6. DOSE CALCULATIONS

Operations at the three ORR facilities may emit airborne and waterborne radionuclides and chemicals. After release, these substances disperse throughout the environment by applicable transport mechanisms, where eventually some may reach and affect humans. This section describes the methodologies used to characterize dispersion of released radionuclides and chemicals and estimate human exposures to and intakes of the dispersed substances. Human exposures to radionuclides are quantified in terms of total EDEs to maximally exposed off-site individuals and the entire population residing within 80 km of ORR and each facility on ORR. Exposures to noncarcinogenic chemicals are characterized by hazard quotients (HQs); exposures to carcinogenic chemicals are characterized by the ratio of the daily intake (DI) to the chronic daily intake (CDI), which is based on a 10^{-5} lifetime risk of developing cancer.

6.1 CONFORMANCE WITH STANDARDS FOR PUBLIC DOSE CALCULATIONS

Dose calculations are performed to demonstrate compliance with regulatory requirements and DOE orders. All models selected to assess environmental transport of and human exposures to substances released from ORR will be appropriate for the physical and environmental situation encountered and for the data available to characterize the situation. Information used in the assessments will be as accurate and realistic as possible. Sources of all input data, including default values, will be documented.

A complete set of potential human exposure pathways will be considered in assessments of radiological and chemical exposure. Pathways that contribute significantly to exposures to the most exposed individual and the entire population residing within 80 km of the facilities on ORR will be evaluated. The pathways that will be evaluated are discussed in Sects. 6.3 and 6.4.

Each calculation will be documented in a file that contains the results of the calculation, a description of all models used, a description of any computer codes used to implement the models, and a complete list of the values and sources of all input data and assumptions used. Descriptions of the models and computer codes may consist of references to published descriptions or of actual mathematical formulations developed for special calculations.

6.2 MAJOR CONSIDERATIONS

DOE Order 5400.5 states that no member of the public shall be exposed to an EDE greater than 100 mrem/yr from DOE activities. Members of the public have the potential to receive radiation and chemical doses from internal and external exposures to materials released to the atmosphere, ground and surface waters, and soils and sediment. In addition, some members of the public may receive external radiation doses through direct external irradiation by radiations emanating from buildings and other objects (e.g., drum storage and burial areas) located within facility and reservation

boundaries. Doses will be estimated for all potentially important exposure pathways relevant to the above exposure modes. Table 6.1 lists environmental release and transport mechanisms that apply to emissions from ORR. Sections 6.3 and 6.4 discuss the environmental transport, food chain, and dosimetric models used to evaluate human exposures due to operations on ORR. Input data to the models will be either site specific (e.g., collected under the environmental monitoring and surveillance activities described earlier in this EMP) or generic (default values). If warranted and possible, studies will be conducted to obtain site-specific values for critical parameters currently characterized by default values. In the absence of nuclide-specific data (i.e., only gross alpha and beta counts), only bounding dose calculations will be made.

Models and computer codes for evaluating public exposures to released radionuclides and chemicals will be selected based on (1) the applicability of the model to the situation being evaluated, (2) the degree to which the model has been documented and verified, and (3) the availability of the data needed to implement the model. Unless otherwise required by regulatory or legal mandates, the simplest model needed to characterize a situation will be used.

Table 6.1. Environmental transport mechanisms applicable to releases from the Oak Ridge Reservation

Releases to air	Remain suspended in air Deposit on ground Deposit on vegetation Deposit on water surfaces
Releases to surface water	Remain dissolved or suspended in water Deposit on ground via irrigation Deposit on vegetation via irrigation Deposit in sediments Infiltrate to groundwater
Releases to groundwater	Remain dissolved or suspended in water Deposit on ground via irrigation Deposit on vegetation via irrigation Flow into surface water
Radionuclides in objects	Remain in fixed sources
Releases to ground surfaces	Remain on ground Dissolve or suspend in surface water Infiltrate to groundwater Become suspended in air

6.3 TRANSPORT MODELS

This section describes the methodologies that will be used to characterize environmental concentrations of materials released from ORR. In some cases, transport models will be used to predict concentrations; in other cases, measured concentrations will be available. Whenever both predicted and measured concentrations are available, the measured concentrations will be used to verify modeling predictions.

