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**Recommendations Concerning
Research and Model Evaluation
Needs to Support Breeder
Reactor Environmental
Radiological Assessments**

C. W. Miller
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MASTER

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EVALUATION NEEDS TO SUPPORT BREEDER REACTOR
ENVIRONMENTAL RADIOLOGICAL ASSESSMENTS

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RECOMMENDATIONS CONCERNING RESEARCH AND MODEL
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ABSTRACT

A project is under way at Oak Ridge National Laboratory which has as its objective the identification of models available for environmental radiological assessments; evaluation of model structure, simplifying assumptions, and data bases; estimation of uncertainties in model output; and, when possible, recommendation of models and parameters which are best suited to particular assessment situations. When needs are identified, recommendations are also made for further environmental and biomedical research.

The purpose of this report is to present recommendations concerning needs for model evaluations, environmental research, and biomedical research to support breeder reactor environmental radiological assessments. Five different areas covered in separate sections of the report may be summarized as follows:

1. More data are needed to specify dry deposition velocities and to validate plume depletion models. More atmospheric dispersion data are required to characterize flow near buildings, in complex terrain, and for travel distances at 100 km or more.
2. Field data are needed for both the calibration and validation of terrestrial food chain transport models, especially those used to assess the impact of acute radionuclide releases. In addition, few results are available regarding the potential importance of terrestrial pathways of human exposure other than those involving beef and dairy cattle and food crops.

3. Efforts are needed to develop models for the estimation of dose from external exposure to photons from a finite, elevated plume resulting from an acute radionuclide release to the atmosphere. The accuracy of doses estimated for exposure to a contaminated ground surface needs to be investigated.
4. Estimates of doses to man from internally deposited radionuclides require additional scrutiny. More refined data are needed especially to determine age-dependent uptake and retention characteristics of various radionuclides in organs of man.
5. Further study of the quality factor associated with tritium is needed to determine its dependence on dose and dose rate. Additional studies are desirable to specify the relative toxicity of various physiochemical forms of tritium in the environment.

Work on the model evaluation project is continuing at this time. As this work proceeds, modification of the recommendations presented in this report may be made to reflect the latest findings of the project staff.

1. INTRODUCTION

Charles W. Miller

Currently, a number of environmental transport and dose calculation models employing different data bases and assumptions are available for 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 structure, 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. The models examined in this project to date include those developed for the prediction of atmospheric and hydrologic transport and deposition, terrestrial and aquatic food-chain bioaccumulation, and internal and external dosimetry.

The purpose of this particular report is to make recommendations concerning needs for model evaluations, environmental research, and biomedical research to support breeder reactor environmental radiological assessments. It has been prepared to assist the staff of the Fast Reactor Safety Technology Management Center with their planning activities. The needs identified in this report are based on the results of the model evaluation project to date. It should be noted, however, that this project is still under way, and other needs may be identified as new information is analyzed.

This report contains summaries of model evaluation and research needs in the areas of atmospheric dispersion and deposition, terrestrial food-chain transport, internal and external dosimetry, and environmental tritium dosimetry. These summaries reflect the work of those individuals who have contributed significantly to the model evaluation effort.

Numerous publications have been produced by the staff of this project. These publications have been summarized by Kanak and Miller (1980). Many of these publications include identification of relevant model evaluation and research needs. For the most part, this report

represents a consolidation and compilation of the needs previously identified in these other publications. As a result, no attempt has been made in this report to rigorously justify each of the needs identified. Instead, the reader should refer to the cited literature for more information about any given topic.

Also, this report does not represent all of the model evaluation and research needs that have been suggested during the course of the project. Instead, this report attempts to present those needs which seem to the authors to be most relevant to the breeder reactor safety program.

The recommendations presented in the report are usually more qualitative than quantitative in nature. Also, the relative importance of the various recommendations is often not rigorously specified. Both of these conditions result from a lack of data. Until more data are obtained relative to some of these needs, it is not possible to quantify their importance with respect to the total breeder reactor radiological assessment process.

As mentioned previously, work on this project is continuing. Current efforts are focused in three major areas:

1. comparison of predictions from various environmental transport models with measured field data to estimate the uncertainty in model output;
2. continued updating of recommendations concerning models and parameters best suited to breeder reactor environmental radiological assessments (Miller et al., 1980); and
3. identification of further model evaluation, environmental research, and biomedical research needs.

