SRNL-TR-2010-00274
Revision 0

Keywords:
Environmental
Dosimetry

Retention: *Permanent*

Environmental Dose Assessment Manual

G.T. Jannik

Report Date: September 16, 2010

Savannah River National Laboratory
Savannah River Nuclear Solutions
Aiken, SC 29808

Prepared for the U.S. Department of Energy under
contract number DE-AC09-08SR22470.

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Printed in the United States of America

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Revision by: G.T. Jannik, September 2010 (SRNL-TR-2010-00274, Rev. 0)
Revision by: P.L. Lee, April 2001 (WSRC-IM-91-1, Rev. 3)
Revision by: G.T. Jannik and A.A. Simpkins, April 1999 (WSRC-IM-91-1, Rev. 2)
Revision by: G.T. Jannik and A.A. Simpkins, October 1995 (WSRC-IM-91-1, Rev. 1)
Revision by: D.M. Hamby, December 1991 (WSRC-IM-91-1, Rev. 0)
Original Version by: J.C. Huang, April 1986 (DPSTM-86-700-1, Rev. 0)

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1.0 INTRODUCTION

1.1 Background

The Environmental Analysis Section (EAS) of the Savannah River National Laboratory (SRNL) has been tasked with standardizing Savannah River Site (SRS) environmental dose assessment methods. The set of environmental transport and dosimetry models that have been chosen employ technically valid methodologies comparable to those accepted by the U.S. Department of Energy (DOE) and other regulating agencies.

This Environmental Dose Assessment Manual (EDAM) presents a discussion of the environmental transport and dosimetry models, and their associated computer codes, selected for standardization at SRS. This manual should serve as a reference document for DOE personnel and their consultants, who will review documents prepared by SRNL. This manual will be reviewed and updated as the need arises.

1.2 Summary

This manual presents the results of standardization efforts in the environmental dose assessment methods used by EAS. The highlights and conclusions of standardizing the environmental transport and dosimetry methods are shown in Figure 1 and are summarized as follows:

1.2.1 *Routine Liquid Releases*

To show compliance with DOE and U.S. Environmental Protection Agency (EPA) regulations (DOE 1990) governing annual dose limits from routine liquid releases, the computer code LADTAP XL© (Simpkins 2004) has been written for SRS use by EAS Environmental Dosimetry Group (EDG) personnel. LADTAP XL© calculates the offsite maximally exposed individual and population doses resulting from the exposure pathways including drinking water, aquatic foods, and recreation exposure pathways. LADTAP XL© is a Microsoft ExcelTM spreadsheet version of LADTAP II (U.S. Nuclear Regulatory Agency (NRC) code of the same name) with improvements in the shoreline exposure and aquatic foods pathway models.

1.2.2 *Accidental Liquid Releases*

To show compliance with governing annual dose limits from non-routine and accidental liquid releases, the computer code LADTAP XL© (Simpkins 2004) has been written for SRS use by EDG personnel. For acute releases, only the drinking water dose is considered to be valid when using LADTAP XL©.

1.2.3 *Irrigation Doses from Liquid Releases*

To show compliance with governing annual dose limits from the potential irrigation of crops with contaminated river water, the computer code LADTAP XL© (Simpkins 2004) has been modified to include the IRRIDOSE model for SRS use by EDG personnel.

1.2.4 *Aquatic Pathway Doses for SRS Performance Assessments*

To support ongoing Performance Assessments (PA) at SRS, two modified versions of the LADTAP XL© code have been created. LADTAP PA (Jannik and Dixon 2006) was developed for the E-Area PA and LADTAP PA FTF (Farfan and Dixon 2007) was developed for F-Tank Farm PA.

