1838

717291

Special Distribution
Limited to Recipients
Listed on Distribution Page

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE CORPORATION
NUCLEAR DIVISION
POST OFFICE BOX X
OAK RIDGE, TENNESSEE 37830

ORNL
CENTRAL FILES NUMBER

ORNL-CF-72-8-17

Date: October 16, 1972

Subject: Status Report on Study of Potential Radiological Impact of Expanding Nuclear Power Industry on the Tennessee Valley Region: Phase I, Critique of Hanford Engineering Regional Model for Environmental Study (HERMES)

To: Distribution

From:

Compiled by

K. E. Cowser, ORNL
F. A. Gifford, ATDL-NOAA
G. F. Stone, TVA

Contributions by

M. J. Bell, ORNL
R. P. Betson, TVA
R. S. Booth, ORNL
K. E. Cowser, ORNL
B. R. Fish, ORNL
F. A. Gifford, ATDL-NOAA
T. M. Jackson
R. T. Jenkins, TVA
K. P. Nelson, ORNL
C. W. Nestor, ORNL
J. P. Nichols, ORNL
R. V. O'Neill, ORNL
B. F. Roberts, TVA
R. Salmon, ORNL
G. R. Siegel, TVA
G. F. Stone, TVA
T. Tamura, ORNL
T. C. Tucker, ORNL
D. H. Walters, TVA
W. H. Wilkie, TVA
W. O. Wunderlich, TVA

REPOSITORY Oak Ridge Operations Records Holding area
COLLECTION Documents 1944-94
BOX No. A-49-7 75-44 2 of 4 Bldg. 2714-H
04-01-61-LMFBR
FOLDER All Other 72 & 73

NOTICE This document contains information of a preliminary nature and was prepared primarily for internal use at the Oak Ridge National Laboratory. It is subject to revision or correction and therefore does not represent a final report. The information is only for official use and no release to the public shall be made without the approval of the Law Department of Union Carbide Corporation, Nuclear Division.

1115989

INTRODUCTION

An interagency study of the potential radiological impact of an expanding nuclear power economy on the Tennessee Valley Region has been undertaken by the Oak Ridge National Laboratory, the Tennessee Valley Authority, and the Atmospheric Turbulence and Diffusion Laboratory-National Oceanic and Atmospheric Administration (ATDL-NOAA) for the Division of Reactor Development and Technology, Atomic Energy Commission.

The study of the Tennessee Valley Region will consider (1) nuclear power requirements to year 2000 and sites for nuclear facilities, (2) radionuclides that may be released and their transport in air and water and concentration in terrestrial and aquatic systems, and (3) estimation and intrepretation of potential dose equivalents and dose commitments to man and dose to other organisms. General agreement of the division of work between the three organizations for the complete study include the following:

TVA--Methods used to project requirements for nuclear generating plants and to predict the water transport of radionuclides.

ATDL-NOAA--Methods used to predict the air transport and deposition of radionuclides;

ORNL--Methods used to predict the time-dependent concentrations of radionuclides in exposure pathways leading to man, to estimate potential dose equivalents and dose commitments, and to interpret the projected doses.

TVA and ORNL will consider collectively the source terms that are employed.

This report provides a critique of the Hanford Engineering Regional Model for Environmental Study (HERMES) as the first task of the DRDT-

1115990A

supported study (referred to as Phase I). The intent of the critique is to determine what changes, if any, may be needed in the various components of HERMES to permit its application to the Tennessee Valley Region. The critique considers only the mathematical model described in report HEDL-TME-71-168[1], and does not take into account any subsequent refinements or changes made in the model. To do otherwise would simply delay the Phase I report.

Individual responsibilities for the critique of the components of HERMES are listed in Attachment I. A listing of individuals responsible for the preparations of HERMES, furnished by J. F. Fletcher, Westinghouse Hanford Company, provided a unique framework for communications between the respective staffs. The excellent cooperation received from those at Hanford eliminated many uncertainties as the details of HERMES were reviewed.

COMMENTS ON COMPONENTS OF HERMES

Organization of the critique follows the documentation of HERMES provided in Reference 1. Comments and particular problems in the application of HERMES to the Tennessee Valley Region are first noted and modifications in HERMES where applicable are then proposed.

Overall Model Structure

The HERMES family of programs, documented in Reference 1, is only in part the version now in operation; but the following comments are directed toward the system as described in the report.

Documentation

The documentation is not sufficiently complete for a system of programs that may become a standard (see pg.11, ref.1). There is no mention in many sections of the text of what parts of the program actually carry out the

1115990B

operations described, and there are no comments in the program listings to indicate where descriptive material might be found in the text. There are no comments in the programs themselves as to features of UNIVAC FORTRAN-V which are not duplicated on other manufacturers' FORTRAN compilers, so the report as it stands does not have general use in making the system operable on any other computer. It would be advisable to use ASA Standard FORTRAN (see ref.2) as far as possible and to follow some general standard for program documentation (see ref.3, for example).

There are a few flow charts in the report, but they are not in standard form (see ref.4), nor are they sufficiently detailed to be of great help in understanding the programs, except in a general way. For most of the programs and subroutines, there are no flow charts at all.

Although there are directions in Appendix D for setting up the input decks for the various programs, there is no information about the number of tape drives, the amount of core storage or the amount of drum storage required for each program. There is also no sample input or output for any program. Therefore, the report does not contain the information necessary to verify that the programs are running correctly.

Programming

It is evident that several different programmers have been involved in the writing and modification of the HERMES programs. As we have already indicated, the programming in some parts of the system uses features of UNIVAC FORTRAN-V not duplicated in other dialects of FORTRAN. For example, COMMON, DIMENSION and other specification statements to be used in several routines are listed only once, and their subsequent uses are indicated by the INCLUDE statement. Also, in contrast to standard FORTRAN, statement

1115991A

numbers in a three-branch IF statement may be omitted if the referenced statement is to be the next statement in the program.

Additional coordination between the different submodels is desirable. For example, the numbers identifying the nuclides used in the calculations change from one submodel to another, and the notation used in the report changes, sometimes drastically, from one submodel to another.

The drum input/output that is used extensively in many sections of the system is done in a variety of ways, either with direct calls of the system subroutine NTRAN, or with other subroutines which call NTRAN. It should be noted that the NTRAN subroutine is not part of FORTRAN-V, but rather is carried over from FORTRAN-IV, UNIVAC dialect (refs.5 and 6). It would be extremely helpful if all occurrences of drum input/output were flagged with appropriate comments. In addition, the setup and release of scratch areas on the drum should be clearly pointed out and comments supplied to indicate the sizes of the drum areas involved.

Electric Power Economy Model and Nuclear Facility Siting

The report on HERMES contains minimal information on the techniques used to project nuclear power contribution to electric utility requirements and siting of nuclear facilities. A critique was possible only because of the cooperation received from the Hanford developers of the model. They supplied us with detailed descriptions of both the PACTOLUS and DAEDALUS codes, and they were candid in answering our questions[7,8].

Our review of these sections of the HERMES model had two objectives; (1) to complete the first part of a study to establish the radiological impact of nuclear facilities on the immediate Tennessee Valley study area, and (2) to evaluate the adequacy of HERMES as a model which could be

1115991B

applicable to many regions throughout the Nation.

Both objectives are based on the goal of making the most realistic projection of (1) the extent to which the operation of nuclear facilities will contribute to the generation of electric power in a study region and (2) the locations of these facilities. Unfortunately, accurate predictions are difficult to make because fuel costs for various alternative types of generating facilities, projections of load growth, interchange arrangements with neighboring systems, transmission facilities, environmental constraints, technology of power generation, and other factors are changing on almost a daily basis. How to handle these highly uncertain factors is subject to considerable debate, and, even if a particular modeling technique could be singled out as the superior model, the planning of a power system to the year 2000 would be only as good as the experience and judgement of the planners in the selection of input and analysis of computer results. Consequently, if one is considering the radiological impact within one particular region, one should use the detailed forecasting and expansion planning obtained from models developed by utilities for their own regions and which reflects the utilities' judgement. This approach would enable a radiological impact study to be based on the most realistic simulation of the numbers and types of nuclear facilities in the region.

On the other hand, if one desires to develop a generalized model (such as HERMES) applicable to many regions, the models developed by utilities would probably be too specialized for general use. Even if a utility model were suitable for HERMES, it probably would not be available because it would be proprietary or confidential in nature. In this case, therefore, a linear program (LP) such as that used in HERMES appears to be the best long-range prediction method available at present, even though it is recognized that the actual growth of

1115992A

the power economy probably will not be along a long-range optimal path.

Because of the above-mentioned differences, our comments and suggestions will be divided into two sections to parallel the two objectives.

