Selection of Models for Ingestion Pathway and Relocation Radii Determination

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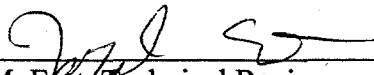
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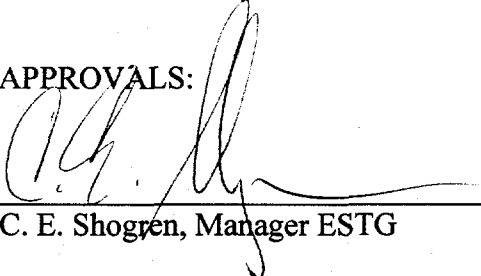
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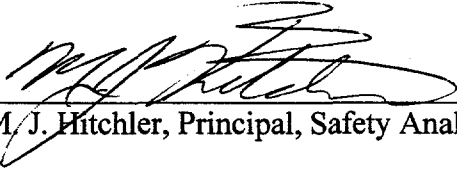K. R. O'Kula, Technical Reviewer   Date

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Abstract

The distance at which intermediate phase protective actions (such as food interdiction and relocation) may be needed following postulated accidents at three Savannah River Site nonreactor nuclear facilities will be determined by modeling. The criteria used to select dispersion/deposition models are presented. Several models were considered, including ARAC, MACCS, HOTSPOT, WINDS (coupled with PUFF-PLUME), and UFOTRI. Although ARAC and WINDS are expected to provide more accurate modeling of atmospheric transport following an actual release, analyses consistent with regulatory guidance for planning purposes may be accomplished with comparatively simple dispersion models such as HOTSPOT and UFOTRI. A recommendation is made to use HOTSPOT for non-tritium facilities and UFOTRI for tritium facilities.

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SELECTION OF MODELS FOR INGESTION PATHWAY AND RELOCATION RADII DETERMINATION (U)

Introduction

Large commercial nuclear power plants normally have an ingestion exposure emergency planning zone (IPZ) radius of 50 miles. The rationale for this radius is presented in NUREG-0654 (NRC 1980) and NUREG-0396 (NRC 1978).

At the request of the States of South Carolina and Georgia, releases from postulated design basis accidents at three nonreactor nuclear facilities at SRS will be evaluated to determine if subsequent contamination of food is significant. Evaluation of postulated releases, in a manner consistent with the rationale for determining the IPZ radius in NRC 1980 and NRC 1978, will provide a perspective on the potential consequences that accidents at existing and operating nonreactor nuclear facilities may have on ingestion pathways. Similarly, determination of the radius at which relocation protective action guidelines are exceeded will provide a perspective on potential long-term consequences.

Background

DOE G 151.1-1, Vol. 2 (DOE 1997) contains Department of Energy (DOE) guidance for determining the radii at which preplanning of protective actions should be performed. Detailed, step-by-step instructions are given for determining the radius at which preplanning of protective actions is needed for the early phase of emergency response. Detailed instructions are not presented for the determination of the radius at which preplanning of protective actions is needed for the intermediate phase. However, the following general principle is presented:

> "... it is DOE policy that emergency management for DOE nuclear facilities be consistent, to the extent practicable, with the requirements of the Nuclear Regulatory Commission (NRC). Basic planning and response principles, as well as the NRC and EPA requirements and their bases, are considered as background for the guidance provided herein."

Following the precedent for NRC-licensed reactors, the radii for preplanning intermediate phase protective actions at SRS facilities should be based on the potential consequences from design basis accidents. Following discussions with the States of South Carolina and Georgia, the accidents selected as initiators will be the most severe design basis accidents (DBAs) documented as part of the existing authorization bases for three SRS facilities. The facilities chosen for analysis (to be performed in early 1999) are the Tritium Facilities, H-Canyon, and the Savannah River Technology Center (SRTC). The last two facilities are non-tritium facilities.

Analyses will be performed for all significant radionuclides in the DBA mixes (i.e., equivalent plutonium will not be used). Radionuclide-specific values are necessary since

pathway transfer factors vary for different elements, and dose values for ingestion may not scale with inhalation dose values.

Approach

The overall approach proposed to evaluate the impact on the food chain may be divided into several steps that follow radioactive material through the environment and food chain to man. Table 1 was adapted from NCRP-50, Environmental Radiation Measurements (NCRP 1976). This table illustrates the steps from release of radionuclides into the environment to the dose that results from ingestion by man.

