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The Evaluation of Models Used for the Assessment of Radionuclide Releases to the Environment

**Progress Report for the Period
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THE EVALUATION OF MODELS USED FOR THE ASSESSMENT OF
RADIONUCLIDE RELEASES TO THE ENVIRONMENT

Progress Report for the Period
April 1976 through December 1977

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CONTENTS

List of Figures	vi
List of Tables	vii
Summary	ix
1. Introduction (<i>F. Owen Hoffman</i>)	1
2. A Model Evaluation Methodology (<i>D. Lynn Shaeffer</i>)	4
2.1 Introduction	4
2.2 Model and Algorithm Examination	6
2.3 Data Evaluation and the Empirical Approach to Model Critiquing	7
2.4 Sensitivity Analysis	12
2.5 Validation	14
2.6 Code Comparison and Model Selection	19
2.7 Conclusions	20
3. Application of the Methodology	27
3.1 A Compilation of Documented Computer Codes (<i>F. Owen Hoffman</i>)	27
3.2 Terrestrial Food Chain Transport of Transuranic Elements (<i>Charles T. Garten, Jr.</i>)	30
3.2.1 Variation in Parameter Values Used to Assess the Terrestrial Food Chain Transport of Plutonium, Uranium and Thorium	30

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CONTENTS (CONT'D)

3.2.2	Identification of Critical Parameters in the Terrestrial Food Chain Transport of Trans-uranic Elements	35
3.2.3	A Comparison of Model Predictions with Field Measurements of Plutonium Concentrations in Agricultural Crops	39
3.3	Atmospheric Dispersion and Deposition Studies (Charles W. Miller)	47
3.3.1	A Comparison of Two Methods of Determining Atmospheric Stability Categories	47
3.3.2	An Examination of Gaussian Plume Dispersion Parameters for Use Over Rough Terrain	51
3.3.3	Sensitivity of Deposition and Plume Depletion Calculations to Variations in the Value of Deposition Velocity	56
3.3.4	An Examination of the NRC Methodology for Estimating Dry Deposition and Plume Depletion	61
3.4	The Evaluation of Critical Parameters for Assessing the Environmental Transport of Radioiodine	71
3.4.1	A Reassessment of the Deposition Velocity for Models Which Estimate the Environmental Transport of Radioiodine from Air to Milk (F. Owen Hoffman)	71

CONTENTS (CONT'D)

3.4.2	A Review of Measured Values of the Milk Transfer Coefficient (f_m) for Iodine (F. Owen Hoffman)	74
3.4.3	Uncertainty in the Dose Calculation for the Grass-Cow-Milk Pathway (D. Lynn Shaeffer and F. Owen Hoffman)	78
3.5	The Evaluation of Selected Internal Dose Conversion Factors	89
3.5.1	The ^{232}Th Dose Conversion Factor Question (H. Robert Meyer and Donald E. Dunning, Jr.)	89
3.5.2	A Review of ^{99}Tc Dose Conversion Factors (Donald E. Dunning, Jr.)	93
3.6	An Evaluation of ^{99}Tc Releases into the Terrestrial Environment - The Need for Additional Research (F. Owen Hoffman and John E. Till)	100
4.	Future Efforts in this Project (F. Owen Hoffman)	107
Appendix A	Meetings and Presentations	109
Appendix B	Abstracts of the Computer Codes	115
Appendix C	Author Index	153
Appendix D	Keyword Index	157
Appendix E	Publications Description Index	161
Appendix F	Title Index	165

LIST OF FIGURES

Fig. 2.1	Flowchart of a methodology for evaluating environmental assessment models	5
Fig. 2.2	Schematic representation of a methodology for inputting parameter values, supported by varying quantities of data, into three basic types of models	9
Fig. 3.1	The center-line ground-level normalized air concentrations as a function of downwind distance calculated with the Jülich data (- - -) and the Smith-Briggs curves (---) for an effective release height of 50 m and Pasquill D stability	55
Fig. 3.2	Short-term average values of deposition velocity (in units of m/sec) for elemental iodine $^{131}\text{I}_2$ versus cumulative percent	80
Fig. 3.3	Short-term average values of the vegetation-to-milk transfer factor (in units of m^2/liter) versus cumulative percent	81
Fig. 3.4	Short-term average values of the decay constant (in units of day^{-1}) for retention on vegetation versus cumulative percent	82
Fig. 3.5	Decay schemes for ^{232}U and ^{232}Th	90

LIST OF TABLES

3.1	Variation in parameter values used for assessing the terrestrial food chain transport of actinides	32
3.2	Variation in predicted actinide concentrations and dose-to-man found by substituting the range of parameter values in Table 3.1 into USNRC 1.109 (1976) formulas for terrestrial food chain transport	34
3.3	Sensitivity coefficients (S) calculated for various TERMOD parameters used in predicting ^{239}Pu food chain transport	38
3.4	A comparison of model predictions from TERMOD and USNRC Regulatory Guide 1.109 formulas with measured Pu concentrations in the SRP wheat field	41
3.5	Percentage occurrence of each stability class determined by three methods for the Kingston Heights meteorological tower during 1975	49
3.6	Normalized ground-level air concentration as a function of selected downwind distances calculated from the Gaussian plume model for each method of determining stability category	50
3.7	Maximum center-line ground-level normalized air concentration and its location calculated for two different release heights using four different sets of dispersion parameters	54
3.8	The plume depletion fraction, $f(x)$, at five downwind distances and four values of deposition velocity, v_d , for a release height and atmospheric stability category chosen to represent a routine radionuclide release assessment	59

LIST OF TABLES (CONT'D)

3.9	The plume depletion fraction, $f(x)$, at five downwind distances and four values of deposition velocity, v_d , for two release heights and atmospheric stability categories chosen to represent an accidental radionuclide release assessment	60
3.10	A comparison of the results of sample calculation of plume depletion and dry deposition rate using the NRC and AIRDOS-II methodologies assuming a release height of 100 m and a release rate of 1 pCi/sec	63
3.11	A comparison of the results of a sample calculation of plume depletion and dry deposition using the NRC and AIRDOS-II methodologies assuming a release height of 1 m and a release rate of 1 pCi/sec	65
3.12	A comparison of published vs corrected equilibrium milk to air transfer coefficients for ^{131}I	73
3.13	Values of f_m for the transfer of iodine into the milk of dairy cows	75
3.14	Values of f_m for the transfer of iodine into the milk of goats	77
3.15	Adult dose conversion factors for ^{99}Tc pertechnetate (millirems/pCi)	94
3.16	Concentration factors for ^{99}Tc based upon soil to aerial parts of wheat seedlings ($\mu\text{Ci/g}$ wet weight of plant per $\mu\text{Ci/g}$ dry weight of soil)	101
3.17	Concentration factors for ^{99}Tc based upon soil to aerial parts of soybean and wheat ($\mu\text{Ci/g}$ wet weight of plant tissue per $\mu\text{Ci/g}$ dry weight soil)	102

SUMMARY

The purpose of this project is to evaluate environmental transport and dose calculational models employed in the assessment of the radiological impact of routine and accidental radioactive discharges. This includes the identification of these models, the evaluation of their conceptualization, simplifying assumptions, and data bases, the estimation of their uncertainties and, if possible, the recommendation of the models and parameters which are best suited to particular assessment situations. Where needs are identified, recommendations will also be made for further environmental and biomedical research.

This report presents individual summaries of the major accomplishments of the project during the reporting period. These may be highlighted as follows:

A generalized conceptual approach to the evaluation of radiological assessment models is described with emphasis being placed on the determination of the validity of such models under a variety of circumstances. Six major tasks are identified and a logical interrelationship between these tasks is developed (p. 4).

Nearly 100 documented computer codes used to calculate the environmental transport and dosimetry of radionuclides are identified. Their capabilities are summarized in the appendices (p. 27).

An assessment of input parameters for the estimation of the terrestrial food chain transport of Pu, U, and Th, and the subsequent dose to the bone of individuals consuming contaminated food indicates that predicted values differ by orders of magnitude depending on the input values used (p. 30).

A sensitivity analysis indicates that a reduction in the uncertainty associated with the parameters representing the fraction of deposition intercepted by vegetation, vegetation biomass, and effective half-life on vegetation will help reduce variation in predictions of terrestrial

food chain transport of actinides and other radionuclides (p. 35).

In a comparison of model predictions with field measurements, predicted Pu concentrations in wheat are within $\pm 10\%$ of values measured in an experimental field at Savannah River Plant (p.39).

When atmospheric stability is determined through three different stability categorization methods using a single meteorological data set, the predicted normalized ground-level air concentration differs by as much as a factor of four depending on the categorization method and downwind distance considered (p. 47).

Comparisons with data gathered in Germany indicate that dispersion over rough terrain may be larger in the atmosphere than is predicted by the Gaussian plume model using any one of three sets of dispersion parameters. This may result in a higher maximum air concentration closer to the source and lower air concentrations further downwind than predicted by the model (p. 51).

The most commonly used model for estimating plume depletion is relatively insensitive to changes in the value of deposition velocity, especially for elevated releases and distances less than 10 km. However, the amount or rate of deposition is directly dependent on the value chosen for deposition velocity (p. 56).

The Nuclear Regulatory Commission techniques for estimating dry deposition and plume depletion are inconsistent in that the deposition estimates are independent of the calculated air concentrations (p. 61).

Experimentally derived values of the deposition velocity for elemental iodine are often misinterpreted as being related to total deposition when in fact most have been related specifically to the deposition on vegetation (p. 71).

A review of the published values of the transfer factor, f_m , used for estimating the concentration of iodine in cow's and goat's milk under routine release conditions leads to the recommendation of the values of 0.01 and 0.5 day/liter for cows and goats, respectively (p. 74).

To ensure that a dose calculated from a multiplicative model has a 99% probability of not underestimating an actual dose, the most probable dose must be enhanced by a factor of $\exp \{(2.326 + \sigma)\sigma\}$, where σ^2 is the sum of the variances of all the statistical parameters included in the calculation (p. 78).

The ^{232}Th dose conversion factor is being examined in light of research that indicates that approximately 97% of the ^{228}Ra daughter is retained in the bone and not eliminated from the body through the blood as is often assumed (p. 89).

Adult dose conversion factors for ^{99}Tc pertechnetate have been calculated based on the INREM-II methodology. The thyroid has been found to receive the highest dose per unit intake by either ingestion or inhalation (p. 93).

Recent data on vegetation uptake of technetium indicates that soil-to-plant concentration factors for this element may be significantly higher than those currently being used in radiological assessments. More information is needed to test the validity of these data before conclusions can be formulated about the significance of ^{99}Tc releases from nuclear facilities (p. 100)

Future efforts in this project will be oriented more directly toward determining the uncertainty associated with environmental transport and dose assessment models. Also consideration will be given to the inclusion of specific surface water and ground-water transport models for evaluation, and other terrestrial and aquatic food-chain pathways which may be of significance for other groups of nuclides of potential importance to the future development of nuclear energy.

1. INTRODUCTION

The determination of compliance with environmental standards for radioactivity releases frequently requires the use of mathematical models. These models are employed as tools to predict the environmental transport and subsequent dose associated with specific radionuclides that may be released during routine or accident situations involved with the operation of nuclear facilities. Because these models can only be approximations of real physical and biological events, a degree of uncertainty is associated with their use. Generally, this uncertainty has been assumed to result in conservative or over-estimates of actual environmental concentrations or doses. Conservative models are useful when their predictions lead to estimates of environmental concentrations or doses that are no cause for concern. If, however, these conservative models predict concentrations or doses which approach or exceed established standards, it is possible that expensive measures would be initiated to alleviate a problem which is solely a product generated by the model. On the other hand, attempts to reduce the conservatism employed by a model to improve its predictive accuracy must also focus on improving predictive precision. A model aimed at predicting only the average or most probable concentration or dose resulting from a given release may run a high risk of underestimating actual concentrations or doses unless the uncertainty associated with its predictive capability is reduced or, at least taken into account. There is a need, therefore, to evaluate the models to determine the degree of uncertainty associated with their predictions.

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Currently, a number of environmental transport and dose calculation models employing different data bases and assumptions are available for the assessment of the radiological impact of routine and accidental discharges. The model evaluation project initiated at Oak Ridge National Laboratory (ORNL) has had as its objectives identification of these models; evaluation of their conceptualization, simplifying assumptions and data bases; estimation of their uncertainties; and, if possible, recommendation of the models and parameters which are best suited to particular assessment situations. Where needs are identified, recommendations are also made for further environmental and biomedical research. Specific isotopes of interest within the present scope of this project have been the transuranics, radioiodines, ^{232}Th and ^{99}Tc . The models selected for study are those developed for the prediction of atmospheric transport and deposition, terrestrial food-chain bioaccumulation, and internal dosimetry. Other nuclides and environmental transport and dosimetric models are to be included within the framework of this model evaluation effort during the remaining course of the project.

This particular report is a summary of the accomplishments of the model evaluation project during the period April 1976 through December 1977. The summaries contained herein reflect the work of those individuals who have contributed significantly to the project. The summaries vary in the amount of detailed discussion presented depending on whether the work has already been published or submitted for publication. Major sections of this report include discussions on the development of a model evaluation methodology, a compilation of computer codes, an assessment

of the environmental transport of the transuranics, studies of atmospheric diffusion and deposition calculations, an evaluation of critical parameters for the assessment of the food-chain transport of radioiodine, an evaluation of dose conversion factors for ^{232}Th and a review of the factors and parameter values used to predict the consequences of an airborne release of ^{99}Tc .

Most of the efforts in this project in July and August of 1977 were oriented toward organization of *A Workshop on the Evaluation of Models used for the Environmental Assessment of Radionuclide Releases*, held in Gatlinburg, Tennessee, on September 6-9, 1977. This workshop was designed to bring together selected experts from the United States and abroad to discuss the strengths, weaknesses and developmental needs of existing radiological assessment models and computer codes. A proceedings of the results and conclusions derived from this workshop will be published in the near future.

It is hoped that the information presented herein will be of significant interest to the scientific community involved with the use and application of environmental radiation assessment models. The authors welcome any comments or criticism regarding the specific contents of this document or other aspects of the model evaluation project.

F. Owen Hoffman
Project Leader

2. A MODEL EVALUATION METHODOLOGY

D. Lynn Shaeffer

2.1 Introduction

A model evaluation methodology has been developed to provide a systematic framework within which the adequacy of radiological assessment models might be examined. A systematic approach is needed to effectively accomplish this task because of the complexity of the various subsidiary issues which must be addressed in answering the question of adequacy. In addition, the diversity of the types of existing models, along with their associated data, are not all amenable to one universal method of analysis. Consequently, a variety of approaches is required for scrutinizing the different kinds of models.

The model evaluation methodology depicted in Fig. 2.1 consists of six major tasks which are designed to confront these different issues. These major tasks are: 1) model examination, 2) algorithm examination, 3) data evaluation, 4) sensitivity analyses, 5) validation studies, and 6) code comparison studies. *Model examination* involves questioning whether anything fundamental was omitted in the initial conceptualization of the model. *Algorithm examination* attempts to determine whether appropriate numerical schemes have been adopted to represent the model in the form of a computer code. *Data evaluation* is intended to ascertain the quality, the quantity and the meaningfulness of the data available for use with the model. *Sensitivity analyses* are studies directed toward identifying those parameters which are most influential in determining model predictions. The identification of these key parameters

Fig. 2.1. Flowchart of a methodology for evaluating environmental assessment models.

enables priorities to be established for performing experiments. *Validation* refers to the attempt to determine the degree to which model predictions agree with field or laboratory measurements of those same quantities. *Code comparison* is simply the process of comparing the strengths and weaknesses of various codes designed to perform similar tasks.

Before any of the major model evaluation functions can be performed an initial model and code inventory must exist. Of particular interest in this study are models developed to predict atmospheric transport, hydrologic transport, terrestrial and aquatic food chain bioaccumulation, and the dose to man resulting from accidental and routine releases of radionuclides from nuclear facilities. An extensive literature search must be performed to identify all those models and their representative computer codes which deal with some aspect of these environmental transport and dosimetry categories.

2.2 Model and Algorithm Examination

Model examination is concerned with determining whether a model correctly represents the phenomena, processes, and actions the model users are concerned about. This determination involves answering the following types of questions: Are all the relevant physical, chemical and biological phenomena properly included in the equations? Are the equations representing the various parameters valid within the intended range of applicability of the model? Are the equations mathematically adequate over the intended range of model applicability? Are the boundary conditions and initial conditions appropriate? Is the approach to the solution the most appropriate one for the intended model application?

Algorithm examination involves questioning whether the numerical technique selected for the computer code is the most appropriate one for the model application. The answer to this question may involve some tradeoffs. Is an increase in computational time worth the gain in accuracy?

2.3 Data Evaluation and the Empirical Approach to Model Critiquing

The meaningfulness of the sensitivity analyses, validation studies, and code comparison studies will be determined by the quality of the available data. Two kinds of available data are needed. One is the data needed for input to the computer codes. The other is the data (i.e., comparison data) to which the predictions of the models must be compared. The aim of the data evaluation process is to determine the quality of both kinds of data.

Data quality refers to how well the data represent the processes being measured. The data will be affected by the presence of measurement errors. These errors are of two types, viz., systematic and random. Systematic errors are those associated with the particular instruments or techniques being used. Random errors arise from unknown variations in the experimental conditions. These errors may result from small inaccuracies in the judgment of the observer or from inherent random fluctuations in the processes being measured.

Data quality is expressed in terms of accuracy, precision and completeness. Measurements which have small systematic errors are said to have high accuracy. If the random errors are small, then the data have high precision. Completeness of the data is important for determining reasonable estimates of accuracy and precision. The larger the number

of measurements in a sample, the better will be the estimate of these quantities.

More often than not, the model developer and model user do not have direct access to the data. The data may have passed through several hands before reaching the user. Frequently the data may be available only in the literature. Information is usually lost and the data may have suffered degradation in the handling and transmittal process. The model user should not use data blindly but attempt to ascertain all that is known about the quality of the data.

Finally, if data required by a particular model are unavailable, then a recommendation that experiments be performed to gather the appropriate data may be required. If these experiments prove to be prohibitively expensive, then the model may have to be redesigned to eliminate those parameters for which data do not exist. If the elimination of all these parameters is not possible then perhaps the model should be preserved by restructuring it to require the minimum number of parameters for which data are nonexistent. Hopefully, the redesigning of the model will not render it inapplicable to those situations for which it was originally developed.

A methodology is needed to provide guidance on how to use the available empirical input data of a given quantity and precision. Such a methodology is shown in Fig. 2.2. The availability of statistical information sometimes permits the development of a probability density function (p.d.f.). If a range of values is available for the data but not enough data points exist to define a p.d.f., it may be possible to assume a p.d.f. and calculate a mean and variance from the given data.

Fig. 5.2. Schematic representation of a methodology for inputting parameter values, supported by varying quantities of data, into three basic types of models.

Most environmental data may be described by either a lognormal, Weibull, or normal distribution function (Pinder and Smith, 1975; Speer and Waite, 1975; Toy and Lindeken, 1975).

The manner in which the input data are used will depend upon the kind of model being evaluated. Three different kinds of radiological assessment models have been identified. These are the multiplicative chain models (MCMs), linear systems models, and complex models. A multiplicative chain model may be defined as one describable by a mathematical relationship of the form

$$z = A \frac{x_1 x_2 \cdot \cdot \cdot x_m}{y_1 y_2 \cdot \cdot \cdot y_n}, \quad (1)$$

where z might be a pollutant concentration or a measure of impact on health, such as dose, A is a constant and the x_i 's and y_i 's represent measurable environmental quantities such as concentration. Also, the ratio x_i/y_i might be a bioaccumulation factor or a concentration ratio* (Vanderploeg et al., 1975). The MCMs are frequently used to estimate the transport of pollutants through terrestrial and aquatic environments. In the radiological area, the computer code FOOD (Baker et al., 1976; Baker, 1977) is an example of the former and the computer code ARRRG (Soldat et al., 1974) is an example of the latter.

The linear systems models are characterized by a system of first-order, linear, coupled differential equations which describe transfers

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*The bioaccumulation factor is defined as the ratio of the concentration per unit weight of a substance contained in one entity (e.g., fish) to the concentration per unit weight or volume in a different entity (e.g., water).

with time of mass or energy from one environmental compartment to another. The coefficients in the differential equations represent transfer rates which are generally assumed to obey first order kinetics. An example of a linear systems model which describes the transport of radionuclides through a terrestrial environment is the computer code TERMOD (Booth et al., 1971; Booth and Kaye, 1971).

Finally, a complex model is defined as one which does not fall into either of the other two categories. These may be, but not necessarily, characterized as nonlinear models, distributed system parameter models (Polis and Goodson, 1976), or models for which there exists no tractable analytic solution relating the inputs to the outputs of a model. Examples in the radiological field are the computer codes ADPIC (Lange, 1973), AIRDOS (Moore, 1977) and SERATRA (Onishi 1977a and b).

The fact that the values for many of the input parameters of a model are statistical in nature means that model outputs are frequently statistical quantities. Therefore, model predictions do have uncertainties associated with them. A realistic assessment of the effects of a postulated set of actions, such as a release from a nuclear facility, requires a knowledge of the uncertainties of the predictions of the models designed to simulate these actions. In fact, it would be nice if these uncertainties could be obtained analytically rather than through the use of a computer. Unfortunately, linear systems models and complex models are not amenable to analytically propagating the statistics through the equations. However, it is possible to propagate lognormal statistics through the multiplicative chain models. Many environmental parameters do appear to obey lognormal statistics. Shaeffer

and Hoffman (1978) have performed an analysis based on lognormal statistics, of the uncertainties of model predictions of the concentration of elemental iodine in cow's milk due to transport through the grass-cow-milk pathway.

2.4 Sensitivity Analysis

The purpose of a sensitivity analysis is to determine the variation in one or more model output quantities caused by a variation of a model input parameter. This kind of study makes possible the identification of those key parameters which are most important in determining model predictions. These key parameters are the ones for which the most reliable data should be obtained. Thus experiments might be recommended on the basis of a lack of quality data for a key parameter. Also, a model might be simplified mathematically if a sensitivity study reveals that model predictions are unaffected by a particular input parameter.

Two general approaches, analytic and numerical, may be taken in a sensitivity analysis. The analytic approach is possible only if the exact mathematical relationship between the inputs and the outputs of a model are known. However, even if this functional relationship is known the analytic approach may not be a tractable one. In the analytic approach, the functional dependence of the output quantities on the input variables is examined to ascertain the strength of this dependence. Analytic sensitivity theory appears to be well developed in the fields of reactor design and neutron physics (Bartine et al., 1974; Gerstl et al., 1977; Oblow, 1976; Oblow, 1977). Successful application of sensitivity theory in these fields, according to Oblow (1976), has been due to

developments in generalized perturbation theory and variational methods. These analytic techniques have potential application to radiological assessment models.

If an analytic approach is not possible then a numerical approach must be adopted. The numerical procedure may be either statistical or non-statistical. The most common method used is the non-statistical procedure of varying the value of an input parameter by a certain percentage on either side of a nominal value, while holding all other parameters constant (Miller et al., 1976; Vithayathil and Hirsch, 1975). Values of a sensitivity coefficient are then calculated to express the sensitivity of an output quantity to each input quantity. The disadvantages of using this method are essentially threefold. First, if the range of values for an input parameter x_i is unknown then the percentage variation to be chosen for the study is completely arbitrary. However, a complete understanding of the nature of the model response requires a knowledge of that response at all perturbation levels over which the parameters are likely to range. Second, a code having a large number of input parameters will require a large number of computer runs when each input variable is individually perturbed while holding all other input parameters constant. Third, misleading results may be obtained when the output is a nonlinear function of the input.

An attempt has been made by McKay et al. (1976) and McKay and Bruckner (1976) to overcome the second and third difficulties. Their research has involved the use of Latin hypercube sampling (LHS) to study the statistical output of a computer code as a result of statistical inputs. The LHS procedure involves dividing each input variable into

equal probability intervals. For each run, one interval from each input variable is sampled according to the p.d.f. of that variable. Thus all input variables are changed simultaneously and each interval of an input is sampled only once.

Computer studies show (McKay et al., 1976) that LHS offers approximately four times the precision afforded by random sampling. In other words the same precision can be obtained by LHS with one-fourth the number of runs required by random sampling. Consequently, the utilization of LHS may result in considerable savings of total computer run time required for sensitivity studies of computer codes which have a large number of inputs and outputs.

A nonparametric partial rank correlation coefficient (PRCC), such as Spearman's (Conover, 1971; Siegel 1956), may be used as a sensitivity coefficient. This type of coefficient has the advantage of removing the effects of all but one input parameter on a given output variable even though all input parameters are varied simultaneously from one run to another.

2.5 Validation

The validation of models and computer codes has been a subject of considerable discussion in the literature. The problem stems from the fact that a model is an abstraction and a mathematical representation of reality. As such a model can never completely duplicate reality under all conditions. In fact some models predict quantities which are not measurable and therefore excluded from possible validation. Also, some models are not meant to be validated and are designed merely for the purpose of guiding research. However, many models are designed for

predictive purposes and often may be compared against historical data. Some of these models are intended to more fully understand fundamental processes and others exist to predict the consequences of a postulated set of actions.

Only those routines or formulae which predict results that are measurable and are not dependent upon inputs unsupported by data can be validated. In other words, predicted results will have meaning only if they depend on experimentally measured parameters. The validity of a model is determined by comparing the predicted quantities with experimental data. Also, the validity need be determined only for those circumstances for which the model is intended, as stated in the model or computer code documentation. If a model or any of its subcomponents cannot be validated due to a lack of data, the model examination procedure must be relied upon to make a judgment as to the reasonableness of the assumptions and the structure of the model.

The kind of validity test to be applied will depend upon the amount and precision of data available. Three types of validity defined here include: statistical validity, deviative validity, and qualitative validity. These concepts are applicable to single output quantities. If the output is statistical in nature then the spread, as measured by the variance, of the statistical distribution of the predicted quantity should be similar to that of the measured distribution and their maxima should lie within some distance of each other. In other words, the accuracy and precision of the predicted and measured quantities should be similar. Various statistical procedures (Zar, 1974) are available for testing whether the accuracy or precision of two different

distributions are in agreement. If application of these tests leads to the conclusion that the two distributions are equivalent, then we say that the model is statistically valid. For certain quantities (e.g., air concentration of radioactivity) of interest to radiological assessments, the predicted quantity x is required to be greater than the measured quantity y , that is, $x > y$. This is typically considered to be a conservative approach. The acceptable degree of discrepancy between predicted and measured quantities must be determined by the decision maker.

If sufficient data are unavailable to characterize the output as statistical then a test of deviative validity might be applied. The deviation of a predicted value from a measured value might be measured in terms of a deviation coefficient defined as

$$D = \frac{x - y}{x} \quad (2)$$

A model is said to possess deviative validity if the model passes the test $D \leq \epsilon_d$, where ϵ_d is a deviative validity criterion supplied by subjective judgment such as that provided by a decision maker concerned with compliance to a regulatory statute. More frequently, however, the concept of qualitative validity is applied. This simply means that the agreement (or disagreement) between model predictions and observed data is rated on a qualitative scale. For example, such a scale might consist of the validity levels excellent, good, fair, poor, and unacceptable. Such a refined scale may not be possible in reality. Again, the dividing line between the different levels must be determined by the decision maker.

From this discussion comes the conclusion that validity is a matter of degree, depends on the information available and is subject to the requirements established by a decision maker.

"Validity consistency" refers to the variation of validity among calculations having different input and comparison data sets. A model may be valid under one set of conditions but invalid under another. Here only the range of conditions for which the model is supposedly applicable, as determined from the model or code documentation, is of concern. The author is aware of at least one model which gave an excellent fit to some observed data and therefore was deemed valid. However, an alternative test performed under different conditions would undoubtedly have proven the model to be invalid because of the inclusion of some incorrect assumptions. The model proved to be valid for one set of conditions only because the incorrectness of the assumptions was not important in that situation. Thus, a model proven to be valid for one set of input parameters may be invalid for another.

Frequently, environmental assessment models are developed without any validation attempts ever being made. For those models which have been validated to some extent, very few have been subjected to a large number of validation experiments performed under different environmental conditions, i.e., "validity consistency." In addition, many models can only be partially validated because of the limited data available. Examples are the environmental transport models of Eraslan et al., (1977) and the ground-water models of Duguid and Reeves (1976) and Reeves and Duguid (1975). Only portions of these models may presently be validated.

A simple multiplicative model for atmospheric transport (Hanna, 1971; Hanna, 1973) has been applied to several different environmental situations (Hanna, 1975; Koch and Fisher, 1976; Hanna and Gifford, 1977). Miller et al., (1976) have applied a combination of a deviation coefficient and a qualitative validity scale to the validation of an ecological system model used to predict pollutant transfer in an aquatic ecosystem. Miller et al. contend that model validation and sensitivity analyses should be an integral part of the model development process. These parallel activities facilitate in guiding an experimental program.

Nappo (1974) presented a methodology for validating air pollution models. This methodology involves the calculation of temporally and spatially averaged linear correlation coefficients. Nappo also uses time-averaged and space-averaged ratios of predicted concentrations to observed concentrations of pollution in air.

Alternative methods to Nappo's are such statistical tests as the paired-sample t tests (Zar, 1974). The two-tailed hypothesis could be used to test whether there is any significant difference between model predictions and the observed data. The one-tailed hypotheses could be useful in ascertaining whether model predictions are higher or lower than the values of the comparison data. If the data are suspected of being non-normal (even if they are log-transformed), then perhaps the Wilcoxon paired-sample test, a nonparametric analogue to the paired-sample t test, would be appropriate. Generally, the performance of more than one type of statistical test is advisable to ensure that errors of Type I or Type II (Zar, 1974) are not committed. Many other statistical

tests not mentioned here are also available. In addition, there is no substitute for visually inspecting the data rather than blindly going through a lot of numerical calculations.

2.6 Code Comparison and Model Selection

This study is concerned with models developed to assess the environmental consequences of routine or accidental releases of radionuclides from a nuclear facility. Meaningful comparisons require selecting codes from the same category (e.g., those mentioned in Sect. 2.1) and the same type of release conditions in the case of radiological assessment. These studies will involve comparing the outputs of different codes with each other, including actual values and the general character of any time dependent behavior. In addition, a comparison should be made of the differences in validity among computer codes. One code may be more valid than another. If any of the model outputs are statistical then the differences in the confidence intervals of the predicted quantities must be ascertained. A comparison must also be made of the input data requirements, programming needs (i.e., debugging and algorithm improvement), computer requirements (e.g., special compilers, macros, overlays, double precision, etc.), sufficiency of documentation and the sufficiency and readability of the printed output. Finally, the time and cost required for execution of each of the codes must be compared. Hopefully, a combination of a knowledge of the structure of the models and codes and the results of the sensitivity studies will reveal the reasons for the differences among the codes and identify needed programming and modeling improvements.

Most assessors agree that models chosen for environmental assessment purposes should be the ones which rely upon available data. Many models include detailed physical, chemical or biological mechanisms for which there are no data. The usefulness of such models is subject to question. Often certain model complexities may be omitted such that the model depends only on available data. A model which lacks input data cannot be validated in its entirety.

Also, most model users agree that a model should be validated not just for one situation but for many (i.e., validity consistency). If more than one such model is available then one may have to determine the tradeoffs of choosing one model over another. Perhaps more than one model should be selected. Many of these decisions involve scientific and engineering judgment. The simplest model which can be acceptably validated is deemed more suitable than a more complex model. This suggests that an attempt should be made to validate the simplest model first. If this attempt fails then the validity of the models representing the next higher level of complexity should be examined, providing that sufficient data exist to permit such an attempt. The validation procedure should be applied to models of progressively increasing complexity until one is found to satisfy the validity criteria.

2.7 Conclusions

A generalized conceptual approach to the evaluation of radiological assessment models has been presented. This approach consists of six major tasks: model examination, algorithm examination, data evaluation, sensitivity analyses, validation studies and code comparison studies.

Emphasis has been placed on identifying those parameters which are most important in determining the predictive outputs of a model. Importance has been attached to the process of collecting quality data. A method has been developed for analyzing multiplicative chain models when the input parameters are statistically independent and lognormally distributed. Latin hypercube sampling has been offered as a promising candidate for doing sensitivity analyses. Several different ways of viewing the validity of a model have been presented and validity has been seen to be a matter of degree, dependent on the information available and subject to the requirements established by the decision maker. In addition, the validity of a model should be determined by comparing model predictions to data obtained from several different environmental situations. The process of selecting suitable models for environmental assessment purposes should give weight to those models which have a minimum need for unknown parameter values. Finally, the simplest model which can be acceptably validated is deemed most suitable for radiological assessment purposes.

REFERENCES

- Baker, D. A., G. R. Hoenes and J. K. Soldat. 1976. FOOD: An interactive code to calculate internal radiation doses from contaminated food products. BNWL-SA-5523.
- Baker, D. A. 1977. User guide for computer program FOOD. BNWL-2209. 39 pp.
- Bartine, D. E., E. M. Oblow and F. R. Mynatt. 1974. Radiation-transport cross-section sensitivity analysis - A general approach illustrated for a thermonuclear source in air. Nucl. Sci. Eng. 55(2):147-167.
- Booth, R. S. and S. V. Kaye. 1971. A preliminary systems analysis model of radioactivity transfer to man from deposition in a terrestrial environment. ORNL/TM-3135. 21 pp.
- Booth, R. S., S. V. Kaye and P. S. Rohwer. 1971. Systems analysis methodology for predicting dose to man from a radioactively contaminated terrestrial environment. pp. 877-893. IN Proc. of the Third National Symposium on Radioecology. Oak Ridge, Tenn. May 10-12, 1971. USAEC Report CONF-710501-P2.
- Conover, W. J. 1971. Practical Nonparametric Statistics. John Wiley and Sons, Inc. New York. 462 pp.
- Duguid, J. O. and M. Reeves. 1976. Material transport through porous media: A finite-element Galerkin model. ORNL-4928. 201 pp.

REFERENCES (CONT'D)

- Eraslan, A. H., E. J. Akin, J. M. Barton, J. L. Bledsoe, K. E. Cross, H. Diament, D. E. Fields, S. K. Fischer, J. L. Harris, D. M. Hetrick, J. T. Holderman, K. K. Kim, M. H. Lietzke, J. E. Park, M. R. Patterson, R. D. Sharp and B. Thomas, Jr. 1977. Development of a unified transport approach for the assessment of power-plant impact. ORNL/NUREG/TM-89. 47 pp.
- Gerstl, S. A. W., Donald J. Dudziak and D. W. Muir. 1977. Cross-section sensitivity and uncertainty analysis with application to a fusion reactor. Nucl. Sci. Eng. 62(1):137-156.
- Hanna, S. R. 1971. A simple method of calculating dispersion from urban area sources. J. Air Poll. Control Assoc. 21(12):774-777.
- Hanna, S. R. 1973. Description of the ATDL computer model for dispersion from multiple sources. pp. 23-32. IN Industrial Air Pollution. Ann Arbor Science, Ann Arbor, Mich.
- Hanna, S. R. 1975. Urban diffusion problems. pp. 209-227. IN Lectures on Air Pollution and Environmental Impact Analysis. American Meteorological Society, Boston, Mass.
- Hanna, S. R. and F. A. Gifford. 1977. Application of the ATDL simple urban dispersion model to Frankfurt, West Germany. IN Proceedings of the NATO/CCMS 8th International Technical Meeting on Air Pollution Modeling and Its Application. Louvain-La-Neuve, Belgium.

REFERENCES (CONT'D)

- Koch, R. C. and G. E. Fisher. 1976. Evaluation of the multiple-source Gaussian plume diffusion model. Geomet, Inc., 50 Monroe St., Rockville, Md. Geomet Report EF-186. 95 pp.
- Lange, R. 1973. ADPIC: A three-dimensional computer code for the study of pollutant dispersal and deposition under complex conditions. UCRL-51462. 60 pp.
- McKay, M. D. and L. A. Bruckner. 1976. On the statistical analysis of an output of a large computer code as a function of the inputs. pp. 142-150. IN Nicholson, Wesley L. and Judith L. Harris (eds.). Proc. First ERDA Statist. Symp. Los Alamos, N.M. Nov. 3-5, 1975. BNWL-1986. 215 pp.
- McKay, Michael D., W. J. Conover and David E. Whiteman. 1976. Report on the application of statistical techniques to the analysis of computer codes. LA-6479-MS. 15 pp.
- Miller, D. R., Gail Butler and Lise Bramall. 1976. Validation of ecological system models. J. Envir. Mgmt. 4:383-401.
- Moore, R. E. 1977. The AIRDOS-II computer code for estimating radiation dose to man from airborne radionuclides in areas surrounding nuclear facilities. ORNL-5245. 146 pp.
- Nappo, C. J., Jr. 1974. A method for evaluating the accuracy of air pollution prediction models. pp. 325-329. IN Proc. Symp. Atmospheric Diffusion and Air Pollution. Santa Barbara, Calif.

REFERENCES (CONT'D)

- Oblow, E. M. 1976. Sensitivity theory from a differential viewpoint. Nucl. Sci. Eng. 59(2):187-189.
- Oblow, E. M. 1977. Sensitivity theory for general non-linear algebraic equations with constraints. ORNL/TM-5815. 17 pp.
- Onishi, Y. 1977a. Finite element models for sediment and contaminant transport in surface waters. Transport of sediments and radionuclides in the Clinch River. BNWL-2227. 103 pp.
- Onishi, Y. 1977b. Mathematical simulation of sediment and radionuclide transport in the Columbia River. BNWL-2228. 89 pp.
- Pinder, John E., III and Michael H. Smith. 1975. Frequency distributions of radiocesium concentrations in soil and biota. pp. 107-125. IN Howell, F. G., J. B. Gentry and M. H. Smith (eds.), USERDA Symp. Ser. CONF-740513. NTIS, Springfield, Va.
- Polis, Michael P. and Raymond E. Goodson. 1976. Parameter identification in distributed systems: A synthesizing overview. Proc. IEEE. 64(1):45-61.
- Reeves, M. and J. O. Duguid. 1975. Water movement through saturated-unsaturated porous media: A finite-element Galerkin model. ORNL-4927. 226 pp.
- Shaeffer, D. L. and F. O. Hoffman. 1978. Statistical analysis of radioiodine transport via the grass-cow-milk pathway. In preparation for submission to Nucl. Technol.