Electrical Power Economy Expansion and Nuclear Facility Siting for the Tennessee Valley Study Region

In this case, we believe that for the immediate study area it would probably be more practical to replace the HERMES power economy and nuclear facility siting models with a list containing TVA's best estimate of nuclear plants that will be installed between now and the year 2000. This list could include capacity factors, tentative locations at existing sites, and the maximum capacity that can be located at an individual site based on current information concerning technical and economic limitations. This list would also include an estimate of the fraction of nuclear additions which will be LMFBR's, HTGR's, LWR's, etc.

The information which TVA would provide would be based in part on a model which can take into account, among other factors, (1) effects of load conditions on plant operation, (2) effects of economics of various types of plants, including gas turbines and pumped storage, (3) forced outage probabilities, (4) scheduled shutdowns for maintenance and refueling, and (5) power generated by Corps of Engineers and ALCOA projects which are operated by TVA.

This approach is considered superior to using the HERMES method for reasons stated earlier and for special conditions that exist for this study area. For example, factors such as interest rates, tax rates, and the debt-to-equity ratio are considerably different for a federal agency such as TVA when compared with private utilities. This would make it necessary to make numerous changes in the power economy model for it to be applicable to the TVA power service area.

1115992B

Even for this study area, however, it would still be necessary to make use of the HERMES approach. This is because the power economy in the regions surrounding the study area must be modeled in order to determine the doses within the study area from radioactive isotopes transported into the region from neighboring nuclear facilities. Since there are numerous utility systems involved, it would be impractical to attempt to use their individual power expansion models. Consequently, for modeling the expansion of nuclear facilities in the area surrounding the study region, we recommend using a modified HERMES approach, as discussed in the following section.

General Model of Electrical Power Economy and Nuclear Facility Siting

We are assuming in this section that it is desirable to retain the basic HERMES approach; therefore, our comments are restricted to the linear programming (LP) method of predicting the expansion of power facilities and to the HERMES method of site selection.

A. Electrical Power Economy Model

The HERMES PACTOLUS-DAEDALUS-LP package is written primarily in machine language for the UNIVAC 1108 computer. Consequently, to convert the codes for use on more commonly available computers would be a relatively long and difficult task. In contract, the Oak Ridge Systems Analysis Code (ORSAC) is essentially identical to the HERMES power economy model and is already operational on the IBM-360 system. Although slight changes would be needed to reduce ORSAC from a national to a regional basis, the changes would be minor compared with that of adapting this portion of HERMES to the IBM system.

Both HERMES and ORSAC have built-in deficiencies. For example, they require all plants to follow one of only two annual predetermined load histories, base loaded or load following. Instead, plant histories should

also consider factors such as interchanges with other power systems, economics of peaking (gas turbines), intermediate fossil plants (conventional or combined cycles), and various energy storage schemes, such as pumped storage, which can have a pronounced effect on nuclear expansion and operation.

The high-temperature, gas-cooled reactor (HTGR) should be included as one of the reactor types. This would necessitate modification of the code to include (1) appropriate cost and performance data in the power economy model, (2) appropriate radwaste treatment systems in the reactor release model, and (3) a model of the associated fuel reprocessing facilities.

HERMES assumes that fuel costs vary essentially linearly with energy production. To arrive at minimum fuel costs, however, one should incorporate the state conditions of the core at various points in time.

Comments on the constraint equations in the matrix generating code DAEDALUS include the following:

1. It is stated in the HERMES report that constraints are added to assure that enough fossil plants are chosen by the LP to "accommodate the needs" of a Power Supply Area (PSA) which has abundant reserves of low-cost fossil fuel. However, as we understand it, the only effort to satisfy such constraints was to place fossil plants that were chosen by the LP into PSA's within the study region that had an abundance of fossil fuels. Since the cost of fossil fuel can vary considerably even within a given PSA, more realistic results could probably be obtained if the sites of new plants were included in the power economy model. This would make it possible for the price of fossil fuel which is used in the cost competition to be a realistic value for each plant.

1115993B

2. Although the DAEDALUS code has constraint equations which provide for the interchange of plutonium and other nuclides with surrounding regions, they apparently were not used in the Year 2000 Study. Use of this option should be considered for future studies.
3. The rate of introduction of new types of reactors is limited by constraint equations. The limitations should be updated to include the latest estimates for the introduction of the LMFBR, HTGR, and any other reactor types which may become available.

B. Nuclear Facility Siting

Since the doses which are calculated by the model are very sensitive to the locations of nuclear facilities in a region, it is essential that sites used in the model be realistic. The assignment of sites for the reprocessing plants is especially critical, since they will probably be the major sources of potential releases of radioactivity. The use of the site criteria as listed in the HERMES report should ensure that sites selected will be within the general area of actual sites chosen by utilities. Of course, if utilities have announced site locations, they should be used in the study. However, it must be made clear in any report of a study of this nature that the specific site locations chosen are not necessarily the same as sites where plants will actually be built. To avoid problems for utilities that may be caused by publishing specific site locations (even though they were hypothetical), one might consider including the requirement that all new plants be assigned to existing and announced sites within the study region. This would avoid having a list which contains a mixture of actual and proposed sites. For the Year 2000 Study, it was assumed that all fuel used by reactors within the study area would be reprocessed within the area. Since this

1115994A

would tend to minimize transportation of spent fuel elements, it appears to be a reasonable constraint. A particular study area, however, may be one in which there are no highly acceptable sites for reprocessing plants (because of topography, population density, or other factors); therefore, to minimize the national radiological impact of the nuclear industry, it may be desirable to have fuel reprocessed in another region. The same comments might apply to the location of burial grounds, uranium enrichment plants, and possibly other nuclear facilities. In this connection, one might also then want to include the radiological impact from the transportation of radioactive materials. The method of site assignment is generally acceptable for this type of analysis and where utility estimates are unavailable. It enables the "growth" of the power economy used in the model to simulate the actual growth within a fairly large region by allowing new plants to be located near areas where power demands are increasing. As suggested in an earlier paragraph, however, one might want to include the site of a plant in the power economy model instead of assigning sites after the plants are chosen.

In the Year 2000 Study, light water reactors were designated as PWR or BWR and a ratio of 3 PWR's to 1 BWR was used. This procedure should be reviewed and changed if present trends indicate a different mix. In addition, the practice of allowing a mix of reactor types at a given site does not seem to follow current trends and possibly should be eliminated.

Radioactive Effluent Characterization

There is no fundamental disagreement with the methods used in HERMES to simulate the major nuclear power and fuel reprocessing plant characteristics which affect radionculide releases to the environment. The technique of modeling each of the various plant processes in order to "follow" the

1159 4B

flow of radionuclides from generation through each component of the clean-up and holdup facilities to the point of emission appears to be a valid approach to the problem.

At the present time, however, the HERMES approach may be too sophisticated for the available data. For example, the detailed modeling of reactor coolant concentrations and radwaste treatment systems does not appear justified because of the scarcity of actual operating data upon which the calibration constants for the various simulation equations could be based. Consequently, consideration should be given to replacing the detailed simulations of fission product generation, fuel failure, and radwaste treatment systems by simpler models or by tables of radionuclides released to the coolant per unit of power generated and overall system decontamination factors for each of several groups of chemically similar isotopes. Similarly, tables of radionuclides released per unit of fuel processed could be prepared for each type of fuel reprocessing plant.

As reliable operating data become available, one could continue to use one of the above alternatives and merely update the simplified models or tables, or one could return to the detailed modeling approach since it would then be possible to assign values to the calibration constants which would enable the model to realistically describe the flow of radionuclides through a nuclear plant.

No matter which approach is used in the future, the model should be extended to include the possibility of wastes bypassing the treatment systems and being released directly to the environment. These unprocessed wastes (such as from turbine gland seal leaks and PWR steam generator leaks) can become very important when plant discharge levels must be reduced to those

1115995A

in the proposed Appendix I to 10 CFR Part 50. At some future date, consideration should be given to other potential radiation sources in the region in addition to nuclear power stations and fuel reprocessing plants. This may include such nuclear facilities as fuel fabrication plants, solid waste burial grounds, uranium enrichment facilities, etc., as well as systems for transportation of radioactive materials.

It may be necessary to alter the DOSIS part of HERMES relatively frequently to accommodate anticipated advances in radwaste treatment technology and fuel quality. For example, we expect that the design philosophy of future radioactive waste treatment and coolant purification systems may have to be changed to provide means to keep coolant activity levels low in order to reduce the consequences of leaks. These changes should be included in HERMES as they occur. Similarly, one should add krypton and xenon removal to the simulation of LWR waste treatment systems as soon as it becomes commonly used. Consequently, to facilitate changing the code, it may be desirable to make many of the factors that are now included in the FORTRAN statements be input variables, or to include them in DATA statements in a single BLOCK DATA subprogram. Also, any other documentation of the code or additional comment statements within the code which would make the simulation of treatment systems more accessible will aid future users of the model.