1.2.5 *Routine Atmospheric Releases*

To show compliance with DOE regulations (DOE 1990) governing annual dose limits from routine atmospheric releases and for other routine atmospheric releases, the computer codes MAXDOSE-SR and POPDOSE-SR (SRNL-modified versions of NRC's XOQDOQ and GASPAR codes) are selected for SRS use. The MAXDOSE-SR code calculates the maximally exposed individual dose to offsite people and the POPDOSE-SR code performs the offsite population dose calculations. Plume and ground gamma-shine, inhalation, and foodstuff ingestion pathways are considered in these codes.

MAXINE is an EXCEL© spreadsheet, used to estimate dose to individuals for routine atmospheric releases of radioactive materials. MAXINE does not contain an atmospheric dispersion model, but rather doses are estimated using air and ground concentrations as input. Minimal input is required to run the program and site specific parameters are used when possible.

1.2.6 *Routine Atmospheric Releases for NESHAP*

To show compliance with EPA's National Emission Standards for Hazardous Air Pollutants (NESHAP) regulations (EPA 1989) governing annual dose limits from routine atmospheric releases, the computer code CAP88 is required at SRS. The CAP88 code calculates the maximally exposed individual dose to offsite people and the offsite population dose. Plume and ground gamma-shine, inhalation, and foodstuff ingestion pathways are considered in this code. CAP88 is not used for other routine dose calculations because the code does not address site-specific factors such as multiple release locations, irregular site boundaries, and uneven terrain.

1.2.7 *Accidental Atmospheric Releases*

For accidental atmospheric releases, the computer code AXAIRQ is used to calculate the plume-exposure doses from potential process-accident or earthquake-induced releases to the atmosphere. The plume-exposure doses include maximum doses to offsite individuals, and population doses to the 80-km population. Exposure pathways include plume and ground gamma-shine and inhalation.

1.2.8 *Near-In Dispersion for Atmospheric Releases*

For maximally exposed individual and population dose calculations for near-in dispersion the SRNL developed computer code VENTSAR XL© (Simpkins 1997) is chosen for SRS use. VENTSAR XL© uses near-in dispersion characteristics to estimate concentrations by taking into account the interaction of plume and air-flow patterns around buildings and plume rise due to buoyancy or momentum.

1.2.9 *Non-Routine Weather Conditions for Atmospheric Releases*

For maximally exposed individual and population dose calculations for specific dispersion characteristics, AXAOTHER XL (Simpkins 1996) is used. AXAOTHER XL is a spreadsheet based on AXAOTHER (Haynes and Taylor 1983) which estimates doses for high-velocity straight winds and tornado conditions.

1.2.9.1 High Velocity Straight Winds

Based on a Gaussian plume model, the dispersion factors associated with high-velocity straight winds have been determined and are available in a graphical form (Garrett and Murphy 1981; Hoel 1985). The chi/Q values are input for the dose calculation code, AXAOTHER XL, for maximum individual and population dose calculations.

1.2.9.2 Tornadoes

Based on a realistic but simplified methodology, the dispersion factors associated with tornadoes have been determined and plotted in a graphical form (Weber and Hunter 1995). The chi/Q values are input for the dose calculation code, AXAOTHER XL, for maximally exposed individual and population dose calculations.

1.2.10 *Residual Radioactivity in Soil and Concrete Slabs*

RESRAD is used to estimate the dose due to residual radioactive contamination at SRS. RESRAD is a PC based computer code designed to calculate radiation doses to the maximally exposed individual. The model considers direct exposure, inhalation of dust and radon, and ingestion of plant foods, meat, milk, aquatic foods, soil, and water pathways. Default exposure scenarios include the resident farmer, suburban resident, and industrial worker. However, other exposure scenarios can be accomplished by adjusting the applicable input parameters. Coding of the software is performed and controlled by the Argonne National Laboratory and the executable file is provided free to users through the RESRAD website: (web.ead.anl.gov/resrad/home2/)

1.2.11 *Residual Radioactivity in Buildings*

RESRAD-Build is used to estimate the dose due to residual radioactive contamination remaining in decommissioned buildings at SRS. RESRAD-Build is an IBM PC based computer code designed to calculate radiation doses to the maximally exposed individual. The model considers direct exposure, inhalation of dust and radon, and incidental ingestion of dust. Coding of the software is performed and controlled by the Argonne National Laboratory and the executable file is provided free to users through the RESRAD website: (web.ead.anl.gov/resrad/home2/)