REFERENCES (CONT'D)

- Siegel, Sidney. 1956. Nonparametric Statistics for the Behavioral Sciences. McGraw-Hill Book Company. New York. 312 pp.
- Soldat, J. K., N. M. Robinson and D. A. Baker. 1974. Models and computer codes for evaluating environmental radiation doses. BNWL-1754. 165 pp.
- Speer, D. R. and D. A. Waite. 1975. Statistical distributions as applied to environmental surveillance data. pp. 117-143. IN Proc., Third Environmental Protection Conference. Chicago, Ill., Sept. 23-26, 1975. CONF-750967. USERDA, Washington, D.C.
- Toy, A. J. and C. L. Lindeken. 1975. The implications of sampling from a log-normal population. pp. 144-167. IN Proc., Third Environmental Protection Conference. Chicago, Ill., Sept. 23-26, 1975. CONF-750967. USERDA, Washington, D. C.
- Vanderploeg, H. A., D. C. Parzyck, W. H. Wilcox, J. R. Kercher and S. V. Kaye. 1975. Bioaccumulation factors for radionuclides in freshwater biota. ORNL-5002. 222 pp.
- Vithayathil, Francis J. and Howard A. Hirsch. 1975. Sensitivity analysis of a simulation model of an agricultural ecosystem - some preliminary results. IN Proc. of Conference on Simulation and Modeling. Pittsburgh, Pa., April, 1975.
- Zar, Jerrold H. 1974. Biostatistical Analysis. Prentice-Hall, Inc., Englewood Cliffs, N.J. 620 pp.

3. APPLICATION OF THE METHODOLOGY

3.1 A Compilation of Documented Computer Codes

3.1.1 Introduction

One of the initial steps in the application of the formalized model evaluation methodology is a compilation of documented computer codes used to calculate the environmental transport and dosimetry of radionuclides. So far, nearly 100 codes have been identified which are applicable to the subject areas of aquatic and atmospheric dispersion, deposition and resuspension, aquatic and terrestrial food chain transport, and the calculation of doses resulting from internal and external modes of radiation exposure. Information about these codes has been incorporated into a computer retrievable data base. This data base includes abstracts of the codes and indexes by author, key words, publication description and title. A reproduction of this information is presented in Appendices B-F in this report.

The capabilities of 83 of these computer codes have been summarized in tabular form and reviewed in two recent publications (Hoffman et al., 1977a and b). This preliminary analysis clearly indicates that the initial efforts to develop assessment methodologies have concentrated on atmospheric dispersion, external dosimetry, and internal dosimetry via inhalation. The incorporation of terrestrial and aquatic food chain pathways into computer codes has been a more recent development and reflects the need for satisfying the current requirements of environmental legislation and regulatory agencies.

Because of the difficulties related to the transferability and documentation of these computer codes and the fact that many of these codes employ the same or basically similar mathematical models, the emphasis of this project has been oriented more toward the specific evaluation of the mathematical models, parameters and parameter values rather than attempting to extend this evaluation to the numerous codes. Code evaluation will be reserved for those cases in which a certain computer code is the only available means of model implementation. The following discussions, therefore, reflect this orientation toward the analysis of environmental transport and dosimetry models, parameters and parameter values which may be employed in the assessment of the environmental consequences of the releases of radioactive materials.

REFERENCES

- Hoffman, F. O., C. W. Miller, D. L. Shaeffer, C. T. Garten, Jr.,
R. W. Shor and J. T. Ensminger. 1977a. A compilation of documented
computer codes applicable to the environmental assessment of
radioactivity releases. ORNL/TM-5830. 76 pp.
- Hoffman, F. O., C. W. Miller, D. L. Shaeffer and C. T. Garten, Jr.
1977b. Computer codes for the assessment of radionuclides released
to the environment. Nucl. Saf. 18(3):343-354.

3.2 Terrestrial Food Chain Transport of Transuranic Elements

Charles T. Hinton, Jr.

The evaluation of environmental transport models with respect to uranium and transuranic elements has proceeded along four major themes: 1) an identification of the possible range of parameter values from a literature survey of field experiments, 2) a corresponding analysis of the range of possible predicted values from model calculations given the possible range of input parameter values, 3) the sensitivity of predictions from representative transport models to changes in the input parameter values, and 4) a comparison of predictions from representative transport models with available measurements from field sites. Although the routine release of transuranic elements from light water nuclear reactors is negligible, there are several steps in the nuclear fuel cycle (e.g., fuel fabrication and fuel reprocessing) which will lead to chronic low-level releases of these elements to the environment. An ongoing objective of the transuranics portion of the model evaluation project has been to evaluate the uncertainties or sources of uncertainty associated with generic assessments of transuranic transport through food chains to man.

3.2.1 Variation in parameter values used to assess the terrestrial food chain transport of plutonium, uranium and thorium

The chief input pathway of industrially processed actinides to terrestrial ecosystems is from atmospheric releases (USAEC, 1974; Hoffman and Kaye, 1976). While various methodologies differ in the parameter values required to predict food chain transport of actinides

to man, most models are dependent, either directly or indirectly, on measurements or generic estimates of the following: 1) fractional interception of deposition by vegetation, 2) vegetation biomass, 3) effective half-life on vegetation, 4) soil to plant transfer coefficients, 5) feeding rates by cattle, 6) feeding rates by man, 7) transfer coefficients from forage to meat, and 8) transfer coefficients from forage to milk. Spatial and temporal variation in these key parameters will produce changes in predictions of dose-to-man from actinides in the food chain. The degree of variation in predictions which can be expected on the basis of varying parameter values will determine what confidence can be placed on generic assessments of environmental impact from nuclear facilities.

Variation in the previously mentioned parameter values for predicting food chain transport of Pu, U and Th is summarized in Table 3.1. This compilation is based on the results of a literature survey. The probability density functions (p.d.f.) which adequately describe variation in the parameters in Table 3.1 are not known. More than likely these frequency distributions are positively skewed since it has been shown that Pu concentrations in soils (Little, 1976) and U concentrations in plants (Dean, 1966) are often characterized by positively skewed frequency distributions in nature. A mean or a midrange can be calculated from data in some literature reports but unless the p.d.f. is known, there is no way of estimating the most probable parameter value. Furthermore, the exact form of the p.d.f. may exhibit temporal and spatial variation.

Nevertheless, using the minimum and maximum parameter values in Table 3.1 it is possible to bracket predictions of actinide concen-

Table 3.1 Variation in parameter values used for assessing the terrestrial food chain transport of actinides

Parameter	Range based on field studies	References
Fraction intercepted by vegetation	0.1 to 0.6	Witherspoon and Taylor (1970), Chadwick and Chamberlain (1970)
Effective half-life on vegetation (d^{-1})	0.0093 to 0.0289	Witherspoon and Taylor (1970), Chamberlain (1970)
Pasture biomass, wet ^a kg m^{-2}	0.1 to 4.5	Koranda (1965), Comar (1966)
Crop biomass, wet ^a kg m^{-2}	1.6 to 48	Whittaker (1970)
Soil to plant transfer (based on wet weight) ^b	Pu: $2\text{E-}4^{\text{c}}$ to $5\text{E-}2$ U: $3\text{E-}5$ to $9\text{E-}2$ Th: $3\text{E-}5$ to $2\text{E-}3$	Dahlman et al. (1976), Hanson and Miera (1976), Mordberg et al. (1976)
Forage to milk transfer, d^{-1}	Pu: $3\text{E-}9$ to $7\text{E-}8$ U: $4\text{E-}5$ to $3\text{E-}4$	Stanley et al. (1976), Chapman and Hammons (1963)
Forage to meat transfer, d kg^{-1}	Pu: $5\text{E-}9$ to $7\text{E-}8$	Stanley et al. (1976)
Forage consumption by cow, wet kg d^{-1}	30 to 70	Comar (1966)
Human consumption of crops, kg yr^{-1}	251 to 390	Hollingsworth and Hobson (1966)
Human consumption of milk, l yr^{-1}	6 to 356	Hollingsworth and Hobson (1966)
Human consumption of meat, kg yr^{-1}	2 to 116	Hollingsworth and Hobson (1966)

^aConverted from dry to wet weight by $\times 4$.

^bSoil to plant transfer factors based on dry weight were converted to wet weight $\times 4$.

^c $2\text{E-}4 = 2 \times 10^{-4}$

trations in food products given a constant and arbitrary deposition rate. The equations and methodology outlined in the U.S. Nuclear Regulatory Commission's Regulatory Guide 1.109 (USNRC, 1976) will be used as an example. In such example calculations, the actual predicted values have little meaning but the range of variation in predicted values illustrates the magnitude of the differences which can be expected when the range of parameter values in Table 3.1 is considered in model calculations.

Using a deposition rate of $1 \text{ pCi m}^{-2} \text{ hr}^{-1}$ for ^{239}Pu , ^{233}U and ^{232}Th , the predicted concentrations in food products and the subsequent dose to man's bone from the consumption of contaminated crops were calculated (Table 3.2). Given the deposition rate, the probability of encountering the maximum or minimum predicted concentration or dose is unknown, but the magnitude of the problem is obvious. Predicted values differ by orders of magnitude depending on the input values used in the formulas. However, the results from Table 3.2 demonstrate a similarity in predictions of concentration and dose with respect to Pu, U, and Th because many of the important parameters in food chain models are considered to be radionuclide independent. Table 3.2 also indicates the existing need for more data from field experiments to supply input values for Th and U in plant to animal to man transfers.

Considering the range of natural spatial and temporal variation in biological, physical and meteorological parameters which affects variation in model predictions what is the most appropriate choice of parameter values to generically predict actinide food chain transport? Ideally we would like to know the probability density functions of each input

Table 3.2 Variation in predicted actinide concentrations and dose-to-man found by substituting the range of parameter values in Table 3.1 into NRC 1.109 (1976) formulas for terrestrial food chain transport

Predicted value	Nuclide		
	Pu	U	Th
Concentration ^a in pasture, pCi kg ⁻¹ wet	0.88 to 5207	0.79 to 5230	0.78 to 5181
Concentration ^b in crops, pCi kg ⁻¹ wet	0.18 to 612	0.09 to 634	0.09 to 586
Concentration in milk, pCi L ⁻¹	1E-7 to 2E-2	2E-3 to 78	ND ^d
Concentration in meat, pCi kg ⁻¹	2E-7 to 2E-2	ND	ND
Dose to man's bone, ^c mrem yr ⁻¹	3E-2 to 180	2E-2 to 215	4E-2 to 410

^aAfter 30 days of continuous exposure.

^bAfter 60 days of continuous exposure.

^cCalculated on the basis of food crops only.

^dND insufficient data.

parameter to arrive at an estimate of the likelihood that a given release will exceed a given standard of dose to man. This statistical approach is not possible given the present state of knowledge about the frequency distributions of parameter values used in food chain transport models. Alternatively one can make assumptions about the form of the probability density functions or one can choose a distribution-free (i.e. nonparametric) approach to generic assessments. Following the principle of parsimony, and minimizing assumptions, a common methodology in generic assessments is to choose parameter values that will lead to a "worst case" scenario and predict the upper-limit dose to the "maximum individual." The reasoning behind such calculations is that if the dose to the maximum individual is less than the dose standard then one can be relatively sure that all other individual exposures are less than the standard. Statistically this corresponds to choosing parameter values that lie beyond three standard deviations of the mean to calculate a release rate that will not exceed the standard 99% of the time. For maximum public safety in assessments of transuranic food chain transport one should choose parameter values that yield predictions of dose to the maximum individual. Electing to use the mean or the midrange of parameter values will result in an assessment of dose to the average or median individual in the population but will not reveal what fraction of the population is exposed to doses beyond a given standard.

3.2.2 Identification of critical parameters in the terrestrial food chain transport of transuranic elements

Predictions of actinide concentrations in food products or resulting dose-to-man from environmental transport models can be orders of magnitude

different depending on the input values used in model calculations. A reduction of variation in such predictions can be accomplished by direct and accurate measurement of parameter values in the vicinity of nuclear facilities releasing actinides to the environment. However, when complex codes or models requiring many input parameters are used to assess environmental transport, then ecologists need to know which parameter values are most important in affecting the model prediction. For example, in a two-parameter model, if parameter A potentially accounts for 80% of the variation in the prediction, and parameter B 20%, then the former must be measured most accurately in the field.

Most environmental transport models which make quantitative predictions about radionuclide concentrations in food can be dissected to identify critical parameters contributing to variation in model predictions. Sensitivity analysis is a useful tool for this purpose. Usually in sensitivity analysis the model parameters are independently varied by some constant percentage of their recommended value and the deviation from predictions based on the recommended values is calculated. Model parameters can then be ranked in order of relative importance to model predictions.

A sensitivity analysis of Pu food chain transport as modeled in the TERMOD methodology (Booth et al., 1971) was undertaken in an attempt to identify critical parameters. Each parameter was varied $\pm 50\%$ of its nominal value. A sensitivity coefficient (S) was calculated as follows:

$$S = (Y_1 - Y_2)/Y_0 \div (X_1 - X_2)/X_0,$$

where

Y_1 = equilibrium prediction given the parameter value +50%,

Y_2 = equilibrium prediction given the parameter value -50%,

Y_0 = equilibrium prediction at nominal parameter value,

X_1 = parameter value increased 50%,

X_2 = parameter value decreased 50%,

X_0 = nominal parameter value.

This sensitivity coefficient was calculated for parameters affecting predictions of ^{239}Pu concentrations in above-surface food crops, milk, meat and ^{239}Pu intake by man (Table 3.3).

Radionuclide independent parameters important to the predicted intake of ^{239}Pu by man in TERMOD include the effective half-life of ^{239}Pu on food crops (TAUES), the fraction of atmospheric deposition intercepted by crops (S1), the fraction of the diet which is contaminated (D1), the consumption rate of crops by man (V) and the dry weight biomass of above-surface food (DSUBF). Similar parameters are important in the pasture grass to meat and milk foodchain. Many of the parameters important in the TERMOD code are equally important in assessments made using NRC Regulatory Guide 1.109 (USNRC, 1976) and FOOD (Baker et al., 1976).

Therefore, accurate measurements of the fraction of deposition intercepted by vegetation, vegetation biomass and effective half-life on vegetation will help reduce variation in TERMOD predictions of ^{239}Pu intake by man. Fortunately vegetation biomass is relatively easy to measure in the field. The other two parameters probably depend more on the characteristics of the particles associated with an atmospheric

Table 3.3 Sensitivity coefficients (S) calculated for various TERMOD parameters used in predicting Pu-239 food chain transport

Parameter	Above surface food	Milk	Meat	Intake by Man
Effective half-life on crops (TAUES)	-1.23			-1.13
Fractional interception by crops (S_1)	1.00			0.91
Crop biomass (DSUBF)	0.06			-1.13
Soil surface area (A)	0.06			0.06
Human consumption (V)	-0.05			0.87
Milking rate (TAUMILK)		-1.34		
Milk capacity of udder (U)		-1.34		
Effective half-life on pasture (TAUGR)		-1.05	-1.05	-0.08
Forage to milk transfer (FSUBM)		1.00		
Milk production by cow (VSUBM)		1.00		
Fractional interception by pasture (S_3)		1.00	1.00	0.08
Pasture biomass (DSUBG)		-0.98	-0.98	-0.08
Pasture consumption by cow (VSUBC)		0.86	-0.15	-0.01
Soil to sink transfer (TAURD)		-0.22	-0.22	-0.02
Soil to pasture transfer (TAURG)		0.17	0.17	0.01
Concentration of Pu-239 in forage (CSUBP)			-1.34	-0.11
Concentration of Pu-239 in meat (CSUBB)			1.00	0.08
Excretion rate from steer muscles (TAUEXC)			1.00	0.08
Meat consumption by man (TAUBM)				0.08
Dietary factor (D_1)				0.91
Dietary factor (D_3)				0.08

release than on the specific nuclide. Measurements of interception and retention of radioactively labelled particulates under conditions existing in the vicinity of nuclear facilities will help reduce uncertainties in generic predictions of actinide intake by man.

3.2.3 A comparison of model predictions with field measurements of plutonium concentrations in agricultural crops

Calculations of dose-to-man from the consumption of food products containing actinides show that plant foods are the most important ingestion pathway because of their large fractional contribution to man's diet and the greater concentration of actinides in crops relative to milk or meat. Because of the low assimilation efficiencies for Pu, U and Th from the mammalian gastrointestinal tract (Durbin, 1975; Pavlovskaya, 1973; Chapman and Hammons, 1963), animal consumers act as a filter for these elements between the environmental release and the subsequent consumption of meat and milk by man. The importance of plant foods in contributing the major portion of Pu and U consumed by man has been confirmed by dietary studies (Hamilton, 1972; Welford and Baird, 1967; Bennett, 1976) and reaffirms the need for validating methodologies used to predict actinide concentrations in food crops.

At the Savannah River Plant (SRP) in South Carolina, studies of plutonium concentrations in test agricultural crops adjacent to a fuel reprocessing plant have been underway for several years. Measurements at this site (summarized from Dahlman and McLeod, 1977) provide a unique opportunity for partial validation of environmental transport models. The measured deposition rate of Pu onto the agricultural field averages $26 \times 10^{-3} \text{ pCi m}^{-2} \text{ hr}^{-1}$. A wheat crop grown on the field contained

$9 \times 10^{-2} \text{ pCi g}^{-1}$ dry weight total Pu (i.e., ^{238}Pu and ^{239}Pu) after four months of continuous exposure. The standing crop biomass of the wheat was $0.36 \text{ dry kg m}^{-2}$ at harvest which yields an inventory of $\sim 32 \text{ pCi m}^{-2}$ of Pu. This information was used to predict and compare Pu concentrations in the SRP wheat using the TERMOD code and NRC Regulatory Guide 1.109 (USNRC, 1976) formulas. Recommended parameter values specific to the NRC formulas and the TERMOD computer code were used except for the following:

- 1) deposition rate = $26 \times 10^{-3} \text{ pCi m}^{-2} \text{ hr}^{-1}$
- 2) crop exposure time = 120 days
- 3) wet vegetation biomass = 1.4 kg m^{-2}
- 4) soil exposure time = 20 years.

A comparison of the model predictions with measured values at SRP is presented in Table 3.4. One problem in the direct comparison of TERMOD and NRC predictions is that the former predicts an inventory ($\mu\text{Ci m}^{-2}$) on a dry weight basis while the latter predicts Pu concentrations (pCi kg^{-1}) on a wet weight basis. To arrive at concentrations in the TERMOD calculation, one must divide by the dry standing crop biomass. Conversion of NRC wet weight units to dry weight units (pCi kg^{-1}) was accomplished by multiplication by a factor of four. TERMOD predicts concentrations at equilibrium, as does the NRC model for this particular example. Table 3.4 shows that the NRC and TERMOD predictions are similar and both are approximately an order of magnitude lower than the measured values of Pu in wheat at SRP.

On the basis of sensitivity analyses, the two parameter values which most likely account for the observed differences between measured and

Table 3.4 A comparison of model predictions from TERMOD and USNRC
Regulatory Guide 1.109 formulas with measured
Pu concentrations in the SRP wheat field

Item	Measured at SRP (dry weight)	TERMOD prediction (dry weight)	NRC prediction (wet weight)	NRC prediction (dry weight)
Pu in wheat pCi kg ⁻¹	90	7	<u>1.7</u> ^a	7 ^b
Pu wheat inventory ^c pCi m ⁻²	32	<u>2.5</u>	2.5	2.5

^aUnderscored numbers are actual predicted values.

^bWet weight to dry weight conversion made by x 4.

^cCalculated by multiplying pCi kg⁻¹ by 0.36 kg m⁻² dry or 1.44 kg m⁻² wet vegetation.

predicted Pu concentrations in wheat are effective half-life on vegetation and the fraction of deposition intercepted by vegetation. The values used to arrive at the model predictions presented in Table 3.4 are 0.0021 hr^{-1} for effective half-life and 0.2 for fractional interception of Pu deposition by wheat. Using Chamberlain's (1970) equation for estimating the proportion of total deposition retained by vegetation on the basis of dry biomass, the fractional interception for the SRP wheat is ~0.6. Additionally from the experiments of Cataldo et al. (1976) one might assume some maximum effective half-life on vegetation for Pu; in this case 0.0003 hr^{-1} from Table 3.1. Substituting these new parameter values into the NRC Regulatory Guide 1.109 (USNRC, 1976) formulas yields a predicted value of 21 pCi kg^{-1} wet for Pu in wheat or $\sim 84 \text{ pCi kg}^{-1}$ dry. This later prediction is within $\pm 10\%$ of the measured Pu concentration in wheat at SRP.

REFERENCES

- Baker, D. A., G. R. Hoenes and J. K. Soldat. 1976. FOOD: An interactive code to calculate internal radiation doses from contaminated food products. pp. 204-208. IN Ott, W. R. (ed.) Environmental Modeling and Simulation. EPA 600/9-76-015.
- Bennett, B. G. 1976. Transuranic element pathways to man. pp. 367-383. IN Transuranium Elements in the Environment. IAEA-SM-199/40. International Atomic Energy Agency, Vienna.
- Booth, R. S., S. V. Kaye and P. S. Rohwer. 1971. Systems analysis methodology for predicting dose to man from a radioactively contaminated terrestrial environment. pp. 877-893. IN Radionuclides in Ecosystems, Proceedings of the Third National Symposium on Radioecology. CONF-710501.
- Cataldo, D. A., E. L. Klepper and D. K. Craig. 1976. Fate of plutonium intercepted by leaf surfaces: Leachability and translocation to seed and root tissues. pp. 291-301. IN Transuranium Elements in the Environment. IAEA-SM-199/60. International Atomic Energy Agency, Vienna.
- Chadwick, R. C. and A. C. Chamberlain. 1970. Field loss of radionuclides from grass. *Atm. Environ.* 4:51-56.

REFERENCES (CONT'D)

- Chamberlain, A. C. 1970. Interception and retention of radioactive aerosols by vegetation. *Atm. Environ.* 4:57-78.
- Chapman, T. S. and J. S. Hammons. 1963. Some observations concerning uranium content and ingesta and excreta of cattle. *Health Phys.* 9:78-81.
- Comar, C. L. 1966. Radioactive materials in animals - Entry and metabolism. pp. 129-157. IN Russell, R. S. (ed.) *Radioactivity and the Human Diet*. Pergamon Press, New York.
- Dahlman, R. C., E. A. Bondietti and L. D. Eyman. 1976. Biological pathways and chemical behavior of plutonium and other actinides in the environment. pp. 41-80. IN Friedman, A. M. (ed.) *Actinides in the Environment*. ACS Symp. Ser. no. 35, American Chemical Society, New York.
- Dahlman, R. C. and K. W. McLeod. 1977. Foliar and root pathways of plutonium contamination of vegetation. pp. 303-320. IN White, M. G. and P. B. Dunaway (eds.), *Transuranics in Natural Environments*. NVO-178.
- Dean, M. H. 1966. A survey of the uranium content of vegetation in Great Britain. *J. Ecol.* 54:589-595.
- Durbin, P. W. 1975. Plutonium in mammals: Influence of plutonium chemistry, route of administration, and physiological status of the animal on initial distribution and long-term metabolism. *Health Phys.* 29:495-510.

REFERENCES (CONT'D)

- Hamilton, E. I. 1972. The concentration of uranium in man and his diet. *Health Phys.* 22:149-153.
- Hanson, W. C. and F. R. Miera, Jr. 1976. Long-term ecological effects of exposure to uranium. LA-6260. 34 pp.
- Hoffman, F. O. and S. V. Kaye. 1976. Terrestrial exposure pathways: potential exposures of man from the environmental transport of waste nuclides. pp. 524-538. IN International Symposium on the Management of Wastes from the LWR Fuel Cycle. CONF-76-0701.
- Hollingsworth, D. F. and E. A. Hobson. 1966. Composition of human diet. pp. 65-83. IN Russell, R. S. (ed.), *Radioactivity and the Human Diet*. Pergamon Press, New York.
- Koranda, J. J. 1965. Agricultural factors affecting the daily intake of fresh fallout by dairy cows. UCRL-12479.
- Little, C. A. 1976. Plutonium in Grassland Ecosystem. Ph.D. Dissertation, Colo. St. Univ., Ft. Collins. 170 pp.
- Mordberg, E. L., V. M. Aleksandruk, G. F. Kouygin, V. Shevchenko, V. M. Bunshtein and G. F. Yuskevich. 1976. The passage of the isotopes of the uranium-radium series into the grain of certain agricultural crops. *Gig. Sanit.* 2:58-61.
- Pavlovskaya, N. A. 1973. Basic patterns of metabolism of Th-232 and its dissociation products in the body. *Gig. Sanit.* 11:55-58. (in Russian).

REFERENCES (CONT'D)

- Stanley, E. R., E. W. Bretthaver and W. W. Sutton. 1976. Absorption distribution and excretion of plutonium by dairy cattle. pp. 493-544. IN White, M. G. and P. B. Dunaway (eds.), Nevada Applied Ecology Group Procedures Handbook for Environmental Transuranics. NVO 166.
- U.S. Atomic Energy Commission. 1974. Proposed Final Environmental Statement - LMFBR Program. WASH-1535.
- U.S. Nuclear Regulatory Commission. 1976. Regulatory Guide 1.109. Calculation of annual doses to man from routine releases of reactor effluents for the purpose of evaluating compliance with 10 CFR Part 50, Appendix I.
- Welford, G. A. and R. Baird. 1967. Uranium levels in human diet and biological materials. Health Phys. 13:1321-1324.
- Whittaker, R. H. 1970. Communities and Ecosystems. McMillan Publ. Co., New York. 162 pp.
- Witherspoon, J. P. and F. G. Taylor, Jr. 1970. Interception and retention of a simulated fallout by agricultural plants. Health Phys. 19:493-499.

3.3 Atmospheric Dispersion and Deposition Studies

Charles W. Miller

One of the principal ways in which radionuclides from nuclear facilities reach the environment is via discharges to the atmosphere. As such, efforts are underway to examine the models and parameters used to estimate atmospheric transport, diffusion and deposition.

3.3.1 A comparison of two methods of determining atmospheric stability categories

Atmospheric stability is an important parameter in models used to estimate downwind air concentrations of radionuclides released by nuclear facilities (Gifford, 1975). Pasquill (1961) introduced the concept of expressing atmospheric stability in terms of stability categories ranging from A, most unstable, to F, most stable.

The U.S. Nuclear Regulatory Commission (1972) allows an applicant for a license for a nuclear facility to use either of two methods to determine stability categories for use in assessing the consequences of both accidental and routine radionuclide releases. The applicant may use a measure of the horizontal wind direction fluctuation, σ_θ , or a measure of the temperature gradient, $\frac{\partial T}{\partial Z}$, between 10 m and 40 m, or higher, on the meteorological tower at the site of the proposed facility. Recent analyses by Culkowski (1977) and Pendergast (1976) have shown that these two methods may give significantly different results when applied to the same meteorological data set.

Hourly observations for 1975 at TVA's Kingston Heights meteorological tower located near the Kingston, Tennessee, steam plant have been analyzed. Stability categories were determined from $\frac{\partial T}{\partial Z}$ between 10 m and 45 m and from σ_θ measured at both 10 m [$\sigma_\theta(10)$] and 45 m [$\sigma_\theta(45)$]. Table 3.5 shows the percentage occurrence of each stability class as determined by each of these three calculations. It can be seen that the three calculations do not give the same results.

The effect of these differences in stability category on downwind air concentrations will depend upon a number of considerations, including the model being used, dispersion parameters used, height of release, and others. As one illustration, Turner (1969) shows the normalized ground-level air concentration as a function of stability category, downwind distance, release height and a limit to vertical mixing as computed by the Gaussian plume model. Table 3.6 shows the annual average normalized concentration at three downwind distances for each of the three stability category determinations calculated by weighting the values from Turner (1969) according to the percent occurrences listed in Table 3.5 assuming a release height of 10 m and a limit to vertical mixing of 1000 m. It can be seen that at a given distance the normalized concentration may vary by as much as a factor of four between the different stability categorization methods used. Such a factor may be significant for some nuclear facilities (Hoffman and Kaye, 1976):

The question none of these comparisons answers is which method, either $\frac{\partial T}{\partial Z}$, σ_θ , or some other, is the best way of categorizing atmospheric stability. Until this question is answered and the

Table 3.5 Percentage occurrence of each stability class determined
by three methods for the Kingston Heights
meteorological tower during 1975

Stability category	Percent occurrence		
	$\frac{T}{Z}$	$\bar{z}(45)$	$\bar{z}(10)$
A	9	8	28
B	2	6	15
C	2	13	22
D	20	30	22
E	41	31	10
F	25	11	3

Table 3.6 Normalized ground-level air concentration as a function of selected downwind distances calculated from the Gaussian plume model for each method of determining stability category

Downwind distance, km	$\frac{ux^*}{Q}, m^{-2}$		
	σ_T/σ_Z	$\sigma_e(45)$	$\sigma_e(10)$
0.1	$3.8E-4^a$	$6.2E-4$	$8.6E-4$
1	$2.7E-4$	$1.9E-4$	$8.8E-5$
10	$1.1E-5$	$7.2E-6$	$2.9E-6$

*u = wind speed, $m \text{ sec}^{-1}$

x = downwind air concentration, $Ci \text{ m}^{-3}$

Q = release rate $Ci \text{ sec}^{-1}$

^a $3.8E-4 = 3.8 \times 10^{-4}$

regulations changed accordingly, the radiological assessor must use care in choosing which categorization scheme to use. The $\frac{\partial T}{\partial Z}$ method is very commonly used because it is easier and less expensive to measure than is σ_z . Since the highest downwind doses are normally found for stability categories E and F, the data shown in Table 3.6 indicate that the $\frac{\partial T}{\partial Z}$ method gives the highest estimates of population dose. However, for elevated releases the highest individual doses often result from the more unstable categories. These same data (Table 3.6) indicate that the σ_z method, especially when measured at lower levels, results in the occurrence of higher doses close to the source than does the $\frac{\partial T}{\partial Z}$ method. As such, it may be necessary for the radiological assessor to compare the results of using both methods in order to ensure that the highest dose estimates have been made for both accidental and routine radionuclide releases.

3.3.2 An examination of Gaussian plume dispersion parameters for use over rough terrain

The Gaussian plume model (Gifford, 1968; Turner, 1969) has gained wide acceptance as a method for estimating downwind concentrations of radionuclides released to the atmosphere (Hoffman et al., 1977a and b). It has been shown that two key parameters in this model are the lateral and vertical dispersion parameters, $\sigma_y(x)$ and $\sigma_z(x)$, respectively (Weber, 1976).

Empirically-determined graphs of $\sigma_y(x)$ and $\sigma_z(x)$ as a function of downwind distance, x , and atmospheric stability have been developed by a number of authors (Gifford, 1976). The most popular set of such graphs is that based on the work of Pasquill (1961) as modified by Gifford

(1961). These graphs have been applied under a wide range of conditions, but they were designed to be used for relatively short downwind distances over flat terrain (Hosker, 1974). Briggs (1973) has proposed a set of graphs of $\sigma_y(x)$ and $\sigma_z(x)$ that are designed to be applicable over a longer distance but which are still applicable only over relatively flat terrain.

Smith (1972) has attempted to extend Pasquill's scheme of $\sigma_z(x)$ to include a variety of surface roughnesses. Pasquill (1976) has recommended that Smith's scheme be used to adjust the Pasquill-Gifford $\sigma_z(x)$ curves whenever the roughness length, z_0 , is greater than 3 cm. Similar work has not yet been reported for $\sigma_y(x)$.

Experiments are underway in Germany to determine dispersion parameters typical of the terrain found there for use in assessing airborne releases from nuclear facilities. At the Jülich Nuclear Research Center (Vogt and Geiss, 1974), $^{64}\text{CuSO}_4$ aerosols of less than 5 μm diameter were released from a height of 50 m and traced out to a distance of 11 km. At Karlsruhe (Thomas and Nester, 1976; Thomas et al., 1976), tritiated water (HTO) and halogenated hydrocarbons have been released from a height of 100 m and measurements taken out to a distance of 2 km. In both of these experiments the material dispersed over a variety of terrain types. A value of $z_0 = 110$ cm has been reported for Karlsruhe (Thomas et al., 1976) while z_0 was reported to range between 40 cm and 100 cm for Jülich (Vogt et al., 1973).

Curves of $\sigma_y(x)$ and $\sigma_z(x)$ derived from the German data have been compared to their Pasquill-Gifford counterparts for stability categories B, C and D. As might be expected from the increase in mechanical

turbulence generated by the roughness elements, the experimental values of $\sigma_y(x)$ and $\sigma_z(x)$ were generally found to be higher than the corresponding Pasquill-Gifford values. The experimentally-determined $\sigma_z(x)$ values have also been compared to Smith's roughness-compensated $\sigma_z(x)$ ($z_0 = 100$ cm). In general, it was found that the empirical values are larger than the Smith values and the measured values increase more rapidly with distance. The empirical values of $\sigma_y(x)$ also tend to be larger than the corresponding Briggs' values, but the extent of this difference generally decreases with distance in each stability class. Thus, there are indications that dispersion over rough terrain may be larger in the atmosphere than is predicted by either the Pasquill-Gifford, Briggs or Smith curves.

The choice of which of these systems of dispersion parameters to use can have a significant effect on estimates of downwind air concentration. Table 3.7 shows the maximum center-line ground-level normalized air concentration and its location (Pasquill, 1974) for two different release heights and Pasquill stability category D as predicted by four different sets of dispersion parameters. It can be seen that the measured dispersion parameters predict the maxima to be closer to the source and sometimes higher in value than either the Smith ($\sigma_z(x)$)-Briggs ($\sigma_y(x)$) or Pasquill-Gifford curves. At the same time, the measured dispersion parameters indicate lower concentrations at longer downwind distances, as illustrated in Fig. 3.1.

Table 3.7 Maximum center-line ground-level normalized air concentration and its location calculated for two different release heights using four different sets of dispersion parameters^a

Method of determination	Downwind location of maximum concentration, m	Maximum normalized concentration, m^{-2}
$H^b = 50m$		
Smith (σ_z) - Briggs (σ_y)	600	$7.0E-5$
Pasquill-Gifford	1200	$4.1E-5$
Karlsruhe Data ^c	320	$4.4E-5$
Jülich Data	250	$8.2E-5$
$H = 100m$		
Smith (σ_z) - Briggs (σ_y)	1800	$1.3E-5$
Pasquill-Gifford	3500	$6.8E-5$
Karlsruhe Data ^c	640	$1.5E-5$
Jülich Data	540	$2.3E-5$

^aAtmospheric stability = Pasquill category D (neutral)

^b H = effective height of release

^cConsidering HTO data only

Fig. 3.1. The center-line ground-level normalized air concentrations as a function of downwind distance calculated with the Jülich data (---) and the Smith-Briggs curves (---) for an effective release height of 50 m and Pasquill D stability.

3.3.3 Sensitivity of deposition and plume depletion calculations to variations in the value of deposition velocity

In environmental radiological assessments, the depletion of airborne plumes by dry deposition processes and the subsequent contamination of ground and vegetation have been estimated through the use of a parameter termed the "deposition velocity." Experimentally derived values of deposition velocity have often been misinterpreted when used for making such assessments (Hoffman, 1977). We have not attempted to determine which value of deposition velocity is most appropriate for a given assessment, but have examined the sensitivity of environmental assessment models to changes in the value of deposition velocity and thus the effect of potential variations of deposition velocity on calculations of radiation dose.

Deposition velocity, v_d , is a transfer factor relating the amount or rate of deposition to the amount of material in air (Chamberlain, 1953); that is,

$$v_d = \frac{\text{amount or rate of deposition}}{\text{concentration in air}} \quad (1)$$

While a range of deposition velocities of 10^{-4} to 10 cm/sec has been reported for aerosols and reactive gases (Sehmel and Hodgson, 1976), a value of $v_d = 1$ cm/sec is commonly used in radiological assessments for estimating both plume depletion and ground surface deposition.

Models which employ v_d to estimate deposition onto ground or vegetation are generally involved in the determination of the dose to man either via external exposure from contaminated ground or internal

exposure from contaminated food. In either case, it can be seen from Eq. (1) that the amount or rate of deposition is directly dependent on v_d . Thus, any percentage change in v_d will introduce a like change in the amount or rate of deposition. As a result, accurate measurements of v_d are needed where deposition on ground or agricultural crops are to be estimated. With the wide range of deposition velocities found in nature, using 1 cm/sec for all radionuclides in the calculation of the dose to man from contaminated ground or food could lead to significant overestimates or underestimates of the dose.

Atmospheric dispersion models for estimating air concentration use v_d to account for plume depletion via dry deposition. The resulting air concentration may be used to calculate an external cloud dose or an internal inhalation dose. This air concentration may also be used to calculate surface deposition, thus resulting in v_d being used twice in the deposition calculation.

The Gaussian plume model (Pasquill, 1961) is the atmospheric dispersion model most commonly used for radiological assessments (Hoffman et al., 1977a and b). This model is adjusted for plume depletion via a formulation (Van der Hoven, 1968) that is nonlinearly related to v_d . To illustrate the sensitivity of this model to changes in v_d , example calculations can be made (Moore, 1977a) of the plume depletion fraction, $f(x)$, where

$$f(x) = \frac{\text{air concentration corrected for dry deposition}}{\text{air concentration uncorrected for dry deposition}} \quad (2)$$

Table 3.8 shows the variation in $f(x)$ with change in downwind distance and v_d for conditions chosen to represent routine radionuclide release situations. Tables 3.9(a) and 3.9(b) show similar calculations for two extreme conditions that might be considered in the evaluation of accidental releases. It can be seen that for elevated releases relatively long distances must be reached before an order of magnitude change in v_d results in a like change in $f(x)$. For the ground-level release case $f(x)$ changes more rapidly, but even here the relationships are quite nonlinear.

These results indicate that the plume depletion model considered here is relatively insensitive to changes in v_d , especially for elevated releases and distances less than 10 km. As a result, variations in v_d should have more influence on estimates of population dose from inhalation and cloud exposure than on estimates of the highest individual dose from these pathways. Most deposition velocity measurements found in the literature are representative of deposition onto vegetation within a given area of ground rather than the total deposition within this area (Hoffman, 1977), and these values have often been misused for plume depletion calculations. The results of this study indicate that for elevated releases this misuse may be acceptable for estimating plume depletion for distance out to a few kilometers. For ground-level releases, however, not using a value of v_d that corresponds to total deposition may result in significant underestimates of plume depletion and, therefore, overestimates of air concentrations and subsequent doses to man.

Table 3.8 The plume depletion fraction, $f(x)$, at five downwind distances and four values of deposition velocity, v_d , for a release height^a and atmospheric stability^b category chosen to represent a routine radionuclide release assessment

Downwind distance, m	v_d , m/sec			
	10^{-4}	10^{-3}	10^{-2}	10^{-1}
	$f(x)$			
10^1	1	1	1	1
10^2	1	1	1	1
10^3	1	1	1	1
10^4	1	0.96	0.68	0.02
10^5	0.97	0.77	0.07	0

^aRelease height = 100 m

^bAtmospheric stability = Pasquill D (neutral).