Although we basically agree with the method used to calculate the fuel rod failure probability, we do not believe, at least for today's fuel quality, that one should exclude the possibility of fuel being manufactured with defects. This could increase the failure probability for a short period early in the life of the rod and fuel rods suffering early failure may not necessarily be removed before allowing significant amounts of fission product

1115995B

release. As fuel quality improves, however, this could be dropped and an equation such as the one used should be realistic.

We suggest that Appendix A, the list of radionuclides considered in the model, be reviewed following completion of the Upper Mississippi River Basin study. Isotopes which did not contribute significantly could then be omitted from future runs. On the other hand, one may want to add isotopes which are not now included. For example, it appears the ^{239}Pu and other transuranic elements should be considered.

Living Patterns Model

The approach used to define geographic coordinates for centroid designation is a reasonable first approximation. But refinement is possible in defining the center of population in a county or larger areas. The Bureau of Census in computing the 1970 population center for the nation actually estimated and recorded the population centers for approximately 250,000 small geographic areas[9]. In the Tennessee Valley Region each county should be lised and its identity retained, rather than combining like counties, with consideration given to use of subcounty units such as Minor Civil Divisions for the largest metropolitan counties. Further study of the Tennessee Valley Region is necessary to judge the acceptability of critieria used in the Living Patterns Model to classify counties as urban, rural-non-farm and rural-farm.

An overly simple approach was taken in projecting population growth to year 2000 using two points in time and assuming no change in age-sex distribution. More sophisticated population projections, adjusted for local fertility and mortiality estimates, have been prepared by TVA and the University of Tennessee Center for Business and Economic Research, and could be used in the model. The national age-sex distribution projected by the Census

1115996A

Bureau should more closely approximate the TVA region age distribution in year 2000 than would the present age distribution[10].

The treatment of food production is quite straightforward. Data are available by county from the Census of Agriculture. Some conversion of these data to a "centroid" area-base was required but there appear to be no real problems. In some cases it was necessary to convert units (e.g., number of cattle to pounds of meat) and it would probably be better to use local figures than to accept conversion factors for other areas. The report combines the original list of foods into 35 categories, distinguishing between fresh and processed food where appropriate. This seems a reasonable approach though further reductions may be necessary in the Tennessee Valley Region based on whether it is possible to distinguish a real difference in concentration between berries and tree fruits, for example.

The transportation and distribution section of the model appears to contain some questionable assumptions. Production and consumption are compared for each centroid and it is assumed that local production will be used to satisfy local needs. Surpluses and deficits are adjusted by comparing the balance with the closest centroids. This latter assumption may not be valid for the Tennessee region. The surplus from an area might be shipped directly to the nearest urban area rather than to a neighboring county. We might also find the produce (total production) from a number of areas is shipped to a common location and then redistributed back to a number of areas. It appears that consideration of local practices of distribution would have to be investigated before a reasonable model could be developed.

Atmospheric Transportation Model

The air transport module of the HERMES code is based on the Gaussian plume model as discussed, for instance, by Gifford[11]. The report indicates

1115996B

how the basic dispersion equation is modified to express long-term (monthly) average concentration, how the vertical dispersion parameter is determined, and how allowance for radioactive decay and removal by dry deposition and precipitation scavenging are incorporated. The model used does not allow for terrain effects or for departures from the simple Gaussian model that can be expected to become important at downwind distances greater than a few kilometers.

The required computer calculations are also outlined in this section. They seem reasonably simple and straightforward and not to have presented any special problems. Consequently, the mathematics of the program itself have not been studied in detail for the purpose of this critique. It was felt that attention could more profitably be directed to the basic atmospheric physics of the problem.

Problems with the existing program

Accepting, for the moment, the physical model used, i.e., with neglect of terrain and long-range shear diffusion effects, there are certain problems of the existing model that should be pointed out.

1. Equation (10), the basic diffusion model should be multiplied by two to account for ground "reflection." This is merely conventional and is not necessarily intended to express a completely real physical effect. Nevertheless, this factor is included in most standard diffusion models and can be accepted as good practice. Equation (12) is the basic equation for the averaged ground concentration upon which all the code calculations are based. Fortunately, both Equations (11) and (12) are in the 2-multiplied form as presented in Reference (1), rather than as stated, having been derived by integration from Equation (10).

1115997A

2. The report by Dickson, et al[12] is used as the basis for the σ_z -values. However, Dickson was discussing the "puff" case, not the "plume" case, and obtained final average concentrations by integrating a "puff" form of the Gaussian equation. Thus the σ_z's used in the HERMES code are not appropriate to a "plume" equation such as Equation (12).

3. Plume depletion by precipitation scavenging can be represented as an exponential removal only in certain very simple cases, such as in which the precipitation is falling through the cloud. Where the possibility of "in-cloud" scavenging exists the situation is more complicated.

4. The assumption that all nighttime dispersion resembles Type D may not be adequate in the hilly terrain prevalent in the Tennessee Valley.

Terrain and long-range diffusion effects

The HERMES code does not try to include these effects, and their omission is certainly the most serious short-coming of the air transport module, expecially as it might be applied to an area like the Tennessee Valley. Of course, these effects were omitted just because they are difficult to account for and no standard procedures are immediately available. In-cloud precipitation scavenging is also more likely to be a problem at longer ranges where the diffusing cloud will have penetrated to depths of the atmosphere more frequently characterized by cloudiness.

Applicability to the Tennessee Valley

Before the atmospheric module of HERMES model can be applied to a region such as the Tennessee Valley, either certain basic modifications must be made to correct and extend the existing module, or else a new model will have to be derived. Either alternative will probably be of the same order of difficulty.

1115997B

The problem of selecting appropriate dispersion coefficeints would need to be carefully reviewed. It is known in principle, cf. Saffman[13], Smith[14], and Pasquill[15], that wind shear effect dominates horizontal dispersion after clouds travel distances of the order of 5 to 10 km. There are a few dispersion experiments applicable at greater distances, cf. for instance, Peterson[16] and Crawford[17,18]. These and the theoretical papers should be collated, and a study should be made to establish the best available dispersion coefficients for great distances.

The basic Gaussian model will probably be found to be an adequate conceptual framework for long-range diffusion, provided adequate dispersion coefficients are established. However, a fundamental decision needs to be made concerning whether to continue using the "long-term averaged plume" version as in the present HERMES code, or whether to go to an "integrated-puff" version as is done in Reference (12). The integrated-puff model is certainly required to study the transient situations contemplated in Reference (12). Whether it may also be required for longer term averages in a situation of irregular terrain will have to be the subject of careful study.

Modification to either the puff or the plume model to account for possible terrain effects on ground level concentration patterns must also be studies. This problem was examined in the recent NOAA Southwest Energy Study[19], and the technique used in this document could serve as a starting point for this difficult problem. It seems that terrain effects will be a particular problem at night. The use in the HERMES model of straight Type D conditions at night may be very wide of the mark in hilly terrain. Reduction of average wind speeds and turbulence levels in valleys will probably require the use of a more stable dispersion type.

1115998A

Any buoyancy or momentum effects on plume rise should also be incorporated into the model using the techniques developed in Oak Ridge[20-22]. In view of possible interactions with cooling-tower plumes in some cases, latent heat and condensation effects from this source should also be considered, cf. Hanna[23].

Finally, all removal effects should be carefully studied. While exponential removal may be an adequate assumption for radioactive decay, dry deposition, and "below-cloud" precipitation scavenging, its applicability to "in-cloud" scavenging is open to question, cf Engelmann[24]. When clouds of material have grown to such a size that they interact directly with natural (or artifical, cf. above) water clouds, then "in-cloud" removal effects become important. This mechanism is probably a significant removal mechanism for atmospheric radioactivity at scales of 10-100 km.

Water Transport Model

The water transport element of the HERMES code WTRAN is designed to calculate the concentration in streams of both dissolved radionuclides and radionuclides adsorbed on sediments. Sources of radionuclides consist of reactors and fuel reprocessing plants, with air-borne constituents dropped on centroids. The procedure consists basically of routing the radionuclides from their source through the river system, adding together the dissolved and suspended loads where tributaries join, and depositing or scouring absorbed radionuclides based upon sediment transport characteristics; all with due regard for radioactive decay.