1.2.12 *Doses to Aquatic and Terrestrial Biota*

RESRAD-Biota (also called the RAD-BCG Calculator) estimates doses for aquatic (fish, shellfish, algae), riparian (raccoon and duck), and terrestrial (deer) biota. The doses are determined using measured radioactivity in soil, sediment, and SRS streamwater. Coding of the software is performed and controlled by the Argonne National Laboratory and the executable file is provided free to users through the RESRAD website: (web.ead.anl.gov/resrad/home2/)

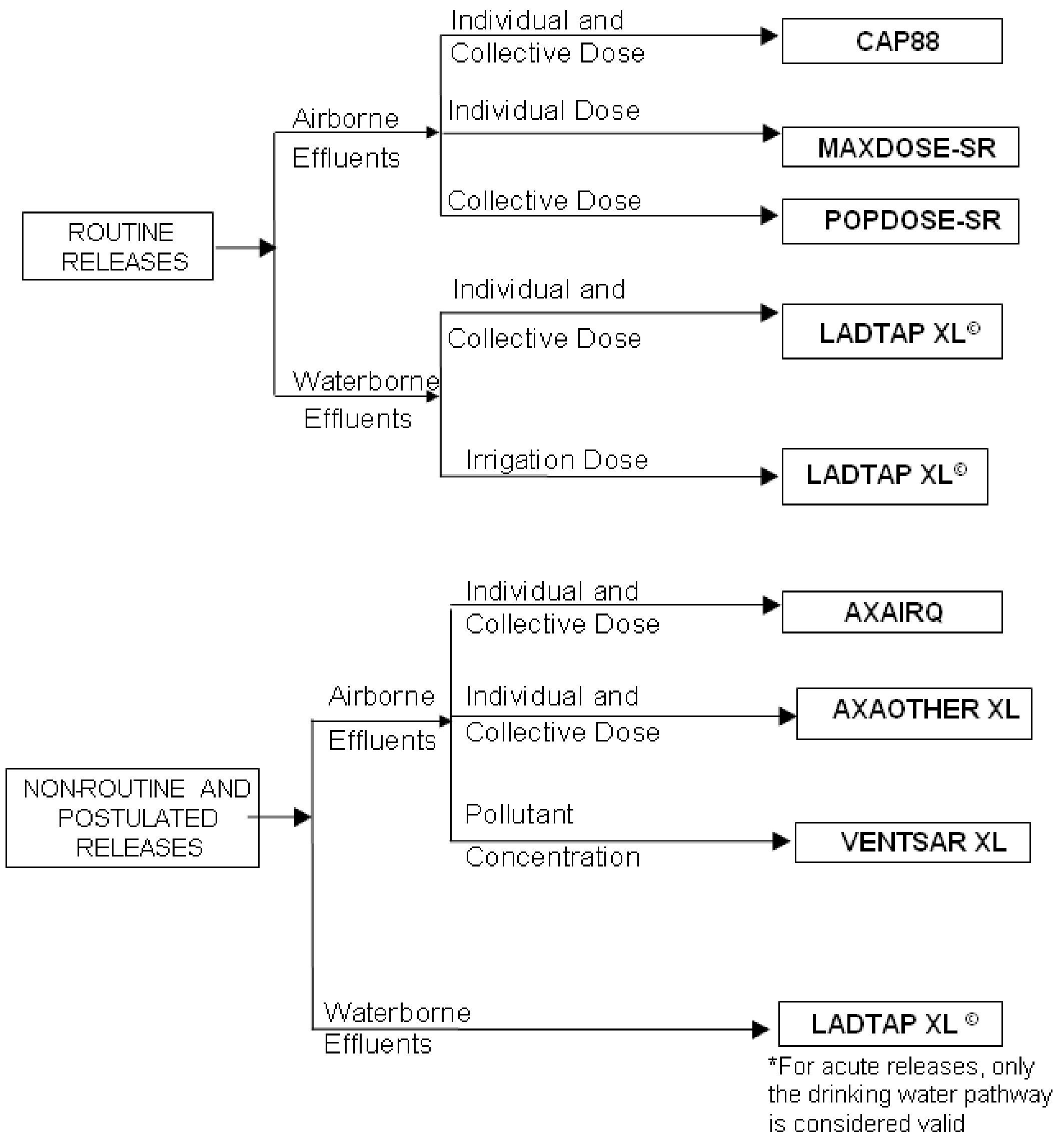

Figure 1-1. Diagram of Consequences Analysis Codes

2.0 DISCUSSION

2.1 Dose Assessment Methods

The general dose assessment methods used in the various dosimetry codes are described in the following sections for routine releases and for accident releases.

2.1.1 *Dose Assessment for Routine Releases*

During routine operations at a nuclear facility, limited amounts of radioactive materials are released to the environment through atmospheric and/or liquid pathways. These releases potentially result in a radiation dose commitment to offsite people. The principal pathways by which people are exposed to releases of radioactivity are:

- Inhalation
- Ingestion
- Skin absorption
- External exposure

Figure 2-1 is a simplified representation of the principal exposure pathways.

