diagram illustrating the electrical analog of groundwater.

Nelson, R.W., and A.E. Reisenauer. 1962, March. TID-7628; Ground Disposal of Radioactive Wastes, J.M. Morgan, Jr., et al (Eds.), Proceedings of the 2nd Conference held in Chalk River, Canada, September 26-29, 1961, (pp. 130-144), 635 pp. (TID-7628).

Source - Reference #11: p. 21.

GROUNDWATER TRANSPORT

Model - Geosphere Transport Model for Risk Evaluation: Calculation of Maximum Concentration of Activity at Given Distances From the Waste Disposal Site Due to Water Invasion

Purpose - A simplified model for the calculation of radioactivity concentration in water due to invasion of water in an underground disposal area of radioactive waste is described.

Description - Computation is based on processes like leaching, hydrodynamic dispersion and diffusion and physico-chemical sorption. A computer program code is written in FORTRAN language for the purpose of a parametric study. The results of an example calculation are given and some limits of such calculations are shown.

P. Buetzer, S. Chakraborty
Risk Analysis and Geologic Modelling in Relation to the Disposal of
Radioactive Wastes into Geological Formations
Workshop on Risk Analysis and Geologic Modelling
Ispra, Italy
May 23, 1977

Source - Reference #26: p. 8

GROUNDWATER TRANSPORT

Model - Groundwater Transport Flow Simulation Model

Purpose - Hydrologic Transport of radionuclides through soils at the Hanford Reservation was modelled; although the modelling was geographically and geologically restricted to conditions obtaining at Hanford, some or all of the modelling techniques may be applicable to the analysis of groundwater transport at other sites.

Description - An analysis of the transport of radionuclides through the soils was done at the Hanford Reservation. It was to determine the nuclear safety of an emergency waste disposal (EWD) crib for both emergencies and fuel element ruptures. Also the analysis was done considering another crib in conjunction with the EWD crib. Featured in this report are the hydrological factors affecting the operation of the crib. A mathematical simulation model was used to predict the groundwater flow system. It was a two-space analysis in the horizontal plane which allowed for the consideration of more than one source, neglected the vertical flow component, (assumed) inflow and outflow surfaces to penetrate the entire system, (assumed) aquifer thickness constant, and (assumed) permeability constant with respect to depth. These assumptions were reasonable due to the proximity of the Columbia River. A major result of this study is 12 to 13 day travel time is more realistic than the present field estimate of 5 days. This is with both cribs in operation.

Cearloch, D.B. and R.D. Mude1
Battelle-Pacific Northwest Laboratories
Environmental and Life Sciences Division
Water and Land Resources Department
Richland, WA

Source - Reference #11: p. 5.

GROUNDWATER TRANSPORT

Model - Hydrodynamic Transport of Radionuclides: One-Dimensional Case with Two-Dimensional Approximation

Purpose - A one-dimensional mathematical model of the transport and hydrodynamic dispersion of radionuclides in granular media is described.

Description - The mathematical formulation consists of the derivation of the transport equations and definition of sundry boundary conditions. The transport equation is reduced to the heat equation by a suitable change of variables and the solution of the resulting transformed boundary value problem. Analytical solutions are given for four sets of boundary conditions and the results are discussed. The analytical solution is limited to a homogeneous aquifer. A method is presented to obtain an approximate two-dimensional solution as a product of the longitudinal transport solution and the four boundary conditions. Another method to approximate the two-dimensional solution represents the initial concentration field as a series of cells, calculates the position of each cell as a function of time by moving them on ground-water flow trajectories, and calculates the concentration field by summing the contributions from each cell.

Holly, D.F.; Guinasso, N.I., Jr.; Essington, E.H.
Atomic Energy Commission
Nevada Operations Office
Las Vegas, NV

Source - Reference #6: p. 142.

GROUNDWATER TRANSPORT

Model - Hydrology model evaluation at the Hanford Nuclear Waste Facility.

Purpose - These codes deal with contaminant flow from waste disposal site via aquatic transport. This is a test of INTERA's transport model.

Description - One and two-dimensional flow and contaminant transport computer models have been developed at Hanford to assess the rate and direction of contaminant movement from waste disposal sites. The primary objective of this work was to evaluate the potential improvement in accuracy that a three-dimensional model might offer over the simpler one and two-dimensional models. Intera's hydrology contaminant transport model was used for this evaluation. Although this study was conceptual in nature, an attempt was made to relate it as closely as possible to Hanford conditions. Two-dimensional model runs were performed over the period of 1968 to 1973 using estimates of waste discharge flows, tritium concentrations, vertically averaged values of aquifer properties and boundary conditions. The well test interpretation runs confirmed the applicability of the areal hydraulic conductivity distribution. Velocity fields calculated by the two-dimensional and three-dimensional models and surface concentration profiles calculated by the two-dimensional and three-dimensional models show significant differences. Vertical concentration profiles calculated by a three-dimensional model show better qualitative agreement with the limited observed concentration profile data supplied by ARHCO.

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1201 Dairy Ashford Road, Suite 200
Houston, TX 77079
713-497-8405

Source - Reference #18: pg. 188.

Model - Infiltration Characteristics of Radioactive Liquid Waste

Purpose - This model describes the migration of radionuclides through porous media.

Description - This mathematical model describes the behavior of various radioactive substances in a waste liquid flowing through porous media. The theoretical analysis takes into account only one dissolved substance in the waste liquid, one-dimensional downward flow, and flow through a homogenous, unsaturated porous soil media. Two fundamental laws are used to derive the new theory; they are Horton's Law of infiltration and Langmuir's theory on monomolecular absorption. The equations representing the above laws are solved using differential equation techniques, and the mathematical presentation is detailed. Two experimental runs were made, one using a sand with 42.9% porosity and moisture content of 3.21%. The second run medium was a surface soil with porosity of 40.8% and moisture content of 46.6%. Qualitatively the experimental and theoretical results coincide well, both are S-shaped. Quantitatively the mutual correspondence is uncertain due inability to determine a constant which controls adsorption behavior.

Dwai, S., T. Goda, and Y. Inoue
Kyoto University
Kyoto, Japan
1960. Disposal of Radioactive Wastes
Proceedings of a Conference held in Monaco, November 16-21, 1959,
(pp. 435-448).

Source - Reference #11: p. 150.

GROUNDWATER TRANSPORT

Model - Iterative Calculation of One-Dimensional Transient, Partially Saturated Flow

Purpose - A technique for the analysis of horizontal, transient, partially saturated flow in porous media is suggested. Such a technique may be applicable in analyzing nuclide transport following a heavy rain, particularly if the LLW is not completely buried.

Description - Horizontal, one-dimensional, transient, partially saturated flow in porous media can be solved numerically by an iterative procedure based on Phillip's method. The equation takes into account saturation, time, horizontal distance, diffusivity, permeability, liquid viscosity, soil porosity, and capillary pressure. Substitution in the original equation reduces it to simpler terms and simpler boundary conditions, which can be handled easily in a computer program. Saturation and permeability at capillary pressure are used as input to determine the diffusivity. An average diffusivity value is calculated with 1000 increments diffusivity for initial estimates. Parameters required for input are: initial saturation, the final saturation, porosity, and the column area as well as parameters needed for the diffusivity calculation. The results listed in the output are: diffusivity and phi values as a function saturation for each iteration and the moisture profile. The profiles are integrated to give the accumulated volume inflow for each time. An error function is also included.

Reisenauer, A.E. 1965, January. BNWL-36 (Part 4); Hanford Radiological Sciences Research and Development Annual Report for 1964, D.W. Pearce and J.K. Green (Eds.), (pp. 4.53-4.55), 571 pp.

Battelle-Pacific Northwest Laboratories
Richland, WA

Source - Reference #11: p. 12.

Model - Land Requirement for a Radioactive Waste Disposal Yard

Purpose - This model estimates the intake by humans of radionuclides through food and air.

Description - A model and the rationale were presented with respect to land use requirements for a hypothetical waste burial site. The thrust of the study was to minimize the intake by humans, of radionuclides through the food and air. A to-space transportation diffusion equation was used to describe the migration of the radionuclides in groundwater. The numerical solution was obtained by solving the equation by Crank-Nicolson type differential approximation and successive over relaxation. A sample run was made for a power plant with a total output of 2000 MWe. Numerous environmental land requirements and socio-political factors were considered. With this model it is possible to locate a burial site which ensures the greatest radiological safety. To locate burial site it is necessary to include a zone where ground water use is prohibited; a zone where use is restricted and a buffer zone. The necessary land area will increase with increasing permeability coefficient, decreasing distribution factor and increasing stratum porosity. Variations in the diffusion coefficient do not change the land requirement greatly.

Inoue, Y. and S. Morisawa
Kyoto University
Department of Sanitary Engineering
Kyoto, Japan
ORNL-TM-4444; 13 pp.
1976

Source - Reference #11: p. 149.

Model - Leaching of Cesium 137.

Purpose - This model describes the behavior of Cesium 137.

Description - A mathematical model used to describe the leaching behavior of Cs 137 from an ion-exchange resin and cement: two methods used were a diffusion equation derived for a plane source model and a rate equation for diffusion coupled with a first-order reaction. The data was analyzed by an empirical polynomial equation. The resin was in a polyethylene matrix. The fraction of cesium leached was a function of the square root of the leaching period for both the cement and the polyethylene. The leaching rate changed after about 30 days indicating that after 30 days the diffusion rate slows due to the lengthening on the diffusion path. Diffusion coefficients predicted by method 1 are 5.4×10^{-6} and 9.7×10^{-11} sq cm/day for the cement and polyethylene, respectively. For method 2, 1.2×10^{-10} and 3.7×10^{-3} sq cm/day for the polyethylene and cement, respectively. It was found by the experiments that method 1 did not describe the whole leaching process but simulated the leaching in the longer period due to its simplicity.

Method 2 had limited application in this study and method 3 provided a convenient polynomial approximation when a rate equation could not be derived.

Moriyama, N., S. Dojori, and H. Matsuzuru
Japan Atomic Energy Research Institute
Tokai, Sbraki, Japan
Health Physics, 32, 549-552
June 1977

Source - Reference #11: p. 146.

GROUNDWATER TRANSPORT
SOIL TRANSPORT

Model - Linear Diffusion and Convection of Chemicals in Soils.

Purpose - This code aids in the analysis of translocation of chemicals in soil.

Description - The movement of some chemicals in soils has been treated theoretically by considering for saturated conditions, the chemical diffusion coefficient, the percolation velocity of the water, the sorptive properties of the soil, the average particle size of the soil, and the fractional number of sorbing sites. A model has been developed for the movement of chemicals in saturated soil, based on Pick's Law, conservation of energy, and a sorption isotherm. Theoretical curves for two different boundary conditions have been developed for realistic values of the water velocity in the pores and the measured diffusion coefficient.

F. T. Lindstrom
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Corvallis, OR 97331
1, 561-565, 1967; LAI, S. H., J. J. Jurinak, and R. J. Wagenet,
Soil Science Society American Journal, 42, 240-243, 1978.

Source - Reference #18: p.234

GROUNDWATER TRANSPORT

Model - Material Transport through Porous Media: A Finite-Element Galerkin Model

Purpose - A two-dimensional transient model for flow of a dissolved constituent through porous media has been developed.

Description - Mechanisms for advective transport, hydrodynamic dispersion, chemical adsorption, and radioactive decay are included in the mathematical formulation. Implementations of quadrilateral finite elements, bilinear spatial interpolation, and Gaussian elimination are used in the numerical formulation. The programming language FORTRAN IV is used exclusively in the computer implementation. A listing of the program is included. This material-transport model is completely compatible with the moisture-transport model (Reeves and Duguid, 1975) for predicting advective Darcy velocities for porous media which may be partly unsaturated. Two simulations have been run and provide partial validation for the model. One is a comparison with a well-known analytical treatment (Lapidus and Amundson, 1952) and is intended as a partial validation. The other simulation, a seepage-pond problem is a more realistic demonstration of the capabilities of the computer model. Simplifying assumptions are made in the treatment of the chemical reactions of dissolved constituents. Reacting species in the soil solution are independent of each other. Local equilibrium is assumed for reversible processes. Only one kind of reversible reaction is permitted, a reaction for which the rate of change is proportional to the total quantity of the constituent presenting both the solid and liquid phase.

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Oak Ridge, TN 37830

Source - Reference #6: p.119

GROUNDWATER TRANSPORT

Model - Mathematical Model of Strontium Movement in Soils.

Purpose - This program models the movement of strontium through soils.

Description - Experimentally measured distributions of strontium in various soils were used to set up a mathematical model of strontium movement. The model established particular leaching patterns for the various solutions utilized. However, the model's applicability in different natural soils in situ after leaching with natural rain water is not known. Further tests are recommended. The model showed that a certain percentage of the strontium moved downward to the next lower layer of soil for each unit volume of surface water which is added to the layer.

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Source - Reference #18: p.238

GROUNDWATER TRANSPORT
SOIL TRANSPORT

Model - Migration of Radionuclides in Model Saturated Zone.

Purpose - This model describes the ability of radionuclides to migrate through a sand layer model.

Description - This mathematical model investigates the leaching of radionuclides from solidified wastes and their migrating characteristics in a sand layer mode. The radionuclides solidified in Portland cement were Sr-90, Cs-137, Co-60, Zn-65, Mn-54, Fe-59, and Ag-110. The sand layer was 50 cm thick, had a porosity of 35.6%, and was essentially sand with no clay. The cation exchange coefficient was found to be 9.7 plus or minus 0.6 ueg/g. Distribution coefficients for each of the radionuclides were: Sr-90, 4.9; Co-60, 25.4; Cs-137, 694.6; Mn-54, 35.2; Zn-65, 30.0; Fe-59, 1.4; and Ag-110, 15.7 ml/g. Of the seven radionuclides sealed in the cement, Sr-90 was detected as having been leached from the matrix. Strontium was leached in great amounts initially but as the experiment continued it was noted that the Sr-90 concentration decreased downstream. This indicated that the sand had the ability to sorb some of the radionuclides. Most of the Sr-90 was leached from the cement after 400 to 500 days and the concentration was considered in a steady state. It was generally possible to forecast the time required for Sr-90 to reach the end of the bed by using the distribution factor value and a factor in an equation presented. Mn-54 and Fe-59 were also controlled by internal diffusion and the dissolution of the cement, while Zn-65 and Ag-110 were controlled by dissolution of the cement. The former was considered to be a Sr-90 pattern and the latter a Co-60 pattern.

Inoue, Y., S. Morisawa, and A. (Translator) Bach.
Kyoto University
Kyoto, Japan
ORNL-TM-4440; 13 pp.
1976.

Source - Reference #11: p. 150.

GROUNDWATER TRANSPORT

Model - Modeling Pollutant Migration in Subsurface Environments.

Purpose - Predicts leachate-pollutant migration and fate in subsurface environments.

Description - A mathematical model has been developed which described the hydrogeologic relations within a leachate/aquifer system. It is usually in the form of a second-order partial differential equation together with a set of auxiliary conditions describing the system's variables and constants. The computer simulation is expressed as two-dimensional concentration profiles which can be oriented in either the vertical or the horizontal domain, under transient or steady-state conditions. The model can be used to simulate subsurface contamination from area sources, such as solid waste disposal sites, wastewater holding basins, wastewater or sludge application sites, raw material stockpiles and recharge of contaminated waters.

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215-692-3030

Ott, W. R. (ed.), Proceedings of the EPA Conference on Environmental Modeling and Simulation, 1976, EPA 600/9-76-016, (p. 522-526), 847 pp.

Source - Reference #18: p.505

GROUNDWATER TRANSPORT

Model - Movement of Radiostrontium in Soils.

Purpose - A mathematical model used to describe strontium migration.

Description - Water plays a key role in moving Sr 90 through the environment by removing strontium from the atmosphere as precipitation and by redistributing strontium in the soil in gravitational water. The former is hard to estimate while the latter, through a climatic water-balance bookkeeping technique, is easier to quantify. According to this technique, when the amount of water exceeds the need of the vegetation and the soil is at its water-holding capacity a water surplus will exist. It is the water surplus which migrates downward through the soil as a leaching solution and is responsible for the redistribution of strontium in the soil. Experiments in a variety of soil types indicated a definite pattern of strontium movement in the soil responding to the various soil and water factors; a certain percentage of the original concentration moves downward to the next lower layer in the soil with every unit of water added. A downward movement depends on the cation-exchange capacity and pH of the soil and the leaching efficiency of the water solution. A mathematical model was set up to describe this pattern of strontium migration by using factorial and exponential functions. Tested against laboratory experiments, the model was successful. The model determined a pattern existed but the time necessary for establishment of such patterns depends on cation-exchange capacity of the soil, pH of the soil, leaching efficiency of the solution, and the volume of the leaching solution applied. A relationship defining leaching efficiency and its role is illustrated. The model was then compared to strontium movement in natural soils. Prediction of strontium migration was poor and this is in part due to lack of fallout values, errors in radiochemical analysis, and non-representative soil samples.

C. E. Thornthwaite; J. R. Mather; J. R. Nakamura, Laboratory of Climatology, Centerton, NJ, April 8, 1960. Science 131 (3406): 1015-1019.

Source - Reference #26: Item 819.

Model - Multiaquifer Model

Purpose - Determines piezometric heads and/or watertable in multiaquifer system.

Description - Non-homogeneous and anisotropic aquifers are represented in 2-D in the horizontal plane. Principal directions of anisotropy can vary. Flow in aquitards is represented by a 1-D (vertical) continuity equation. Any number of pumping or recharge wells can be put into any of the aquifers. Dupuit approximation is used for the watertable aquifer. The flow of water in aquitards is represented by a 1-D vertical transient continuity equation (valid at all values of time). Leakage flux at aquifer/aquitar interface is determined by differentiating the aquitar heads and applying Darcy's Law.

Galerkin Finite Element formulation of the transient continuity equation is used for both aquifers and aquitards.

The iterative solution cycle starts with a calculation of aquifer heads, then aquitar heads, then leakage fluxes. These are substituted back into the aquifer equation, and the cycle is then repeated.

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Source - Reference #12: p. B-17.

GROUNDWATER TRANSPORT

Model - NRC Models for Evaluating the Transport of Radionuclides in Groundwater.

Purpose - The models describe the movement of radionuclides through the ground.

Description - A series of models has been developed for evaluating dispersion of radionuclides in groundwater. These models have been used to predict the migration of radionuclides released to the groundwater under normal and accidental circumstances. They are part of a larger set of radionuclide dispersion models that are used for both groundwater and surface water.

The groundwater models are based on the solution of the three-dimensional equation for the conservation of mass in uniform media with simple geometries. The models account for advection with groundwater flow, dispersion in the aquifer, radioactive decay, and the sorption of chemically active ions on the aquifer medium. The point concentration model is used for calculating the concentration downgradient from the source in a three-dimensional aquifer of infinite lateral extent, and either constant or infinite thickness. The flux model is used to compute the rate of radioactive material which enters a surface water body that intercepts the groundwater flow. This flux can then be utilized as input to models describing dispersion of radionuclides in surface waters.

Limited confirmation has been performed with field data from deep well injections. Results are reasonably accurate considering the simplicity of the model.

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Hydrology-Meteorology Branch
Division of Site Safety and Environmental Analysis
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Source - Reference #14: p. 1193.

GROUNDWATER TRANSPORT

Model - Numerical Simulation of Dispersion in Groundwater Aquifers

Purpose - This code can be used to simulate salt water intrusion problems.

Description - This mathematical model describes a fundamental flow equation for a mixture of miscible fluids, derived by combining the law of conservation of mass, Darcy's Law and an equation of state describing the pressure volume temperature concentration relationship. The equations were solved using an implicit finite difference technique for several different cases of dispersion relationships and various geometries.

D.L. Reddel and D. H. Sunada
Colorado State University
Fort Collins, CO
Hydrology Paper No. 41; 79 pp.
June 1970

Source - Reference #11: p. 115.

GROUNDWATER TRANSPORT

Model - Partially-Saturated Transient Groundwater Flow Model Theory and Numerical Implementation.

Purpose - The model is designed to predict moisture flow in sediments as a function of time and space.

Description - The mathematical development of a computer model used to test the formulation for simulating isothermal, unsaturated, liquid flow in heterogeneous media is described. Such a model is needed because radwastes at Hanford are stored in the ground in unsaturated sediments lying between 45 and 60 m above the regional water table and because the vadose zone is relied upon as a safety factor to minimize radwaste access to the ground water in case of storage tank leakage. The model is designed to predict moisture movement in sediments as a function of time and space for the initial and boundary conditions specified. Some of the assumptions for the model are: 1) Darcy's law is valid for types of sediments and gradients in the vadose zone; 2) pressure head is a unique function of the volumetric moisture content; 3) hysteresis is a second order effect; 4) soil is isotropic; 5) flow is isothermal; 6) hydraulic conductivity is a unique function of the moisture content; and 7) hydraulic characteristics of the sediments are not altered by the chemical composition of the waste. A brief theoretical analysis and functional description of the soil characteristics are provided. In the model, due to nonlinearities of the descriptive equations, finite difference approximation (Crank-Nicholson method) and an iterative technique (Gauss-Seidel) were used to obtain the solutions. When used the model proved to be computationally slow and somewhat impractical as a management tool but showed the equation could be solved for flow entering dry soils.

A. E. Reisenauer; D. B. Cearlock; C. A. Bryan; G. S. Campbell, Battelle Pacific Northwest Laboratories, Richland, WA; University of Montana, Water and Land Resources Department, Missoula, MT; Washington State University, Pullman, WA, 1975. BNWL-1713; 32 pp.

Source - Reference #26: Item 752.

GROUNDWATER TRANSPORT

Model - Radioactive- and Chemical-Waste Transport in Groundwater at National Reactor Testing Station, Idaho: 20-Year Case History and Digital Model

Purpose - Digital modeling techniques were applied to analyze the movement and distribution of radionuclides (and industrial wastes) in the Snake River.

Description - Industrial and low-level radioactive liquid wastes at the National Reactor Testing Station (NRTS) in Idaho, have been discharged to the Snake River Plain aquifer since 1952. The movement and distribution of these wastes has been monitored and data are presented. The aquifer is probably more than 1000 feet thick, but a thickness of 250 feet was used in this study, on the basis of apparent layering effects in the aquifer. The upper layer appears to be somewhat separated from, and more permeable than, the lower layer. The model assumes that flow in the aquifer obeys Darcy's Law, which, for this aquifer, may or may not be completely valid. The total waste discharge to the aquifer at NRTS has averaged about 1×10^9 (E +9) gallons per year, and contained small quantities of tritium, Sr-90, Cs-137, Co-60, chloride, hexavalent chromium, various acids and bases, and heat. Tritium and chloride have dispersed over a 15-square mile area of the aquifer in low but detectable concentrations, and have migrated as much as 5 miles down gradient from discharge points. The movements of the cationic wastes solutes, particularly Sr-90 and Cs-137, have been significantly retarded owing to sorption phenomena, principally ion exchange. Cs-137 has shown detectable migration in the aquifer and the Sr-90 has migrated only about 1.5 miles from a discharge well. Digital modeling techniques have been applied successfully to the analysis of this complex waste-transport system by numerical solution of the coupled equations of groundwater motion and mass transport. Transmissivities for the model were obtained by flow-net and pumping station analyses. Porosity of the aquifer in the waste-transport model was assumed to be 10%, based on the best available evidence. The most speculative inputs are the dispersivities and distribution coefficients. No effective way of measuring these coefficients in the field is presently practical because of large scale aquifer inhomogeneities.

Robertson, J.B., and J.T. Barraclough. 1973. CONF-730919 (Vols. 1-2); "Underground Waste Management and Artificial Recharge," J. Braunstein (Ed.), Proceedings of the 2nd International Symposium held in New Orleans, Louisiana, September 26-30, 1973, (pp. 291-322), 931 pp.

Source Reference #11:, p. 81.

Model - Radionuclide Migration

Purpose - This model predicts the migration of Strontium 90.

Description - A mathematical model for predicting the migration of Sr 90 in a model stratum are derived. The first technique used is the numerical solution of a transportation-diffusion equation describing the transportation phenomena of Sr 90 in the stratum. The second one is a time-transformation technique which predicts a Sr 90 distributing in the stratum based on the distribution of a tritiated water. The model is built on the equation of migration of radionuclides in saturated zones. This is then coupled with the Laplace equation for flow velocity. The solution is arrived at by using a Crank-Nicolson type differentiation and a successive overrelaxation method. Results, described at discrete time intervals, and indicated that the tracer at 45 cm in the model stratum reached a level of $1.8 \times 10(E-3)$ after 8.5 days. The experimental results show the first technique has difficulties predicting Sr-90 migration. This may be minimized by considering local disturbances in the stratum. Results using the tracer were agreeable to the observed distribution and it took only about 1/50 of the time required for the actual distribution of strontium in the stratum.

Inoue, Y., S. Morisawa, and A. Bach (Translator)
Kyoto University
Department of Sanitary Engineering
Kyoto, Japan
ORNL-TM-4441; 11 pp.
1976

Source - Reference #11: p. 149.

Model - Simultaneous Dispersion and Decay of Radioactive Wastes.

Purpose - This model simulates the transport and decay of a radioactive substance in a solidified waste.

Description - A mathematical model is derived to describe the rate process governing the transport and decay of a radioactive substance in a solidified waste and a surrounding fluid. Steps of the derivation are shown. A certain radioactive component distributed in the solidified waste dissolves in the water and then diffuses out of the slab to the surrounding fluid because of the concentration difference. The decay of the radioactive substance in both the slab and the surrounding fluid of the system is in irreversible first order rate process. The analytical expressions for the change of concentration of the radioactive substance are derived through the use of a Laplace transformation technique both as a function of time and position for the porous body and as a function of time for the surrounding fluid. The mathematical expressions are useful in predicting concentrations in the system as well as in determining the effective diffusivity and the decay coefficient of the radioactive substance.

S. K. Choi, L. T. Fan, and L. E. Erickson
Kansas State University
Department of Chemical Engineering
Manhattan, KS
Health Physics, 22, 177-186
February 1972

Source - Reference #11: p. 117.

GROUNDWATER TRANSPORT

Model - Simultaneous Transport of Water and Reacting Solutes Through Multilayered Soils Under Transient Unsaturated Flow Conditions

Purpose - This code is used in solving problems dealing with solutes in groundwater.

Description - The model is capable of predicting the one dimensional (vertical) movement of water and multisolutes through multilayered soil systems under transient unsaturated flow conditions. The multilayered system was treated as a series of homogeneous layers and a 2-step implicit finite difference method was used to solve the resulting set of flow equations. The mass transport equation was solved by the Crank-Nicolson method. The pressure based model considers both infiltration redistribution and evaporation. Cubic spline functions are used to describe the soil hydraulic properties.

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Source - Reference #18: p.231

GROUNDWATER TRANSPORT

Model - Soil Moisture Transport in Arid Site Vadose Zones.

Purpose - This model simulates nonisothermal soil moisture transport.

Description - A theoretical mathematical model based on conservation of momentum expressions developed to analyze nonisothermal soil moisture transport. The field work and theoretical work will be intergrated to formulate a detailed water balance which will be able to predict fluid inputs which could generate migration to the water table.

R. E. Isaacson, L. E. Brownell, R. W. Nelson, and E. L. Roetman
Atlantic Richfield Hanford Co.
Richland, WA
ARH-SA-169; CONF-740312;
IAEA/SM-182/6
March 1974.

Source - Reference #11: p. 97.

Model - Stochastic Model of Tracer Flow.

Purpose - This model describes tracer movement in fluid flow.

Description - A "three-velocities" model describes movement of a tracer in fluid flow. Stochastic equations are solved by the Laplace transform to yield usable forms. The model includes: the finite flow velocity of the tracer, particles; tracer concentration at a given time and space point; satisfies the law of fluid continuity; and converges to the "piston-flow" model. The model also describes the dispersion phenomenon and the tracer conservation law. From the calculations and consideration concerning relations between the model parameters, the model may be applied to the determination of mean residence time of water in the hydrologic system; calculation of parameters of porous medium estimation based on experiments; and interpretation of the curves of the tracer flow through two adjacent aquifers having different velocities of filtration.

M. Nawalany, Warsaw Polytechnic University, Institute of Environmental Engineering, Warsaw, Poland, 1976. Journal of Hydrological Sciences, 31-2), 47-59.

Source - Reference #26: Item 807.

Model - Subsurface Containment Transfer

Purpose - This model is used to assist in radionuclide migration analysis.

Description - The problem of subsurface, radioactive-contaminant transfer is investigated theoretically through the development of a two-dimensional model which considers the simultaneous flow of water and mass. The method of characteristics is utilized to solve a mass-balance equation that considers physical transport by radioactive decay and binary exchange. The study demonstrated the influence of the following parameters on the physical aspects of contaminant transport: hydraulic conductivity, site location within a recharge area and porous-medium dispersivity. With respect to the parameters controlling the chemical and nuclear processes, radioactive half-life, cation-exchange capacity, selectivity coefficient, ion charge and weathering rates play important roles in determining the pattern of contaminant dispersal. Geologic layering adds complexity to the patterns of dispersal because the controlling parameters vary within the flow region. The extent of the contaminant plume is fixed by the physical transport processes. The chemical and nuclear processes tend to reduce the size of the contaminated region to some fraction of that which is attributable to the physical processes alone. Because of the large number of variables that influence the dispersal of contaminants away from sites of emplacement, it is impossible to adequately approach the problem of site location and design utilizing empirical principles or established guidelines. The only satisfactory way of predicting patterns of contaminant migration is to incorporate field-determined parameters in a properly designed and calibrated mathematical model. Only in this way can the effects of all important processes be evaluated simultaneously.