Table 1: Illustrative pathway for internal radiation exposure from airborne radionuclide effluent

Pathway Step	Variable	Product of Variables
Source	Source term (Q)	Radioactive material released (Bq) Q
Dispersion	Dispersion (χ/Q)	Time-integrated airborne concentration (Bq s m^{-3}) $Q(\chi/Q)$
Cumulative Deposition	Deposition velocity (V_d)	Radioactive material per unit area (Bq m^{-2}) $Q(\chi/Q) V_d$
(Comparison basis: deposition)		
Environmental and Biological Transfer	Transfer coefficient (T_r)	Radioactive material per unit mass of environmental or biological medium (Bq kg^{-1}) $Q(\chi/Q) V_d T_r$
(Comparison basis: concentration in food)		
Human Intake	Intake rate (I)	Radioactive material intake per unit time (Bq s^{-1}) $Q(\chi/Q) V_d T_r I$
Human Absorbed Dose Rate	Intake rate to absorbed dose rate conversion factor (k)	Absorbed dose per unit time (rad s^{-1}) $Q(\chi/Q) V_d T_r I k$

The first pathway step describes the amount of material released to the environment. As mentioned previously, source terms from the worst design basis accidents at three facilities will be chosen. Tritium releases will be modeled as gas or water vapor. Releases from non-tritium facilities will be modeled as particulates.

The dispersion pathway step transports the release to locations of interest. The cumulative deposition pathway step quantifies the amount of contaminant deposited on the ground (or directly on the foodstuff in some cases). Further discussion of models for

the dispersion and deposition pathway steps are discussed in the "selection criteria" and later sections.

Environmental and biological transfer coefficients relate the concentration of radionuclides in one compartment of the pathway to another. For example, radionuclides may be transferred from the compartment "pasture" to the compartment "milk". Although in Table 1 only one transfer coefficient value is shown (T_r), radioactive contaminants may pass through multiple compartments to reach man. Each compartment would be described by a separate coefficient, and the overall value obtained by taking the product of the coefficients from each compartment. When available, site-specific transfer coefficients will be used. Otherwise, default values derived from Regulatory Guide 1.109 (NRC 1977a), or more recent publications (e.g., IAEA Technical Reports Series No. 364, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments (IAEA 1994) or Radiological Assessment (Till and Meyer 1983)) are recommended.

The product of variables after applying environmental and biological transfer factors (the radioactive material per unit mass of environmental or biological medium) may be compared to Derived Intervention Levels (DILs) in recent Food and Drug Administration (FDA) guidance (FDA 1998). The intake rate and dose rate conversion factor in the last two rows of Table 1 are incorporated in the derivation of the DIL for each group of nuclides.

Notwithstanding the most recent FDA guidance, it must be recognized that current DOE guidance recommends the use of the old FDA guidance (DOE 1997, section B.2.1, Radiological Protective Action Criteria). Since the new FDA guidelines were issued recently, it is presumed that DOE guidance will be revised to reference the new guidelines. The new FDA guidelines appear to be much more restrictive than the old guidelines.

An alternative to comparing concentrations in food to DILs is to use deposition as the basis for comparison. This requires applying environmental and biological transfer factors to DILs, to obtain depositions equivalent to each DIL for each pathway. Relatively simple dispersion/deposition codes can then be used to calculate the impacts from releases, e.g., determine the radius within which each limiting deposition value is exceeded.

Considerations for selecting a dispersion/deposition model follow.

Selection Criteria

Several technical factors enter into the selection of atmospheric dispersion models. The selected model(s) should be fundamentally equivalent to models used for similar purposes at commercial reactors. For accidents releasing a mix of radionuclides, the input routines should have the capability to run a mix of nuclides. The model should have a validation and verification pedigree. Additionally, the model should be among, or

be consistent with, those models that will actually be used or available following a release. The model should allow the user to modify dispersion and deposition parameters to site-specific values. It should also have adequate documentation.

If several models are found that meet the technical factors, preference will be given to the simplest one(s). Choosing the least complex model has several advantages. In general, the time needed to construct input files and run a simple model is shorter. Fewer input parameters reduce the likelihood of a transcription error. Additionally, the results from simple models may be more easily verified by hand calculations than those from complex models.

