WSRC-MS-98-00027

Evaluating Postulated Tritium Releases on a Large DOE Site Using the UFOTRI Probabilistic Consequence Model

Charles E. Murphy, Jr.
Westinghouse Savannah River Company
Savannah River Technology Center
Aiken, SC 29808

Kevin R. O'Kula, and Jackie M. East
Westinghouse Safety Management Solutions, Inc.
1993 South Centennial Avenue, SE
Aiken, SC 29803

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-96SR18500 with the U. S. Department of Energy.

Abstract

The UFOTRI computer model is applied to postulated accident conditions for tritium facilities at the Savannah River Site in the southeastern United States. Predicted doses are dominated by food ingestion pathways, and are evaluated from Complementary Cumulative Distribution Functions. For plume passage and reemission during the acute phase after release, the 95^{th} percentile dose factor per unit HTO release is 1.2E-8 rem/curie (3.3E-21 Sv/Bq). Other than food pathway assumptions, major sensitivities include surface roughness length, wind direction persistence, wet deposition and dispersion parameters.

Introduction

The Savannah River Site (SRS) in the southeastern United States is a major center in the United States Department of Energy (DOE) Complex for processing, storing, stabilizing, and dispositioning of tritium and other nuclear materials. To support safe operations at SRS, an authorization basis must be documented. The safety analysis supporting the authorization basis is developed containing consequence analysis of postulated accident conditions, as well as the impacts from normal operations. These analyses take into account physical features of the Site, topography and physical layout of the facility, and distance to potential receptors, as well as regional meteorology. The consequences of tritium releases, in particular, are influenced heavily by the characteristics of the region of transport. For analysis of potential doses and health effects from acute tritium releases to maximally exposed individuals at the Site boundary and to the neighboring general public, the Kernforschungszentrum Karlsruhe (KfK) probabilistic consequence assessment model, UFOTRI, has been implemented. This paper discusses application of UFOTRI to SRS and environs for the assessment of hypothetical accidental conditions to offsite receptor populations. Dose per unit activity factors are reported for hypothetical releases of tritium oxide from SRS. The major sensitivities of the consequence results are described.

Consequence Methodology & Application Domain

Consequence Bases and Savannah River Site Characteristics

Preparation of accident and consequence analysis supporting the Authorization Basis for operation of U.S. DOE nuclear facilities follows a prescribed regulatory framework [1,2]. The endpoint consequence typically applied to evaluate individual accident conditions is the 95th percentile, direction-independent, consequence to receptors representing the general public. The 95th percentile dose, for example, is the numerical dose exceeded five percent of the time and independent of direction, based on meteorological variability. The location of the closest boundary allowing uncontrolled access to the point of release is the nominal evaluation distance. The receptor is termed the maximally exposed offsite individual (MOI), and is radiologically exposed through inhalation and skin absorption pathways for postulated atmospheric tritium releases. The MOI receptor is assumed to remain exposed throughout plume passage. Other consequence calculations for DOE facilities are often required to support probabilistic and environmental impact analyses. Assessments of this nature take into account spatially varying populations, and extend from the reservation boundary to the Ingestion Planning Zone (IPZ) 50-mile radius (81 km). Maximum, 95th percentile, and mean statistical measures of consequence are determined. The doses account for inhalation, skin absorption and food ingestion pathways.

A polar grid map of SRS with origin shown relative to the Site configuration and extending to a distance of 20 miles (~32 km) is shown in Figure 1. SRS covers a predominantly rural area of approximately 310 square miles (~800 km^2) located in west central South Carolina in the southeastern United States. The Savannah River forms much of the Site's western border. SRS is forested by evergreen and several major species of deciduous trees. Regions outside the SRS reservation boundary are mostly rural, with major population centers north and northwest. SRS itself is relatively flat, with rolling hills in some areas, and river valley characteristics along the southwest quadrant.

Figure 1. 20-mile Polar Grid for SRS-Based UFOTRI Dose Calculations
(1-mile radial increments to 10 miles; 2-mile increments out to 20 miles)

2.2 The UFOTRI Atmospheric Dispersion Model

The UFOTRI (Unfallfolgenmodell fur Tritiumfreisetzungen) computer model was developed by the German laboratory, Kernforschungszentrum Karlsruhe Gmbh, (KfK), to assess radiological consequences due to postulated accidental atmospheric releases from nuclear facilities [3]. UFOTRI describes the behavior of tritium in the biosphere and calculates the radiological impact on individual receptors and populations due to inhalation, skin absorption and uptake of contaminated foodstuffs. Time-dependent processes modeled include dispersion, deposition, reemission, conversion of tritium gas (HT) into tritiated water vapor (HTO) by the soil, and conversion of HTO into organically bound tritium (OBT). The source term model accounts for release duration, release height, tritium species being released, and thermal energy released. A Gaussian module is applied for the initial release of HT/HTO and reemission up to seven days after release. The reemission model addresses evaporation from soil and transpiration from vegetation. UFOTRI considers major transfer processes in the environment (atmosphere, soil, plant, and animal), and is unique in that the initial plume passage model is integrated with the reemission (area source) model.