At SRS, the potential effects of routine radioactive releases have been assessed annually since operations began. Since 1972, annual offsite dose estimates have been published in site environmental reports, which are made available to the public. For all routine environmental dose calculations performed since 1978, SRS has used environmental transport models based on codes developed by the NRC (NRC 1977a). The NRC based transport models use DOE accepted methods, consider all significant exposure pathways, and permit detailed analysis of the effects of routine operations.

When calculating radiation doses to the public from routine releases, SRS uses the concept of the maximally exposed individual. However, because of the conservative lifestyle assumptions used in the dose models, no such person is known to exist. The generalized parameters used for the maximally exposed individual dose calculations are:

- For airborne releases: someone who lives at the SRS boundary 365 days per year and consumes large amounts of milk, meat, and vegetables produced at that location
- For liquid releases: someone who lives immediately downriver of SRS (near Savannah River Mile 120) 365 days per year, drinks 2 liters of untreated water per day from the river, consumes a large amount of Savannah River fish, and spends the majority of time on or near the river

SRS conservatively combines the airborne pathway and liquid pathway dose estimates, even though the two doses are calculated for hypothetical individuals residing at different geographic locations. This is done to demonstrate compliance, which is documented annually in the SRS Environmental Report, with the DOE Order 5400.5 (DOE 1990) all-pathway dose standard of 100 mrem per year.