Table 3.9 The plume depletion fraction, $f(x)$, at five downwind distances and four values of deposition velocity, v_d , for two release heights and atmospheric stability categories chosen to represent an accidental radionuclide release assessment

(a) Release height = 50 m, Atmospheric stability = Pasquill A (extremely unstable)

<u>Downwind distance,</u>	<u>v_d, m/sec</u>			
m	10^{-4}	10^{-3}	10^{-2}	10^{-1}
	$f(x)$			
10^1	1	1	1	1
10^2	1	1	1	0.99
10^3	0.99	0.99	0.94	0.56
10^4	0.99	0.99	0.86	0.22
10^5	0.99	0.98	0.79	0.09

(b) Release height = 0 m, Atmospheric stability = Pasquill F (moderately stable)

<u>Downwind distance,</u>	<u>v_d, m/sec</u>			
m	10^{-4}	10^{-3}	10^{-2}	10^{-1}
	$f(x)$			
10^1	1	1	1	1
10^2	1	0.97	0.72	0.03
10^3	0.99	0.86	0.21	0
10^4	0.96	0.67	0.02	0
10^5	0.83	0.15	0	0

3.3.4 An examination of the NRC methodology for estimating dry deposition and plume depletion

The U. S. Nuclear Regulatory Commission (NRC) has recently proposed a new methodology for estimating dry deposition of elemental radioiodines and other particulates and attendant plume depletion (USNRC, 1977). This represents a departure from the methods commonly used for such calculations (see Sect. 3.3.3). In an attempt to evaluate the effective difference in the results of using both methods, a sample calculation has been made and the results compared.

The NRC has presented a series of figures which give the plume depletion fraction and the relative deposition rate as a function of downwind distance for three different atmospheric stabilities (stable, unstable, and neutral) and four different release heights (0, 30, 60 and 100 m). These curves are based on a solution to the basic "K-theory" diffusion equation for an infinite crosswind-oriented line source assuming partial retention of the effluent material at ground-level (Markee, 1967). The deposition velocities used in the model are based on measurements of radioiodine deposition as a function of wind speed taken at Idaho Falls, Idaho (Pelletier and Zimbrick, 1970).

To use the plume depletion curves, one first calculates the air concentration at a given location using one of the dispersion models acceptable to the NRC (USNRC, 1977). This undepleted air concentration is then multiplied by the appropriate stability-category weighted plume depletion fraction taken from the figure provided. This new, adjusted air concentration is then used to estimate the dose to man due to inhalation and external exposure to the plume.

In contrast, the amount of deposition on to the ground per unit area is estimated independently of the calculated air concentration. Instead, the appropriate stability category weighted relative deposition rate from the figures provided is

- 1) multiplied by the wind direction weighted fraction of the released material which is blown into the sector of interest, and
- 2) divided by the crosswind distance at the downwind distance of interest.

If the concentration is not assumed to be uniform across the sector, an additional correction factor must also be applied.

To compare the NRC methodology with that commonly used (Van der Hoven, 1968), an example calculation has been made. Atmospheric dispersion was estimated using the Gaussian plume model in its 22.5° sector-averaged form as implemented by the AIRDOS-II computer code (Moore, 1977a). AIRDOS-II was also used to calculate plume depletion and deposition using the standard methods and assuming a deposition velocity of 1 cm/sec, as is commonly done in radiological assessments (Hoffman, 1977). The meteorology used in the calculation was that developed for Oak Ridge National Laboratory (Moore, 1977b). A release rate of 1 pCi/sec was assumed.

Table 3.10 shows the resulting air concentration and ground deposition rate calculated by both the AIRDOS-II and NRC methodologies assuming a 100 m release height. Only the sector with the highest concentrations is shown, but a preliminary examination indicates similar

Table 3.10 A comparison of the results of a sample calculation of plume depletion and dry deposition rate using the NRC and AIRDOS-II methodologies assuming a release height of 100 m and a release rate of 1 pCi/sec

Downwind distance, m	Undepleted air concentration pCi/cm ³	Depleted air concentration, pCi/cm ³		Ground deposition rate, pCi/cm ² - sec	
		AIRDOS-II	NRC	AIRDOS-II	NRC
100	2.1E-17	2.1E-17	2.1E-17	2.1E-17	4.0E-14
500	4.0E-13	4.0E-13	4.0E-13	4.0E-13	7.3E-13
1000	3.6E-13	3.6E-13	3.6E-13	3.6E-13	4.7E-13
5000	1.6E-13	1.5E-13	1.6E-13	1.5E-13	5.9E-14
10000	8.8E-14	6.9E-14	8.1E-14	6.9E-14	2.0E-14
50000	1.5E-14	4.4E-15	1.2E-14	4.4E-15	2.0E-15
100000	7.4E-15	9.2E-16	5.2E-15	9.2E-16	6.4E-16

results for the other fifteen sectors. It can be seen that the depleted air concentrations are very similar in value, with the NRC values becoming higher in value as the downwind distance increases. The two methodologies also yield similar values for the estimated ground deposition rate except that at a downwind distance of 100 m, the NRC method gives a significantly higher rate of deposition. It is interesting to note that at distances greater than 100 m the NRC results are sometimes actually lower than the AIRDOS-II results.

Table 3.11 shows the results of a similar calculation made assuming a 1 m release height. Again the NRC method gives a generally higher air concentration than does AIRDOS-II. However, until a distance of 1000 m to 5000 m is reached, the NRC estimates of ground deposition are less than the estimates generated by AIRDOS-II.

In making a radiological assessment one normally attempts to determine the maximum impact on individuals and populations. Only one sample calculation has been made, but its results indicate that the NRC methodology does not always estimate as high a ground deposition rate as does the more well-known deposition estimation technique, especially for low-level releases. As such, for a given situation one might want to calculate ground deposition by both methods and use the higher results of the two to calculate the dose to man from ingestion of contaminated food and exposure to contaminated ground. In the case of air concentration the NRC methods did consistently give the higher values of the two methods compared. One should make sure that is the case in each particular assessment situation considered, however.

Table 3.11 A comparison of the results of a sample calculation of plume depletion and dry deposition using the NRC and AIRDOS-II methodologies assuming a release height of 1 m and a release rate of 1 pCi/sec

Downwind distance, m	Undepleted air concentration pCi/cm ³	Depleted air concentration, pCi/cm ³		Ground deposition rate, pCi/cm ² - sec	
		AIRDOS-II	NRC	AIRDOS-II	NRC
100	6.4E-10	4.4E-10	6.2E-10	4.4E-10	6.7E-11
500	3.1E-11	1.5E-11	3.0E-11	1.5E-11	6.7E-12
1000	8.6E-12	3.4E-12	7.8E-12	3.4E-12	2.2E-12
5000	6.7E-13	1.4E-13	5.3E-13	1.4E-13	1.5E-13
10000	2.5E-13	3.4E-14	1.8E-13	3.4E-14	4.2E-14
50000	3.8E-14	1.4E-15	2.0E-14	1.4E-15	2.5E-15
100000	1.7E-14	4.2E-16	7.0E-15	4.2E-16	7.2E-16

REFERENCES

- Briggs, G. A. 1973. Diffusion estimation for small emissions (draft).
Contribution No. 79, Atmospheric Turbulence and Diffusion Laboratory,
Oak Ridge, Tennessee. 64 pp.
- Chamberlain, A. C. 1953. Aspects of travel and deposition of aerosol
and vapour clouds. British Report U.K.A.E.R.E.-H.P./R. 1261.
38 pp.
- Culkowski, W. M. 1977. An investigation of various atmospheric
stability criteria at the one-hundred meter level in East
Tennessee. Presented at the 70th Annual Air Pollution Control
Association Meeting, Toronto.
- Gifford, Jr., F. A. 1961. Use of routine meteorological observations
for estimating atmospheric dispersion. Nucl. Saf. 2(4):47-57.
- Gifford, Jr., F. A. 1968. An outline of theories of diffusion in
the lower layers of the atmosphere. Chap. 3. IN Slade D. (ed.),
Meteorology and Atomic Energy 1968, U.S.A.E.C.-TID-24190.
- Gifford, Jr. F. A. 1975. Atmospheric dispersion models for environ-
mental pollution applications. Chap. 2. IN Lectures on Air
Pollution and Environmental Impact Analyses, Am. Met. Soc.,
Boston, Mass. 23 pp.
- Gifford, Jr., F. A. 1976. Turbulent diffusion-typing schemes: A
review. Nucl. Saf. 17(1):68-86.

REFERENCES (CONT'D)

- Hoffman, F. O. and S. L. Kaye. 1976. Terrestrial exposure pathways: potential exposures of man from the environmental transport of waste nuclides. pp. 524-536. IN Proceedings of the International Symposium on the Management of Wastes from the LWR Fuel Cycle. Denver, Colorado, July 11-16, 1976, CONF-76-0701.
- Hoffman, F. O. 1977. A reassessment of the deposition velocity in the prediction of the environmental transport of radioiodine from air to milk. Health Phys. 32(5):437-441.
- Hoffman, F. O., C. W. Miller, D. L. Shaeffer, C. T. Garten, Jr., R. W. Shor and J. T. Ensminger. 1977a. A compilation of documented computer codes applicable to environmental assessment of radioactivity releases. ORNL/TM-5830. 70 pp.
- Hoffman, F. O., C. W. Miller, D. L. Shaeffer and C. T. Garten, Jr. 1977b. A compilation of computer codes for the assessment of radionuclides released to the environment. Nucl. Saf. 18(3): 343-354.
- Hosker, R. P. 1974. Estimates of dry deposition and plume depletion over forests and grassland. pp. 291-308. IN Physical Behavior of Radioactive Contaminants in the Atmosphere, Symposium Proceedings, Vienna, 12-16 November 1973. STI/PUB/354, Vienna, Austria.
- Markee, Jr., E. H. 1967. A parametric study of gaseous plume depletion by ground surface absorption. pp. 602-613. IN Mawson, C. A. (ed.), Proceedings of USAEC Meteorological Information Meeting, Chalk River, Ontario, Canada, September 11-14, 1967. AECL-2787.

REFERENCES (CONT'D)

- Moore, R. E. 1977a. The AIRDOS-II computer code for estimating radiation dose to man from airborne radionuclides in areas surrounding facilities. ORNL-5245. 146 pp.
- Moore, R. E. 1977b. Personal communication.
- Pasquill, F. 1961. The estimation of the dispersion of windblown material. *Meteorol. Mag.* 90(1063):33-49.
- Pasquill, F. 1974. *Atmospheric Diffusion (Second Edition)*. Wiley, New York.
- Pasquill, F. 1976. Atmospheric dispersion parameters in Gaussian plume modeling, Part II. Possible requirements for change in the Turner workbook values. EPA-600/4-76-0306. 44 pp.
- Pelletier, C. A. and J. D. Zimbrick. 1970. Kinetics of environmental radioiodine transport through the milk-food chain. pp. 257-267. IN Reinig, W. C. (ed.), *Environmental Surveillance in the vicinity of Nuclear Facilities*, Charles C. Thomas Publishers, Springfield, Ill.
- Pendergast, M. M. 1976. Estimating diffusion coefficients from meteorological data. DP-MS-76-64. 44 pp.
- Sehmel, G. A. and W. H. Hodgson. 1976. Predicted deposition velocities. pp. 399-422. IN Engelmann, R. I. and G. A. Sehmel (eds.), *Proceedings Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants [1974]*, Richland, Washington, September 4-6, 1974. ERDA Symposium Series 38, CONF-740921.

REFERENCES (CONT'D)

- Smith, F. B. 1972. A scheme for estimating the vertical dispersion of a plume from a source near ground level. Chap XVII. In Proceedings of the Third Meeting of the Expert Panel on Air Pollution Modeling, Paris, France, 2-3 October 1972. NATO-CCMS Report 14, North Atlantic Treaty Organization, Brussels, Belgium.
- Thomas, P. and K. Nester. 1976. Experimental determination of the atmospheric dispersion parameters over rough terrain; Part 2, Evaluation of measurements. German Report KFK 2286, Karlsruhe Nuclear Research Center. 103 pp.
- Thomas, P., W. Hübschmann, L. A. König, H. Schüttelkopf, S. Vogt and M. Winter. 1976. Experimental determination of the atmospheric dispersion parameters over rough terrain; Part 1, Measurements at the Karlsruhe Nuclear Research Center. German Report KFK 2285, Karlsruhe Nuclear Research Center. 130 pp.
- Turner, D. B. 1969. Workbook of atmospheric dispersion estimates. U.S. Public Health Service, Publication No. 999-AP-26. Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio. 86 pp.
- U.S. Nuclear Regulatory Commission. 1972. Onsite meteorological programs. Safety Guide 23. 6 pp.
- U.S. Nuclear Regulatory Commission. 1977. Regulatory guide 1.11', Methods for estimating atmospheric transport and dispersion of gaseous effluents in routine releases from light-water-cooled reactors, Revision 1. 24 pp.

REFERENCES (CONT'D)

- Van der Hoven, I. 1968. Deposition of particles and gases. pp. 202-208. IN Slade, D. (ed.), Meteorology and Atomic Energy, 1968. U.S.A.E.C. TID-24190.
- Vogt, K. J., H. Geiss, H. Nordsieck, G. Polster and F. Rohloff. 1973. Investigations on the propagation of spent air streams in the atmosphere, report of results: July 1971 to December 1972 (Part 1). German Report. Jül-998-ST, Jülich Nuclear Research Center, 126 p. Also translated as BNWL-TR-207.
- Vogt, K. J. and H. Geiss. 1974. Tracer experiments on the dispersion of plumes over terrain of major surface roughness. Presented at the First Asian Regional Congress on Radiation Protection, Bombay, India, 15-20 December 1974, CONF-741219-4. Also German Report JUL-1131-ST, Jülich Nuclear Research Center, 34 pp.
- Weber, A. H. 1976. Atmospheric dispersion parameters in Gaussian plume modeling, Part I. Review of current systems and possible future developments. EPA-600/4-76-030a. 58 pp.

3.4 The Evaluation of Critical Parameters for Assessing the Environmental Transport of Radioiodine

3.4.1 A reassessment of the deposition velocity for models which estimate the environmental transport of radioiodine from air to milk

3.4.1.1 Introduction

Among the first models in this project to be subjected to an in-depth analysis were those which have been employed to calculate the environmental transport of radioiodine from air to milk. Our analysis revealed a misinterpretation of experimentally derived values of deposition velocity for elemental iodine. This misinterpretation has prevailed in the literature despite the fact that the transport of radioiodine from air to milk during periods of dry deposition has already been the subject of numerous published assessments. This circumstance has apparently stemmed from the confusion of deposition velocity as related to a total deposit per unit of ground surface area with a deposition velocity related to deposition on vegetation growing within a specified ground surface area. Almost all of the deposition velocities which have been experimentally determined for elemental iodine have been related specifically to a deposition on vegetation and not to total deposition. Values determined for vegetation-only deposition velocities have been interpreted as being related to total deposition when used in assessment models. Therefore, the inclusion of an additional parameter in radioiodine assessment models to account for the fractional interception of the total deposition by vegetation leads to an underestimation of the contamination of vegetation and the subsequent contamination in milk.

In Table 3.12 the first column of air to milk transfer coefficients for element ^{131}I have been calculated by assessment models which have included this error; the second column of coefficients has been adjusted by us to correct for the use of the additional vegetation interception parameter.

These corrections have been made without considering the influence of the standing crop biomass of pasture vegetation on both the areal deposition of radioiodines and the effective area grazed by cows. When this effect is taken into account, the air to milk transfer coefficient for elemental ^{131}I approximates $6000 \text{ m}^3/\text{liter}$.

Experimental investigations of deposition velocities on pasture vegetation using small particulate aerosols ($< 4 \mu\text{m}$) and organic iodides indicate that the air to vegetation transfer for these physiochemical forms would be at least a factor of 20 to 200, respectively, less than the value calculated for the elemental form of radioiodine. Details of this investigation have been recently published (Hoffman, 1977).

Table 3.12 A comparison of published vs corrected equilibrium milk
to air transfer coefficients for ^{137}Cs

Assessment models	Air to milk transfer coefficients ($\text{m}^3_{\text{air}}/\text{liter}_{\text{milk}}$)	Corrected air to milk transfer coefficients ($\text{m}^3_{\text{air}}/\text{liter}_{\text{milk}}$)
Bayer (1972)	1000	1300
Bryant (1964)	1420	5600
Fletcher and Dotson (1971)	590	2400
Hoffman (1973)	1610	4000
Killough and McKay (1976)	1050	4200
Palms et al. (1975)	440	1750
Soldat (1976)	590	2400
USAEC (1974)	560	2200
USEPA (1973)	1200	4800
USNRC (1975)	1810	3600

3.4.2 A review of measured values of the milk transfer coefficient (f_m) for iodine

F. Owen Hoffman

Most of the published assessments of the environmental transport of iodine have used 1×10^{-2} day/liter as the value for the parameter f_m , the transfer coefficient relating the concentration per liter of milk to the daily amount of the element taken in by a cow (Hoffman, 1977). The U.S. Nuclear Regulatory Commission (NRC) in its Regulatory Guide 1.109 (USNRC, 1976), however, has recommended a value of 0.6×10^{-2} day/liter for cow's milk and a value of 6×10^{-2} day/liter for goat's milk. To evaluate the adequacy of these recommended values, a literature survey was initiated to compile values of f_m for both cow's and goat's milk. Care was taken to select values which would be representative of equilibrium conditions between iodine intake and the subsequent iodine concentration in milk because these conditions would be approximated during a prolonged release.

The results of the literature survey of f_m values for cow's milk are presented in Table 3.13. Although the value of 0.6×10^{-2} day/liter recommended in Regulatory Guide 1.109 is within the range of reported averages, it appears to be more closely related to the lower values given for ^{131}I . It is of interest to note that Lengemann and Comar (1964) suggest that values for ^{131}I significantly lower than 1×10^{-2} day/liter can probably be attributed to low dietary intakes of stable iodine. Considering that the f_m recommended by the NRC is supposed to be representative of the transfer of stable iodine into milk, the

Table 3.13 Values of f_m for the transfer of iodine into the milk of dairy cows

f_m (day/liter)	Comments	Reference
1×10^{-2}	Iodine in the form of ^{131}I ; range $0.5 - 2.7 \times 10^{-2}$; taken from the data of Lengemann and Swanson (1957).	Comar (1962)
1.1×10^{-2}	Average of fifteen trials on nine cows fed ^{131}I twice daily for about 14 days.	Lengemann and Comar (1964)
0.42×10^{-2}	Average for three cows fed ^{131}I twice daily.	Lengemann (1969)
1.3×10^{-2}	Average from ^{131}I monitoring data at Monticello Nuclear Power Station; f_m values derived from milk to grass concentration ratios assuming a 10 kg/day ingestion rate.	Weiss <u>et al.</u> (1975)
0.67×10^{-2}	Average derived from ^{131}I milk to grass concentration ratios monitored at Dresden Nuclear Power Station.	Weiss <u>et al.</u> (1975)
0.81×10^{-2}	Average derived from 110 samples of ^{131}I in grass and milk at site #2 near Quad Cities Nuclear Power Station.	Weiss and Keller (1977)
3.5×10^{-2}	Average derived from 111 samples of ^{131}I in grass and milk at site #4 near Quad Cities Nuclear Power Station.	Weiss and Keller (1977)
3.99×10^{-2}	Average for stable iodine derived from an extensive review of tracer experiments and milk and forage concentrations reported in the literature.	Ng <u>et al.</u> (1977)
0.8×10^{-2}	Average derived for ^{131}I based upon differences between the isotope and the stable element transfer into milk.	Ng <u>et al.</u> (1977)
1.0×10^{-2}	Recommended value for radioactive assessments performed in the USA.	Garner (1971)
0.55×10^{-2}	Recommended value for radioiodine assessments performed in the UK; based on data of Garner <u>et al.</u> (1960).	Garner (1971)

commonly used value of 1×10^{-2} day/liter appears to be the more appropriate value for assessment calculations.

The results of the literature survey of f_m values for goat's milk are presented in Table 3.14. The values in Table 3.14 are approximately a factor 5 to over 10 times larger than the NRC Regulatory Guide value of 6×10^{-2} day/liter, with the exception of the last entry which was based on the preliminary phases of the experiments performed by Lengemann and Comar (Binnerts et al., 1962). The NRC recommended value of 6×10^{-2} day/liter, therefore, appears to be inconsistent with the data available for f_m relative to the goat.

One of the objectives of the model evaluation project, is to make near-term recommendations about the most appropriate models or parameter values to be employed in the environmental assessment of radioactivity releases. Our analysis of the published values of f_m suitable for the prediction of the transfer of iodine from forage to milk under conditions of a routine release leads us to recommend a deviation from the values chosen by the NRC for both cow's and goat's milk. For generic assessments, a f_m for goat's milk of 0.5 day/liter and an f_m for cow's milk of 1×10^{-2} day/liter, appear to be appropriate for iodine.

Table 3.14 Values of f_m for the transfer of iodine into the milk of goats

f_m (day/liter)	Comments	Reference
0.5	Average for nine goats at the end of 25 days of daily oral administration of ^{131}I .	Lengemann (1970)
0.48	Average for six goats receiving ^{131}I daily.	Lengemann (1970)
0.62	Average for six goats receiving ^{131}I daily, plus an additional 4 mg stable iodine.	Lengemann (1970)
0.37	Average for 16 goats sampled from the 15th to the 21st day of ^{131}I dosing; (steady state conditions had not been achieved, however).	Lengemann (1970)
0.47	Average for two mix breed milk goats orally dosed twice daily with ^{131}I .	Lengemann (1969)
0.65	Average value for ^{131}I steady state; taken from unpublished data.	Comar (1963)
0.26	Average of data plotted for fourteen goats given ^{131}I twice daily for periods ranging from 12.5 to 24.5 days.	Lengemann and Wentworth (1966)
0.48	Average derived from stable element data for diet intake and milk concentrations for goats.	Comar (1965)
0.17	Average value for a single goat given ^{131}I twice daily (steady state value not reported).	Binnerts et al. (1962)
0.06	Average value for a single goat given ^{131}I twice daily (steady state value not reported).	Binnerts et al. (1962)

3.4.3 Uncertainty in the dose calculation for the grass-cow-milk pathway

D. Lynn Shaeffer and F. Owen Hoffman

Currently, the uncertainty associated with the prediction of dose resulting from a release of elemental $^{131}\text{I}_2$ and its subsequent environmental transport from air to milk is being studied. We have estimated the probability of underpredicting the dose received by a child's thyroid following a short-term release of elemental $^{131}\text{I}_2$. The resulting dose may be calculated from the simple multiplicative chain model (Hoffman, 1977) given by

$$z = A \chi \frac{V_g (C_m/C_v)}{\lambda_{\text{eff}}}, \quad (1)$$

where z is the dose (millirem/year), A contains the appropriate conversion factors, χ is the air concentration (pCi/m^3), V_g represents deposition velocity (m/sec), C_m/C_v is the vegetation-to-milk transfer factor (m^2/liter) and $\lambda_{\text{eff}}(\text{days}^{-1})$ is $\ln 2$ divided by the effective half-life on vegetation. Our preliminary efforts have focused on a statistical analysis of V_g , (C_m/C_v) and λ_{eff} . In this analysis we ignore the statistical nature of the dose-conversion factor and air concentration. The constant A is

$$A = (\text{D.C.F.}) \times I_m \times k \quad (2)$$

where

D. C. F. = dose conversion factor of 1.4×10^{-2} millirem/pCi
(Hoenes and Soldat, 1977),

I_m = milk consumption rate, assumed to be 300 liter/year (ICRP, 1975),

$k = 86,400$ sec/day.

Short-term (on the order of hours or days) average values of deposition velocity for elemental $^{131}\text{I}_2$ (Chamberlain and Chadwick, 1953; Chamberlain and Chadwick, 1966; Megaw and Chadwick, 1959; Bunch, 1968; Heinemann et al., 1976) were shown to be lognormally distributed (Fig. 3.2). We plot on a logarithmic probability graph the values of deposition velocity versus the cumulative percent function $F(V_g)$, for each value of V_g , calculated from the formula $F(V_g) = 100 q/(n + 1) \%$, where q is the ordinal number, from 1 to n , of V_g in the population of n values.

Similarly, we plot data obtained for C_m/C_v at Monticello (Weiss et al., 1975) on probability paper (Fig. 3.3) and find that these data also fit a lognormal distribution. Values for λ_{eff} (Markee, 1971; Heinemann et al., 1976) are plotted on a probability graph (Fig. 3.4) and these too appear to be lognormally distributed.

Thus we see from Eq. (1) and the discussion in Sect. 2.3 that the dose z is also lognormally distributed. For the data plotted in Figs. 3.2 through 3.4 the variances σ_1^2 , σ_2^2 , and σ_3^2 associated with $\ln V_g$, $\ln (C_m/C_v)$ and $\ln \lambda_{\text{eff}}$, respectively, are 0.655, 0.181 and 1.42×10^{-2} . The total variance σ^2 associated with $\ln z$ is

$$\sigma^2 = \sigma_1^2 + \sigma_2^2 + \sigma_3^2 = 0.85. \quad (3)$$

We see that the major part of the dose uncertainty is due to the uncertainty in the deposition velocity.

For the data analyzed in this study, we find that the calculated dose having the greatest probability of occurrence would also have an 81% chance of underestimating actual doses under the conditions assumed by the predictive model. Similarly, we find that the calculated

Fig. 3.2. Short term average values of deposition velocity (in units of m/sec) for elemental iodine $^{131}\text{I}_2$ vs cumulative percent.

ORNL-DWG 77-18957

Fig. 3.3. Short term average values of the vegetation-to-milk transfer factor expressed in units of m^2/liter vs cumulative percent.

Fig. 3.4. Short term average values of the decay constant (in units of day^{-1}) for retention on vegetation vs cumulative percent.

median dose and mean dose would have a 50 and 32% chance, respectively, of underestimation. We also calculate that a dose 19 times greater than the most probable dose resulting from a given air concentration would have to be calculated in order to achieve a 99% chance that an actual dose would not be underestimated. These numbers may change depending on the data used for the various parameters. In this analysis we used what appear to be the best data available in the literature.

To ensure that a dose calculated from a multiplicative model has a 99% probability of not underestimating an actual dose, the most probable dose must be enhanced by a factor of $\exp \{(2.326 + \sigma)\sigma\}$, where σ^2 is the sum of the variances of all the statistical parameters included in the calculation. Likewise, the median dose must be enhanced by a factor of $\exp(2.326\sigma)$.

REFERENCES

- Bayer, A. 1972. Die altersabhängigen Ingestions-Dosisfaktoren g_G and g_G' von Jod-131. Kernforschungszentrum Karlsruhe, Federal Republic of Germany, KFK-1582. 36 pp.
- Binnerts, W. T., F. W. Lengemann and C. L. Comar. 1962. Radioiodine metabolism in the goat after simultaneous single and daily administration. J. Dairy Sci. 45:427.
- Bryant, P. M. 1964. Derivation of working limits for continuous release rates of iodine-131 to atmosphere in milk producing area. Health Phys. 10:249.
- Bunch, D. F. (ed.). 1968. Controlled environmental radioiodine tests, Progress report number three. IDO-12063. 77 pp.
- Chamberlain, A. C. and R. C. Chadwick. 1953. Deposition of airborne radioiodine vapor. Nucleonics 11(8):22-25.
- Chamberlain, A. C. and R. C. Chadwick. 1966. Transport of iodine from atmosphere to ground. Tellus XVIII(2):226-237.
- Comar, C. L. 1963. Factors influencing the biological availability of fallout radionuclides for animals and man. Fallout, Food, and Man, November-December:1402.
- Comar, C. L. 1966. Radioactive materials in animals-entry and metabolism. pp. 127-157. IN Russell, R. S. (ed.), Radioactivity and Human Diet. Pergamon Press, Oxford.

REFERENCES (CONT'D)

- Fletcher, J. F. and W. L. Dotson. 1971. HERMES - A digital computer code for estimating regional radiological effects from the nuclear power industry. HEDL-TM-71-168.
- Garner, R. J., B. F. Sansom and H. G. Jones. 1960. Transfer of ^{131}I into milk following single and daily dosing. J. Agric. Sci. 33:238.
- Garner, R. J. 1971. Transfer of radioactive materials from the terrestrial environment to animals and man. CRC Crit. Rev. Environ. Contr. 2:337.
- Heinemann, K., M. Stoepler, K. J. Vogt and L. Angeletti. 1976. Studies on the deposition and release of iodine on vegetation. ORNL-tr-431.. Jül-1287. Reports of the Jülich Nuclear Research Center. 58 pp.
- Hoenes, G. R. and J. K. Soldat. 1977. Age-specific radiation dose commitment factors for a one year chronic intake. NUREG-0172. 103 pp.
- Hoffman, F. O. 1973. Environmental variables involved with the estimation of the amount of ^{131}I in milk and the subsequent dose to the thyroid, IRS-W-6, Institut für Reaktorsicherheit der TUV e.v., Federal Republic of Germany. 52 pp.
- Hoffman, F. O. 1977. A reassessment of the deposition velocity in the prediction of the environmental transport of radioiodine from air to milk. Health Phys. 32(5):437-441.
- International Commission on Radiological Protection. 1975. Report of the task group on reference man. ICRP Publication No. 23. Pergamon Press, New York. 480 pp.

REFERENCES (CONT'D)

- Killough, G. G. and L. R. McKay. 1976. A methodology for calculating radiation doses from radioactivity released to the environment. ORNL-4992. 493 pp.
- Lengemann, F. W. and C. L. Comar. 1964. Metabolism of I^{131} by dairy cows during long-term daily administration of the radioisotope. Health Phys. 10:55.
- Lengemann, F. W. and E. W. Swanson. 1957. A study of the secretion of iodine in milk of dairy cows using daily oral doses of iodine-131. J. Dairy Sci. 40:216.
- Lengemann, F. W. and R. A. Wentworth. 1966. Predicting the total intake of radioiodine of humans consuming goats' milk. Health Phys. 12:1655.
- Lengemann, F. W. 1969. Radioiodine in the milk of cows and goats after oral administration of radioiodate and radioiodine. Health Phys. 17:565.
- Lengemann, F. W. 1970. Metabolism of radioiodine by lactating goats given iodine-131 for extended periods. J. Dairy Sci. 53:165.
- Markee, Earl H., Jr. 1971. Studies of the transfer of radioiodine gas to and from natural surfaces. NOAA TM ERL ARL-29. 28 pp.
- Megaw, W. J. and R. C. Chadwick. 1959. Unpublished. Communicated by Chamberlain, A. C. 1960. Aspects of the deposition of radioactive and other gases and particles. Int. J. Air Pollut. 3:63-88.

REFERENCES (CONT'D)

- Ng, Y. C., C. S. Colsher, D. J. Quinn and S. E. Thompson. 1977.
Prediction of the dose to man from radionuclides released to
the biosphere: Forage-cow-milk pathway. UCRL-51939. 139 pp.
- Palms, J. M., V. R. Velur and F. W. Boon. 1975. The environmental impact
of ^{129}I released by a nuclear fuel-reprocessing plant. Nucl. Saf. 16(5):
593-602.
- Soldat, J. K. 1976. Radiation doses from iodine-129 in the environment.
Health Phys. 30:61-70.
- U.S. Atomic Energy Commission. 1974. Interim licensing policy on as-
low-as-practicable for gaseous radioiodine releases from light-
water-cooled nuclear power reactors. Regulatory Guide 1.42,
Revision 1.
- U.S. Environmental Protection Agency. 1973. Environmental analysis
of the uranium fuel cycle, Part II - Nuclear Reactors. EPA-520/9-
73-003-C. 169 pp.
- U.S. Nuclear Regulatory Commission. 1975. Reactor safety study.
WASH-1400 (NUREG-75/014). Appendix VI.
- U.S. Nuclear Regulatory Commission. 1976. Regulatory Guide 1.109,
Calculation of annual doses to man from routine releases of
reactor effluents for the purpose of evaluating compliance
with 10 CFR Part 50, Appendix I (for comment). Office of
Standards Development. 69 pp.

REFERENCES (CONT'D)

- Weiss, B. H., P. G. Voilleque, J. H. Keller, B. Kahn, H. L. Krieger, A. Martin and C. R. Phillips. 1975. Detailed measurement of ^{131}I in air, vegetation and milk around three operating reactor sites. NUREG-75/021.
- Weiss, B. H. and J. H. Keller. 1977. Enhancement of radioiodine concentration in milk due to wet processes in the environment. Paper 184 presented at the 1977 annual meeting of the International Radiological Protection Association, Paris, France.

3.5 The Evaluation of Selected Internal Dose Conversion Factors

3.5.1 The ^{232}Th dose conversion factor question

H. Robert Meyer and Donald E. Dunning, Jr.

An investigation has been initiated regarding published discrepancies in ^{232}Th (4n chain) Dose Conversion Factors (D.C.F.). ERDA 1541 (USERDA, 1976), a Light Water Breeder Reactor generic impact statement, presents a ^{232}Th D.C.F. a factor of 6.3 higher than published in ORNL-4992 (Killough and McKay, 1976). Similar disparities are evident when comparisons are made between ERDA 1541 and other documents. Although other factors enter into the question, the major point of disagreement relates to the method of treatment of daughter elements formed by decay of the 4n chain parent. As is evident in Fig. 3.5, both ^{232}U and ^{232}Th decay to ^{228}Th , then through the remainder of the 4n decay chain to stable ^{208}Pb . Uranium-232 decays to ^{228}Th via a single, 5.3 MeV alpha emission, ^{232}Th via three steps, a 4.01 MeV alpha emission to ^{228}Ra , followed by serial beta emissions. The total energy released in the two decay chains nearly equal.

In contrast, the ICRP (1959) lists effective energies (to bone, per disintegration) as 270 MeV for ^{232}Th , and 1200 MeV for ^{232}U ; these effective energies are critical in the calculation of dose conversion factors to be used in the estimation of long-term dose commitments. The discrepancy between the effective energies calculated for the two radionuclides is based on the ICRP (1959) assumption that the ^{228}Ra atoms produced by the decay, in bone, of a thorium parent should be assumed to be released from bone to blood, then distributed in the same manner as would occur if radium were injected intravenously. As a result, the presence

Fig. 3.5. Decay schemes for ^{232}U and ^{232}Th .

of ^{228}Ra in the ^{232}Th decay chain implies, under the ICRP assumption, that 90% of the ^{228}Ra created within bone is eliminated from the body. Therefore, most of the potential dose from the remaining 4n chain alpha decay events is not accrued within the body, and the total effective energy for the ^{232}Th chain is a factor of 4.4 lower than that for ^{232}U .

Continuation and reevaluation of the research (Reynolds et al., 1957; Van Dilla and Stover, 1956), leading to the above dissimilarity indicated that the presumption of a major translocation of ^{228}Ra out of bone was suspect (Stover et al., 1965a; Mays, 1967; Kaul, 1973; Bernard and Snyder, 1968; Stover et al., 1965b), and that sufficient evidence existed to substantiate retention of approximately 97% of ^{228}Ra in bone. Recalculation of effective energies for the ^{232}Th chain has led to a value of 1681 MeV in ERDA 1541, a substantial modification, indicating the possible need for more restrictive limits with respect to ^{232}Th releases. ERDA 1541 contains a rather detailed discussion of this question (Volume 3, pp IX E 16 through IX E 25), including a summary of the evidence regarding ^{228}Ra translocation rates.

Marshall et al. (1972) have developed equations which describe the distribution and retention of radium and other alkaline earths in man. When these equations are used to model the retention of radium isotopes in bone, the D.C.F. for the ^{232}Th chain is calculated to be significantly less than either of those indicated above. Furthermore, the matter of direct translocation of ^{228}Ra from bone then becomes relatively unimportant, as the ^{232}Th isotope contributes the majority of the dose commitment under the conditions imposed in this new model.

Currently, work is continuing to investigate other parameters involved in calculating a D.C.F. for ^{232}Th . The results of this work will be used to recommend a value to be used in future assessments involving releases of this radionuclide.

3.5.2 A review of ^{99}Tc dose conversion factors

Donald E. Dunning, Jr.

A review of dose conversion factors derived for ^{99}Tc pertechnetate has been conducted to reevaluate the potential radiological significance of releases of this isotope into the environment. Technetium-99 is routinely released by uranium enrichment facilities.

Knowledge of the chemical form of technetium is crucial to assessing its distribution in the body. Pertechnetate ion (TcO_4^-) concentrates in the thyroid, salivary glands, kidneys, and gastrointestinal tract (Beasley *et al.*, 1966; Harper *et al.*, 1964; Kazem *et al.*, 1967; Smith, 1965). Aggregated and colloidal forms of technetium are localized in the liver (Harper *et al.*, 1964; McAfee *et al.*, 1964). Numerous other chemical complexes of the element have specific clinical applications due to their characteristic localization in particular tissues.

Table 3.15 presents estimates of dose conversion factors in millirems per pCi intake of ^{99}Tc pertechnetate based upon three different sets of metabolic assumptions for a reference adult. The dose conversion factors in set (A) of Table 3.15 have been derived from basic metabolic information given by the International Commission on Radiological Protection (ICRP, 1959). Biological retention of technetium is described by a single exponential term for each organ of concern.

The second set of dose conversion factors in Table 3.15 (B) is computed from data in the WASH-1400 reactor safety study (USNRC, 1975), which estimates a thyroid uptake factor of 0.54% from blood and describes

Table 3.15 Adult dose conversion factors* for ^{99}Tc pertechnetate (millirems/pCi)

Reference	Pathway	Total body	Bone	Kidneys	GI tract ⁺	Thyroid
A ^a Hoernes and Soldat, 1977	Ingestion	5.0E-8	1.3E-7	2.3E-6	6.1E-6	ND
	Inhalation	1.3E-8	3.1E-8	5.8E-7	7.5E-6	ND
B ^b USNRC, 1975	Ingestion	2.5E-7	4.1E-7	4.1E-7	8.0E-7	4.6E-6
	Inhalation	1.8E-7	2.7E-7	2.7E-7	1.3E-7	3.0E-6
C ^c Killough et al., (in press)	Ingestion	2.1E-7	3.6E-7	4.6E-7	3.2E-6	1.4E-5
	Inhalation	1.7E-7	2.7E-7	3.5E-7	5.1E-7	1.1E-5

^aSet (A) was derived from basic dosimetric data given by the International Commission on Radiological Protection (ICRP, 1959).

^bSet (B) represents a calculation based on the dosimetric data in WASH-1400 (USNRC, 1975), using the INREM-II computer code (Killough et al., 1977).

^cSet (C) was calculated with the INREM-II methodology and data base.