As this work continues, modifications of the information contained in this report will be made as required.

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2. ATMOSPHERIC DISPERSION AND DEPOSITION

Charles W. Miller

One of the principal ways in which radionuclides from breeder reactor facilities reach the environment is through discharges to the atmosphere. These discharges result in doses to man as a result of exposure to the contaminated air, and exposure to surfaces and ingestion of food-stuffs contaminated by radionuclides removed from the plume by deposition processes.

There are a number of environmental mechanisms that can effect the magnitude of these doses. These mechanisms include:

1. deposition and plume depletion,
2. building wake effects,
3. terrain-induced dispersion effects, and
4. distance between source and receptor.

While this is not an exhaustive list, these specific items have been identified during the model evaluation project as having potentially significant effects on the doses predicted for breeder reactor radioactivity discharges. As a result, a number of research and model evaluation needs related to these mechanisms have been identified.

2.1 Deposition

Particulates and reactive gases may deposit on the surface of the earth through the processes of dry and wet deposition. These processes affect doses to man from atmospheric releases of radionuclides in two ways:

1. deposited material serves as a source of surface and/or food-chain contamination, and
2. deposition results in a reduction in the amount of material transported downwind in air through plume depletion.

Wet deposition occurs sporadically during specific rain or snow events, but dry deposition processes occur continuously and thus must be accounted for during all radiological assessments.

More specifically, dry deposition is the process by which particles and reactive gases deposit on various surfaces (soil, grass, leaves, etc.) via impingement, electrostatic interactions, chemical reactions, and other processes. These processes are often parameterized in terms of the deposition velocity, v_d (m/s), which is given by (Van der Hoven, 1968):

$$v_d = \frac{d}{x} \quad , \quad (1)$$

where

d = rate of deposition ($\text{Bq/m}^2 \cdot \text{s}$),

x = ground-level air concentration (Bq/m^3).

Equation (1) applies when the gases or particulates in the plume are small enough not to be significantly affected by gravity as they travel downwind. If the plume contains larger particles, however, the gravitational settling velocity, v_g , is also used in the process of accounting for the effects of dry deposition.

Appropriate values of v_d and v_g must be determined for use in calculating downwind consequences of breeder reactor radioactivity discharges. Compilations of deposition velocity measurements have recently become available (Sehmel, 1979; McMahon and Denison, 1979), but they have not been critically reviewed to determine the best values for breeder reactor applications. Also, models for v_d of aerosols have been proposed (Sehmel and Hodgson, 1979; Hanna, 1980), but they have not been extensively tested against field data to determine if they are appropriate for assessment purposes.

Recent sodium release tests to the atmosphere (Johnson et al., 1978; Johnson and Nelson, 1979) have shown that the sodium aerosol tends to form agglomerates and falls out rapidly. However, more such tests are needed to establish quantitatively the effect of this mechanism on subsequent downwind doses. These tests should include measurements of aerosol size and the parameters necessary to determine their associated v_d (Eq. 1) if at all possible. Until this information is available, the sodium release test data cannot be truly used for model validation

purposes since at least one of the input parameters (v_d) was not measured during the tests.

A number of different models for estimating plume depletion have been proposed (Hosker, in press). The only way to determine which model is most accurate is to compare model predictions with field measurements. However, during the course of this project no data have been found that are adequate for validating plume depletion processes. Like the sodium release tests discussed above, all of the data sets examined have failed to include measurements of at least one input parameter needed for the plume depletion models being considered. Until such a data set becomes available, one cannot specify the true accuracy associated with a dispersion-deposition calculation or specify the most appropriate values of v_d and v_g to use for breeder reactor assessments.

2.2 Building Wake Effects

An important consideration in the determination of the effective release height of a plume is plume entrainment in the wake of the leeward side of the reactor containment building. Field experiments of tracer gas releases need to be conducted that will allow separation of building wake atmospheric diffusion effects from meander effects. Currently available data can then be adjusted to remove the meander effect.

A number of procedures have been suggested for accounting for building wake effects in dispersion modeling (Hosker, 1979). Until the data discussed above become available, existing data sets should be compared with as many of these procedures as feasible given the potential for the confounding effect of plume meander in at least a portion of the data. Some comparisons have been made between recent data sets (Sagendorf et al., 1979) and the procedures accepted by the U.S. Nuclear Regulatory Commission (USNRC, 1977). However, these data sets need to be compared with other predictive schemes, too. Both adjustments to the commonly used Gaussian plume model and other modeling procedures, such as particle-in-cell techniques, for example, should be considered when making these comparisons.