6.3.1 Atmospheric Transport

Contaminants released into the atmosphere may remain suspended in air and may deposit on soil, vegetation, and water surfaces (Table 6.1). Atmospheric transport models are used to calculate annual-average ground-level airborne concentrations of contaminants and associated rates of deposition on the ground and vegetation. Deposition onto water surfaces is not evaluated since the potential consequences of such deposition are negligible relative to those of contaminants that remain airborne and those that deposit on soil and vegetation.

Calculations of airborne concentrations and deposition rates of radionuclides released to the atmosphere are estimated using the CAP-88 assessment package, which is specified by EPA for demonstrating compliance with the *National Emission Standards for Hazardous Air Pollutants; Standards for Radionuclides* (40 CFR Part 61, Subpart H). The CAP-88 computer codes are used to calculate annual-average ground-level air concentrations and deposition rates at selected environmental locations. The locations are selected to (1) allow identification of the maximally exposed individual for each source, each facility, and the entire ORR and (2) characterize exposures of the entire population within 80 km of ORR.

Releases of chemicals are characterized only to the extent required by facility-specific permits. These characterizations, although incomplete, indicated that detailed dispersion and exposure modeling were unwarranted.

Whenever possible, site-specific parameter values will be used to quantify radionuclide and chemical releases [e.g., release rates, particle size in terms of activity median aerodynamic diameter (AMAD), and chemical composition]; meteorological variables (e.g., wind speed and direction, atmospheric stability class, air temperature, rainfall rate, and mixing layer height); and source parameters (e.g., release height, stack diameter, exit gas velocity and temperature, and location with respect to exposed persons). These parameters will be evaluated using data collected under the environmental monitoring, sampling, and surveillance programs. Release-rate values will be used only if they are statistically greater than zero. If reliable particle-size data are not provided, an AMAD of 1.0 μm will be assumed unless use of a different available size is requested by the facility operator. If reliable chemical-composition (solubility) data are not provided, the solubility class that gives the highest EDE via inhalation will be used.

Each major emission source at ORNL and ETTP will be modeled separately. Emissions from major sources at Y-12 will be modeled using a single, centrally located 20-m-high release point. A comparison of calculated air concentrations at air monitoring stations located around Y-12 shows

that concentrations calculated using the single release point generally were slightly (less than 2 times) higher than concentrations calculated using the seven major emission sources at Y-12 (O'Donnell and Cotter 1992).

Use of the CAP-88 (for radionuclides) and Industrial Source Complex, Long Term (ISCLT) codes (for chemicals) for estimating airborne concentrations of radionuclides and chemicals has been approved by EPA. Both codes calculate similar conservative (high) concentrations, even in the fairly complex terrain in the vicinity of ORR. Based on 1989 and 1990 data, calculated concentrations (using CAP-88) of uranium at monitoring stations located around Y-12 exceed measured concentrations by a factor of between 1.5 and 20 (O'Donnell and Cotter 1992).

Doses calculated from ambient air monitoring data are compared to doses calculated by CAP-88 at nearby locations to verify that the atmospheric dispersion codes are not underestimating significantly airborne concentrations of radionuclides around ORR.

6.3.2 Surface Water Transport

Contaminants released to surface water may remain dissolved or suspended in water, deposit in sediments, and be deposited by irrigation on the ground surface and vegetation. Since opportunities for direct human exposure to sediments are limited, and irrigation is not widely practiced along the Clinch River system, sedimentation and irrigation are of lesser importance than other pathways such as air. Nevertheless, sediment will be analyzed and its pathway evaluated as part of the surveillance program. Most of the impact from sedimentation is due to uptake of contaminants by fish and their subsequent ingestion by humans, as discussed in Sect. 6.4.6. A water-use survey of the Clinch/Tennessee River system is conducted each year; the results of the latest available survey will be used to quantify drinking water populations and fish harvests.

Quantities of radionuclides and chemicals released to surface waters are determined by sampling at points of discharge. Concentrations of these substances in surface waters accessible to the public are quantified by sampling. A simple dilution model will be used to determine if there is a possible discrepancy between the sampling data and the radionuclide and chemical release data. A more complex model will be implemented if warranted.

6.3.3 Groundwater Transport

Contaminants released into groundwater may remain dissolved or suspended in the water and may be deposited by irrigation near ORR on the ground surface and vegetation. Because use of groundwater for irrigation is uncommon, deposition by irrigation is not considered an important pathway and is not evaluated. Currently, groundwater transport is modeled as part of the CERCLA process.