ND = No data reported for the thyroid

* = Dose conversion factor as used in this paper is the 50 year integrated dose resulting from a unit intake of ^{99}Tc .

+ = Dose conversion factors in (B) and (C) are calculated for the lower large intestine, which is the critical segment of the GI tract.

biological retention with a multicompartment exponential model of Beasley et al. (1966). A fractional uptake of 95% in the GI tract is assumed.

Other studies have indicated a rapid initial pertechnetate uptake of approximately 2% to the thyroid, with some estimates as high as 8 to 10% in euthyroid (Kazem et al., 1967) and 6 to 30% in hyperthyroid individuals (Harper et al., 1964). From this range of values, 2% has been adopted in the third set of dose conversion factors in Table 3.15 (C). This selection of an appropriate uptake factor is an additional uncertainty in the calculations.

In parts (B) and (C) of Table 3.15, biological retention of ^{99}Tc in organs other than the GI tract is estimated using the multicompartment exponential model described by Beasley et al. (1966). This model is based upon a clinical study with relatively short-lived isotopes ($^{95\text{m}}\text{Tc}$, ^{96}Tc) and one might be somewhat skeptical about applying this metabolic model to the long-lived ^{99}Tc isotope (radioactive half-life = 7.8×10^7 days). Clinical studies indicate a rapid decrease of pertechnetate concentrations in the thyroid (McAfee et al., 1964), but these are based upon a single administration to the patient. Extrapolation of this behavior for continuous environmental exposure might not be justified. Studies of these short-lived isotopes do not provide information concerning possible long-term ^{99}Tc retention, if any, in tissues of interest. Additionally, it is recognized that the retention model presented by Beasley et al., (1966) was based upon total-body elimination of technetium and would not necessarily be representative of retention in individual organs. However, in lieu of organ-specific

data, the Beasley model has been used to estimate the dose conversion factors for organs other than the GI tract in (B) and (C) of Table 3.15. This lack of data represents an additional uncertainty in the assessment of ^{99}Tc releases to the environment.

The INREM-II methodology (Killough et al., 1977) with which the dose conversion factors in Table 3.15 (B) and (C) were calculated, employs an adaptation of the ICRP Task Group Lung Model (Morrow et al., 1966) and a catenary GI tract model based on the transit times of Eve (1966) to describe the dynamics of retention in the respiratory and gastrointestinal tracts, respectively. For the calculation of the GI tract dose conversion factors in (C) of Table 3.15, a fractional uptake of 80% is assumed within the small intestine.

One must also be concerned that the dose to specific organs could be significantly greater for a child than for an adult under identical conditions of exposure. When only the difference in organ mass is considered, the dose conversion factor is elevated one order of magnitude for ingestion and inhalation. Other physiological and extrinsic age-dependent differences would certainly influence uptake and retention of ^{99}Tc . For example, differences in dietary habits would make milk a more prominent component of the child's diet than that of the adult. It is evident that further studies are needed to specify dose conversion factors for ^{99}Tc applicable to critical groups of the population.

REFERENCES

- Bernard, S. R. and W. S. Snyder. 1968. Personal communication.
- Beasley, T. M., H. E. Palmer and W. B. Nelp. 1966. Distribution and excretion of technetium in humans. *Health Phys.* 12:1425.
- Eve, I. S.. 1966. A review of the physiology of the gastrointestinal tract in relation to radiation doses from radioactive materials. *Health Phys.* 12:131-162.
- Harper, P. V., K. A. Lathrop, R. J. McCardle and G. Andros. 1964. The use of technetium-99m as a clinical scanning agent for thyroid, liver and brain. Vol. II. IN *Medical Radioisotopes Scanning*. International Atomic Energy Agency, Vienna.
- International Commission on Radiation Protection. 1959. Report of committee 2 on permissible dose for internal radiation. Publication 2, Pergamon Press.
- Hoenes, G. R., and J. K. Soldat. 1977. Age-specific radiation dose commitment factors for a one-year chronic intake. NUREG-1072.
- Kaul, A. 1973. Tissue distribution and steady state activity ratios of thorium 232 and daughters in man following intravascular injection of Thorotrast. RISO-294. pp. 14-30. IN Faber, M. (ed.), *Toxicity of Thorotrast*. Proceedings of the 3rd International Meeting held in Copenhagen, Denmark, April 25-27, 1973. Universitat Berlin, Klinik fur Radiologie und Nuklearmedizin-Nuklearmed. Physik und Strahlenschutz, Berlin, German Federal Republic.
- Kazem, I., P. Gelinsky and P. Schenck. 1967. Organ visualization with technetium 99m preparations. *Br. J. Radiol.* 40:292.

REFERENCES (CONT'D)

- Killough, G. G., and L. R. McKay. 1976. A methodology for calculating radiation doses from radioactivity released to the environment. ORNL-4992.
- Killough, G. G., D. E. Dunning, S. R. Bernard and J. C. Pleasant. Estimates of internal dose equivalent to 22 organs of reference man for various radionuclides (inhalation and ingestion). Oak Ridge National Laboratory Report (in press).
- Killough, G. G., J. C. Pleasant and D. E. Dunning. 1977. INREM-II: a computer implementation of recent models for estimating the dose equivalent to organs of reference man from an inhaled or ingested radionuclide. ORNL/NUREG/TM-84. (in press).
- Marshall, J. H., E. L. Lloyd, J. Rundo, J. Liniecki, G. Marotti, C. W. Mays, H. A. Sissons and W. S. Synder. 1972. Alkaline earth metabolism in man. ICRP Publication 20, Pergamon Press.
- Mays, C. W. 1967. Letter to G. C. Butler, 25 August.
- Morrow, P. E., D. V. Bates, B. R. Fish, T. F. Hatch and T. T. Mercer. 1966. Deposition and retention models for internal dosimetry of the human respiratory tract. Health Phys. 12:173-207.
- McAfee, J. G., C. F. Fueger, H. S. Stern, H. N. Wagner, Jr. and T. Migica. 1964. ^{99m}Tc pertechnetate for brain scanning. J. Nucl. Med. 5:811.

REFERENCES (CONT'D)

- Reynolds, J. C., P. F. Gustafson and L. D. Marinelli. 1957. Retention and elimination of radium isotopes produced by decay of thorium parents within the body. ANL-5689. 22 pp.
- Smith, E. M. 1965. Internal dose calculation for ^{99m}Tc . J. Nucl. Med. 6:231.
- Stover, B. J., D. R. Atherton, D. S. Buster and F. W. Brueger. 1965a. The thorium decay series in adult beagles: Ra^{224} , Pb^{212} , and Bi^{212} in selected bones and soft tissues. Radiat. Res. 26:132-145.
- Stover, B. J., D. R. Atherton, D. S. Buster and N. Keller. 1965b. The Th^{228} decay series in adult beagles: Ra^{224} , Pb^{212} and Bi^{212} in blood and excreta. Radiat. Res. 26:226-243.
- Till, J. E. 1976. Assessment of the radiological impact of ^{232}U and daughters in recycled ^{233}U HTGR fuel. ORNL/TM-5049. 41 pp.
- U.S. Energy Research and Development Administration. 1976. Final environmental statement, light water breeder reactor program. ERDA 1541, 5 Vols.
- U.S. Nuclear Regulatory Commission. 1975. Calculation of reactor accident consequences. Appendix IV. IN Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants. WASH-1400, PB-248206, NUREG 75/104.
- Van Dilla, M. A. and B. J. Stover. 1956. On the role of radiothorium (Th^{228}) in radium poisoning. Radiobiology 66:400-401.

3.6 An Evaluation of ^{99}Tc Releases Into The Terrestrial Environment — The Need For Additional Research

F. Owen Hoffman and John E. Till

Recent data on vegetation uptake of technetium indicate that soil-to-plant concentration factors for this element may be significantly higher than those currently being used in radiological assessments (Till et al. 1978). Previously, assessments of the radiological significance of technetium releases to the environment have assumed a soil-to-plant concentration factor of 0.25 pCi/kg wet weight plant tissue per pCi/kg dry weight soil (Killough and McKay, 1976; USNRC, 1977; Baker et al., 1976; Baker, 1977). Laboratory experiments, on the other hand, suggest that concentration factors might be 2 to 3 orders of magnitude greater than the value of 0.25 (Tables 3.16 and 3.17). If the values reported from these experiments were to be adopted in radiological assessment models, current release rates of ^{99}Tc from uranium enrichment facilities would have the potential of being in violation of regulatory standards.

In order for valid concentration factors for the soil-to-plant transfer of ^{99}Tc to be obtained, experiments should be conducted when a state of equilibrium between concentrations in soil and concentrations in vegetation has been attained; the vegetation should be representative of forage at the time of consumption by grazing animals or food crops at the time of harvest; the levels of ^{99}Tc used in these experiments should approximate, if possible, the environmental concentrations resulting from routine releases. None of the experimental data available on

Table 3.16 Concentration factors for ^{99}Tc based upon soil to aerial parts of wheat seedlings ($\mu\text{Ci/g}$ wet weight of plant per $\mu\text{Ci/g}$ dry weight of soil)^a

Type of soil	Concentration factor			
	Soils watered with solution containing ^{99}Tc		Soils moist incubated with ^{99}Tc	
	Unfertilized	Fertilized	Unfertilized	Fertilized
Bearden	166	83	165	18
Hegne	213	137	128	32
Hibbing	185	129	253	56
Nicollet (surface)	228	158	268	127
Nicollet (subsurface)	213	209	249	326
Omega	124	76	53	40
Bergland	191	144	130	86
Arveson	130	48	89	91
Waukegan	209	158	269	189
Zimmerman	200	149	153	107
(Sapric peat)	106	112	143	54

^aDerived from the experiments by Gast et al. (1976) by using conversion factors for dry to wet weight provided by Thorvig (1977).

Table 3.17 Concentration factors for ^{99}Tc based upon soil to aerial parts of soybean and wheat ($\mu\text{Ci/g}$ wet weight of plant tissue per $\mu\text{Ci/g}$ dry weight of soil)^a

Concentration of Tc ($\mu\text{g Tc/g}$ soil)	Concentration Factor	
	Soybeans	Wheat
0.01	35	38
0.1	17	43
1.0	95	no growth
5.0	19	no growth

^aDerived from the experiments by Wildung *et al.* (1975, 1977).

^{99}Tc are representative of these conditions. The potted plant experiments performed by Wildung et al. (1977) and Gast et al. (1976) did not achieve an equilibrium between soil and vegetation ^{99}Tc concentrations; the vegetation was not grown to maturity nor was it representative of food crops at the time of harvest; and the levels of ^{99}Tc used were far in excess of the environmental concentrations to be expected around nuclear installations releasing ^{99}Tc .

Release rates of ^{99}Tc from gaseous diffusion plants have been reported to range between 0.54 Ci/year (USERDA, 1976) and 5.9 Ci/year (USERDA, 1977). Assuming a ^{99}Tc release rate of 1 Ci/year and a soil-to-plant concentration factor of 50, Till et al. (1978) calculated doses to a reference adult located 1600 m downwind from the point of release to be 18 millirems to the GI tract and 80 millirems to the thyroid. The previously assumed factor of 0.25 would have produced corresponding calculated doses of 0.13 millirem and 0.57 millirem, respectively. This preliminary assessment indicates that there is the potential for violating the recently promulgated nuclear fuel cycle standards of the Environmental Protection Agency (40 CFR Part 190). Field studies, however, are needed to confirm these indications.

On the basis of this information, the following recommendations can be made regarding the need for additional research oriented toward specific objectives:

1. Determine the present levels of ^{99}Tc in samples of vegetation and animal food products taken near the vicinity of currently operating gaseous enrichment plants in order to establish whether or not a problem actually exists. The following investigations would be of importance

regardless of the results of this initial monitoring exercise. Failure to detect predicted levels of ^{99}Tc would indicate a need to test the parameter values assumed by the predictive model.

2. Determine vegetation-to-soil concentration ratios for the pertechnetate ion ($^{99}\text{TcO}_4^-$) under field conditions to derive values appropriate for use in radiological assessment models.

3. Determine the residence time of ^{99}Tc in the root zone of soil. The U.S. Nuclear Regulatory Commission in its Regulatory Guide 1.109 recommends for the purpose of establishing compliance with 10 CFR Part 50, Appendix I, that the root zone of the soil is assumed to be continuously exposed for 15 years with the only loss from this zone due to radioactive decay (USNRC, 1977). This assumption leads to a substantial buildup of ^{99}Tc in soils. However, because of the apparent mobility of $^{99}\text{TcO}_4^-$ in soils (Wildung et al., 1977), the assumed 15-year accumulation time may be unrealistic. Field research must be relied upon to produce the information to confirm or refute the recommendation of the Nuclear Regulatory Commission.

4. Estimate the availability of ^{99}Tc to mammalian herbivores and the subsequent concentrations of the nuclide in mammalian food products of importance to man.

5. Reevaluate internal dose conversion factors for ^{99}Tc in specific organs of various age groups as discussed in Sect. 3.5.2 of this report.

REFERENCES

- Baker, D. A., G. R. Hennes and J. K. Soldat. 1976. FOOD - An interactive code to calculate internal radiation doses from contaminated food products. BNWL-SA-5523. 5 pp.
- Baker, D. A. 1977. User guide for computer program FOOD. BNWL-2209.
- Gast, R. G., E. R. Landa and L. J. Thorvig. 1976. The behavior of technetium-99 in soils and plants. pp. 1-76. IN Progress Report for the Period April 1, 1974-March 31, 1977, USERDA Contract No. EY-76-5-20-2447. COO-2447-5.
- Killough, G. G. and L. R. McKay. 1976. A methodology for calculating radiation doses from radioactivity released to the environment. ORNL-4992. 493 pp.
- Thorvig, L. 1977. University of Minnesota, personal communication.
- Till, J. E., F. O. Hoffman and D. E. Dunning. 1978. An assessment of ^{99}Tc releases to the atmosphere - A plea for applied research. ORNL/TM-6260.
- U.S. Environmental Protection Agency. 1976. Environmental radiation protection requirements for normal operations or activities in the uranium fuel cycle. 40 CFR Part 190, EPA-520/4-76-016.
- U.S. Energy Research and Development Administration. 1976. Final environmental statement, U.S. nuclear power export activities. ERDA-1542.
- U. S. Energy Research and Development Administration. 1977. Environmental statement, Portsmouth Gaseous Diffusion Plant expansion. ERDA-1549, Vol. 1.

REFERENCES (CONT'D)

- U.S. Nuclear Regulatory Commission. 1977. Regulatory guide 1.109. Calculation of annual doses to man from routine releases of reactor effluents for the purpose of evaluating compliance with 10 CFR Part 50, Revision 1. 80 pp.
- Wildung, R. E., T. R. Garland and D. A. Cataldo. 1975. Accumulation of technetium from soil by plants - A potential mechanism for uptake and toxicity. BNWL-SA-5393.
- Wildung, R. E., T. R. Garland and D. A. Cataldo. 1977. Accumulation of technetium by plants. Health Phys. 32:315-317.

4. FUTURE EFFORTS IN THIS PROJECT

5. Open Questions

The results accomplished on the evaluation of models used to assess the environmental significance of releases of radioactivity during the period April 1976 through December 1977 have been summarized in this progress report. Future efforts in this project will be oriented more directly toward determining the uncertainty associated with these models. However, our investigations have already revealed a general need for validation experiments to be performed in order to test the accuracy and precision of model predictions.

To be of value, validation studies should involve more than just a mere comparison of model predictions with observed data. Comparisons must also include an analysis of the inherent assumptions employed by the model and the actual conditions prevailing during the course of the validation experiment. Many early attempts to validate radiological assessment models have failed to do so. The conditions assumed by the model differed considerably from the conditions prevailing during the experiment; thus, an apparently reasonable fit of model results and observed data has often been the result of fortuitous events or compensating errors.

Where data is not available for the purposes of performing validation, research will be recommended to generate these data. However, until such time as this information becomes available, the estimation of model uncertainties will be restricted to an analysis of the statistical variability of input parameters and the sensitivity of model calculations to values

chosen for these parameters. This type of analysis is entirely dependent on the quality and quantity of data available and, at best, can only be used as an indication of the predictive uncertainty of the model.

However, for those models, which are impractical or unfeasible to validate, such as those employed to calculate doses resulting from internal pathways of exposure, the estimation of uncertainty can only be determined through a statistical analysis of data available for input.

Future efforts will also consider the inclusion of specific surface water and ground-water transport models for evaluation and other terrestrial and aquatic food-chain pathways which may be of significance for other groups of nuclides of potential importance to the future development of nuclear energy. Hopefully, future efforts in this project will also lead to the identification of other pertinent needs for environmental and biomedical research and the opportunity to coordinate such research to improve our capability to perform environmental radiological assessments. A successful completion of the evaluation exercise will eventually result in recommendations regarding the most suitable models to employ for particular assessment situations as well as in specification of those areas where additional model development may prove to be warranted.

APPENDIX A. MEETINGS AND PRESENTATIONS

F. O. Hoffman, D. L. Shaeffer and C. T. Garten, Jr., each attended one or more days of the Nevada Applied Ecology Group "Symposium on the Dynamics of Transuranics in Terrestrial and Aquatic Environments," October 5-7, 1976 at Gatlinburg, Tennessee.

C. W. Miller attended the American Meteorological Society's "Third Symposium on Atmospheric Turbulence, Diffusion, and Air Quality," October 19-22, 1976 at Raleigh, North Carolina.

C. W. Miller attended a DOE program review of the NOAA Atmospheric Turbulence and Diffusion Laboratory in Oak Ridge, Tennessee, March 15-17, 1977.

F. O. Hoffman participated in a DOE exercise involving the identification of ongoing DOE and other federally funded research which may be applied to the environmental and health assessment of various energy technologies. This exercise was held in Gaithersburg, Maryland, May 2-6, 1977.

On June 13-17, 1977, C. W. Miller and F. O. Hoffman visited Lawrence Livermore Laboratory and the Idaho National Engineering Laboratory to participate in discussions concerning research attempts to validate assessment models, the analysis of key parameters and data bases, and the situations in which more advanced atmospheric and food-chain transport models may be required. On June 11, F. O. Hoffman participated in a special discussion on environmental radioiodine modeling and validation studies with Henry Till at EPRI, Palo Alto, California.

F. O. Hoffman, D. L. Shaeffer, and C. W. Miller attended the 22nd Annual Meeting of the Health Physics Society, July 5-8, 1977, in Atlanta, Georgia. D. L. Shaeffer presented a paper entitled, "AQUAMOD - A Computer Code for Simulating the Bioaccumulation and Transport of Radionuclides

in Aquatic Environments". C. W. Miller gave a presentation on behalf of the entire model evaluation project entitled, "A Compilation and Preliminary Evaluation of Models Used for the Assessment of Radio-nuclides Released to the Environment."

C. W. Miller attended the American Meteorological Society/Air Pollution Control Association Joint Conference on Applications of Air Pollution Meteorology, November 29-December 2, 1977, in Salt Lake City, Utah.

F. O. Hoffman and D. L. Shaeffer attended the American Nuclear Society meeting in San Francisco, California, November 27-December 2, 1977. F. O. Hoffman gave a paper on behalf of the entire model evaluation project entitled, "Evaluation of Models for Assessing Compliance with Environmental Radiation Regulations." During the same week Hoffman and Shaeffer gave a presentation at Lawrence Livermore Laboratory on the evaluation of models.

APPENDICES B-F

J. Timothy Ensminger and Roberta W. Shor

A computerized data base containing information on the individual codes included in this study is maintained by the Ecological Sciences Information Center at ORNL. The following appendices are taken from that data base. Appendix B contains bibliographic information and abstracts of the documents included in the data base as of January 1978. Appendices C through F consist of author, keyword, publication description, and title indexes, respectively.

To obtain additional information concerning the data base, or to initiate a search, please contact:

J. T. Ensminger
Oak Ridge National Laboratory
Ecological Sciences Information Center
P.O. Box X, Building 2029
Oak Ridge, Tennessee 37830

Telephone: (615) 483-8611, ext. 3-6173
or FTS: 850-6173

APPENDIX B. ABSTRACTS OF THE COMPUTER CODES

<1>

Beaven, P.; Deguid, J.F., Water Movement Through Saturated-Unsaturated Porous Media: A Finite - Element Galerkin Model

1975, February. CNEL-4927; 236 pp. (Oak Ridge National Laboratory, Oak Ridge, TN 37830)

A two-dimensional transient model for flow through saturated-unsaturated porous media has been developed. 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 integrals, 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 formulation of the governing equations and the computer implementation are presented. The report is intended for use as a complete user's manual and contains a listing of the computer code (in FORTRAN) along with both input and output data for two example problems. The results of a computer simulation are compared with experimental data obtained by J.D. Boulet and A.E. Hilbert from an inclined soil slab at Coscoate 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 B.A. Freeze is made. By exploiting the flexibility of the finite-element geometrical discretization, the user may easily reduce computer running time by a factor of two. This code solves for the fluid velocity which is to be used as input to another model which treats material transport. The air-water system is treated as a single phase (no air pockets allowed). (auth) (DL)

The code requires an extensive data base. The geometry and geology of the region under investigation must be specified.

<2>

Alonso, A., "BURE" - A Digital Code to Evaluate the Hazards of Different Types of Reactor Accidents

1965. CNEL-650807; Physics 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)

An analytical method has been developed to assess abnormal reactor behavior and has been coded for digital computation. 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 atmosphere diffusion of the escaping nuclides under a variety of atmospheric conditions. External and inhalation doses to individuals within the radioactive plume may be assessed at different distances derived 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 amount 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. (auth)

An obscure statement is made to the effect that certain parts of the code are conventional and therefore will not be fully developed. It is not clear whether the effect of ground contamination is included in the calculation of dosage.

<3>

Cooper, B.L., EGAD - A Computer Program to Compute Dose Integrals from External Gamma Emitters

1972, September. ES-1304; 28 pp. (Savannah River Laboratory, Aiken, SC 29801)

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 constraints 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 sigma sub z (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 sigma sub z 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 radionuclide dose. The code is currently being used in this manner as a part of the overall man-rem evaluation program at Savannah River and permits gamma dose calculations to be performed at a rate in excess of 20,000 individual cases per second on the IBM 360/65, including the processing time for the meteorological data involved. (auth)

<4>

Scidat, J.R., Modeling of Environmental Pathways and Radiation Doses from Nuclear Facilities

1971, October. BNEL-SA-3939; 33 pp. (Battelle,

(4) COMET.
Pacific Northwest Laboratories, Richland, WA
99352)

A computer model was developed which calculates total annual radiation doses and 50-year dose equivalents 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. 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. (auth)

This paper has been updated by ESNL-1754 (1974) and modified in its implementation by ONSOP Reg. Guide 1.105 (1976). The approach is that which was incorporated into the NERBES code. The dose program utilizes data generated by or stored in other portions of NERBES, but could be operated independently if such data were available directly.

(5)
Kilough, G.C.; Schuer, P.S.; Turner, W.D., INREP
- A COMET Code Which Implements ICRP 2 Models
of Internal Radiative Dose to Man

1975, February. COMET-5002; 140 pp. (Oak Ridge
National Laboratory, Oak Ridge, TN 37830)

INREP is a COMET 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. The first version of INREP was described in 1968 by Turner, Eysse, and Schuer (1968). The code has subsequently undergone a number of modifications, with the result that the 1968 report is now obsolete. In view of the continuing usage of INREP, however, the present report is intended to provide up-to-date documentation. (auth) (FOR)

Currently in the process of being updated to include the effects of cross irradiation

among internal organs.

(6)
Chester, B.O., Biological Dose and Radiological
Activity from Nuclear Reactor or Nuclear Weapon
Fission Products

1974, December. ESNL-4996; 89 pp. (Oak Ridge
National Laboratory, Oak Ridge, TN 37830)

This report describes the use of a computer code, YIELDIS, that performs rapid, accurate calculation of dose and activity from the fission products in a nuclear reactor core or from a nuclear weapon. For example, 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. (auth) (FOR)

This documentation of the YIELDIS code is continuing. The reader should utilize care in reviewing this manuscript. The term "Ingestion" often appears to be misused. The code assumes that an atmospheric dispersion model is already available. The documentation is rather opaque; consequently the implementation of this code would be difficult without the assistance of the author.

(7)
Turner, W.D., The INREP II Computer Code for
Estimating External Doses to Populations from
Construction of a Sea Level Canal with Nuclear
Explosives

1969, July 21. CTC-8; 91 pp. (Union Carbide
Corporation, P.O. Box 5, Oak Ridge, TN 37830)

INREP II is a computer code to estimate the dose equivalent rate and the total dose equivalent from both beta and gamma radiation resulting from submersion in contaminated water, submersion in contaminated air, and exposure to a contaminated surface. There can be more than one environmental release, and exposure can begin at any time after the first release. INREP II considers contributions from environmental releases and from nuclide chains. For a particular problem the user may choose to calculate either the dose rates, or the total doses, or both for any of the three modes of exposure. A separate solution array is printed for each mode of exposures. (auth)

This code has been updated by INREP III, INREP II has evolved from INREP by considering nuclide decay solvents.

(8)
Stallmann, F.W.; Fan, F.B.R., ACRA - A Computer

<8> CONT.

Program for the Estimation of Radiation Doses Caused by a Hypothetical Reactor Accident

1973, April. CSRI-TR-8082; 82 pp. (Oak Ridge National Laboratory, Oak Ridge, TN)

The radioactive material released to the atmosphere on account of a hypothetical reactor accident is transported away by the wind and is dispersed to a 3-dimensional normal distribution. The physical 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 varies 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 100 isotopes. Computer time is about 2 seconds per receptor and time interval. This time may be doubled if inversion layers are present. (auth)

Mathematical analysis based on CSRI-8086. Density distribution of the dispersed cloud is assumed to be Gaussian. Only linear nuclear decay sequences are handled. This code has been updated by JCEA II in which the effects of plume depletion resulting from wet and dry deposition are considered.

<9>

Hillough, G.G.; Schwer, F.S.,
INCR-Conversional Computer Codes to Implement
ICBF-10-10A Models for Estimation of Internal
Radiation Dose to Man

1974, March. CSRI-8516; 93 pp. (Oak Ridge National Laboratory, Oak Ridge, TN)

The INCR codes are special purpose conversational program written to function in a time-sharing environment. They have been implemented on the CSRI FIF-10. These codes use ICBF-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. INCRS 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 INCRS 1 refers to quantity of material deposited in the organ, not total quantity introduced into the body. The output of INCRS 1 is a tabulation of time (days), dose rates (rem/day), and doses (rem.) INCRS 2 computes dose rate and dose resulting from depletion 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, INCRS 2 secures parameter values associated with the material and its critical organ from a direct-access file stored in the user's disk area. This stored data base is one feature which distinguishes the capabilities of INCRS 2 from those of INCRS 1. A second distinction is the meaning of the term 'intake.' For INCRS 2, this term refers to the quantity of material inhaled or ingested into the body

(the user chooses the route of intake).

INCRS 2 converts the intake into a proportionate deposition in the critical organ for the calculations. The output of INCRS 2 is capable of an optional typewritten graph of dose vs. time. Computationally, INCRS 3 is identical to INCRS 2, and these codes access the same direct-access files. The codes differ only in the form of output. INCRS 3 provides punched-card output which can serve as input to other codes such as graphical programs. Explanatory comments are included only at points where INCRS 3 differs substantially from INCRS 2. (FOR)

<10>

Segendorf, J.P., A Program for Evaluating
Atmospheric Dispersion from a Nuclear Power
Station

1974, May. NOAA TR ESI ARI-82; 12 pp. (National Oceanic and Atmospheric Administration, Air Resources Laboratory, Idaho Falls, ID)

A computer code (SEE for Site Evaluation Program) is described. 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 included. The program is written in Fortran IV and uses 256 K memory on an IBM 360/75 computer. Plume rise may be calculated using formulas from Briggs, or it may be ignored. (CWA)

Only the ratio effluent concentration/source strength is calculated, not concentrations or doses. Building wake effects are included but not cloud deposition and depletion.

<11>

Martin, J.A., Jr.; Nelson, C.P.; Cony, F.A.,
ATERN Program Manual: A Computer Code for
Calculating Doses, Population Doses, and Ground
Depositions Due to Atmospheric Emissions of
Radionuclides

1974, May. EPA-560/1-74-C08; 127 pp. (U.S. Environmental Protection Agency, Office of Radiation Programs, Field Operations Division, Washington, DC 20460)

A computer code useful for the calculation of doses to the general population due to atmospheric emissions of radionuclides is presented and discussed. The code is written in Fortran IV, requires 109K storage, and runs in about 20 seconds on an IBM 370 system. A standard sector-averaged gaussian-diffusion equation is solved repeatedly for each radionuclide, wind sector, stability class and downwind distance. Radionuclide contributions to doses of up to four critical organs are summed and printed by sector and downwind distance. Population doses (person-rem) are also calculated. The code accounts for the following physical processes: cloud diffusion, ground and inversion-lid reflections, radionuclide decay by time of flight, first daughter-product buildup, ground deposition of particulates and halogens (independently), cloud depletion, in-plant holdup and decontamination factors, and sector-to-sector contributions to external gamma dose. The code is dose model independent in the sense that dose conversion factors, provided as input data, are used for calculations of dose that are proportional to radionuclide concentrations in the cloud, and

<11> CCNT.

dose conversion tables obtained from a model that considers the finite extent of the overhead cloud, also required as input data, are used for calculations of whole body dose due to external gamma emitters in the cloud. A set of dose tables obtained using one finite cloud model (ECAL) are provided in this manual. Up to 20 radionuclides can be considered in a single picture. The program has been written to be used to evaluate routine releases, but the authors state that it can be used, with limitations, for accidental releases, especially those of several hours duration. Activity density on the ground is calculated and printed out, but no doses due to ground deposition are calculated. (Auth) (CNS)

<12>

Luguid, J.E.; Reeves, P., Material Transport through Porous Media: A Finite - Element Galerkin Model

1576, March. OBNL-8520; 210 pp. (Oak Ridge National Laboratory, Oak Ridge, TN 37830)

A two-dimensional transient model for flow of a dissolved constituent through porous media has been developed. 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 quadrature are used in the numerical formulation. The program using 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 mixture-transport model (Reeves and Luguid, 1975) for predicting advective Darcy velocities for porous media which may be partly saturated. In addition to a description of the mathematical formulation, the numerical treatment and the computer implementation results of two computer simulations are included in this document. One is a comparison with a well-known analytical treatment (Larimer and Anderson, 1952) and is intended as a partial validation. The other simulation, a seepage-face problem, is a more realistic demonstration of the capabilities of the computer model. Complete listings of input and output are given in the appendices so that this simulation may be used for check-out purposes. This report, thus, is intended to be a comprehensive description of the material-transport computer model. Simplifying assumptions are made in the treatment of the chemical reactions of dissolved constituents. Reacting species in the solid solution are independent of each other. Local equilibria 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 present in both the solid and liquid phase. (Auth) (ELS)

<13>

Fletcher, J.F.; Ertson, W.L., NEBPES - A Digital Computer Code for Estimating Regional Radiological Effects from the Nuclear Power Industry

1971, December. NEEL-TN-71-160; 259 pp. (Sandford Engineering Development Laboratory, Richland, WA)

The NEBPES 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 NEBPES 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 40,000 MW generating capacity (nuclear and fossil) at 18 separate sites, and reprocessing plants at 9 sites. The air transport code (AIRTRAN) 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 (4) ingestion of food and water over numerous food-chain pathways. Life habits and dietary differences are also considered in the code (LPH). (FOR)

Extensive modification of the NEBPES model has occurred, and is being prepared for publication. The current model does not consider near-site conditions, however this publication is the primary documentation for many parameters that are used in later codes which are designed to calculate near-site doses. The NEBPES model is large and complex in order to provide comprehensive estimates of population dose over regions of the size indicated.

<14>

Trubey, D.R.; Kays, S.V., The EXERN III Computer Code for Estimating External Radiation Doses to Populations from Environmental Releases

1971, December. OBNL-TN-8322; 62 pp. (Oak Ridge National Laboratory, Oak Ridge, TN 37830)

EXERN III is a computer code to estimate the dose equivalent rate and the total dose equivalent from beta, positron, electron, and gamma radiation resulting from submersion in contaminated water, submersion in contaminated air, and exposure to a contaminated surface. There can be more than one environmental release, and exposure can begin at any time after the first release. EXERN III considers contributions from environmental releases and from nuclide decay chains. For a particular problem the user may choose to calculate either the dose rates, or the total doses, or both for any of the three modes of exposure. A separate solution array is printed for each mode of exposure. EXERN III is a revised version of EXERN II which was available earlier. The principal revisions include treatment of positron and electron radiations, selection of nuclear data from a data base, variable dimensioning of large data arrays, and free field input. The code is available from the Radiation Shielding Information Center. (Auth)

<15>
Baker, L.A.; Scenen, G.B.; Schilder, J.B., Food -
An Interactive Code to Calculate Internal
Radiation Doses from Contaminated Food Products

1976, February. BNL-58-5523; 5 pp. (Pattelle,
Pacific Northwest Laboratories, Richland, WA
99352)

The computer code Food calculates internal
doses due to ingestion. Fourteen types of
produce, grains and animal products are
considered. Vegetation is contaminated by
air or irrigation water via direct deposition
on leaves or uptake from soil through root
systems. Doses may be calculated for total
body plus six internal organs for 19
radionuclides. Food is compatible for usage
along with ABBAC. The term "irrigation"
means sprinkler irrigation. The
translocation of externally deposited
radionuclides to the edible parts of plants
is assumed independent of the radionuclide.
Bulk transfer factors for elements lacking in
radionuclide data were taken to be one-half
those in report NCR-10763. The assumption
is made that plants obtain all their carbon
from either CO₂ and animals obtain all
their carbon through ingestion of plants.
Because the transfer of carbon from water to
air or soil is unknown, Food conservatively
assumes that plants obtain all their carbon
from the irrigation water. Thus carbon
concentrations in plants could be high by an
order of magnitude. (BIS)

<16>
Watts, J.P., Modeling of Radiation Doses from
Chronic Aquatic Releases

1976, July. DR-NC-75-126; 13 pp. (Savannah
River Laboratory, Aiken, SC 29801)

A general model and corresponding computer
code, called Cardccc, were developed to
calculate potential dose estimates from
chronic releases via aqueous pathways.
Cardccc uses the internal dose portion of the
ABBAC 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
contribution in the source term. The 1976
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
radiochemical analysis of water and fish
samples. The whole body dose from water
consumption was 1.05 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 6.20 mrem calculated from
monitoring data and 0.14 mrem from the model.
Cesium 137 was the principal contributor
to the 70-year whole body dose from fish
consumption. (auth) (BIS)

<17>
Gogolak, C.V., Comparison of Measured and
Calculated Radiative Exposure from a Boiling
Water Reactor Plume

1977, September. HASL-277; 25 pp. (Health and
Safety Laboratory, United States Atomic Energy
Commission, New York, NY 10014)

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 Ray 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 Noses' 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, Capri's formula is used
for gamma energies greater than 0.1 MeV, and
Berger's formula is used for gamma energies
less than 0.1 MeV. Exposure rate is averaged
over 4 atmospheric stability classes, 16 wind
directions and 8 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 BGA, 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-peak
exposures separately match the data more
accurately than those that do not. (BIS)

<18>
Not given, NISC Computer Code Calculations,
ACPA-II Internal Integration Code Estimation of
Radiation Doses Caused by a Hypothetical Reactor
Accident

1976, July. CCC-23; 75 pp. (Oak Ridge National
Laboratory, Oak Ridge, TN)

The purpose of ACPA-II is to expand the
capability of ACPA-I to include the effects
of fallout, washout, and ground
contamination. The built-in containment
model of ACPA-I was eliminated and the
emission of nuclides to the atmosphere is
described by a step function of time. This
decision to separate the containment model
calculation from the meteorological part of
the calculations was prompted by the fact
that the containment models vary depending on
the radionuclides, the leakage pathways, and
the filter mechanisms involved. The program
computes external dose, internal dose, and
ground contamination as a function of
location and points in time. The three
dimensional aerosol distribution is used for
dispersion, and the cloud concentration
accounts for washout by rain, fallout, and
radioactive decay. Fallout is described by
Chamberlain's model. (auth) (BIS)

<19>
McGee, R.E., AIRACS - A Computer Code for
Estimating Population and Individual Doses
Resulting from Atmospheric Releases of
Radionuclides from Nuclear Facilities

1975, January. CSNI-TN-4687; 80 pp. (Oak Ridge
National Laboratory, Oak Ridge, TN 37830)

<19> COBOL

ALSDOS, a Fortran IV computer code, was written to estimate population and individual doses resulting from the continuous simultaneous atmospheric release of as many as 36 radionuclides from a nuclear facility. This report presents details of the code and complete instructions for its use. Five pathways to man are considered: (1) inhalation of air containing radionuclide gases or particulates, (2) ingestion of contaminated air, (3) exposure to surfaces contaminated by radioactive fallout, (4) ingestion of food produced on contaminated ground surfaces, and (5) immersion in contaminated water, as by swimming. Dose and dose components are estimated for each pathway and the following eleven reference organs: whole body, GI tract, bone, thyroid, lungs, muscle, kidneys, liver, spleen, testes, and ovaries. The environmental model in ALSDOS consists of a 20 x 20 square grid with the nuclear facility located at the center. The size of each grid is specified in the input data. Human population, numbers of beef and dairy cattle, and identification as to whether an area is predominantly used for production of vegetable crops or is a water area are specified for each of the 400 grids. Population doses are summarized in output tables in every possible manner--by nuclides, pathways, and organs. The highest individual dose received in the area and its location are printed in the output. ALSDOS is partially validated against data available in the literature. (auth) (LLS)

<20>

Tanner, W.L.; Faye, S.V.; Schuer, L.S., EYREN and INBEN Computer Codes for Estimating Radiation Doses to Populations from Construction of a Sea-Level Canal with Nuclear Explosives

1968, September 16. 4-1752; 193 pp. (Oak Ridge National Laboratory, Oak Ridge, TN 37830)

INBEN is a computer code to estimate the dose equivalent rate and the total dose equivalent from both beta and gamma radiation resulting from submersion in contaminated water, submersion in contaminated air, and exposure to a contaminated surface. There can be more than one environmental release, and exposure can begin at any time after the first release. INBEN is a computer code to estimate the cumulative dose equivalent to body organs resulting from a continuous intake. The code parameters are dependent on the age of the individual, and the intake is a function of post-detection time and the individual's age. Although the codes were specifically written to estimate doses to populations from construction of a sea-level canal, they may be useful in other dose-estimation studies involving releases of radioactive materials to the environment. (auth)

This is the first documentation of these codes which have been revised and updated via INBEN II and INBEN III and INBEN IV

<21>

Engelmann, W.J.; Davis, W.F., Low-level Isentropic Trajectories and the MILES Computer Program for the Montgomery Stream Function

1968, April. BNWL-661; 31 pp. (Pacelle, Pacific Northwest Laboratories, Richland, WA)

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

Isentropic analysis reveals vertical sections of the material and predicts where the material will appear in the air near the ground. This report presents an example of such a trajectory, provides a thorough error analysis of isentropic data, and gives the details of a digital analog simulation computer program for obtaining isentropic data. These trajectories can be calculated using teletype weather data, and precipitation scavenging may be included if desired. The solutions are found using the Modified Integral Digital Analog Simulator (MIDAS) technique. (Auth) (CW)

This program calculates long distance three-dimensional trajectories for particles or gases in the air of any type, for fast radioactive decay. Radioactive decay corrections are not included in the code.