2.3 Terrain Effects

Most atmospheric dispersion field studies have been conducted over relatively flat, smooth terrain. As a result, the accuracy of dispersion models can be estimated reasonably well under these circumstances (Hoffman et al., 1978; Little and Miller, 1979). So few experiments have been performed in rough or hilly terrain, however, that it is difficult even to make an educated guess as to the accuracy of dispersion models under these conditions (Hoffman et al., 1978). Terrain features induce a number of effects in the plume transport process. Rough surfaces, such as those covered with trees, buildings, and other obstacles to air flow, tend to increase the mechanical turbulence in the atmosphere and hence the overall diffusion of the plume. This can lead to a decrease in air concentration as one goes downwind when compared to similar conditions without the influence of roughness (Miller, 1978). There can also be a decrease in air concentration over rough surfaces due to increased deposition and subsequent plume depletion (Hosker, in press). Complex terrain features such as mountains and valleys can lead to channeling effects, mountain-valley breeze situations, and other complex air flow regimes that are difficult to model (Egan, 1975). Much theoretical and observational work is needed to quantify the effect of rough and complex terrain features on downwind concentrations of radionuclides released to the atmosphere.

Many major population and industrial centers are located along river, ocean, and lake coastlines. Again, however, few major atmospheric dispersion studies have been conducted in these environments (Lyons, 1975). Instead, the results of inland diffusion studies have been routinely applied to coastal situations. Limited field studies indicate, however, that interactions of the atmosphere with the land-water interface can lead to very complex flow conditions which can complicate the prediction of air concentration (Lyons, 1975).

If breeder reactor facilities are to be located in complex terrain and shoreline environments, more measurements are needed to quantify the effect of these locations on the downwind concentration of radionuclides released from these facilities. Such data should then be used to specify the accuracy of dispersion models commonly used today, such as the

Gaussian plume model. The data would also be used to determine when other, more complex, non-Gaussian procedures are required to estimate the radionuclide air concentrations.

2.4 Travel Distance

Most atmospheric dispersion data presently available have been collected within 10 km of the tracer release point. However, radiological doses are routinely calculated to downwind distances of 80 km; e.g., Miller et al., 1980. These calculations must be made on the basis of unsupported extrapolation of the available data.

Recently, a volume of data describing ^{85}Kr surface air concentrations within 150 km of the Savannah River Plant (SRP) has become available (Telegadas et al., 1980). Staff from the Savannah River Laboratory are planning a limited-attendance workshop for November, 1980, at which time comparisons between predictions from various air quality models and the ^{85}Kr observations will be discussed. In addition, the SRP data base, other data sources, and modeling procedures that might be applicable for dose assessments out to 100 km were discussed at the Symposium on Intermediate Range Atmospheric Transport Processes and Technology Assessment held in Gatlinburg, Tennessee, October 1-3, 1980, as part of this model evaluation project.

While the SRP data set is a step forward in the area of intermediate range atmospheric transport, other data sets are also needed. Both tracers of opportunity, such as the ^{85}Kr released by SRP, and specifically designed tracer releases should be utilized. These data sets should then be compared to predictions from various models to determine what procedures should be used to estimate air concentrations out to 100 km from the release point and to ascertain the accuracy of these predictions under a variety of terrain and meteorological conditions.

2.5 Conclusions

Four environmental processes that have potentially significant effects on doses predicted for breeder reactor radionuclide discharges have been discussed: deposition, building wake effects, terrain effects,

and plume travel distance. More field data need to be collected to specify and validate dose assessment models that include these environmental processes. These recommendations are made with the full realization and understanding that such data gathering may be difficult, time consuming, and expensive. However, without such data it will be impossible to quantify accurately the effect of these environmental processes on radiological dose predictions.

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3. TERRESTRIAL FOOD CHAIN TRANSPORT

Laura M. McDowell-Boyer

A number of deficiencies exist in the available data necessary to model the transport efficiency of radionuclides by terrestrial food chains. These deficiencies exist not only in the data used to quantify food-chain model parameters such that predictions of radionuclide concentrations in compartments following release to the environment can be made, but also in the data necessary to test the validity or predictive capabilities of such models. In addition, little effort has been documented to date regarding the potential importance of pathways of human exposure to radionuclides other than those involving beef and dairy cattle and food crops.