6.4 ENVIRONMENTAL PATHWAY MODELS

This section describes the methodologies that will be used to characterize mechanisms for human uptake and exposure to the contaminant concentrations described in Sect. 6.3. As in Sect. 6.3, both modeling results and sampling data will be used, as available, to obtain contaminant concentrations in media and foods to which humans may be exposed. *Regulatory Guide* 1.109 models (NRC 1977) will be used unless better site-specific models and data are available.

6.4.1 Contaminants in Air

Potential direct pathways of human exposure to airborne contaminants include inhalation (breathing), immersion, and absorption through the skin. Indirect pathways, which are discussed in the following sections, involve deposition of contaminants on soil (Sect. 6.4.4), crops (Sect. 6.4.5), water (Sect. 6.3.1), and inhalation by terrestrial animals (Sect. 6.4.6).

The AIRDOS-EPA and DARTAB computer codes of the CAP-88 package are used to calculate total EDEs from inhalation of and immersion in air containing radionuclides. AIRDOS-EPA uses air concentrations that it calculates at each selected location (Sect. 6.3.1) and *Regulatory Guide* 1.109 pathway models to calculate the quantities of radionuclides inhaled by a person who remains at a selected location for the entire year.

The inhaled quantities and air concentrations are passed, as input data, to the DARTAB computer code, which combines them and the inhalation and immersion dose conversion factors (DCFs) given in the RADRISK database to calculate a total EDE to an individual at each selected location from inhalation of and immersion in contaminated air. DCFs used in the DARTAB computer code are chosen based on particle size (AMAD) and solubility class. In the absence of actual data, a 1.0 μm (AMAD) particle size and the solubility class yielding the highest dose via inhalation are assumed. DARTAB is used also to calculate the collective EDE from inhalation and immersion to the population residing within 80 km of ORR.

6.4.2 Contaminants in Surface Water

Potential direct pathways of human exposure to contaminants in surface waters include ingestion (drinking water), immersion (swimming, wading, showering), direct irradiation (boating, skiing, shoreline use), and inhalation (breathing water vapor while showering). Indirect pathways involve deposition on soil and crops by irrigation (Sect. 6.3.3), deposition in sediments (Sect. 6.3.2), uptake by fish (Sect. 6.4.6), and ingestion by terrestrial animals (Sect. 6.4.6).

At present, the direct pathways evaluated include drinking water, swimming, boating, and shoreline use. *Regulatory Guide* 1.109 models are used to estimate radiation doses due to immersion in and direct irradiation from surface water for the annual environmental report for ORR. Both measured and calculated (Sect. 6.3.2) nuclide concentrations are used in the calculations, which are performed using the LADTAP.XL computer code (Hamby 1991) or its equivalent.

For radionuclides, EDEs are calculated for drinking water at nearby drinking water plants. (Data for water before entry into a drinking water plant is used; water plant outputs are not sampled.) A population dose estimate is made for the entire population residing within 80 km of the ORR. For chemicals, HQs for noncarcinogenic chemicals and intake to chronic daily intakes [I/I (10^{-5})] ratios for carcinogenic chemicals are calculated. For ASER, both chemical and radiation dose estimates from drinking water will be performed using measured concentrations in drinking water when such concentrations are available.

6.4.3 Contaminants in Groundwater

Potential direct pathways of human exposure to contaminants in groundwater include ingestion (drinking water), immersion (showering), and inhalation (breathing water vapor while showering). Indirect pathways involve deposition on soil and crops by irrigation (Sect. 6.3.3) and ingestion by terrestrial animals (Sect. 6.4.6).

Dose calculations will be made for the drinking water pathway if measurable concentrations of radionuclides are found in water samples collected from wells in the off-site well sampling program. These calculations will be performed upon notification of their need by the entity conducting the well sampling program. The primary use of the well sampling data is to verify that concentrations of radionuclides and chemicals from ORR are not causing concentrations in off-site groundwater that exceed regulatory limits. Verification is based on comparison of measured concentrations with federal and state standards and with historical concentrations for each contaminant found.

6.4.4 Contaminants in Soil

Contaminants may reach soil by deposition of airborne materials, materials contained in irrigation water, and direct dumping. Potential direct pathways of human exposure to contaminants in soil include inhalation of resuspended soil, ingestion of soil, and direct exposure to (being near or in contact with) the soil. Indirect pathways involve uptake of contaminants from soil by crops (Sect. 6.4.5).