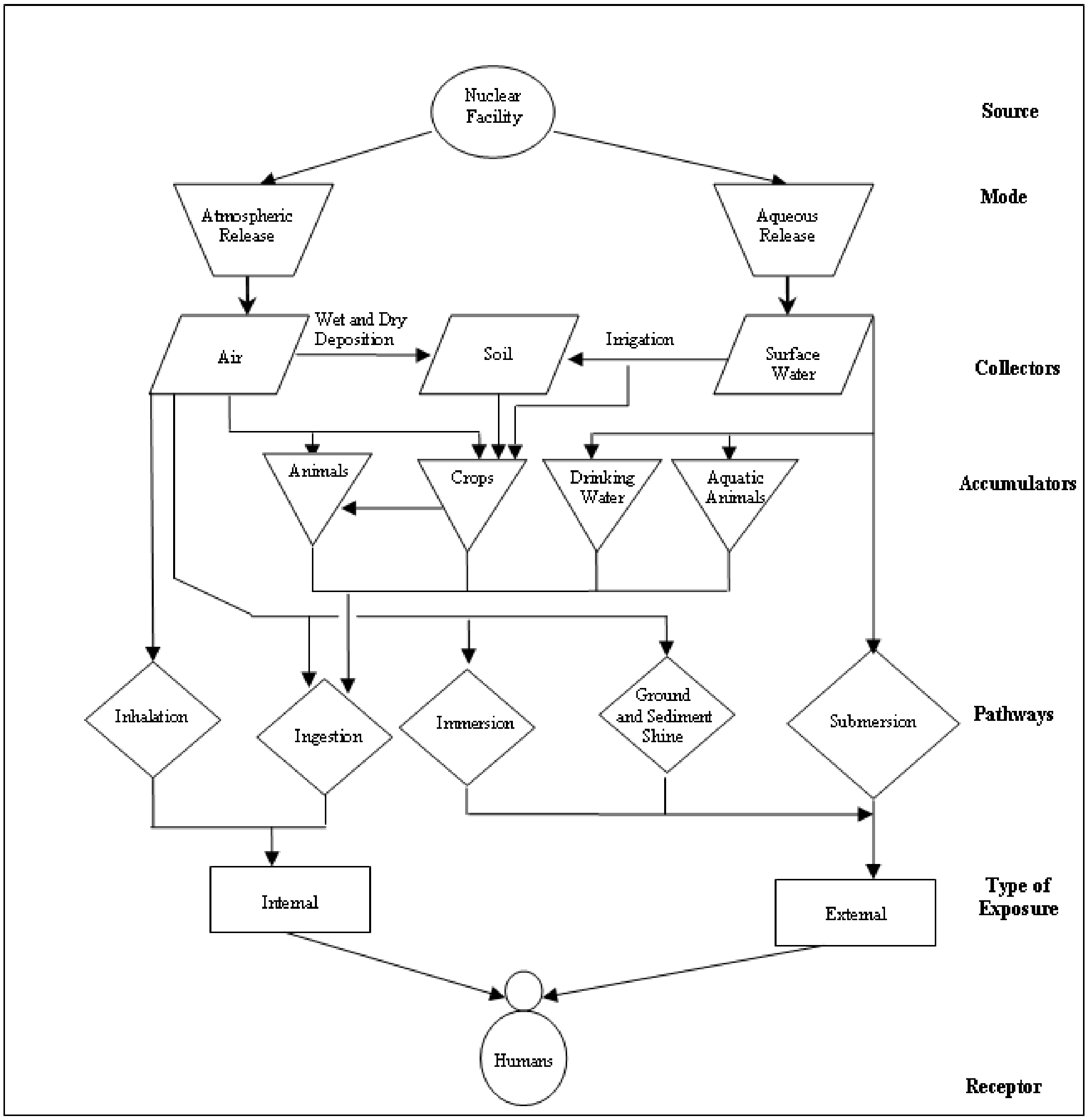

Figure 2-1. Exposure Pathways to Humans from Atmospheric and Aqueous Releases

2.1.2 *Dose Assessment for Accidental Releases*

Accidents in one of the SRS facilities can result in an airborne release, a liquid release, or a combination of both. Accidents causing an environmental release may result from natural phenomena (such as high-velocity straight winds, tornadoes, earthquakes, etc.), man-made external events (such as vehicle/building collision, aircraft crash, etc.), or process incidents (such as process upsets, equipment malfunction, operator error, etc.).

Radiological consequences following postulated accidental radioactive releases from SRS facilities can be estimated using one or more of SRNLs dose assessment computer codes. Computer code packages different from those used for routine releases are used to assess environmental consequences resulting from accidental airborne releases because of the differences in characterizing atmospheric dispersion under different meteorological conditions.

2.1.2.1 Airborne Accidental Releases

Three different computer codes are used to analyze short duration accidental airborne releases at SRS depending on the conditions associated with the release. AXAIRQ is used to analyze postulated accidents involving both ground level and elevated releases. Results from AXAIRQ are typically used for Safety Analysis Reports (SARs), Hazard Assessment Documents (HADs), and Environmental Impact Statements (EISs). VENTSAR XL© is used to predict downwind pollutant concentrations resulting from releases affected by building wake effects and plume rise. AXAOTHER XL is used to model releases with high velocity straight winds or tornado conditions.