<22>

Bell, G.D.; Noughton, J., Risk Evaluation for Stack Releases

1969. AMSE (5) 8 173; 18 pp. (United Kingdom Atomic Energy Authority, Risley, England)

A method of calculating the risk to the population distribution around a reactor site is presented for both ground level and elevated releases. The reactor is assumed to satisfy a control curve of the Parker type for accidental releases of radioactivity, and the dose-risk relationship is assumed to be a 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-C curves). The program 'STRAF II' used in these calculations is described.

The program depends on having input the number of men per curie air concentration for a given radionuclide and the number of casualties of a given type per man for that radionuclide. (CW)

<23>

Cooper, P.E., WHEI, A Siting Code to Estimate Dose Probability Distributions from Measured Meteorology Data

1969. Health Physics, 16, 735-738. (Savannah River Laboratory, E. I. duPont de Nemours and Co. Aiken, SC 29801)

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

<23> COMPT.

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 various data input (wind speed, direction, temperature) or full input including measured standard deviations of the horizontal and vertical wind directions. (Auth)

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

<24>

Clarke, D.W., A Multi-Compartment Model for Studying the Dose-Intake Relationship for Radioactive Isotopes

1972, April. PD/B/W 2291; 38 pp. (Central Electricity Generating Board, Berkeley Nuclear Laboratories, United Kingdom)

A model (CEBIC) has been developed in which the various organs of the body are represented by single or multi-compartment, 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 (ICRP 10 (1968) and by Voilleque (1971), who has published details of a simplified compartment model which he developed (Voilleque, 1970). The program, which has been designated CEBIC (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. A complete user's guide to the program has been provided by Clarke and Beynon (1972) in which running details are given including input/output specifications. (Auth) (PDN)

The compartment model CEBIC is a FORTRAN IV 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 VEEBIE program.

<25>

Cruz, F.D., "Endora" Computer Program for an Estimate of the Radiation Dose in the Evaluation of Risks for Nuclear Power Plants and Radioactive Facilities

1971, March. SS/01/71; JBB1-tr-2618; 4 pp. (Junta De Energia Nuclear, Spain)

The program ES.DC.DA. (Estimacion de Dosis

Biologicas resultant de radiacion ionizante) estimates the dosage 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 8 subroutines: ESD 1. Generates an inventory of fission products according to the operating process (s.c., burst?) of the fuel of the facility. ESD 2. Determines the quantity of fission products emitted to the atmosphere through the stack or the containment building, taking into account 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 submergence in the radioactive cloud as well as the internal doses received by the various organs of the human body by inhalation. This report includes the mathematical models used, the simplifying assumptions adopted, the data used, lists and flowcharts of the specific subroutines, as well as the necessary instructions for their use. 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. (Auth) (CUN)

<26>

Eckert, P.J., A Fortran Program for the Calculation of the Potential Hazards from an Accidental Fission-Product Release - 70182

1968, July. WAFB-TN-308; 22 pp. (Bettis Atomic Power Laboratory, Pittsburgh, PA)

A FORTRAN program (70182) 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. (Auth) (CUN)

<27>

Steys, J.J.; Kim, Y.S., Users manual for Code EICAN: A code to Calculate Gamma Photon Dose from an Airborne Radioactive Release

1966, November. B05-329 (B05 Corporation, 1730 N Street, N.W., Washington, DC 20036)

A FORTRAN IV code - EICAN - 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

<27> COBOL

spatial distribution of the Gaussian. Input options allow the user to choose source term mode, cloud thickness, cloud wind speed, cloud stability class, cloud drift direction, air attenuation and build-up coefficients and source phase fraction. The code user's requirements and COMPILE listing are given, along with a sample input and output. The code has been optimized with respect to computer execution time. (Auth)

This code was designed to be used as part of the space nuclear propulsion program, but for release from nuclear power facilities.

<28>

Charab, I., Atmospheric Dispersion of Fission Products Including the Effects of Building Emission and Radioactive Decay

1967, May. Nuclear Applications, 3, 244-249. (Argonne National Laboratory, Argonne, IL 60439)

Sutton's diffusion equation, which is commonly used for the computation of atmospheric dispersion of fission products, is modified to account for the effect of dilution of the fission products due to mixing of the contaminated air inside the reactor building with air prior to exhaust. The effect of radioactive decay is also considered. The resulting integral equation is solved for a specific example using a Romberg integration subroutine, and the application of the equation to a washout calculation is described. The solution is done by a Fortran program on a CDC-160A computer. (Auth) (COP)

As written, this code is designed for accidental rather than routine reactor releases.

<29>

Yance, S.J., A Procedure to Determine the Relative Extent of Reactor Fission Product Releases Under Various Meteorological Conditions

1966, July. HASL-148; 45 pp. (Health and Safety Laboratory, New York Operations Office, New York, NY)

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. A procedure for the application of these programs and graphs to the review and evaluation of reactor safety problems is presented. The code handles both instantaneous and continuous point sources. Cloud depletion by both wet and dry processes are included using Chesterlain's procedure. The only dose calculated is the inhalation dose to the thyroid. (Auth) (COP)

This early report should be read with care as there is some question of the use of the term rainfall and dose, and on the derivation of the thyroid dose equation.

<30>

Longe, P., ADPIC: A Three-Dimensional Computer Code for the Study of Pollutant Dispersion and

Deposition Under Complex Conditions

1971, December. GPHL-1442; 41 pp. (Lawrence Livermore Laboratory, Livermore, CA)

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, valleys, 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 non-consistent advection field. The method is based on the particle-in-cell technique with the collection of deposition represented by Lagrangian particles in a 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 code of a CDC 1600 to run. It may be scaled to handle different size problems, 20 m x 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. (Auth) (COP)

<31>

Hubschmann, W.; Nagel, D., ISOLA II - A Fortran IV Code for the Calculation of the Long-Term Alpha- and Gamma-Dose Distributions in the Vicinity of Nuclear Installations

1976, December. HW 213; 74 pp. (Gesellschaft für Kernforschung mbH., Karlsruhe, Germany)

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 coded with simultaneously. The emission rates are considered to be constant during the given time interval. Optionally, either the isodose 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. Input and output are shown for a specific case. (Auth)

<32>

Binford, P.L.; Parish, J.; Kuo, P.-C.K., Estimation of Radiation Doses Following a Reactor Accident

1967. GPHL-8086; 26 pp. (Oak Ridge National Laboratory, Oak Ridge, TN 37830)

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 calculation presented here is concerned only with the thyroid dose due to iodines and the whole body dose due to fission and actinides, it can easily be adapted to handle other radioisotopes. The

<32> CCOT.

Basic assumptions include instantaneous release of a given quantity of radioactive material into a reactor building followed by dispersal 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 deposition such as filtration. A Fortran IV computer program "PLUPR" has been written for the purpose of solving the equations developed. The code calculates dose due to inhalation and from subsurface in the gamma emitting cloud. (Auth) (EIS)

<33>

Houston, J.B.; Stronge, D.L.; Watson, E.C.,
EACBIV - A Computer Program for Calculating Organ
Dose from Acute or Chronic Radionuclide Inhalation

1974, December. ENU-8-389; 139 pp. (Batelle,
Pacific Northwest Laboratories, Richland, WA
99352)

The computer program, EACBIV, permits rapid and consistent evaluation 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 Group on Lung Dynamics, and a single 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 19 organs and tissues from inhalation of any one or combination of radionuclides considered by the ICRP. A various 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 case. Output of the code consists of the effective radiation dose to the selected organs at selected time intervals, for each radionuclide inhaled or indicated by the input. (FOR)

This edition of EACBIV has been updated by a supplementary document (ENU-8-389 SUPP, 1975) to include dose to the GI tract via inhalation. Information pertaining to Pasquill Stability Categories are given for distances out to 100,000 ft, but the atmospheric dispersion model does not include the effects of wet or dry deposition or plume depletion. Setchen and Pasquill atmospheric dispersion information is also stored in the data base.

<34>

Stronge, D.L., EACBIV - A Computer Program for
Calculating Organ Dose from Acute or Chronic
Radionuclide Inhalation: Modification for
Gastrointestinal Tract Dose

1975, February. ENU-8-389 SUPP; 105 pp.
(Batelle, Pacific Northwest Laboratories,
Richland, WA 99352)

The computer program EACBIV uses the lung

model proposed by the International Commission on Radiological Protection (ICRP) Task Group on Lung Dynamics to calculate the effective dose to the respiratory tract and other organs following either acute or chronic inhalation of radionuclides. The program has now been extended to calculate the dose to the four gastrointestinal tract compartments: stomach (S), small intestine (SI), upper large intestine (ULI) and lower large intestine (LLI). The ICRP G.I. tract model is used to describe movement of material within the G.I. tract compartments with input to the G.I. model described by the lung model of EACBIV. (Auth) (FOR)

This is an expanded version of ENU-8-389 (1974). It incorporates the ICRP G.I. tract dose assessment model.

<35>

Stronge, D.L.; Watson, E.C.; Houston, J.B.,
SUBDOS1 - A Computer Program for Calculating
External Doses from Accidental Atmospheric
Releases of Radionuclides

1975, June. ENU-8-351; 169 pp. (Batelle,
Pacific Northwest Laboratories, Richland, WA
99352)

A computer program, SUBDOS1, has been developed for calculating external gamma and beta doses to individuals from the accidental release of radionuclides to the atmosphere. Characteristics of SUBDOS1 are: (1) Doses from both gamma and beta radiation are calculated as a function of depth in tissue, summed and reported as skin, eye, gonadal and total body dose. (2) Doses are calculated for releases within each of several release time intervals. Up to six time intervals can be allowed and separate nuclide inventories and atmospheric dispersion conditions are considered for each time interval. (3) Radioactive decay is considered during the release and/or transit using a chain decay scheme with branching to account for transitions to and from isomeric states. (4) The dose from gamma radiation is calculated using a numerical integration technique to account for the finite size of the plume. (5) The program computes and lists the normalized air concentrations at ground level as a function of distance from 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 SUBDOS1 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 SUBDOS1, the tissue depth is 1 cm. (Auth) (FOR)

SUBDOS1 does not consider the dose resulting from radionuclides deposited in the body and its organs via inhalation.

<36>

Otter, J.W.; Connors, P.A., Description of the
CONRADIX-III Code

1975, June. TI-001-130-053; 22 pp. (Atomic
International Division, Rockwell International,
Canoga Park, CA 91304)

The CONRADIX-III (Containment and Meteorology of environmental Radiation Exposure) Code is described briefly, input instructions are given, and test cases and Fortran coding are listed. Changes from the previous version (CONRADIX-II) include variable weather

<36> COMET.

modelling for external doses, a direct site meteorology option, and an improved direct dose formulation. The 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 cleanup rates in each level. Filtration in each containment region may be by isotopic class (active 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 for up to 12 body organs (thyroid, liver, lung, etc.) due to inhaling the airborne radioactivity, and the external gamma and beta doses from the cloud. Leakage and cleanup rates, and initial inventory are input data. A direct numerical technique, designed especially for quasi-linear differential equations, is used to solve the time dependent isotope population equations. Meteorology models may be that of Pasquill or site meteorology. Factors are given in this document for computing internal doses with the ICRP-2 model. The cloud gamma dose is obtained by integrating over an axisymmetric Gaussian cloud for Pasquill meteorology or from a semi-infinite cloud for direct site meteorology. The external beta dose calculation assumes a semi-infinite radioactive cloud. (Auth) (CVR)

<37>

Kerfield, G.P.; Loh, W.B.; Sayer, V.B.; Rachmans, D.R.; Morris, B.A., Curie-Dose-Thunderhead A Digital Computer Program for External and Internal Radiation Dose Calculations

1967, June. WAA-59-2886; 35 pp. (Atomic International, a Division of North American Aviation, Inc.)

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

<38>

Scidat, J.R.; Schinca, B.B.; Bahat, D., Models and Computer Codes for Evaluating Environmental Radiation Doses

1970, February. WASH-1750; 160 pp. (Battelle, Pacific Northwest Laboratories, Richland, WA 99222)

Since WEDNES is considered too complex and unsuitable for the evaluation of the radiological consequences of point-source releases, a simplified model for calculation of radiation doses from radioactive effluents

was developed and programmed into a conversational language, providing the fast turnaround time required. The new model is divided into four independent parts, each written as a separate program: (1) ASSEG: calculates individual and population doses from liquid effluents (2) CPTD: calculates internal radiation doses to four common classes of aquatic organisms and to organisms which consume them (3) FOOD: calculates doses from consumption of food crops and animal products produced on irrigated farms (4) GSCDF: calculates doses from gaseous effluents to individuals, and to the total population within 50 miles. It includes an option for building wake effects but does not calculate plume depletion. The model can be used to calculate radiation doses to the total body and selected organs of individuals and population groups, and to organisms other than man. It includes all air and liquid exposure pathways thought to be significant and for which a reasonable amount of supporting data is available. Internal doses to man are based on a 1-year radionuclide intake, assuming no prior accumulation in the body. The radionuclide content of ingested food is assumed to be at equilibrium with the environment. This paper discusses the models in detail and describes the programs ASSEG, CPTD, and GSCDF; the program FOOD is still being developed and is not included in this report. The question-and-answer format of these programs allows them to be used by nonprogrammers. Although the programs, which are in the BASIC language, were originally intended specifically for nuclear reactors, they are applicable to any nuclear facility which releases radioactive effluents to air or water. (PCR)

This is the document upon which many of the models recommended by the NSC in Reg. Guide 1.109 is based. The Dose Conversion Factors are for the calculation of annual doses, not dose commitments. The data base for much of the material discussed has been taken directly from the original WEDNES code.

<39>

Luna, R.E.; Church, H.W., CIPOT, Model for Computation of Aerosol Transport and Diffusion in the Atmosphere

1969, January. SC-38-64-555; 47 pp. (Sardin Laboratories, Albuquerque, NM)

In conjunction with Poller 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 C.S. code describing gravitational fallout of a log-normal size distribution of particles in a vertically varying wind field and a J.V. 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 sizes 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

<39> CCB7.

minutes above origin is at the initial position of the cloud. Details of the development of the unique line source equations used in the model are given, indicating the analytical method used to account for linearly changing transport direction over the length of the source. In addition, the expressions used to calculate turbulent spread, deposition, particle fall rates and transport vectors are discussed in terms of appropriate experiment and Gaussian theory. Various input and output options are described 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. Detailed instructions are given for preparing the input data for the program. A sample problem is used to illustrate the usefulness of the program in solving a fairly arbitrary selection of inputs. Both the input preparation and output interpretation for the sample problem are given in some detail. The program may be used for both continuous and instantaneous releases. (Auth) (CWN)

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Teeten, D., Areas Affected by Ground Deposition of Cs 137 and Description of the Computer Code ABCD

1974. IAEA-SM-188/35; Siting of Nuclear Facilities, Proceedings of a Symposium held in Vienna, Austria December 9-13, 1974. pp. 497-515 (Institute for Atomenergij, Bjeller, Norway)

The paper deals with the combined probability analysis and parametric study of Cs 137 deposition after a postulated nuclear reactor accident. The study is performed for a 1000 MW(th) reactor at a site typical of the Oslo Fjord area. No efforts have been made to determine definite accident 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 them 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 releases; initial heat at release point; heat generated during plume transport 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 ABCD has been developed for this analysis, adaptable to a large range of calculations connected to atmospheric releases during accident conditions as well as normal operations, e.g. calculation of reference levels for air 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 in this paper, other isotopes may be treated in a similar manner. (Auth) (CWN)

<41>

Hendrickson, H.M., EXOSE, A Computer Program for Calculating the External Gamma Dose from Airborne Fission Products

1968, September. PB81-211; 101 pp. (Fallville, Pacific Northwest Laboratories, Richland, WA)

The EXOSE 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 PFE. 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 aerosol model and Simpson and Pequay'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. (Auth) (CWN)

The Simpson-Pequay stability constants are based on experiments done at Hanford and they should be examined carefully for their applicability to other areas.

<42>

Bacon, J.S.; Parks, B.L.; Fiazewycz, B.G., RUBY, A Program for the Calculation of Activity Releases and Potential Doses from a Pressurized Water Reactor Plant

1975, May. Not Given (Carolina Power and Light Company, Raleigh, NC)

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

<42> CORF.

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. (Auth) (CWN)

One notable feature of CORF is its scrap-paper ability. Complete printout of all available information results in approximately 175 pages of output per period. (sic)

<43>

Cellowski, W.B.; Patterson, W.R., A Comprehensive Atmospheric Transport and Diffusion Model

1976, April. ORNL/RSP/EATC-17; 117 pp. (Oak Ridge National Laboratory, Oak Ridge, TN 37830)

A comprehensive version of the Atmospheric Transport Model (ATM) is described that includes the effect of aerodynamic roughness on dispersion constants, clarifies the role of the terminal velocity and deposition velocity, incorporates a tilting plane for heavy particulates, and includes an episodic calculation of exposure series. This model also limits the various 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 is applied to the vicinity of three power plants, and correlations between model predictions and observed values are presented. The dispersion calculation is based on the Gaussian plane model, corrected by the above considerations. The model allows the use of point sources, line sources, area sources, and windblown resuspension sources. (Auth) (CWN)

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. (CWN)

<44>

MacDonald, H.P., Assessment of Environmental Hazards Following Nuclear Reactor Accidents

1971. IAEA-SM-140/38; CORF-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 (Central Electricity Generating Board, Berkeley Nuclear Laboratories, Berkeley, Gloucestershire, United Kingdom)

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 ZENIE (Environmental Evaluation of Radioactive Isotopic Effluents) which 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 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. 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. (Auth) (FCH)

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Hills, H.T.; Dahlgren, P.C.; Olson, J.S., Ground Level Air Concentrations of Dust Particles Downwind from a Tailings Area During a Typical Windstorm

1970, September. ORNL-TR-8175; 61 pp. (Oak Ridge National Laboratory, Oak Ridge, TN 37830)

This paper describes an atmospheric transport model for suspension by wind of toxic particulates that have been deposited upon the ground surface. Dimensional arguments are given relating suspension and saltation rates. Sample calculations of ground level air concentrations are carried out for a square tailings area containing uranium mill dust. A list of the computer code and sample output from this code are included. Ground level air concentrations downwind from the source are calculated with a Gaussian plane equation modified for plume depletion due to dry deposition. (Auth) (CWN)

<46>

Strange, D.L.; Hendrickson, W.R.; Watson, E.C., BACER - A Computer Program for Calculating Potential External Dose from Airborne Fission Products Following Postulated Reactor Accidents

197, June. ORNL-B-69; 67 pp. (Battelle, Pacific Northwest Laboratories, Richland, WA 99352)

BACER, a computer code, permits rapid and consistent estimates of whole body dose resulting from exposure to a plume of airborne radionuclides accidentally released from a nuclear reactor. An attempt has been made to make the program flexible enough so that new models, as they are developed, can be incorporated without extensive reprogramming. The mathematical models used in BACER include: (1) Source inventory-choice of radionuclides, decay schemes (photo energies), quantity (initial activity). (2) Aerosol behavior within containment spaces. (3) Leakage rates from containment barriers (multiple containment effects). (4) Atmospheric dispersion. (5) Cloud size effect on external dose estimates. (6) Build-up factors. (7) Whole body dose from a cloud. Each of the preceding stages is incorporated into the model and program;

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COMET. However, there are several possible starting places for the calculation depending on the information that is available. (CDB)

Cloud depletion calculations due to ground deposits have not been included because of the large amount of computer space required. However, a depletion factor as a function of distance may be included through a punch-card input. A Gaussian plume atmospheric dispersion model is used because it is the most widely accepted method of dispersion assessment.

<47>

Reich, B.S.; Bohner, P.S., Methodology for Prediction of Dose to Man from Environmental Release of Radioactivity

1975. Radiocology, Proceedings of the Fourth National Symposium held at Oregon State University, Corvallis, Oregon May 12-16, 1975, 25 pp., unpublished (Oak Ridge National Laboratory, Oak Ridge, TN 37830)

A systems analysis approach has been taken in the development of a computer code called AQUAROC in order to simulate radionuclide movement through aquatic food chain pathways. The major objective of this model is to estimate the time-dependent intake by man of radionuclides released into an aquatic ecosystem. A secondary objective is to estimate the environmental buildup of long-lived radionuclides if released over extended time periods. These objectives are achieved within the extent and accuracy of existing data. However, the model is structured so that in the event of data limitations the predicted radionuclide intakes by man are more likely to be overestimated than underestimated. Transfer coefficients of AQUAROC are expressed in terms of basic environmental and ecological data so that the model can be realistically applied to a variety of aquatic systems. The data required to implement the model for a particular system are limited to that which is easily measurable and/or often available, and the more important model parameters are identified. (B12)

AQUAROC exists as a code but the working conditions of that code is unknown. Also, there is no documentation on the code itself.

<48>

Cooper, B.Z., RADOS, A Code to Estimate Gamma Dose from a Cloud of Radioactive Gases.

1967, June. OR-1098; 23 pp. (Savannah River Laboratory, Aiken, SC 29801)

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 400 meters downwind from the release point; and the gamma energies should be in the specified range. As a group, 14 isotopes, 1 receptor-point problem requires approximately 1.75 seconds on the IBM System/360-45. This is approximately 8 percent of the running time for the more detailed COMBAT code. Dispersion is essentially based on the Gaussian assumption. It is used for accidental releases from reactors. (B12) (CDB)

<49>

Willis, C.A.; Spangler, G.A.; Rhodes, W.A., A New Technique for Reactor Siting Dose Calculations

1970. Health Physics, 19, 87-94 (McDonnell Douglas Astronautics Company, Santa Monica, CA)

The COMBAT code was developed to calculate radiation doses from accidents postulated for advanced reactors with sophisticated engineered safeguards. The use of a direct numerical technique, designed especially for quasilinear differential equations, to solve the leakage and decay chains, permits the inclusion of several special features. These include the capability for considering up to four levels of containment, each with an independent time-varying leak rate. Provision is also included for filtration, particle coagulation and fallout, and special cleanup systems. Shielding may be introduced between the various containment shells. A full fission product inventory (plus special isotopes) is used with input release fractions. The meteorology model is that of Pasquill and Gifford. Internal doses are determined with the International Commission on Radiological Protection (ICRP) model. The cloud gamma dose is obtained by integrating over the anisotropic Gaussian cloud; this calculation is simplified by assuming a single air attenuation kernel for all gammas. (B12)

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Stronge, D.L.; Watsch, F.C., A Computer Program for Calculating Annual Average External Doses From Chronic Atmospheric Releases of Radionuclides

1973, June. BNWL-2-264; 132 pp. (Batelle, Pacific Northwest Laboratories, Richland, WA 99352)

In KRONIC the 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 can give significant contributions to the external total body dose. The beta dose contribution is easily calculated using a semi-infinite cloud model. This model may be used because the range of beta particles in air is short compared to the dimensions of plumes considered. The gamma dose calculation is more complicated because of the relatively long range of photons in air. To properly determine the gamma contribution it is necessary to perform a space integration over the plume volume. The integration technique used in the reactor accident analysis computer program SACS is employed in KRONIC except that here the plume width is determined by sector boundaries rather than by a Gaussian concentration gradient. The

<40> CCRT.

gamma dose is calculated as a tissue dose at the body surface, at 1 cm depth and at 10 cm depth. The beta dose and gamma doses are reported separately, however, the beta dose and gamma surface dose may be added and reported as skin dose if desired. (PCH)

Mathematical models and a computer program are described for calculation of annual average beta and gamma doses resulting from chronic release of radionuclides to the atmosphere.

<41>

Peaves, P.; Fowler, E.G.; Cramer, V.E., A Computer Code for Analyzing Point Atmospheric Releases of Short-Lived Radioactive Nuclides

1972, October. ORNL-TM-3412; 20 pp. (Oak Ridge National Laboratory, Oak Ridge, TN 37830)

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. (Auth)

<42>

Doziels, D.G.; Schuchman, J.C.; Jorke, R.T., The Estuarine Version of the COLNEAT Digital Simulation Model

1970, June. EPNL-1382; 40 pp. (Pattelle, Pacific Northwest Laboratories, Richland, WA 99362)

COLNEAT is an aquatic dispersion model which in this case was modified to simulate spatial and temporal variations of temperature, salinity, and radionuclide concentration above the salt intrusion in coastal plain estuaries where the river flow is dominant. This report explains the modifications and describes a case study of the Columbia River estuary. (CTC)

<43>

Blaine, P.A.; Bramblett, E.L., AISITE II, A Digital Computer Program for Investigation of Reactor Siting

1968. NAA-SR-9982; 94 pp. (Atomic International, Cosmo Park, CA)

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 computations 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. (Auth)(CTC)

<44>

McDon, L.L.; Bivard, J.B., Computational Method for Calculation of Radiological Dose Resulting from Hypothetical Fission Product Release

1970, July. SC-83-70-338; 148 pp. (Reactor Studies Division 222, Sandia Laboratories, Albuquerque, NM)

An improved method for the calculation of radiological doses resulting from the release of fission products is presented, including the derivation of, and the limitations of, the inhalation dose equation. The method is applied in the linked computer codes FISSP and CIGOD to the calculation of external and internal doses resulting from the hypothetical release and dispersal of 24 fission product nuclides and metastable states. The sensitivity of the results to parameter variation is reported, including a study of the influence of unlisted MPC values upon the inhalation doses. (Auth)

<45>

Travis, J.B., A Model for Predicting the Redistribution of Particulated Contaminants from Soil Surfaces

1975, August. LA-6035-MS; 67 pp. (Los Alamos Scientific Laboratory, Los Alamos, NM 87545)

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 characterizes important soil and surface conditions, and basic conserving control volumes are constructed on each cell. Material is transported through the vertical and top surfaces of a control volume by a modified Ragnold-Chapin horizontal flux formulation and modified Gillette vertical flux formulation, respectively. The vertical emissions, considered as puffs from area sources, create a regular time interval a contaminant cloud which is proportional to the suspended ground concentration. These puffs diffuse downward 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 this predictive tool is demonstrated by calculations involving mixtures of particulate Pu 239 Pu 241 in highly erodible 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. Radioactive decay is not considered. The model essentially assumes a one time external deposition. (Auth)(CTC)

<46>

Willson, T.D.; Lenham, A.B., A CDC 6400 Program for Calculation of Inhalation and External Dose for Establishing Reactor Siting Distance Requirements

1967, January. NAFI-W-65; 24 pp. (General Electric Company, Knolls Atomic Power Laboratory, Schenectady, NY)

<54> COBT.

The Dose E Program has been written to facilitate the calculation of distance factors for nuclear reactor sites as described in the well known USARC Document "Calculation of Distance Factors for Power and Fast Reactor Sites", TID-18000. 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 fissile product release for a time TAD subsequent to the time of release and based upon a given reactor operating history. (Auth)

This document does not contain a complete description of the conceptual model on which DOSE E is based.

<57>

McGowan, J.B.; Reid, E.B., INDEC: A Computer Code for Calculating Dose Equivalent from Internal Deposition of Plutonium at Hanford

1971, October. BNWL-B-4 1; 40 pp. (Battelle, Pacific Northwest Laboratories, Richland, WA 99122)

Presented here are the procedures and mathematical models used in developing INDEC, a computer program for computing the dose equivalent to body organs from intake of plutonium. The program was designed specifically to use the data recorded on the Hanford Internal Exposure (HIE) System (1) magnetic tape as input. Transfer as was possible, the recommendations of the Advisory Committee on Dose from Plutonium and other Transuranics are followed. (2) Some deviations were made where errors, omissions, or inconsistencies were found, after consultation with members of the Committee. In the current version of the program only plutonium and its immediate inorganic daughters are considered. The program could, however, be expanded to include other transuranic nuclides. At present, only a few depositions of transuranic nuclides other than plutonium are recorded out of about 450 individuals involved in a total of over 700 plutonium intakes. (Auth)

<58>

Booth, P.S.; Faye, S.V.; Polver, P.S., A Systems Analysis Methodology for Predicting Dose to Man from a Radioactively Contaminated Terrestrial Environment

1971, May. COMF-710501; CBWL 546; Radiocology, Nelson, E.J. (Ed.), Proceedings of the Third National Symposium held in Oak Ridge, Tennessee, May 10-12, 1972, pp. 877-892. (Oak Ridge National Laboratory, Oak Ridge, TN 37830)

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 (a) 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 $1 \mu\text{Ci}/\text{cm}^2$ of each radionuclide. These predicted intakes were used as input to an internal dosimetry model which calculated dose commitments for each radionuclide and pathway. The results of these calculations are discussed in relation to individual radionuclide contributions to dose commitment. 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. The predicted intakes are calculated with a computer code called TERNOD. The internal dosimetry calculation is performed with the INDEF computer code. (Auth) (DL3)

This is the first of two slightly different reports describing TERNOD.

<59>

Booth, P.S.; Faye, S.V., A Preliminary Systems Analysis Model of Radioactivity Transfer to Man from Deposition in a Terrestrial Environment

1971, October. COMF-TN-3135; 21 pp. (Oak Ridge National Laboratory, Oak Ridge, TN 37830)

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. The intake rates and total intakes of 25 radionuclides were predicted for a "standard" man based on a hypothetical fallout of $1 \mu\text{Ci}/\text{cm}^2$ of each radionuclide. In the first few days after deposition, milk and directly contaminated plant parts provided the greatest intake of radioactivity from this mixture of radionuclides. After about 30 days, the intake rate via beef was 2.5 times more important than that from directly contaminated parts. Finally by 500 days, the intake rate from plant parts contaminated by uptake from the soil was the most important source of radioactivity to man in the contaminated area. This generalized dynamic model is sufficiently versatile that it can be applied to many terrestrial environments and to all radionuclides. This first version of the model is to undergo future refinements. (Auth)

This is one of two slightly different reports describing TERNOD. This report presents some results not contained in the earlier report.

<60>

Heller, P.; Schikowski, W.; Vickenhauser, A., MUNDO - A Digital Code for Computing Accident Dose Rates in Reactor Environments

1967, September. NFK-653; ZNR 3684d; ZURPWF-461; 33 pp. (Institut für Angewandte Reaktorphysik, Karlsruhe, Germany)

<40> C007.

The PSB20 computer code calculates the dose equivalent received at the point P 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 factors, 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. Inhalation and ingestion are calculated for inhalation, external exposure to the plume, and external exposure to the ground. Ingestion and soil deposition are not considered. (POM)

<41>

Braaten, L.; Herzelle T.; Foss, L.; Zaro, G.,
VADSCA: A Simple Code for the Evaluation of
Ecological Exposure Due to Radioactive Discharges

1973, Sept., ICSP-7209007-12; Proceedings of the
Third International Congress of the International
Radiation Protection Association, held in
Washington, DC, September 9-16, 1973, pp.
IC72-IC77 (Italian National Electric Energy
Agency (ENEL))

The code consists of two parts, one for liquid discharges (VADSCA-LI) and one for gaseous discharges (VADSCA-GAS). It incorporates the transfer parameters of twenty-four radionuclides in the case of liquid discharges, and of twenty radionuclides 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, lungs, liver) 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 regimes, 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 VADSCA-LI covers twenty-four radionuclides including some fission products, some activation products, plus an alpha emitter. VADSCA-LI calculates the doses to four special groups, namely, fishermen, other workers, local populations, 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 VADSCA-GAS, twenty nuclides are considered, including eight noble gases (fission and activation products, various isotopes as particulate, and H₂, H₂, C¹⁴ in the form of vapor. Atmospheric diffusion is calculated with Pasquill's theory adapted to the meteorological data available. In its present form VADSCA-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 3×10^{-2} m/s. (POM)

This report is a description of the capabilities and applicability of VADSCA. No reference is given for complete documentation of the code. The code VADSCA-LI is written in FORTRAN; it needs 20 K memories and it takes approximately 17 seconds in a GE 635 computer. VADSCA-GAS is written in FORTRAN and needs 60 K memory and takes about 60 seconds in a GE 635 computer.

<42>

Coates, P.L.; Porter, W.B., PSAC -- A
Radiological Safety Analysis Computer Program

1966, May, IDO-17191; 204 pp. (Phillips
Petroleum Company, Atomic Energy Division, Idaho
Operations Office)

PSAC is designed to compute the potential radiological doses resulting from either a continuous or instantaneous release of radioactive fission products to the atmosphere. The program has been developed as part of ICRP and the general nuclear safety program to provide a generalized computer program for a complete parametric investigation of the radiological hazards. The doses considered are cloud gamma, deposition gamma, ingestion, and inhalation. They are based upon the release of up to 100 isotopes, the relative abundance of each isotope being dependent upon the operating history of the nuclear reactor under consideration. Included are the mathematical models, conversion factors, assumptions, flow charts, program listings, and other data considered pertinent to the overall development of this program. The program is written in SYRACIC LANGUAGE (RAP) for the IBM 7080 computer and is divided into the following five major categories: (1) Core -- The fission product inventory generated for a given set of operating conditions. (2) Cloud Gamma Dose -- The external gamma dose received as a consequence of exposure to airborne radioactive materials. (3) Deposition Gamma Dose -- The external gamma dose received as a consequence of exposure to deposited fission products. (4) Inhalation Dose -- The internal dose to eight critical organs received as a consequence of inhaling airborne radioactive materials. (5) Ingestion Dose -- The internal dose to the thyroid received as a consequence of ingesting iodine contaminated milk. This dose is calculated using the inhalation dose conversion factor and multiplying this factor times a correction factor to account for bioaccumulation and milk consumption. (POM)

A FORTRAN version of this code has been published in ICR-17261 (1968, June). Sutton's equation is used for atmospheric dispersion. Although the description of the code refers to the prediction of ingestion doses, these exposures are only calculated via a single adjustment factor converting the inhalation dose factor to an ingestion dose factor. The ingestion pathway is only determined for exposure to the thyroid.

<43>

Richardson, L.C., User's Manual for the Portran
Version of PSAC A Radiological Safety Analysis
Computer Program

1968, June, IDO-17261; 136 pp. (Phillips
Petroleum Company, Atomic Energy Division, Idaho
Operations Office)

This report constitutes a user's manual for the PORTTRAN version of the PSAC computer

<43> CONT.

code. The mathematical model and equations are described in IBC 17151, BEAC -- A Radiological Safety Analysis Computer Program, by S.L. Costen and W.S. Horton, dated May 1966. The program computes the potential radiological doses resulting from either a continuous or instantaneous release of radioactive fission products to the atmosphere. The doses considered are cloud gamma, depositive gamma, ingestion, and inhalation. They are based upon the release of up to 450 isotopes, the relative abundance of each isotope being dependent upon the operating history of the nuclear reactor under consideration. The program is divided into the following five major categories.

(1) Core -- The fission product inventory generated for a given set of reactor operating conditions. (2) Cloud Gamma Dose -- The external gamma dose received as a consequence of exposure to airborne radioactive materials. (3) Depositive Gamma Dose -- The external gamma dose received as a consequence of exposure to deposited fission products. (4) Inhalation Dose -- The internal dose to one of nine critical organs received as a consequence of inhaling airborne radioactive materials, and (5) Ingestion Dose -- The internal dose to one of nine critical organs received as a consequence of ingesting radioactive materials. This report constitutes a user's guide for a later version of the code written for the next part in FCBTBAV IV for the IBM 7040. With the exception of input options, input and output format changes, the addition of an option for calculation of the horizontal and vertical diffusion coefficients using Fomquist's parameters, and the inclusion of building turbulence effects, this version is the same as the original (machine language) version. The mathematical models and calculations are the same as described in IBC-17151 and are not described in this report. (Auth) (FOM)

A user-supplied multiplier is needed in order to convert the inhalation dose to an ingestion dose.

<44>

Wachay, T.F.; Ely, J.F., Jr., Calculation of Radiological Consequences Using IBMPC Computer Program

1974, February. GAI-TB-1011; 210 pp. Gilbert Associates Incorporated, 525 Lancaster Avenue, Reading, PA 19603

IBMPC 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 or 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 containment(s) 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 term 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.

<45>

Plato, P.A.; Benker, E.F.; Bauer, W., Computer Model for the Prediction of the Dispersion of Airborne Radioactive Pollutants

1967. Health Physics, 13, 1197-1215 (University of Miami, School of Medicine, Miami, FL)

Presented are two computer programs written for an IBM 1601/7040 digital computer in a FORTRAN IV computer language. The programs are called PAES and APADS, acronyms for Radiological Atmospheric Dispersion Study and Alternate PAES, 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 670 points throughout an observation area surrounding the smoke source, allowing contour lines of equal concentrations to be drawn. The PAES 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 APADS 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. (Auth)

<46>

Plato, P.A.; Benker, E.F.; Bauer, W., Some Examples and Limitations of the PAES and APADS Computer Programs

1969. Health Physics, 16, 383-391 (University of Miami School of Medicine, Miami, FL 33152)

Computer programs dealing with the prediction of the dispersion of airborne radioactive pollutants have already been written. Continued use of these programs has shown the flexibility of these programs, as well as some of their weaknesses. Presented in this paper are examples of both conditions. The PAES program predicts the path of smoke from the source to one of the boundaries of the observation area. The APADS program uses

<65> CONT.

average meteorological conditions to predict the air concentrations resulting from long term releases of a nuclear power plant. Both PARS and PARS programs have proved to be extremely flexible in their handling of various sizes of observation areas. To further improve the flexibility of PARS, additional work is needed to allow it to differentiate between turning and convecting conditions and to handle the condition of wind calm. (Auth) (J71)

<67>

Wong, P., A Fortran Program to Determine Absorbed Organ Dose Due to Inhalation of Radionuclides

1967, January. CSDBE-22-67-7; 106 pp. (U.S. Naval Radiological Defense Laboratory, San Francisco, CA 94135)

A FORTRAN computer program has been developed to determine the various internal doses 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 123 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. (Auth)

<68>

Clarke, B.S., The WEIBEL Program for Assessing the Radiological Consequences of Airborne Effluents from Nuclear Installations.