Obviously, many simplifications were necessary to model this system, both because of complexity of the "real world" situation and the paucity of data. Therefore, a philosophy had to be adopted to guide development of the model. Page 10 of the HERMES report states that in each case where assumptions were made, they were made to approximate the "most likely" conditions as

1159988

constituents can vary by an order of magnitude on major streams in the Tennessee Valley. For example, the median calcium concentration on the Clinch River is about 60 ppm, while that on the Little Tennessee River is about 4 ppm. This difference would affect the K_D for ^{90}Sr. If the total exchange capacity of sediments in both rivers can be typified by the Clinch River 17 meq/100 gms, the K_D for ^{90}Sr is calculated to be 50 ml/gm in the Clinch River and 850 ml/gm in the Little Tennessee River. The K_D for other radionuclides could also be affected by differences in mineral quality. In particular, any K_D values obtained from measurements made outside this area should be verified.

There is a program in WTRAN called LAKE which calculates the concentrations of dissolved radionuclides in lakes fed by local runoff. This routine appears to be developed specifically for Lake Michigan and may not be applicable elsewhere.

Modifications to existing WTRAN codes will have to be made to accommodate TVA's reservoirs. Specifically, one algorithm will have to be devised to handle sediment deposition in backwater areas on tributary streams. The present technique of linking sediment transport to flow would be difficult to adapt. Another algorithm will have to be developed to handle the flow through stratified reserviors. Programing these algorithms will probably involve changes of the present computation sequence in WTRAN. Because of the many cross linkages among subroutines, programing of these modifications would probably have to be done jointly with HEDL programmers.

Radioactive Dose Model

Much of the section entitled "Radioactive Dose Model" is inadequate for application to the Tennessee Valley Region. With the possible exception of dose from exposure to contaminated ground (see below), none of

opposed to "worst condition" assumptions. However, some of the algorithms in WTRAN seem to reflect the latter assumptions. For example, the overland flow and erosion processes are not modeled. Rather, the simplifying assumption is made that each month all of the air-dropped radionuclides enter the stream system so that modeling consists of simply adding each month's contribution to the stream system with appropriate decay. For the DOSE model, however, the assumption is made that none of the air-dropped radionuclides moved into the water system and therefore built up in the plow layer. These assumptions greatly simplify modeling; however, they reflect a "worst condition" approach since the same radionuclides cannot be available in both systems. The point illustrated by this example is that it is difficult for a user to evaluate the appropriateness of model algorithms or assumptions because apparently the stated philosophy was not always strictly followed. Moveover, recommending modifications to the model is difficult because it is not obvious how closely the "most likely" conditions need to be approximated.

The buildup of radionuclides on sediments prior to the year 2000 is not clear from the report. Presumably, based upon a statement on page 2 of the report, deposition is back calculated 5 to 10 years. However, this back calculation apparently is made based upon the read-in flows for the year 2000. The description for subroutine FLREAD, page 77, suggests that the flow data are not restricted to monthly average conditions; median or low flows may also be used. However, were low flows to be used for the year 2000, the back calculations would also be based upon these flows, which would lead to improbable results.

The distribution coefficient K_D used to determine the portion of a radionuclide adsorbed upon sediments probably should be measured in this area at representative streams. The concentration of some of the mineral

1115999B

the inadequacies specifically relate to any peculiarities of the Tennessee Valley; rather, they are intrinsic in the model. A fundamental difficulty in the present form of HERMES is that an overcomplexity of nuclides, pathways, and target organs tends to obsure the picture, thus the further refinement mentioned on HERMES, page 2, is certainly desirable; however, we would caution that some of the more suspect features of HERMES be revised before decisions are made to eliminate what might turn out to be major contributors to dose. Review of the basic assumptions used in HERMES (see Appendix) indicates that, where questionable, the majority of the assumptions (70%) tend to underestimate dose. However, the most serious defects appear to be in the calculation of dose to skin (Table 5) and in the treatment of internal dose due to intake of tritium (Appendix).

HERMES does not consider the effect of resuspension on either internal or external dose. In discussions of this point, Hanford people indicated that resuspension was ignored because "we don't know enough about it." We would have to agree that little is known about resuspension, and, based on attempts to estimate the effect of resuspension in other contexts[25], our intuition suggests that it is not a major pathway; however, we probably know as much about resuspension as we do about some of the other factors treated in detail by HERMES. Furthermore, doses resulting from resuspension are in addition to those from other pathways, and a parametric analysis should be made to justify its omission.

There is no provision in the HERMES code to account for the contribution to the radiation dose from world-wide buildup of tritium and kryption-85 from the operation of nuclear facilities. According to preliminary estimates of EPA[26], this contribution may average 0.06 mrem/yr in the United States, about a 15% increase over the dose from local sources in the year 2000.

1116000A

HERMES considers only dose to man. There is no estimation of dose to biota. In light of present requirements for environmental impact statements, which were not stressed at the time HERMES was conceived, TVA and ORNL should reconsider this point.

The food pathways model equations do not appear to be representative of a real system. In most cases, concentration in the food is considered to be directly proportional to intake. The inadequacy of this approach can be seen by considering a cow which is suddenly taken off contaminated food. The model (Equation 21) predicts that milk concentrations immediately fall to zero, whereas, in fact, concentration in milk simply declines exponentially at a rate determined by the effective half-life. A more appropriate model would consider food concentration in its relationship to body burden in cows, which in turn is directly related to ingestion and elimination rates. We recommend that the basic equations in this section be changed. A reasonable approach would be to establish a flow chart for the system and develop a set of differential equations describing changes in the body burdens of the various compartments or pools in the system. The set of equations could then be solved to yield time dependent body burdens and food concentrations. This approach would result in a more realistic set of equations and would involve very few additional parameters. Transfer of radionuclides from the environment into food products was estimated by Booth and Kaye[27] using a systems analysis model designed around the available environmental data. Their results for transfer of some nuclides from milk are given in Table 1 along with comparable results listed in HERMES Table III-4. Considering the differences in the ORNL and the HERMES models and in view of the fact that input data for the two models were taken, in most cases, from different sources, the comparisons are rather good.

1116000B

Table 1. Comparison of Transfer Coefficients from Feed to Milk Resulting from the HERMES and ORNL Models

Nuclide	ORNL Model* f_m	HERMES Model** S_d
^{3}H	0.020	0.020
^{65}Zn	0.039	0.030
^{89}Sr (or ^{90}Sr)	0.002	0.001
^{131}I (or ^{133}I)	0.020	0.010
^{137}Cs	0.014	0.005

*$f_m = 0.0075\ \tau_{g,c}$, where $\tau_{g,c}$ is the transfer parameter tabulated in ref. 27.

**S_d from Table III-4, page 92, of the HERMES report.

1116001A

We have no specific argument with the sources of data used, but, as stated by the authors on page 87, the data available are quite limited. In fact, only three or four nuclides have been investigated in sufficient detail to warrant the level of modeling in the report. A priori, it can be stated that it is not possible to predict accurately concentrations of 50 nuclides in 16 food products based on our current information. An examination of the tables of model parameters reveals that the authors were forced to make rather crude guesses for the vast majority of the parameters. Under these circumstances, the health physicist frequently employs the method of conservative estimates. That is, he chooses values for the parameters which would cause the concentration to be at least as large and probably larger than the real value. This approach certainly was not followed in HERMES. Table 2 below shows a comparison of cesium concentration in milk (Equations 21 and 22) utilizing parameters taken from the report with the concentration based on conservative parameter values. While one might quibble about the choice of conservative parameters, increasing some and decreasing others, the point remains that uncertainties in the parameters could well lead to an order of magnitude difference in the predicted concentration.

In its complexity, the HERMES food pathways model may imply to a reader that we are able to deal with the food pathways at a level of sophistication that is at present far beyond our ability to quantify. Reading the equations in the report, one may be led to conclude that the model yields a reasonable estimate of food concentrations, while, in fact, the estimate may be wrong by several orders of magnitude for any given centroid. Consequently, we recommend that the food pathways model not be retained in its present form. It is our opinion that an explicit error analysis or comparison with a well designed experimental test will show how poor the estimate is.

1116001B

Table 2. Comparison of HERMES and "Conservative" Estimates of Cesium Concentration in Milk Using Equations 21 and 22

Parameter	Estimate from HERMES	Based on Conservative Estimates*	Parameter	Estimate from HERMES	Based on Conservative Estimates*
S_d	0.005	0.008**	Y_g (July)	0.35	0.25
Q_{fd} (July)	55	69	ϵ_{gm} and ϵ_{sm}	110	160
R	0.25	0.4	B_g	0.00064	0.00112
Y_f (July)	1.8	1.0	Q_{sd} (July)	13	17
λ_E	0.0496	0.03	$t_{\theta s}$	3 (assumed)	1.0
t_f	30	50	Y_s (July)	2.3	1.6
B_f	0.04	0.07	B_s	0.04	0.07
P	224	112	G_d	90	117
Q_{gd} (July)	36	45	N_d	0	0.05
λ_r	0.0000632	0.0000632	L_{dm}	50	75
$t_{\theta g}$	1 (assumed)	0.5	Concentration in milk	0.034	0.401**
T_g	0.1	0.3			

*These values reflect the judgment and opinion of R. V. O'Neill regarding possible variations in the values used by HERMES. They were not chosen to be more "realistic," rather to observe the result of applying a conservative stress to the HERMES estimates.