2.1.2.2 Surface Water Accidental Releases

Postulated accidents resulting from SRS operations may involve liquid releases to onsite streams that eventually reach the Savannah River. The maximally exposed individual and population dose commitments resulting from postulated aqueous releases of radioactive materials are predicted using the LADTAP XL© spreadsheet.

Models characterizing acute uptake and retention of radionuclides by aquatic foods (fish, invertebrates, etc.) are not utilized in LADTAP XL©. However, doses from the consumption of aquatic foods can be estimated assuming steady-state conditions, recognizing that such doses are conservative and overestimated. Development of a model to estimate radionuclide concentrations in fish and invertebrates under acute exposure conditions has not been completed at SRS. Until these studies are complete, dose resulting from acute releases will be estimated using only the drinking water pathway.

The offsite individual who will receive the maximum dose from an accidental liquid release is a hypothetical person who lives on the shore of the Savannah River near River Mile 120, where complete mixing is assumed to have occurred. It is assumed that this individual drinks 2 L/d of untreated river water.

2.2 <u>Dosimetry Code Descriptions</u>

At SRNL, the consequence analysis computer codes were originally selected after a thorough review of existing methods and associated software. The evaluation criteria for computer codes included the following:

- Acceptability to the regulatory agencies
- Adaptability
- Versatility
- Availability

The selected computer codes are stored in write-protected datasets with access limited to authorized personnel (i.e. EDG personnel). For a complete description of the software quality assurance requirements governing environmental dose assessments, refer to Jannik (2010).

2.2.1 *EDG Originated Codes*

Since the last revision of this manual in 2001, EDG has been systematically creating detailed code-specific user's manuals that include

1) The code's background information and methods
2) User information including program features, input, job control language (JCL), and output
3) Verification of calculations performed.

In lieu of repeating these details in this manual, the following references are provided to the codes originated and "owned" by EDG:

- LADTAP XL© Simpkins (2004)
- LADTAP PA Jannik and Dixon (2006)
- LADTAP PA FTF Farfan and Dixon (2007)
- MAXDOSE-SR Jannik and Lee (2010)
- POPDOSE-SR Jannik and Lee (2010)
- AXAIRQ Simpkins (1995a and b)
- AXAOTHER XL Simpkins (1996)
- VENTSAR XL© Simpkins (1997)
- MAXINE Simpkins (2002a)

2.2.2 *Non-EDG Originated Codes*

To show compliance with NESHAP (EPA 1989) regulations, the use of the EPA supplied CAP88 dosimetry code is required. Two versions of this code are currently available for use at SRS. They are the original CAP88 code, which resides on the SRS mainframe computer, and CAP88 PC version 3.0.

For residual radioactivity in soil and buildings and for estimating doses to biota, DOE guidance (DOE 1990) requires the use of the RESRAD family of dosimetry codes, which were developed by Argonne National Laboratory (http://web.ead.anl.gov/resrad). Currently, three RESRAD codes have been incorporated into the EDG Software QA Plan (Jannik 2010). They are the original RESRAD, RESRAD-BUILD, and RESRAD Biota.

In lieu of repeating the details of these codes in this manual, the following references are provided to the non-EDG originated codes "owned" and used by EDG:

- CAP88 — Beres (1988)
- CAP88 PC — EPA (2007)
- RESRAD — Yu, et al. (2001)
- RESRAD-BUILD — Yu, et al. (2003)
- RESRAD-Biota — DOE (2004)

2.3 Dosimetry Code Input Parameters

Most of the physical and behavior input parameters required for use in environmental dosimetry calculations performed at SRS are documented in Jannik et al. (2010). The other datasets required for environmental dosimetry calculations are described in the following sections.