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Department of Geology
Edmonton, Alberta, Canada
Journal of Hydrology, 27, SI-71 1975

Source - Reference #11: p.156

GROUNDWATER TRANSPORT

Model - The Permeability Integral: A Key to Measurement in Heterogeneous Porous Media

Purpose - Although not actually a model in the strict sense, the technique described below provides permeability distribution for porous media. These distributions can be useful in determining potential pathways for nuclide migration.

Description - An analysis is provided of the efficient solution of the partial differential equation defining permeability distributions for heterogeneous porous media. The three results necessary for the solution of the problem are the permeability integral, the recently derived stream functions for heterogeneous media, and the complete differential of the potential. The manipulations of these three results are briefly outlined and final result, permeability distribution, is noted. Simultaneous solution of a pair of ordinary differential equations followed by integration of the derived permeability integral is the solution method. The procedure is accurate as well as efficient.

Nelson, R.W. 1965, January. BNWL-36 (Part 4); Hanford Radiological Sciences Research and Development Annual Report for 1964, D.W. Pearce and J.K. Green (Eds.), (pp. 4.27-4.29), 571 pp. (BNWL-36, Part 4).

Battelle-Pacific Northwest Laboratories
Richland, WA

Source - Reference #11: p. 14.

GROUNDWATER TRANSPORT

Model - The Transmissivity Iterative Calculation Routine: Theory and Numerical Implementation

Purpose - With some empirical input, transmissivity or hydraulic conductivity is modelled. This model provides input for water transport models and analyses.

Description - A computer routine is developed to determine two dimensional space dependent transmissivity or hydraulic conductivity values using numerical integration of appropriate transport equation along streamlines, with input values of water table potential surface and some field measured transmissivities or hydraulic conductivities. The computer code is applied to the water table aquifer of Hanford Reservation and the results are utilized in a water transport model. The methodology developed is straightforward and the only drawback to its usefulness is the requirement of considerable data for accuracy.

Cearlock, D.B., K.L. Kipp, and D.R. Friedrichs. 1975, May. BNWL-1706; 74 pp. Battelle-Pacific Northwest Laboratories, Water and Land Resources Department Richland, WA

Source - Reference #11 p. 16.

GROUNDWATER TRANSPORT

Model - The Use of Galerkin Finite-Element Methods to Solve Mass-Transport Equations

Purpose - The model successfully simulated solute transport for an unreactive conservative solute chloride, a solute with a first-order irreversible rate reaction, radioactive decay, and a solute with equilibrium-controlled ion exchange.

Description - The partial differential equation that describes the transport and reaction of chemical solutes in porous media was solved using the Galerkin finite-element technique. These finite elements were superimposed over finite-difference cells used to solve the flow equation. Both convection and flow due to hydraulic dispersion were considered. Linear and Hermite cubic approximations (basis functions) provided satisfactory results; however, the linear functions were found to be computationally more efficient for two-dimensional problems. Successive over relaxation (SOR) and iteration techniques using Tchebyscheff polynomials were used to solve the sparse matrices generated using the linear and Hermite cubic functions, respectively. Comparisons of the finite-element methods to the finite-difference models, and to analytical results, indicated that a high degree of accuracy may be obtained using the method outlined. The technique was applied to a field problem involving an aquifer contaminated with chloride, tritium, and strontium-90.

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Mail Box 413, Box 25046
Denver, Federal Center
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Source - Reference #28: p.1,49

GROUNDWATER TRANSPORT

Model - Three-Dimensional Transient Saturated-Unsaturated Flow in a Groundwater Basin.

Purpose - To calculate water flow in a groundwater basin under saturated-unsaturated condition with a transient.

Description - A three-dimensional finite difference model has been developed for the treatment of saturated-unsaturated transient flow in small nonhomogeneous, anisotropic geologic basins. The uniqueness of the model lies in its inclusion of the unsaturated zone in a basin wide model that can also handle both confined and unconfined saturated aquifers, under both natural and developed condition. The integrated equation of flow is solved by the line successive overrelaxation technique. The model allows any generalized region shape and any configuration of time variant boundary conditions. When applied to natural flow systems, the model provides quantitative hydrographs of surface infiltration, groundwater recharge, water table depth, and stream base flow. Results of simulations for hypothetical basins provide insight into the mechanisms involved in the development of perched water tables. The unsaturated basin response is identified as the controlling factor in determining the nature of the base flow hydrograph. Application of the model to developed basins allows one to simulate not only the manner in which groundwater withdrawals are transmitted through the aquifers, but also the changes in the rates of groundwater recharge and discharge induced by the withdrawals. For any proposed pumping pattern, it is possible to predict the maximum basin yield that can be sustained by a flow system in equilibrium with the recharge-discharge characteristics of the basin.

R. A. Freeze, IBM
Water Resources Research
Yorktonw Heights, New York 10598
7(2) pp. 347-366 (1971)

Source - G. T. Yeh (by phone)

Model - Transport Model: Theory and Computer Implementation

Purpose - Transport of radionuclides through saturated or unsaturated sediments at the Hanford Reservation was modelled. The model appears to have general applicability to groundwater/soil transport problems.

Description - A transport model was developed to predict the movement of radiocontaminants in the saturated and unsaturated sediments of the Hanford Reservation. The model is designed to work in conjunction with either the unsaturated hydraulic flow model or the unconfined aquifer model developed at BNWL. Transport model utilizes hydraulic velocities generated by these models together with soil waste reactions to predict contaminant movement. In the report, the fundamental model equations are first formulated, then specific forms of distribution and movement of dissolved minerals and radioactive elements present in trace quantities. The mathematical model is based on the two dimensional form of this general diffusion convection equation which considers variable dispersion coefficients and variable media thickness, as well as all possible source and sink terms. The numerical algorithm used is based on particle in a cell technique (method of characteristics). The program has been tested and verified on both one dimensional and two dimensional test problems, in addition to a large scale test using field data gathered by sampling numerous wells in the Hanford Area. A difficulty was in obtaining detailed and accurate space dependent hydrological parameters required by the model.

Ahlstrom, S.W., R.G. Baca, and R.J. Serne. 1973. BNWL-175; 74 pp. Battelle-Pacific Northwest Laboratories, Water and Land Research Department Richland, WA

Source - Reference #11, p. 15.

GROUNDWATER TRANSPORT
SOIL TRANSPORT

Model - Unsaturated Zone Model

Purpose - The code models long term migration tendencies of TRU wastes buried in soil and basalt. It can be applied to multi-phase soil/rock columns, using varied precipitation and evapo-transpiration rates.

Description - The code predicts concentration gradients within a column of soil and rock for any specified component at some time specified. The method of solution is the application of a tri-diagonal matrix solution to a heterogeneous one-dimensional vertical formation. This code assumes a thin plate source and applies Darcy's Law to fractured media.

As input the user must supply--inventories, media characteristics, component chemical characteristics, precipitation and evapo-transpiration rates, sorption, coefficient solubilities, and decay coefficients. Many parameters are input only once, the remaining parameters are simple. The code outputs saturation in each layer, also isotopic inventories and total inventories in a format simple for reading.

The code is written in FORTRAN-IV for use on a CYBER 70, and typically requires 70K and .2 CPU sec per year of simulation.

Paul T. Dickman
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FTS 583-0610

Source - EG&G Idaho

GROUNDWATER TRANSPORT

Model - Water Movement Through Saturated-Unsaturated Porous Media: A Finite - Element Galerkin Model.

Purpose - A two-dimensional transient model for flow through saturated-unsaturated porous media. The relevance for LLW management is in the analysis of groundwater transport.

Description - This model numerically solves the governing partial differential equations, which are highly nonlinear. The model code uses quadrilateral finite elements for the geometrical assembly, bilinear Galerkin interpolation for the spatial integration, and Gaussian elimination for the solution of the resulting matrix equations. In addition to the usual constant-flux and constant-head boundary conditions, the code is capable of applying pressure-dependent boundary conditions at the ground surface. Thus, infiltration into or seepage from this surface may be simulated. Each element may be assigned different material properties that allow the investigation of layered geologic formations. The results of a computer simulation have been compared with experimental data obtained by J.D. Hewlett and A.R. Hibbert from an inclined soil slab at Coweeta Hydrologic Laboratory in North Carolina. The computer model gives good results in this simulation. The Galerkin finite-element method is found to be superior to the finite-difference method used by previous investigators. A comparison with a finite-difference model developed by R.A. Freeze is made.

Reeves, M.; Duguid, J.D.
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

Source - Reference #6: p. 116.

SOIL TRANSPORT

Model - CHARSOIL

Purpose - This code calculates one-dimensional dynamic mechanical behavior of soils.

Descriptions - CHARSOIL is an application of the method of characteristics for calculating one-dimensional dynamic behavior of soils. A constant thickness zoned soil may consist of layers each having specific properties--shear modulus, density, maximum shearing strength, and visco-elastic coefficient. Underlying the soil is a rock base which may be horizontal or inclined. Dynamic excitation of the soil is introduced at the rock-soil interface by shearing stresses produced by rock motions. At the upper surface of the soil a slab may be included to simulate the dynamic influence of the weight of a building. Response of the soil can be evaluated on the basis of elastic, viscoelastic, or non-linear (Ramberg-Osgood) soil behavior and plastic slip can be included.

Required input data include: soil properties for each layer; chosen number of depth segments for which calculations are to be made; selection of type of soil model to be treated; inclination of base rock (and soil surface); specifications of velocity of excitation at base for equal time increments.

Information printed out includes: shear; velocity (and slip velocity); displacements (and slip displacements) at each section; acceleration of ground surface; and information for plotting a hysteretic shearing stress-shearing strain curve at any layer.

V. L. Streeter, E. B. Wylie, and F. E. Richart, Jr.
University of Michigan
Ann Arbor, Michigan 48104

Source - Reference: Streeter, Wylie, and Richart, "Soil Motion Computation by Characteristics Method," Journal of Geotechnical Engineering Division, Vol. 100, No. GT3, pp. 247-263, March 1974.

SOIL TRANSPORT

Model - LUSH2

Purpose - The program finds the complete seismic response of a plane finite element model representing a soil-structure system.

Description - The program differs from more conventional finite element programs in that it, in an appropriate manner, takes into account the strong nonlinear effects which occur in soil masses subjected to strong earthquake motions. This is achieved by a combination of an equivalent linear method and the complex response method. The latter method makes it possible to work with different damping in each element and to consider higher frequencies than most other methods of dynamic analysis.

The input motion is assumed to be specified as acceleration time histories at a rigid boundary of the finite element model, usually the base, and different time histories may be specified for the horizontal and vertical components of the input motion.

The basic output from LUSH is the time history of motion of all nodal points of the system. These time histories may be written on a magnetic tape together with the input information to form a permanent record of the problem and its solution, or they may be punched, printed, or plotted as time histories of displacement or accelerations or in the form of acceleration and velocity spectra.

J. Lysmer
Department of Civil Engineering
University of California
Berkeley, CA 94720

Source - Reference: Lysmer, et al., "LUSH--A Computer Program for Complex Response Analysis of Soil Structure Systems," Earthquake Engineering Research Center, Report No. 74-41, University of California, Berkeley, April 1974.

Model - RAMM: A System of Computer Programs for Radionuclide Pathway Analysis Calculations

Purpose - A generalized system of computer programs to analyze the movement of radionuclides through the environment to man.

Description - A generalized system of computer programs, designated RAMM (Radioactive Materials Management) system, has been developed to assist in the analysis of the movement of radionuclides through the environment to man. RAMM incorporates the GASP IV continuous/discrete simulation system. A nodal approach is used whereby the system to be analyzed is split up into parts small enough that the distribution of nuclides within the node may be taken to be homogenous. Pathways are defined between nodes, and appropriate transfer coefficients are input or generated. Nodes are general "containers of nuclides" and may be volumes, such as a volume of water or a body organ, or surfaces such as a square meter of land surface. Nodes may be defined as belonging to streams within which movement may be by transportation as well as by diffusion. Output includes the time dependent contents of the nodes and dose rates, integrated doses and dose commitments of selected nodes.

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Atomic Energy of Canada, Limited
Whiteshell Nuclear Research Establishment
Pinawa, Manitoba ROE ILO

Source - Reference #6: p.149

ATMOSPHERIC TRANSPORT
SOIL TRANSPORT

Model - SDIST: Wind Effectuated Redistribution of Surface Contamination

Purpose - This code is used in analyzing redistribution effects of wind over soil.

Description - A mathematical model was developed for use for computer calculations of the redistribution of surface soil contaminants as a function of downwind distribution and erosion or weathering variables. A computer program, SDIST, was developed for plotting the concentrations as a function of time for each space interval and steady state isopleths.

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Source - Reference #18: p. 5.

Model - UTM (Unified Transport Model)*

Purpose - The Unified Transport Model (UTM) allows simulation of the transport, accumulation, and redistribution of trace contaminants in the environment.

Description - The air, land, and aquatic systems are represented by three major model components, designed to be run in sequence. The atmospheric component is based upon a Gaussian plume model and calculates deposition rates of aerosols for any point within a watershed. Concentrations of airborne aerosols at ground level are also calculated. The model includes consideration of point, area, line, and windblown sources for air pollutants. Deposition occurs by dry fallout and also by washout caused by rain falling through the plume. Air concentrations and depositions depend upon source strength, atmospheric stability, and wind speed and direction patterns. The spatial resolution of the atmospheric module now extends to a radius of 50 kilometers from any point source. One can use the model to simulate larger areas by constructing a mosaic of sub-area calculations. The deposition values calculated by the atmospheric model are used for input to the land component of the UTM.

The terrestrial component is structured to receive atmospheric wet and dryfall input to a watershed canopy and then simulate its movement until it is discharged in streamflow. The model simulates the amount of material washed from the canopy to the land surface during rainfall and allows for the exchange and uptake or adsorption of materials on surface soil. Surface runoff and scouring of soil particles are considered together with leaching of trace elements into the soil profile. An experimentally derived equilibrium distribution coefficient is used to estimate the concentrations of contaminants in subsurface soil water. This estimated concentration and the rate of soil water drainage are combined to estimate a subsurface input to the stream channel.

Finally, the outputs from the terrestrial component of the UTM enter the channel component, where flows are routed using a kinematic wave approximation. This portion of the program simulates transport of dissolved and particulate materials in streamflow. Suspended and bedload transport are considered by the model. Mixing and exchange between the aqueous and solid phases for the particular chemical species of concern are also simulated. If point-source discharges of known strength are released to the stream, the channel component is capable of simulating their introduction and subsequent transport.

M. R. Patterson (ORNL), Oak Ridge National Laboratory,
Oak Ridge, TN 37830

Source - Reference #3

*Program components of the UTM appear in the "Other LLW Models" category.

ATMOSPHERIC TRANSPORT
SOIL TRANSPORT

Model - A Model for Predicting the Redistribution of Particulate Contaminants from Soil Surfaces.

Purpose - The model predicts redistribution of soil-contaminant mixtures.

Description - A computerized model was developed to describe the redistribution of wind eroding soil-contaminant mixtures. Potentially mobile particulate contaminants can, in the first approximation, be assumed to be indistinguishable from the wind eroding soil in which they are distributed. A grid network characterized important soil and surface conditions, and mass conserving control volumes are constructed on each cell. Material is transported through the vertical and top surfaces of a control volume by a modified Bagnold-Chepil horizontal flux formulation and modified Gillette vertical flux formulation, respectively. The vertical emissions, considered as puffs from area sources, create at regular time intervals a contaminant cloud which is proportional to the suspendable ground concentration. These puffs diffuse downwind under time dependent wind velocity and atmospheric stability conditions, maintaining during the time interval a three-dimensional Gaussian distribution of concentration with cloud volume. Material from each puff is deposited in downwind cells, leading to the possibility of many different flights from these new sources. The usefulness of the predictive tool is demonstrated by calculations involving mixtures of particulate Pu-238/Pu-02 in highly erodeable soils under dust storm conditions. Time dependent surface concentration and breathing zone exposure isopleths, evolving from a small contaminated area, show the potential hazard from wind eroding toxic materials.

J. R. Travis, Los Alamos Scientific Laboratory, Los Alamos, NM, 1974. LA-UR-74-1340; CONF-740921; Part of Proceedings of the Atmospheric-Surface Exchange of Particulate and Gaseous Pollutants Symposium held in Richland, Washington, September 4-6, 1974, (58 p.).

Source - Reference #26: Item 509.

ATMOSPHERIC TRANSPORT
SOIL TRANSPORT

Model - A Model for Redistribution by Wind of Surface Contamination.

Purpose - A theoretical model has been formulated to predict the long range time and space redistribution by wind of surface contamination.

Description - In the case of long-lived isotopes, such as Pu239, this redistribution is of paramount importance. Creep, saltation, suspension (followed by diffusion and deposition), and weathering are considered to effect a one dimensional flow pattern spatially described by an unlimited number of continuous intervals. Within each interval the contamination concentration is described as a function of time by a first order differential equation. Possible applications and extensions are discussed.

A. J. Amato, "A Mathematical Analysis of the Effects of Wind on Redistribution of Surface Contamination," WASH-1187, 7p., Sept. 1971, Norfolk State College, Department of Mathematics, Division of Biology and Medicine, Washington, D.C. 20545.

Source - Reference #26: Item 198.

GROUNDWATER TRANSPORT
SOIL TRANSPORT

Model - A Radionuclide Transport Model for Shallow Land Burial Sites.

Purpose - The model describes the movement of radionuclides through soil. Its applicability is general to LLW management.

Description - A state-of-the-art computer code has been developed that calculates the transport of pollutants through soils. The computer code calculates the one-dimensional transient response of a soil column to infiltrating water carrying a pollutant that interacts with the soil. The soil can initially contain a specified amount of water (0-100% of pore volume), and the surface boundary conditions can reflect either a variable rainfall or a variable pond height. The interaction includes both absorption and diffusion. These are the dominant interaction mechanisms for most heavy metals. However, the structure of the code is such that other mechanisms can be easily incorporated. Because of these capabilities the code is applicable to the evaluation of shallow land burial sites typically utilized for disposal of low-level radioactive wastes.

Among the major factors governing the movement of pollutants from residuals down through the soil profile are the characteristics of the residuals and the soils. Among the former are hydraulic conductivity (the ability of the material, sludge, etc., to transport fluid), leachability (the parting of soluble constituents under the effects of the percolating liquid), the extent of release of particulates (the washing out of suspended solids), the chemical behavior of interstitial fluids, and the presence of complexing agents. Important soil characteristics are hydraulic conductivity, the chemical environment, and the microbial environment.

The utilization of such a computer code requires that available data be examined and field investigations initiated as necessary to establish the physical properties that comprise the input to the code. Then, the leachate characteristics of the soil would be experimentally determined in order to precisely establish the conductivity of the soil and to quantify the interaction mechanisms between the radionuclides and the soil. Finally, a calculational parametric survey of the soil response would be performed.

The product of this assessment would be concentration-time and flux-time curves at depths corresponding to aquifers. These results would be used to determine the bottom-line impact, that is, the concentration of radionuclides in the aquifers surrounding an actual or proposed burial site.

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Source - Reference #14: p. 1161

SOIL TRANSPORT

Model - Documentation and Application of SCEHM a Model for Soil Chemical Exchange of Heavy Metals.

Purpose - This code simulates transport of heavy metals in a soil system.

Description - SCEHM, a computer model simulating the transport of heavy metals through the soil system in a forested watershed, has been developed and linked with the Terrestrial Ecosystem Hydrology Model. SCEHM deals with deposition infiltration, exchange, and flow of particulates emitted from a smelter. Particulates are deposited onto the litter layer, dissolved and infiltrated into the soil according to a solubility constant, exchanged with the soil by using simplified Kd relationship, and transported through the soil by moisture movement. The model is applied to Crooked Creek Watershed to simulated the six-year build up of lead, cadmium, zinc, and copper around a lead smelter. The results indicate that the model can accurately predict the accumulation of heavy metals which remain as free cations in the soil solution. It also can be used to help understand the individual chemistry of a particular heavy metal. The model is explained and a FORTRAN IV version is listed. Input parameters are described. Sample input and output for the model are also presented.

C. L. Begovich; D. R. Jackson, Oak Ridge National Laboratory, ORNL-NSF-EATC-16 (1975).

Source - Reference #26: Item 1056.

GROUNDWATER TRANSPORT
SOIL TRANSPORT

Model - Linear Diffusion and Convection of Chemicals in Soils.

Purpose - This code aids in the analysis of translocation of chemicals in soil.

Description - The movement of some chemicals in soils has been treated theoretically by considering for saturated conditions, the chemical diffusion coefficient, the percolation velocity of the water, the sorptive properties of the soil, the average particle size of the soil, and the fractional number of sorbing sites. A model has been developed for the movement of chemicals in saturated soil, based on Pick's Law, conservation of energy, and a sorption isotherm. Theoretical curves for two different boundary conditions have been developed for realistic values of the water velocity in the pores and the measured diffusion coefficient.

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Corvallis, OR 97331

1, 561-565, 1967; LAI, S. H., J. J. Jurinak, and R. J. Wagenet,
Soil Science Society American Journal, 42, 240-243, 1978.

Source - Reference #18: p.234

Model - Migration of Gaseous Radionuclides Through Soil Overlying a Uranium Ore Deposit: A Modeling Study

Purpose - The models presented are applied to migration of gaseous radionuclides from soil.

Description - Several one-dimensional mathematical models are derived to simulate the distribution of radionuclides in soil overlying uranium ore deposits. The migration of gaseous products away from the ore is simulated by mechanisms of molecular diffusion and advective transport. A homogeneous overburden containing no uranium or radium is assumed throughout. The study is intended to be a first step in analyzing the feasibility of detecting uranium ore by remote geochemical measurements. A steady-state diffusion model predicts the detectability of radon-222 and some of its daughter products several tens of meters from a uranium deposit. In reality this range would be shortened by the masking effect of radon generated in the overlying soil itself. Krypton-85 is found to be only marginally detectable even in the immediate vicinity of the ore. Xenon-133 would be detectable at half the range of Rn-222. The effect of soil gas motion as an additional transport mechanism is evaluated using both steady-state and transient models. A constant soil gas velocity of 1×10^{-4} cm/sec causes gaseous radioisotope activities to change by several orders of magnitude. Detectability of uranium could be significantly increased if long-term soil gas motion is confirmed. A transient numerical model is used to simulate barometric influences on the migration of Rn-222 away from an ore deposit. It was found that near-surface effects are $\pm 15\%$ which would not appreciably affect the detectability of uranium by geochemical means.

H. W. Jeter, J. D. Martin, D. F. Schutz
Teledyne Isotopes
Westwood, NJ
GJBX--67-77, 1977

Source - Reference #18: p.233

SOIL TRANSPORT

Model - Migration of Plutonium in Natural Soils

Purpose - This model predicts the transport of plutonium in soil.

Description - A mathematical model used to evaluate the migration of plutonium in surface soils as it applies to both fallout and industrial contamination. The study plot investigated was the vicinity of Heidelberg and comprehensive fallout from ISPA (450 km south) was extrapolated to determine input quantities. Calculated cumulative depositions were shown to agree well with observed Pu concentrations in the Heidelberg soils. Data on Pu distribution in soils provided by the Health and Safety Laboratory (HASL) were applied for the study plot in southwestern Germany. The removal of PuO_2 particles from a given layer was observed to behave exponentially with a turnover time of approximately 5 to 6 years. The case of instantaneous soil contamination is considered with the development of a box model leading to Poisson-type equation which computes a migration velocity of 0.8 cm per year. The comparative migration velocities of PuO_2 and $\text{Pu}(\text{NO}_3)_4$ were evaluated and PuO_2 was shown to migrate two orders of magnitude faster than the nitrate form.

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ABRA
Karlsruhe, German Federal Republic
CONF-75110S; IAEA-SM-199/3;
STI/PUB/410

Source - Reference #11: p. 140.

Model - Migration of Radionuclides in Model Saturated Zone.

Purpose - This model describes the ability of radionuclides to migrate through a sand layer model.

Description - This mathematical model investigates the leaching of radionuclides from solidified wastes and their migrating characteristics in a sand layer mode. The radionuclides solidified in Portland cement were Sr-90, Cs-137, Co-60, Zn-65, Mn-54, Fe-59, and Ag-110. The sand layer was 50 cm thick, had a porosity of 35.6%, and was essentially sand with no clay. The cation exchange coefficient was found to be 9.7 plus or minus 0.6 ueg/g. Distribution coefficients for each of the radionuclides were: Sr-90, 4.9; Co-60, 25.4; Cs-137, 694.6; Mn-54, 35.2; Zn-65, 30.0; Fe-59, 1.4; and Ag-110, 15.7 ml/g. Of the seven radionuclides sealed in the cement, Sr-90 was detected as having been leached from the matrix. Strontium was leached in great amounts initially but as the experiment continued it was noted that the Sr-90 concentration decreased downstream. This indicated that the sand had the ability to sorb some of the radionuclide. Most of the Sr-90 was leached from the cement after 400 to 500 days and the concentration was considered in a steady state. It was generally possible to forecast the time required for Sr-90 to reach the end of the bed by using the distribution factor value and a factor in an equation presented. Mn-54 and Fe-59 were also controlled by internal diffusion and the dissolution of the cement, while Zn-65 and Ag-110 were controlled by dissolution of the cement. The former was considered to be a Sr-90 pattern and the latter a Co-60 pattern.

Inoue, Y., S. Morisawa, and A. (Translator) Bach
Kyoto University
Kyoto, Japan
ORNL-TM-4440; 13 pp.
1976.

Source - Reference #11: p. 150.

Model - Subsurface Containment Transfer

Purpose - This model is used to assist in radionuclide migration analysis.

Description - The problem of subsurface, radioactive-contaminant transfer is investigated theoretically through the development of a two-dimensional model which considers the simultaneous flow of water and mass. The method of characteristics is utilized to solve a mass-balance equation that considers physical transport by radioactive decay and binary exchange. The study demonstrated the influence of the following parameters on the physical aspects of contaminant transport: hydraulic conductivity, site location within a recharge area and porous-medium dispersivity. With respect to the parameters controlling the chemical and nuclear processes, radioactive half-life, cation-exchange capacity, selectivity coefficient, ion charge and weathering rates play important roles in determining the pattern of contaminant dispersal. Geologic layering adds complexity to the patterns of dispersal because the controlling parameters vary within the flow region. The extent of the contaminant plume is fixed by the physical transport processes. The chemical and nuclear processes tend to reduce the size of the contaminated region to some fraction of that which is attributable to the physical processes alone. Because of the large number of variables that influence the dispersal of contaminants away from sites of emplacement, it is impossible to adequately approach the problem of site location and design utilizing empirical principles or established guidelines. The only satisfactory way of predicting patterns of contaminant migration is to incorporate field-determined parameters in a properly designed and calibrated mathematical model. Only in this way can the effects of all important processes be evaluated simultaneously.

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Journal of Hydrology, 27, SI-71 1975

Source - Reference #11: p.156

SOIL TRANSPORT

Model - Transport and Reactions of Ions in Soils

Purpose - This model describes chemical and physical factors that affect ion transport in soil.

Description - The mathematical model addresses itself to the physical and chemical factors influencing the transport of ions in soils. The main factors are: flow phenomena, interphase mass transfer, adsorption desorption, and surface reactions. It is shown that the kinetics of orthophosphate removal from solution by a soil can be described as a series process involving interphase mass transfer, adsorption, and surface reaction. The mathematics of the kinetics is presented in some detail. Applications of these theories to certain heavy metals and transuranic elements are discussed briefly.

Novak, L. T.
Cleveland State University
Cleveland, OH
AICHE Symposium Series No. 166;
Water-1976: 1. Physical, Chemical
Wastewater Treatment, G.F. Bennett
(Ed.), Vol. 73.

Source - Reference #11: p. 115.

Model - Unsaturated Zone Model

Purpose - The code models long term migration tendencies of TRU wastes buried in soil and basalt. It can be applied to multi-phase soil/rock columns, using varied precipitation and evapo-transpiration rates.

Description - The code predicts concentration gradients within a column of soil and rock for any specified component at some time specified. The method of solution is the application of a tri-diagonal matrix solution to a heterogeneous one-dimensional vertical formation. This code assumes a thin plate source and applies Darcy's Law to fractured media.

As input the user must supply--inventories, media characteristics, component chemical characteristics, precipitation and evapo-transpiration rates, sorption, coefficient solubilities, and decay coefficients. Many parameters are input only once, the remaining parameters are simple. The code outputs saturation in each layer, also isotopic inventories and total inventories in a format simple for reading.

The code is written in FORTRAN-IV for use on a CYBER 70, and typically requires 70K and .2 CPU sec per year of simulation.

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Source - EG&G Idaho

GENERAL TRANSPORT
RISK ASSESSMENT

Model - AMRAW: Risk Assessment Method for Radioactive Waste Management.

Purpose - This model provides calculational methods for risk assessment in radioactive waste management systems.