In order to delineate needs associated with parameter values for terrestrial food chain models, one must first specify the type of model being considered (i.e., whether the model is to simulate an equilibrium, or steady-state system or whether it is to simulate a dynamic system). Models available which simulate steady-state systems generally require annual average data pertinent to agricultural practices and processes. However, if a model is needed to simulate a dynamic system which considers seasonal aspects of agricultural processes, entirely different data are needed. These include means to describe dynamic transfer rates between trophic levels in the food chains at particular times of the year, rather than depicting transfer as a process that occurs at a constant rate throughout the year.

Equilibrium, or steady-state, models are the most widely used types of terrestrial transport models for assessment purposes (Soldat, 1978). In general, these models rely on the use of concentration factors (i.e., ratios) to quantify transfer between trophic levels in the environment, such that one may predict the annual average nuclide concentration in one trophic compartment given the average concentration in the supporting compartment. The few dynamic models being developed (Simmonds, Linsley, and Jones, 1979; Pleasant, McDowell-Boyer, and Killough, 1980), which allow assessment of food chain transport following acute releases of radionuclides to the environment, require more information related to the uptake rates.

3.1 Deficiencies in Parameter Values

As was mentioned previously, food chains considered in available models generally involve beef and dairy cattle and food crops. A discussion of deficiencies in available data necessary to describe transfer through each of these trophic pathways follows.

3.1.1 Contamination of vegetation

Radionuclide contamination of edible crops and animal feeds is quantified in terms of parameters describing the interception and retention efficiency of the pertinent portions of plant species, and parameters describing root uptake efficiencies of these plants.

3.1.1.1 Interception fraction. Interception fractions, which characterize the fraction of depositing radionuclides initially retained by portions of crop plants, have been empirically determined by several investigators for grasslands (Chamberlain, 1970; Peters and Witherspoon, 1972), cereal crops (Aarkrog, 1969; Aarkrog and Lippert, 1971), and vegetative portions of soybean, sorghum, peanut, clover, and squash plants (Witherspoon and Taylor, 1970; 1971). Data regarding interception efficiencies of edible portions of vegetable crops are not available and are not readily extrapolated from data for other species since surface characteristics vary greatly between species. It follows that one should not assume a constant interception fraction for all types of crops per unit area of cropland, even if the productivity (kg/m^2) of that land remains fairly constant, due to the variation in surface area-to-mass ratios for different crop types. In addition, dynamic models require information regarding interception efficiency as a function of crop growth (Pleasant, McDowell-Boyer, and Killough, 1980) with empirical data being preferable to theoretical geometric considerations regarding surface area changes with mass.

3.1.1.2 Retention half-times. Retention half-times are generally assumed to be constant for all types of crops, nuclides, and geographic areas. However, there are indications that retention by different crop species or parts is differentially affected by rainfall (Chamberlain, 1970; Witherspoon and Taylor, 1970) and that different nuclides are

differentially absorbed by plant tissues, and thus not available for leaching from plant surfaces to the same degree (Middleton, 1959; Aarkrog, 1969; Keppel, 1969). The assumption of constancy, therefore, may lead to erroneous conclusions regarding loss rates due to weathering of plant surfaces. Thus, more data on retention half-times should be obtained for crop species and nuclides of importance. Furthermore, retention half-times that vary during the crop growth cycle and with seasons (Chamberlain, 1970; Witherspoon and Taylor, 1970; Aarkrog and Lippert, 1971), necessitate the consideration of such variation in dynamic models. This latter phenomenon is not widely documented for species of agricultural importance, and its significance should be evaluated. The effect that washing and processing of surface contaminated crops have on the radionuclide content is also not well documented, although it is potentially of great importance in areas where the major crop may be one that is normally processed before consumption, and will likely vary greatly with species and nuclide.

3.1.1.3 Root uptake parameters. The parameter describing root uptake of radionuclides by crops in steady-state transport models is the concentration ratio, sometimes called the bioaccumulation factor. This parameter is usually interpreted as the concentration of a radionuclide in mature portions of crops (on either a fresh- or dry-weight basis) to the steady-state soil concentration of that nuclide (on a dry-weight basis).