1975. Health Physics, 25, 267-288 (Central Electricity Generating Board, Berkeley Nuclear Laboratories, Berkeley, Gloucestershire, England)

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 behaviour 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. WEIBEL then

evaluates the inhalation and the cloud beta doses, while integration over the volume of the plume leads to estimation of the cloud gamma exposure. WEIBEL is written in FORTRAN IV (IV) and execution on the IBM 370/160 computer requiring 150 Kbytes of fast core storage. Execution times vary with the degree of precision requested in the cloud gamma dose, but typically doses and exposures may be evaluated at the rate of 100 observation points per minute. (Auth)

A time-dependent code for atmospheric dispersion and dosimetry used extensively in the United Kingdom for environmental assessment is presented.

<69>

Valliquet, P.G., ARES, A Code for Acute Aerosol Inhalation Exposure Calculations

1976. Health Physics, 19, 827-832 (Health Services Laboratory, U.S. Atomic Energy Commission, Idaho Falls, ID)

ARES 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 Foe (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. (Auth)

<70>

Specht, E.; Martin, C.; Otter, J.H.; Hart, B., Description of the COMBAT-22 Code

1975, February. TI-001-130-048; 113 pp. (Atomic International Division, Rockwell International, Canoga Park, CA)

The COMBAT-22 (Containment and Radiology of environmental Accidents 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 isothermic 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 (including 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

(70) CONT.

to solve the leakage (as well as containment region failure) and decay chains. The meteorology model is "as of tonight". Factors are given in this document for computing lateral flows with the ICFP-2 or the TGL "New Lag" models. The cloud mass flow is obtained by integrating over an anisotropic Gaussian cloud. The external beta dose calculation assumes a semi-infinite radioactive cloud. This code represents a modification of the earlier COMBUST code. (auth) (09)

(71)

Orishi, V.; Johnson, P.A.; Pace, J.C.; Valley, L.L., Studies of Columbia River Water Quality, Development of Mathematical Models for Sediment and Radionuclide Transport Analysis

1976, January. ERL-2-472; 42 pp. (Pavlovic, Pacific Northwest Laboratories, Richland, WA 99322)

The program undertaken by ERL to study the water quality of the Columbia River consists of two separate requests: (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 sediment 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 Peavy Dam for the initial sensitivity analysis. In addition, three 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. For the Temperature Analysis Program, river water temperature data supplied by the U.S. Geological Survey for six EDA-sponsored temperature recording stations have been analyzed and cataloged on storage devices associated with EDA's CDC 6600 located at Richland, Washington. These models may be used to study the transport of radionuclides routinely or accidentally released from a nuclear reactor. (auth) (215)

Contains a description of two different 2-D transport models, the names of which were obtained via private communication with V. Orishi. PETRA 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. SPARTAN 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 SDS 11/05.

(72)

Staro, G.V.; Gendell, L.L., Regional Effluent Dispersion Calculations Considering Spatial and Temporal Meteorological Variations

1976, May. ERL 2-48; 67 pp. (Air Resources Laboratories, National Oceanic and Atmospheric Administration, Idaho Falls, ID)

An objective regional trajectory analysis scheme has been combined with a Gaussian diffusion model to yield a technique called

"REGION" (mesoscale diffusion). The trajectory analysis scheme utilized wind data from a network of tower-mounted wind sensors to consider the effects of spatial variations of horizontal wind flow near the surface, incorporated time changes in rates of diffusion, and used an upper level list to vertical mixing. The REGION calculations of total integrated concentrations were compared with corresponding conventional calculations, using wind rose joint frequency statistics (single wind roses). Comparisons were made within a region about 175 by 150 km, and for time spans from 4 hr to 1 yr. The diagnostic comparisons of regional dispersion effects from each technique showed significant differences over the range of scales considered. Effluent reentrainments and stagnations, related to local wind variations about terrain features, were believed to produce localized zones of enhanced exposure to airborne effluents. These zones were not resolved by the conventional wind rose model. For short or accidental type of emissions, the greatest shortcoming of the single wind-station dispersion model was its failure to identify, when applied within a region of spatially variable winds, the subregion which would be affected. At distances beyond about 25 to 50 km, the wind rose model calculations were significantly biased to overestimation of annual total integrated concentrations by about an order of magnitude. The inability of the wind rose model to accommodate time changes in stability category during effluent transport to the more distant receptors was the single most influential factor of this bias. Current usage of the wind rose technique for regional dispersion calculations, especially at the larger distances, incorporates some systematic bias in the evaluations. These shortcomings are points of concern and should be recognized with whatever impact assessment schemes are to be utilized within the mesoscale or regional domain. (auth)

(73)

Fletcher, J.P.; Betson, W.L.; Johnson, L.L.; Betson, P.L., Modeling the Regional Transport of Radionuclides in a Water United States River Basin

1973. COM-73060-4; EPA-56-172/06; Environmental Behavior of Radionuclides Released in the Nuclear Industry, Proceedings of a Symposium held in Aix-les-Bains, France, May 14-18, 1973, pp. 445-446 (Hanford Engineering Development Laboratory, Richland, WA; Tennessee Valley Authority, Knoxville, TN)

A comprehensive study of the radiological implications of large-scale use of nuclear power generation, addressed to the Tennessee-Cumberland River Basins in the year 2000, is being undertaken. In the course of this study computer modelling techniques have been developed to evaluate the movement of radionuclides, by water and air transport, from points of release at a large number of plant sites and to calculate patterns of radionuclide concentration throughout the region of study. Air transport calculations utilize a modification of the bivariate normal equation, with the vertical parameter sigma(z) characterized as a function of distance from the source, stability and mixing layer depth. Local variations in air flow caused by major terrain features are modelled. Deposition of the airborne radionuclides by wet and dry precipitation processes is accounted for and the concentrations of deposited radionuclides are

(73) CCOT.

calculated. The model uses contributions from all sources to provide resultant patterns of concentrations of airborne and deposited radionuclides, including contributions from radionuclides in solution and attached to sediments. Effects of flow stratification and sediment trapping in reservoirs are considered. The solution of air-deposited radionuclides and their subsequent transport in ground and surface waters are modeled. Computational routines are provided for simulating radionuclide transport in each stream in the basin and for calculating the resultant concentrations in solution and associated with resuspended and deposited sediments. Together, the air and water transport models are designed to calculate regional patterns of radionuclide concentrations in the environment that result from the operation of nuclear facilities in a region. These concentration patterns can then be applied to the evaluation of radiological dose to man. (Auth)

(74)

Cowan, F.E.; Booth, B.S.; Fish, E.B.; Seyler, H.E.; Witherspoon, J.E.; Siegel, G.P.; Wilkie, H.B., Methods of Estimating Dose to Man from Regional Growth of Nuclear Power

1973. CCOT-73C03-4; EPA-447-272-87; Environmental Behavior of Radionuclides Released in the Nuclear Industry, Proceedings of a Symposium held at Aix-les-Bains, France, May 16-18, 1973, pp. 867-882. (Cat Ridge National Laboratory, Oak Ridge, TN; Tennessee Valley Authority, Muscle Shoals, TN; Tennessee Valley Authority, Chattanooga, TN; Hanford Engineering Development Laboratory, Richland, WA)

In co-operation with the United States Atomic Energy Commission (USAE), the Cat Ridge National Laboratory (CNRL), the Tennessee Valley Authority (TVA), the Atmospheric Turbulence and Diffusion Laboratory-National Oceanographic and Atmospheric Administration (ATDL-NOAA), and the Hanford Engineering Development Laboratory (HEDL) have undertaken a joint study of the potential radiological impact of an expanding nuclear power program on the Tennessee Valley basin (TVB). The TVB study involves an appraisal of the generation, management, and control of radioactive effluents from nuclear facilities in the region to the year 2000. Consideration is given to nuclear power requirements to the year 2000 and sites for nuclear facilities, to radionuclides that may be released and their transport in air and water and concentration in terrestrial and aquatic systems, and to the estimation and interpretation of the potential dose to man. This is the second region study initiated by the USAE in the continental United States of America, the first considering the region defined as the Upper Mississippi River Basin (URB). A computer model known as REBRES (Hanford Engineering Regional Model for Environmental Studies) was developed by HEDL and applied in the TVB study. The model permits estimates, on a regional basis, of the potential radiation dose that may be received by individuals and population groups as a result of radioactive materials estimated to be released from reactors and fuel reprocessing plants. Modifications in REBRES are discussed within the context of the uniqueness of the TVB and additions or improvements based on the initial application of REBRES. The paper, one of three companion reports, includes information on the data requirements and the components of REBRES concerned with the estimation of dose to man

from internal and external intake of exposure. (Auth)

(75)

Goliat, J.W.; Baker, D.B.; Bailey, J.F., Applications of a General Computational Model for Composite Environmental Radiation Doses

1973. EPA/447-272-82; EPA-447-272-82; Environmental Behavior of Radionuclides Released in the Nuclear Industry, Proceedings of a Symposium held at Aix-les-Bains, France, May 16-18, 1973, 19 pp. (Battelle, Pacific Northwest Laboratories, Richland, WA)

A mathematical model for calculation of a large potential-personne initial computer of regional radiation dose resulting from large-scale use of nuclear energy was previously developed and reported. This general model has now been subdivided 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 facilities, body organs, and pathways from which radiation doses are to be calculated. They include at the present time: approximately 100 radionuclides, including transuranics; doses to whole body, skin, bone, lungs, thyroid, and gastrointestinal tract; sub-programs for direct submergence, inhalation of radionuclides other than radionuclides (resuspension of deposited radionuclides is not included), ingestion of water and aquatic foodstuffs along with external dose from water and sediments, ingestion of irrigated crops, thyroid dose from inhalation and ingestion of irrigated crops, thyroid dose from inhalation, and ingestion and dose to aquatic biota can also be calculated. Dose factors in the programs for the various media-radionuclide-crop 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 computerized model has been the calculation for the U.S. Atomic Energy Commission of 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. (Auth)

(76)

Jotson, V.L., A Regional Air Transport Model for Radiological Dose Studies

1973. CCOT-73C01-2; HEDL-SA-476; Realism in Environmental Control, Proceedings of the Nineteenth Annual Technical Meeting and Equipment Exposition of the Institute of Environmental Sciences, held at Anaheim, CA, April 2-6, 1973 (Hanford Engineering Development Laboratory, Richland, WA)

A computer code, REBRES, 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. The radionuclide air

<76> GUY.

transport models. AS188, of the code is described. The three types of data used include: source to receptor travel distance; effluent source rate and concentration characteristics; and meteorological variables including wind speed and direction, atmospheric stability, mixing depth, and precipitation characteristics. (C)

<77>

Sedemann, J.P., Comparison of Mathematical Models for Calculation of External Gamma Dose from Originating from Release of Radioactivity to the Atmosphere

1976, July. BIR-2-1724; 176 pp. (Danish Atomic Energy Commission, Sinoe Research Establishment)

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 GDC5, which is an implementation of a gamma dose model developed at Birc. Good agreement was found between GDC5 and seven other models, one of which was experimentally verified within a downward distance of a few kilometers. Estimated gamma doses from unit releases of fourteen noble gases and iodines for two weather categories (Pausill types D and F), and with three different release heights (0.28 and 100 meters) calculated with four of the models (including GDC5), are given tabularly and graphically for values of downward distance from 0.1 to 5.0 kilometers. (Auth)

<78>

Siehaus, P., Long-Term Aspects of the Environmental Burden from Energy Production: CO₂ and H₂

1975, February. Ph. D. Thesis; 161 pp. (Technische Hochschule, Aachen, West Germany)

Carbon dioxide and tritium emissions from fossil or nuclear power plants were studied. The analysis for possible effects of alternative strategies to meet future energy demand on the temperature of the atmosphere depends on the mathematical model of the global carbon dioxide cycle which uses nonlinear differential equations. Is there have to be substitutives of fossil power plants by nuclear facilities another model was constructed to simulate the water cycle of the northern and southern hemispheres by which it is possible to compute the effects of tritium emissions in the future. (Auth)

Extensive bibliography contains 189 references

<79>

Artemova, B.E., Methods for the Calculation and Prediction of Contamination of Close-to-Ground Air Layers by Stack Emission of Nuclear Power Plants

1976, May. Archiv fuer Energiewirtschaft, 28(10), 503-512 (Not given)

Two fast methods are described which are suitable for the practical calculation of air pollution, the Serren-Pasquill method

introduced by the British Atomic Energy Commission and a Gaussian model to calculate the air pollution due to industry. The advantages and disadvantages of both methods are comparatively explained with experimental data. (C)

<80>

Abilene, T.B., Peck, R.P., Transport Modeling in the Environment Using the Discrete-Parcel-Random-Walk Approach

1976, April. Modeling, Proceedings of the Environmental Protection Agency Conference held at Cincinnati, OH, April 1976, 4 pp. (Pavellie, Pacific Northwest Laboratories, Richland, WA)

When formulating a mathematical model for simulating transport processes in the environment, the system of interest can be viewed as a collection 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 random random walk concept is used for 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 computer 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. (Auth)

Communication with one of the authors revealed that there are actually two distinct codes, i.e., one for ground water transport (DPRWGW) and one for surface water transport (DPRWSC). The last two letters stand for "coastal reactors," the original application of the code. These codes are written in FORTRAN IV for a PDP11/45 computer. Core requirements are 42K bytes. The codes are overlaid. Data requirements are 20 million words. Data are sequenced and stored on disk.

<81>

Shih, C.S.; Glynn, E.P., Radioactivity Transport in Water - Mathematical Model for the Transport of Radionuclides

1967, June. ERI-66-6702; CRR-19; 179 pp. (Center for Research in Water Resources, University of Texas at Austin, Austin, TX 78712)

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 on transport. Instantaneous release of dye and continuous release of Sr85, 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 Sr85 into the model river provided data for establishing the relationship between the analytical solution and a proposed mathematical model.

(82) COG2.

Further studies were conducted for the analysis of source specific dispersion coefficients, and transport estimates. One of the important factors affecting the transport of fission products in the model were studied. The more important coefficients were found to increase with increased velocity. High uptake of fission products may be provided by increased turbulence and the presence of an electric field. An experimental relationship was established between the Sherwood's number and the Reynolds number for the model system (83).

This code may be applied to accident or routine releases. It was written in FORTRAN 65 for a CDC 3600 computer.

(83)

Harford, R. L., Buntick, W. E., Cope, R. E., Case Techniques for Estimating the Results of the Estimation of Radiactive Effluent from CSBL Stacks

1976, October. CSBL-76-107; 177 pp. (Oak Ridge National Laboratory, Oak Ridge, TN 37831)

The basic purpose of this report is to delineate a procedure for determining (a) the maximum possible release rates for each of the five stacks at CSBL under normal operating conditions, and (b) the consequences of the inadvertent release of a relatively large quantity of radioactive material from one of the stacks. For routine releases a Gaussian dispersion model is used with the "mix" and "mix-stability category climatology" for CSBL to calculate the annual average stack dilution factor for each stack and for each of 16 wind directions. This is done by the computer program CSBL1. The information is combined with the stack release rate to insure that the annual average ground-level concentration due to all stacks at the controlled area facility does not exceed the various permissible concentration. Holland's formula for plume rise is used to correct the stack height for the initial velocity of the stack effluent and corrections are applied for the presence of an inversion. For accidental releases the release is of a short duration and the meteorological conditions are assumed to be known and to remain constant throughout the release. The program CSBL2 uses the Gaussian dispersion model to calculate (a) the ground-level stack-dilution factors along the plume centerline, and (b) the coordinates of the isopleths of constant, given stack-dilution factors. Calculations are compared with measurements at 5 sampling points around CSBL. (84)

(85)

Venzel, E. B., A Computer Code to Calculate Doses Resulting from Releases of Radionuclides to the Atmosphere

1976, July. CSBL-76C702; Proceedings of the 1976 Annual Meeting of the Health Physics Society, held in Houston, Texas, July 7-11, 1976 (Allied Chemical Corporation, Idaho Falls, ID 83404)

The Radiological Safety Analysis Computer Code (RSAC) is used to calculate the radiological consequences of the release of radionuclides to the atmosphere. A revised version of the code, RSAC-2, can be used to calculate (1) fission product inventory source terms, (2) lung doses using either the clearance model developed by the ICRP Task Group on Lung Dynamics or the ICRP Committee II model, (3) gastrointestinal tract doses

using either the model developed by Dolphin and Evans or the ICRP Committee II model, (4) doses to various internal organs using biokinetic models of the ICRP Committee II, (5) skin and bone marrow doses, and (6) thyroid gland doses using either a "simple" model or the "age-dependent" model. RSAC2 is a versatile code written in FORTRAN 65 for the CDC 3600 computer. Significant features and typical results of the code are presented. (86)

(86)

Case, R. L., The Internal Dosimetry, A. J. Fraumeni, Jr., Radiological Dose Rate from a Radioactive Cloud and Associated Parameters for Nuclear Safety

1976, March. Forsberg Atomic Research, (87), (88) (Not listed)

A program for calculating the external dose rate from a radioactive cloud was written in FORTRAN language (translated 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 dispersion and modifications. The numerical integration was performed using the Legendre-Gauss quadrature technique together with the polar coordinate system developed by E. C. Hansen. The time required for the integration was found around forty minutes on the CDC-3600 computer. The typical results from the program are shown in graphical form putting emphasis on the safety of the persons in the vicinity of a nuclear ship. To help the discussion, the results from the usual method of evaluation based on the assumption of infinitely spread cloud are also presented. Thus, the most safety factors involved in the conventional analysis are easily estimated as functions of downwind distance. For example, the actual finite cloud dose for the meteorological category 2 is lower than that computed for the infinite cloud by a factor of approximately 75 at 1000 downwind distance, and by a factor of approximately 2 even as far from the stack as 15 km. Another important result of the calculation is the remarkable discrepancy between the inside and the outside concentration lines at distances close to the stack. It must be remembered, however, that the basic equation for the region was made by extrapolating the available data. For this reason, the results may be considered as a measure for estimating the safety factors involved in the conventional analysis. (89)

(89)

Stecher, E., Estimation of Population Losses from a Nuclear Power Plant During Normal Operation

1975, July. DTSC-W-1809; 162 pp. (Danish Atomic Energy Commission, Bisco Research Establishment)

A model is presented for estimation of the potential air submergence and inhalation radiation doses to people located within a distance of 1000 km from a nuclear power plant during normal operation. The model was used to calculate these doses for people living 200 to 1000 km from a hypothetical nuclear power facility sited near the geographical center of Denmark. Two sources of radioactivity considered include the unit release of 15 isotopes of noble gases and iodines and liquid effluent releases from two types of 1000 MWe light water power reactors (SWR and SWR). Parameter variations were made and analyzed in order to obtain a better understanding of the mechanisms of the model.

(85) 1987.

Atmospheric dispersion was calculated using a Gaussian plume model corrected for dry deposition, wet deposition, and radioactive decay. (Auth) (CNS)

This document is based to a large extent on a number of U.S.A.R. reports and models, such as P2PRTS.

(86)

Vocke, E. Prediction Methods of Concentration Fields of Radionuclides and Radiation Doses in the Environment of Nuclear Power Plants with Extraordinary Emissions

1973, April. GSI-TR-11-1073; 37 pp. (Technische Universität of Hannover, Germany)

The radiative risks from radionuclides from nuclear power plant waste storage and leaks are estimated. Currently used methods and formulas are listed and discussed. The formulas are evaluated in form of diagrams concerning the direct radiation out of the reactor, the core area and gamma radiation from the exhaust air plume, the exposure due to the inhalation of contaminated air, and the radiation from radioactive deposits. (CP)

(87)

Plachy, V.; Fubik, I.; Horavsek, J. General Model for Evaluating Transport of Radioactive Products Released to Environment and its Consequences

Not given. IRI-HP-867; pp. 268-274 (Vyschny Gata Instytut, Jaroslava Boharica, Czechoslovakia)

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 in the main protective barriers of nuclear power plants. A block diagram is presented of the model and the respective main programs are characterized. (IRIS)

(89)

Acso, G.P.; DeCris, E.J.; Wilcox, T.P.; Witham, J.R., RISC: Radiological Inhalation Safety Code for IBM 7090

1963, June. Transactions of the American Nuclear Society, 6, 106-107 (Aerojet)

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, lung, 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 source, 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 accident power excursions at stationary power plants, vehicle launch or test facilities, and from in-flight vehicles. The basic diffusion theory of G.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 capillary temperature inversion are determined in the program from a subroutine applicable for low-altitude releases. Also, the reflection of the cloud source material due to weather and dry fallout may be taken into account by executing a separate option. The radionuclide source terms for each of 17 specified positions fourfold are also computed in a subroutine which considers specific fissile and decay times. This part of the program also permits dose normalization so that the output is in terms of Rem/Year or Rem/Ru. (CNS)

(89)

Lee, E.; Park, E.; Sedgley, D.B., GADOSH and DISE - Programs to Calculate Environmental Consequences of Radioactivity Release

1964, April. GA-1117; 62 pp. (General Atomic, San Diego, CA 92134)

GADOSH 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 diffusion, fallout, and transport. The companion program DISE is also available to include the effects of a time dependent accidental fissile 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 118 isotopes requires approximately 4 computations of IBM 7044 machine time for the basic GADOSH program. The program was written specifically for the High-Temperature Gas-cooled Reactor (HTGR) type of plant. (Auth)

(90)

Couchman, W.L.; DeGazio, A.W.; Fio, Y.C., WUSSE-1, A Nuclear Pocket Safety Evaluation Code for the Control Data 3600

1966, December. WU-190; 242 pp. (Nuclear Utility Services, Inc., Washington, DC)

The WUSSE-1 Code evaluates the radiation hazards resulting from the rapid release of fission products from a nuclear rocket engine. WUSSE-1 is programmed in FORTRAN 3600 for use on a CONTROL DATA 3600. WUSSE-1 requires 64K memory. Six tapes are used in addition to those required by the SCOPY Monitor System. A library tape containing nuclear and atmospheric diffusion data is necessary for the operation of the code. The library tape generation routine and the library data are described in Appendix Y. The program determines several different doses at positions down- and cross-wind from the point of the excursion. This program considers only a release occurring in the lower atmosphere (or near the ground). The code has several options which permit selection of the kinds of doses to be calculated. The models and parameters employed are believed to represent the best information available at the time of preparation. It is anticipated that the models and parameters may change as the nuclear rocket program matures and the WUSSE-1 code is designed for ready replacement of models or parameters as better information becomes available. (Auth)

 

the BTE Program for Effective Performance. The BTE Computer graphics assist for the purpose of obtaining the effective elements shared by internal body parts that are interconnected of individual direct performance, isolated and internal to a body part. The internal body parts are shared in the program are shared, first, performance, first, second, and third. The results are presented at the end of the performance of the program with the following data. The program creates a diagram of the body parts, showing whether the main elements are directly with a particular body part, and suggest effective elements. The average of the main elements, the individual body parts, and the individual body parts for each element of a body part are presented in the program for the program. (BTE)

Reffner, John Taylor, John Porter, John A.
Reverend - (Catholic) John T. Porter, John A.
Reverend - (Catholic) John T. Porter, John A.

The Air Resources Laboratory has developed a computerized performance trajectory model inserted routinely for calculating the transport, diffusion, and transformation of effluents of chemical and radioactive materials. Research on a year of trajectories at 1-hourly time intervals may be calculated forward or backward in time from any point in the Northern Hemisphere for distances up to 5000 miles. Trajectory concentrations are winds at any altitude above sea level or winds averaged through any desired layer above average terrain. Computer output includes a history of individual trajectory and points after selected iterations, plotted trajectories for any desired geographic or other boundary or Polar stereographic projections, and plotted maps showing percent frequency of trajectory reversals over grid squares. A Gaussian plume model is combined with the trajectory model to calculate long-term (monthly, or yearly, annual) near 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) near ground-level air concentrations for selected sampling statistics. Computer output includes plotted maps showing long-term concentrations and deposition amounts, and tables of short-term concentrations above the concentrations from individual plumes are identified. (Open)

Isotson, B.L.; Fletcher, J.F., *Neohelminthological Aspects of the Year 2000: Parasitological Study*

[illegible][illegible]

the 1990s, the number of people in the world who are under 15 years of age is expected to increase from 1.1 billion to 1.5 billion. The number of people aged 65 and over is expected to increase from 200 million to 400 million. The number of people aged 15 and over is expected to increase from 3.5 billion to 4.5 billion. The number of people aged 15 and over is expected to increase from 3.5 billion to 4.5 billion. The number of people aged 15 and over is expected to increase from 3.5 billion to 4.5 billion.

The first step in the derivation of the model is the identification of the variables that are relevant to the problem. In this case, the variables are the number of people in the population, the number of people who are infected, and the number of people who are recovered. The second step is to write down the equations that describe the dynamics of the system. These equations are based on the assumption that the population is well-mixed, meaning that every individual has an equal chance of coming into contact with any other individual. The third step is to solve the equations. This can be done analytically, but it is often more difficult than it sounds. The fourth step is to interpret the results. This involves understanding what the numbers mean in the context of the problem.

This code can be applied to confidential or routine releases. It was added in February of 1974 to the 1974 revision.

Yakovlev, G. I.; Valovskiy, V. I.; Vlasovskiy, E. I., 1970-
A Program for Calculation of Ionospheric
Dispersion of Activities from Geomagnetic Index
Reactions

<95> OOST.

1975. 2:2-144; 30 pp. (Chada Borbe, Pilsen, Czechoslovakia)

This paper gives a description of the programmes RTTC-B (reactor-crash outflows) and RTTC-B (operational outflow statistics). A complete list of the used formulae for both cases based on the Pasquill-Gaussian model of the problem is given. 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. Lifting 5. Dispersion. 6. High stack (h is greater than or equal to 2.5h sub t), h = stack height, h sub b = building height. 7. Short stack (h sub b is less than h is less than 2.5h sub 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. 11. Statistical fluctuations of the wind direction for the case of reactor-crash outflow. For cases 6, 7, 8 a uniform system of formulae is used in contradiction to the American and German systems. A short description of that method is given in this paper. 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 programmes including this effect will be published later. The output of the programmes are the surface concentrations and the total deposition intensities. The programmes RTTC-B and RTTC-B are linked to a system of programmes solving the transport of activities or a nuclear power establishment. The link of the RTTC-programmes are the programmes DOSIS and INTERCOMP (to be published). (Auth) (JTE)

<96>

Martin, J.A., Jr.; Robbins, C.; Nelson, C.B.; Cousins, R.E., Jr.; Collier, B.A., A Computer Code (RVBDC) TO Calculate Population Doses from Radioactive Liquid Effluents and its Application to Nuclear Power Reactors of the Mississippi River Basin

1976, October. OBP/ERD-76-8; 86 pp. (U.S. Environmental Protection Agency, Office of Radiation Programs, Environmental Analysis Division, Washington, DC 20460)

A computer program RVBDC has been developed to calculate population doses due to releases of radionuclides into flowing streams. 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. A program manual for RVBDC is included in this report. RVBDC 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 discussed. (Auth)

<97>

O'Brien, K.; Sano, B.S., Absorbed Dose Rates in Humans from Exposure to Environmental Gamma Rays

1976. Transactions of the American Nuclear

Society, 19, 475-480 (U.S. Atomic Energy Commission, New York, NY)

The propagation of environmental gamma rays through the human body is accounted for by using the 3-D Monte-Carlo computer code DISCOS which is based on the NRD 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 DISCOS, the present 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. (JTE)

<98>

Petzer, R.G., Concentration Factors and Transport Models for Radionuclides in Aquatic Environments a Literature Report

1976, May. EPA-600/3-76-054; 56 pp. (Environmental Monitoring and Support Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Las Vegas, NV 89116)

The relative risks to man from radionuclides released to the environment depend heavily on their accumulation or concentration by aquatic organisms. The organisms which accumulate these radionuclides present in the environment may be useful as indicators for environmental monitoring purposes. In addition, these organisms may be directly in food chain pathways to human. Literature is reviewed and summarized in regard to biological concentration of radionuclides in freshwater and marine environments. Concentration factors for elements found in organisms are tabulated for plants, invertebrates, and fish in marine and freshwater environs. Literature is also reviewed on models developed to calculate the possible radiation dose delivered to humans from radionuclides released into aquatic environments. The model approaches summarized range from simple generalized forms which, at best, give order of magnitude estimates to detailed models for a specific area which may be used to guide waste discharge practices. (Auth)

<99>

Dionne, P.J.; Harrington, T.P., Digital Simulation of Two Models of the Biological Disposition of Inhaled Plutonium

1976, March. BNWL-B-462; 66 pp. (Battelle, Pacific Northwest Laboratories, Richland, WA 99352)

Two mathematical models which describe the retention and translocation of inhaled plutonium were simulated on BNWL's minicomputer system BISEVA. Equation parameters are obtained by matching the simulation to data gathered by several studies at BNWL. Interactive graphics techniques are described which facilitate the data fitting process. This document is meant to serve as a progress report on a continuing effort towards development of mathematical models to describe the disposition of inhaled plutonium. The tabular and graphical results found in the appendices of this report do not represent what we feel are the best possible data fits but only samples of output available from the model. At this time we

<99> CONT.

feel that additional model development will probably be required to test fit the data. (Auth)

<100>

Clarke, D.H.; Utting, D.E., Initial Estimates of Doses to Human Body Organs Following Acute Exposure to Radioactive Fission Products

1976, August. EC/B/81762; 122 pp. (Central Electricity Generating Board, Research and Development Department, Berkeley Nuclear Laboratories)

A method has been developed which evaluates the dose commitment to human body organs following a single acute exposure to radioactive fission products. In this report all the fission products from T₉₂ to T₁₄₁ 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 (M) for the IBM 360/75 and is called SAORCH. The calculations that have been performed for this report are the first results obtained with SAORCH 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. (Auth)

<101>

Reynon, S.H., A Guide to the Use of the Cedric Program for Radioactive Dose Calculations

1972, September. BD/B/82294; 27 pp. (Berkeley Nuclear Laboratories, Central Electricity Generating Board, United Kingdom)

CEDRIC is a Fortran IV(B) computer program which evaluates dose distributions throughout the organs of the human body, following intakes of radioactive isotopes via inhalation, ingestion, through a wound or by absorption through the skin. In this paper a complete description of the input data and program options are given, together with a comprehensive example. Details of the development of the CEDRIC compartment model and the method adopted for the solution of the differential equations have been described in the associated report, EC/B/82291. (Auth)

<102>

Clarke, D.H., A Users Guide to the WEFIE Program

1973, April. BD/B/82407; 53 pp. (Central Electricity Generating Board, Research Department, Berkeley Nuclear Laboratories)

A complete description is given of the input data requirements for the reactor safety analysis program WEFIE. Details are included that enable users abroad to compile the program and to create the library data sets used by WEFIE, and the procedure by which temporary modifications to any single library member may be made during a run are specified. Finally a complete test case is included, both input and output, to facilitate program testing on other computers. WEFIE is written in Fortran IV (level B) and is compiled under release 20.6,

CPT - 2 on the IBM 370/165 computer. A list of subroutines and functions required by the program is also included, together with a comprehensive description of the computer supplied functions for dealing with, the free format reading routine, suppression of error messages and assessing job execution times. (Auth)

<103>

Martin, J.A., Jr., Dose Modeling for Nuclear Facilities

1974, October. ENEC Publication (PDA) 74-0010; Radiation Control, Proceedings of the 6th Annual National Conference held at San Antonio, TX, April 29-May 2, 1974, pp. 274-280. (Office of Radiation Programs, Environmental Protection Agency)

The Environmental Protection Agency's Office of Radiation Programs is developing a computerized Comprehensive Dose Computational System (CDCS) to support its standard setting activities. Portions of CDCS will include environmental transport and dose models which will accept source terms as input and will calculate the movement of radionuclides from source to man to provide data on dose and health effects. One of these submodels of CDCS, a code called AIBEN, is the subject of this paper. This code calculates diffusion doses, ground depositions, and population doses resulting from atmospheric releases of radionuclides. Excellent correlations between field measurements and surveillance data and AIBEN model predictions have been observed. The use of a verified model such as AIBEN can be a cost-effective adjunct to a surveillance or monitoring program. It can also be used to obtain an overview of changes in the radiological quality of the environment due to nuclear fuel cycle operations. The code runs in about 20 seconds on an IBM 360 computer with a G level compiler and 190K storage. It is written in elementary FORTRAN and is extensively annotated, hopefully facilitating its use. (Auth)

<104>

Tucker, T.C.; Fields, D.E., Digital Topography, Calculation of Watershed Area and Slope

1976, April. CBRI/BSR/EATC-20; 52 pp. (Oak Ridge National Laboratory, Oak Ridge, TN 37830)

Some parameters needed in watershed simulation models are directly related to the topography of the watershed. Computer-assisted techniques have been developed which can determine watershed boundaries, area, and surface slope from location-elevation data read from contour maps or obtained by more direct means. These techniques are applied to the Walker Branch Watershed. Digital topography will probably save neither time nor money unless applied to watersheds many times larger or more complex than Walker Branch and for which gridded elevation data already exist. The present application shows the importance of a pre-existing data base, since about 90% of the effort was devoted to obtaining the data base. Because some results were obtained while the computer codes were under development, an accurate account of man-hours required to obtain the results is not available. One computer run for the 101 by 89 grid used requires 290K bytes of core and less than 10 seconds CPU on the IBM 360/91. From our experiences in applying these codes to another watershed it is estimated that 3-5

<105> COBT.

runs, with less than one-half man-day per run required for setup, interpretation, and interaction, would probably suffice for a given application. The time is, of course, highly dependent upon the size and complexity of the watershed and, because manual elimination of false retention basins is used, the accuracy of the data base. Further development of these computer codes would allow determination of average length and slope of the overland flow plane and of the stream bed. It is unlikely that the stream cross section can be determined by such digital techniques without an increase in data density of one or two orders of magnitude. (JTE)

<106>

Scilly, C.E.; Guirasso, W.L., Jr.; Washington, P.B., Hydrodynamic Transport of Radionuclides: One-Dimensional Case with Two-Dimensional Approximation

1971, September. NUC-1225-174; 97 p. (U.S. Atomic Energy Commission, Nevada Operations Office, Las Vegas, NV)

One-dimensional mathematical models of the transport and hydrodynamic dispersion of radionuclides in granular media are described. The mathematical formulation consists of the derivation of the transport equations and definition of 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 lateral dispersion solution for each of 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 lines of ground-water flow trajectories, and calculates the concentration field by summing the contributions from each cell. Computer programs to evaluate each of the solutions are presented in Appendices together with sample outputs and sufficient information to enable the reader to use them. (Auth)

<106>

Coper, B.E., Integrated Environmental Modeling System for Noble Gas Releases at the Savannah River Plant

1973. CONF-730915; Noble Gases, Stanley, B.E. and Moghissi, A.A. (Eds.), Proceedings of a Symposium on Noble Gases held in Las Vegas, NV, September 28 - 30, 1973, (pp. 175-191), 680 pp. (Savannah River Laboratory, Aiken, SC 29801)

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 estimated distribution of material assumed to be released as effluents 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 critical measurements, and are subsequently used to generate another library of 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 counties of interest (including noble gases). Multiple source points are considered within a single pass to obtain the integrated effects from all sources. The total man-rem exposure to the local population out to 100 km resulting from SRP operation is about 0.3% of that received from natural activity. The noble gases contribute about 11% of this fraction. Current efforts at SRP are directed toward improving the above methods, and toward applied research to develop, verify, and use techniques reliable out to several 100 km and beyond. (Auth) (JTE)

<107>

Treby, C.E.; Rantsev, P.P.; Poussin, R.B., Computer Codes and Data Available from the Radiation Shielding Information Center

1975. CONF-751106; Radiation Physics, Proceedings of the International Symposium held at Calcutta, India, November 20-December 4, 1974, 5 pp. (Oak Ridge National Laboratory, Oak Ridge, TN 37830)

The Radiation Shielding Information Center (RSIC) is a technical institute serving the international shielding community. It acquires, selects, stores, retrieves, evaluates, analyzes, synthesizes, and disseminates information on shielding and ionizing radiation transport. The major activities include: (1) operating a computer-based information system and answering inquiries on radiation analysis, (2) collecting, checking out, packaging, and distributing large computer codes, and evaluated and processed data libraries. The data packages include multigroup coupled neutron-gamma-ray cross sections and terms coefficients, other nuclear data, and radiation transport benchmark problem results. (Auth)

<108>

Brownell, G.S.; Alpert, W.M., Use of Computers to Calculate Radiation Dose from Metabolic Models

1973, October. International Congress Series Number 339, (Part 2); Radiology, Proceedings of the Thirteenth International Congress held at Madrid, Spain, October 15-20, 1973, pp. 521-527 (Physics Research Laboratory, Massachusetts General Hospital, Boston, MA)

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

<108> COMB.

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 models. 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. The calculations involved in these operations are described. (JTE)

<109>

Sawyer, D.S.; Jordan, D.F.; Eline, J.B., Dynamic Model of Water Movement in Soil Under Various Climatological Conditions

1971. CCBF-750809; Tritium, McQuinn, A.A. and Carter, R.W. (Eds.) (University of Puerto Rico at Mayaguez, Mayaguez, Puerto Rico; Puerto Rico Nuclear Center, Mayaguez, Puerto Rico; Argonne National Laboratory, Argonne, IL)

A study was conducted to ascertain if a previously developed kinetic equation ecosystem model (NEEA) 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 the tritium between the observed data and the prediction. For example, the peak concentration after 76 days was predicted to be at 18 cm in depth and to have a value of 3.10×10^3 dpm/ml. This compares well with an observed peak of between 25 cm and 30 cm and a concentration of 10 ± 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 ecosystem. 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 (either in a tropical rain forest soil or, possibly, a grassland 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, NEEA, appears to be sufficiently general to give satisfactory predictions of water movement in a tropical rain forest, grasslands and desert soil. (JTE)

<110>

Shearer, D.L.; Minott, D.B.; Nilst, G.B., Development of Vertical Dispersion Coefficients for Rolling Terrain Environments

1977, January. TBC-000-8026-1; 120 pp. (The

Research Corporation of New England, Wethersfield, CT 06094)

Data from US 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 comprise total dispersion. Derived coefficients are representative of 10 minute sampling time, and are compared with Pasquill-Gifford dispersion coefficients for flat terrain. (S)

The program is written in Fortran IV (S) compiler for the IBM and Basic Fortran for the Univac 90/10 CS 3.5. Extensive documentation is presented.

<111>

Bailey, R.B., BETA: A Computer Program for Calculating Beta-Dose Rates From Point and Plane Sources

1973, August. E5/2/8 2763; 82 pp. (Central Electricity Generating Board, Berkeley Nuclear Laboratories, United Kingdom)

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. (auth)

Extensive Documentation is presented. The program is written in Q/S 770, Fortran IV (R).