**The ORNL model results (see Table 1) suggest that 0.014 is a realistic value. This would indicate that the concentration in milk could be as much as 0.7.

1116002A

Many of the functions in the HERMES model are appropriate for single pastures or relatively small areas. In our opinion it is not adequate to assume that all cows, chickens, and fish are the same throughout the region and to take the sum of the pastures and rivers. The key to the problem is given on page 86 where the authors admit that changes in land-use and agricultural practices can be expected to occur. That is, the total process being considered over the entire region may well be dominated by the influence of factors not even considered in the model[28]. Consequently, we recommend that for future applications, perhaps as much effort and consideration be placed on land-use dynamics and changes in agricultural practices as were placed on the model for a single pasture in the present model. Explicit consideration would have to be given to all regional-scale processes which would influence concentration. One example is future irrigation practice and the buildup of radionuclides in the plow layer. Pathways of potential exposure to man include a direct external source and internal source by soil to crop transfer.

The ICRP considers genetically significant dose to be an important concept in the assessment of exposures to populations[28]. HERMES provides an estimate of dose received by an individual as a result of radionculide intake during the year 2000 and from various external sources. A dose commitment is calculated as the total internal dose for the succeeding 50 years resulting from intake during only year 2000. No estimate is made of the internal dose to individuals in year 2000 as a consequence of exposure beginning with the first year of the study and progressing up to year 2000. HERMES does not provide an estimate of genetically significant dose.

Where estimates were available from other sources, comparisons were made with HERMES estimates of immersion dose, Tables 3 and 4. While most

1116002B

Table 3. Comparison of Dose Factors for Immersion Exposure in Contaminated Air

Nuclide	Dose Factors [(mrem/hr)/(pCi/m^3)] x 10^8				
	Skin			Total Body	
	HERMES[a]	EXREM[b] (ORNL)	Snyder[c] (ORNL)	HERMES[a]	EXREM[d] (ORNL)
^{3}H	0	0	-	0	-
^{85}Kr	16	17	20	0.22	0.21
^{90}Sr	13	13	-	0.024	-
^{90}Y	87	87	-	58	-
^{95}Zr	84	85	-	68	74
^{95}Nb	75	82	-	64	77
^{131}I	49	54	-	31	41
^{132}I	270	270	-	200	220
^{133}I	88	100	-	44	60
^{135}I	200	350	-	150	330
^{134}Cs	170	170	-	130	160
^{137}Cs	70	77	-	47	61
^{138}Cs	300	320	250	180	220
$^{138}Xe+^{138}Cs$	480	500	370	300	310

[a]From Table III-33, page 149, in HERMES (skin = basal layer; total body = 5-cm depth).

[b]EXREM code (ref. 30) results for β-dose rate at skin surface were corrected to the basal layer of the epidermis as indicated in the footnote to Table 5.

[c]Reference 31 (skin = basal layer).

[d]Total body dose is approximated by the γ-dose to the skin.

1116003

Table 4. Comparison of Dose Factors for Immersion Exposure in Contaminated Water

Nuclide	Dose Factors [(mrem/hr)/pCi/liter] x 10^8			
	Skin		Total Body	
	HERMES[a]	EXREM[b] (ORNL)	HERMES[a]	EXREM[c] (ORNL)
^{3}H	0	0	0	-
^{90}Sr	15	14	0.054	-
^{90}Y	96	91	1.3	-
^{95}Zr	180	170	150	160
^{95}Nb	160	170	140	160
^{131}I	95	100	68	86
^{132}I	550	520	440	470
^{133}I	150	170	96	130
^{135}I	400	710	330	700
^{134}Cs	350	350	290	340
^{137}Cs	140	150	100	130

[a]From Table III-35, page 154, in HERMES (skin = basal layer; total body = 5-cm depth).

[b]EXREM code (ref. 30) (skin = basal layer); see footnote to Table 5.

[c]Total body dose is approximated by the γ-dose to the skin.

1116004

of the dose estimates are comparable, in a few cases the computed doses differ significantly (e.g., ^{135}I). The probable sources of disagreement are in the decay schemes assumed by the various authors.

HERMES considers only gamma radiation from contaminated ground and computes skin and total body (5 cm depth) doses at 1 meter above the surface. The dose estimates are reduced by a factor of 2 to account for rough ground. Calculations of dose to skin at 0.5, 0.75 and 1 meter have been made using the EXREM code of Kaye and Rohwer[28]; these are compared with similar estimates from HERMES in Table 5. The EXREM doses include beta contribution, corrected to refer to the basal layer of the epidermis, as well as that of the gamma radiation. In the case of many radionuclides, the beta dose to the skin is very much larger than the gamma dose, and there is a significant increase in dose rate at 0.5 meter over that at 1 meter. It is clear that by treating only the gamma component and by restricting attention to the 1-meter dose, HERMES ignores a significant contribution to the skin dose. Thus, the assumption (HERMES, page 148) that the dose factors from contaminated ground are independent of body size is not valid. The beta component of the radiation field should be included, and 0.5 meter should be chosen as the appropriate point to calculate dose factors for children (average 4-year-olds). In view of the fact that most of the population is urban and exposed to relatively smooth roadways, parking lots, etc., and considering that much of the skin surface is not covered by clothing, particularly in the case of children, the factor of 2 reduction for rough ground should be reconsidered and possibly dropped.

In many parts of the Tennessee Valley region, the topography is dominated by moderately high ridges and rather narrow valleys. It may be worthwhile to compute dose estimates from ground deposits on the inside surface of an infinite half-cylinder to compare the ridge and valley situation with that of an infinite plane source as assumed by HERMES.

1116005

Table 5. Comparison of Dose Factors for Exposure while Standing on Contaminated Ground

Nuclide	Dose Factors [(mrem/hr)/(pCi/m^2)] x 10^{10}					
	Skin				Total Body	
	2 x HERMES[a] (1 meter)	EXREM[b] (1 meter)	EXREM[b] (0.75 meter)	EXREM[b] (0.5 meter)	2 x HERMES[a] (1 meter)	EXREM[c] (1 meter)
^{3}H	0	0	0	0	0	-
^{90}Sr	0	41	130	420	0	-
^{90}Y	-	2400	3000	3700	-	-
^{95}Zr	120	140	160	230	120	130
^{95}Nb	140	140	150	170	120	130
^{131}I	68	110	200	470	56	73
^{132}I	400	1500	2000	2800	340	380
^{133}I	90	1100	1500	2300	74	110
^{135}I	280	840	1000	1300	240	540
^{134}Cs	280	330	440	740	240	280
^{137}Cs	98	170	250	510	82	110
^{138}Cs	480	3100	3600	4400	420	340

[a]From Table III-34, page 152, in HERMES (skin = basal layer; total body = 5-cm depth).

[b]EXREM code was run for a point 108 cm above the contaminated surface. With respect to the attenuation of β's, this is approximately the equivalent to 100 cm of air plus approximately 9 mg/cm^2 of tissue. The β-dose correction factors obtained by comparing the 108-cm dose to that at 100 cm in air were used also for the other distances as well as for immersion in air and water (Tables 3 and 4).

[c]Total body dose is approximated by the γ-dose to the skin.

1116006

From a practical standpoint, the assessment of population exposures can be accomplished by dividing the population into groups that are small and homogeneous with respect to factors which influence dose. Age is a convenient characteristic to differentiate population groups, and this characteristic has been used in the Radioactive Dose Model. However, the infant is included in the age group 0 to 11 years, and dose to this group is based on the habits and characteristics of a 4-year-old. The infant may turn out to be the critical segment of the population (group receiving the largest dose) and should be considered separately in the dose assessment.

We disagree with the placement of strontium in the "insoluble" category and of cerium in the "very insoluble" category with respect to solubility of inhaled radionuclides (HERMES Table III-38). In our experience, strontium[32] should be considered in the soluble category and cerium[33] should be classed as "insoluble" in the context as used in HERMES.

The assumptions used in the calculation of internal dose due to the intake of tritium are seriously in error (see Appendix). While the relative significance of tritium is in no way indicated in the HERMES report, personal contact with HEDL personnel suggests that it is the major factor in assessing dose. For this reason it is especially important to revise the basis for estimating dose from tritium. In this regard, we further recommend the inclusion of skin as an organ in the calculation of internal dose.