Values of this parameter are usually derived from experiments involving plants grown in greenhouses or laboratories. Extrapolation to field conditions under which the values will be used may be inadequate in some cases. This deficiency results because pot experiments likely will not simulate field conditions with respect to leaching of radionuclides out of the root zone, normal plant productivity, and normal rooting patterns of the plants being studied. Another problem possibly encountered in extrapolating from laboratory to field conditions involves the effects that plant roots may have on soil concentrations in the limited environment of the pots, such that the soil concentration is not maintained at steady-state. Because data on uptake of radionuclides

under field conditions are often scant (and nonexistent for many nuclides), a great amount of uncertainty exists in choosing appropriate concentration ratios for use in steady-state models, particularly when available data show a range of values over two or three orders of magnitude.

Dynamic models have additional data requirements concerning root uptake parameters, since they are used in situations when soil concentrations are not in steady state. Such models require measurement of radionuclide concentrations in plant tissues over time, as well as soil concentrations throughout the same time period. Time-dependent data of this type are not available for the great majority of radionuclides. Thus, prediction of plant concentrations following acute contaminating events are often made only on the basis of a number of theoretical assumptions regarding the dynamics of the root uptake process that have not been empirically justified.

3.1.2 Contamination of beef

Contamination of beef is generally parameterized in steady-state models by a transfer coefficient defined as the ratio of the fresh-weight nuclide concentration in the muscle of cows at time of slaughter to the animals' daily radionuclide intake. The deficiencies associated with this parameter involve not only the paucity of data with which to derive parameter values, but also the ambiguity of the parameter definition. Since the beef transfer coefficient is used in steady-state models, one assumes that the nuclide content of the muscle should be at equilibrium when measured. The time necessary to reach equilibrium depends on the retention time of the nuclide in the muscle. This latter parameter, the retention time, is rarely known for tissues such as the muscle or skeleton in cows, and consequently it is unknown what length of time tracer experiments should be carried out to insure that equilibrium is achieved. In addition, the lack of data with which to derive the beef transfer coefficients for most nuclides necessitates the estimation of the value of this parameter from collateral information (Ng, Colsher, and Thompson, 1979). Dynamic food-chain models require information with which to estimate retention of nuclides in muscle following

acute exposure of animals to radionuclides, and this information is not available. In light of these deficiencies, it is recommended that appropriate experiments be done to derive the necessary information with which beef transfer coefficients can be estimated for nuclides of concern for both steady-state and dynamic models. This information should consist mainly of retention data for various tissues in cows, such as muscle and skeleton, in order that equilibrium values, loss rates, and intertissue transfer rates for dynamic models can be estimated.

3.1.3 Contamination of milk

Probably the most comprehensive documentation of transfer coefficients describing feed-to-milk transfer of radionuclides is found in a document compiled by Ng et al. (1977). However, data from which to derive coefficients are not available for a number of radionuclides and deficient for others, again necessitating the estimation of such values from collateral data (Ng et al., 1977). Thus, it is important that data be collected for these nuclides if they have potential for release to the environment.

In addition to the above specific comments, data used to describe transfer through all of these pathways have one major deficiency in common. This deficiency involves the paucity of such data from which any parameter value is derived as well as the lack of consistency between experimental designs and conditions producing such data. These two factors, along with natural geographic variation, contribute to the wide range in possible values associated with the parameters discussed above, the inability to describe statistical distributions of the range of values, and the great uncertainty associated with each parameter. Consequently, a great uncertainty exists in the predictive capability of models using the described parameters.

3.2 Validation Data Deficiencies

In addition to large uncertainties in model predictions, a lack of validation data with which to test food-chain models further detracts from their usefulness. Before results predicted by food-chain models

can be used to assess the consequences of environmental contamination by radionuclides, it is extremely important that model verification be carried out to establish assurance that the model adequately simulates the results of transport mechanisms in a particular food chain. First, however, parameters known to vary greatly between geographic locations should be measured to calibrate the model at the site from which validation data will be obtained. Then, validation can be accomplished with the use of either data collected in an area affected by an already existing chronic or acute source term, or data collected from experiments designed to represent a particular contamination scenario. In either case, the data obtained for validation should be independent of data used to establish parameter values in the model.