Description - A Radioactive Waste Management Systems Model was developed and implemented by the University of New Mexico under contract with the U.S. Environmental Protection Agency. The systems model and associated computer code called AMRAW (Assessment Method for Radioactive Waste), has two parts. The first part, AMRAW-A, consists of the Source Term (Radioactive inventory versus time), the Release Model, and the Environmental Model. The Release Model considers various geologic and man-caused events which are potential mechanisms for release of radioactive material beyond the immediate environs of a repository or other location; the risk analysis mode uses events distributed probabilistically over time, and the consequence analysis mode uses discrete events occurring at specified times. The Environmental Model includes: 1) the transport to and accumulations at various receptors in the biosphere, 2) pathways from these environmental concentrations, and 3) resulting radiation dose to man.

The second part of the system model, AMRAW-B, is the Economic Model which calculates health effects corresponding to the various organ dose rates from AMRAW-A, collects these health effects in terms of economic costs and attributes these costs to radionuclides, decay groups, and elements initially in the waste inventory. Implementation, with calculated results, of AMRAW for Terminal Storage in a Bedded Salt Reference Repository has been accomplished. Preliminary demonstrations for the repository operations phase of waste management and terminal storage in a shale formation have also been accomplished; possible applications to other radioactive and nonradioactive hazardous materials have been discussed. AMRAW uniquely links all analytic steps together in a continuous calculation sequence.

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Source - Reference #10: June 1978, p.v

DOSIMETRY
FOOD CHAIN
SURFACE WATER TRANSPORT

Model - AQUAMAN

Purpose - AQUAMAN is a computer code for calculating dose commitment to man from aqueous releases of radionuclides.

Description - AQUAMAN is an interactive computer code for calculating values of dose (50-year dose commitment) to man from aqueous releases of radionuclides from nuclear facilities. The data base contains values of internal and external dose conversion factors, and bioaccumulation (freshwater and marine) factors for 56 radionuclides. A maximum of 20 radionuclides may be selected for any one calculation. Dose and cumulative exposure index (CUEX) values are calculated for total body, GI tract, bone, thyroid, lungs, liver, kidneys, testes, and ovaries for each of three exposure pathways: water ingestion, fish ingestion, and submersion. The user is provided the option at the time of execution to change the default values of most of the variables, with the exception of the dose conversion factor values. AQUAMAN is written in FORTRAN for the PDP-10 computer.

D. L. Shaeffer, and E. L. Etnier
Oak Ridge National Laboratory
Oak Ridge, TN 37830
ORNL/TM-6618, p. 27, Feb. 1979.

Source - Reference #25: p. 36.

DOSIMETRY
SURFACE WATER TRANSPORT

Model - AQUAMOD: A Systems Analysis Model for Calculating Radionuclide Transport Between Receiving Waters and Bottom Sediments.

Purpose - This code is used in analyzing radionuclide transport between receiving waters and bottom sediments and the resulting doses to man.

Description - Equilibrium radionuclide concentrations in waters receiving radioactive effluents and in bottom sediments associated with the receiving waters were calculated so that potential doses to man and biota and radionuclide buildup in the environment could be determined realistically. A four-compartment systems analysis model was developed to predict dynamic radionuclide transfer. The dependent variables of the model are the receiving water, interstitial water intermingled with the bottom sediments, bottom sediment particles that undergo sorption-desorption reactions with the interstitial water, and bottom sediment particles that undergo only sorption reactions with the interstitial water. The model was used to generate two tables. The first table gives equilibrium radionuclide concentrations in the receiving water when radionuclide transfer to bottom sediments are possible, divided by the receiving water concentrations when transfers to bottom sediments are ignored. These factors are always less than unity, since radioactivity must be conserved, and adding sediments to the system adds another compartment where radionuclide concentrations will equilibrate. The other table lists ratios of equilibrium radionuclide concentrations in sediments, divided by their corresponding receiving water concentrations. These concentrations in the sediments can be used to calculate external doses to a person sunbathing or fishing. Preliminary results indicate that the usual effect of a neglect of sediment interactions is an overestimation of the total potential dose to man from the radionuclides. This neglect of sediment interactions overestimates receiving water concentrations which, in turn, overestimates potential doses from important pathways (drinking water or eating fish) directly related to the receiving water concentration. This would not be the case, however, for a situation where exposure to radionuclides in sediments is the critical pathway. The results for Cs-137 are particularly interesting since it often causes a major fraction of the calculated dose for a typical release. For environmental parameters appropriate to freshwater lakes in the northeastern states, neglecting sediment interactions could result in potential doses approximately 4 times too high from Cs-137 contained in potable water and edible fish. Further, increasing only the Kd value of a sample of sediment from 27,000 to 270,000 (which reflects various freshwater environments) increases this factor from approximately 4 to approximately 25.

Booth, R.S.
Oak Ridge National Laboratory
P. O. Box X, Oak Ridge, TN 37830

Source - Reference #18: p. 151.

DOSIMETRY
FOOD CHAIN
SURFACE WATER TRANSPORT

Model - ARRRG, Aqueous Release of Radionuclides Report Generator.

Purpose - ARRRG calculates annual individual and population doses resulting from radionuclides released with liquid effluents. It is part of the HERMES computer program.

Description - ARRRG calculates annual individual and population doses resulting from radionuclides released to surface-water bodies. Eight environmental pathways are modeled: eating fish, crustacea, molluscs, and algae; drinking surface water; direct external radiation from shoreline; water immersion (swimming), and direct external radiation from boating. Doses are calculated for skin, total body, gastrointestinal-lower large intestinal tract, thyroid, bone, liver, lung, and kidney. The output format specifies contributions to the dose by nuclide and by pathway.

Currently ARRRG is operational with the capability of calculating doses for 6 organs and 200 radionuclides. The user inputs the following variables from an interactive terminal: the name of the facility under investigation; decay between release and point of exposure (holdup), usages, and mixing ratios by pathway; reactor coolant flow, shoreline width factor and reconcentration factor parameters.

J.K. Soldat, N.M. Robinson, and D.A. Baker (1974)
Battelle, Pacific Northwest Laboratories
Richland, WA

Hoenes, Glenn R.
Battelle, Pacific Northwest Laboratories
Post Office Box 999
Richland, WA 99352
509-942-3754; FTS 444-7511 EXT 942-3754

Source - Reference #8: p. 207-208, #12 p. 2-27, B-39.

SURFACE WATER TRANSPORT

Model - CAFE-1

Purpose - CAFE-1 is a two-dimensional, depth-averaged finite-element circulation model to calculate wind and tide induced flow in lakes and estuaries.

Description - A "CAFE-1", a two dimensional, depth-averaged finite element circulation model, has been developed. All input data requirements, as well as an explanation of printed, punched and file written output information have been documented. Two example problems have been worked through. In the first, CAFE-1 is used to calculate the solution of tide and wind induced flow in a rectangular estuary. In the second, wind induced flow is calculated in a rectangular lake. There are also three accessory programs which utilize velocity output from "CAFE-1." The first is a depth-averaged drogue path program, and the second and third plot drogue paths and velocity vectors, respectively.

J. R. Pagenkopf, G. C. Christodoulou, B. R. Pearce, and J. J. Connor, "A Users Manual for "CAFE-1, A Two Dimensional Finite-Element Circulation Model", Technical Report No. 217, Ralph Parsons Laboratory, MIT, Cambridge, MA, (August 1976).

Source - Reference: Report cited above.

SURFACE WATER TRANSPORT

Model - CAFE-2

Purpose - CAFE-2 is a two-dimensional, two-layer finite element circulation model to calculate tide and wind induced flow in an estuary with a thermocline.

Description - CAFE-2 is a two dimensional, two-layer finite element circulation model. All input data requirements, as well as an explanation of printed, punched and file written output information have been documented. An example problem has been solved where CAFE-2 is used to calculate the solution of tide and wind induced flow in a rectangular estuary with a thermocline. There are three accessory programs which utilize velocity output from "CAFE-2." The first is a two-layer drogue path program, and the second and third plot drogue paths and velocity vectors respectively.

J. R. Pagenkopf, G. C. Christodoulou, B. R. Pearce, and J. J. Connor, "A Two Layer Finite Element Circulation Model", Technical Report No. 220, Ralph M. Parsons Laboratory, MIT, Cambridge, MA, (December, 1976).

Source - Reference: Report cited above.

SURFACE WATER TRANSPORT

Model - DISPER-1

Purpose - DISPER-1 is a two-dimensional, depth-averaged finite element dispersion model to calculate the solution of a release in a straight channel with uniform flow.

Description - DISPER-1 is a two dimensional, depth-averaged finite element dispersion model. All input data requirements, as well as an explanation of printed, punched and file written output information, is documented. DISPER-1 has been used in an example problem to calculate the solution of a release in a straight channel with uniform flow.

J. R. Pagenkopf, G. C. Christodoulou, B. R. Pearce, and J. J. Connor, "A Two-Dimensional Finite Element Dispersion Model," Technical Report No. 218, Ralph M. Parsons Laboratory, MIT, Cambridge, MA, (August, 1976).

Source - Reference: Report cited above.

SURFACE WATER TRANSPORT

Model - DISPER-2

Purpose - DISPER-2 is a multi-layer finite element dispersion model to calculate the concentration of a constituent released in a straight channel with stratified flow conditions.

Description - DISPER-2 is a multi-layer, finite element dispersion model. All input data requirements, as well as an explanation of printed, punched and file or disk written output information is documented. DISPER-2 has been used to calculate the concentration of a constituent released in a straight channel with stratified flow conditions. DISPER-2 has an accessory program which plots element concentration data from punched cards generated from "DISPER-2".

G. C. Christodoulou, J. R. Pagenkopf, B. R. Pearce, and J. J. Connor, "A Multilayer Finite Element Dispersion Model", Technical Report No. 221, Ralph M. Parsons Laboratory, MIT, Cambridge, MA, (December, 1976).

Source - Reference: Report cited above.

GROUNDWATER TRANSPORT
SURFACE WATER

Model - DPRWGW and DPRWCR, Transport Modeling in the Environment Using the Discrete-Parcel-Random-Walk Approach.

Purpose - The codes describe the transport of radionuclides by ground water and surface water.

Description When formulating a mathematical model for simulating transport processes in the environment, the system of interest can be viewed as a continuum of matter and energy or as a large set of small discrete parcels of mass and energy. The latter approach is used in the formulation of the Discrete-Parcel-Random-Walk (DPRW) Transport Model. Each parcel has associated with it a set of spatial coordinates as well as a set of discrete quantities of mass and energy. A parcel's movement is assumed to be independent of any other parcel in the system. A Lagrangian scheme is used for computing the parcel advection and a Markov random walk concept is used to simulating the parcel diffusion and dispersion. The DPRW technique is not subject to numerical dispersion and it can be applied to three-dimensional cases with only a linear increase in computation time. A wide variety of complex source/sink terms can be included in the model with relative ease. Examples of the model's application in the areas of oil spill drift forecasting, coastal power plant effluent analysis, and solute transport in groundwater systems are presented. DPRWGN is used for analyzing groundwater transport and DPRWCR is used for analyzing surface water transport.

Ahlstrom, S.W.; Foote, H.P.
Battelle, Pacific Northwest Laboratories
Richland, WA

Source - Reference #6: pg. 136.

SURFACE WATER TRANSPORT

Model - FETRA & SERATRA: Studies of Columbia River Water Quality, Development of Mathematical Models for Sediment and Radionuclide Transport Analysis

Purpose - These are 2D riverine and estuarine water quality codes used to generate isotopic inventories in various bodies of water.

Description - The program undertaken by PNL to study the water quality of the Columbia River consists of two separate segments: (a) Sediment and Radionuclide Transport Program, and (b) Columbia River Temperature Analysis. For the Sediment and Radionuclide Transport Program, quasi-two dimensional (longitudinal and vertical directions) mathematical simulation models have been developed for determining radionuclide inventories, their variations with time, and movements of sediments and individual radionuclides in the freshwater region of the Columbia River below Priest Rapids Dam. These codes are presently being applied to the river reach between Priest Rapids and McNary Dams for the initial sensitivity analysis. In addition, true two-dimensional (longitudinal and lateral directions) models have been formulated and are presently being programmed to provide more detailed information on sediment and radionuclide behavior in the river. FETRA is the 2-D (lateral and longitudinal) finite element transport model used for estuaries, coastal areas and wide lakes. It is written in FORTRAN IV for a Cyber 7600 computer. SERATRA is the 2-D (vertical and longitudinal) sediment and radionuclide transport model used for narrow estuaries, rivers, and deep lakes. It uses finite differencing and is written in FORTRAN IV for the PDP 11/45.

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Richland, WA 99352

Source - Reference #6: p.134

GENERAL TRANSPORT

Model - HERMES: A Digital Computer Code for Estimating Regional Radiological Effects from the Nuclear Power Industry

Purpose - This model is used in estimating regional radiological effects resulting from operation of nuclear facilities.

Description - The HERMES model is designed to calculate radionuclide release and radiation dose occurring within a study area in a given year. While cumulative radionuclide release as such is not considered, the accumulated buildup and deposition of key radionuclides is "back-calculated" for a five-to-ten year period for use in dose calculations. The initial development of the HERMES model was based on a study of the region comprising the upper Mississippi and lower Missouri River basins, excluding the Chicago metropolitan area. To estimate the effects on dose in the study area caused by air transport of radionuclides from adjacent regions, an "air envelope" some 200 miles in width was included around the study area. Considerations in the study included the operation of 400,000 MW generating capacity power plants (nuclear and fossil) at 186 separate sites. The air transport code (ARTRAN) utilizes monthly climatological data applied to standard mathematical models for diffusion, deposition, and transport. The water transport code (WTRAN) calculates diffusion from emission points, concentrations in sediments and surface water at each location requested, and ground water transport. The code (DOSE) considers exposure to the whole body and six specific organs in (1) direct submersion in air or water, (2) inhalation, (3) external exposure from surface contamination, and (4) ingestion of food and water over numerous food-chain pathways. Life habits and dietary differences are also considered in the code (LPM). Present structure allows calculations for up to 50 radionuclides; 200 release points; and 300 receptor locations. More recent applications have been for the Tennessee Valley region and Southwest Environmental Study.

J. F. Fletcher, W. L. Dotson
Hanford Engineering Development Laboratory
Richland, WA 99352
509-942-6523; FTS 444-6523
HEDL-TME-71-168; 759 pp., 1971

Source - Reference #18: p.305

SURFACE WATER TRANSPORT

Model - HN: Multi-layer Hydrodynamical Numerical Model.

Purpose - This model computes vertically integrated motion through multiple layers.

Description - The multilayer Hydrodynamical-Numerical (HN) model (W. Hansen type) is, in many respects, similar to Hansen's single-layer HN model. The hydrodynamical formulas present vertically integrated motion through given layers. The lower layer is partly driven by friction, which is proportional to the mean density relations of the layers, and partly by horizontal pressure gradients caused by the inclination of the surface as well as of the interface.

Taivo Laevastu, "A Multilayer Hydrodynamical-Numerical Model (W. Hansen): Model Description and Operating/Running Instructions," Technical Note No. 2-74, Jan. 1974, Environmental Prediction Research Facility, Naval Postgraduate School, Monterey, California 93940

Source - Reference: Article cited above.

SURFACE WATER TRANSPORT

Model - HN: Single-Layer Hydrodynamical Numerical Model.

Purpose - This model is a vertically integrated hydrodynamical-numerical single layer model of the W. Hansen type.

Description - A single-layer, vertically integrated, Hydrodynamical-Numerical (HN) model has been developed. The model is an adaptation of one developed by Professor Walter Hansen, University of Hamburg, and tested over the course of two decades. The documentation includes the setting up of the model for a given area and the selection and preparation of input data.

"A Vertically Integrated Hydrodynamical-Numerical Model (W. Hansen Type)" Technical Note No. 1-74, Jan. 1974, Oceanography Department, Environmental Prediction Research Facility, Naval Postgraduate School, Monterey, California 93940.

Source - Reference: Article cited above.

SURFACE WATER TRANSPORT

Model - HOTSED: A Discrete Element Model for Simulating Hydrodynamic Conditions and Absorbed and Dissolved Radioisotope Concentrations in Estuaries

Description - A model has been developed to study the feasibility of simulating one-dimensional transport of radioisotope-tagged sediment in tidal-dominated estuaries. A preliminary one-dimensional model for simulating hydrodynamic, thermal, and dissolved radionuclide concentrations in tidal estuaries was merged with an improved version of the SEDTRN model, a multi-sediment-size class model of bedload and suspended sediment transport. The improved SEDTRN model, which employs a velocity-based rather than an energy-based sediment transport rate calculation and accounts for nonzero channel bed slope, is given credence by comparing its results in stand-alone form to those obtained using the parent model. Results of the latter model have been shown to compare favorably to field measurements. The combined preliminary model is called HOTSED. Details of model modifications, the addition of printer plot output capability, and a discussion of input and output structures are available. The HOTSED model is applied to the Hudson River under tidal-transient conditions and the transport "tagged" or radioisotope-bearing sediment is simulated. The code is designed specifically for applications with dominant tidal cycling. It requires, for a 76-element channel system, 270 thousand bytes of storage and, for a simulation of 25 hours, has an execution time of approximately five minutes on the IBM system 360/91 computer.

D. E. Fields, D. M. Hetrick
Oak Ridge National Lab., TN (USA)

Source - Reference #26: p. 3,4

SURFACE WATER TRANSPORT

Model - HTM: Simulation of the Hydrologic Transport of Radioactive Aerosols.

Purpose - This code is concerned with transport of radionuclides in atmospheric fallout.

Description - Deals with hydrological models as "carrier" systems and simulates material flow through the system by following the transport of the dissolved or suspended material.

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Building 1505
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Oak Ridge, TN 3783030476

Source - Reference #118: p.166

DOSIMETRY
GROUNDWATER TRANSPORT
SURFACE WATER TRANSPORT

Model - LADTAP: Liquid Annual Doses to All Persons

Purpose - To calculate doses received by individuals and populations through liquid pathways for the implementation of NRC Regulatory Guide 1.109.

Description - None available at the time of presentation of this document. See Regulatory Guide 1.109 for a description of the calculational model and parameters that this code implements.

Mike Bell
USNRC
System Dynamics and Reliability Group
Washington, D.C.

Source - Reference #30

SURFACE WATER TRANSPORT

Model - LIDSR

Purpose - LIDSR evaluates the radiological exposures associated with liquid effluent pathways to the environment.

Description - NOT PRESENTLY AVAILABLE.

P. P. Staneavage, and D. G. Abbott
General Electric Co.
Boiling Water Reactor Systems Department
San Jose, CA
NEDM-20609-01, p. 33, August 1976.

Source - Reference #25: p. 170.

SURFACE WATER TRANSPORT

Model - LODIPS: Pollutant Transport in Natural Streams

Purpose - This code is used in determining the effect of pollutants in streams.

Description - A mathematical model has been developed to estimate the downstream effect of pollutant releases to tributary streams and rivers. The one-dimensional dispersion model was employed along with a dead zone model to describe stream transport behavior. Options are provided for sorption/desorption, ion exchange, and particle deposition in the river. The model equations are solved numerically by the LODIPS computer code. The solution method was verified by application to actual and simulated releases of radionuclides and other chemical pollutants.

M. R. Buckner; D. W. Hayes, Savannah River Laboratory, Aiken, SC 29801
April 1975, CONF 750413 (Part 2), Computational Methods in Nuclear Engineering, Proceedings of the Conference held at Charleston, South Carolina, April 15-17, 1975, pp. 123-139.

Source - Reference #26: Item 1297.

GROUNDWATER TRANSPORT
SURFACE WATER TRANSPORT

Model - MOC

Purpose - This model computes potentiometric heads and solute transport in flowing water.

Description - The model predicts the flow of water according to Darcy's Law and continuity equation. Capabilities include solute transport by convection and hydrodynamic dispersion, with the dispersion coefficient treated as second-order tensor. The code solves for both transient or steady-state flow. It can readily incorporate simple chemical reactions, radioactive decay, or adsorption.

The model solves a finite difference form of the flow equation using an iterative ADI procedure. The solute-transport equation is solved using the method of characteristics. Applications include the following: Transient position of interface between fresh water and salt water; cross-sectional model; flow is density dependent--Pinder and Cooper (1970); Movement of salt water in confined limestone aquifer; vertical leakage through confining bed; area in Georgia--Bredehoeft and Pinder (1973); Salinity increases in alluvial stream-aquifer system were related to irrigation practice; coupled streamflow routing model; applied to management problems; area in Colorado--Konikow and Bredehoeft (1974); Movement of industrial and low-level radioactive liquid wastes in interbedded basalt flows and unconsolidated sediments; effects of radioactive decay and adsorption included in model; area in Idaho--Robertson (1974); Contamination of shallow alluvial aquifer by seepage from sewage-treatment ponds; area in California--Robertson (1974); High chloride industrial wastes seeped out of unlined disposal ponds and spread through underlying alluvial aquifer; area in Colorado--Konikow (1976).

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Denver Federal Center
Denver, CO 80225

J.D. Bredehoeft
U.S.G.S.
National Center
Mail Stop 413
Reston, VA 22092

Source - Reference #12: pp. B-18, 19.

Model - RAMM: A System of Computer Programs for Radionuclide Pathway Analysis Calculations

Purpose - A generalized system of computer programs to analyze the movement of radionuclides through the environment to man.

Description - A generalized system of computer programs, designated RAMM (Radioactive Materials Management) system, has been developed to assist in the analysis of the movement of radionuclides through the environment to man. RAMM incorporates the GASP IV continuous/discrete simulation system. A nodal approach is used whereby the system to be analyzed is split up into parts small enough that the distribution of nuclides within the node may be taken to be homogenous. Pathways are defined between nodes, and appropriate transfer coefficients are input or generated. Nodes are general "containers of nuclides" and may be volumes, such as a volume of water or a body organ, or surfaces such as a square meter of land surface. Nodes may be defined as belonging to streams within which movement may be by transportation as well as by diffusion. Output includes the time dependent contents of the nodes and dose rates, integrated doses and dose commitments of selected nodes.

R. B. Lyon
Atomic Energy of Canada, Limited
Whiteshell Nuclear Research Establishment
Pinawa, Manitoba R0E 1L0

Source - Reference #6: p.149

Model - RIBAM: River Basin Model

Purpose - This is a generalized model for river basin water quality management planning.

Description - RIBAM is a computerized mathematical model which predicts water quality for 17 constituents. Predicted water quality profiles throughout the basin for varying sets of waste loads and flow regimes can be compared with each other and with desired water quality goals. RIBAM is suited for determining the waste load allocations necessary for achieving water quality standards in rivers.

Marshall, Richard N.
Raytheon Company
Environmental Systems Analysis
Portsmouth, RI 02871
401-847-8000

Source - Reference #18: p. 178.

DOSIMETRY
SURFACE WATER TRANSPORT

Model - RVRDOS: A Computer Code (RVRDOS) to Calculate Population Doses from Radioactive Liquid Effluents.

Purpose - A computer program RVRDOS has been developed to calculate population doses due to releases of radionuclides into flowing streams.

Description - Concentrations of the radionuclides downstream take into account dilution, decay, and the ingrowth of a daughter product. Population doses to four organs are calculated for drinking water and fish ingestion pathways. Individual doses due to swimming may also be estimated. RVRDOS has been used to calculate population doses due to releases from nuclear power reactors on the Mississippi River Basin during 1973. The data base for these calculations and a summary of the calculations are available.

J. A. Martin, Jr.
U. S. Environmental Protection Agency
Office of Radiation Programs
Environmental Analysis Division
Washington, DC 20460

Source - Reference #6: p.140

SURFACE WATER TRANSPORT

Model - SEDONE

Purpose - SEDONE is a computer code for simulating tidal-transient, one-dimensional hydrodynamic conditions and three-layer, variable-size sediment concentrations in controlled rivers and estuaries.

Description - The general-usage computer code SEDONE is used for simulating fast-transient (tidal-transient), one-dimensional hydrodynamic and three-layer, variable-size sediment concentration conditions in controlled rivers and tidal estuaries. The code is particularly designed for application to site-specific problems that require accurate predictions of the sedimentation phenomena under severely reversing flow conditions. Input data to the code include modified geometry contours of the channel cross-sections with corrections for the embayment areas, flow conditions at the controlled dams, tidal conditions at the ocean ends, rainfall conditions in the geographical region, stream flow, drainage flow, and ground-water-seepage flow conditions, and the physical properties of the sediment size classes that determine the settling and resuspension effects which control the sedimentation. The formats of the input data are completely generalized. The code also has a user-specified option to include only the simulations of sediment concentration conditions by incorporating previously computed and stored results for the surface elevation and flow rate conditions, thereby excluding the computations for the solution of the hydrodynamic conditions. This option substantially reduces the computational cost of repeated simulations.

D. M. Hetrick, A. H. Eraslan, and M.R. Patterson
Oak Ridge National Laboratory
Oak Ridge, TN 37830
ORNL/NUREG/TM-256, p. 285, 29 Nov. 1978.

Source - Reference #25: pp. 38, 39.

Model - SEGOL

Purpose - The SEGOL model is a coupled model for contaminant transport and flow. The flow system is for combined saturated and partially saturated flow.

Description - The transport equations are solved using a Galerkin Finite Element approach. The model solves for three-dimensional combined partially saturated and saturated flow. Since solution for both saturated and partially saturated flow is possible, the free surface is very nicely handled. At the same time, a more realistic representation of flow from ponds or lakes is provided by the model, rather than requiring the assumptions involved when only saturated models are used. The SEGOL model utilizes finite elements for the numerical reduction with isoparametric elements. It is an operational model and has been tested, but has not yet been extensively used with field problems. A severe test case involving imbibition led the author to indicate that a spacial discretization of a few centimeters may be necessary for such problems.

G.A. Segol, "A Three-Dimensional Galerkin Finite Element Model for the Analysis of Contaminant Transport in Variably Saturated Porous Media - User's Guide," June 1976, Department of Earth Sciences, University of Waterloo, Waterloo, Ontario, Canada.

Source - Reference #13: p. 91.

SURFACE WATER TRANSPORT

Model - SERATRA: Sediment and Radionuclide Transport Model.

(For Description See FETRA & SERATRA)

SURFACE WATER TRANSPORT

Model - SIMFD: A Surface Impoundment Model by Finite Difference

Purpose - SIMFD calculates the flow rate, velocity field, and concentration distribution of pollutants in surface impoundments with any number of islands.

Description - A surface impoundment model by finite-difference (SIMFD) has been developed. SIMFD computes the flow rate, velocity field, and the concentration distribution of pollutants in surface impoundments with any number of islands located within the region of interest. SIMFD is written in FORTRAN IV. Two sample problems have been solved to illustrate the application and validity of the model.

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Source - Author

SURFACE WATER TRANSPORT

Model - SIMFE: Surface Impoundment Model in Finite Element

Purpose - To simulate flow circulation and pollutant transport and dispersion in natural or artificial lakes.

Description - A surface impoundment model in finite element (SIMFE) has been developed to enable the simulation of flow circulation and pollutant transport and dispersion in natural or artificial lakes, reservoirs or ponds with any number of islands. This surface impoundment model consists of two sub-models: hydrodynamic and pollutant transport models. Both submodels are simulated by the finite element method. While the hydrodynamic model is solved by the standard Galerkin finite element scheme, the pollutant transport model can be solved by any of the twelve optional finite element schemes built in the program. SIMFE is written in FORTRAN IV. Two sample problems have been solved. One was for an idealized system with a known solution to show the accuracy and partial validation of the models. The other was applied to Prairie Island for a set of hypothetical input data, typifying a class of problems to which SIMFE may be applied.

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Source - Author

Model - TEHM: A Terrestrial Ecosystem Hydrology Model

Purpose - The model can describe movement of radionuclides through the ground.

Description - The terrestrial ecosystem hydrology model (TEHM) combined mechanistic models for climatic and hydrologic processes with vegetation properties to explicitly simulate interception and through fall; infiltration; root zone evaporation, transpiration, and drainage; plant and soil water potential; unsaturated and saturated subsurface flow; surface runoff; and open channel flow. It is also possible to use the TEHM with models for forest stand biomass dynamics and chemistry and exchange of heavy metals to study the transport and fate of trace contaminants at a watershed scale. Walker Branch Watershed has been used as an example to illustrate development of the required input parameters and variables that are necessary to execute the TEHM. In all cases, emphasis has been placed on objective, physically based methods. When simulations of interception loss, soil moisture content, and base flow and storm flow are compared with observation, the overall adequacy of the model may be assessed. For user convenience, the documentation includes a complete discussion of input formats, example data input sets, output summaries, and a microfiche listing of the complete source deck and program output.

As presented, the TEHM provides an operational tool and a model structure and data management capabilities that will be useful for future hydrologic simulation work. From that viewpoint, the TEHM represents an important step forward in establishment of an objective framework for the study of terrestrial ecosystems.

FORTTRAN IV is the language and IBM 360 the computer used in TEHM. WHTM is a part of TEHM.

Huff, D.D.; Luxmoore, R.J.; Rankin, J.B.; Begovich, C.L.
Oak Ridge National Laboratory, Oak Ridge, TN 37830

Source - Reference #6: p. 152.

Model - UTM (Unified Transport Model)*

Purpose - The Unified Transport Model (UTM) allows simulation of the transport, accumulation, and redistribution of trace contaminants in the environment.