1116007

SUMMARY AND CONCLUSIONS

Overall Model Structures

HERMES should be converted to ASA Standard FORTRAN and modified to include consistent terminology, suitable documentation, and a listing of sample problems. We believe many advantages can accrue if the documentation and format of HERMES would permit convenient transfer of the program to other computers. Of perhaps greatest importance would be the ability to cross check and compare results obtained at the different sites; this would insure a reliability in application of a very complex set of subroutines. The ease of understanding and implementing changes in the program with standard FORTRAN would likely encourage widespread acceptance and use of HERMES and improve its eventual capabilities.

Electric Power Economy Model and Nuclear Facility Siting

It is recommended that for the immediate Tennessee Valley Study Area the Electrical Power Economy and Nuclear Facility Siting models of HERMES be replaced with a list of nuclear generating plants which TVA estimates will be added to this region between now and the year 2000. The list would also contain general locations for the plants. For the area surrounding the TVA power service area, we recommend use of ORSAC in place of these components of HERMES because it is already operational on the IBM system. Plant load histories should be variable rather than predetermined. The high-temperature, gas cooled reactor (HTGR) should be included as one of the reactor types.

Radioactive Effluent Characterization

The components of HERMES used to provide radiological source terms incorporate a degree of sophistication that now exceeds available operating

1116008

experience. Tables that list radionuclide releases from various nuclear facilities that have their own unique radwaste treatment systems are believed to represent a more convenient method of describing source terms. These data should reflect the considered judgement of the AEC, utilities, and industry and be compatible with similar information now used in the preparation of environmental impact statements. The tabular approach should simplify the incorporation of changes in source terms until such time that a more detailed modeling procedure is justified. The tabular data should include all effluents of potential significance at reactor and fuel reprocessing plants and all radionuclides from such facilities that may contribute a significant part of the radiation dose. A future consideration of the regional study would be the inclusion of other potentially significant radiation sources of the nuclear fuel cycle that may result in the exposure of man and the environment.

Living Patterns Model

The living patterns model is principally a data bank to store information on the habits and characteristics of inhabitants in the Upper Mississippi River Basin and on the location and production of food and water in the area. As such, it does not have general application to other regions of the country without modifications. Population centroids should, in general, be specified for each country within a study region and population projections should be improved by including fertility and mortality estimates in the calculation. Region specific information is necessary to convert food production to food consumption and to route surplus food to centroids representing deficit areas.

1116009

Atmospheric Transportation Model

A basic decision must be made of which form of the Gaussion model provides the best estimate of diffusion from a continuous point source. Careful study and documentation is necessary to justify a choice between the "long-term average plume" version and the "integrated-puff" version for application in the Tennessee Valley Region. Appropriate dispersion coefficients must be selected for use with the model. Modifications of the model should also be considered to account for (1) peculiarities of the environment such as terrain effects and "in-cloud" precipitation and (2) peculiarities of the source such as buoyancy and momentum effects on plume rise and interactive effects with cooling tower plumes.

Water Transport Model

Modifications in the water transport component (WTRAN) of HERMES are necessary to accommodate basic differences in the occurrence of surface waters in the Tennessee Valley Region. This region is characterized by numerous reservoirs and operation of these reservoirs influence the movement of both suspended solids and dissolved materials. Allowance must be made for sediment deposition in backwater areas on tributary streams and for flow through stratified reservoirs. Information should also be developed on the distribution of radionuclides between suspended solids and solution for representative streams in the Tennessee Valley. And finally, to maintain Consistency in the report, either the text should be revised to acknowledge that a justifiable "worst case" assumption was followed in allocating the air-drop radionuclides to greatly simplify the computations or the allocation of the air-drop radionuclides between the water and land phases should be more realistically programmed.

1116010

Radioactive Dose Model

Portions of the food pathways model (FPM) used in HERMES imply a level of sophistication that is not consistent with the available environmental data. Yet, on the other hand, likely local and regional differences and changes in land use and in agricultural practices are not included. A comparison of the HERMES estimate of cesium concentration in milk with one based on possible conservative values of the system parameters suggests that real variations within and between regions (or, equivalently, uncertainty in the values used in the FPM) can lead to an order of magnitude difference in the resulting dose estimates. The most significant omissions from the Radioactive Dose Model were calculations of dose to infants, the dose to children at 0.5 meter above a contaminated surface, the β-component of the radiation field above the surface, the treatment of tritium, and the dose to aquatic and terrestrial organisms other than man.

1116011

REFERENCES

1. J. F. Fletcher and W. L. Dotson, HERMES--A Digital Computer Code for Estimating Regional Radiological Effects from the Nuclear Power Industry, HEDL-TME-71-168 (Dec. 1971).

2. W. P. Heising, History and Summary of FORTRAN Standardization Development for the ASA, Communications of the ACM 7, 590-625 (1964); Appendixes, Comm. of the ACM 8, 287-88 (1965); USA Standard FORTRAN (USAS X3.9-1966), USA Standards Institute, New York (1966); Clarification of FORTRAN Standards-Initial Progress, Comm. of the ACM 12, 289-94 (1966); J. N. Haag, Comprehensive Standard Fortran Programming, Hayden Book Co., Inc., New York (1969).

3. K. V. Roberts, The Publication of Scientific FORTRAN Programs, Computer Physics Communications 1, 1-9 (1970).

4. Ned Chapin, Flowcharting with the ANSI Standard: A Tutorial, Computing Surveys 2, 119-46 (1970)

5. Sperry Rand Corp.,1107 Thin-Film Memory System FORTRAN-IV Programmer's Reference Manual, UNIVAC Data Processing Department Report UP-3569, Rev. 1 (1966).

6. Sperry Rand Corp., UNIVAC 1100 Series FORTRAN V, UNIVAC Report UP-4060, Rev. 2 (1971).

7. C. H. Bloomster, J. H. Nail, and D. R. Haffner, PACTOLUS: A Code for Computing Nuclear Power Costs, USAEC Report PNWL-1169, Pacific Northwest Laboratory, Richland, Wash., (1970).

8. R. L. Engel, DAEDALUS II: A Computer Code to Generate a Linear Programming Model of a Nuclear Power Economy, Pacific Northwest Laboratory, Richland, Wash. (In Preparation).

9. Personal Communication M. A. Meyer to R. E. Kemper, "Computation of Center of Population by the Bureau of the Census", April 12, 1972.

10. "Projections of the Population of the United States by Age and Sex (Interim Revisions): 1970 to 2020", U. S. Department of Commerce, Bureau of the Census, Series P-25, No. 448 (August 6, 1970).

11. F. Gifford,"An Outline of Theories of Diffusion in the Lower Layers of the Atmosphere," Meteorology and Atomic Energy 1968 (D. Slade, Ed.) Chapter 3 (1968).

12. C. R. Dickson, Meteorology for the Loss of Fluid Test Reactor - Progress Report, USAEC IDO-12059 (1967).

13. P. G. Saffman, "The Effect of Wind Shear on Horizontal Spread from an Instantaneous Ground Source,"Quarterly J of Roy. Meteor. Soc. 88, 382-93 (1962).

1116012

14. F. B. Smith, "The Role of Wind Shear in Horizontal Diffusion of Ambient Particles," Quarterly J of Roy. Meteor. Soc. 91, 318-29 (1965).

15. F. Pasquill, "The Influence of the Turning of Wind with Height," Phil. Trans. Roy. Soc. Lond. A, 265, 173-81 (1969).

16. K. R. Peterson, "Continuous Point Source Plume Behavior Out to 160 Miles," J. App. Meteor. 7, 217-26 (1969).

17. T. V. Crawford, "A Computer Program for Calculating the Atmospheric Dispersion of Large Clouds," UCRL-50179, 56 (1966).

18. T. V. Crawford, K. R. Peterson, and J. B. Knox, "Predictions of Long Distance Radioactivity and Radiation Doses to Man in 13 Hypothetical Excavation Applications," UCRL-50936, 51, Rev. 2 (1971).

19. I. Van der Hoven, et al., "Southwest Energy Study, Report of the Meteorology Work Group," Appendix E, by NOAA for U.S. Dept. of Interior, (DRAFT 1972).

20. G. A. Briggs, Plume Rise, vi, 81, USAEC, DTI, TID-25075 (1969).

21. G. A. Briggs, "Some Recent Analyses of Plume Rise Observations," Proceedings of 1970 Int. Air Poll. Conference of the Int. Union of Air Poll. Prevention Associations (to be published).

22. G. A. Briggs, "Plume Rise: A Recent Critical Review," Nuclear Safety 12, 15-24 (1971).

23. S. H. Hanna, "Rise and Condensation of Large Cooling Tower Plumes, Jounal of Appl. Meteor.,(to be published in August 1972).