3.3 Pathway Deficiencies

Finally, it should be mentioned that a number of potential pathways of food-chain contamination leading to human exposure to radionuclides are neglected in many currently used models. Much of the reason for this neglect is undoubtedly the even greater lack of information with which to quantify transport through other pathways which may involve poultry, swine, and tobacco smoke. The importance of these latter products in man's diet and the potential for contamination of the associated food chains should be evaluated in order to determine the need to characterize more fully these pathways of radionuclides to man.

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4. EXTERNAL DOSIMETRY

David C. Kocher

Estimates of dose to individuals from external exposure to photons or electrons emitted by radionuclides dispersed in the atmosphere or on the ground are often based on the assumption that the source region is effectively semi-infinite or infinite in extent with a uniform radionuclide concentration. This assumption leads to the concept of the dose-rate conversion factor, which, for a given radionuclide, radiation type, and mode of exposure, gives the dose-equivalent rate to a particular body organ per unit concentration. External dose-rate factors for radionuclides of potential importance in the breeder reactor fuel cycle for immersion in a semi-infinite, uniformly contaminated atmospheric cloud and exposure at a height of 1 m above an infinite, smooth, and uniformly contaminated ground surface were given in Tables 7.2 and 7.3 of the report ORNL-5529 (Miller et al., 1980).

Because of the relatively short range of electrons in air (less than 40 m for energies less than 10 MeV), the assumption of an infinite source with uniform concentration will usually provide a realistic estimate of dose from external exposure to electrons. For photons, on the other hand, the mean-free-path in air may be 250 m or more. Thus, for radionuclides which emit significant numbers of high-energy photons, the sources may have to be dispersed approximately uniformly over distances as large as 1 km from the receptor position in order for the use of dose-rate factors to give accurate estimates of dose. It is obvious that such a condition is not encountered in many realistic exposure situations, such as exposure to finite plumes from acute releases to the atmosphere or at locations close to the point of release. Therefore, efforts are needed to develop models for the estimation of dose from external exposure to photons from realistic finite sources. For example, the model given in the NRC Regulatory Guide 1.109 (USNRC, 1977) estimates dose from a constant, chronic release to the atmosphere using a vertically finite, sector-averaged Gaussian plume model. An area in which model development is particularly needed is the estimation of photon dose from an elevated plume.

For exposure to a contaminated ground surface, estimates of photon dose to body organs are usually based on the assumption that the ratio of organ dose to dose at the body surface is independent of the mode of exposure, so that the known ratio for immersion in contaminated air can be applied. The accuracy of this assumption is unknown; it may result in particularly inaccurate dose estimates for small deep-lying organs. The difficulty arises as follows. For immersion in contaminated air, the angular distribution of photons incident upon the body surface is assumed to be isotropic.* For ground surface exposure, however, the angular distribution is decidedly anisotropic and, furthermore, the anisotropy varies with height above ground. In addition, the energy distribution of photons at the body surface for monoenergetic sources on the ground also varies with height and is not the same as the energy distribution from monoenergetic sources in air. Thus, it seems unlikely that the ratio of organ dose to dose at the body surface could be the same for the two exposure modes. This assumption has not been tested either theoretically or experimentally. The application of Monte Carlo techniques to the estimation of photon dose-rate factors for contaminated ground surface would, in principle, be very useful, but a proper calculation would be very time consuming and expensive. It is possible that experiments to measure doses in a phantom for ground surface exposure would be more feasible.

A second difficulty with estimation of dose from a contaminated ground surface concerns the electron dose-rate factor for skin. The dose-rate factors are estimated by replacing the thickness of the dead layer of tissue between the body surface and the radiosensitive tissue of the skin by an equivalent thickness of air, which is then added to the assumed 1 m height of the body surface above ground. This approach is necessary because specific absorbed fractions for transport of electrons through two different media have not been developed. Implicit in

*It would, in fact, be of interest to perform calculations of photon angular distributions near the boundary of a semi-infinite, uniformly contaminated atmospheric cloud to test the assumption that the angular distributions are isotropic.

this approximation is the assumption that the angular distribution of electrons at the body surface from ground-surface exposure is isotropic, which is certainly not the case. In addition, the calculated dose-rate factors have not been properly averaged over the height of the body surface above ground for an exposed individual standing on the ground. Thus, the calculated dose-rate factors may be considerably in error.

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5. INTERNAL DOSIMETRY

Donald E. Dunning, Jr.