Description - The air, land, and aquatic systems are represented by three major model components, designed to be run in sequence. The atmospheric component is based upon a Gaussian plume model and calculates deposition rates of aerosols for any point within a watershed. Concentrations of airborne aerosols at ground level are also calculated. The model includes consideration of point, area, line, and windblown sources for air pollutants. Deposition occurs by dry fallout and also by washout caused by rain falling through the plume. Air concentrations and depositions depend upon source strength, atmospheric stability, and wind speed and direction patterns. The spatial resolution of the atmospheric module now extends to a radius of 50 kilometers from any point source. One can use the model to simulate larger areas by constructing a mosaic of sub-area calculations. The deposition values calculated by the atmospheric model are used for input to the land component of the UTM.

The terrestrial component is structured to receive atmospheric wet and dryfall input to a watershed canopy and then simulate its movement until it is discharged in streamflow. The model simulates the amount of material washed from the canopy to the land surface during rainfall and allows for the exchange and uptake or adsorption of materials on surface soil. Surface runoff and scouring of soil particles are considered together with leaching of trace elements into the soil profile. An experimentally derived equilibrium distribution coefficient is used to estimate the concentrations of contaminants in subsurface soil water. This estimated concentration and the rate of soil water drainage are combined to estimate a subsurface input to the stream channel.

Finally, the outputs from the terrestrial component of the UTM enter the channel component, where flows are routed using a kinematic wave approximation. This portion of the program simulates transport of dissolved and particulate materials in streamflow. Suspended and bedload transport are considered by the model. Mixing and exchange between the aqueous and solid phases for the particular chemical species of concern are also simulated. If point-source discharges of known strength are released to the stream, the channel component is capable of simulating their introduction and subsequent transport.

M. R. Patterson (ORNL), Oak Ridge National Laboratory,
Oak Ridge, TN 37830

Source - Reference #3

*Program components of the UTM appear in the "Other LLW Models" category.

ATMOSPHERIC TRANSPORT
DOSIMETRY
FOOD CHAIN
SURFACE WATER TRANSPORT

Model - VADOSCA: A Simple Code for the Evaluation of Population Exposure Due to Radioactive Discharges.

Purpose - This is a combination liquid-gas isotopic distribution model, with doses calculated using varying environmental parameters.

Description The code consists of two parts, one for liquid discharges (VADOSCA-II) and one for gaseous discharges (VADOSCA-GAS). It incorporates the transfer parameters of twenty-four radioisotopes in the case of liquid discharges, and of twenty radioisotopes in the case of gaseous discharges. It allows the evaluation of the concentrations of the various isotopes in all the compartments of the critical paths outlined in the International Commission on Radiological Protection (ICRP) Publication No. 7, and the evaluation of the annual doses for five critical organs (whole body, G.I. tract, thyroid, bones, lung) for the various critical groups of population on the basis of environmental parameters such as the time of residence in a certain area, diet, type of activity, hydrological regimen, irrigation methods, and meteorological conditions. Although extremely simple, the code allows rapid performance of all the evaluations required to define the amount of radioactivity that can be released and the associated exposures. In its present form, the code VADOSCA-II covers twenty-four radionuclides including some fission products, some activation products, plus an alpha emitter. VADOSCA-II calculates the doses to four special groups, namely, fishermen, other workmen, local population, farmers. A separate calculation is made for the doses originated by drinking water. The doses are evaluated for five critical organs and they are expressed in mrem/year if the discharges are expressed in Ci/yr. In VADOSCA-GAS, twenty nuclides are considered, including eight noble gases (fission and activation products, various isotopes as particulates, and H-3, N-13, C-14 in the form of vapor. Atmospheric diffusion is evaluated with Pasquill's theory adapted to the meteorological data available. In its present form VADOSCA-GAS does not take into account particular effects such as the cloud depletion due to deposition, down draft and building effect; the particulate deposition rate is assumed constant at $3 \cdot 10^{-2}$.

Bramati, L.; Marzullo, T.; Rosa, I.; Zara, G.
Italian National Electric Energy Agency

Source - Reference #6: p. 131.

DOSIMETRY
SURFACE WATER TRANSPORT

Model - WATER: Water Code.

Purpose - This code concerns itself with the environmental impact of radionuclides in liquid effluents.

Description - A FORTRAN IV code that models radionuclide releases into a flowing river and the subsequent dose to individuals and the population via various pathways. The code uses RG 1.109-dose factors, river flow data, and release data for the source. The doses are calculated at public water supplies and for swimmers at the nearest public use area.

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Environmental Planning
River Oaks Bldg.
Muscle Shoals, AL 35660
205-383-4631 EXT 2767; FTS 872-8767

Source - Reference #18: p.197

GROUNDWATER TRANSPORT
SURFACE WATER TRANSPORT

Model - WHTM: Wisconsin Hydrologic Transport Model

Purpose - The model describes radionuclide transport by movement through the ground.

Description - A user's guide for the Wisconsin Hydrologic Transport Model (WHTM) is presented to enable the simulation of trace contaminant transport by the hydrologic cycle. This hydrologic transport model is based on the Stanford Watershed Model and forms a major component of the Unified Transport Model being developed at ORNL. WHTM includes the hydrologic transport of a trace contaminant by entrainment in overland flow, infiltration, impervious area runoff, and base flow. Chemical exchange reactions are simulated with a simple ion-exchange submodel for interaction with the soil and a sheet erosion submodel for transport of the trace contaminant that is sorbed on the surface of eroded soil particles. Detailed instructions for the application of the WHTM are given, and lists of the FORTRAN IV source decks and sample input data are provided. Simulation of the hourly flow in seven reaches of a stream channel system for a period of one year can be done on the IBM System 360/91 computer in about four minutes.

Since the publication of the WHTM user's manual in 1974, several useful adjustments to the program have been implemented. They include corrections to syntax, incorporation of effects of forest litter on contaminant transport, corrections to syntax, corrections to include conservation of mass on the theoretical plate ion-exchange algorithms, reintroduction of ion-exchange processes in subsurface soils, and the inclusion of some diagnostic print options. A description of each change is available, together with a comprehensive example of the results obtained when the revised WHTM is used.

Patterson, M.R.; Munro, J.K.; Fields, D.C.; Ellison, R.D.; Brooks, A.A.; Huff, D.D. Oak Ridge National Laboratory, Oak Ridge, TN 37830

Munro, J.K.; Huff, D.D., Corrections and Revisions to the FORTRAN IV Version of Wisconsin Hydrologic Transport Model 1977, May, ORNL/NSF/EATC-29; 40 pp. (Oak Ridge National Laboratory, Oak Ridge, TN 37830)

Source - Reference #6: p. 151.

DOSIMETRY
FOOD CHAIN
SURFACE WATER TRANSPORT

Model - A Model for Predicting the Transport of Radionuclides in the Marine Environment.

Purpose - This is a mathematical model to describe the transport of radionuclides in the marine environment, their accumulation in marine organisms, and their consequent dose to man.

Description - Expressions for the internal radiation dose to Standard Man are then derived on the basis of this model. These expressions give conservatively high estimates of the potential internal radiation dose, which can be compared with radiation-protection guides to determine the necessity, if any, of radiological safety measures. The model derivation starts with an instantaneous point-source solution to a partial differential equation that has been shown to be an adequate description of the physical dispersion process in the ocean. An expression for the radionuclide concentration in the ocean resulting from a fallout input is developed from this point-source solution. This expression indicates that vertical diffusion is the controlling mechanism for dispersion soon after the fallout deposition, and that convection controls dispersion later. From this observation, two simpler expressions are derived, one for early and one for later times. The simpler expressions for describing dispersion of a fallout input are used to define a mixing volume which then is considered to be the receptor of both the fallout and the terrestrial radionuclide inputs. The terrestrial input is due to direct groundwater contamination and terrestrial fallout. From these concepts, an expression is derived for the radionuclide concentration in the mixing volume. This expression is then combined with a seawater-seafood-man food-chain model to arrive at expressions for the infinite internal radiation dose to man.

S. G. Bloom, and G. E. Raines. Battelle Memorial Institute, Columbus Laboratories, 505 King Avenue, Columbus, Ohio 43201, BMI-171-123, 16 p., 1969.

Source - Reference #26: Item 201.

SURFACE WATER TRANSPORT

Model - A Numerical Model for the Hydrologic Transport of Radioactive Aerosols from Precipitation to Water Supplies.

Purpose - The model is used to predict radionuclide concentrations in water which originates from atmospheric sources.

Description - A numerical model of the transport of nuclear debris from the atmosphere by precipitation through the surface-water portion of the hydrologic cycle has been prepared. The model collates the significant parameters involved, such as the physical and chemical properties of biologically important radionuclides (e.g., Sr 90) in aerosols, their deposition by precipitation under Pacific coast cyclonic conditions, and their movement through the catchment basin during precipitation and runoff. The model is based upon the quantitative estimation of these parameters under conditions given by an existing computer model (formulated by N. H. Crawford and R. K. Linsley), which traces the movement of water through the basin to predict the runoff hydrograph. The numerical model should serve as an index of predictability for radionuclide concentration in water supplies originating from atmospheric sources and as a means to locate areas where additional numerical knowledge of hydrologic processes is needed.

D. D. Huff; P. Kruger, Stanford University, Civil Engineering Department, Stanford, CA 1967. Part of Scott, G.E. (Ed.), Isotope Techniques in the Hydrologic Cycle.

Source - Reference #26: Item 314.

SURFACE WATER TRANSPORT

Model - A Revised Oceanographic Model to Calculate the Limiting Capacity of the Ocean to Accept Radioactive Waste.

Purpose - This model is used to estimate the ability of the ocean to accept radioactive wastes.

Description - A model was constructed for calculating the limiting capacity of the ocean. Sedimentation and sorption are taken into account as well as surface and deep circulation. Sorption of radionuclides depends on the particle size and the chemical interaction between the sediments and the radionuclides. Activity is principally incorporated into the sediments by the scavenging action of particles during sedimentation. Depth of penetration of the activity is determined by: sediment movement due to water currents, burial of sediments due to further sedimentation, sediment mixing due to biological activity within the sediments, diffusion of activity within the sediment profile and interstitial water movement with the sediments. The distribution coefficients for ocean bed and coastal sediments range from $5 \times 10(E+1)$ to $1 \times 10(E6)$. The short term model is designed to handle surface water concentration from low-level radwastes disposed on the ocean floor. It evaluates transfer and dilution of activity in the vicinity of the disposal area. The long-term model calculates widespread concentrations by considering the water mass exchange between the basins in the North Atlantic system. Again transport and dilution of activity is evaluated. Examples are available to show the usefulness of the model.

G. A. M. Webb; P. D. Grimwood, National Radiological Protection Board, Harwell, Didcot, Oxfordshire, England, December 1976. NRPB-R58; 19 pp.

Source - Reference #26: Item 801.

SURFACE WATER TRANSPORT

Model - Cycling of Elements in Estuaries.

Purpose - This model deals with metals cycling in estuaries

Description - Meaningful evaluation of the ecological stresses imposed by man's release of heavy metals or radioisotopes into estuaries requires an improved understanding of the interactions between the waste materials and the functional components of the ecosystem. A conceptual systems model has been developed as the preliminary phase in the development of dynamic mathematical models of elemental cycling.

Gordon W. Thayer
National Marine Fisheries Service
Atlantic Estuarine Fisheries Center
Beaufort, NC 28516
909-728-4595

Source - Reference #18: p.206

Model - Development of a Unified Transport Approach for the Assessment of Power-Plant Impact UTA

Purpose - These mathematical models are used to describe the transport and properties of power plant emissions on rivers, lakes, etc.

Description - Mathematical models are being developed for fast-transient, one-and two-dimensional transport of thermal, radiological, chemical, and biological properties in rivers, estuaries, lakes, and coastal regions for assessing the impact of power-plant operations. The models have been applied and validated at several sites where data are available. The models include submodels for sediment transport, exchange of a soluble isotope with sediment, and zone-matching models to connect near-field problems of reentrainment and recirculation with far-field convective transport. Several types of automated data preparation have been introduced, and the codes have been designed to allow input of specified plant operating conditions for given durations. The UTA provides a common basis for calculating the transport of intensive quantities that depend on basic flow properties, which can be obtained from a common set of data for geometry, bathymetry, and meteorology that must be prepared only once. The formulation and calculation are based on a stable set of algorithms that have been tested and proven valid.

E. J. Akin, J. M. Barton, J. L. Bledsoe
Oak Ridge National Lab., TN (USA)
March 1, 1977

Source - Reference #27, Item 53

SURFACE WATER TRANSPORT

Model - Disposal of Low-Level Liquid Radioactive Wastes in Inland Waterways.

Purpose - This model is used to determine the ability of waterways to purify themselves of radwaste.

Description - A mathematical model was developed to investigate the ability of rivers or lakes to purify themselves of radwastes. Self-purification mechanisms include precipitation and deposition, adsorption on the bottom, and biological uptake in aquatic plants and animals. These mechanisms depend on the following factors: hydro-meteorological; chemical, biochemical, and physical; radioactive characteristics; stream use; cost of disposal relative to alternative methods; and feasibility of procedure for monitoring and control. Of all these factors the major one is longitudinal mixing (hydro-meteorological). The mixing is brought about by: 1) the non-uniform distribution of velocity caused by the curvature of and shear at the solid boundaries of the flow; 2) eddy diffusion associated with the turbulence of the moving stream; and 3) irregular displacements such as caused by wind and thermal currents. Tests were conducted on the Mohawk River near Albany, N.Y. and Cochichewick, near Lawrence, MA. In the Mohawk River test 4.5 curies of P-32 was released to a flow of 1100 cu ft/sec. It was found that the peak of activity diminished down stream and the peaks became broader. A mathematical model was derived to calculate the longitudinal dispersion coefficient. By combining the experimental and mathematical results it was computed that 1600 curies could be added to the Mohawk River daily and not exceed the maximum permissible concentration for drinking water ($2 \times 10(E-4)$ uCi/liter). Furthermore, the uptake of radionuclides is dependent on the amounts of non-radioactive elements of the same chemical species and upon the concentration of these naturally occurring in the stream. Several radioisotopes were used in the Cochichewick Brook tests; Rb-86, I-131, Sr-89, Mo-99, P-32, and Ce-141. From these tests it was found that large recoveries are correlated with large flow rates in the stream when bottom deposits containing activity from prior runs are eroded.

H. A. Thomas, Jr.
Harvard University
Division of Engineering and Applied Physics
Cambridge, Mass.
TID-7517 (Part 1B)
December, 1955

Source - Reference #11: p. 116.

SURFACE WATER TRANSPORT
DOSIMETRY

Model - Effects of Rainstorms and Runoff on Consequences of Nuclear Reactor Accidents.

Purpose - The model describes the transportation of radionuclides from rain and the resulting runoff. The code also computes health consequences of reactor accidents.

Description - A preliminary model describing the effects of washout and runoff on the consequences of a nuclear reactor accident is presented. The most important new feature of this stratified model relative to the model in WASH-1400 is the spatial structure of rainstorms and runoff consisting of four levels of rain activity that are normalized by rain gage data. The predicted concentrations of radioactivity and resultant health consequences of the stratified model are compared with those of the model in WASH-1400 for simplified rainstorms with fixed meteorological conditions, an actual rainstorm, and a stratified sample run consisting of 91 separate reactor accidents. In the case of individual storms and runoff, the spatial structure of the rain in the new model can result in health consequences that are significantly different from those of the WASH-1400 model. The differences between the predictions of the two models are small for the stratified sample run.

Ritchie, L.T.; Brown, W.D.; Wayland, J.R.
Sandia Laboratories
Albuquerque, NM 87115

Source - Reference #6: pg. 150.

ATMOSPHERIC TRANSPORT
SURFACE WATER TRANSPORT

Model - Fission Products Field Release Test

Purpose - See Description

Description - Contains model for determining concentrations for radioactivity in surface water.

Air Force Weapons Center
Air Force Nuclear Aircraft Research Facility
Kirtland Air Force Base, NM
Report ANRF 59-32T; AFSWC-TR-59-44; September 1959.

Source - Reference #18: p. 76.

GENERAL TRANSPORT

Model - General Model for Evaluating Transport of Radioactive Products Released to Environment and its Consequences.

Purpose - The model describes transport of radionuclides released from normal operation of nuclear power plant.

Description - A mathematical model is described for the evaluation of the transport and behavior of radioactive products released into the environment during the operation of nuclear power plants. It is based on the behavior of the products on the main protective barriers of nuclear power plants. A block diagram is presented of the model and the respective main programs are characterized.

Hladky, E.; Kubik, I.; Moraveck, J.
Vyskumny Ustav Energeticky,
Jaslcuske Bohunice, Czechoslovakia.

Source - Reference #6: pg. 138.

SURFACE WATER TRANSPORT

Model - Heavy Metals in Estuarine Benthic Organisms and Sediments: Data and Model

Purpose - This code is designed to model the movement of heavy metals in an estuarine environment.

Description - Coastal industrial development and subsequent heavy metal release requires an understanding of environmental contamination that can result. A dynamic model has been developed in close association with a detailed environmental surveillance program of an estuarine ecosystem. The program and model traces the heavy metals from release into the water column and subsequent interactions between the air-water interface, pelagic zone, and sediments. The interaction between phytoplankton, zooplankton, benthic organisms, and predators is accounted for.

J. R. Wayland, J. H. Baker, J. T. Ivy, C. A. Bedinger, Jr.
Albuquerque, NM
3rd ERDA Environmental Protection Conference held in Chicago, Illinois,
September 23, 1975.

Source - Reference #18: p.211

Model - Land Requirement for a Radioactive Waste Disposal Yard

Purpose - This model estimates the intake by humans of radionuclides through food and air.

Description - A model and the rationale were presented with respect to land use requirements for a hypothetical waste burial site. The thrust of the study was to minimize the intake by humans, of radionuclides through the food and air. A to-space transportation diffusion equation was used to describe the migration of the radionuclides in groundwater. The numerical solution was obtained by solving the equation by Crank-Nicolson type differential approximation and successive over relaxation. A sample run was made for a power plant with a total output of 2000 MWe. Numerous environmental land requirements and socio-political factors were considered. With this model it is possible to locate a burial site which ensures the greatest radiological safety. To locate burial site it is necessary to include a zone where ground water use is prohibited; a zone where use is restricted and a buffer zone. The necessary land area will increase with increasing permeability coefficient, decreasing distribution factor and increasing stratum porosity. Variations in the diffusion coefficient do not change the land requirement greatly.

Inoue, Y. and S. Morisawa
Kyoto University
Department of Sanitary Engineering
Kyoto, Japan
ORNL-TM-4444; 13 pp.
1976

Source - Reference #11: p. 149.

Model - Marine Transport of Radionuclides

Purpose - This is a preliminary mathematical model for predicting the transport of radionuclides in the marine environment.

Description - A diffusion model is given for fallout onto ocean surface, groundwater and surface runoff from the land and the internal dose to man resulting from consumption of marine organisms.

S.G. Bloom and G.E. Raines (BMI-171-123)
Battelle Memorial Institute
Columbus, OH 43201

Source - Reference #18: p. 302.

SURFACE WATER TRANSPORT

Model - Mathematical Model for Fate of Pollutants in Near-Shore Waters.

Purpose - This code is designed to trace the path of pollutants in a surface water system.

Description - Modified mathematical techniques have been utilized to develop a computer program for calculating and predicting the fate of pollutants in the near-shore waters of Lake Michigan. The program requires little computer time and is more amenable to prediction of conditions at greater distances or times from the source. The effects of multiple sources, boundaries, and reaction on decay rates were considered in the development of this particular mathematical model. The model also considers variable diffusion coefficients and variable velocities. Use of transforms and Green's function avoids the finite differences approach, permits rapid calculation, and results in a stable answer for long distances from the source.

W. J. Wnek, E. G. Fochtman
6(4), 331-337, 1972

Source - Reference #18: p.214

SURFACE WATER TRANSPORT

Model - Mathematical Model for the Transport of Radionuclides in Water Surface.

Purpose - This code was developed to describe transport of radionuclide in streams.

Description - The purpose of this study was to develop a mathematical model which describes the transport of radionuclides injected instantaneously in a stream. Particular emphasis was directed to the influence of sediments of transport. Instantaneous release of dye and continuous release of Sr-85, respectively, were used to measure the dispersion and mass transfer coefficients. Aquaria and model river experiments were undertaken to determine various parameters which define the mechanism of sorption and desorption of radionuclides by sediments. Instantaneous injection of Sr-85 into the model river provided data for establishing the relationship between the analytical solution and a proposed mathematical model. FORTRAN programs were designed for the analyses of gamma spectra, dispersion coefficients, and transport equations. Some of the important factors affecting the transport of Sr-85 in the model river were studied. The mass transfer coefficient was found to increase with increased velocity. High uptake of Sr-85 by sediments may be provided by increased temperature and the presence of an organic pollutant. An exponential relationship was established between the Sherwood's number and the Reynold's number for the model river.

Shih, C.S.; Gloyna, E.F.
University of Texas
Center for Research in Water Resources
Austin, TX 78712
415-271-2211

Source - Reference #18: p. 201

SURFACE WATER TRANSPORT

Model - Mathematical Models for the Dispersion of Radionuclides in Aquatic Systems

Purpose - These codes are used to model exchange mechanisms in water substrates.

Description - Models are presented of exchange mechanisms for exchange of radionuclides between water and substrates and dispersion by water movement.

Armstrong, N.E.; Gloyna, E.F.
University of Texas
Austin, TX 780712
512-471-5602

Nelson, D.J. and F.C. Evans (Eds.), Proc. Second Nat. Symp. Radioecol., (pp. 329-335), 774 pp.; CONF-670503.

Source - Reference #18: p. 149.

DOSIMETRY
FOOD CHAIN
SURFACE WATER TRANSPORT

Model - Methods and Techniques Relevant to Marine Disposal of LLW or Marine Contamination by LLW.

Purpose - Models covered include marine pathways for radionuclides, aquatic and terrestrial food chains, and dosimetry. The discussion thus has relevance for many aspects of LLW management, particularly marine disposal.

Description - A number of studies on circulation models and dose rate models are briefly discussed. Marine pathways are evaluated for intermittent releases of low-level wastes. The radionuclides of interest are Zn-65, Cs-137, Co-60, Mn-54. It is their concentration in edible marine organisms that are of concern. Also the concentrations of the above radionuclides are discussed with respect to bottom sediments. Various methods of treating wastes with strontium, plutonium, and ruthenium are briefly considered. Also, leach rates were compared by three methods of mathematical analysis. The present and past land burial and storage techniques have been adequate. However, such practices may not be sufficient in the future. Computer analysis of a one-dimensional transient response of a soil column to infiltrating water is mentioned. Assessments of power plant impacts are now including one- and two-dimensional mathematical models for the transport of dissolved radionuclides. Effects of sediment-radionuclide interaction, routine and accidental discharges, and aquatic and atmospheric dispersion, deposition, and resuspension are included. The aquatic and terrestrial food chain transport and the calculation of doses resulting from internal and external modes of exposure are considered as well. When comparing the behavior of plutonium and americium in marine and freshwater environments, there is no preference of uptake between the two transuranics. The major reservoirs of plutonium and americium are the sediments in both environments.

Blaylock, B.G. 1978, June.
Journal of the Water Pollution Control
Federation 50(6), 16 pp.
Oak Ridge National Laboratory
Environmental Sciences Division
Oak Ridge, TN 37830

Source - Reference #11: p. 46.

Model - Modeling of Environmental Pathways and Radiation Doses from Nuclear Facilities

Purpose - A computer model was developed which calculates total annual radiation doses and 50-year dose commitments to several categories of persons at population centers and continues these calculated doses into integrated (man-rem) annual and 50-year doses for large populations. The application to LLW management is general.

Description - The dose model was designed as one portion of an overall computer program developed to delineate the nuclear facilities expected in the year 2000, the radionuclides released to air and water, their diffusion, dispersion, and reconcentration in the environment, and the resulting radiation doses to people. Equations for calculating dose factors were derived from those given by the International Commission on Radiological Protection (ICRP). Effective decay energies for various radionuclides were calculated from the ICRP model, which assumes that all the radionuclide is in the center of a spherical organ with an appropriate effective radius. Where data were lacking, metabolic parameters for the Standard Man were used for other ages as well. The model includes a sub-routine which calculates radionuclide concentrations in a wide variety of foods at time of harvest from concentrations in air, irrigation water, and soil. The latter concentrations are output from previous portions of the overall computer program. The tremendous variety of data required for proper dose assessment is not always available in the literature. Such data has been extrapolated from environmental studies of fallout nuclides and from planned laboratory and field studies of a limited number of nuclides.

J. K. Soldat
Battelle, Pacific Northwest Laboratories
Richland, WA 99352

Source - Reference #6: p.116

SURFACE WATER TRANSPORT

Model - Numerical Modeling of Pollutant Transport Using a Lagrangian Marker Particle Technique

Purpose - This code is used in modeling surface water transport of pollutants.

Description - A derivation and code was developed for the three dimensional mass transport equation, using a particle-in-cell solution technique, to solve coastal zone waste discharge problems where particles are the major component.

M. Spaulding
National Aeronautics and Space Administration
Langley Research Center
Langley Station, VA
N--76-28682, 1976

Source - Reference #18: p.203

Model - Radioactivity Transport in Water

Purpose - This code models radionuclide migration in aquatic systems.

Description - Studies were undertaken to obtain a more accurate concept of the transport of radionuclides in aquatic systems. Various stages of this research were completed and published previously in progress reports, and are listed in the references. These reports describe the dispersion, uptake, release, and transport of Sr-89, Cs-137, Ru-103, Co-58, and Cr-51. Transport data were obtained by conducting laboratory, model river, and field tests. Canal, river, and estuarine environments provided the necessary field information on hydrodynamic dispersion and on uptake and release of radionuclides by sediments. Model river data provided most of the useful uptake and release information involving special sediments, plants, and aquatic environments. Topics discussed include the factors affecting radionuclide transport, the use of model rivers to study continuous release of radionuclides, and the influence of various environmental factors on the accumulation and desorption of mercurials by a fresh water alga. Radioactive isotopes of mercury in the form of mercuric mercury and methyl mercury were used as tracers.

Gromiec, M.J.; Gloyna, E.F.
University of Texas
Center for Research in Water Resources
Austin, TX

Report No. EHE-73-1; CRWR-97; Monitoring Agency Rept. No. 18; 1973, 80 pp.

Source - Reference #18: pp. 161.

SURFACE WATER TRANSPORT

Model - Radioactivity Transport in Water. Numerical Solutions of Radionuclide Transport Equations and Role of Plants in Sr-85 Transport

Purpose - This model provides numerical solutions to radionuclide transport equations.

Description - The role of plants in Sr-85 transport in aquaria and a model river was examined, and a numerical solution to the dispersion equation with convection was derived and extended to include plant sorption. Using the macrophyte, *Vallisneria spiralis* Michx., it was found that almost instantaneous equilibrium was reached with Sr-85 in solution through adsorption followed by a slower and more complete uptake by absorption. A characteristic pattern of uptake and release was observed after instantaneous releases into aquaria and at stations downstream from the point of release in a model river. Under continuous release, uptake tended toward an equilibrium level which was a function of the amount of attached algae present. It was concluded for conditions used in this study that plants played a negligible role in Sr-85 transport. The uptake of Sr-85 by plants after instantaneous release could be modeled using a sorption-desorption equation. Instantaneous dye and Sr-85 releases were made in the model river to determine the dispersion coefficient and tracer cloud velocity with the two station method using only a selected portion of the concentration-time curves. The cut-off point for this portion was the point where one-tenth the peak value was observed. Solutions of the numerical model using constants calculated in this manner gave better fit to the observed data than methods previously used. Constant release data could also be predicted with this model using revised initial conditions. A numerical solution to the equations relating dispersion to plant uptake was also derived but not extensively tested. It was concluded that numerical solutions hold more promise in this area than analytical solutions because of their versatility and ease of computation.

Armstrong, N.E.; Gloyna, E.F.;
Center for Research in Water Resources, University of Texas at Austin,
Austin, TX 78712

Source - Reference #6: p. 139.

SURFACE WATER TRANSPORT

Model - Radionuclide Decay in Steady State Reservoirs.

Purpose - This code is used in simulating simple network of surface water bodies and the decay of radionuclides emplaced in them.

Description - The natural decay of a radionuclide during detainment in a reservoir by large scale circulation processes is considered under steady state conditions. It is shown that when the residence time distribution is a step function, a one-parameter model is defined with the least possible effluent radioactivity. A second one-parameter model, yielding significantly greater radioactivity, is defined if the reservoir contents are uniformly mixed. Reservoir models of higher complexity may be constructed by a systematic linking together of the one-parameter model, yielding significantly greater radioactivity, is defined if the reservoir contents are uniformly mixed. Reservoir models of higher complexity may be constructed by a systematic linking together of the one-parameter models. Effluent radioactivities determined by the only possible two-parameter models are less than or equal to that of the uniformly mixed model. This fact is demonstrated by several specific examples.

M. L. Thiebaut; H. J. Thiebaut, National Oceanic and Atmospheric Adm. and National Center for Atmos. Research, Water Research, 8, 447-453, (1973).

Source - Reference #26: Item 1032.

SURFACE WATER TRANSPORT

Model - Simulation of Major Inorganic Chemical Concentrations and Loads in Streamflow.

Purpose - This code is designed to model inorganic constituents in streamflow.