<112>

Buchner, R.P.; Hayes, D.W., Pollutant Transport in Wetland Systems

1975, April. CCBF 750413 (Part 2); Computational Methods in Nuclear Engineering, Proceedings of the Conference held at Charleston, South Carolina, April 15-17, 1975, pp. 123-139 (Savannah River Laboratory, Aiken, SC 29801)

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. (auth)

Partial documentation is presented. No description of the code is included.

<113>

Baker, D.A., User Guide for Computer Program FOOD

1977, February. EHWL-2209; 34 pp. (Battelle, Pacific Northwest Laboratories, Richland, WA)

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99:12)

An interactive code, FPCF, has been written in BASIC for the IBM/PC 1100 to facilitate calculation of internal radiation doses to man from radionuclides in food products. In the dose model, vegetation may be contaminated by either air or irrigation water containing radionuclides. The model considers two mechanisms for radionuclide contamination of vegetation: 1) direct deposition on leaves and 2) uptake from soil through the root system. The user may select up to 16 food categories with corresponding consumption rates, grazing patterns and either irrigation rates or atmospheric deposition rates. These foods include various kinds of produce, grains and animal products. At present, doses may be calculated for the total body and six internal organs from 146 radionuclides. Some variables can be displayed at the local terminal. Further details on percent contributions to dose by nuclide and by food type are available from an auxiliary high-speed printer. This output also includes estimated radionuclide concentrations in soil, plants and animal products. (Auth)

Extensive Documentation is presented. This is part of RESRAD model.

<116>

Kirkegaard, P.; Lovberg, L., Computer Modelling of Terrestrial Gamma-Radiation Fields

1978, September. Disc-303; 80 pp. (Danish Atomic Energy Commission Research Establishment, Birc, Denmark)

The plane, one-dimensional photon transport equations is considered in the case of two adjacent media, where one media 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-P sub 1 approximation, involving separate treatments of the upstreaning and the downstreaning flux, and a numerical method for solution of the corresponding equations 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 neutron 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. (Auth)

Program written in Fortran for the P 6700 (Danish Computer Installation at Birc).
Extensive documentation is presented.

<115>

Franklin, A.R., A Transient, Two-Dimensional, Discrete-Element, Far-Field Model for Thermal Impact Analysis of Nuclear Plant Discharges in Coastal and Offshore Regions. Part 1: General Description of the Mathematical Model and the Results of an Application

1975, February. (SOL 8902; 146 pp. Oak Ridge National Laboratory, Oak Ridge, TN 37830)

A far-field mathematical model is presented for aperiodic simulation of short-time (within tidal cycle) transient, two-dimensional temperature distributions in large coastal and offshore regions resulting from the condenser cooling water discharges of power plants. The Telerian FIDDE (fluid-in-discrete-element) formulation employs the integral form of the conservation principles for mass and thermal energy in variable-sized discrete elements that span the specified flow region. The contributions of vertical variations of the velocity components and temperature are rigorously incorporated in the development of depth-averaged, two-dimensional energy transport fluxes by spatially integrating the conservation equations over the enclosure surfaces of the discrete elements. The general mathematical formulation considers completely arbitrary, transient oceanic flow conditions, which include periodic tidal, geostrophic and wind-induced currents, as locally specified inputs to the model. The fundamental differences, both from physical and mathematical considerations, between meso-scale and micro-scale eddy turbulence, shear flow dispersion, and stratification are discussed in detail to establish a realistic formulation of depth-averaged, nonconvective thermal energy fluxes associated with the general turbulent transport phenomenon. The surface heat-transfer effect is formulated according to a short-wave model (hourly variations) which approximately incorporates solar irradiation, black body back radiation, evaporation, and convection modes for the conditions of the ocean surface in coastal and offshore regions. The resulting mathematical system of weakly coupled, nonlinear, ordinary differential equations is numerically integrated, from arbitrarily specified initial conditions, by the Runge-Kutta-Gill method with a time step size based on a stability criterion for explicit methods. The general mathematical model is applied to the assessment of the thermal impact of a hypothetical, salient generating station in a coastal region where the oceanic flow conditions are assumed to be strictly periodic tidal currents without any appreciable net drift of sufficient duration to remove the heated effluent out of the far-field region. The numerical simulation indicates that the periodic flow conditions cause considerable variations in the temperature distributions during the day and the tidal cycles, which result in severe recirculation and re-entrainment of the heated water between the intakes and the discharges of the different units. This thermal interaction effect ultimately leads to a gradual, long-term increase of the temperatures in the immediate vicinity of the discharge structures and also in the far-field zone, which could cause adverse environmental impact in the coastal region. It is concluded that steady-state near-field studies of the individual discharges are definitely inadequate, and a transient far-field analysis which considers the variations in oceanic flow conditions is essential for the realistic assessment of the thermal impact of a large nuclear power plant in a coastal or offshore region. (Auth)

Partial Documentation, contains graphical representation of a hypothetical example.

<116>

Strange, D.L.; Watson, E.C.; Kennedy, S.R.,

<116> CONT.

BEIC-A Computer Program for Estimating Health Effects from Inhalation and Ingestion of Radionuclides

1976, December. UCRL-2192; 148 pp. (Petrillo, Pacific Northwest Laboratories, Richland, WA 99122)

The computer program BEIC calculates the risk equivalence of damage from internally deposited radionuclides to damage from external whole-body irradiation. The calculation gives an estimate of the microcurie intake per radionuclide that would result in a risk equivalent to receiving 1 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 BEIC was taken from the computer program IACPIB, which uses the models of the respiratory tract adopted by the Task Group on Lung Dynamics. BEIC 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 radiative dose per microcurie intake by inhalation or ingestion to any of 23 organs and tissues. A maximum of 10 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 1 rem of external whole-body irradiation.

The program is written in Fortran for a CDC (CYBER) computer. Extensive documentation is presented.

<117>

Lange, P.; Dickerson, H.H.; Petersen, H.B.; Sherman, C.A.; Sullivan, T.J., Particle-in-Cell vs Straight-Line Airflow Gaussian Calculations of Concentration and Deposition of Airborne Particles out to 70 km for two Sites of Differing Meteorological and Topographical Character

1976, Oct. UCRL-52123; 67 pp. (Lawrence Livermore Laboratory, Livermore, CA 94550)

Two numerical models for the calculation of air concentration and ground deposition of airborne effluent releases are compared. The Particle-in-Cell (PIC) model and the Straight-Line Airflow Gaussian model were used for the simulation. Two sites were selected for comparison: the Hudson River Valley, New York, and the area around the Savannah River Plant, South Carolina. Input for the models was synthesized from meteorological data gathered in previous studies by various investigators. It was found that the PIC model more closely simulated the three-dimensional effects of the meteorology and topography. Overall, the Gaussian model calculated higher concentrations under stable conditions with better agreement between the two methods during neutral to unstable conditions. In addition, because of its consideration of exposure from the retarding plume after flow reversal, the PIC model calculated air concentrations over larger areas than did the Gaussian model. (Auth)

ASPIC code is described in UCRL 7617 (1975, May), UCRL 51662 (1973, Oct.) and UCRL 76170 Rev. 1 (1975 Oct.).

<118>

Wagel, G.; Papadogiannis, D., WOLGA 1, A Fortran IV Program for Calculation of the Gamma-Dose Rate from Radioactive Effluent Air Released by one or several Continuously Emitting Sources

1975, October. CBST-22-6159; 878-2189; 22 pp. (Gesellschaft für Nuclear Research mbH, Karlsruhe, Germany)

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 direction 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 (KfK), 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. (Auth)

The program is written in Fortran IV for the IBM/370-168. Extensive Documentation is presented.

<119>

Gill, C.F., A Computer Technique for Calculating the Radiological Consequences of Pressurized Water Reactor Power Plant Hypothetical Accidents

1975. Ph.D. Thesis, Engineering Department (University of Missouri-Rolla, Department of Mechanical Engineering, Rolla, MO)

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, D0SE5, 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 D0SE5, 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 D0SE5 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. (Auth)

Specific accidents are analyzed. D0SE5 is

<119> CCST.

not described as to the computer required or input language. Partial documentation is presented.

<120>

Levin, J.P., A Two-Dimensional Transport Model of the Atmosphere

1976. Ph.D. Thesis, Department of Astrophysics (University of Colorado, Boulder, CO 80502)

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 fifteen kilometers. 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 fissioner-135 from low latitude United States nuclear tests, and Zirconium-95 from high latitude Chinese nuclear tests. The overall distribution of the tracers, their rate of spreading, the rate of decrease of the surface 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 nitric and nitric oxides are computed in the stratosphere. (Auth)

The model has been computerized using a CDC 7600 computer but no details of the program are listed. Partial documentation is presented.

<121>

Watson, S.B.; Snyder, W.S.; Ford, E.B., TINED: A Computer Program for Calculating Cumulated Activity of a Radionuclide in the Organs of the Human Body at a Given Time, t, After Deposition

1976, Dec.. ORNL/CSD/TN-17; 150 pp. (Oak Ridge National Laboratory, Oak Ridge, TN 37830)

TINED is a computer program designed to calculate cumulated activity in the various source organs at some time t after deposition. TINED 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 112 K core storage for execution. (Auth)

Extensive documentation is presented

<122>

Wong, L.F.; Acta, D.W., A Generalized Air Quality Assessment Model for Air Force Operations - An Operator's Guide

1976, July. AFML-78-74-5a; 80 pp. (Argonne National Laboratory, Argonne, IL 60439)

The Energy and Environmental Division of Argonne National Laboratory has developed a set of computer programs under contract to the United States Air Force Weapons Laboratory. This package is designed to serve as a generalized model that can be used to assess the impact of Air Force operations on the air environment at the air base level. This report is a user's manual for these computer programs and as such outlines the overall flow of the programs, the links between programs and the input data required to implement each program. This document is intended to provide detailed instructions as to input flow and act to supply technical or scientific basis. A companion document subtitled, "Phase 1 Technical Report" discussed the modeling theory and methods. This is one of 5 reports, with the final report not yet completed. The computer program is operated by the Environmental Technical Applications Center, U.S. Air Force, Building 159, Navy Yard Annex, Washington, DC. (Auth) (US)

No listing of language or computer is included, however extensive instructions are given. Radioactivity is not included in the discussion.

<123>

Erskan, A.W.; Patterson, M.P.; et al, Development of a Unified Transport Approach for the Assessment of Power Plant Impact

1977, March. CSNL/NEDEC/TN-99; 87 pp. (Oak Ridge National Laboratory, Oak Ridge, TN 37832)

Progress during the first 18 months in implementation of the Unified Transport Approach (UTA) is summarized in this report, which covers the period through December 1976. The goal of this project is to develop mathematical models 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 work is funded by the Health and Environmental Research Branch of Nuclear Regulatory Research in the U.S. Nuclear Regulatory Commission. Development and validation of these models are illustrated in applications at several sites where data is 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 containment 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

<123> CONT.

Intensive quantities that depend on basic flow properties, which can be obtained from a chosen set of data for density, barometry, and meteorology that must be prepared only once. The formulas and calculations are based on a stable set of algorithms that have been tested and proven valid. The user can then focus on understanding and interpreting thermal, chemical, or radiological transport results with confidence that the basic calculations are direct, efficient, and meaningful. Recent work in each of the three areas is described. (Auth)

This program is written in Fortran IV for the CDC-6600. Complete documentation is presented.

<124>

Willoughby, G.G., 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

1977, May. ORNL-5260; 86 pp. (Oak Ridge National Laboratory, Oak Ridge, TN 37830)

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 Con/arc System Modeling Program III (MSMP III) simulation language, is presented. The model treats the ocean as a diffusive region with respect to vertical transport of carbon, and the nonlinear variation of CO_2 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 CO_2 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. (Auth)

Extensive documentation is presented. The program is written in IBM-CONARC III simulation language for the IBM/360.

<125>

Sternan, C.A., A Base-Consistent Model for Wind Fields over Complex Terrain

1976, December. UCRL-76172 Rev. 2; 34 pp. (Lawrence Livermore Laboratory, Livermore, CA 94550)

An adjustment model was developed to provide a pollutant transport model with input wind fields that are base-consistent, three-dimensional, and also representative of

the available meteorological measurements. Interpolated three-dimensional mass winds were adjusted in a weighted least-squares sense to satisfy the continuity equation within the volume specified. The upper and lateral boundaries above topography were assumed to be open and thus allowed mass flow through the boundaries. The bottom boundary was determined by the topographic elevations of the area being studied. The topographic boundary was assumed to be solid. (Auth)

<126>

Lang, R., ADPIC - A Three-Dimensional Particle-in-Cell Model for the Dispersion of Atmospheric Pollutants and Its Application to Regional Tracer Studies

1976, October. UCRL-76170 Rev. 2; 37 pp. (Lawrence Livermore Laboratory, Livermore, CA 94550)

A hybrid Lagrangian-Eulerian atmospheric transport-diffusion model was developed to calculate the three-dimensional distribution of atmospheric pollutants in transient-region flow fields. This Atmospheric Diffusion Particle-in-Cell (ADPIC) code was validated against several existing closed-form analytical solutions including a puff release in steady, unidirectional shear flow, and a puff release with scale-dependent horizontal and vertical eddy diffusion coefficients. These tests showed that the ADPIC results were within a 4 percent error when compared to the analytic solutions. Regional tracer studies at the National Reactor Test Station Idaho Falls, Idaho, and at the Savannah River Laboratory, Aiken, South Carolina, were also used to compare the code against field measurements. (Auth)

See ADPIC, UCRL-51462 also UCRL-76171. Use no citations from this report.

<127>

Wendell, L.L., Program Descriptions, Supplement to Mesoscale Wind Fields and Transport Estimates Determined from a Network of Wind Towers

1976, May. NOAA-TN-ESL-ABL-83; 66 pp. (Air Resources Laboratories, Idaho Falls, ID)

A computer program has been developed to analyze objectively two-dimensional wind data from a mesoscale network of stations. The result is a graphic display of the network wind field at any particular time and a plot of computed air trajectories as a function of time and point of origin. A brief description, a list of input variables, and program listings for the computer program are provided. (Auth)

This report refers to work in NOAA-TN-ESL-ABL-2 as does NOAA-TN-ESL-ABL-84 (NESDIT). Extensive documentation is presented.

<128>

Bider, J.L.; Beal, S.K., A Model to Estimate the Local Radiation Dose to Man from the Atmospheric Release of Radionuclides

1977, April. WAPL-TN-1273; 36 pp. (Bettis Atomic Power Laboratory, West Mifflin, PA)

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

<128> CCST.

model considers dose components resulting from ingestion in the plane, ingestion of contaminated food, inhalation of gaseous and suspended radioactivity, and exposure to ground deposits. The dose components 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. (Auth)

Partial documentation

<129>

Tecaro-Isellarte, G., A Numerical Model for the Study of Dispersion of Radioactive Pollutants in Air

1974. COMF-731110; IAEA-SM-307/27: Physical Behavior of Radioactive Contaminants in the Atmosphere, a conference held in Vienna, Austria, Nov. 12-16, 1973 (pp. 311-318), 222 pp. *Interatomic Radioattività Ambientale*, CNEN-CIS Casaccia, Rome, Italy)

A method is described for 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 synoptological features in the area examined. The model makes it possible to study the particular cases of various concentration and to determine, on the basis of the various permissible concentrations in air, the various 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 EURS of the Comitato Nazionale per l'Energia Nucleare, Savigliano, Italy. In particular, the various dischargeable amounts of Pu 239, R3 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. (Auth)

The program is written in FORTRAN IV for the IBM 360/44. Partial documentation is presented.

<130>

Kaiser, G.L., A Guide to the Use of TIRION-A Computer Program for the Calculation of the Consequences of Releasing Radioactive Material to the Atmosphere

1976, November. SDD B 62; 45 pp. (United Kingdom Atomic Energy Authority, Safety and Reliability Directorate)

A brief description is given of the contents

of TIRION, which is a computer program that has been written for use in calculations of the consequences of releasing radioactive material to the atmosphere. This is followed by a section devoted to an account of the control and data cards that make up the input to TIRION. (Auth)

PORTMAN DISLEY ILL 4-72

<131>

Bladon, L.J.; Van Eyme, G.W., Evaluation of a Digital Computer Method for Analysis of Compartmental Models of Ecological Systems

1964, February. CML-78-2418; 44 pp. (College of Forestry and Natural Resources, Colorado State University, Fort Collins, CO)

This report presents results of development and testing of a PORTMAN program for exploration and analysis of data from experiments in which the system may be depicted by a compartment model. Both real and artificial data were used to check for rate and type of convergence toward the minimum sum of squares of deviations of observed from predicted data values for each compartment. Data with known degree and kind of error were generated to simulate various degrees of noise encountered in real biological data. Results of these computer studies are presented in graphic and tabular form, limitations of the program are discussed, and program and subroutine listings with directions for use are given in appendices. (Auth)

The program is written in FORTRAN 63 for the CDC 6400 and 1600, and in FORTRAN IV for the IBM 360/75 and 7090. Extensive documentation is presented.

<132>

Not Given, The Colne River Simulation Model

1972, August. HETI-THE 72-103; 79 pp. (Manford Engineering Development Laboratory, P.O. Box 1970, Rickland, SA 99352)

The COLNEAT river simulation model has been used primarily to simulate water temperatures in a flowing stream. However, the mathematical model, originally developed to estimate the effect on the Columbia of the Hanford Production reactors, has been formulated and structured in such a manner that it can be used to simulate the behavior of pollutants other than waste heat. Testing and application of the model to "real world" situations has prompted development of specialized routines to include provisions for handling transient flow, reverse flow, diffusional transport and density currents. The model has been tested under a variety of conditions and has given excellent results. Contained within this report are discussions of the underlying theory, the development of the computer model, the results of various model tests, and a brief user's guide. (Auth)

The program is written in FORTRAN IV for the UNIVAC 1108. Extensive documentation is presented.

<133>

Sorensen, W., Computer Simulation of Iodine-131 Transfer from Fallout to Man

1974, September. Inter. Air, Soil Pollut., 4, 65-87 (Niels Bohr Institute, University of Copenhagen, Blegdassevej 17, Copenhagen, Denmark)

<137> CCOT.

A compartment model has been constructed to depict the principal routes of ^{131}I transfer from fallout to man. Thyroid accumulation and excretion have been modeled 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 northern Scandinavia.

<138>

Buang, T.C., Review and Development of Aerosol Analytical Methods

1976, September. CERN-14107; 84 pp. (Purdue Research Reactor Department, General Electric Co., Sunnyvale, CA 94084)

Recently developed aerosol behavior codes such as HAA-1, HAA-2 and the modified HAA-3E with spray removal were reviewed. The most significant modifications incorporated in these models were evaluated to determine their adequacy of INPUS's safety analyses. A sensitivity analysis was performed to study the direct relationship between radiological doses calculated by the CCOTAFIX code and arbitrarily selected input parameters to the HAA-1 code. Doses calculated by using clean-up factors from HAA-1 were compared to those calculated from HAA-3E. A preliminary model and associated computer code (GASP) were developed to assess the attenuation of aerosols in leakage paths. The GASP 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. The input instructions, sample problems and program listing for the GASP code are presented. (auth)

Input to CCOTAFIX.

<139>

Lynn, B.B., BAHN: A System of Computer Programs for Radionuclide Pathway Analysis Calculations

1976, September. AECL-5527; 30 pp. (Atomic Energy of Canada Limited, Whiteshell Nuclear Research Establishment, Pinawa, Manitoba R0X 1L0)

A generalized system of computer programs, designated BAHN (Radionuclide Materials Management) system, has been developed to assist in the analysis of the movement of radionuclides through the environment to man. BAHN 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 homogeneous. 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 metre 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. (B3)

<140>

Valent, G.D., A Guide to the Use of TIDIC - A Computer Program for the Calculation of the Consequences of Releasing Radioactive Material to the Atmosphere

1976, November. EEC B 62; 67 pp. (United Kingdom Atomic Energy Authority, Bignhall Lane, Culcheth Wirral, Merseyside, Wirral, Merseyside)

A brief description is given of the contents of TIDIC, which is a computer program that has been written for use in calculations of the consequences of releasing radioactive material to the atmosphere. This is followed by a section devoted to an account of the control and data cards that make up the input to TIDIC. (auth)

The program is written in Fortran for the Plessey ICL 4-72. It is partially documented.

<141>

Onishi, Y., Mathematical Simulation of Sediment and Radionuclide Transport in the Columbia River

1977, August. ENEC-2228; 93 pp. (Battelle, Pacific Northwest Laboratories, Richland, WA 99352)

Mathematical simulation of radionuclide transport was conducted by applying the finite element sediment and constituent transport model, SESTRA, to the Columbia River between the Priest Rapids and McNary Dam near the 190A Sanford Reservation. Model computations were performed to solve time-dependent, longitudinal and vertical distributions of sediments and radionuclides by taking into account sediment-radionuclide interaction. Sediment transport was modeled for three sediment size fractions (i.e., sand, silt and clay), and radionuclide transport was simulated for dissolved and particulate nuclides. Particulate radionuclides were analyzed for those adsorbed by sediment in each sediment size fraction. Five cases were simulated in this study to identify the effects of river sediments on radionuclide migration: (1) continuous release of Zr^{95} without adsorption mechanisms (2) continuous release of Zr^{95} with adsorption (3) instantaneous release of Zr^{95} without adsorption (4) instantaneous release of Zr^{95} with adsorption (5) radionuclide resuspension. Sediment and radionuclide results of the verification test case, Case 2, indicate very good agreement with measured data. It was revealed that particulate Zr^{95} concentrations increase from 0 to 70% of the total radionuclide concentrations within approximately 80 km downstream from the Sanford reactors. Nuclide concentrations associated with clay sediment are approximately three times higher than those attached to silt because of clay's greater cation exchange capacity. Sand adsorbs the least amount of nuclides among the sediments. Further downstream, particulate nuclide concentrations are reduced because contaminated suspended sediments were deposited in the river bed in the slow moving area. This resulted in the total Zr^{95} concentrations in this area for Case 2 being only 25 to 50% of those for Case 1. Similar results were obtained for the other cases. The present study demonstrates that the SESTRA code is capable of predicting the transport of both particulate and dissolved radionuclides by taking into account the radionuclide-sediment interaction. However, complete verification of the model is required before reliable predictions can be made concerning the migration of radionuclides

<137> CCMT.

and contaminated sediments within river systems. (25) (272)

See also ERM 8-47 and ERM-2227. The language in ERM 19, the code is partially documented in this report.

<138>

Partridge, J.E.; Broadway, J.A.; Phillips, C.D.; Wadham, S.I.; Dolack, C.L., Air Pathway Exposure Model Validation Study at the Sarcinelle Nuclear Generating Plant

1976, September. EPA 520/5-76-017; 26 pp.
(Eastern Environmental Radiation Facility, PO Box 1009, Montgomery, AL 36109; E.E. Environmental Protection Agency, Waterside Hall Bldg, 401 N Street SE, Washington, DC 20460)

The primary objective of this study was to validate the CPM mathematical model (AIDEM) for estimating radiative exposures due to atmospheric radioactive releases. This validation was to be accomplished by comparing the model prediction with actual field measurements. The field measurements were made using geonitronized ionization chambers and thermoluminescent dosimeters. The predictions obtained using the AIDEM model were also compared to the predictions of several other existing models. For three models AIDEM, AIDEM-51, and ERM, the mean predicted/measured exposure ratios for external exposure were 1.25, 1.29, and 1.26, respectively, and standard errors of the means were less than 0.3. The use of the short-term accident code ACMA did result in markedly increased error. In summary, based on the assumption of actually distributed data, the model AIDEM demonstrated the predicted/measured exposure ratio closest to unity. Use of this or other similar models for predicting external exposures has been shown to be quite acceptable for most applications. Further studies in this area should emphasize extending the analysis to a wider range of distances from the release point. Furthermore, analysis of particulate from a source having a higher release rate should be included. The usefulness of PIC's for making low-level exposure measurements was demonstrated by this study. The ability of this instrument to accurately measure exposure rates of a few 10/hr above natural background was clearly evident. The results of this study exhibit the ability of this type TID to accurately measure total environmental exposures in the range of a few mR per month. However, the ability to accurately measure an increase of 5 mR per year above natural background is questionable. This is due to difficulty in determining the natural background portion of the total exposure. The method used to account for natural background in this study is not as desirable or accurate as an extended (1 to 2 years) preoperational survey. Unless seasonal and other variations in natural background can be accurately determined, it will be impossible to measure facility contributions in the range of 5-10 mR/year with this type TID. It is the low cost involved the TID's might serve as an integral portion of an external radiation monitoring system including both TID's and PIC's. (25)

For AIDEM see EPA-520/5-76-004.

<139>

Pitchie, L.T.; Brown, W.D.; Wayland, J.E., Effects of Rainstorm and Runoff on Consequences

of Nuclear Reactor Accidents

1976, October. SAND-76-0419; 30 pp. (Sandia Laboratory, Albuquerque, NM 87115)

A preliminary model describing the effects of rainstorm and runoff on the consequences of a nuclear reactor accident is presented. The most important new features of this stratified model relative to the model in SAND-7607 is the spatial structure of rainstorm and runoff consisting of four levels of rain activity that are characterized by rain gauge data. The predicted concentrations of radioactivity and resultant health consequences of the stratified model are compared with those of the model in SAND-7607 for simplified rainstorm 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 SAND-7607 model. The differences between the predictions of the two models are small for the stratified sample run. (auth)

Partial documentation is given. Changes in the model used in SAND-7607 (CCMT) are described.

<140>

Robertson, J.B., Numerical Modeling of Subsurface Radioactive Solute Transport from Waste-Seepage Ponds at the Idaho National Engineering Laboratory

1977, January. EEO-22057; OSGS Open File Report 76-717; 69 pp. (U.S. Geological Survey)

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 (15m 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 convections, 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 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 "hop-scotch" 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. Although chloride and tritium reached the aquifer several years ago, the model analysis suggests that the more easily sorbed solutes, such as cesium 137 and strontium 90, would not reach the aquifer in detectable concentrations within 150 years for the conditions assumed. However, a change in chemistry or hydraulic

<100> CCBT.

conditions could increase the solubility of adsorbed heavy metals. Such changes might result from changes in waste disposal practices and effluent chemistry, flooding from the Big Lost River, or future irrigation activity. (Auth)

Partial documentation is reported.

<101>

Large, B., AEFIC - A Three-Dimensional Transport-Diffusion Model for the Disposal of Atmospheric Pollutants and its Validation against Regional Tracer Studies

1975, May. OGBL-76170 preprint; 22 pp. (Lawrence Livermore Laboratory, Livermore, CA)

A hybrid Lagrangian-Eulerian atmospheric transport-diffusion model has been developed and validated for the purpose of calculating the three-dimensional distribution of atmospheric pollutants in transient region flow fields. This code, AEFIC, has been validated against several existing closed form analytical solutions including a puff release in steady unidirectional shear flow, and a puff release with scale dependent horizontal and vertical eddy diffusion coefficients. These verification tests indicate that the AEFIC calculation method reproduced the standard deviation of the pollutant distribution within 5 percent. Regional tracer studies at WHT Idaho Falls, Idaho and Savannah River Laboratory, Aiken, South Carolina have also been used to validate the code against field measurements. (Auth)

<102>

Husro, J.F.; Huff, E.D., Corrections and Revisions to the FCBTAN IV Version of the Wisconsin Hydrologic Transport Model

1977, May. OGBL/HSP/EATC-25; 40 pp. (Oak Ridge National Laboratory, Oak Ridge, TN 37830)

Since publication of the WHTM user's manual in 1970, 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, incorporation of effects of forest litter on contaminant transport, corrections to include conservation of mass in the theoretical plate ion-exchange algorithm, reintroduction of ion-exchange processes in subsurface soils, and the inclusion of some diagnostic print options. A description of each change has been presented, together with a comprehensive example of the results obtained when the revised WHTM is used. Thus, this report updates older versions of the WHTM. (Auth)

WHTM uses Fortran IV language in an IBM 360 computer. The code is extensively documented in attached microfiche.

<103>

Patterson, B.D.; Husro, J.F.; Fields, D.Z.; Ellison, B.D.; Brooks, A.A.; Huff, E.D., A User's Manual for the Fortran IV Version of the Wisconsin Hydrologic Transport Model

1970, October. OGBL-HSP-EATC-7; EFWB-IEP-70-0; 252 pp. (Oak Ridge National Laboratory, Oak Ridge, TN 37830)

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 transfer watershed model and forms a major component of the Unified Transport Model being developed at OGBL. WHTM includes the hydrologic transport of a trace contaminant by entrainment in overland flow, infiltration, interflow 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 FCBTAN 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 360/50 computer in about four minutes. (Auth)

The WHTM uses Fortran IV language in an IBM 360 computer. The code is extensively documented.

<104>

Baynon, S.W., A Guide to the Use of the CEDRIC Program for Radioactive Dose Calculations

1972, September. EC/E/R 2290; 27 pp. (Berkeley Nuclear Laboratories, Central Electricity Generating Board, Cited Kingdom)

CEDRIC is a Fortran IV(M) computer program which evaluates dose distributions throughout the organs of the human body, following intakes of radioactive isotopes via inhalation, ingestion, through a wound or by absorption through the skin. In this paper a complete description of the input data and program options are given, together with a comprehensive example. Details of the development of the CEDRIC compartment model and the method adopted for the solution of the differential equations have been described in the associated report, EC/E/R2291. (Auth)

CEDRIC uses FCBTAN IV(M) language in an IBM 370 computer. Partial documentation is presented in EC/E/R2291 and in this report.

<105>

Clarke, P.H.; Dittig, D.Z., Initial Estimates of Doses in Human Body Organs Following Acute Exposure to Radioactive Fission Products

1970, August. EC/E/R1752; 122 pp. (Berkeley Nuclear Laboratories, Research and Development Department, Central Electricity Generating Board, United Kingdom)

A method has been developed which evaluates the dose commitment to human body organs following a single acute exposure to radioactive fission products. In this report all the fission products from ^{235}U to ^{137}Cs 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(M) for the IBM 360/75 and is called SAUROF. The calculations that have been performed for this report are the first results obtained with SAUROF for use in reactor safety assessment programs. Although

(10b) CONT.

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. (Auth)

Fortran IV(IV) is the language used for the IBM 340/7 computer. The program is extensively documented.

(10c)

Ruff, D.L.; Lumsden, D.J.; Pasht, J.P.; Regehr, C.L. TERN: A Terrestrial Ecophysiology Hydrology Model

1977, April. NAPS-74-0; GAO/NSF/ENR-77; 147 pp. (Oak Ridge National Laboratory, Oak Ridge, TN 37830)

The terrestrial ecophysiology hydrology model (TERN) combines 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 TERN 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 TERN. In all cases, emphasis has been placed on objective, physically based methods. When simulations of interception loss, soil moisture content, and base flow and stem 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.

is presented. The TERN 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 TERN represents an important step forward in establishment of an objective framework for the study of terrestrial ecosystems.

Fortran IV is the language and IBM 340/7 computer used is TERN. TERN is a part of TERN. Extensive documentation is included in attached microfiche.

(10d)

Rider, J.L.; Deal, L.H. A Model to Estimate the Local Radiation Dose to Man from the Atmospheric Release of Radionuclides (TUN Development Program)

1977, April. NAPS-78-1273; 16 pp. (Atomic Power Laboratory, Westinghouse, Bensenville, IL)

A model was developed to estimate the radiation dose constituents received by people in the vicinity of a facility that releases radionuclides into the atmosphere. This model considers dose constituents resulting from ingestion in the place, ingestion of contaminated food, inhalation of gaseous and suspended radioactivity, and exposure to ground deposits. The dose constituents 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. (Auth)

Partial documentation.

APPENDIX C. AUTHOR INDEX

AUTHOR INDEX

- Ablettree, S.W. 80
 Alcano, A. 2
 Algert, B.W. 100
 Arzo, C.F. 22
 Armstrong, B.E. 90
 Artemova, B.E. 79
 Baca, B.G. 71
 Bailey, F.D. 111
 Baber, D.A. 15, 30, 75, 112
 Barish, J. 32
 Beal, S.F. 120, 147
 Bogovich, C.L. 106
 Bell, G.E. 22
 Peterson, B.F. 73
 Reynon, S.H. 101, 140
 Bistford, P.T. 22, 42
 Blaine, B.B. 53
 Bledsoe, L.J. 131
 Borton, I.L. 50
 Borne, J.S. 82
 Borth, B.S. 47, 50, 59, 70
 Brantel, I. 61
 Brasblett, R.L. 53
 Broadway, J.A. 130
 Bratta, B.B. 103
 Brown, W.E. 139
 Brewell, G.S. 100
 Buckner, B.E. 112
 Charak, I. 20
 Chester, B.C. 6
 Church, H.W. 39
 Clarke, F.W. 20, 60, 100, 102, 145
 Ccates, B.L. 62
 Ccavers, F.B. 36
 Cooper, B.E. 3, 23, 40, 106
 Cogo, B.W. 82
 Corley, J.F. 75
 Couchman, P.L. 90
 Cousins, B.E., Jr. 96
 Ccaver, F.T. 51, 70
 Cruz, P.D. 25
 Culikowski, W.W. 43
 Culliton, B.A. 96
 Cui, P.A. 11
 Dahman, B.C. 45
 Daniels, B.S. 52
 Daeer, W. 65, 66
 Davis, W.F. 21
 DeAgazio, A.W. 90
 DeBois, P.J. 80
 Dickerson, B.H. 117
 Dionne, P.J. 99
 Detmon, W.L. 13, 73, 76, 93
 Dequie, J.B. 1, 12
 Dunham, A.B. 56
 Eckert, B.J. 26
 Ellisen, P.E. 103
 Ellisen, T.W. 56
 Fly, R.F., Jr. 60
 Fogelmann, P.J. 21
 Franzen, A.H. 115, 123
 Fessington, F.H. 105
 Fortner, G.J. 92
 Fields, D.E. 100, 143
 Fish, B.W. 70
 Fletcher, J.F. 13, 73, 93
 Fcote, H.F. 90
 Fcrid, H.W. 121
 Fowler, P.G. 51
 Gill, C.F. 119
 Gloyne, E.P. 81, 90
 Gogolak, C.V. 17
 Guirasso, B.L., Jr. 105
 Haurick, T.F. 82
 Harrington, T.P. 99
 Harris, W.A. 37
 Hart, R. 70
 Hayes, D.W. 112
 Hedemann, J.P. 77
 Heffter, J.L. 92
 Heid, K.R. 57
 Heller, F. 60
 Hendrichsen, B.H. 41, 46
 Hilst, G.R. 110
 Hilty, E.L. 71
 Hladky, E. 87
 Hoenes, G.B. 15
 Helly, D.F. 105
 Horton, B.H. 62
 Bougros, J. 22
 Bcstaa, J.B. 23, 35, 57
 Huang, T.C. 130
 Rotachanan, V. 31
 Huff, B.D. 102, 103, 106
 Ito, T. 80
 Iyori, I. 80
 Joske, B.T. 52
 Johnson, P.A. 71
 Jordan, D.P. 109
 Kaiser, G.D. 130, 136
 Kou, F.D.K. 9, 32
 Kaya, S.V. 10, 20, 55, 59
 Kenfield, G.P. 37
 Kennedy, W.E. 116
 Killough, G.G. 9, 9, 120
 Kin, Y.S. 27, 90, 91
 Kirkegaard, P. 110
 Kline, J.P. 109
 Kolesewycz, B.G. 42
 Kubik, I. 87
 Lahn, W.R. 37
 Lauen, S.J. 29
 Lange, B. 30, 117, 126, 141
 Lee, E. 89
 Lewis, J.P. 120
 Icyborg, L. 110
 Luna, B.E. 39
 Luxmoore, R.J. 146
 Lyon, R.B. 135
 MacAdams, B.W. 37
 MacDonald, B.P. 40
 Mack, B.J. 49
 Mackay, T.P. 60
 Maslin, J.D. 106
 Martin, C. 70
 Martin, J.A., Jr. 11, 46, 103
 Parzullo, T. 61
 Maskevitz, B.F. 107
 Menker, D.P. 65, 6
 Mills, E.T. 45
 Minott, D.W. 110
 Moore, B.E. 19
 Moravoch, J. 87
 Murto, J.K. 102, 103

AUTHOR INDEX

- Begel, D. 31, 110
 Nelson, C.E. 11, 96, 138
 Biehans, V. 78
 Beichl, S. 85
 C'Brien, S. 97
 Clack, J.S. 85
 Celahi, V. 71, 137
 Citer, J.B. 36, 70
 Papadopoulos, D. 118
 Ferks, B.L. 82
 Fartridge, J.P. 138
 Fattelson, P.B. 83, 123, 182
 Fetter, D.C. 98
 Peterson, E.E. 73
 Feternot, W.P. 117
 Phillips, C.B. 138
 Flato, F.A. 65, 66
 Reeves, R. 1, 12, 51
 Bricados, W.A. 89
 Richardson, L.C. 63
 Fider, J.L. 128, 187
 Ditchie, L.S. 139
 Divard, J.R. 58
 Ebbins, C. 96
 Schertser, J.E. 180
 Dickinson, W.R. 38
 D'Amor, F.S. 5, 5, 20, 87, 58
 Egan, I. 61
 Ecto, D.R. 122
 Ecessia, B.W. 107
 Segendorf, J.V. 10
 Eanna, D.S. 97
 Easner, D.S. 109
 Eato, R. 88
 Eayer, W.B. 37
 Schikarski, W. 60
 Sedgley, E.E. 89
 Shearer, P.I. 110
 Sherman, C.B. 117, 125
 Shih, C.S. 81
 Siegel, G.B. 78
 Snyder, W.S. 74, 121
 Seldat, J.R. 8, 15, 38, 75
 Scanshous, J.C. 52
 Sorensen, B. 133
 Spangler, G.A. 89
 Spacht, E. 70
 Stallman, F.W. 8
 Starr, G.E. 72
 Steyn, J.J. 27
 Strong, E.L. 33, 38, 38, 46, 50, 116
 Sullivan, T.J. 117
 Taylor, A.E. 92
 Travis, J.B. 55
 Trebey, D.E. 18, 107
 Tucker, T.C. 108
 Turner, W.E. 5, 7, 20
 Tweten, D. 80
 Nitting, B.F. 100, 185
 Valente, V. 95
 Van Dyne, G.P. 131
 Veverka, O. 95
 Vlachovsky, V. 95
 Vcelz, E. 86
 Villique, F.G. 69
 Wanger, L.E. 122
 Watson, F.C. 33, 35, 46, 50, 116
 Watson, S.E. 121
 Watts, J.B. 16
 Weiland, J.P. 139
 WenJell, I.L. 72, 127
 Wenzel, D.B. 83
 Wickenhauser, A. 60
 Wilcox, T.F. 88
 Wilkie, W.W. 78
 Willie, C.A. 89
 Windham, S.T. 138
 Witherspoon, J.D. 78
 Withness, J.R. 81
 Wong, P. 67
 Yamaji, A. 88
 Zera, G. 61
 Zuccero-Labelarte, G. 129