Contemporary estimates of dose to man from internally deposited radionuclides may be reasonable as point estimates for an average adult. However, our current understanding of the variability in doses among individuals is "crude," at best. Several investigators have attempted to quantify variability in estimates of dose for various radionuclides (Schubert, Brodsky, and Tyler, 1967; Dunning and Schwarz, in press; Schwarz and Dunning, in press). In general, most current dose estimates should be attributed little more than an order of magnitude (perhaps within a factor of 3-10) precision.

Numerous research needs exist to define better the estimates of internal dose. Many more data are needed to determine age-dependent uptake and retention characteristics of various radionuclides in organs of man. Dosimetry models should also be developed or refined to incorporate other age-dependent considerations, such as changes in photon-specific absorbed fractions for individuals of different ages due to changing organ sizes and geometries. Such factors as the distribution of bone endosteal surface area between cortical and trabecular bone and the sizes of marrow cavities in trabecular bone also require careful scrutiny on an age-dependent basis.

Additional research is also needed to determine better the relative radiosensitivities of various organs. Quantification of potential health risks resulting from a given organ dose is the factor of paramount importance in any dosimetric assessment.

As in any endeavor, it is important to assess data and methodological requirements in terms of the particular end use. In this regard, it is likely that specialized research needs for internal dosimetry may differ for occupational, environmental, accidental, and medical exposure situations.

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6. DOSES DUE TO ENVIRONMENTAL RELEASES OF TRITIUM

P. S. Rohwer, E. L. Etnier, and H. R. Meyer

Methodology for estimation of dose to man from environmental tritium evolved out of general concerns for radiation exposure of man from all sources. Specific interest in tritium has its origin across a broad span of time and programs, including (1) basic radiobiology research studies, (2) nuclear weapons development and effects studies, (3) peaceful applications of nuclear explosives, (4) fission-based nuclear fuel cycles, and (5) studies related to the development of fusion reactors. Tritium has always attracted attention in nuclear power programs because it frequently is present in large quantities compared to most other radionuclides if isotopes with short radioactive half-lives are disregarded. Because of the relatively large quantities involved, the estimated dose contribution from tritium may be substantial even though the dose per unit activity is one of the lowest of all radioisotopes.

A portion of the Fast Reactor Safety Program has involved engineering and environmental analysis of routine releases of radionuclides from nuclear fuel cycle facilities. Two studies of the environmental radiological impact of reprocessing advanced fuels have been performed to date (Tennery et al., 1976; Tennery et al., 1978). In both cases, tritium contributed the majority of estimated dose to total body and most individual organs for the maximally exposed individual, with the assumption that no containment of tritium was employed at the reprocessing plants. In addition, tritium is consistently found to contribute a significant part of the dose from reprocessing of light water reactor fuel (Finney et al., 1977) and high temperature gas-cooled reactor fuel (Davis et al., 1976). The importance of tritium with respect to radiological dose calculations suggests the need for further research to better establish radiotoxicity and estimate dose.

Renewed interest in tritium at this time is the result of a combination of factors, not all of which are unique to tritium. First, today's more restrictive dose limits prompt reexamination of any radionuclide which contributes noticeably to the estimated total dose. Second, revised ternary fission yield data for fast reactor fuels suggest that

previous estimates of tritium production via that process may have been low by as much as one order of magnitude (Buzzelli et al., 1976; Buzzelli and Langer, 1977). Third, recent experimental results suggest that it may be desirable to increase the quality factor (Q) for tritium beta particles from the present recommended value of 1 to a higher value (~ 2), particularly for low dose rates and low doses (Dobson and Kwan, 1976; Dobson et al., 1977; Till et al., 1980). The estimated dose for tritium exposure would increase in direct proportion to any increase in Q. This point leads to a more general question: what is the relative significance to man of small radiation doses received at low dose rates? All radiation dose to man is assessed against radiation safety standards established on the basis of dose-effect relationships observed at high dose and high dose rates, and linearly extrapolated to zero effect at zero dose. This consideration is not unique to exposures from tritium; however, tritium is frequently used as a research tool in low dose and dose-rate studies, and the dose patterns anticipated for tritium encountered in the environment will be low.