2.3.1 *Dose Commitment Factors*

Since 1989, the dose conversion factors used with the SRS consequence analysis codes were based on International Commission on Radiological Protection (ICRP) dosimetry method recommendations provided in ICRP-26 (ICRP 1977) and ICRP-30 (ICRP 1979) and obtained from DOE/EH-0070 (DOE 1988a) and DOE/EH-0071 (1988b). Beginning in 2010, EDG will transition all dosimetry codes to the dose factors based on ICRP-60 (ICRP 1991) dosimetry method recommendations as obtained from Federal Guidance Report 12 (EPA 1993) for external exposures and ICRP-72 (ICRP 1996) for internal exposures.

The following dosimetry codes used by EDG already incorporate these updated dose factors: LADTAP PA FTF, CAP88 PC, RESRAD and RESRAD-Build.

Most regulations applicable to environmental dosimetry calculations require the use of dose factors for one age group, adults. However, age-specific dose factors for selected radionuclides exist in ICRP-72 (ICRP 1996) and should be used when required.

2.3.1.1 Internal Dose Commitment Factors

Internal doses estimated using the ICRP recommended dose factors are 50-year dose-commitments from a one-year intake. More specifically, these dose estimates are based on continuous intake over a one-year exposure period, and an associated dose commitment extending over a 50-year period from initial intake. Internal dose factors account for progeny ingrowth once the nuclide has been inhaled.

Atmospheric tritium also enters the body through skin absorption (ICRP 1979; Pinson and Langham 1957). The rate at which uptake occurs via skin absorption is approximately equal to one-half the inhalation uptake rate (ICRP 1979). To account for this pathway, the inhalation dose factor for tritium oxide has been increased by 50% over the value given in DOE (1988b). The predicted inhalation dose for all dose assessments involving tritium oxide, therefore, includes tritium uptake via skin absorption with the exception of the EPA required code, CAP88.

2.3.1.2 External Dose Commitment Factors

External dose factors for gamma and beta exposures exist for ground, water and air immersion geometries. Except for AXAIRQ, the external doses are calculated in all dose assessment packages using a semi-infinite plume model. AXAIRQ gives the user the option to choose between three external exposure models.

The external dose factors recommended by ICRP do not include contributions from radioactive progeny. However, when determining dose via external pathways the contribution from progeny ingrowth can be significant. The dose factor library accessed by the MAXDOSE-SR and POPDOSE-SR dose assessment packages was updated in 1991 so that progeny radiation would be considered when estimating external dose for certain radionuclides (Hamby 1991). The AXAIRQ program includes progeny ingrowth.

For calculating external doses resulting from plume gamma shine in the AXAIRQ code, the total-body dose factors for 23 photon energy groups were developed (Pillinger and Huang 1986). Photon energies and relative intensities were obtained from the DRALIST Radioactive Decay Data (RSIC 1981). Reference data and computational means to evaluate the photon energy absorption coefficients for air and tissue were taken from the DOSFACTOR II computer code (RSIC 1981).

2.3.2 *Breathing Rates*

Breathing rate is dependent on age and physical activity. To ensure reasonable and consistent inhalation dose calculations, four standard sets of breathing rates have been selected (Huang and Marter 1983), two for assessing routine releases and two for assessing accidental releases. The breathing rates used in the computer codes for inhalation dose calculations for the maximally exposed individual (MEI) and population are shown in Table 2-1. As stated previously, only adult receptors are assumed in the dose assessment modeling at SRS. Age-specific breathing rates are provided for comparison and should be used as needed.

Table 2-1. Breathing Rates Used for Inhalation Dose Calculations at SRS

Breathing Rate (m^3/yr) for Assessing Routine Releases			**Breathing Rate (m^3/yr) for Assessing Accidental Releases**	
Group	MEI	Population	MEI	Population
Adults	8,000	5,548	12,000	10,500
Teenagers	8,000	5,548	12,000	10,500
Children	3,700	3,700	7,800	6,840
Infants	1,400	1,400	2,500	2,190

Note: Breathing Rates Used for Inhalation Dose Calculations at SRS are from Huang and Marter 1993.