Description - A computer program for simulation of concentrations and loads of major inorganic chemical constituents has been developed based upon (1) continued daily records of index variables such as specific conductance or stream discharge, and (2) derived functional relationships between solute concentrations and one or both of the index variables. The simulation program estimates daily concentrations and loads of the major inorganic constituents and computes weekly, monthly, and annual time-weighted and discharge-weighted average concentrations. An ionic balance is calculated in each case where the relative abundance of the major ions is simulated or averaged. Numerous input and output options are provided. Two peripheral programs to the streamflow chemical-quality simulation program have been developed for obtaining the earlier-formatted daily constituent records.

Timothy D. Steele

Source - Reference #18: p.204

Model - Simulation of Radionuclide Movement in Freshwater Region of Columbia River

Purpose - The movement of radionuclides in a specific body of fresh water is simulated, although the techniques developed may be of some use in analyzing radionuclide behavior in other freshwater bodies.

Description - A quasi-two-dimensional mathematical simulation model has been developed for determining radionuclide inventories, their variations with time, and movements of sediments and individual radionuclides in the freshwater region of the Columbia River below Priest Rapids Dam. Numerical examples are given. River temperature data accumulated by USGS is also analyzed. Also included is a general review of the quasi-two-dimensional models developed in fresh water.

Onishi, Y., P.A. Johanson, R.G. Gaca, and E.L. Hilty. 1976, January. RNWI-R-452; 41 pp.
Battelle Pacific Northwest Laboratories
Richland, WA

Source - Reference #11: p. 11.

SURFACE WATER TRANSPORT

Model - SR-90 in the Great Lakes: Concentration-Time Model.

Purpose - This model deals with SR-90 concentrations in the Great Lakes.

Description - Concentration-time models for SR-90 in the Great Lakes deal with transient concentrations of a radionuclide in a chain of mixed lakes and in a chain of periodically stratified lakes. In the model, the lakes receive time-dependent input of SR-90 from atmosphere and land (0 to 10% of annual deposit in the land drainage basins). Removal of SR-90 from lake water is by outflow and decay. In the five Great Lakes computed concentrations of SR-90 rise from nil (assumed) in 1953 to a maximum in 1964 to 1965, followed by a gradual decline until 1969. Computed concentrations are comparable to the range of reported values. However, a closer agreement between the model and reported concentrations requires the rates of input in 1962 to 1964 to be higher than the mean, as well as the rates of removal to be faster (by 6 to 8%) than the removal by decay and mean outflow. Seasonal stratification of the lakes has virtually no effect on mean annual concentrations of SR-90.

A. Lerman
Northwestern University
Evanston, IL
Journal Geophysical Research, 77(18), 3256-3264, 1972.

Source - Reference #18: p.172

Model - Stochastic Model of Tracer Flow.

Purpose - This model describes tracer movement in fluid flow.

Description - A "three-velocities" model describes movement of a tracer in fluid flow. Stochastic equations are solved by the Laplace transform to yield usable forms. The model includes: the finite flow velocity of the tracer, particles; tracer concentration at a given time and space point; satisfies the law of fluid continuity; and converges to the "piston-flow" model. The model also describes the dispersion phenomenon and the tracer conservation law. From the calculations and consideration concerning relations between the model parameters, the model may be applied to the determination of mean residence time of water in the hydrologic system; calculation of parameters of porous medium estimation based on experiments; and interpretation of the curves of the tracer flow through two adjacent aquifers having different velocities of filtration.

M. Nawalany, Warsaw Polytechnic University, Institute of Environmental Engineering, Warsaw, Poland, 1976. Journal of Hydrological Sciences, 31-2), 47-59.

Source - Reference #26: Item 807.

SURFACE WATER TRANSPORT

Model - The Stanford Watershed Model IV.

Purpose - The Stanford Watershed Model IV has been successful in reproducing the continuous outflow hydrographs in over forty watersheds by digital simulation of the hydrologic processes.

Description - Additions to this model are being made to include the simulation of the transport of specific radioactive aerosols through the watershed. Subroutines for the IBM 7090 computer program are being developed to evaluate the chemical and physical parameters in the elements of hydrologic aerosol transport. A discussion of the important transport element sub-routines, which include deposition, vegetal interception, soil surface interactions, and channel transport, is given for the important radiotracer elements strontium and cesium.

D. D. Huff, and P. Kruger, "The Chemical and Physical Parameters in a Hydrologic Transport Model for Radioactive Aerosols," Part of Proceedings from International Hydrology Symposium Held in Fort Collins, Colorado, September 6-8, 1967, (p. 128-135).

Source - Reference #26: Item 247.

SURFACE WATER TRANSPORT

Model - Transport Model for Long Term Radionuclide Release into a Stream Ecosystem.

Purpose - This code deals with aquatic transport of radionuclide in a stream system.

Description - A mathematical model was developed which can be used to predict the behavior and transport of radionuclides into a stream ecosystem. The long-term effects resulting from continuous releases of cesium-134 and strontium-85 into a stream ecosystem typical of the local area were evaluated. The data obtained were used to verify a basic transport prediction model.

Yousep, Y.A.; Gloyna, E.F.
Florida Technological University
Orlando, FL

Source - Reference #18: p. 216.

GENERAL TRANSPORT
RISK ASSESSMENT

Model - AMRAW: Risk Assessment Method for Radioactive Waste Management.

Purpose - This model provides calculational methods for risk assessment in radioactive waste management systems.

Description - A Radioactive Waste Management Systems Model was developed and implemented by the University of New Mexico under contract with the U.S. Environmental Protection Agency. The systems model and associated computer code called AMRAW (Assessment Method for Radioactive Waste), has two parts. The first part, AMRAW-A, consists of the Source Term (Radioactive inventory versus time), the Release Model, and the Environmental Model. The Release Model considers various geologic and man-caused events which are potential mechanisms for release of radioactive material beyond the immediate environs of a repository or other location; the risk analysis mode uses events distributed probabilistically over time, and the consequence analysis mode uses discrete events occurring at specified times. The Environmental Model includes: 1) the transport to and accumulations at various receptors in the biosphere, 2) pathways from these environmental concentrations, and 3) resulting radiation dose to man.

The second part of the system model, AMRAW-B, is the Economic Model which calculates health effects corresponding to the various organ dose rates from AMRAW-A, collects these health effects in terms of economic costs and attributes these costs to radionuclides, decay groups, and elements initially in the waste inventory. Implementation, with calculated results, of AMRAW for Terminal Storage in a Bedded Salt Reference Repository has been accomplished. Preliminary demonstrations for the repository operations phase of waste management and terminal storage in a shale formation have also been accomplished; possible applications to other radioactive and nonradioactive hazardous materials have been discussed. AMRAW uniquely links all analytic steps together in a continuous calculation sequence.

S. E. Logan
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Source - Reference #10: June 1978, p.v

GENERAL TRANSPORT

Model - BIOTRAN: Transuranic Biological Transport Model.

Purpose - This model analyzes the cycling of radionuclides in ecosystems.

Description - BIOTRAN simulates ecosystems, biomass density, and the cycling of transuranics in ruminant herds. The model uses biomass as a vector for predicting radionuclide uptake and surface deposition of plutonium in plants and animals.

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Los Alamos, NM 87545
505-667-5862; FTS 843-5862

Source - Reference #8: p.179

Model - CLUETT, MERTAUGH, MIKLIN

Purpose - (1) Predict the demographic structure in the vicinity of a large construction project as a result of immigration in response to primary and secondary employment opportunities, 2) to estimate implied demands for services.

Description - The model uses standard demographic techniques, such as extrapolations based on measures of fertility, mortality, "baseline" net migration, and age and sex distributions to establish a base case for the demographics of the area under consideration.

Regional construction labor force participation rates and unemployment rates are estimated. The regional labor force participation rates and the weighted construction unemployment rates are used to estimate the number of unemployed construction workers available for the project. It is assumed that all unemployed workers will be employed on the project. It is assumed that some employed construction workers change their jobs to work on the project, and that some of these workers will be replaced by in-migrants. The remaining work force is assumed to be composed of in-migrants.

Secondary employment is estimated by means of a region specific employment multiplier, and in-migrants are estimated. "Surplus" in-migrants --that is, in-migrants who come to the region in response to perceived job opportunities, but who cannot find employment--are also estimated. The family size and age and sex distribution of in-migrants are estimated from available data.

The in-migrants are then distributed within the "commuting range" of the project on the basis of estimates of housing availability and the use of a gravity model. Given this distribution, social impacts are estimated, largely in terms of increased demand for goods and services relative to the demand that would be expected given the baseline case.

The program was used to simulate demographic processes for the DOE Generic Environmental Impact Statement.

Cluett, Mertaugh, and Miklin
Battelle Human Affairs Research Center
4000 N.E. 41st St.
Seattle, WA 98105

Source - Reference: Cluett, Mertaugh, and Miklin, A Demographic Model for Assessing the Socioeconomic Impact of Large Scale Industrial Development Projects, draft, 1977.

GENERAL TRANSPORT

Model - CODAC-NO.4: A Computer Program to Calculate Nuclide Yields in Complex Decay and Activation Chain

Purpose - Calculates radioactive nuclide yields in any given complex decay and activation chain in accordance with a given irradiation history.

Description - This code represents a version of the CODAC-NO.1 code. The code developed is capable of calculating radioactive nuclide yields in an any given complex decay and activation chain in accordance with a given irradiation history. Input method and formats used for this code are very simple for any kinds of nuclear data (for example, decay, partial decay, branching decay, activation and fission). A list of FORTRAN statements, list of input parameters and definitions, and examples of input data and output are given in this report. In addition to previous examples, details of input data prepared for a concrete complex chain involved in fission and activation are also given. The code is also capable of following fission product transport and release phenomena accompanying general nuclear reactions. Details of input data prepared for these concrete cases and subprogram modifications for user's definitions are also described.

T. Takeda
Japan Atomic Energy Research Inst., Tokyo
August 1977

Source - Reference #26: p. 10,11

DOSIMETRY

Model - CUMEX, A Cumulative Hazard Index for Assessing Limiting Exposures to Environmental Pollutants.

Purpose - This code is designed to calculate potential health impact based on received dose of various pollutants including radionuclides.

Description - A hazard index methodology called CUMEX has been developed for limiting human exposure to environmental pollutants. Hazard index is defined as Q/Q_L , where Q is exposure and Q_L is a limit which should not be exceeded because of health risk.

Mathematical formulations for hazard indices are developed for each sampling medium corresponding to each effluent type. These hazard indices are accumulated into composite indices such that total human intake overdose would not exceed the health risk limit. Mathematical formulation for composite hazard indices or CUMEX indices for multiple pollutants are presented.

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Source - Reference #21

SITING
SEISMICITY
RISK ASSESSMENT

Model - EQRISK

Purpose - EQRISK evaluates chosen sites for earthquake risk.

Description - Seismic events are considered as point sources; their occurrence in space is defined by the user. A variety of parameters may be used to quantify ground shaking such as peak ground acceleration, velocity, displacement, Modified Mercalli intensity, spectral velocity, etc. An attenuation function must be specified by the user, and may be in analytical form or (with slight reprogramming) in tabular form. Output gives annual risks (probabilities of equaling or exceeding) for chosen values of the parameter values for preselected risk levels. Output is easily obtained for sites on a grid; thus the program is suitable for seismic mapping. Cartesian or longitude-latitude coordinates may be used.

Several sets of information are required to run the program. The ground motion parameter must be determined and values for risk evaluation must be specified. The "attenuation functions" giving the expected value of the chosen parameter as a function of earthquake size and source-to-site distance must be input, as well as the statistical dispersion of this relationship. The seismicity of the region must be specified, in terms of seismic source areas, activity rates, b values, and maximum magnitudes. Finally, the location of the site(s) of interest must be given.

In addition to the input data, the total computed risks for the parameter values specified are output, for each site of interest. The risks from each seismic source may be output, if desired, by the user. Also, if particular risk levels have been input, the parameter values associated with these risk levels are calculated and printed.

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Denver Federal Center
Denver, CO 80225.

Source - Reference: McGuire, "EQRISK--Evaluation of Earthquake Risk to Site," U.S. Dept. of the Interior, Open File Report 7G67, 1976.

GENERAL TRANSPORT

Model - HERMES: A Digital Computer Code for Estimating Regional Radiological Effects from the Nuclear Power Industry

Purpose - This model is used in estimating regional radiological effects resulting from operation of nuclear facilities.

Description - The HERMES model is designed to calculate radionuclide release and radiation dose occurring within a study area in a given year. While cumulative radionuclide release as such is not considered, the accumulated buildup and deposition of key radionuclides is "back-calculated" for a five-to-ten year period for use in dose calculations. The initial development of the HERMES model was based on a study of the region comprising the upper Mississippi and lower Missouri River basins, excluding the Chicago metropolitan area. To estimate the effects on dose in the study area caused by air transport of radionuclides from adjacent regions, an "air envelope" some 200 miles in width was included around the study area. Considerations in the study included the operation of 400,000 MW generating capacity power plants (nuclear and fossil) at 186 separate sites. The air transport code (ARTRAN) utilizes monthly climatological data applied to standard mathematical models for diffusion, deposition, and transport. The water transport code (WTRAN) calculates diffusion from emission points, concentrations in sediments and surface water at each location requested, and ground water transport. The code (DOSE) considers exposure to the whole body and six specific organs in (1) direct submersion in air or water, (2) inhalation, (3) external exposure from surface contamination, and (4) ingestion of food and water over numerous food-chain pathways. Life habits and dietary differences are also considered in the code (LPM). Present structure allows calculations for up to 50 radionuclides; 200 release points; and 300 receptor locations. More recent applications have been for the Tennessee Valley region and Southwest Environmental Study.

J. F. Fletcher, W. L. Dotson
Hanford Engineering Development Laboratory
Richland, WA 99352
509-942-6523; FTS 444-6523
HEDL-TME-71-168; 759 pp., 1971

Source - Reference #18: p.305

POLLUTANTS CARCINOGENS

Model - HYBRID: A Computer Program for Rapidly Solving Flowing or Static Chemical kinetic Involving Many Chemical Species

Purpose - This computer program evaluates problems involving chemically reacting gas mixtures.

Description - A HYBRID chemical kinetic computer program was assembled which provides a rapid solution to problems involving flowing or static, chemically reacting, gas mixtures. The computer program uses existing subroutines for problem setup, initialization, and preliminary calculations and incorporates a stiff ordinary differential equation solution technique. A number of check cases were recomputed with the HYBRID program and the results were almost identical to those previously obtained. The computational time saving was demonstrated with a propane-oxygen-argon shock tube combustion problem involving 31 chemical species and 64 reactions. Information is available to enable potential users to prepare an input data deck for the calculation of a problem.

A. G. McLain, C. S. R. Rao
National Aeronautics and Space Administration
Langley Research Center
Langley Station, VA (USA)
July 1976

Source - Reference 27, Item 51

Model - IMGRID

Purpose - IMGRID can be used for land management; social and environmental impact analysis; ecosystem definition; and demographic, economic, and social trend analysis.

Description - IMGRID requires the definition of the geographic region of concern. This region is subdivided into a grid of arbitrary fineness. To each grid cell numerical values are assigned. Each value may represent the presence or absence of whatever is being studied within that grid cell, or more generally, the degree to which a given object or subject of study is present within the grid cell. For example, a value for the density of hardwoods within each cell might be entered into that grid.

Once these inputs are provided, IMGRID allows for some data manipulation, such as cumulating the values of adjacent grid cells in order to identify concentrations of, say, hardwoods.

The most important facet of IMGRID is that it permits overlays of different grids, such as soil type, population density, land use, and human behavior space among many others. This overlay capacity permits the user to develop an integrated systems view of the area under study, and to simulate consequences of man-made or natural (or both) changes to a given system, of to interactions among different types of systems.

David F. Sinton
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Harvard Graduate School of Design
Cambridge, Mass.

Source - Reference: Sinton, et al., IMGRID: A System for Manipulating Information in a Grid Cell Data File (copy available from SAI/OR).

FUEL PROJECTION

Model - KWIKPLAN; Fuel Cycle Requirement Projection Code.

Purpose - Models fuel cycles, reprocessing loads, mining requirements, fuel usage, recycle stockpile for given power levels and reprocessing capacities.

Description - This code predicts reprocessing loads, load-rated exposure, U/Th mining requirements, Pu produced/recycled/stockpiled. Requires reactor life mode (i.e., charge and discharge each year), power levels and reactor composition. It can be used in conjunction with WASPR.

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Source - Reference #5: ORNL/TM - 5880

Model - LUSP

Purpose - LUSP was intended as a decision aid in the siting of power plants. Without substantial modifications, the program may be used for siting any type of facility, or more generally, for a wide variety of planning, impact and land use analyses.

Description - As with IMGRID, a map of the area under study is overlaid by a grid of arbitrary cell size. Each cell may then be characterized by up to 99 variables, although practice to date has been to limit cell characterization to around 50 variables, using the remaining 49 variable "slots" to store what are called "suitability scores." The "suitability score" for each cell is a weighted average of sums of the products of "compatibility indices" for each variable and "importance weights" for each variable. A "compatibility index" is a measure of the degree to which a characteristic of a cell (i.e., a variable) is compatible with the requirements of a power plant. The "importance weight" is a measure of the significance of a given cell characteristic (variable) for the siting of a power plant.

Once suitability scores are computed, the results are shown graphically, with the suitability of each cell being indicated by the shading of the cell. LUSP allows the variation of "importance weights," thus permitting the user to determine "suitability" with emphases on different types of variables, such as socioeconomics, physical characteristics, or access to transportation.

When the "suitability score" cells are used for other variables, then LUSP becomes essentially similar to IMGRID.

J. E. Dobson, J. S. Jolbert
Energy Division
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Oak Ridge, TN.

Source - Reference: J. S. Jolbert and J. E. Dobson, A Cell Based Land Use Screening Procedure for Regional Siting Analysis, ORNL/NUREG/TH-80.

Model - MAPPER

Purpose - This code is useful in forecasting equipment requirements.

Description - MAPPER is a computer program for predicting equipment requirements. It was designed as an aid to management and can interpret component production requirements backward from shipping schedules to the process of interest, calculate equipment capacity, display six months prior equipment utilization and process yield data.

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Source - Reference: R. J. DiPrima, "Manufacturing Program for Predicting Equipment Requirements (MAPPER)," GEPP-103, 1973.

WASTE PROJECTIONS

Model - NIMROD: The Forecasting of Radioactive Wastes.

Purpose - This code is used in simulating movement of radionuclides through the fuel cycle.

Description - A mathematical model developed to represent generation and subsequent movements of radionuclides arising in a nuclear power program. This model has been written into a computer program, NIMROD, by means of which estimates may be obtained of the inventories and throughputs of radionuclides in nuclear installations, including reprocessing plants and storage facilities. The operation and application of the model are illustrated by results obtained on the basis of a recent forecast of the nuclear power program in the UK up to the year 2000 A.D. Present results indicate that the quantities of long lived radioactive wastes resulting from the reprocessing of fast reactor fuel will not be markedly greater than those from current types of thermal reactors.

A. Martin, H. (Mrs.) Apsimon, OECD Nuclear Energy Agency and the International Atomic Energy Agency, OECD-Paris 1972-OCDE. Paper given at Symposium on Management of Radioactive Wastes from Fuel Reprocessing, 1972, pp. 55-75.

Source - Reference #26: Item 893.

Model - RAMM: A System of Computer Programs for Radionuclide Pathway Analysis Calculations

Purpose - A generalized system of computer programs to analyze the movement of radionuclides through the environment to man.

Description - A generalized system of computer programs, designated RAMM (Radioactive Materials Management) system, has been developed to assist in the analysis of the movement of radionuclides through the environment to man. RAMM incorporates the GASP IV continuous/discrete simulation system. A nodal approach is used whereby the system to be analyzed is split up into parts small enough that the distribution of nuclides within the node may be taken to be homogenous. Pathways are defined between nodes, and appropriate transfer coefficients are input or generated. Nodes are general "containers of nuclides" and may be volumes, such as a volume of water or a body organ, or surfaces such as a square meter of land surface. Nodes may be defined as belonging to streams within which movement may be by transportation as well as by diffusion. Output includes the time dependent contents of the nodes and dose rates, integrated doses and dose commitments of selected nodes.

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Source - Reference #6: p.149

Model - REDIQ

Purpose - This model calculates risk equivalence of dosage from internal and external irradiation.

Description - The computer program REDIQ calculates the risk equivalence of dosage from internally deposited radionuclides to dosage from external whole-body irradiation. The calculation gives an estimate of the microcurie intake per nuclide that would result in a risk equivalent to receiving one rem of external whole-body irradiation. The program allows for internal deposition resulting from either inhalation of radioactive aerosols or ingestion of contaminated food. The inhalation portion of REDIQ was taken from the computer program DACRIN, which uses the models of the respiratory tract adopted by the Task Group on Lung Dynamics. REDIQ also uses a simple exponential model for retention by an organ of interest, and the gastrointestinal tract model of the International Commission on Radiological Protection (ICRP).

For each nuclide specified, the program first calculates the radiation dose per microcurie intake by inhalation or ingestion to any of 23 organs and tissues. A maximum of ten organs may be specified for any one case. The values for dose per microcurie intake are then coupled with relative risk values for each organ being considered, to arrive at the estimated intake equivalent to one rem of external whole-body irradiation.

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Source - Reference #8: p.208

Model - STRAP II: Risk Evaluation for Stack Releases

Purpose - A method of calculating the risk to the population distribution around a reactor site is presented for both ground level and elevated releases.

Description - The reactor is assumed to satisfy a control curve of the Farmer type for accidental releases of radioactivity, and the dose-risk relationship is assumed to be simple power law. Results are presented in which iodine is imagined to be released, on a number of typical sites. The resulting frequency distributions of thyroid cancer have been calculated and are given in the form of frequency-casualty curves (f-N curves).

The program depends on having input the number of rem per curie air concentration for a given radionuclide and the number of casualties of a given type per rem for that radionuclide.

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Risley, England

Source - Reference #6: p.121

RISK ASSESSMENT

Model - SWIFT: Risk of Methodology for Geologic Disposal of Radioactive Waste: The Sandia Waste Isolation Flow and Transport Model

Purpose - The model was developed for use by NRC in the analysis of deep geological nuclear waste disposal facilities.

Description - It is based upon an existing model which treats the injection of liquid chemical wastes into deep saline aquifers. Complete documentation of SWIFT is provided. Comparison of SWIFT results with the analytical solution for constant velocity and diffusivity condition and with the origen code results for static conditions is presented. A discussion of possible future developments is given.

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Source - Reference #26: p. 8

Model - UTM (Unified Transport Model)*

Purpose - The Unified Transport Model (UTM) allows simulation of the transport, accumulation, and redistribution of trace contaminants in the environment.

Description - The air, land, and aquatic systems are represented by three major model components, designed to be run in sequence. The atmospheric component is based upon a Gaussian plume model and calculates deposition rates of aerosols for any point within a watershed. Concentrations of airborne aerosols at ground level are also calculated. The model includes consideration of point, area, line, and windblown sources for air pollutants. Deposition occurs by dry fallout and also by washout caused by rain falling through the plume. Air concentrations and depositions depend upon source strength, atmospheric stability, and wind speed and direction patterns. The spatial resolution of the atmospheric module now extends to a radius of 50 kilometers from any point source. One can use the model to simulate larger areas by constructing a mosaic of sub-area calculations. The deposition values calculated by the atmospheric model are used for input to the land component of the UTM.

The terrestrial component is structured to receive atmospheric wet and dryfall input to a watershed canopy and then simulate its movement until it is discharged in streamflow. The model simulates the amount of material washed from the canopy to the land surface during rainfall and allows for the exchange and uptake or adsorption of materials on surface soil. Surface runoff and scouring of soil particles are considered together with leaching of trace elements into the soil profile. An experimentally derived equilibrium distribution coefficient is used to estimate the concentrations of contaminants in subsurface soil water. This estimated concentration and the rate of soil water drainage are combined to estimate a subsurface input to the stream channel.

Finally, the outputs from the terrestrial component of the UTM enter the channel component, where flows are routed using a kinematic wave approximation. This portion of the program simulates transport of dissolved and particulate materials in streamflow. Suspended and bedload transport are considered by the model. Mixing and exchange between the aqueous and solid phases for the particular chemical species of concern are also simulated. If point-source discharges of known strength are released to the stream, the channel component is capable of simulating their introduction and subsequent transport.

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Oak Ridge, TN 37830

Source - Reference #3

*Program components of the UTM appear in the "Other LLW Models" category.

Program components of the Unified Transport Model

<u>Model Name</u>	<u>Model description and linkages</u>
ATM	Calculates the atmospheric transport and concentration and wet and dryfall deposition of trace contaminants originating from point sources, area sources, line sources, and windblown sources. Operates as stand alone model (monthly resolution) or linked with PRECIP.
CERES	Calculates plant growth and respiration, standing crop biomass of leaves, stems, fruits and roots, and storage pools of sugars, live tissue, and dead or woody tissue. Also computes translocation of carriers (transpired water and phloem sugar movement). Has been used with the linked PROSPR-LAND package.
CHNSED	Calculates sediment transport and the exchange of contaminants between water and mobilized sediments in open channel flow. Depends upon the HTM-CHANL linkage to derive water and sediment inputs. Uses SEDTRN model to compute amount and composition of bed and suspended sediment load. Could be used with the LAND-PROSPR-CHANL linkage.
CHANL	Calculates open channel flow hydraulics for natural channels and lakes or ponds, using a kinematic wave approximation. Generates hydrographs for as many as 3 locations in a basin with as many as 7 stream reaches. Depends upon specification of channel inflow rates at 30-minute intervals.
DIFMAS	Calculates mass flow of solutes carried by soil water to the root/soil interface, and allows for diffusion in response to a concentration gradient. Depends upon the PROSPR-CERES-SCEHM linkage for specifying soil water flow, root density, and solute concentrations.
DRYADS	Calculates the uptake of contaminants through leaves and roots and the uptake of gases by leaves. Depends upon the PROSPR-CERES-SCEHM-DIFMAS linkage.
GENCRD	An interactive program used to generate a rectangular or polar coordinate grid of sampling points for use as input for the ATM. The toxicant deposition rates computed by ATM and the coordinates for these sampling points can then be used to obtain deposition rate isopleths or to obtain an area weighted deposition rate for a land segment of arbitrary geometry.
HTM	Calculates runoff, erosion, and ion exchange and transport of contaminants and sediments to a stream channel (reach). It is based upon the Stanford Watershed Model, and runs as an integral part of the Wisconsin Hydrologic Transport model (WHTM).
LAND	Control program for the terrestrial components of the UTM. Establishes climatic data files and accepts model parameters and initial conditions, and generates runoff input files for the aquatic component of the UTM. Depends upon PRECIP for water input, and can use deposition data from ATM.

ODMOD Calculates soil water potential and concentration of trace contaminant in a many-layered pseudo two-dimensional soil. Operates as a stand-alone model.

OPTRM Determines an optimal set of model parameters read by the LAND component of the UTM. An iterative execution of LAND and CHANL is used to minimize an objective function that quantifies the dissimilarity between observed and simulated flow or contaminant transport values.

PROSPR Simulates atmosphere-plant-soil moisture relations on a day-to-day or hourly basis. Calculates soil water potential and content in as many as 8 soil layers, evapotranspiration, and plant water potentials. Operates as a stand alone model (daily) or in conjunction with LAND (hourly or quarter-hourly).

PRECIP Accepts and creates files for precipitation and wetfall deposition data, and maintains a master inventory file for type and amount of data stored. PRECIP controls the assembly of the precipitation and deposition data that are input to LAND. Operates as a stand alone model or as an integral part of the WHTM or with the ATM.

PNTSRC Allows the introduction of average daily point-source inputs of water and contaminants to any specified reach in the channel system. Depends upon CHANL for operation with the UTM.

SCEHM Simulates the transport of heavy metals through the soil system in a forested watershed; including deposition, infiltration as a function of solubility, ion exchange, and mass transport in saturated and unsaturated drainage. Depends upon PROSPR, and is usually operated with PRECIP, ATM, and LAND.

SEDTRN Computes sediment transport rate as both suspended and bed load material. Also calculates particle size composition of the sediment using an iterative procedure and the composition of stream bed materials. Operates as a stand-alone model with the driver code CH, using input flow data, or may be operated with simulated flow data provided by the CHNSED version of CHANL.

SNOMLT Simulates the energy balance on a snowpack, including consideration of radiation (short-and long-wave), convection, advection, ground heat, and snowpack (thermal) quality. Depends upon LAND and PRECIP.

SOLAR Adjusts daily observations of solar radiation for the slope and azimuth of a specified watershed segment and distributes the daily total into hourly increments based on solar altitude. Operates as a stand-alone model or together with LAND.

SUBSRF Simulates runoff from hydrologic (variable) source areas, distributes unsaturated flow between stream input and deep soils, and estimates groundwater storage and flow. Depends upon the LAND-PROSPR linkage.

SULCAL Calculates the rate of oxidation of SO_2 to various species of sulfate dissolved in aerosol droplets or in the form of particles of ammonium sulfate as a function of time and distance from the SO_2 source. Operates as stand-alone model or coupled to the ATM.

WASTE PROJECTIONS

Model - WASPR: Waste Projection Code.