The atmospheric model is coupled to a first-order compartment module, which describes dynamically the longer-term behavior of the two different chemical forms of tritium in the food chain. The long-term model accounts for food ingestion doses from contaminated foodstuffs. Consequences are output in the form of complementary cumulative distribution function (CCDF) tables. Version 4.0 of UFOTRI was released in 1993 incorporating improvements to plant/exchange, soil/atmosphere exchange, plant, and photosynthesis (OBT formation) models

[4,5]. Version 93/4.20P of UFOTRI, for personal computer applications and last updated in October 1997, is applied here.

Figure 2 shows the overall framework for a UFOTRI calculation utilizing stratified random sampling of the meteorological data. A meteorological preprocessing code (METPRE) is applied to produce UFOTRI-ready meteorological data. TRAJEC prepares weather sequences and their fate up to the most distant grid position chosen by the consequence analyst. SAMPLE then creates the 144 weather categories representing the characteristic meteorology over a yearlong period. The probability (number of occurrences in the period) of these categories is also calculated. SAMPLE selects one sequence in each of the 144 categories, and develops a file for input into UFOTRI. UFOTRI then calculates 144 sets of deterministic dose results. A third auxiliary program, EVAL, evaluates the sets of dose outcomes from UFOTRI and weighs the results by the probabilities of the sequences to generate the CCDFs.

Once the meteorological baseline conditions are defined both spatially and temporally (steps 1 through 3 in Figure 2), UFOTRI may be executed repeatedly. This process generates dose output files (step 4), and ultimately to calculation of CCDF files (step 5).

Each UFOTRI (Step 4) deterministic calculation is performed in the framework shown in Figure 3. After input data are read, each release phase is processed in terms of hourly data. Once the plume is modeled for maximum downwind travel distance and effects, the area source model is implemented until the user-specified end time is reached. The compartment model is then used to estimate long term ingestion doses. This process is repeated until all phases are completed. At this point, additional weather sequences are read in, until all sequences are processed.

Figure 2. Frame for Probabilistic UFOTRI Calculation with Auxiliary Codes

Figure 3. UFOTRI Weather Sequence Processing for Acute and Long-Term Phases

Results for SRS Application

The MOI-plume passage cases, and full inhalation and ingestion cases are discussed in this section.

Plume Passage Dose to Maximum Offsite Receptor

UFOTRI probabilistic results for the MOI receptor (12 km from the source point) were calculated conservatively assuming an evergreen coverage fraction of approximately 0.5, or more than twenty percent less than observed. Other point estimates for key environmental transport variables are specified conservatively.

The base case doses at the 95th level of consequence are 1.12E-08 rem/Ci for plume passage (inhalation and skin absorption), and 1.23E-08 rem/Ci for plume passage and reemission (3.0E-21 Sv/Bq and for plume passage and 3.3E-21 Sv/Bq for plume passage + reemission phases, respectively). The results show less than a 5% change with differing assumptions on release elevation, vegetation coverage, soil type, or soil moisture. Larger differences (10% to factors of about four) result from surface roughness length, dispersion parameters (Briggs or Pasquill-Gifford), wind shift (including versus excluding), and release time changes.

Total Dose to Offsite Receptors

Total doses to offsite receptors, accounting for inhalation, skin absorption, and food ingestion, were calculated for offsite receptors near the fenceline/reservation boundary, at mid-range (33 km) and for the far-field (69 km). The HTO dose results for maximum, 95th percentile, and mean are listed in Table 1. Food consumed is assumed to come from the area impacted by the accidental release such that the all food compartments contribute to the ingestion dose. The 95th percentile and mean doses are 1.7E-04 rem/Ci and 7.4E-05 rem/Ci, respectively, for the receptor at the reservation boundary. Doses at the 33-km receptor (mid-range) are approximately 75% to 80% less, and more than 90% less at the 69-km receptor (far-field). The dose component attributable to ingestion is over 90% of the total for most grid locations. Base case (Case 1) assumed best-estimate point values for environmental and dispersion inputs. Cases 2 through 10 doses are normalized by the corresponding Case 1 levels of consequence for the distance in question.

Although use of the food pathways model for the full dose calculations tended to dominate the results, other sensitivities may be identified. Changes made to the area fraction assumed for evergreen coverage and soil type yielded little impact (Cases 2, 3, and 8). Less than 20% change resulted with soil moisture content (Cases 4 and 5). Significant increases are indicated with changes in the dispersion parameters and surface roughness length applied (Cases 6 and 7), and not crediting wind shift (Case 9). Omitting rainout (Case 10) is observed to decrease doses.