An assessment of the potential impact of siting a major nuclear facility (such as a fuel reprocessing plant) is often performed early in the engineering/design phase of the plant. A large fraction of the data base required for assessment of a hypothetical facility is necessarily estimated, based on imperfect knowledge of the general region in which the facility may be constructed. We have found that, in certain cases, choice of the dilution coefficient for tritium entering the drinking water supply of a "maximally exposed individual" can significantly influence total estimated doses for a fuel cycle facility. In fact (for an individual assumed to derive drinking water directly from precipitation), making the assumption that no dilution of atmospheric tritium occurs can increase the total estimated dose (from all radionuclides released) to this individual by up to 50% in certain cases (Till et al., 1980). While only limited data are available [Savannah River Laboratory monitoring information reported by Tadmor (1973) and Ashley, Zeigler, and Quinsenberry (1979)], our interpretation suggests that, for the maximally exposed individual, the concentration of tritium in rain-derived drinking water may in fact be within a factor of 1/4 to 1/2 of that

measured in atmospheric moisture at the same location near the releasing facility. Research to establish the existence of such conditions at other tritium-releasing facilities is necessary.

Recently, a study was completed of the radiological aspects of environmental tritium, including both a review and comparison of representative examples of the methodologies available to estimate dose to man from tritium, and comments on the general application of this overall methodology to assess environmental releases of tritium (Till et al., 1980; Rohwer and Etnier, 1980). Listed below are some of the research needs related to environmental tritium releases that are suggested as a result of this study:

1. There is a need for more experimental data concerning ternary fast fission tritium yield of the fissile materials, ^{232}Th , ^{238}U , ^{233}U , ^{235}U , and ^{239}Pu . Buzzelli and Langer (1976) report the tritium yield of these materials in a fast spectrum to be much higher than values previously used for radiological assessments. (See Till et al., 1980, for a more complete discussion.)
2. During its radioactive decay, a tritium atom is transmuted to a helium atom regardless of position in a molecular structure. Such transmutation effects have been shown to cause marked differences in the tritium effects on DNA, RNA, and protein measured in lower organisms, and the possibility of biological effects in humans should be investigated further. Carsten (1979) reviews transmutation effects in lower organisms, and suggests that they are unimportant with relation to HTO ingestion. Rohwer and Etnier (1980) also assert that transmutation effects in humans might be insignificant. However, key positioning could increase the possibility of significant effects due to transmutation, and therefore further research might be warranted, particularly in the case of ingestion of organically bound tritium.

3. Recent experimental data on the relative biological effectiveness (RBE) for tritium, as well as potential long-term, genetic effects from chronic, low-level exposures, suggest that the radiological significance of tritium beta particles might be underestimated. Till et al., (1980) discuss this problem. Additional research is desirable with special emphasis placed on the dependence of RBE on dose, dose rate, experimental endpoint, and choice of reference radiation.
4. Currently, it is assumed that all tritium in food is metabolized like ordinary water, and inputs directly into the body-water compartment where it is later incorporated into the organic component of the human body. It is estimated that this organically bound tritium in the human body results in approximately a 20% increase to total dose potential (Rohwer and Etnier, 1980). However, the contribution to total dose that organically bound tritium in food would make if it were incorporated directly into the organic fraction of the human body is an area needing further study.
5. There is a need for further research to characterize the conversion of HT to HTO in environmental systems. For instance, Murphy and Pendergast (1979) find high values of HTO concentration in soil following releases that were predominantly HT. More work is necessary to make estimates of the conversion rate over a variety of conditions. There is also uncertainty concerning the amount of HT and HTO released under varying conditions (Carsten, 1979).
6. It is generally assumed for tritium dose calculations that the ratio of HTO in vegetation to that in the atmosphere is 0.5 based on the model by Anspaugh et al. (1972). However, more recent data published by Murphy and Pendergast (1979) suggest that the concentration of tritium in vegetation may be nearly equal to that in air under chronic

exposure conditions. HT conversion to HTO in soil, as well as HTO absorption by vegetation roots from soil are both areas requiring further research. Experiments quantifying the vegetation-to-air tritium ratio for mature plants and their fruits would be helpful for accurate dose assessments for tritium.

7. Development of a global mathematical model to describe the movement of HT and HTO in ecological systems taking into account latitude variations and conversion of HT to HTO in the soil and atmosphere is warranted.
8. Studies are needed for both HT and HTO involving the effects on man of chronic low exposures to validate current risk estimates.
9. Research is required to determine a range of typical tritium dilution coefficients for use in the estimation of dose to individuals living near tritium-releasing facilities.

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