Purpose - This computer program was designed to calculate the projected volume and radioactivity of high-level waste, intermediate-level alpha waste, nontransuranic waste and ore tailings. It has been used to calculate additional waste types, spent fuel accumulation, and shipping requirements.

Description - A program has been written to calculate the volume, radioactivity, thermal power, isotopic composition, and toxicity of various waste streams resulting from projections of power levels of several reactor types in a nuclear economy. The program uses mass-flow projections, a description of waste characteristics, and reactor discharge compositions to produce tabular and isotopic output in a form described by the user. ORIGEN routines are used to calculate the effect of decay during and after the accumulation.

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Source - Personal communication memorandum from Charles W. Alexander, Engineering Coordinator and Analysis Section, Chemical Technology Division, Oak Ridge National Laboratory.

MANAGEMENT AND PLANNING
WASTE INVENTORY

Model - WASTRAC

Purpose - Waste processing logistics calculations.

Description - WASTRAC has been developed to model storage, treatment, packaging, and shipment to disposal of waste streams. WASTRAC computes waste volume and waste isotopics (quantity of each radionuclide). Waste volume is a function of year, waste type, and waste management step. The output of WASTRAC is the waste volume and curies of each isotope in each waste stream at each step in the waste management system. Each treated waste stream is classified by container type and by the surface dose class for the treated waste containers.

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BNL
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Source - Reference: U.S. Department of Energy, "Technology for Commercial Radioactive Waste Management," DOE/ET-0028, May 1979.

RISK ANALYSIS

Model - Analytical Model for Computation of Reliability of Waste Management Facilities with Intermediate Storages.

Purpose - This code is used in determining reliability of waste management facilities.

Description - A high reliability is called for in waste management facilities within the fuel cycle of nuclear power stations which can be fulfilled by providing intermediate storage facilities and reserve capacities. A model based on the theory of Markov processes is described which allows computation of reliability characteristics of waste management facilities containing intermediate storage facilities. The application of the model is demonstrated by an example.

A. Kallweit; F. Schumacher, Kernforschungszentrum Karlsruhe (German, F.R.). Inst. fuer Datenverarbeitung in der Technik, January 1977.

Source - Reference #26: Item 1105.

Model - A Pathology and Risk Assessment Model.

Purpose - This model is related to the health hazards of energy-related chemical and radioactive environmental pollutants.

Description - A computer program was developed that takes the existing mortality and fertility data on a given population and applies dose-response coefficients and estimated increments of exposure to chemical or radioactive effluents and derives the excess deaths by age and sex for 5-year intervals. The program was used in an analysis of the health effects of airborne coal combustion effluents.

M. W. Rosenthal, (Ed), "Pathology and Risk Assessment", Division of Biological and Medical Research Annual Report, 1976, Argonne National Laboratory, ANL-77-55, pp. 75-97.

Source - Reference #25: p. 172.

GENERAL TRANSPORT

Model - General Model for Evaluating Transport of Radioactive Products Released to Environment and its Consequences.

Purpose - The model describes transport of radionuclides released from normal operation of nuclear power plant.

Description - A mathematical model is described for the evaluation of the transport and behavior of radioactive products released into the environment during the operation of nuclear power plants. It is based on the behavior of the products on the main protective barriers of nuclear power plants. A block diagram is presented of the model and the respective main programs are characterized.

Hladky, E.; Kubik, I.; Moraveck, J.
Vyskumny Ustav Energeticky,
Jaslcuske Bohunice, Czechoslovakia.

Source - Reference #6: pg. 138.

Model - Land Requirement for a Radioactive Waste Disposal Yard

Purpose - This model estimates the intake by humans of radionuclides through food and air.

Description - A model and the rationale were presented with respect to land use requirements for a hypothetical waste burial site. The thrust of the study was to minimize the intake by humans, of radionuclides through the food and air. A to-space transportation diffusion equation was used to describe the migration of the radionuclides in groundwater. The numerical solution was obtained by solving the equation by Crank-Nicolson type differential approximation and successive over relaxation. A sample run was made for a power plant with a total output of 2000 MWe. Numerous environmental land requirements and socio-political factors were considered. With this model it is possible to locate a burial site which ensures the greatest radiological safety. To locate burial site it is necessary to include a zone where ground water use is prohibited; a zone where use is restricted and a buffer zone. The necessary land area will increase with increasing permeability coefficient, decreasing distribution factor and increasing stratum porosity. Variations in the diffusion coefficient do not change the land requirement greatly.

Inoue, Y. and S. Morisawa
Kyoto University
Department of Sanitary Engineering
Kyoto, Japan
ORNL-TM-4444; 13 pp.
1976

Source - Reference #11: p. 149.

Model - Modeling of Environmental Pathways and Radiation Doses from Nuclear Facilities

Purpose - A computer model was developed which calculates total annual radiation doses and 50-year dose commitments to several categories of persons at population centers and continues these calculated doses into integrated (man-rem) annual and 50-year doses for large populations. The application to LLW management is general.

Description - The dose model was designed as one portion of an overall computer program developed to delineate the nuclear facilities expected in the year 2000, the radionuclides released to air and water, their diffusion, dispersion, and reconcentration in the environment, and the resulting radiation doses to people. Equations for calculating dose factors were derived from those given by the International Commission on Radiological Protection (ICRP). Effective decay energies for various radionuclides were calculated from the ICRP model, which assumes that all the radionuclide is in the center of a spherical organ with an appropriate effective radius. Where data were lacking, metabolic parameters for the Standard Man were used for other ages as well. The model includes a sub-routine which calculates radionuclide concentrations in a wide variety of foods at time of harvest from concentrations in air, irrigation water, and soil. The latter concentrations are output from previous portions of the overall computer program. The tremendous variety of data required for proper dose assessment is not always available in the literature. Such data has been extrapolated from environmental studies of fallout nuclides and from planned laboratory and field studies of a limited number of nuclides.

J. K. Soldat
Battelle, Pacific Northwest Laboratories
Richland, WA 99352

Source - Reference #6: p.116

GENERAL TRANSPORT
DOSIMETRY

Model - Nevada Applied Ecology Group Plutonium Study Modeling Program: Plutonium Transport and Dose Estimation Model.

Purpose - This model predicts Pu-239 transport and radiation dose.

Description - A computer program based on a matrix exponential method was used to solve a system of ordinary differential equations which simulate the behavior of Pu-239 in desert ecosystems such as those found at and near the Nevada Test Site. The model was used to estimate the rates of Pu-239 transport, via several environmental pathways, to Standard Man, who was assumed to live in a contaminated area. These estimates were then used to calculate radiation doses and dose commitments, as a function of time, to different organs. The model provides a method for evaluating the potential radiological hazard to man due to the presence of Pu-239 in a given area. However, the studies designed to implement the model, by providing accurate estimates of critical parameters, are still in progress. Therefore, the results to date are incomplete and inconclusive. On the basis of present assumptions and parameter values, the model indicates a 70-year dose commitment to the pulmonary lymph nodes of 13.6 rem per pCi (Pu-239)/g (soil).

W. E. Martin; S. G. Bloom; R. J. Yorde, Jr., Battelle Columbus Laboratories, Columbus, OH, July 1974. CONF-731048; NVO-142; Part of Dunaway, P. B. and White, M.G. (Eds.), The Dynamics of Plutonium in Desert Environments, Proceedings of the NAEG Plutonium Environmental Studies Program Symposium held in Las Vegas, Nevada, October 2-3, 1973, (p. 331-360), 369 p.

Source - Reference #26: Item 412.

RISK ASSESSMENT

Model - Transportation Safety Studies Model.

Purpose - A generic model of radioactive materials transportation risks is being developed; as a part of this development, transportation risks for LLW are being considered.

Description - The objective of the Transportation Safety Studies Program is to develop and use a model for calculating the risks associated with the shipping of radioactive materials. An assessment of the risk in shipment of chlorine by rail has been initiated. A fault tree indicating the various ways that chlorine can be released during transport has been drawn and other system description information has been gathered. Work on an assessment of the risk in transporting UF_6 continued. The system description has been completed. Fault trees have been drawn, and a survey questionnaire to obtain human factor data has been produced. Efforts to develop transportation accident environment information for the large UF_6 containers were started. Work also continued on developing an assessment of the risk in the shipment of low-level beta-gamma wastes. The dose conversion factors and waste dispersion fractions have been defined for the beta-gamma wastes.

L. D. Williams; 1976, March. BNWL-1978
Nuclear Waste Management and Transportation Quarterly
Progress Report
October through December, 1975,
A.M. Platt (Comp.), (pp. 51-55), 63 pp. (BNWL-1978)
Battelle-Pacific Northwest Laboratories
Richland, WA

Source - Reference #11: pp. 8,f.

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3.0 LOW LEVEL WASTE MONITORING TECHNIQUES AND EQUIPMENT

The following sections describe surveillance procedures applicable to low-level radioactive waste disposal (Section 3.1) and procedures to improve the containment of low-level radioactive waste (Section 3.2) at the disposal site. The discussion presented in Section 3.1 is the main emphasis of this portion of the document, while Section 3.2 is a less exhaustive treatment of the handling and storage of radioactive wastes. In Section 3.1, the basis for reappraisal of the requirements for understanding site dynamics is presented; followed by a generic discussion of monitoring equipment, instrumentation, and techniques including studies of gas emanations from burial grounds, borehole logging techniques, and aerial surveillance capabilities. After this discussion, three case studies are presented, which describe monitoring techniques, procedures and instrumentation of three different sites currently used for subsurface disposal of low level wastes.

In Section 3.2, long term containment requirements, aspects of volume reduction, preventive practices which reduce risks of on-site management of radioactive wastes, and in-situ detection of transuranium wastes are addressed. A brief summary and conclusions are presented in Section 3.3.

3.1 MONITORING PROCEDURES USED IN SURVEILLANCE OF LOW-LEVEL RADIOACTIVE WASTE DISPOSAL SITES

INTRODUCTION

Section 3.1 covers monitoring procedures used in the surveillance of LLW disposal sites. This section presents general background material, a general discussion of monitoring technology and a discussion of monitoring methods used at Maxey Flats, West Valley, and Idaho National Engineering Laboratory (INEL). Geophysical well logs, aerial measuring systems, radiological sensors, camera and other systems are also addressed.

Background

Some sites for land disposal of low- and intermediate-level radioactive wastes have been operating for more than 30 years. Although most low-level radioactive waste has been in the form of solids disposed of in burial grounds, liquid wastes have been disposed of by discharge into the ground at Savannah River, Idaho, and Hanford. Less than high-level radioactive wastes have also been disposed of in hydro-fractured shale deposits at Oak Ridge (Weeren, 1979). Nevertheless, the combination of hydrologic characteristics and engineering features which would assure that radioactivity in such disposal sites would not create a public health hazard has not been determined (Comptroller General of the United States, 1976).

Earlier assumptions about secure containment of buried radioactive wastes are falling by the wayside as monitoring data are accumulated and the resulting uncertainty is spurring new research. One of the most significant discoveries has been that soluble radioactive materials leached from the burial point would not be automatically restrained from migrating through the ground by the ground's intrinsic binding properties. The belief that the ground's ion exchange (sorption) properties would trap and retain any dissociated radionuclides was prominent in waste management thinking well into the 1970's (Mayer, 1979). Radionuclide migrations from burial trenches of tens to hundreds of feet have been observed (Mayer, 1979). The development of planning to achieve a predetermined level of burial technology performance was proposed by ERDA on the heels of the Comptroller General's 1976 recommendations (Steger, 1979).

Unfortunately, a clear administrative decision as to what the predetermined level of burial and monitoring technology performance should be has not been made. Current NRC standards for protection (10 CFR 20; 25 FR 10914, November 17, 1960; and amendments through 43 FR 52202, November 9, 1978) for burial ground disposal of radioactive wastes are still relatively unstructured. Limitations are imposed on waste quality, burial depth, and burial frequency. Permissible human exposure

levels are scaled to background levels of each radioactive isotope. EPA-sponsored sampling and analytical procedures for verifying industrial releases of radionuclides (40 CFR, Part 136) and drinking water radionuclide levels (40 CFR 141; 40 FR 59565; December 24, 1975; 41 FR 28402, July, 1976) are generally standard procedures described in methods documents dating from the mid-1970's and earlier and thus may be out of date. Representative monitoring schedules devised by commercial burial site operators are presented in Table 1.

New disposal sites could be required as soon as the beginning of the next decade. The expectation that new burial locations will soon be required emphasizes the need for surveillance studies at existing burial grounds. These studies can provide information to appropriately select new disposal sites as well as assess the hazard of radionuclide release from the present sites.

The U.S.G.S. is now conducting geohydrologic studies at five commercial burial grounds (Robertson, 1979; Mayer, 1979). These existing disposal situations are being used as laboratories to develop new disposal site criteria (Robertson, 1979). DOE also has an active research and development program to determine proper practices for land disposal of solid low-level radioactive waste in relation to predetermined levels of performances (Steger, 1979; Webster, 1979). Fuel cycle wastes constitute an ever higher proportion of low-level wastes although they constituted less than one percent of the total in 1962 (Mayeer, 1979). Limits for the amounts of radioactive waste which can be safely stored are also under study.

Both studies and surveillance should encompass groundwater, air, vegetation, and soil assessments (Steger, 1979). Although monitoring in these media has been routinely conducted in burial ground surveillance programs, little basis existed for determining whether samples were obtained at the most satisfactory points (Comptroller General of the United States, 1976). The adequacy of surveillance programs to serve as a warning system for a potential human health risk, which is their primary

Table 1. Representative Monitoring Schedules at Commercial Burial Sites

Disposal site	Water	Air	Vegetation	Soil	Other
Barnwell	10 onsite wells, semiannually; offsite water supplies, annually.	Offsite, continuous.	Offsite, annually.	Offsite, weekly.	Offsite, animals, annually.
Beatty	1 onsite well, monthly; offsite wells, monthly.	Continuous.	Offsite, quarterly.	Offsite, quarterly.	None
Maxey Flats	8 onsite wells, monthly; offsite water samples, quarterly.	Continuous.	4 samples onsite, 4 offsite, quarterly.	4 samples onsite, 4 offsite, quarterly.	None
Richland	3 onsite wells, quarterly; offsite surface water, semiannually.	Continuous.	Onsite, quarterly.	Onsite, quarterly.	None
Sheffield	8 onsite wells, quarterly; offsite surface water, quarterly.	Continuous.	Offsite, quarterly.	Offsite, quarterly.	None
West Valley	2 onsite streams, quarterly; offsite surface water, weekly.	Offsite, continuous.	Offsite, annually.	Offsite, quarterly.	Offsite, animals and fish, semi-annually; milk, weekly.

Source: Comptroller General of the United States, 1976 .

justification, has been and remains in doubt until radionuclide transport processes are better understood. Table 2 gives a general overview of migration related uncertainties at selected disposal areas. Questions also remain regarding the biological transport mechanisms which could distribute radioactive materials. Depending on findings, measurement procedures presently employed in specialized research projects may be absorbed into required standard monitoring procedures.

In addition to studies of existing sites, extensive baseline studies are recommended by Steger for the selection of future disposal sites, with special emphasis to be given to the local geohydrological system, since water would be the most likely agent from transport of radionuclides from a future burial site (Steger, 1979).

In sum, the management of low-level waste has gone from a period of uncritical acceptance of assumptions about the safety of shallow land burial to a period of increasingly deep and systematic questioning, a (and often refutation) of those assumptions. As a result of this questioning, LLW management is entering a new period, that of siting and monitoring new disposal sites in a scientifically valid manner, calculated to ensure the safety and welfare of the public.

MONITORING TECHNOLOGY

General Considerations

In general, sample analyses have included gross radioactivity (alpha, beta, gamma) and specific radionuclides such as tritium (Comptroller General of the United States, 1976). The gross activity measurements have especially been used because of their low cost, speed, and ease of use (NCRP, 1976). The development of improved spectrometric counting systems, in particular for gamma rays and alpha particles, coupled with use of computers, and the need for specific radionuclide measurements for dose assessment and pathway analysis have obviated much of the utility of total activity measurements. Gamma-ray spectrometry has eliminated radiochemical analysis requirements for many radionuclides. When used in conjunction with group chemical separations for complex

Table 2. Information Needed at Selected Disposal Sites
For Predicting Rate and Direction of Migration

Disposal Site	Major Information needed related to the
Los Alamos Scientific Laboratory	<ul style="list-style-type: none"> --most likely paths of migration, --effects which layering and fractures may have on migration, -- net water infiltration from precipitation (the amount of water that is not evaporated or transpired and is free to move downward), --rate that radionuclides are dissolved by water, --rate of erosion that might exhume some buried wastes, and --amount of water which might be contaminated.
Idaho National Engineering Laboratory	<ul style="list-style-type: none"> --extent and orientation of fracturing in the geology underlying the site, --rate and direction of water infiltration, and --most likely paths of migration through the geological formations.
Hanford	<ul style="list-style-type: none"> --rate of infiltration, --rate and direction of ground water movement, and --interconnection between shallow and deep aquifers.
Beatty	<ul style="list-style-type: none"> --rate of infiltration and --direction and rate of ground water movement.
Barnwell	<ul style="list-style-type: none"> --extent of porous and permeable sand and gravel and --fluctuations in the water table.
Sheffield	<ul style="list-style-type: none"> --permeability of the soil, including geologic characteristics which may have high permeabilities, such as fissures in the glacial deposits, sand stringers, and coal seams; --depth to the water table and its fluctuations; and --direction and rate of ground water movement.

Table 2. Information Needed at Selected Disposal Sites
For Predicting Rate and Direction of Migration
(continued)

Disposal Site	Major Information needed related to
Maxey Flats	--extent and orientation of fracturing in the geology underlying the site and --direction and rate of ground water movement.
West Valley	--direction and rate of ground water movement, --source of water in and connection between sand deposits, --ion exchange capabilities of the soil, and --extent of fracturing

The information above was summarized from geological and other reports on disposal sites and supplemented by discussions with, and comments by officials and staffs of disposal site operators; ERDA, USGS, NCR, EPA, and various States. The information does not include every major disposal site and is not necessarily exhaustive for each site listed.

Source: Comptroller General of the United States, 1976.

mixtures, gamma-ray spectrometry can conveniently be used to assess nearly all combinations of gamma emitters. Thus, fewer beta emitters need to be analyzed using radiochemical techniques. Analysis of alpha emitters has been simplified by improved separation methods and spectrometric counting techniques (NCRP, 1976). Gross activity counting can be used as a check that specific analyses have accounted for alpha and beta activities in a sample, for surveying general radioactivity levels (recognizing over- and under-estimation of specific nuclides), and in repeated rapid measurements of samples whose relative radionuclide composition is known and constant (NCRP, 1976).

In general, improvements in analysis procedures are based on application and development of the specific analysis approaches cited above. Essentially similar approaches were being carried out a decade ago at nuclear power plants (Joint Committee on Atomic Energy, U.S. Congress, 1969). In addition to the refinement of such approaches, new sampling and preparation procedures for counting have been developed; complementing studies on factors influencing transport mechanics such as leach rates determination (lysimetric tests at existing burial grounds), organic complexing after burial, and ion exchange capacities are being carried out (Steger, 1979); and development of borehole geophysical techniques including direct measurement of subsurface radioactivity is underway (Steger, 1979).

A new feature of trench water sampling is the maintenance of anoxic conditions during collection and filtration. This procedure is followed because of the tendency for ferric hydroxide precipitation when the samples are exposed to air. The ferric hydroxide interferes with separation of the leachate (Weiss et al, 1979). The system as used at Maxey Flats includes plastic tubing, a peristaltic pump, an inert gas cylinder with a pressure regulation valve, sample bottle, waste valve, waste line coiled to act as an air barrier, and a waste tank. The sample bottle is initially filled with argon. Before the sample is taken, the lines are purged of air by diversion of trench water to a waste tank. The sample bottle is then flushed of gas by inflow of

trench water, the sample is taken, and argon is used to displace some of the sample at the top of the bottle to minimize the chance of breakage. The sample is cooled to, and maintained at, approximately 4°C before filtration. The filtration system consists of the sample bottle containing trench water, a filtration vessel with filter, two nitrogen cylinders with pressure regulation valves, an air barrier vent, and plastic tubing connecting the other components. After air is purged from the filtration system with nitrogen, the sample is transferred through the filter to the filtration vessel.

Radiochemical Procedures

Although the requirements for analysis of specific radioisotopes are dependent on the media in which they are found, the other analyses to be performed, the objectives of the analysis, and the resources available, certain methods have come to be acknowledged. These techniques are always subject to review and examination. They will be changed as the state-of-the-art advances. For example, all the trench water radionuclide measurements performed at Maxey Flats before 1976 are now held to be invalid. The samples were collected from sump pumps in which oxidation and precipitation probably occurred which did not take place in the rest of the trench (Husain et al., 1979). This situation spurred development of anaerobic sampling and filtration procedures (Hasain et al., 1979).

Table 3 presents a representative listing of procedures for analyzing different sample media for given isotopes. Purely instrumental methods, for instance, which do not require significant sample handling or modification, are not included. Most of the commonly identified radioisotopes of concern at the waste sites have been covered in the discussions of monitoring at specific sites.

Measurement of Radiation

This section is a summary discussion of instruments used in radiation measurement.

Table 3. Summary of Radiochemical Procedures for Environmental Samples

Analyte	Sample	Preparation: Dissolution	Chemical Separation	Method of Measure- ment	Detection Limit*
^7Be ^{24}Na ^{36}Cl ^{38}Cl	Precipitation, air	Filter paper— leach with acidic carrier solution	Cl separated as AgCl ; ^{24}Na measured in residue; other radionuclides removed with cation resin; Be separated as hy- droxide	Two parameter gamma-ray spectrometry	10 fCi l^{-1} (precipi- tation) 0.05 fCi m^{-3} (air)
^{14}C	Food, air	Combust, to CO_2	CO_2 purified by expansion, condensation, drying agents	Internal gas counter, an- ticoincidence shielded	5 pCi g^{-1} (carbon)
^{14}C	Water	Add oxalate carrier	C oxidized to CO_2 in acid solution, CaCO_3 collected	Beta counter (gas flow or liquid scintil- lation)	10–100 pCi (depend- ing on C content)
^{24}Na	Precipitation	Add Na carrier	Na separated by ion exchange, hydroxides scavenged, Na measured in filtrate	β - γ coincidence counter	0.02 pCi l^{-1}
^{32}P	Sea water	Add PO_4^{3-} car- rier	P oxidized with HClO_4 , NH_4 phosphomol- ybdate extracted into isoamyl alcohol; precipitated as MgNH_4PO_4	Beta counter	1 pCi l^{-1}
^{59}Fe	Various		$\text{Fe}(\text{OH})_3$ precipitated, dissolved, ex- tracted, and added to scintillation mix- ture; or hydroxide dissolved in H_3PO_4 , NH_4Cl and colorless complex counted	Liquid scintil- lation counter	0.5 pCi g^{-1} (iron)
^{131}I	Milk	Add HCHO and I carrier	I separated on anion-exchange resin, puri- fied by extraction; PdI_2 precipitated	Beta counter	0.25 pCi l^{-1}
^{137}Cs	Milk, bone, vegetation ash, soil, water	Fuse— Na_2CO_3 or leach— HNO_3	Ca precipitated; Cs separated on NH_4 phosphomolybdate, purified by ion ex- change, precipitated as Cs_2PtCl_6	Beta counter	1 pCi per sample
^{137}Cs	Milk, water	—	Ion-exchange on K cobaltihexacyanofer- rate	Gamma-ray spectrometry	0.01 to 10 pCi l^{-1} (varies with vol- ume)
^{137}Cs	Sea water	—	Cs separated on NH_4 phosphomolybdate, silica gel mixture; SiO_2 dissolved with HF	Gamma-ray spectrometry	0.1 pCi l^{-1}
^{141}Ce ^{144}Ce	Precipitation	Add Ce carrier	Ce separated by oxidation-reduction and solvent extraction cycles	Gamma-ray spectrometry with $\text{Ge}(\text{Li})$ detector	1 pCi per sample
^{210}Pb	Bone	Ignite—dis- solve in HBr	Pb extracted into quaternary amine; PbSO_4 precipitated and counted	Beta counter (^{210}Bi counted)	1 pCi per sample
^{210}Pb	Water, soil, ores	Treat with acids, fuse— KF and $\text{Na}_2\text{S}_2\text{O}_8$, dis- solve— HCl	Pb and Bi extracted into diethyl dithiocar- bamate; ^{210}Bi separated from Pb by ex- traction in dithizone	Beta counter (^{210}Bi counted)	1 pCi per sample
^{210}Pb ^{210}Po	Bone, tissue	Dissolve in mineral acids	^{210}Po deposited on Ag from HCl , ^{210}Pb de- termined by deposition of ^{210}Po after in- growth	Alpha counter	0.02 pCi per sample
^{210}Pb ^{210}Po	Sea water	Add carriers	Pb and Bi carriers precipitated with CaCO_3 , separated by hydroxide precipi- tation, ^{210}Po deposited on Ag for count- ing; ^{210}Pb determined by deposition of ^{210}Po after ingrowth	Alpha counter	0.1 pCi per sample

Table 3. Summary of Radiochemical Procedures for Environmental Samples
(continued)

Analyte	Sample	Preparation; Dissolution	Chemical Separation	Method of Measure- ment	Detection Limit*
²²⁶ Ra ²²⁸ Ra	Soil vegeta- tion	Plant—dissolve in acids; soil—ex- change with NH ₄ acetate	²²⁶ Ra, ²²⁸ Ba tracers and Ba carrier added; Ra precipitated with BaSO ₄ , separated from Ba by ion exchange; electrodepos- ited for counting	Alpha spec- trometry	1 fCi g ⁻¹
²²⁸ Ra ²²⁸ Th	Vegetation, food, soil, bone	Ash—dissolve mineral acids; soil— fuse Na ₂ CO ₃	Th extracted by ethylhexyl phosphoric acid, ²²⁴ Ra daughter removed with HNO ₃ after ingrowth and counted; Ra precipitated with PbSO ₄ , purified as PbBr ₂ , ²²⁸ Ac daughter extracted and counted	Alpha and beta counters	1 pCi Ra, 20 fCi Th per sam- ple
²³² Th	Bone	Ignite at 600°C	Irradiate with neutrons, dissolve in HCL, separate ²³³ Pa by anion exchange	Gamma-ray spectrometry of ²³³ Pa	0.1 ng g ⁻¹
Th	Various	Ash, dissolve with acids and	Coprecipitate with BaSO ₄ , dissolve in DTPA	Fluorescence of Th-morin complex	10 pg ml ⁻¹ 10 ng g ⁻¹
⁹⁰ Sr	Bone	Ignite, dissolve in HCl	⁹⁰ Y extracted into ethylhexyl phosphoric acid; impurities removed by amine ex- traction	Beta counter	1 pCi per sample
⁹⁰ Sr	Food vegeta- tion, tissue milk, soil, water	Evaporate, ig- nite, fuse with Na ₂ CO ₃ ; Soil—fuse with Na ₂ CO ₃ or leach with NaOH, HCl; ⁸⁸ Sr and Sr carrier added	Sr separated, purified by nitrate precipita- tions, ⁹⁰ Y precipitated and counted	Beta counter	0.5 pCi per sample
⁹⁰ Sr ¹³⁷ Cs	Sea water	Acidify—HCl; added car- riers	Cs removed by NH ₄ phosphomolybdate, purified, precipitated as Cs ₂ PtCl ₆ ; Sr precipitated, ⁹⁰ Y daughter separated and counted	Beta counter	0.5 pCi per sample
⁹⁹ Tc	Water	—	Tc purified by precipitation, solvent ex- traction; electrodeposited for counting	Beta counter	0.5 pCi l ⁻¹
^{108m} Ag ^{110m} Ag	Biological Samples	Grind in blender with water	Slurry treated with NaOH-AgCN solu- tion; Ag electroplated on Pt, dissolved, AgCl precipitated	Gamma-ray spectrometry (4π coinci- dence counter)	1 pCi per sample
¹³¹ I	Milk, Water	—	Milk—I first separated by anion ex- change. Milk and water—I extracted into CCl ₄ and toluene; and decolorized with UV light in presence of 2-methyl-1- butane	Liquid scintil- lation counter	0.3 pCi l ⁻¹
Th	Various	Dissolve as nec- essary	Coprecipitated with Ca oxalate, purified by ion-exchange	Colorimetric, with thorin or other dyes	1 μg
th-Cf	Soil	Treat with acids; fuse—KF, Na ₂ S ₂ O ₇ , dis- solve—HCl	Actinides coprecipitated with BaSO ₄ , sep- arated by solvent extraction after ad- justing oxidation states, electrodepos- ited for counting	Alpha spec- trometry	1 fCi g ⁻¹
U	Water	—	Extraction into methyl isobutyl ketone	Fluorescence of U in fused NaF	5 ng l ⁻¹

Table 3. Summary of Radiochemical Procedures for Environmental Samples
(continued)

Analyte	Sample	Preparation; Dissolution	Chemical Separation	Method of Measure- ment	Detection Limit ^a
²³⁷ Np ²³⁹ Pu	Pitchblende	Dissolve in mineral acids	Np(IV) extracted into trifluoroacetylacetonone, purified by anion exchange; Pu(III) coprecipitated with LaF ₃ and UF ₆ , purified by anion exchange and electrodeposited	Np—mass spectrometry Pu—alpha spectrometry	1 fCi Pu g ⁻¹ (sample) 0.4 ag Np g ⁻¹ (sample)
Pu	Soil, air particulates	Soil—ash, extract with hot HCl; particulates—ash, dissolve—mineral acids and fusion	Pu separated and purified by cation and anion exchange; electrodeposited for counting	Alpha spectrometry	1 fCi g ⁻¹
Pu	Soil	Fuse—Na ₂ CO ₃ , dissolve—HNO ₃	Phosphates precipitated and Pu purified by anion exchange; electrodeposited for counting	Alpha spectrometry	1 fCi g ⁻¹
Pu	Soil	Leach with mineral acids	Pu purified by anion exchange; electrodeposited for counting	Alpha spectrometry	1 fCi g ⁻¹
Pu	Water, air, soil, food, vegetation	Treat with mineral acids	Pu purified by anion exchange; electrodeposited for counting	Alpha spectrometry	1 fCi g ⁻¹

Limits are as reported in, or inferred from, references. Note that these limits are expressed in several units: weight weight/volume or weight, activity, activity/sample, activity/volume, or weight, and activity/weight element (i.e., specific activity).