The resuspension and soil ingestion pathways are not evaluated because their potential consequences are insignificant relative to those from inhalation of newly emitted contaminants and ingestion of foodstuffs. The AIRDOS-EPA and DARTAB computer codes are used to calculate total EDEs due to direct irradiation by radionuclides on soil. AIRDOS-EPA calculates concentrations of radionuclides at each selected location (Sect. 6.3.1) as if deposition had occurred for 50 years. A person is assumed to remain unprotected at a location for the entire year. Ground concentrations and exposure times are passed as input data to the DARTAB computer code, which combines them and the DCFs for exposure to a contaminated ground surface (from the RADRISK database) to calculate total EDEs to an individual at each selected location. DARTAB is used also to calculate the collective EDE to the population residing within 80 km of ORR from exposure to contaminated ground surfaces.

6.4.5 Contaminants in or on Vegetation

Contaminants may reach vegetation (food and feed crops) by deposition of airborne materials, uptake from soil, and deposition of materials contained in irrigation water, which is not evaluated (Sects. 6.3.2 and 6.3.3). The only significant potential direct pathway for human exposure to contaminants in food crops is ingestion. Indirect pathways involve ingestion of feed crops by terrestrial animals (Sect. 6.4.6).

The AIRDOS-EPA computer code uses *Regulatory Guide* 1.109 models and parameters to estimate concentrations of radionuclides in vegetables at selected locations (Sect. 6.3.1) due to deposition from the air and uptake from soil. Other *Regulatory Guide* 1.109 models and parameters are used to estimate human intakes of the vegetables and, thus, of the radionuclides. The code treats radionuclide deposition as if it had occurred for 50 years. The radionuclide intakes are supplied as input data to the DARTAB computer code, which combines them and the DCFs for ingestion (from the RADRISK database) to calculate total EDEs to an individual residing at each location and the entire population residing within 80 km of ORR.

The environmental surveillance program provides concentrations of radionuclides and chemicals in food crops. These concentrations, if available, and the intake models and parameters described above will be used to provide additional estimates of doses from ingestion of locally grown foods.

6.4.6 Contaminants in Terrestrial Animals and Fish[1]

Contaminants may accumulate in terrestrial animals from eating contaminated feed, drinking contaminated water (not modeled), and breathing contaminated air (not modeled). Contaminants may accumulate in fish when they eat contaminated foods and reach equilibrium with contaminants in the aquatic environment. Potential direct pathways for human exposure to contaminants in terrestrial animals and fish are eating meat and fish and drinking milk.

The AIRDOS-EPA computer code uses *Regulatory Guide* 1.109 models and parameters to estimate concentrations of radionuclides in beef and milk due to consumption of feed contaminated with radionuclides released to the atmosphere. Other *Regulatory Guide* 1.109 models and parameters are used to estimate human intake values of milk and beef and, thus, of the radionuclides. The radionuclide intake values are supplied as input data to the DARTAB computer code, which combines them and the DCFs for ingestion (from the RADRISK database) to calculate total EDEs to an individual residing at each location and the entire population residing within 80 km of ORR.

A second set of estimates of potential doses is based on measured concentrations of contaminants. Maximum individual doses are calculated for ingestion of milk containing measured quantities of radionuclides and of fish containing measured quantities of radionuclides and chemicals. Potential doses from ingesting deer and water fowl harvested legally from the reservation are calculated.

6.4.7 Radionuclides in Objects

[1] See Sect. 6.6 for discussion on estimating doses to aquatic and terrestrial animals.

The only identified source of potential exposure to the public from radiation emanating from radionuclides contained in structures and other objects was scattered gamma radiation from the experimental cesium plots near the Clinch River and from UF_6 cylinder storage areas at ETTP near Poplar Creek. The section of Poplar Creek affected by the cylinder storage areas runs through ETTP and is used at times by fishermen. Theoretical doses, using measured exposure rates, are calculated to hypothetical, maximally exposed individuals. Calculated doses will be modified to reflect any changes in the measured dose rates. If other sources of direct radiation are identified, appropriate exposure scenarios will be devised and doses estimated.

Gamma dose rates from the cylinder yards at ETTP are measured either directly with a tissue-equivalent dose response meter or with environmental dosimeters placed in locations accessible to the public in the vicinity of the cylinder yards. The calculated EDEs are based on the measured dose rates and are adjusted for gamma background readings established at the ambient air monitor stations surrounding ETTP. Neutron measurements are also obtained in the vicinity of the cylinder yards, but the readings have been negligible. Results of the direct radiation monitoring program at ETTP are included each year in ASER.