APPENDIX D. KEYWORD INDEX

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SYNONYM INDEX

- ACCIDENTAL BREASTS 2, 5, 6, 7, 8,
9, 10, 11, 18, 20, 21, 22, 23,
24, 25, 26, 28, 29, 30, 32, 33,
34, 35, 36, 37, 38, 40, 41, 42,
44, 47, 48, 49, 50, 55, 56, 57,
58, 59, 60, 62, 63, 64, 65, 66,
70, 71, 72, 80, 81, 82, 83, 84,
88, 89, 90, 91, 92, 94, 95, 102,
119, 130, 134, 136, 139, 145
- ACBA 8
- ACBA-II 10
- AECIC 30, 117, 125, 126, 141
- ABIB 69
- AGE-DEPENDENCY 0, 5, 13, 20, 84,
93
- AIR SUSPENSION 2, 4, 7, 8, 11, 13,
14, 17, 18, 19, 20, 22, 23, 25,
26, 27, 31, 32, 35, 36, 37, 38,
41, 42, 44, 46, 50, 53, 55, 56,
60, 61, 62, 63, 64, 66, 67, 70,
74, 75, 76, 77, 83, 84, 85, 86,
88, 89, 90, 93, 100, 101, 102,
103, 106, 110, 119, 119, 147
- AIRCRAFT 119, 122
- AIRDOCS 19
- AIRER 11, 103, 130
- AIRER-SI 130
- AIRWAY 122, 147
- APPLICATOR 57, 76
- AIRIALS 13, 15, 16, 38, 58, 59,
121
- AQUADOD 47
- ABAC 130
- AREAS 65, 66
- AFCON 40
- ABCON 76
- ABDUC 15, 16, 38
- ASTPAN 4, 13, 73, 76
- ATH 43
- ATDCSPHERE 2, 3, 7, 8, 10, 11, 13,
15, 17, 18, 19, 21, 22, 23, 25,
26, 27, 28, 29, 30, 31, 32, 33,
35, 36, 37, 38, 39, 40, 41, 42,
43, 44, 45, 46, 48, 50, 51, 53,
54, 55, 56, 61, 62, 63, 64, 65,
66, 67, 68, 69, 70, 72, 73, 76,
77, 79, 82, 83, 84, 85, 86, 87,
88, 89, 90, 92, 93, 95, 102, 103,
104, 110, 117, 118, 120, 122,
125, 126, 127, 128, 129, 130,
134, 136, 139, 141, 147
- BIII 35
- BETA 111
- EIVAR 35
- CABCON 15, 120
- CABCON 14 73, 76
- CABCOCC 14
- CASTLE 15, 42
- CEBIC 24, 101, 144
- CPS-74 16
- CERICAL PCBH 137, 140, 142, 143,
145, 146
- CEROS 50
- CLOUD 2, 3, 8, 10, 11, 17, 18, 25,
27, 29, 32, 35, 36, 37, 38, 40,
44, 48, 49, 50, 53, 54, 55, 56,
60, 61, 62, 63, 64, 65, 66, 68,
70, 73, 75, 76, 77, 83, 84, 86,
89, 90, 92, 102, 106, 110, 118,
122, 147
- CLOUD CODE 54
- CCLRENT 52, 132
- CCBU 139
- COMPUTER CODE 1, 2, 3, 4, 5, 6, 7,
8, 9, 10, 11, 12, 13, 14, 15, 16,
17, 18, 19, 20, 21, 22, 23, 25,
26, 27, 28, 29, 30, 31, 32, 33,
34, 35, 36, 37, 38, 39, 40, 41,
42, 43, 44, 45, 46, 47, 49, 49,
50, 51, 52, 54, 55, 56, 57, 58,
59, 60, 61, 62, 63, 64, 66, 67,
70, 71, 72, 76, 77, 80, 81, 82,
83, 84, 86, 89, 90, 91, 92, 93,
94, 95, 96, 97, 99, 103, 104,
105, 107, 109, 110, 111, 112,
113, 114, 115, 116, 117, 118,
119, 121, 122, 123, 124, 125,
126, 127, 128, 129, 130, 131,
132, 133, 134, 135, 136, 137,
138, 139, 140, 141, 142, 143,
144, 145, 146, 147
- CONDALEX 49, 134
- CONDALEX-II 70
- CONDALEX-III 36
- CONSY2 121
- CONCENTRATION 65
- CCVSOL 129
- CCVS 13
- CBTR 34
- CENP III 124
- CURIE 37
- CURION 76
- DACHIN 32, 34, 116
- DEPOSITION 4, 68, 93, 112
- DIET 4, 13, 15, 16, 38, 58, 59,
61, 74, 93, 133
- DIPORT 39
- DISDOX 57
- DISPERSION 1, 2, 3, 8, 10, 11, 12,
13, 14, 17, 18, 19, 21, 22, 23,
25, 26, 28, 29, 30, 31, 32, 33,
35, 36, 37, 38, 39, 40, 41, 42,
43, 44, 45, 46, 48, 50, 51, 52,
53, 54, 55, 60, 61, 62, 63, 64,
65, 66, 70, 71, 72, 73, 76, 78,
79, 80, 81, 82, 83, 84, 85, 87,
88, 89, 90, 92, 93, 94, 95, 96,
98, 102, 103, 104, 106, 109, 110,
115, 117, 118, 120, 122, 125,
126, 127, 128, 129, 130, 134,
136, 138, 139, 141, 147
- DOSE 13, 37
- ECSE 2 56
- ECSES 119
- ECSET 49
- EPH 80
- EPHUCB 40
- EPHUCU 40
- FINISHING WATER 4, 13, 16, 39, 41,
75, 93, 94, 94
- EPI DEPOSITION 2, 11, 12, 15, 18,
19, 29, 30, 34, 35, 40, 41, 43,
44, 45, 51, 55, 60, 61, 62, 63,
73, 74, 85, 86, 89, 92, 93,
95, 103, 111, 124, 130, 136, 141
- ERIP 44
- REAL 3, 11
- ESDCSA 24
- ESDCSE 41
- EGAN 27
- EREN 20
- EPYER II 7
- EREN III 14
- EXTERNAL HYPOSPH 2, 3, 4, 6, 7,
8, 11, 13, 14, 17, 18, 19, 20,
22, 23, 25, 26, 27, 31, 32, 35,
36, 37, 38, 41, 42, 44, 46, 48,
50, 53, 56, 60, 61, 62, 63, 64,
68, 70, 74, 75, 76, 77, 83, 84,
85, 86, 89, 92, 93, 101, 102,
103, 104, 109, 111, 114, 119,
124, 128, 136, 139, 147
- FABOBT 115, 123
- PEOSE 50
- FETRA 71
- FISH 4, 13, 16, 47, 56, 90
- FISP 68
- FISSE 54
- FIIDE 115
- PCOB 4, 13, 15, 16, 38, 75, 100,
101, 113
- YCOD CHAIN 15, 38, 47, 58, 59, 61,
75, 90, 113, 133, 135
- PCPAGE 4, 13, 58, 74
- GADOSE 89
- GALP 134
- GAMP 114
- GASP IV 135
- GAUSSIAN DISTRIBUTION 2, 3, 8, 10,
11, 13, 17, 18, 19, 23, 24, 27,
28, 29, 31, 32, 33, 35, 36, 37,
38, 39, 40, 41, 43, 44, 45, 46,
48, 49, 50, 60, 61, 62, 63, 70,
72, 82, 84, 85, 88, 89, 90, 95,
110, 117, 130
- GDOX 77
- GENERAL MODELS 2, 4, 10, 13, 20,
30, 38, 52, 61, 65, 122, 123

SYNOPSIS INDEX

- GRASS 15, 50, 59, 123
 GPCDR 30
 GSCUD 1, 2, 4, 6, 7, 11, 12, 13, 14, 18, 19, 20, 30, 40, 51, 55, 62, 63, 68, 83
 GSCUD WATER 1, 12, 13, 73, 86, 93, 102, 109, 132, 140, 142, 143, 144
 GSCUD, SUBRELIN 61
 H-3 4, 15, 16, 19, 73, 76, 78
 HADON-1 120
 HADON-2 124
 HEDDS 4, 13, 36, 73, 74, 75, 76, 93, 113
 HEDDLOGIC TRANSPORT 100, 105, 109, 112, 123, 132, 135, 140, 142, 143, 144, 137, 139
 INDIVIDUALS 2, 4, 5, 11, 16, 18, 19, 20, 32, 38, 41, 42, 47, 48, 53, 54, 56, 57, 61, 67, 68, 75, 76, 80, 85, 91, 97, 98, 100, 101, 108, 111, 113, 119, 121
 IDECS 1 9
 IDECS 2 9
 IDECS 3 9
 INFORMATION 107
 INGESTION 4, 5, 6, 5, 13, 15, 16, 19, 20, 24, 32, 38, 42, 56, 59, 61, 67, 69, 74, 75, 93, 91, 93, 96, 98, 100, 101, 113, 116, 121, 141, 147
 INSULATION 2, 4, 5, 6, 8, 9, 11, 13, 18, 19, 20, 24, 25, 26, 29, 32, 33, 34, 36, 37, 38, 42, 44, 49, 53, 58, 59, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 74, 75, 76, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 93, 99, 100, 101, 102, 103, 104, 105, 106, 109, 121, 122, 130, 144, 145, 147
 IREX 64
 ISBN 5, 20, 50
 INTERNAL EXPOSURE 5, 6, 8, 9, 11, 13, 15, 20, 24, 25, 26, 29, 32, 34, 36, 37, 42, 44, 49, 53, 58, 59, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 74, 75, 82, 85, 86, 88, 89, 90, 91, 93, 97, 98, 99, 100, 101, 102, 103, 104, 108, 111, 113, 116, 119, 120, 128, 130, 136, 144, 145, 147
 ICEBER 15, 22, 29, 42, 61, 76, 77, 85, 119, 145
 ICEBER 131 133
 IRRIGATION 4, 13, 15, 61, 75, 113
 ISOLA II 31
 KECOTIC 35, 50
 KETPROB 19, 61, 73, 76
 KETPROB 05 129
 LIFE HABITS 4, 13, 36, 61, 74, 93, 113
 LCDIPS 112
 LER 4, 13
 MATH 122
 MATHEMATICAL MODELS 1, 3, 4, 5, 6, 7, 8, 9, 10, 14, 16, 17, 18, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 57, 58, 59, 60, 62, 63, 64, 65, 66, 67, 69, 70, 71, 72, 73, 77, 78, 79, 80, 81, 82, 93, 94, 95, 96, 97, 98, 99, 100, 102, 93, 94, 95, 96, 98, 99, 100, 104, 106, 108, 109, 110, 112, 115, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 132, 134, 137, 138, 139, 140, 142, 143, 146, 147
 MATHEN 125, 141
 MEASURES 110
 MEASUREMENT 92, 110, 112, 120, 137, 140
 MEAT 15, 50, 59, 113
 MESEA 109
 MESODIF 72
 METEC-H 95
 METEC-H 95
 PETRO-1 95
 MILK 4, 15, 30, 42, 50, 59, 113, 133
 MONDO 60
 MC102 26
 MOBILE GASES 17, 19, 73, 77, 85, 106, 119, 145
 MUSE 2
 MUSE-1 90
 MUS 91
 ODSNAC 123
 PARTICLE-DIFFUSION 21, 65, 66, 71, 80, 81, 94, 117, 126, 141
 PHYSICAL FORM 33, 41, 43, 137, 140
 PLANTS 4, 15, 50, 59, 81, 94, 131, 146
 PLUTONIUM 57, 76, 99, 129
 POPULATIONS 2, 4, 11, 13, 19, 20, 22, 30, 42, 50, 53, 61, 75, 85, 93, 94, 103, 106, 124, 136
 PUDRO 57
 RACER 46, 50
 RADIATION ROSE 5, 6, 7, 11
 RADIOACTIVE DECAY SCHEDULES 2, 6, 12, 14, 17, 18, 27, 28, 32, 35, 36, 37, 38, 41, 42, 47, 48, 53, 54, 56, 57, 61, 67, 68, 75, 76, 80, 85, 91, 97, 98, 100, 101, 108, 111, 113, 119, 121, 141, 147
 RADIOACTIVE DECAY SCHEDULES 46, 51, 62, 85, 95, 96, 101, 102, 147
 RADICOR 123
 RADIOS 23
 RADIS 65, 66
 RADTOD 123
 RADU 135
 REACTORS 6, 29, 30
 REDIG 116
 REDISTRIBUTION 55
 RELISH 82
 RESUSPENSION 43, 45, 55, 137
 REVIRE 24, 61, 98, 119, 120
 RISC 84
 RISK ASSESSMENT 135, 147
 RUCRUC 127
 ROUTINE DELAYS 3, 4, 5, 7, 9, 10, 11, 13, 14, 15, 16, 17, 19, 20, 21, 24, 25, 29, 30, 31, 33, 34, 39, 39, 42, 43, 47, 52, 51, 53, 56, 58, 59, 61, 62, 63, 65, 68, 71, 72, 74, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 91, 92, 93, 94, 95, 96, 98, 102, 103, 104, 124, 130, 136, 140
 RRR 130
 RSAC 62, 63, 83
 RSAC-2 83
 RYRDS 96
 SAMPLE PROBLEM 113, 116, 118, 121, 131, 132, 134, 142, 143, 146
 SARCOS 24, 190, 145
 SEDIMENT 4, 7, 38, 47, 61, 71, 73, 75, 81, 93, 94, 123, 137
 SEDORE 123
 SEP 10
 SERATRA 71, 137
 SHORE LINE 30
 SHORELINE 4, 13, 14, 20, 110, 115, 123
 SHW 101, 103, 106, 119, 144
 STARR 82
 STRAP II 22
 STROTIUM 81, 94
 SUBDOJA 35
 SURFACE WATER 7, 15, 16, 30, 38, 47, 52, 61, 71, 73, 75, 78, 80, 81, 87, 93, 94, 96, 98, 100, 112, 113, 115, 123, 131, 132, 133, 135, 137, 142, 143, 146
 TERN 146
 TERNOD 50, 59
 THUNDERHEAD 37

EXTENDED INDEX

TIME-DEPENDENCE 2, 10, 18, 20, 20,
26, 32, 33, 30, 40, 47, 52, 50,
56, 57, 58, 59, 62, 63, 68, 71,
72, 80, 81, 90, 110, 122, 126,
127, 132, 137, 141, 143

TINER 121

TINER 130, 136

TOPOGRAPHY 13, 30, 41, 72, 110,
117, 122, 126

TRANSPORT 137

TRANSDUCTIONS 12

TRITON 100, 105, 120, 140

TROUBLE 81

TROUBLE 10, 11, 01, 1, 25, 63,
60, 76, 110, 115, 11

UFA 123

UFA 100

UFGSCA 61

UFGSCA-CDS 61

UFGSCD-LI 61

UFGTICS 117, 131, 132, 133,
137, 130, 129, 140, 141, 146

VEGETABLES 0, 13, 15, 50, 59, 113

VERIFICATION 10, 17, 19, 20, 43,
45, 47, 50, 50, 59, 61, 72, 61,
62, 90, 105, 109, 110, 120, 131,
101

WASTE DISPOSAL 100

WATER SUPPLY 0, 7, 13, 10, 15,
20, 30, 61, 70, 92, 96, 123

WATER 20, 40

WATER DEPOSITION 2, 11, 13, 15, 18,
19, 21, 20, 29, 30, 43, 62, 63,
72, 76, 82, 80, 89, 92, 92, 92,
103, 113, 126, 139, 141

WATER 102, 103

WCLCA 1 110

WCLUES 101, 106

WCLC 23

WCLAB 0, 13, 73

WCLON 19, 61, 73, 76

WCLLES 6, 8

APPENDIX E. PUBLICATIONS DESCRIPTION INDEX

PUBLICATION DESCRIPTION INDEX

AKL-5527 135	CTC-8 7	IAEA-SB-100/36 64
APOL-29-70-50 122	DOE Publication (PDA) 70-0010 103	IAEA-SB-172/00 73
ANSE (5) 8 173 22	DE-85-74-126 16	IAEA-SB-172/01 70
Archiv fuer Energiewirtschaft, 20(196), 503-512 79	DE-1090 02	IAEA-SB-107/27 129
ATIS-TULL-1073 66	DE-1304 3	IAEA-SB-100/35 00
BBBL-B-240 50	ETPD-TDP-74-0 143	IAEA-SB-172/02 75
BBBL-B-351 35	ECPE/TDP-76-0 146	IDO-17151 62
BBBL-B-309 33	ECO-22057 100	ICC-17261 63
BBBL-B-309 SUPP 30	EME-00-6702 01	IBIS-07-007 07
BBBL-B-050 57	EME-12-67C3E 4-	International Congress Series Number 339, (Part 2) 109
BBBL-B-052 71	Environmental Behavior of Radionuclides Released in the Nuclear Industry, Proceedings of a Symposium held in Aix-en-Provence, France, May 10-18, 1973, pp. 009- 005 73	B-1752 20
BBBL-B-062 99		IASL-B-65 56
BBBL-B-69 06		IFK 2210 31
BBBL-SA-3929 0	Environmental Behavior of Radionuclides Released in the Nuclear Industry, Proceedings of a Symposium held in Aix-en-Provence, France, May 10-18, 1973, pp. 067- 002 70	IFK-2109 110
BBBL-SA-5523 15		IFK-653 60
BBBL-1302 52	Environmental Behavior of Radionuclides Released in the Nuclear Industry, Proceedings of a Symposium held in Aix-en-Provence, France, May 10-18, 1973, 19 pp. 75	IA-6035-85 55
BBBL-1750 30		Modeling, Proceedings of the Environmental Protection Agency Conference held in Cincinnati, OH, April 1976, 5 pp. 90
BBBL-2110 116		NAA-SB-0000 17
BBBL-2209 113		NAA-SB-9992 53
BBBL-2220 137		NCAA TR EPL APL-02 10
BBBL-001 21	FFA 520/5-76-015 130	NCAA-TR-EPL-APL-03 127
BBBL-0511 25	FFA-520/1-76-000 11	
BBBL-011 01	FFA-600/3-76-050 90	Noble Gases, Stanley, B.P. and Roghiani, A.A. (Eds.), Proceedings of a Symposium on Noble Gases held in Las Vegas, NV, September 20 - 28, 1973, (pp. 175-191), 600 pp. 106
CCC-213 10	FFL APL-00 72	NCT Given 02
Computational Methods in Nuclear Engineering, Proceedings of the Conference held at Charleston, SC, April 15-17, 1975, pp. 77-92 93	FFL APL-50 92	Nuclear Applications, 3, 203-206. 20
Computational Methods in Nuclear Engineering, Proceedings of the Conference held at Charleston, South Carolina, April 15-17, 1975, pp. 123-139 112	FFP 36004 60	NDS-156 91
CCDF-750012 (Part 2) 112	FFP707-061 60	NDS-100 90
CCDF-650007 2	Fission Product Release and Transport Under Accident Conditions, Proceedings of the International Symposium held at Oak Ridge, Tennessee, April 5-7, 1965, pp. 1000-1090, 1209 pp. 2	NDS-329 27
CCDF-710501 50	GP-6511 89	NVO-1229-179 105
CCDF-710705 00	GAH-TD-101P 64	CBEL 0940 115
CCDF-710009 109	GFAP-70107 130	CBEL 506 50
CCDF-730001-2 76	IBSL-100 29	CBEL-DSF-VNTC-7 103
CCDF-730503-5 72, 70, 75	IBSL-277 17	CBEL-TR-2010 131
CCDF-7309007-02 61	Health Physics, 13, 1105-1115 65	CBEL-TR-3135 59
CCDF-730915 106	Health Physics, 16, 303-391 66	CBEL-TR-3107 02
CCDF-731110 125	Health Physics, 16, 735-730. 23	CBEL-TR-3613 51
CCDF-700702 03	Health Physics, 19, 027-032 69	CBEL-TR-4002 0
CCDF-701109 107	Health Physics, 19, 07-50 09	CBEL-TR-0322 10
CCDF-750013 (Vol. 2) 93	Health Physics, 25, 267-200 60	CBEL-TR-0375 05
CBOS-10 01	IBDL-20-510 76	CBEL-TR-0607 19
CBOS-23 90	IBDL-THE 72-103 132	CBEL-TR-2620 25
	IBVL-THE-71-160 15	

BIBLIOGRAPHIC DESCRIPTION SHEET

CBRL-44-0255 119
 CBRL-0004 32
 CBRL-4916 5
 CBRL-4927 1
 CBRL-4929 12
 CBRL-4994 6
 CBRL-5003 5
 CBRL-5260 124
 CBRL/CSD/TB-17 127
 CBRL/NSP/EATC-17 23
 CBRL/NSP/EATC-20 104
 CBRL/NSP/EATC-27 104
 CBRL/NSP/EATC-29 102
 CBRL/NSP/EATC-31 122
 CEC-14 94
 CEE/TAB-76-4 94
 Ph. D. Thesis 78
 Ph.D. Thesis, Department of Astrophysics 120
 Ph.D. Thesis, Engineering Department 179
 Physical Behavior of Radioactive Contaminants in the Atmosphere, a conference held in Vienna, Austria, Nov. 12-16, 1973 (pp. 211-218), 522 pp. 129
 pp. 204-205 87
 Proceedings of the Third International Congress of the International Radiation Protection Association, held in Washington, DC, September 9-10, 1973, pp. 1072-1077 67
 Proceedings of the 19th Annual Meeting of the Nuclear Physics Society, held in Houston, Texas, July 7-11, 1974 87
 Radiation Control, Proceedings of the 6th Annual National Conference held at San Antonio, TX, April 20-May 2, 1974, pp. 234-246 102
 Radiation Physics, Proceedings of the International Symposium held at Calcutta, India, November 30-December 4, 1974, 5 pp. 107
 Radiocology, Nelson, B.J. (Ed.), Proceedings of the Third National Symposium held in Oak Ridge, Tennessee, May 10-12, 1972, pp. 177-193 56
 Radiocology, Proceedings of the Fourth National Symposium held at Oregon State University, Corvallis, Oregon May 12-14, 1975, 25 pp., unpublished 87
 Radiology, Proceedings of the Thirteenth International Congress held at Madrid, Spain, October 15-20, 1973, pp. 523-527 101
 Rapid Methods for Measuring Radioactivity in the Environment, Proceedings of the International Symposium held in Munich, Germany, July 5-9, 1974, pp. 47-64 84
 RI/B/ 2294 144
 RI/B/02194 101
 RI/B/02251 24
 RI/B/02763 111
 RI/B/03762 150, 145
 RI/B/02407 102
 Realism in Environmental Control, Proceedings of the Fifteenth Annual Technical Meeting and Equipment Exposition of the Institute of Environmental Sciences, held at Anaheim, CA, April 2-5, 1973 74
 RISO-4-1726 77
 RISO-M-1808 95
 Riso-303 114
 SMO-76-0424 139
 SC-88-68-555 79
 SC-98-70-330 54
 Senpaku Gijyutsu Kenkyujo, 5(2), 44-62 84
 Siting of Nuclear Facilities, Proceedings of a Symposium held in Vienna, Austria December 9-13, 1974, pp. 497-515 40
 SPA 9 42 130, 136
 SS/01/71 25
 TI-001-130-C40 70
 TI-001-130-C51 36
 Transactions of the American Nuclear Society, 4, 106-107 84
 Transactions of the American Nuclear Society, 19, 879-880 97
 TSC-COD-0024-1 110
 Tritium, Raghunani, S.K. and Carter, R.W. (Eds.) 109
 UCRL-51042 30
 UCRL-52133 117
 UCRL-76170 preprint 101
 UCRL-76170 Rev. 2 124
 UCRL-76172 Rev. 2 122
 USGS Open File Report 76-717 140
 USPHS-79-67-7 67
 WAPP-TN-1273 124, 147
 WAPP-TN-340 26
 Water, Air, Soil Pollut., 4, 65-87 133
 ZJE-146 55

APPENDIX F. TITLE INDEX

BLANK PAGE

TITLE INDEX

- "Fodora" Computer Program for an Estimate of the Radiologic Dose in the Evaluation of Risks for Nuclear Power Plants and Radioactive Facilities 28
- "HARP" - A Digital Code to Evaluate the Hazards of Different Types of Reactor Accidents 1
- A CDC SAS Program for Calculation of Inhalation and Internal Dose for Estimating Reactor Siting Distance Requirements 56
- A Comprehensive Atmospheric Transport and Diffusion Model 43
- A Computer Code (HUSKIN) to Calculate Population Doses from Radioactive Liquid Effluents and or Application to Nuclear Power Reactors on the Mississippi River Basin 56
- A Computer Code for Analyzing Passive Atmospheric Releases of Short-Lived Radioactive Nuclides 64
- A Computer Code to Calculate Doses Resulting from Release of Radionuclides to the Atmosphere 65
- A Computer Program for Calculating Annual Average Internal Doses from Chronic Atmospheric Releases of Radionuclides 50
- A Computer Technique for Calculating the Radiological Consequences of Pressurized Water Reactor Power Plant Hypothetical Accidents 116
- 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 120
- A Fortran Program for the Calculation of the Potential Hazards from an Accident: Fission-Product Release - PC102 26
- A Fortran Program to Determine Absorbed Organ Dose Due to Inhalation of Radionuclides 67
- A Generalized Air Quality Assessment Model for Air Policy Operations - An Operator's Guide 122
- A Guide to the Use of the Cedric Program for Radiologic Dose Calculations 101
- A Guide to the Use of the CHEDIC Program for Radiologic Dose Calculations 100
- A Guide to the Use of Titric - A Computer Program for the Calculation of the Consequences of Releasing Radioactive Material to the Atmosphere 136
- A Guide to the Use of Trior-A Computer Program for the Calculation of the Consequences of Releasing Radioactive Material to the Atmosphere 130
- A Non-Consistent Model for Wind Fields over Complex Terrain 125
- A Model for Predicting the Redistribution of Particulated Contaminants from Soil Surfaces 55
- A Model to Estimate the Local Radiation Doses to Man from the Atmospheric Release of Radionuclides 128
- A Model to Estimate the Local Radiation Doses to Man from the Atmospheric Release of Radionuclides (HSP Development Program) 107
- A Multi-Compartment Model for Studying the Dose-Take Relationship for Radioactive Isotopes 20
- A New Technique for Reactor Siting Dose Calculations 49
- A Numerical Model for the Study of Dispersion of Radioactive Pollutants in Air 129
- A Preliminary Systems Analysis Model of Radioactivity Transfer to Man from Deposits in a Terrestrial Environment 59
- A Procedure to Determine the Relative Effect of Reactor Fission Product Releases Under Various Meteorological Conditions 28
- A Program for Computing External Dose Path from a Radioactive Cloud and Numerical Examples for Nuclear Ships 88
- A Program for Evaluating Atmospheric Dispersion from a Nuclear Power Station 70
- A Personal Air Transport Model for Radiological Dose Studies 76
- A Regional-Continental Scale Transport, Diffusion, and Deposition Model 92
- A Systems Analysis Methodology for Predicting Dose to Man from a Radioactively Contaminated Terrestrial Environment 50
- A Transport, Two-Dimensional, Discrete-Element, Far-Field Model for Thermal Impact Analysis of Power Plant Discharges in Coastal and Offshore Regions. Part 1: General Description of the Mathematical 115
- A Two-Dimensional Transport Model of the Atmosphere 106
- A User's Manual for the Fortran IV Version of the Viscous Hydrologic Transport Model 103
- A User Guide to the HAZIIE Program 102
- Assorted Dose Rates in Humans from Exposure to Environmental Gamma Rays 97
- CEBA - A Computer Program for the Estimation of Radiation Doses Caused by a Hypothetical Reactor Accident 8
- CEPIC - A Three-Dimensional Particle-in-Cell Model for the Dispersal of Atmospheric Pollutants and Its Comparison to Regional Tracer Studies 126
- CEPIC - A Three-Dimensional Transport-Diffusion Model for the Dispersal of Atmospheric Pollutants and Its Validation Against Regional Tracer Studies 101
- CEPIC: A Three-Dimensional Computer Code for the Study of Pollutant Dispersal and Deposition Under Complex Conditions 37
- CEPIS, A Code for Source Personal Inhalation Exposure Calculations 69
- Air Pathway Exposure Model: Validation Study at the Monticello Nuclear Generating Plant 110
- CEPIS - A Computer Code for Estimating Population and Individual Doses Resulting from Atmospheric Releases of Radionuclides from Nuclear Facilities 19
- CEPIS Program Manual: A Computer Code for Calculating Doses, Population Doses, and Ground Deposition Due to Atmospheric Emissions of Radionuclides 11
- CEPIS II, A Digital Computer Program for Investigation of Reactor Siting 63
- Applications of a General Computational Model for Composite Environmental Radiation Doses 75
- Areas Affected by Ground Deposition of Cs-137 and Description of the Computer Code HZCMA 81
- Assessment of Environmental Hazards Following Nuclear Reactor Accidents 66
- Atmospheric Dispersion of Fission Products Including the Effects of Building Dilution and Radioactive Decay 29
- BETA: A Computer Program for Calculating Beta-Dose Rates from Soil and Plant Sources 111
- Biological Dose and Radiological Activity from Nuclear Reactor or Nuclear Weapon Fission Products 6
- Comparison of Mathematical Models for Calculation of External Gamma Doses Originating from Releases of Radioactivity to the Atmosphere 77
- Comparison of Measured and Calculated Radiation Exposure from a Boiling Water Reactor Plume 17
- Computation of Radiological Consequences Using HAZIC Computer Program 68
- Computational Method for Calculation of Radiological Dose Resulting from Hypothetical Fission Product Release 50
- Computer Codes and Data Available from the Radiation Shielding Information Center 107

TITLE INDEX

- Computer Model for the Prediction of the Frequency of Airborne Radioactive Particles 47
- Computer Modeling of Terrestrial Gamma-Radiation Fields 116
- Computer Simulation of Iodine-131 Transfer from Fallout to Man 113
- Concentration Factors and Transport Models for Radionuclides in Aquatic Environments: a Literature Report 98
- Continuity and Discontinuity in the ECOSYS IV Version of the Biogeochemical Transport Model 142
- Core-Cross-Threshold: A Digital Computer Program for Internal and External Radiation Dose Calculations 11
- ECOSYS - A Computer Program for Calculating Organ Dose from Acute or Chronic Radionuclide Inhalation 1
- ECOSYS - A Computer Program for Calculating Organ Dose from Acute or Chronic Radionuclide Inhalation: Modifications for Gastrointestinal Tract Dose 14
- Description of the COMRAD-III Code 16
- Description of the COMRAD-III Code 16
- Development of a Unified Transport Approach for the Assessment of Power Plant Impact 123
- Development of Practical Dispersion Coefficients for Polluting Terrain Environments 110
- EXTRAC, Model for Computation of Neutral Transport and Diffusion in the Atmosphere 19
- Digital Simulation of Two Models of the Biological Disposition of Inhaled Plutonium 65
- Digital Topography, Calculations of Watershed Area and Slope 108
- Dose Modeling for Nuclear Facilities 103
- Dynamic Model of Water Movement in Soil Under Various Climatological Conditions 109
- Effects of Rainout and Dryfall on Consequences of Nuclear Reactor Accidents 139
- ECOE - A Computer Program to Compute Ecological Integrals from External Gamma Isotopes 1
- Estimation of Population Tumor from a Nuclear Power Plant During Normal Operation 85
- Estimation of Radiation Doses Following a Reactor Accident 12
- Evaluation of a Digital Computer Method for Analysis of Compartmental Models of Ecological Systems 121
- EXTRAC, A Computer Program for Calculating the Potential Gamma Dose from Airborne Fission Products 47
- EXTRAC and ECOSYS Computer Codes for Estimating Radiation Doses to Populations from Construction of a Sea-Level Canal with Nuclear Explosives 10
- EXTRAC - An Interactive Code to Calculate Internal Radiation Doses from Concentrated Food Products 11
- EXTRAC and ECOSYS - Programs to Calculate Environmental Consequences of Radioactivity Release 89
- General Model for Evaluating Transport of Radioactive Products Released to Environment and its Consequences 87
- Ground Level Air Concentrations of Gaseous Radionuclides from a Tailings Area During a Typical Windspeed 85
- EXTRAC - A Digital Computer Code for Estimating Potential Radiological Effects from the Nuclear Power Industry 13
- Hydrodynamic Transport of Radionuclides in a Three-Dimensional Case with Two-Dimensional Approximation 118
- INTEC-Environmental Computer Codes to Implement ECOSYS-III Model for Estimation of Internal Radiation Dose to Man 6
- Initial Estimates of Doses to Human Body Tissues Following Acute Exposure to Radioactive Fission Products 100, 101
- INTEC - A FORTRAN Code Which Implements ECOSYS Models of Internal Radiation Dose to Man 7
- Integrated Environmental Modeling System for Mobile Gas Releases at the Savannah River Plant 106
- INTEC II - A FORTRAN IV Code for the Calculation of the Long-Term Alpha- and Gamma-Dose Distributions in the Vicinity of Nuclear Installations 11
- Long-Term Aspects of the Environmental Burden from Energy Production: CO₂ and R₁ 78
- Low-Level Inertial Transport and the HIRIS Computer Program for the Secondary Stress Function 11
- Natural Transport through Porous Media: A Finite-Element Collocation Code 12
- Mathematical Aspects of the Year 2000 Radiological Study 91
- Mathematical Simulation of Sediment and Radionuclide Transport in the Columbia River 117
- NEPTO-1 A Program for Calculations of Atmospheric Dispersion of Activities from Nuclear Power Reactors 95
- Methods for Prediction of Dose to Man from Environmental Release of Radioactivity 47
- Methods for the Calculation and Prediction of Concentration of Close-to-Ground Air Layer by Stack Emission of Various Power Plants 14
- Methods of Estimating Dose to Man from Regional Growth of Nuclear Power 14
- Modeling of Environmental Pathways and Radiation Doses from Nuclear Facilities 8
- Modeling of Radiation Doses from Chronic Aquatic Releases 16
- Modeling the Regional Transport of Radionuclides in a Water-Contaminated States River Basin 13
- Models and Computer Codes for Evaluating Environmental Radiation Doses 14
- NEPTO - A Digital Code for Computing Airborne Dose Rates in Reactor Stacks 41
- Numerical Modeling of Subsurface Radioactive Solute Transport from Waste-Storage Basins at the Idaho National Engineering Laboratory 141
- NEPTO-1, A Nuclear Reactor Safety Evaluation Code for the Control Data Model 47
- NEPTO Effective Dose Rates 47
- Particle-Cell vs. Straight-Line Airline Gaussian Calculations of Concentration and Deposition of Airborne Radionuclides as a Function of the Size of Differing Meteorological and Topographical Character 117
- Rellevant Transport in Several Regions 11
- Prediction Methods of Concentration Fields of Radionuclides and Radiation Doses in the Environment of Nuclear Power Plants with Extraordinary Position 86
- Program Descriptions, Supplement to Generalized Wind Fields and Transport Estimates Determined from a Network of Wind Towers 117
- PRIDE: A Computer Code for Calculating Dose Equivalent from Internal Deposition of Plutonium at Sanford 47
- PRIDE - A Computer Program for Calculating Potential Internal Dose from Airborne Fission Product's Following Postulated Reactor Accidents 86
- Radioactivity Transport in Water: Mathematical Model for the Transport of Radionuclides 91
- Radioactivity Transport in Water: Analytical Solutions of Radionuclide Transport Equations and Role of Plants in SR-85 Transport 98

TITLE INDEX

- BEEGS**, A Code to Estimate Gamma Dose from a Cloud of Radioactive Gases. 48
- BPMR**: A System of Computer Programs for Radionuclide Pathway Analysis Calculations. 135
- BREIG**-A Computer Program for Estimating Health Effects from Inhalation and Ingestion of Radionuclides. 116
- Regional Effluent Dispersal Calculations Considering Spatial and Temporal Meteorological Variations**. 72
- Review and Development of Aerosol Analytical Methods**. 136
- BISC Computer Code Calculations, ACDS-II Normal Integration Code** Estimation of Radiation Doses Caused by a Hypothetical Reactor Accident. 18
- BISC: Radiological Inhalation Safety Code for IBM 7090**. 86
- Risk Evaluation for Stack Releases**. 22
- BMC -- A Radiological Safety Analysis Computer Program**. 62
- BREY**, A Program for the Calculation of Activity Released and Potential Doses from a Pressurized Water Reactor Plant. 42
- Some Examples and Limitations of the PADS and APAS Computer Programs**. 46
- Some Techniques for Estimating the Results of the Emission of Radioactive Effluent from CSUL Stacks**. 82
- Studies of Columbia River Water Quality, Development of Mathematical Models for Sediment and Radionuclide Transport Analysis**. 71
- STECOSA - A Computer Program for Calculating External Doses from Accidental Atmospheric Releases of Radionuclides**. 25
- TERR: A Terrestrial Ecosystems Hydrology Model**. 106
- The Colne River Simulation Model**. 132
- The Estuarine Version of the CCMAT Digital Simulation Model**. 52
- The EYBER II Computer Code for Estimating External Doses to Populations from Construction of a Sea Level Canal with Nuclear Explosives**. 7
- The EYBER III Computer Code for Estimating External Radiation Doses to Populations from Environmental Releases**. 14
- The WZBER Program for Assessing the Radiological Consequences of Airborne Effluents from Nuclear Installations**. 68
- 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**. 121
- Transport Modeling in the Environment Using the Discrete-Parcel-Pandas-Walk Approach**. 40
- Use of Computers to Calculate Radiation Doses from Metabolic Models**. 108
- User Guide for Computer Program PCOD**. 119
- User's Manual for the Fortran Version of ESAC A Radiological Safety Analysis Computer Program**. 63
- User's Manual for Code PIGAR: A Code to Calculate Gamma Photon Dose from an Airborne Radioactive Release**. 27
- VADOSCA: A Simple Code for the Evaluation of Population Exposure Due to Radioactive Discharges**. 61
- Water Movement Through Saturated-Unsaturated Porous Media: A Finite Element Galerkin Model**. 1
- WELGA 1, A Fortran IV Program for Calculation of the Gamma-Dose Rate from Radioactive Effluent Air Released by one or Several Continuously Emitting Sources**. 118
- WSED, A Siting Code to Estimate Dose Probability Distribution from Measured Meteorology Data**. 23