Source: NCRP, 1976.

Direct continuous measurement devices are either integrating dosimeters or dose-rate instruments. Integrating dosimeters include thermoluminescent dosimeters (TLD), film, and ionization chambers. TLD's are the integrating dosimeter of choice, being sensitive and reliable and showing long-term stability. Various configurations and materials are employed. Claimed sensitivities are on the order of 0.2 mR. Although the dosimeters are inexpensive, a complete reader/dosimeter system costs in the thousands of dollars. LiF and CaF₂ are the most common TLD materials for environmental surveillance work. The TLD's are designed for specific types and energy ranges of radiation.

Environmental dose rates can be measured with various instruments. These include Geiger-Mueller counters, air ionization counters, pressure argon counters, and scintillation detectors. They usually have meter readout and some can be obtained with graph readouts. Dose rate ranges on the order of 10 μ R/hr and below to upwards of 100 μ R/hr are covered by this series of instruments. Accuracy is generally 20 percent but is ± 5 percent for the pressure argon chamber. The energy ranges are on the order of approximately 50 keV to 1.3 to 5 MeV. All these detectors can be used to measure gamma radiation and the Geiger-Mueller counter and air ionization chamber can also be used to measure beta particles.

The measurement of radioactivity in samples is generally done with three categories of instruments: gas ionization detectors, scintillation detectors or phosphors, and solid state detectors. Energy emitted in the radioactive decay event is converted into an electrical pulse which can be recorded. Total radioactivity can be recorded by summing the pulses over time interval or converting to a pulse rate. In spectral analysis, pulses are sorted out by energy and the number of pulses at each energy level is stored separately. A pulse height analyzer is used in this process.

The Geiger-Mueller counter is a sealed tube gas ionization detector. The tube contains a counting gas, anode, cathode and typically a second gas which provides pulse quenching characteristics. The counter characteristics include good sensitivity, high background, low counting

efficiency and inability to distinguish between types or energy of radiation. Shielding can be used to exclude lower energy beta particles. The GM counter is inexpensive, relatively trouble-free and can easily be used with simple rate meters or scalers. Almost any planchet is suitable.

End-window proportional counters are gas ionization detectors which can be used for counting moderate to high activity levels in samples which cannot be fixed on a planchet or sample holder.

The gas flow window counter ("low-background counter") can be used for beta and alpha analyses of samples in planchets. They are low-background only when background suppression such as anti-coincidence circuiting is used. Energy spectrometry is possible in the proportional mode. Some of these instruments have a moveable window. Windowless counting can be used to improve detection of very low beta energies such as from ^3H and ^{14}C . Certain designs produce a relatively good statistical counting accuracy. Counting efficiencies of 35 percent for ^{14}C and 50 percent for ^{90}Sr can be obtained with window flow counters. Gamma counting efficiency is very low--on the order of 1 to 5 percent.

Scintillation detectors are made of various materials from organic and inorganic crystals to liquid and solid solutions. The liquid scintillation counter is especially well suited to counting low energy beta emitters such as ^3H or ^{14}C . The sample is mixed with the liquid scintillation medium. Cooling may be required for the lowest levels of activity. Most detectors are coupled to an analyzer with at least two channels. More than one beta emitter can be counted if their E_{max} values differ by a factor of at least three.

A zinc sulfide scintillation counter can be used for alpha counting of environmental samples. It is not quite as sensitive as an internal proportional alpha counter with flat samples but is not subject to contamination.

The gamma scintillation spectrophotometer is a pulse height analyzer connected to a suitable scintillation detector. A single channel system is adequate for counting tracer activity but for low activity mixtures of nuclides the multichannel system is needed to control counting time. The detector system is typically a sodium iodide crystal optically coupled to a photomultiplier tube. Crystal size is important. Too large a crystal increases background. Too small a crystal will reduce counting efficiency. Efficiency is lower for higher energies.

A plastic scintillator has been developed as a beta detector. It has sensitivity to particles as low as 60 keV and 100 percent efficiency for beta particles passing through the protective foil window.

Solid state detectors or diodes show an instantaneous conductivity when high-energy particles or radiation interact with them. A high voltage supply is required. The solid state detectors are suitable for gross counting or energy spectrometry.

Surface barrier detectors are designed for detection of charged particles. Appropriate dimensions allow optimization for either alpha or beta particles. Normally spectrometry with this detector is performed in a vacuum chamber to minimize air degradation of particle energy. Gross counting may be done in the atmosphere. These detectors have low background and are especially adaptable to low-level counting.

Pulse height analyzers can be used with detectors to provide alpha, beta, or gamma energy spectrum analyses of various degrees. They vary from simple upper- and lower-level discrimination to systems capable of sorting energy into thousands of channels. Computers often have built-in pulse height analyzer capabilities. Various display and readout options are available.

Mass spectrometry is a valuable tool to discriminate related radio-nuclides which emit alpha radiation at energies which cannot be readily distinguished. Isotope analysis can be conducted with the appropriate

instrumentation. The best mass spectrographs are capable of measuring 107 atoms or about 4 fg (femto grams or 10^{-15} grams) of an actinide element (NCRP, 1976). Most of the above discussion of detector instrumentation is presented in AIF (1975). Table 4 presents a summary of laboratory counting equipment from this source.

Geophysical Well Logs

Not only can well logging be used to describe geological features but gamma spectral logging techniques provide in-situ data on the vertical and lateral distribution of gamma-emitting radioisotopes (Keys et al., 1979). Gamma spectrometry is possible with a spectral probe that will transmit energy dependent pulses. Photons from radioactive decay of different isotopes have characteristic energies. Neutron activation analysis is available to increase the range of elements which can be detected.

Borehole gamma spectrometry permits continuing monitoring without expensive new drilling and coring and provides identifications and semi-quantitative analyses in real time without waiting for laboratory results. This technique has been used at Oak Ridge and Maxey Flats. Together with measurements which may be used to interpret subsurface water movement, bore hole in-situ radionuclide determinations provide an excellent tool for the study of radionuclide migrations in ground water. Table 5 presents the isotopes which might be identified by bore hole gamma spectrometry. Alpha and beta particles cannot be detected since they do not penetrate the well casing and probe shell. Future research will probably improve the determination of reliable characteristic spectra for the individual gamma-emitting isotopes under bore hole conditions. Another area for improvement is the detection limit. Model studies indicate, that in the presence of natural radioactivity, the detection limit for an individual isotope, with photopeak energy greater than about 500 keV and gamma yield close to 100 percent is about 0.2 pCi/g specific activity. For the example of ^{60}Co and in terms of mass concentration, this is approximately one part in 10^{16} . Counting

Table 4. Laboratory Sample of Counting Equipment

Counter Type	Window	Gas	Applicable to Counting				Spectro- metry	Automatic Sample Changing	Service Life*	Price Range**
		GM Proportional	Alpha	Beta	Lo Beta	Gamma				
2 Pi gas flow	80-900 $\mu\text{gm}/\text{cm}^2$	Option	X	X	X		Option	Option	Poor to good	\$1,500-\$10,000
2 Pi gas flow	Windowless	Option	X	X	X		Option	Option	Poor to good	\$1,500-\$10,000
4 Pi gas flow	$\sim 900 \mu\text{gm}/\text{cm}^2$	Option	X	X	X		Option	Option	Fair to good	\$2,000-\$10,000
Internal gas	Windowless	Option			X		Option		Poor	N.A.
ZnS scintillator	$\sim 900 \mu\text{gm}/\text{cm}^2$		X				Option		Fair	\$2,000-\$5,000
Plastic scintillator	$\sim 800 \mu\text{gm}/\text{cm}^2$			X				Option	Good	\$2,000-\$5,000
Liquid scintillator			X	X	X		Option	Option	Good	\$10,000-\$20,000
NaI scintillator						X	Option	Option	Good	\$5,000-\$30,000
Surface barrier			X	X			Option		Fair	\$2,000-\$5,000
Volume drift						X	Option		Fair	\$10,000-\$35,000
Window analyzer			X	X	X	X	X		Good	\$1,000-\$4,000
Multi-channel analyzer			X	X	X	X	X		Poor to good	\$5,000-\$30,000

* Good 0-8 hours maintenance/year
 Fair 9-24 hours maintenance/year
 Poor >24 hours maintenance/year

** Prices are for complete counting systems including detector, pre amp, amplifier, discriminator, high voltage, scaler/ratemeter, etc., but excluding the cost of an energy analyzer unless it is an integral part of the counting system. 1973 prices.

N.A. Not Available

No entry indicates information not applicable

Source: AIF, 1975.

Table 5. Gamma Emitting Radioisotopes in Wastes that might be Identified by Borehole Spectrometry

Element	Mass Number (A)	Half Life	Energy of Most Important Gamma Photons (MeV)	Principal Means of Production
Kr	85	10.76 y	0.514	fission
Mn	54	313 d	0.835	activation
Mo	99	66 h	0.740, 0.140, 0.181	fission
Nd	147	11.06 d	0.091, 0.533	fission
Np	237	2.14×10^6 y	0.030, 0.086, 0.145	^{241}Am daughter
Nb	95	35.0 d	0.765	fission
Ru	103	39.5 d	0.497, 0.610	fission
Ru	106	368 d	0.512, 0.62	fission
Sm	151	87 y	0.022	fission
Na	22	2.62 y	0.511, 1.275	activation
Ag	$^{110\text{m}}$	255 d	0.658, 0.885	activation
Sr	89	52.7 d	0.91	activation
Te	$^{129\text{m}}$	34.1 d	0.027, 0.69, 0.466	fission
Te	132	77.7 h	0.230, 0.67, 0.773	fission
Tm	170	134 d	0.084	activation
Sn	113	115 d	0.255, 0.393	activation
Sn	$^{121\text{m}}$	76 y	0.037	activation
U	235	7.1×10^8 y	0.185	fuel
U	233	1.62×10^5 y	0.042, 0.097	activation
Y	91	58.8 d	1.21	fission
Zn	65	245 d	1.115	activation
Zr	95	65.5 d	0.724, 0.756	fission

*This table was compiled from a number of widely scattered sources in the literature. It lists those radioisotopes that have been detected or are likely to be detected as contaminants at waste disposal sites. List includes only radioisotopes with gamma energies high enough that detection in a borehole is thought possible under ideal conditions. Detection limits and the effect of borehole conditions and other radioisotopes in the environment are not yet known.

Source: Keys, et al., 1979.

Table 5. Gamma Emitting Radioisotopes in Wastes that might
be Identified by Borehole Spectrometry*
(Continued)

Element	Mass Number (A)	Half Life	Energy of Most Important Gamma Photons (MeV)	Principal Means of Production
Am	241	458 y	0.0596	²⁴¹ Pu daughter
Am	243	7.95 x 10 ³ y	0.075	activation
Sb	124	60.4 d	0.603	activation
Sb	125	2.7 y	0.428, 0.6	fission
Ba	140	12.8 d	0.537	fission
Cd	113 ^m	13.6 y	0.265	fission
Ce	141	32.5 d	0.145	activation
Ce	144	244 d	0.134	fission
Cs	134	2.046 y	0.604, 0.796	fission
Cs	137	30.0 y	0.662	fission
Cr	51	27.8 d	0.320	activation
Cm	243	32 y	0.209, 0.228, 0.278	activation
Cm	244	17.6 y	0.043	activation
Cm	245	9.3 x 10 ³ y	0.13, 0.173	activation
Co	57	270 d	0.122	activation
Co	58	71.3 d	0.810	activation
Co	60	5.263 y	1.173, 1.332	activation
Eu	152	12.7 y	0.122, 0.344, 1.408	activation
Eu	154	16 y	0.123, 0.724, 1.00, 1.278	activation
Eu	155	1.811 y	0.087, 0.105	activation
Eu	156	15.4 d	0.089, 0.812, 1.15, 1.24	daughter
Au	198	2.697 d	0.412	activation
I	129	1.7 x 10 ⁷ y	0.04	fission
I	131	8.05 d	0.364, 0.637	fission
Fe	59	45.6 d	1.095, 1.292	activation

error is greater if background activity is greater or several radioisotopes are present. The detection limit is also greater if only low energy gamma radiation is emitted.

Semiconductor detectors would seem to offer the prospect of an improvement in resolution of at least an order of magnitude over present scintillation detectors. However, the need to maintain the semiconductor detector at cryogenic temperatures seems prohibitive. The primary emphasis of future research is expected to be improvements in spectral data characterization and analysis.

Aerial Measuring Systems

In the event of accidental releases of nuclear materials or for use in routine documentation and surveillance, an aerial radionuclide detection and study system is available. The following account is excerpted from Jobst (1969).

The Aerial Measuring Systems (AMS) program has been developed by the Department of Energy (DOE) and its predecessors, the Atomic Energy Commission (AEC) and the Energy Research and Development Administration (ERDA), to ensure that all energy "programs and operations are conducted in a manner that will protect the public, ensure occupational safety and health, and preserve the environment in accordance with nationally accepted norms."

The objectives of AMS missions concern safety and environmental assessment and include (1) accident response, (2) baseline documentation, (3) accurate definition of man-made contribution to the radiation environment at sites of interest to DOE, and (4) integrated remote-sensing capability to support DOE-related programs. The AMS also provides routine radiological surveys of nuclear reactors and other licensed facilities for the Nuclear Regulatory Commission (NRC). One of the primary purposes of AMS is fast response to a major accident or natural disaster. Fixed-wing and rotary aircraft, fully equipped with remote-sensing systems, are based on both the East and West Coasts to permit

rapid response. The main operational base of AMS is in Las Vegas, Nev.; a smaller permanent staff is maintained at Andrews Air Force Base in Washington, D. C. The AMS supports the Interagency Radiological Assistance Program (IRAP).

AMS sensor systems include large-volume gamma scintillator arrays, neutron detectors, meteorological sensors, large-format aerial mapping cameras, multispectral aerial cameras, a multichannel scanner, air-sampling equipment, and extensive ground support equipment, including dedicated computers for data processing and a sophisticated multimode communication system. When not responding to an emergency or disaster situation, AMS is routinely used to provide background hydrological, geological, ecological, and radiological baseline data on sites of interest to DOE. These include all operating nuclear power plants, radioactive waste storage facilities, and all DOE nuclear and energy development sites.

Radiological Sensors: The AMS relies primarily on arrays of sodium iodide crystals to detect gamma radiation from aerial platforms. Crystals of various sizes and arrays of various weights and configurations are assembled as required.

For relatively small areas, AMS relies heavily on a pair of detector pods, each containing ten 12.7-cm-diameter by 5.1-cm-thick sodium iodide [NaI(Tl)] detectors. These are attached to the outside of the H-500 helicopter fuselage. Even though the H-500 has a limited range (500 km), its variable speed (0 to 100 km/hr) and low altitude capability provide a very flexible platform for precision radiation surveys. Survey patterns are regularly flown at an altitude of 30 m, with a speed of 100 km/hr and a line spacing of 30 m. In a typical day of survey work, the H-500s are airborne approximately 4 hr. By operating from a support base at the site, which is easily accomplished, this system can fly over 400 km of survey line and complete a 10-km² site within one day.

Gamma counts from all 20 detectors are summed. Count rates, gamma spectral data, aircraft position information, clock time, live time, radar altitude, and meteorological data are recorded on magnetic tape for subsequent analysis. Several real-time displays keep the two-man crew abreast of survey progress.

Special importance is attached to the vertical and horizontal position of the aircraft at all times. Since the source signal drops sharply with increasing altitude, radar altimeter readings that are accurate to ± 0.6 m are recorded every second. During processing, count rates are corrected for altitude variations.

Fixed reference points are established at each site by positioning a pair of transponders from a microwave ranging system (MRS). The master unit, in the helicopter, interrogates the slaves and calculates aircraft position to better than ± 3 m. These data are recorded each second. A computer, also linked to the ranging system, drives a steering indicator in the cockpit. By "flying the needle," the pilot can fly programmed survey lines with great accuracy. This, in turn, assures complete coverage of the site and provides maximum assurance that even weak radioactive sources will be detected.

All data from radiological and meteorological sensors, as well as time and position information, are automatically recorded by the Radiation and Environmental Data Acquisition and Recording (REDAR) System.

The sensitivity of various AMS detector system is a complicated function of crystal volume, survey altitude, gamma-ray energy, source distribution, aircraft speed, and other variables. Table 6 shows typical response parameters for a large array of crystals (40 detectors, 12.7 by 5.1 cm) flown at an altitude of 30 m by a helicopter.

In addition to the gamma-ray detector systems, AMS has also developed sensitive neutron detector arrays for aerial deployment. The detector is a 7-cm-diameter by 188 cm-long tube filled with ^3He under high pressure and surrounded by a polyethylene moderator. An array of 24 tubes

Table 6. Large-Array Conversion Factors

Isotope	Relaxation length, cm	Sample depth, cm	Detector response		
			nCi/m ² counts/sec	nR/hr* counts/sec	fCi/g counts/sec
¹³⁷ Cs	5	3	0.94	3.4	9.4
¹³⁷ Cs	5	10	0.94	3.4	5.4
¹³⁷ Cs	15	3	1.8	3.2	7.4
¹³⁷ Cs	15	10	1.8	3.2	6.0
⁶⁰ Co	5	3	0.51	7.65	5.1
⁶⁰ Co	5	10	0.51	7.65	3.0
⁶⁰ Co	15	3	0.94	7.24	3.8
⁶⁰ Co	15	10	0.94	7.24	3.1
²⁴¹ Am	5	3	8.3		83.0
²⁴¹ Am	5	10	8.3		48.0
²⁴¹ Am	15	3	2.0		81.0
²⁴¹ Am	15	10	2.0		65.0

*Measured at 1 m above ground.

with appropriate power supply and counting electronics can be quickly mounted on the H-500 or other helicopter. These arrays are useful for neutron sources, some of which emit gamma rays of such low energy that they are nearly undetectable with sensitive NaI detector arrays.

Camera Systems: AMS employs several camera systems, primarily on fixed-wing aircraft (Twin Bonanza, Convair 580-T, and King Air A-100). Occasionally, military aircraft are used as aerial platforms. One system consists of four Hasselblad 500 EL/M cameras mounted closely and aligned to yield identical fields of view. Synchronous framing provides multispectral photography on 70-mm film; 10 to 80 percent overlap between frames provides full coverage. By proper selection of film sensitivity and optical filter combinations, this system can be used to cover any four wavelength bands in the spectrum from visible to near-infrared (400 to 900 nm).

Imagery obtained with this system is of very high quality and extremely useful when comparative information regarding the spectral properties of surface objects is required. Either 80- or 50-mm lenses are used. With the latter, each frame covers 18 by 18 km, centered on the nuclear reactor or other site of interest.

The Hasselblad multispectral system is routinely used for documentary photographic studies near nuclear power plants. When provided with a photographic data base recorded at the time of plant startup, a photo interpreter can detect changes in vegetation type or growth stress in existing vegetation by comparing these with similar imagery obtained after the plant has been in operation for some time. Such changes may be related to power plant operation. Changing land use and demographic studies are made possible because complete coverage of each power plant is provided every few years by AMS.

Other Systems: The Twin Bonanza and King Air aircraft are equipped with gas- and particulate-sampling systems to permit real-time sampling of airborne contaminants. The King Air system permits isokinetic sampling with 13-cm-diameter filters at 24 liters/sec. For high-efficiency gamma

spectroscopy, the filters are analyzed on board with a sodium iodide detector. Filters are counted immediately after exposure and at carefully selected intervals thereafter to separate and identify the short- and long-lived isotopic contaminants. For high resolution, GeLi or high-purity Ge detectors are employed. These systems include various ports for whole gas sampling or the addition of other instruments, such as a nephelometer or a multistage Lundgren cascade impactor. Particles are collected on thin mylar films which can be analyzed by alpha-particle-induced X-ray fluorescence or by inductively coupled plasma optical spectroscopy.

MONITORING EXPERIENCE

The following case studies illustrate not only the use of specific monitoring instruments, but also many of the other techniques and procedures that might be followed in site monitoring.

Maxey Flats Monitoring Methods

Some details of the Maxey Flats monitoring procedures are presented below. Trench water analysis involved determination of inorganic, organic, and radiochemical components. Weiss et al., (1979) report measurements on water samples from ten trenches. The inorganic laboratory analysis consisted of: determination of dissolved cations by atomic absorption on filtered and acidified samples; determination of bicarbonate, carbonate, and alkalinity by titration with standard HCl; and anion determination by Auto Analyzer II techniques. Other measurements were taken in the field. Radiochemical analysis consisted of (1) gross alpha and gross beta activities measurements on evaporated aliquots by 2π gas flow counting; (2) tritium measurements by liquid scintillation counting of a distilled, unacidified sample aliquot; (3) ^{90}Sr determination by separation and counting of the sample equilibrium yttrium-90 in a low-level anticoincidence counter; and (4) measurement of gamma emitters and Americium-241 with a Ge(Li) detector and multi-channel analyzer. Filtered trench water samples were analyzed for

dissolved organic carbon with a Beckman Total Organic Carbon Analyzer. Subsequently organic compounds were extracted, concentrated, and analyzed by gas chromatography. A Perkin-Elmer Model 900 chromatograph with a flame ionization detector and a 6' x 1/8" stainless steel column packed with 5% OV-1 on chromosorb W (HP) 80/100 mesh was used in this preliminary analysis. Identification of extracted compounds was carried out by combined gas chromatography-mass spectrometry. Instrumentation for this analysis included a Hewlett-Packard (HP) gas chromatograph 5700/HP 5983A EI/CI dodecapole mass spectrometer and an HP 5933 data system. Comparison of known spectra from the HP library, EPA-NIH library, and Aldermaston Eight Peak Index of Mass Spectra was used in confirming identifications. Some peaks could not be identified.

Surveillance at Maxey Flats has also been concerned with radioactive releases at the evaporator plant and releases to the offsite environment (Montgomery and Blanchard, 1979; Montgomery et al., 1977). The trenches are repeatedly pumped in an attempt to keep them dry. The pumped leachate is stored in large tanks prior to volume reduction at the evaporator plant.

A sampler was specially designed to analyze stack discharges (Montgomery et al., 1977). At the same time atmospheric releases were sampled, in-plant samples of the liquid waste being evaporated were taken. The stack sampler consisted of a nylon nozzle inserted downward into the stack. The sampled air was pumped continuously to sample collectors through a rubber hose. Water vapor was removed by condensation in glass flasks immersed in ice-water baths. Subsequently, particles were moved by passage of the essentially dried air through a Mine Safety Appliances glass fiber filter (type 1106). Air flow rate was kept constant by a regulator on the vacuum pump and measured by a pre-calibrated Gelman type 8223 flow meter.

Water samples from the stack tests were composited in a plastic bottle and passed through a 0.8 μ m membrane filter to remove suspended solids. The filter was dried, weighed and mounted on a stainless steel planchet.

The air filter was sealed in a plastic bag. A yellow oily deposit prevented gross alpha particle measurements. Analysis of plastic bottles and rubber hose by gamma-ray spectrometry showed no adherence of radioactivity to internal surfaces.

Radionuclide detection limits are given in Table 7. These apply generally to the implant waste samples as well as the stack sample analyses. Measurement of radioactivity was by gamma-ray spectrometry or radiochemical techniques.

The implant samples were filtered with a membrane filter with a pore size of 0.45 μ m to remove suspended solids. If these solids were at a high level, a glass fiber prefilter was also used. The water and suspended solids fractions were analyzed by gamma-ray spectroscopy using Ge(Li) detectors. Selected samples were also analyzed to determine ^3H and ^{90}Sr contents. Water fractions were adjusted to standard volumes before counting.

In the gamma-ray spectrometry analyses, radionuclides which emit gamma rays of 40 to 2048 keV were analyzed with 55 or 85 cm³ Ge(Li) detectors coupled to 2048 channel pulse height analyzers. Air and membrane filters were laid on the detector face to be counted whereas filtered water was placed in a plastic container for this purpose. Detection efficiencies for sample geometries and volumes were determined by calibrations with mixed gamma-ray radioactivity standards for point sources and solutions prepared by the National Bureau of Standards.

Tritium in duplicate 1 ml aliquots of filtered water was diluted to 100 ml and distilled. One ml of distillate was mixed with 19 ml of Instagel scintillation solution and counted for three 100-minute periods in a liquid scintillation counter (Packard Tri-carb liquid scintillation spectrometer).

Strontium was chemically separated from fractions of the samples and counted for 100-minute intervals with low background Geiger-Mueller beta-particle detectors. Strontium 90 was distinguished from ^{89}Sr by

Table 7. Sensitivity Levels for Analyses of Evaporator Effluent,* $\mu\text{Ci/ml}$

Radionuclide	Air filter	Water	Membrane filter
12.3 -y ^3H	---	3×10^{-7}	---
5730 -y ^{14}C	---	3×10^{-8}	---
2.60 -y ^{22}Na	5×10^{-13}	1×10^{-8}	5×10^{-9}
313 -d ^{54}Mn	2×10^{-12}	1×10^{-8}	4×10^{-9}
2.7 -y ^{55}Fe	2×10^{-11}	3×10^{-8}	1×10^{-8}
5.26 -y ^{60}Co	2×10^{-12}	1×10^{-8}	1×10^{-9}
244 -d ^{65}Zn	2×10^{-12}	1×10^{-8}	1×10^{-9}
28.5 -d ^{90}Sr	1×10^{-14}	5×10^{-9}	1×10^{-10}
369 -d ^{106}Ru	1×10^{-11}	1×10^{-7}	4×10^{-9}
2.77 -y ^{125}Sb	2×10^{-12}	4×10^{-8}	2×10^{-9}
8.06 -d ^{131}I	1×10^{-12}	1×10^{-8}	1×10^{-9}
2.07 -y ^{134}Cs	1×10^{-12}	1×10^{-8}	1×10^{-9}
30.0 -y ^{137}Cs	1×10^{-12}	1×10^{-8}	1×10^{-9}
1600 -y ^{226}Ra	4×10^{-12}	1×10^{-7}	3×10^{-9}
6.13 -h ^{228}Ac	2×10^{-12}	2×10^{-8}	2×10^{-9}
87.7 -y ^{238}Pu	5×10^{-14}	4×10^{-11}	8×10^{-12}
2.4×10^4 -y ^{239}Pu	5×10^{-14}	4×10^{-11}	8×10^{-12}
433 -y ^{241}Am	1×10^{-12}	9×10^{-8}	2×10^{-9}
Gross alpha	---	1×10^{-9}	5×10^{-9}

* Values calculated at the 99.7% (3 σ) confidence level and based on typical sample volumes and counting intervals.

Source: Montgomery, et al., 1977.

separation and counting of the ^{90}Y daughter. This separation involves precipitation of carbonates and ion exchange separation of Ca and Sr with EDTA. After two weeks of ingrowth, ^{90}Y is separated, precipitated and counted.

Gross alpha-particle activity of the membrane filters or 100 ml of filtered water dried on a stainless steel planchet was counted for 900 minutes with internal proportional counters.

Plutonium was chemically separated from fractions of the stack samples with the addition of a known amount of ^{242}Pu to determine chemical yield. The plutonium was electrodeposited on stainless steel planchets and analyzed by alpha spectrometry for 4000 minutes. The spectrometer consisted of an Ortec 400 mm² diameter silicon surface barrier detector and a 512-channel pulse height analyzer. The detector resolution was approximately 50 keV fwhm (full width at half maximum) at 5-40 MeV and its efficiency was approximately 25 percent.

Carbon-14 in the filtered water fraction of the stack samples was oxidized to CO_2 , converted to CaCO_3 precipitate and measured with a low-background beta counter on a stainless steel planchet. Iron-55 was measured with a xenon-filled x-ray proportional counter and a multichannel pulse-height analyzer after chemical separation.

A more ambitious survey of environmental radioactivity than the routine program of the operator at Maxey Flats was carried out by the EPA during the period October, 1974 to August, 1975. Sampling of offsite well water, surface water, stream bed sediment and foods (milk, tomatoes, grapes, cucumbers, corn, and watermelon) was carried out.

Surface and well water grab samples were filtered through Whatman #40 filter paper (2 μm openings). After separation from the water, suspended sediment settled from a large volume surface water sample was processed in the same manner as stream bed sediment samples. Analyses of the water filtrates included $^3\text{H}(\text{HTO})$, ^{90}Sr , and gamma-ray emitting

radionuclides. Large volume samples of well water were subjected to more sensitive analyses. They were acidified to a pH of 2 in the field with concentrated HCl. Gamma-emitting radionuclides from 20 to 1 volumes were concentrated by ion exchange before analysis. Four to 1 volumes were used for ^{90}Sr analysis and twice for ^{226}Ra and ^{228}Ra .