6.5 INTERNAL DOSIMETRY MODELS

The results of all dose calculations will be reported in terms of total EDE, the sum of EDEs received during the year from external exposures plus the 50-year committed EDEs from intake of radionuclides during the year. All DCFs used in the calculations will be obtained from the following sources and any revisions to them. For calculations using CAP-88, the DCFs supplied with the package, in the RADRISK data file, will be used. Factors to be used in all other calculations are given in DOE/EH-0070, *Internal Dose Conversion Factors for Calculation of Dose to the Public*; EPA-520/1-88-020, Federal Guidance Report No. 11, *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*; and EPA 402-R-93-081, *External Exposure to Radionuclides in Air, Water, and Soil*. Although not used in specific dose calculations, the DCGs given in DOE Order 5400.5 may be used to infer the acceptability or magnitude of doses associated with measured concentrations of radionuclides in environmental media.

6.6 RADIATION DOSE TO NATIVE AQUATIC AND TERRESTRIAL ORGANISMS

DOE Order 5400.5, Chap. II, sets an absorbed dose rate limit of 1 rad/day to native aquatic organisms from exposure to radiation or radioactive releases into the aquatic environment. To demonstrate compliance with this limit, the methodology described in the DOE Standard *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*, DOE-STD-1153-2002, (DOE 2002) is used to estimate absorbed dose rates to aquatic organisms. The absorbed doses are calculated using the Radionuclide Biota Concentration Guide (RAD-BCG) calculator or when available, the RESRAD-BIOTA computer code. Other methods may also be used to estimate absorbed doses to aquatic organisms. Though it is not currently required by DOE Order 5400.5, the

RAD-BCG calculator (or RESRAD-BIOTA code) may be used as a screening tool to estimate whether doses to terrestrial organisms exceed the absorbed dose of 0.1 rad/day.

6.7 QUALITY ASSURANCE

All algorithms and methods used to perform dose calculations for demonstrating compliance with NESHAP requirements and DOE Order 5400.5 will be documented.

6.8 *REGULATORY GUIDE* PERFORMANCE CRITERIA

a. Except where mandated otherwise (e.g., compliance with 40 CFR Part 61), the assessment models selected for all environmental dose assessments *should appropriately characterize the physical and environmental situation encountered. The information used in dose assessments *should** be as accurate and realistic as possible.**

All models selected to assess environmental transport of and human exposures to substances released from ORR will be appropriate for the physical, chemical, and environmental situation encountered and for the data available to characterize the situation.

Information used in the assessments will be as accurate and realistic as possible. When available, site-specific data will be used rather than model default parameters. Average (rather than maximum) values measured over the period of the calendar year will be used in the assessment to represent more realistic conditions.

b. Complete documentation of models, input data, and computer programs *should be provided in a manner that supports the ASER or other application.**

Complete documentation of the models used, any assumptions made, and the input data will be maintained by the entities performing the calculations.

c. Default values used in model applications *should be documented and evaluated to determine appropriateness to the specific modeling situation.**

Where site-specific data exists, these values are input into the model. All values, including the default values, are maintained by the entities performing the calculations.

d. When performing human food chain assessments, a complete set of human exposure pathways *should be considered, consistent with current methods, and *should** be documented supporting the site EMP.**

Through the years, all known human exposure pathways have been considered and evaluated. The primary pathways that contribute to the dose are discussed in detail in this

section. During the annual review of the EMP, new pathways resulting from changes in the operations or from new facilities will be evaluated.

e. Surface and groundwater modeling *should be conducted as necessary to conform with the applicable requirements of the state government and the regional office of the EPA.**

Currently there are no specific or explicit surface or groundwater modeling requirements from the state of Tennessee or EPA Region 4. However, ER work plans developed by Y-12 frequently include groundwater modeling, and subsequently the plans are approved by the regulators. As an example, Y-12 has performed groundwater modeling for the S-3 Ponds.

f. The general QA program provisions of Chap. 10 of this guide *should be followed as they apply to performing calculations that assess dose impacts.**

The entities performing the calculations documents all algorithms and methods used in performing dose calculations. This documentation will be consistent with applicable QA requirements from Chap. 10 of the *Regulatory Guide*, DOE/EH-0173T (DOE 1991a).