24. R. J. Engelmann, "Scavenging Prediction Using Ratios of Concentration in Air and Precipitation," Proceeding of Symposium on Precipitation Scavenging, Richland, Washington, July 2-4, 1970, USAEC Symposium Series 22 (1970).

25. B. R. Fish, ed., Surface Contamination (Pergamon Press, Oxford, 1967).

26. C. R Miller, Personal Communication, June 1972, Draft of report "Estimates of Ionizing Radiation Doses in the United States 1960-2000" Draft dated June 1971.

27. R. S. Booth and S. V. Kaye, "A Preliminary Systems Analysis Model of Radioactivity Transfer to Man from Deposition in a Terrestrial Environment," ORNL-TM-3135 (Oct. 1971).

28. International Commission on Radiological Protection, Recommendations of the International Commission on Radiological Protection (adopted Sept. 7, 1965) ICRP Publication 9 (1966).

1116013

29. a. S. V. Kaye and P. S. Rohwer, "Dose-Estimation Studies Related to Proposed Construction of an Atlantic-Pacific Interoceanic Canal with Nuclear Explosives: Phase III," ORNL-4579 (Dec. 1970).

b. W. D. Turner, "The EXREM II Computer Code for Estimating External Doses to Populations from Construction of a Sea-Level Canal with Nuclear Explosives,", CTC-8 (July 21, 1969)

30. a. W. S. Snyder, Unpublished dose calculations (Oct. 1971).

b. L. T. Dillman, "Scattered Energy Spectrum for a Monoenergetic Gamma Emitter Uniformly Distributed in an Infinite Cloud," Health Physics Division Annual Progress Report for Period Ending July 31, 1970, ORNL-4584, 216-22 (July 31, 1970).

31. L. B. Farabee, "Absorption of ^{90}Sr from a Puncture Wound," Health Physic Annual Progress Report for Period Ending July 31, 1966, ORNL-4007, 266-267 (July 31, 1966).

32. G. W. Royster, Jr., B. R. Fish, and L. B. Farabee, "In Vitro Methods of Estimating Relative Solubility in Body Fluids," presented at the 9th Annual Conference on Bioassay and Analytical Chemistry, San Diego, California (October 10-11). Abstract in USAEC report TID-7696.

1116014

Attachment I

HERMES Critique Responsibility[a]

Section II Overall Model Structure
C. W. Nestor, ORNL, and T. C. Tucker, ORNL

Section III HERMES Code Elements

A. Electrical Power Economy Model
G. R. Siegel, TVA; T. M. Jackson, TVA; R. T. Jenkins, TVA; D. H. Waters, TVA; and R. Salmon, ORNL

B. Nuclear Facility Siting
G. R. Siegel, TVA; T. M. Jackson, TVA, R. T. Jenkins, TVA; and D. H. Waters, TVA

C. Radioactive Effluent Characterization
J. P. Nichols, ORNL; M. J. Bell, ORNL; G. R. Siegel, TVA; and B. F. Roberts, TVA

D. Living Patterns Model

Centroid Designation, Population Centers K. P. Nelson, ORNL

Drinking Water, Work and Recreation, B. R. Fish, ORNL

Food Production and Consumption, R. V. O'Neill, ORNL

E. Atmospheric Transport Model
F. A. Gifford, ATDL-NOAA

F. Water Transport Model
W. O. Wunderlich, TVA; R. P. Betson, TVA; and T. Tamura, ORNL

G. Radioactive Dose Model
B. R. Fish, ORNL; R. V. O'Neill, ORNL; R. S. Booth, ORNL; K. E. Cowser, ORNL; and W. H. Wilkie, TVA

Appendix C Fission and Activation Product Generation Analysis
J. P. Nichols, ORNL

[a]Underlined names denote primary responsibility

1116015

APPENDIX

ANALYSIS OF KEY ASSUMPTIONS USED IN THE CALCULATION OF RADIATION DOSES IN HERMES

1. (Page 147) External Exposure--The infinite-source assumption, or a modified version of it, is reasonable for calculations of doses from submersion in air, immersion in water, and contaminated land surfaces. However, doses from overhead clouds and plumes cannot be calculated using this assumption. Overhead clouds could be expected to contribute significant doses near BWR's and fuel reprocessing plants which generally employ high stacks.

2. (Page 147) The assumption that beta particles external to the body do not irradiate internal organs is valid.

3. (Page 147) The methods used to obtain gamma radiation dose at 5-cm depth in tissue are not discussed either in the text of HERMES or in NBS Handbook 85, which is referenced. While 5 cm may be a convenient number, specifically for describing the average depth of blood-forming organs in the adult, it is not a valid number for other age groups or for all internal organs, particularly bone and thyroid. Therefore, this refinement is considered to be invalid.

4. (Page 148) A 2π geometry was assumed for both gamma and beta doses from submersion in contaminated air. This assumption is approximately valid for gamma irradiation, although a larger factor could be applied to an erect human because of ground scatter of gamma rays and because of relatively small geometric effects. For beta irradiation the 2π factor slightly underestimates the real situation for most of the convex surfaces of the human body. The statement that "..the physical arrangement approaches the infinite volume (4π geometry)" is quite obviously incorrect because of the beta ranges of only a few millimeters in body tissue. Such a statement would be correct only for an infinitely small tissue volume suspended in air.

1116016

5. (Page 148) Equation 39 appears to be incorrect. Effective beta and gamma energies can be summed and multiplied by a common factor only if a small-tissue approximation is employed, as in the following relation which is valid for sea-level locations (pressure corrections may be required in some cases):

$$(D.F.)_{submersion} = \left(2.13 \times 10^{-3}\right)\left(\frac{1}{1293}\right)\left(\frac{293}{273}\right)\left(1.14\right)\left(\frac{1}{2}\right) \times \left(\bar{E}_\beta + E_\gamma\right)$$

$$\left(\frac{g\text{-mrad}}{MeV}\right)\left(\frac{dis}{pCi\text{-}d}\right)\left(\frac{mrem}{mrad}\right) \times \left(\frac{m^3 \text{ air @ STP}}{g}\right) \times \left(\frac{^oK}{^oK}\right) \times \left(\frac{^s tissue}{^s air}\right)$$

$$\times \left(\frac{2\pi}{4\pi}\right)\left(\frac{MeV}{dis}\right)$$

$$(D.F.)_{submersion} = 1.01 \times 10^{-6}\left(\bar{E}_\beta + E_\gamma\right) \text{ mrem/hr per pCi/m}^3.$$

This equation is strictly applicable only if all gamma interactions occur in air and all tissue dose is delivered by beta particles and electrons. The constant 8.87×10^{-7} appearing in HERMES Eq. 39 is low by about 12%. Equations 39 and 41 include a factor $\bar{E}_\gamma$ defined as the average gamma energy per disintegration. There is no discussion to clarify what is meant by an average gamma energy and how this relates to depth dose.

6. (Page 148) The assumption that radiation fields are not significantly perturbed by the presence of a person is contradicted by the admission of a gamma depth-dose correction, and the assumption that dose factors are independent of body size is valid only if the 5-cm depth-dose correction is not employed. While this is a relatively minor point, it may be used to support use of the gamma dose to skin in lieu of the 5-cm depth dose to approximate total body dose.

7. (Page 148) Material deposited from the air or from irrigation water onto the ground is not at all typified by a "nearly uniform, thin sheet of contamination," rather it is as uneven and inhomogeneous as the earth's surface. However, a dose model based on an infinite plane source is acceptable because the resulting dose estimates will probably be conservative.

8. (Page 150) No definitive justification was supplied for the inclusion of the factor of 0.5 in Eq. 40 for these doses. No discussion is supplied to indicate how buildup of radioactivity in ground layers and sediment is predicted. This is an important detail.

9. (Page 151) Water Immersion--As commented above, the assumption that external dose factors do not vary with person size is invalid if gamma surface-to-depth-dose ratios for 5 cm are used. These dose factors will certainly underestimate doses to children.

10. (Page 151) Although the statement "for beta radiation, the geometry is approximately 2π" is correct, the corresponding discussion for air submersion (p. 148) mentions a 4π geometry for beta radiation in contradiction.

11. (Page 153) The assumption that dose factors for water surface exposures are approximately one-half the corresponding dose factors for in-water activities is considered to be valid.

12. (Page 153) Transpiration of Tritium--The assumption that the transpiration dose is equal to the inhalation dose from tritium is corroborated by the ICRP.[a] The absorption rate by each route is approximately 10 μCi absorbed per minute per μCi of tritium per liter in the ambient air.[b,c] Because tritium rapidly equilibrates

---

[a] ICRP Publication 10, "Report of Committee IV on Evaluation of Radiation Doses to Body Tissues from Internal Contamination due to Occupational Exposure," Pergamon Press, Inc., New York, 1968.