Four to 1 samples of cow's milk were analyzed with gamma-ray spectrometry and for $^3\text{H}(\text{HTO})$, and ^{90}Sr . In some cases the cows' drinking water was also analyzed for ^3H .

Vegetable samples were analyzed for gamma-ray-emitting radionuclides, and ^3H . In selected cases ^{90}Sr was also determined.

Sediments from stream beds were obtained with a garden trowel from low points in the stream channels. Analyses included gamma-ray spectrometry and, in some cases, ^{90}Sr , ^{238}Pu , and ^{239}Pu .

The analytical methods for the offsite environmental monitoring study are presented in Table 8. These methods overlap with the procedures for samples from the evaporator plant.

West Valley Monitoring Methods

In an active research program conducted by the state of New York at the West Valley commercial low-level radioactive waste disposal operations, emanation of gaseous ^3H and ^{14}C through the trench covers has been identified as an important pathway for uncontrolled releases of radioactivity to the environment (Matuszek et al, 1979). West Valley is the first site where such emissions have been studied but they may be generated at all radioactive waste burial sites. Radionuclide concentrations of trench water pumped into liquid waste tanks at Maxey Flats are similar to those found at West Valley. The West Valley site resembles many other sites in the eastern U.S. and may provide a model system for generic monitoring procedures development. There are similarities at both West Valley and Maxey Flats with sanitary landfills. The concentrations of non-radioactive chemical species are similar and include

Table 8. Radiochemical Methods for Environmental and Test Well Samples

Sample type	Quantity analyzed	Radionuclide	Method
Water	1-2 l	γ -emitters (dissolved)	Filtration, evaporation to 100-200 ml, γ -spectrometry. ^A
Water	8-20 l	γ -emitters	Preconcentration by ion exchange (anion and cation), γ -spectrometry.
Water	4-8 ml	^3H (HTO)	Distillation, liquid scintillation counting. ^B
Water	1-4 l	^{90}Sr	Precipitation of carbonates, ion exchange separation of Ca and Sr with EDTA. After 2 weeks ingrowth, ^{90}Y separated, precipitated and counted with gas flow beta counters. ^C Reference 1
Water	1-4 l	^{226}Ra	Coprecipitation of Ra with BaSO_4 , emanation of ^{222}Rn , scintillation counting of ^{222}Rn and daughters. ^D Reference 2
Water	1-4 l	^{228}Ra	Coprecipitation of Ra with BaSO_4 , separation of ^{228}Ac with yttrium oxalate, beta counting. Reference 3
Water	1-4 l	^{238}Pu , ^{239}Pu	Coprecipitation of Pu with $\text{Fe}(\text{OH})_3$, KF fusion, pyrosulfate fusion, solvent extraction, electrodeposition and alpha spectrometry. ^E References 4, 5
Sediment	1-500 g	γ -emitters	Sediment dried, ground, and sieved through #10 mesh screen, counted by γ -spectrometry.
Sediment	1-10g	^{90}Sr	^{90}Sr leached with boiling 1 N HCl, carbonates precipitated and processed as for ^{90}Sr analysis of water. Reference 1
Milk	4-5 ml	^3H (HTO)	Azeotropic distillation of HTO, liquid scintillation counting. Reference 7
Milk	1 l	γ -emitters	Preconcentration on cation ion-exchange column, gamma-ray spectrometry. Reference 7

Table 8. Radiochemical Methods for Environmental and Test Well Samples
(continued)

Sample type	Quantity analyzed	Radionuclide	Method
Milk	1 l	^{90}Sr	^{90}Y separated after 14 days ingrowth by anion exchange, precipitation as oxalate, and beta counted. Reference 8
Garden produce	~ 400 g wet wt.	γ -emitters	Edible parts homogenized with blender, counted by γ -spectrometry.
Garden produce	4-9 g wet wt.	^3H (HTO)	Edible parts homogenized with blender, tissue water separated by azeotropic distillation and counted by liquid scintillation.
Garden produce	200 g wet wt.	^{90}Sr	Aliquot of homogenized sample evaporated to dryness, ashed at 450°C, ash processed as soils for ^{90}Sr determination. Reference 1

Notes:

- A Gamma Spectrometry - Radionuclides that emit gamma rays were identified and measured with a calibrated gamma-ray spectrometer consisting of a 55- or 85-cc Ge(Li) detector plus a 2048-channel pulse height analyzer.
- B Liquid Scintillation Counting - Tritium (HTO) was determined by liquid scintillation counting with a Packard Tri-Carb liquid scintillation spectrometer. The scintillation solution was a commercial preparation, Instagel. The samples were prepared by mixing 4 ml or 8 ml of the water sample with an appropriate volume of Instagel to give a total volume of 20 ml. Counting efficiencies were determined by counting standard solutions of tritiated water under the same conditions.
- C Beta Counters - Strontium-90 and ^{228}Ac were counted after chemical separation with low-background (1-2 cpm) end-window Geiger-Mueller detectors. Counting efficiencies were previously determined for the radionuclides of interest as a function of sample thickness.
- D Radon Counters - Radon-222 plus daughters were counted with a Lucas type ZnS(Ag) scintillation cell and a scintillation counter which consists of a 5.0 cm photomultiplier tube and associated electronics. Additional details regarding the scintillation counter and the calibration of the scintillation cells are given in reference 2.

Table 8. Radiochemical Methods for Environmental and Test Well Samples
(continued)

Alpha Spectrometry - Electrodeposited Pu samples were counted with an alpha-particle spectrometer consisting of an Ortec 400 mm²-diameter silicon surface barrier detector and a 512-channel pulse height analyzer. The detector resolution was approximately 50 keV fwhm at 5.40 MeV. The detector efficiency was approximately 25 percent.

1. Porter, C. R., et al., "Determination of Radiostrontium in Food and Other Environmental Samples," Environmental Science and Technology 1, 745 (1967).
2. Krieger, H. L., "Interim Radiochemical Methodology for Drinking Water," EPA-600/4-75-008/Revised, 16 (1976).
3. Ibid., p. 24.
4. Sill, C. W., U.S. ERDA Health Services Laboratory, Idaho Falls, unpublished procedure (1974).
5. Sill, C. W., Puphal, K. W. and Hindman, F. D., "Simultaneous Determination of Alpha-emitting Nuclides of Radium through Californium in Soil," Anal. Chem. 46, 1725 (1974).
6. Moghissi, A. A., et al., "Separation of Water from Biological and Environmental Samples for Tritium Analysis," Anal. Chem. 45, 1565 (1973).
7. Porter, C. R., "Rapid Field Method for the Collection of Radionuclides from Milk," in Proceedings of the First International Conference of Radiation Protection, Rome, 339 (1966).
8. Porter, C. R., et al., "Determination of Strontium-90 in Milk by an Ion-Exchange Method," Anal. Chem. 33, 1306 (1961).

Source: Montgomery, et al., 1977.

appreciable amounts of organic complexing agents representative of anaerobic decomposition products. The resulting aqueous complexing with radionuclides greatly increases the quantities in solution as opposed to suspension (Matuszek et al., 1979). Rising water levels in the West Valley trenches have prompted discharges to local streams (Matuszek et al., 1976; Husain et al., 1979).

Monitoring studies at West Valley between March, 1975, and October, 1976, were described by Husain et al. (1979). These studies were directed at analysis of the burial trenches, surface and underground water, and air.

Samples were obtained from burial trenches by driving well points into them. This entailed hand-auguring a 5 or 7.5 cm diameter hole about 100 cm into the soil cover. Then a 3-cm diameter galvanized pipe with a 60- to 90-cm-long screen was driven to about 60 cm above water level or until trench gas was smelled. After a gas sample was collected, the pipe was driven deeper to a predetermined level. Trench water was withdrawn from functional well points with a peristaltic pump and from a 20-cm-diameter observation pipe extending from a gravel-filled sump in each trench. Samples were immediately transported to the laboratory in ordinary 2-liter plastic bottles. The water was analyzed for inorganic anions, cations and radiochemicals. Nitric acid preservative was added to the samples destined for cation analysis. Samples for anion analysis were frozen and shipped in dry ice. Samples destined for Fe(II)/Fe(III) analysis and dissolved ^{14}C analysis were collected in pressure-capped glass bottles. Five ml of HCl was added to the bottles used with samples for iron analysis.

Trench gas was trapped under a 7.5m x 7.5m plastic tarpulin. The plastic was placed over the trench cover with the edges stamped into the cap. Trapped air was pumped from under the tarpulin which was left overnight. The next day, approximately 1 m³ of gas was pumped into a 16-l steel cylinder.

Analysis on these samples entailed gas chromatography/mass spectrometry to identify organic constituents and counting of the ^{55}Fe , ^{63}Ni , ^{90}Sr , ^{238}Pu , and $^{239-240}\text{Pu}$ nuclides after chemical separation. Samples analyzed for HTO were vacuum distilled to remove interfering radionuclides. Cesium-134 and Cesium-137 activities (gamma) were counted with a 45-cc Ge(Li) counter. Surface water samples were analyzed for gross- α , gross- β , and HTO.

Soil cores were analyzed in an earlier study (Matuszek, et al., 1976). They were obtained by drilling with a hollow core auger, lowering a hollow-tube sampler through the auger, and driving the tube into the soil in front of the auger. Samplers either separated longitudinally (split spoon) or did not separate (Shelby tube).

Void space water was distilled under vacuum from a 100g part of each core sample. Ten ml of this water was then used for HTO measurement in a liquid scintillation spectrophotometer as a gel suspension. Gamma-spectrometry was performed using a large-volume Ge(Li) crystal on a second part of each sample. A third part of the core was decomposed by NaOH- Na_2CO_3 fusion and subsequently analyzed for α and β -emitting radionuclides, ^{90}Sr in particular.

Studies to characterize the emission of gaseous tritiated compounds have been carried out at West Valley. The pressure difference between the trench atmosphere and the outside atmosphere has been monitored and related to gas production rates in the trench atmosphere in order to determine bulk permeability of the trench cover and gas release rates (Lu and Matuszek, 1979). Measuring devices and associated apparatus included an electrically operated pressure-differential transducer in the trench and a generator, a constant-voltage transformer, a power supply, and a digital multimeter. Trench-gas samples include copious amounts of $^3\text{HCH}_3$, ^3HHO , ^3HH , and other tritiated hydrocarbons. In addition, other gaseous radionuclides present are ^{85}Kr , ^{222}Rn , ^{14}CO , $^{14}\text{CH}_4$ and ^{14}C -hydrocarbons. Samples of the trench gas were analyzed by mass spectrometry and radiochemical means to obtain the molecular and radionuclide concentrations used to estimate release rates.

INEL (Idaho National Engineering Laboratory) Monitoring Methods

Studies at the Maxey Flats and West Valley sites are representative for the eastern, more humid regions of the country where the majority of low-level wastes are produced. The INEL waste sites may be taken as representative of an arid region. Even in arid or semiarid regional disposal sites, some waterborne migration of radioactivity has been observed (Matuszek et al., 1979). A large number of studies concerned with radionuclides in biological media have been carried out at INEL in addition to surveillance of primary media. Ambient air quality monitoring is carried out by low and high volume sampling. Filters are quantitatively analyzed for gross alpha, gross beta, and major gamma-emitting isotopes. Surface water samples have been collected from runoff locations, an onsite pit, and the Big Lost River (Adams et al., 1979). Water samples are collected in 4 to 1 polyethylene bottles. Subsurface water from the Snake River Plain aquifer is sampled from a well sealed at approximately 65 m below the surface, four 183-m wells and the production well for the RWMC (Adams et al., 1979).

Moisture logging of soil is conducted by obtaining readings with a combined neutron source (3 Ci Am-Be) and thermal neutron detector lowered into test wells. Subsurface moisture movement in soil is investigated with a network of 47 moisture-monitoring cells at depths from 1.8 cm to 15 cm below the surface (Adams et al., 1979).

Soil samples are obtained from the surface, 15- and 30-cm depths. Gamma radiation surveys of the SDA (Surface Disposal Area) were conducted with 18 Geiger-Mueller tubes in a lead-clad boom monitor. The counts-per-minute readings were converted to mR/h by comparison with spot determinations using a calibrated Ludlum 14-C GM instrument. Surveying with the boom monitor was performed at a height of 0.9m. Exposure from penetrating radiation (primarily gamma) at the RWMC perimeter is estimated with an array of 23 thermoluminescent dosimeter stations. Each station has a TLD packet located approximately 1 m above the ground surface. Each packet contains five Harshaw TLD-700 chips (3.18 mm

square by 0.89 mm thick). The packets are changed semiannually (Adams et al., 1979).

Certain pad cells containing TRU-contaminated waste are directly monitored to determine relative humidity and condensation conditions. Dew point and temperature measuring probes located at various depths in the cells are connected to an electrical 12-channel recorder. Painted steel corrosion coupons were retrieved from selected pad monitor pipes in 1978 after three years exposure and inspected (Adams et al., 1979).

Implanted TLD's have been used to estimate radiation doses to small mammals in the SDA vicinity. Population studies indicate that a significant proportion of the small mammal population is in close contact with radioactive waste or waste-contaminated areas in the SDA for varying periods of time. Tissue sample analysis has been initiated to determine radionuclides in selected small mammals and vegetation.

The analysis of air and water samples consists of gross alpha and beta activities and a gamma scan. Subsurface water samples are analyzed for gamma emitters, ^3H , ^{238}Pu , ^{239}Pu , and ^{90}Sr . Soil is analyzed for transuranics and major gamma emitters.

The procedures for α -scanning and gross α and β activity determination of water samples are presented below (Filbe, 1979). The 4 to 1 water sample is reduced to 1 to 1 by boiling. The reduced sample is placed in a Marinelli beaker and counted for 16-2/3 hours with a germanium lithium detector (utilizing a standard NBS mixed fission product source for calibration). The 1 to 1 sample is then boiled down to 50 ml in the original boiling vessel. Next 1 to 2 ml is evaporated on 2" stainless steel planchettes and counted in a gas proportional α , β counter (Beckman or Tennelec). The evaporation is used to verify the initial measurement. The α , β counter is calibrated against an Amersham scale Cs-137 standard and a calibrated U-233 α -standard. Background readings are subtracted from measured activities.

Soil sample analysis (Filke, 1979) consists of the following steps. Strontium-90 and actinide separation is performed according to standard analytical chemistry methods. An Amersham scale control run is carried out monthly. Strontium-90 is precipitated as a yttrium oxalate and counted in the Beckman or Tennelec gas proportional α , β counter. The ^{90}Sr yield is determined by an ^{85}Sr spike. Actinides are counted with a surface barrier detector and an alpha spectrometer. The latter is either an EG&G Ortec or a Kicksort instrument. Plutonium and Am yields are determined by isotopes prepared by the Radiological and Environmental Sciences Laboratory at INEL. Strontium is counted for up to 100 minutes and Am and Pu up to 100 minutes (as needed).

Detection limits lie between 0.001 to 1.0 pCi depending on the determination; error is 2 percent to 100 percent in the highest and lowest activity samples, respectively. The Environmental Measurement Lab Quality Assurance Program is in effect at the analytical lab on a quarterly basis.

Core sampling studies and geophysical logging have also been performed at Idaho to study the radionuclide content below buried waste and above the underlying basalt at the RWMC and to analyze other geologic samples obtained with improved core drilling techniques (Humphrey and Tingey, 1978; Barraclough, et al., 1979).

Drill-coring methods were used to core sediment layers from rotary and cable-tool wells (Barraclough et al., 1978). After retrieval of the drive-core sediment sampler assembly through the drill pipe, the inner steel liner was removed and sealed at both ends with wax prior to processing. Analysis for specific radionuclides was made by alpha and gamma spectrometry and by chemical separation.

Soil and tissue samples from near INEL were studied for Pu and Am contamination (by Markham et al., 1978). They established a 72-station sampling grid around the SDA and took additional samples from other sensitive points.

Soil cores 4 cm deep and 10 cm in diameter were obtained from the center and each of four corners of a 1-m square and composited. The composited sample was oven dried, thoroughly mixed, and ground lightly to breakup aggregates. The sample was screened through a 0.5 mm mesh. The ≤ 0.5 mm portion of the sample, containing most of the soils weight, was mixed and a 10-g amount selected for analysis. Analysis was carried out with the potassium fluoride and pyrosulfate fusion method of Sill. Soil weights and sample areas were used to compute nCi/m².

Deer mice were kill-trapped and dissected into components: lungs, hides, gastrointestinal tracts with contents, and the remaining contents. Separate instruments were used in dissections. Tissues from each trapping station were pooled to increase sensitivity. The tissues were weighed and frozen after dissection.

Hides were wet-ashed by the same techniques as with the soil samples. Other tissues were wet-ashed, dissolved in nitric acid, and any remaining insoluble material separated by filtration. The insoluble material was fused with a small quantity of potassium fluoride and the fusion cake acid dissolved in nitric acid and combined with the filtrate. Polonium-210, Pu and Am were extracted, the ²¹⁰Po removed by extraction into triaurylamine, and electro-deposition was carried out. Minimum detection limits generally varied from 0.0005 to 0.001 pCi/g ($P \leq 0.05$) for all tissues except lungs, which averaged a factor of 10 higher. Plutonium-239 and ²⁴⁰Pu were not distinguished from each other.

Halford and Markham (1978) describe the TLD surgical implementation procedure widely used in radioecological studies at Idaho. Lithium fluoride TLD-700 (3.0 x 3.0 x 0.9 mm) extruded ribbon thermoluminescent dosimeters from Harshaw Chemical Company were used to measure radiation dose and exposure because they have radiation absorption characteristics similar to those of living tissue and have a nearly flat response over a wide range of gamma energies. The dose (exposure) ranges are from 15 mrem to 3×10^5 rem. A plus or minus 10 percent error is associated with TLD measurements due to chip variability, reader variability, and other factors.

TLD measurements were made with two chips as a check on accuracy. Each packet of two chips was wrapped with aluminum foil, then heat sealed in laminating plastic. The aluminum foil and plastic shielded out most beta radiation. Packet size was 2 x 8 x 10 mm.

When packets were retrieved they were read with a Harshaw Model 2000A Thermoluminescent Detector with a photomultiplier tube and NaI light source. This was used with a Model 2000B Automatic Integrating Picoammeter which converts light output to readout in nanocoulombs. The nanocoulombs were converted to dose equivalent (mrem) for tissue dose and exposure (mR) for air dose. TLD readings were calibrated with a ^{226}Ra source. Several TLD packets were kept in the laboratory to measure background correction. If the total dose or exposure with background subtracted was below the low range value, it was recorded as 0.

Air gamma exposures were determined by attaching dosimeter packets to wooden posts 5 cm above the ground at the trapping stations in the control and trap studying grids. These site dosimeters were exposed for eight days and removed.

TLD packets were implanted in anesthetized animals (rodents) at the base of the head. A 5-mm incision was made in the skin, a small pocket hollowed out under the skin and a TLD packet inserted. The incision was closed with sutures and, after a recovery period, the marked animals were released at their capture site.

TLD packets from animals which were retrapped after carrying their packets for four or more days were removed and new ones implanted. Animals that died during handling were placed in a 70-ml plastic vial and analyzed for whole body burdens of gamma emitting radionuclides on a 65 cm³ Ge(Li) crystal coupled to a multichannel analyzer. Internal dose calculations were made using ICRP principles and the assumptions that radionuclides were in equilibrium with the body and uniformly distributed within it.

In another study, Craig et al. (1979) studied radionuclides in raptors on the INEL site. Young American Kestrels, Long-eared Owls, and Marsh Hawks were temporarily removed from their nests for analysis. Each young bird was studied to determine the whole body burden of gamma-emitting radionuclides by being placed in a ventilated 1800 ml plastic container with absorbent material on a 65 cm³ germanium-lithium crystal in a shielded chamber, connected to a multichannel analyzer. Presumptive food (rodents) were snap-trapped and analyzed for radionuclide content by whole-body scans.

A number of papers detailing ecology studies are published in a symposium edited by Markham and Arthur (1978). In addition to basic ecological studies, at least three papers deal with studies using the implantable TLD devices and some cover tissue and blood sample analysis studies. Related topics are covered in the 1978 Ecological Studies Progress Report (Markham, 1978). A new device in the later report is a confinement, rotation, and detection system for whole-body gamma-ray counts of live ducks (Morton et al., 1978). This device assures reproducible counting geometries, eliminates movements during the count, and reduces the problem of heterogeneity.

Neutron activation analysis is discussed as a means to improve analysis of a low activity compound (I-129) in vegetation. After neutron activation of I-129 to I-130, detection limits of approximately 0.15 Bq (4 μ toCi, or 10^{-18} Ci) per sample were obtainable.

3.2 PROCEDURES, TECHNIQUES, AND EQUIPMENT FOR HANDLING AND STORING LOW-LEVEL RADIOACTIVE WASTE

Introduction

This section covers prevalent and, to some degree, advanced and experimental techniques and procedures for the handling and storage of low-level radioactive wastes. As a starting point, the principles of LLW burial as presented in the National Academy of Sciences report "The Shallow Land Burial of Low-Level Radioactively Contaminated Solid Waste" (1976) are used. Four of the main points listed [(1) long-term management and containment, (2) exhumation of TRU waste, (3) volume reduction, and (4) good housekeeping and careful segregation] are addressed in this section. Monitoring systems are addressed elsewhere in this report. The other principles relate more to cost analyses, records management, and policies governing ownership of the sites than to handling and storage procedures and techniques and consequently are not addressed here. Time and budgetary constraints also limited the scope of issues addressed.

Long Term Management and Containment

On-site construction and operation procedures can be improved to enhance the long-term containment of LLW. Structural improvements include clay or bentonite caps as moisture barriers with rip-rap to prevent surface erosion (Ford, Bacon, and Davis, 1979). Also, varying types of asphaltic covers can be constructed, including asphalt concrete, soil asphalt and hot liquid asphalt. A soil layer with rip-rap is recommended for asphalt covers (Ford, Bacon and Davis, 1979). Other moisture barriers include plastic membranes covered with soil, concrete, and stainless steel. These three types are known to have many disadvantages such as cost (steel), ease of penetration (plastic), cracking (concrete). Additional research and improvement of these materials would likely be necessary before any substantial benefits would be gained by their use.

Operational and design improvements in burying LLW include (1) the use of temporary weather shields such as a movable building to reduce the LLW exposure to rainfall and subsequent leaching, (2) sand filler in the trenches with the LLW packages to reduce surface subsidence and (3) improved trench design (Ford, Bacon, and Davis, 1979).

Trenches are more than pits in which "garbage" is dumped. The soils and other geologic characteristics of the site are generally considered the exclusive containment medium for the radioactive components of the LLW. Thus, it is possible to augment the radioactive retention capacity of the soil(s) by placing a 1m clay layer in the bottom to the trench to increase ion exchange capacity. The single most important factor affecting nuclide containment after burial is the extent to which groundwater and surface water contact and subsequently leach the waste. A gently sloping (1° incline) trench with a sump or drain on the low end of the trench will help dewater the trench and retard radionuclide migration from the site. A sand layer along the trench bottom or a drainage ditch (1 ft²) filled with crushed rock along the bottom of each trench wall would facilitate water flow to the drain (Ford, Bacon, and Davis, 1979). The practice of using sand or rock is already followed at several burial sites in the U.S. The sump or drain water should be processed to remove the radionuclides.

It should be noted that empirical data demonstrating the degree of enhancement in LLW containment of these suggested structural and operational improvements were not located during this study.

Non-high-level wastes from nuclear power plants consist primarily of liquid effluents and resins. The European practice of conditioning the wastes may involve embedding in bitumen, thermosetting resins, or polymer impregnated cement (Sousselier, 1976). Of these methods, embedding in bitumen, a chemically inert, impervious, plastic, microorganism-resistant and cheap material is most developed on an industrial scale (Sousselier, 1976). The other methods of waste conditioning were in the study to pre-pilot plant stage in 1976. These three methods are considered alternatives to embedding in concrete, a method with several disadvantages.

Exhumation of TRU Waste

The relative human exposure risks associated with exhuming the TRU waste in LLW burial grounds were considered by the National Academy of Sciences panel to be greater than leaving the waste where it is. If a decision is made to exhume these wastes however, then research efforts on enhanced radiation protection may be advisable. A study of the techniques and procedures for handling high level wastes as applied to this problem would be one example.

Volume Reduction

Volume reduction techniques for combustible solids include (1) compression with trash compactors and other types of packers, balers and baggers, (2) incineration/pyrolysis, (3) acid digestion, and (4) molten salt combustion. Size reduction, melt-down casting, dissolution and electropolishing may be used for reducing the volume of noncombustible solids (Clark and Lerch, 1979). Liquid wastes can be evaporated or combusted (in some cases). Pretreatment (sorting, shredding and classification) is also a recommended procedure.

Compression or compaction can reduce volume by 70 to 80 percent (Clark and Lerch, 1979). Since the packing is generally not relied on for any nuclide containment after the package is buried, little effort has apparently been spent on the containment potential of various types of packages. Although additional research in this area may be warranted, fiberglass packaging is currently under study (Kniazewycz and Ash, 1979).

There are several incineration devices in use. These include (1) a vortex incinerator (General Electric, Wilmington), (2) a reactor waste vortex incinerator (Yankee Rowe), (3) a reactor waste incinerator (Ontaric Hydro), (4) a cyclone incinerator (Mound Laboratory), (5) a molten salt process (Atomics International), (6) a Rotary kiln incinerator (Rocky Flats), (7) a hearth incinerator (Rocky Flats), (8) a fluidized bed incinerator (Rocky Flats), (9) a controlled-air incinerator (Los Alamos), and (10) an acid digestion process (Hanford). Each incinerator type is discussed by Clark and Lerch (1979) and the reader is directed to their work for details.

The molten salt process, which reduces waste to approximately 2 percent of its original volume (McKenzie, Grantham and, Paulsen, 1979) is also a candidate for dissolution of non-combustible solids but more study is needed to determine its economic feasibility (Sousselier, 1976).

One overall problem in handling solid or liquid LLW is the generation of secondary wastes. Equipment and materials used may become contaminated; consequently, careful "systems" planning is required to minimize the total volume of waste to eventually be stored.

Housekeeping

While policy issues related to housekeeping practices are considered beyond the scope of this report, the human element must be considered. Ultimately, it is the operator of the site who digs the trenches, accepts and buries the waste, and carries on the day to day operation of the site. In such a position the site operator exercises significant

control on just how effectively a site will operate. Thus, if new or better technology becomes available a management structure must be maintained that will issue the proper directions and provide the appropriate education.

A related consideration is the potential risk associated with theft of expensive contaminated items such as tools and other equipment, such as that which occurred at the Nevada site (USNRC, 1977). Good housekeeping procedures are necessary to prevent such occurrences.

Segregation

Historically, some TRU wastes were buried along with LLW. Recently this practice has been halted, but the potential hazard posed by transuranium nuclides still exists.

In order to detect these nuclides various devices are used. A survey-type device with a ^{239}Pu sensitivity of 1.3 nanocuries (200 nanograms), unattenuated for a point source and 120 nanocuries/m² for an area source (NAS, 1976) has been in existence for several years. The sensitivity of this instrument can be increased an order of magnitude by substituting a nuclear instrumentation scaler for the count-rate meter and using a counting time of at least 20 minutes. A thermalized neutron source device (Idaho Nuclear Corporation) can also be used, and advances in instrumentation continue to occur. Thus, the problem with the existing TRU wastes buried in shallow burial grounds is not detection or lack of instrumentation capable of accurate detection, but what to do should uncontained nuclides be detected.

3.3 SUMMARY AND CONCLUSIONS

The technology of monitoring for release of radioactivity from low-level waste disposal burial grounds has advanced rapidly in recent years, and it now appears to be adequate. Increased use of spectroscopy combined with computer technology has resulted in greater ease in the identification and measurement of trace quantities of radionuclides in environmental samples. However, radiochemical procedures involving separation methods are needed for more nuclides. Aerial monitoring methods provide a rapid survey technique for locating and identifying radioactive species. Monitoring experience at three waste disposal sites, Maxey Flats, West Valley, and INEL illustrates the difficulties involved in detecting and measuring the radionuclides that have been released, and in determining the magnitude of the sampling and analysis programs required for these efforts.

A brief review of procedures, techniques and equipment for handling and storing low-level radioactive waste shows that a number of methods exhibit promise of improving the retention of radionuclides in low-level waste disposal areas and reducing the volume of waste to be buried. Some techniques, such as keeping the waste above the water table level and limiting surface water runoff have been applied, but fixation or encapsulation of wastes, as well as methods of reducing waste volume, are being improved.

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4.0 OTHER HAZARDOUS MATERIAL MODELS

This section contains preliminary lists of models identified as relevant to the description of the behavior of non-radioactive hazardous materials in the environment. All models were drawn from the compilation of models described in Section 2 of this document, which covered the behavior of radioactive contaminants. The models listed in this section have been tentatively assessed to be as relevant for non-radioactive contaminants as for radionuclides. The models are identified by their acronym or title and page number in Section 2. The models are categorized using the same framework developed for Section 2.

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