Table 1. Inhalation + Ingestion Dose from Unit HTO Release

Case	Offsite Receptor Dose (rem/Ci-HTO)		
	Near-Field (12 km)	Mid-range (33 km)	Far Field (69 km)
1. Base	a. Max.: 2.11E-04 b. 95th: 1.71E-04 c. Mean: 7.39E-05	a. Max.: 9.24E-05 b. 95th: 3.69E-05 c. Mean: 1.81E-05	a. Max.: 4.28E-05 b. 95th: 1.29E-05 c. Mean: 5.29E-06
2. "High" Evergreen	a.Max/95th: 1.00/1.00 b. Mean: 1.00	a.Max/95th:1.02/1.00 b. Mean: 1.00	a. Max/95th:1.0/1.00 b. Mean: 0.99
3. "Low" Evergreen	a. Max/95th:1.00/0.98 b. Mean: 0.99	a. Max/95th:0.97/0.97 b. Mean: 0.98	a. Max/95th:0.99/0.98 b. Mean: 0.99
4. "High" Soil Moisture	a. Max/95th:1.09/1.00 b. Mean: 1.04	a. Max/95th:0.98/1.05 b. Mean: 1.04	a. Max/95th:0.96/0.95 b. Mean: 1.01
5. "Low" Soil Moisture	a. Max/95th:1.02/1.05 b. Mean: 0.93	a. Max/95th:1.18/1.00 b. Mean: 0.94	a. Max/95th:1.00/1.14 b. Mean: 1.02
6. Briggs Dispersion Parameters	a. Max/ 95th:1.78/1.89 b. Mean: 1.80	a. Max/ 95th:1.39/1.43 b. Mean: 1.34	a. Max/ 95th:1.14/1.43 b. Mean: 1.19
7. MOL Dispersion Parameters	a. Max/95th:1.44/1.54 b. Mean: 1.58	a. Max/95th:2.07/1.17 b. Mean: 1.27	a. Max/95th:1.03/1.85 b. Mean: 1.18
8. Soil Type	a. Max/95th:1.05/1.00 b. Mean: 1.02	a.Max/95th:1.00/1.02 b. Mean: 1.00	a. Max/95th:0.99/1.00 b. Mean: 1.00
9. Wind Shift	a. Max/95th:1.35/1.29 b. Mean: 1.50	a.Max/95th:1.24/1.89 b. Mean: 1.78	a. Max/95th:1.71/1.81 b. Mean: 2.27

10. Wet Deposition	a. Max./95th:0.98/1.00 b. Mean: 0.95	a. Max/95th:0.87/1.00 b. Mean: 0.73	a. Max/95th:0.45/1.00 b. Mean: 0.93

Conclusions and Insights from UFOTRI Analysis

The UFOTRI probabilistic consequence methodology has been applied to assess postulated releases of tritium oxide from Savannah River Site nuclear facilities. The assessment provided the following insights:

- The maximum radiological exposure exceeded five percent of the time at the reservation boundary and for Authorization Basis application purposes, accounting for inhalation during plume passage and reemission for a period of approximately one week, is 1.2E-08 rem per curie of HTO released.
- The *total* dose (including food ingestion) exceeded five percent of the time to an individual at the boundary, is 1.7E-04 rem per curie of HTO released. For SAR applications, UFOTRI assumes consumption of contaminated foodstuffs during a long-term phase following the end of the acute phase.
- The mean, or expected dose is approximately 40% of the 95^{th} percentile dose level, regardless of the offsite receptor location.
- The major sensitivities are surface roughness length, dispersion parameters, and wind shift. In most *actual* accidental release cases, food countermeasures are expected and ingestion-based doses would not be incurred.

Acknowledgments

The authors are deeply appreciative of the technical discussions and suggestions regarding UFOTRI implementation provided by Dr. Wolfgang Raskob. This paper was prepared in connection with work done under Contract No. DE-AC09-96SR18500 for the U. S. Department of Energy. By acceptance of this paper, the publisher and/or recipient acknowledges the U. S. Government's right to retain a nonexclusive, royalty-free license in and to any copyright covering this paper, along with the righted paper.

References

1. U.S. Department of Energy. Safety Analysis Reports. DOE Order 5480.23, Washington, D.C., 1992.
2. U.S. Department of Energy. Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports. DOE Standard DOE-STD-3009-94, Washington, DC, 1994.
3. Raskob W. UFOTRI: Program for Assessing the Off-Site Consequences From Accidental Tritium Releases. Kernforschungszentrum Karlsruhe GmbH, Karlsruhe, KfK 4605, July 1990.
4. Raskob W. Modeling of Tritium Behavior in the Environment. Fusion Technology 1992:636-644.
5. Raskob W. Description of the New Version 4.0 of the Tritium Model UFOTRI Including User Guide. KfK GmbH, Karlsruhe, KfK 5194, August 1993.