A perspective on the necessary level of complexity in the dispersion/deposition model may be obtained from regulatory documents. NUREG-0396 (NRC 1978), p. I-20, identifies the "simple, theoretical, Gaussian plume model" for performing initial projections of dose during an incident (this is for early phase predictions). For the ingestion pathway (intermediate phase), the 50 mile IPZ radius (for large commercial reactors) is based on DBA analyses assuming worst possible meteorology and a straight-line trajectory (p. I-34). An acceptable method for performing these analyses is found in Regulatory Guide 1.4 (NRC 1974). The model that is recommended in Regulatory Guide 1.4 is the Gaussian plume model. Regulatory Guide 1.109 (NRC 1977a) describes an acceptable method to calculate the annual doses to man from routine releases of reactor effluent. The annual dispersion factor is calculated using a Gaussian model from Regulatory Guide 1.111, (NRC 1977b). Clearly, the Gaussian dispersion model has been accepted by the NRC, and was used as the underlying dispersion model for the determination of the radius for preplanning ingestion pathway protective actions. EPA has also issued acceptable methods to evaluate airborne pollutants based on the Gaussian model.

While the Gaussian models are often used early in the response to an accident, their use during the intermediate phase is not recommended. The NRC Response Technical Manual (NRC 1992), on p. K-1, cautions responders to "use verified measurements, not dose model projections" when assessing the need for protective actions. Following a major release, potentially affected areas will be identified by radiation surveys. Samples of food, water, and milk will be analyzed to determine contaminant levels. In some cases, the need for interdiction will be evaluated by applying environmental and biological transport coefficients to measured depositions to predict contaminant levels in foods.

Several models were considered for determining the consequences of releases from SRS facilities. These included ARAC, MACCS, HOTSPOT, WINDS (coupled with PUFF-PLUME), and UFOTRI.

Model Attributes

ARAC is a particle-in-cell model developed by Lawrence Livermore National Laboratory (LLNL). The particle-in-cell model is more realistic and potentially can address more

complex meteorological conditions than Gaussian models. It provides three-dimensional modeling of airborne effluent transport. Access is via a remote terminal back to LLNL. It is one of the dispersion models used in the Federal Radiological Monitoring and Assessment Center (FRMAC).

HOTSPOT is a Gaussian model that is also used in the FRMAC. It runs on a personal computer, and most parameters are user-definable. The underlying Gaussian model is widely accepted by the EPA and NRC, forming the basis for most emergency planning predictions. It will also usually predict estimates that are conservative (i.e., higher than actual observed values). Its use is limited to relatively simple meteorology. Inhalation dose and deposition may be calculated using HOTSPOT, in addition to time-integrated concentrations.

MACCS couples a Gaussian dispersion model with advanced pathway and consequence models. It has been used to predict the consequences of severe commercial reactor accidents.

WINDS (coupled with PUFF-PLUME) was developed specifically for SRS, and would be used following an actual event to provide rapid estimates of dose from a passing plume. Ingestion pathways are not included in dose estimates. Predictions, based on multiple meteorological stations, would be made by SRS and provided to the States. The PUFF-PLUME model basis is Gaussian.

UFOTRI was developed at the German Karlsruhe laboratory to assess the radiological consequences of accidental atmospheric tritium releases. UFOTRI models tritium-specific processes such as the conversion of tritium gas (HT) into tritiated water (HTO), re-emission after deposition, and conversion of HTO into organically bound tritium (OBT) (O'Kula 1998). UFOTRI calculates inhalation/skin absorption doses from the plume passage and couples the short-term atmospheric dispersion model with a first order compartment module that dynamically describes the long-term behavior of tritium in the food chains (Raskob 1990, 1993). It should be noted that verification and validation tests for this model have not been completed at SRS, although it has been used for licensing facilities in Germany.

Recommendation

The model(s) chosen to estimate the potential consequences from SRS design basis accidents (DBAs) should use methodology consistent with EPA guides for protective actions (EPA 1992), Regulatory Guide 1.145 (NRC 1982), NUREG-0654 (NRC 1980), and NUREG-0396 (NRC 1978). Several models were considered for these analyses. A Gaussian dispersion model would satisfy the consistency requirement stated above and provide an adequate model for the sorts of calculations to be performed. The use of a Gaussian model is also repeated in DOE guidance for emergency planning (DOE 1997):

> "The following modeling recommendations are provided as guidance to consequence analysts.

- Use of a straight line Gaussian model as the atmospheric dispersion portion of the code is acceptable in most cases for emergency planning.

- Radiological computer codes should be verified to ensure that Dose Conversion Factors (DCFs) and exposure times used are consistent with the desired results [e.g., total effective dose equivalent (TEDE) or committed effective dose equivalent (CEDE)]...."