[b] E. A. Pinson and W. H. Langham, "Physiology and Toxicology of Tritium in Man," J. Appl. Physiol. 10, 108 (1957).

[c] R. V. Osborne, "Absorption of Tritiated Water Vapour by People," Health Phys. 12, 1527 (1966).

1160018

with all body water, the assumption that tritium absorbed via transpiration does not deliver a dose to bone, lungs, or GI tract is invalid. Furthermore, since tritium does not contribute to skin dose except as an internal emitter and because skin is not among the internal organs considered by HERMES, it appears that a significant dose factor may have been overlooked by HERMES. Tritium dose to the basal layer of the epidermis can be expected to be at least as large as that to the total body. In addition, while there is no explicit statement explaining the details of calculating dose to the GI tract due to the inhalation of tritium, references to ICRP equations (page 155) and the form of Eq. 43 lead us to question whether HERMES erroneously calculates the dose assuming the tritium to be dispersed only in the contents of the GI tract or whether it is properly taken to be the same as the total body dose.

13. (Page 155) Internal Dose--The methods outlined by the Medical Internal Radiation Dose Committee of the Society of Nuclear Medicine are favored by some health physicists for the calculation of internal dose. However, we concur with the decision to base the HERMES calculations on the methods described by the ICRP.

14. (Page 155) Equation 42 is correct.

15. (Page 155) Equation 43 is incorrect and should be replaced by the following relation:

$$(\text{D.F.})\ \begin{matrix}\text{inhalation}\\ \text{GI tract-LLI}\end{matrix} = \frac{51.2 \times 10^{-3}\, f_a (1 - f_1)\, e^{-\lambda_r t'}\, \mathcal{E}\left(1 - e^{-\lambda_r \tau'}\right)}{2\, m\, \lambda_r}$$

$$\left(\frac{\text{g-mrad}}{\text{MeV}}\right)\left(\frac{\text{dis}}{\text{pCi-d}}\right)\left(\frac{\text{MeV-mrem}}{\text{dis-mrad}}\right)\left(\frac{\text{d}}{\text{g}}\right)$$

$$(\text{D.F.})\ \begin{matrix}\text{inhalation}\\ \text{GI tract-LLI}\end{matrix} = \frac{0.0256\, f_a (1 - f_1)\, e^{-\lambda_r t'}\, \mathcal{E}\left(1 - e^{-\lambda_r \tau'}\right)}{m\, \lambda_r}\ \frac{\text{mrem}}{\text{pCi}}\,.$$

The neglect of the radioactive decay during transit in the lower large intestine (included in the fraction $(1-e^{-\lambda_r \tau'})$) will result in an overestimate of the dose from radionuclides having half-lives in the order of days or less. Apparently the assumption was made that short-lived radionuclides would not be taken into the body in significant quantities, and this assumption is probably unjustified. The HERMES model for GI tract dose neglects the contribution of nuclides such as the iodines and cesiums which can contribute significant doses to the small intestine and virtually none to the lower large intestine. The values assumed for f_a are in agreement with ICRP Publication 2. The mass of the contents of the lower large intestine should be 135 g to be consistent with a more recent figure recommended to the ICRP by Eve.[a] The use of 150 g as given in ICRP Publication 2 will result in underestimates of the doses by approximately 11%.

16. (Page 157) The value of including refined estimates of the average beta energies can be debated. The ICRP has not endorsed this complication; however, there is no reason not to use accurate $\bar{E}/E_o$ values if these can be generated easily.

17. (Page 157) It is not clear as to what footnote (a) to Table III-37 refers. If this refers to the GI tract data, the values should be changed from 35 to 32 and from 100 to 95 for reasons discussed above.

18. (Page 158) Values for t' and τ' should be based on adult values of 0.75 and 1.0 days, respectively, in order to be consistent with Eve's recommendations to the ICRP (see ref. I. S. Eve). The corresponding values for the child are 0.18 and 0.23 days and for the teen are 0.53 and 0.70 days. However, from statements made by Eve[a] it appears doubtful that transit time in the young will scale linearly with body weight in comparison with adults.

---

[a] I. S. Eve, "A Review of the Physiology of the Gastrointestinal Tract in Relation to Radiation Doses from Radioactive Materials," Health Phys. 12, 131 (1966).

19. (Page 158) A listing and a discussion of the probable chemical and physical forms should be provided for the radionuclide releases of reactors and fuel reprocessing plants in order to justify the categorizations employed for the various pathways.

20. (Page 159) Equations 44 and 45 are incorrect. The correct forms are as follows:

$$\text{(D.F.) ingestion, internal organs} = \frac{0.074\, \mathcal{E}\tau\, f_w (1 - e^{-\lambda_e t})}{m}$$

$$\text{(D.F.) ingestion, GI-LLI} = \frac{0.0256\, \mathcal{E}\tau'\, e^{-\lambda_r t'} (1 - f_1)(1 - e^{-\lambda_r \tau'})}{m\, \lambda_r}$$

where λ_e and λ_r are the effective and radiological decay constants, respectively. The same comments above that referred to Eq. 43 also apply to Eq. 45.

21. (Page 159) The assumption that all nuclides in food and water are in soluble form is questionable. This assumption will tend to underestimate the dose to the lower large intestine.

22. (Page 160) It is not made clear how HERMES includes the effects of radionuclide buildup in the environment, particularly for food chains, surface contamination, and sedimentation.

23. (Page 88) As discussed in the main body of this document, Eq. 21 is not an adequate representation of the dynamic system to be expected. Similar comments may be made about Eqs. 25 (p. 105), 27 (p. 108) and 29 (p. 109). While, in principle, the same applies to Eq. 31 (p. 113), it may be considered of no practical significance because equilibrium between fish flesh and the local water is, in most respects, rapidly attained as pointed out in HERMES.

24. (Page 89) Equation 22 has two typographical errors in it. On the first line, the second parenthesis contains an equals sign which should be a plus sign; and on the second line, the premultiplier of the summation sign contains an extraneous equals sign.

25. (Page 90) The capital W appearing in the definition of the radionuclide concentration in the plow layer of stored feed from water deposition probably should be a lower case w and appear as a subscript.

1116022

Internal Distribution

S. I. Auerbach
J. A. Auxier
M. J. Bell
F. T. Binford
L. L. Bennett
R. S. Booth
A. A. Brooks
K. E. Cowser
C. W. Craven
F. L. Culler
B. R. Fish
D. A. Gardiner
J. H. Gibbons
S. V. Kaye
J. L. Liverman
K. P. Nelson
C. W. Nestor
J. P. Nichols
R. V. O'Neill
P. S. Rohwer
R. Salmon
W. S. Snyder
E. G. Struxness
R. C. Taeuber
T. Tamura
J. R. Totter
D. B. Trauger
T. C. Tucker
R. I. Van Hook
A. M. Weinberg
J. P. Witherspoon

External Distribution

N. F. Barr, Division of Biomedical and Environmental Research, USAEC, Washington, D. C. 20545

R. P. Betson, TVA, 331 Evans Building, Knoxville, Tennessee 37902

D. F. Cope, USAEC, DRDT-ORNL Site Office, Oak Ridge, Tennessee 37830

R. J. Engelmann, Division of Biomedical and Environmental Research, USAEC, Washington, D. C. 20545

J. F. Fletcher, Washington Hanford Company, P. O. Box 1920, Richland, Washington 99325

F. E. Gartrell, TVA, 719 Edney Building, Chattanooga, Tennessee 37401

F. A. Gifford, ATDL-NOAA, Oak Ridge, Tennessee 37830

C. L. Osterberg, Division of Biomedical and Environmental Research, UASEC, Washington, D. C. 20545

J. Pidkowicz, USAEC, DRDT-ORNL Site Office, Oak Ridge, Tennessee 37830

B. F. Roberts, TVA, 303 Power Building, Chattanooga, Tennessee 37401

G. R. Siegel, TVA, 524 Power Building, Chattanooga, Tennessee 37401

S. Strauch, Division of Reactor Development and Technology, USAEC, Washington, D. C. 02545

G. F. Stone, TVA, 719 Edney Building, Chattanooga, Tennessee 37401

1116023

M. J. Whitman, Division of Reactor Development and Technology, USAEC, Washington, D. C.

W. H. Wilkie, TVA, Muscle Shoals, Alabama

W. O. Wunderlich, TVA, 7th Floor, Valley Fedelity Building, Knoxville, Tennessee 37902

N. B. Hughes, Jr., TVA, 403 Power Building, Chattanooga, Tennessee 37401

H. G. Parris, TVA, 415 Power Building, Chattanooga, Tennessee 37401

R. O. Thomas, TVA, 415 Power Building, Chattanooga, Tennessee 37401

1116024