Historically, radii for preplanning emergency actions have been based on simple meteorological conditions. Under unchanging meteorological conditions, ARAC, MACCS, WINDS, and HOTSPOT should give comparable results. Since minimizing code complexity should maximize clarity and economy, HOTSPOT is proposed as the model to be used to perform dispersion and deposition calculations for non-tritium releases. Deposition values resulting in concentrations in food equal to FDA DILs may then be calculated in a spreadsheet format. Deposition footprints (and radii) at which FDA DILs are exceeded may be determined using HOTSPOT.

The computer model UFOTRI is proposed for assessment of the Tritium Facilities DBA. The higher degree of pathway model complexity available in UFOTRI is needed to assess the effects of an acute release of tritium to the environment. The underlying dispersion model is Gaussian, consistent with regulatory recommendations. If UFOTRI is unavailable due to verification and validation concerns, HOTSPOT or another Gaussian dispersion model may be used to obtain time-integrated concentrations of tritiated water vapor. Appropriate environmental and biological transfer factors will then be applied in a spreadsheet format to obtain concentrations of tritium in foodstuffs.

Relocation

The Manual of Protective Action Guides And Protective Actions For Nuclear Incidents (EPA 1992) provides methods to calculate projected external gamma dose and inhalation dose during the intermediate phase of emergency response. Dose conversion factors (mrem received over time periods of interest, per unit deposition or per unit air concentration of resuspended material) are presented for major fission products. These dose conversion factors are based on DOE/EH-0070 (DOE 1988) (external dose) and Federal Guidance Report No. 11 (EPA 1988) (inhalation dose).

EPA 1992 does not provide inhalation dose conversion factors for transuranics. These dose conversion factors may be obtained from Federal Guidance Report No. 11 (EPA 1988), or more current guidance from the International Commission on Radiological Protection (ICRP). The most current ICRP ingestion dose conversion factors are used by the FDA to calculate DILs for ingestion pathways. Since the most current ICRP guidance represents the state-of-the-art in our understanding of the behavior of radionuclides in the body, and already forms the basis for ingestion pathway interdiction criteria from the FDA, its use as a basis for relocation decisions is recommended. However, it must also be recognized that the basis used in most current U.S. and State

regulations is ICRP-30 (ICRP 1979). In the event of an actual release, it seems probable that decisions would be based on the best models, incorporating the results of research since ICRP-30 was written. Therefore, inhalation dose conversion factors based on the most recent ICRP publications are proposed as the basis for relocation calculations.

A major parameter for relocation calculations is the resuspension factor. Resuspension factors specific to the SRS area will be selected for dominant radionuclides in each SRS accident scenario. The equivalent effect for tritium, reemission from soil and vegetation, will be modeled using site-specific values, when available.

Summary

HOTSPOT is recommended for the analysis of the radii at which intermediate phase actions must be taken for SRTC and H-Canyon authorization basis DBAs. For the Tritium Facilities DBA, UFOTRI is recommended. In general, site-specific parameters will be applied when available. Food pathway transfer factors from the most recent ICRP, IAEA, NCRP, and NRC recommendations will be used wherever possible. These factors represent the state-of-the-art in describing the movement of radionuclides through the food chain. Limiting values of cumulative deposition, resulting in concentrations of radionuclides in foodstuffs equivalent to the most recent FDA DILs, will be derived and used as the basis to determine the maximum radii for ingestion pathway protective actions. Similarly, dose from resuspension will be calculated using the most recent inhalation dose factors from ICRP, and site-specific resuspension factors.

Table 2 summarizes the approach that will be taken to sequentially model or determine each pathway step in Table 1. Site-specific transfer coefficients will be used whenever available.

Table 2: Recommended modeling of pathway steps

Pathway Step	Model – SRTC and H-Canyon	Model – Tritium Facilities
Source	Most severe Design Basis Accidents	Most severe Design Basis Accident
Dispersion	HOTSPOT 95% worst case meteorology	UFOTRI 95% worst case meteorology
Cumulative Deposition	HOTSPOT and site specific parameters	UFOTRI and site specific parameters
Environmental and Biological Transfer	Site-specific transfer coefficients when available; ICRP/IAEA/NCRP/NRC	Site-specific transfer coefficients when available; ICRP/IAEA/NCRP/NRC
Human Intake	Implicit in FDA Derived Intervention Levels	Implicit in FDA Derived Intervention Levels
Human Absorbed Dose Rate	Implicit in FDA Derived Intervention Levels	Implicit in FDA Derived Intervention Levels

Areas exceeding protective action guides for relocation will be determined using the same models used for the ingestion pathway calculations. The most recent inhalation dose factors from ICRP, and site-specific resuspension factors are recommended for use in resuspension calculations.

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