2.3.3 *Agricultural Data Base*

An agricultural database including the annual production of milk, meat, and produce is required when population doses resulting from routine releases are to be calculated. Statistical sources include state crop and livestock reporting services, and the US Department of Agriculture. The agricultural databases for the SRS-area were updated in 2010 (Jannik et al. 2010).

2.3.4 *Topographic Data*

The topography of SRS and its vicinity is representative of the Coastal Plain with gently rolling hills and elevations ranging from 100 to 500 feet above sea level. Terrain elevations directly affect the effective stack height and effective height of the inversion layer in the transport calculations. Maximum elevations within 22.5-degree sectors between SRS facilities and each incremental distance to 50 miles are determined during execution of the dose assessment codes.
The height of the plume as it travels from the release point may be adjusted to account for changes in terrain. The terrain file is a binary file called 'TPGY100.bin'. This terrain database is a product of Oak Ridge National Laboratory (ORNL) and contains elevations above mean sea level referenced by coordinates of latitude and longitude. These data are used to develop an array of maximum changes in elevation, relative to the release point's elevations. This array is then called to determine the reduction in plume height required for a specific compass sector and downwind location. The plume height is reduced to account for the fact that if the plume is traveling in a straight line and a receptor is standing on elevated ground, they are closer to the plume.

2.3.5 *Offsite Population Distribution*

The population data for a given calendar year for geographical divisions, formed by subdividing the 50-mile-radius circle centered on the release point into 22.5-degree compass sectors and circles at radii of 10, 20, 30, 40, and 50 miles, are the required input for offsite population dose calculations for airborne releases.

Due to rapidly changing work assignments, onsite population distributions will be determined on an as needed basis, using the current information available on the SRS website (http://www.srs.gov/SRSPortal)

2.3.5.1 Offsite Population Distribution

Within the 50-mile radius of SRS, the total population for 2000 was 713,500, determined using the 2000 census of the U.S. population. For establishing the offsite population distribution, a population database was prepared for SRS by SRNL (Simpkins 2002b). The data were supplied for the population residing in a 2^0 by 2^0 study area converted to 1 minute grid cells. This database is transformed by the POPDOSE-SR and AXAIRQ codes into polar coordinates of 16 compass sectors and varying radial distances out to the 50-mile radius. The POPDOSE-SR and AXAIRQ codes can prepare a polar coordinate database for any release point input into the code. The POPDOSE-SR and AXAIRQ codes also have the capability of generating offsite population distributions relative to the user-specified release location. A separate, fixed-polar-coordinate database was prepared for use with the CAP88 code, which does not have the capability of transforming the grid into polar coordinates.

2.3.5.2 Population Served by Downriver Drinking Water Plants

In 2009, the operators of the three public drinking water plants that are located downriver of SRS estimated that the following populations were served:

- Beaufort-Jasper Water and Sewer Authority (Chelsea Plant) 77,000 people
- Beaufort-Jasper Water and Sewer Authority (Purrysburg Plant) 58,000 people
- City of Savannah Industrial and Domestic Water Supply Plant 26,300 people

These totals will be updated annually for use in the SRS Site Environmental Report.

2.3.6 *Meteorological Data*

Meteorological data at SRS have been collected regularly since 1965. The system has been modified, upgraded, and expanded over the years. The measurement facilities consist of eight 61-meter meteorological towers located onsite and an instrumented 335-meter television tower (WJBF) located in Beech Island, SC. Local wind characteristics are represented by the meteorological data collected at these facilities.

To show compliance with DOE environmental orders, potential offsite doses from releases of radioactivity to the atmosphere are calculated with the quality-assured meteorological data for A-Area, K-Area (for combined releases from C-Area, K-Area, and L-Area), and H-Area (for combined releases from all other areas). The meteorological databases for the years 2002–2006, are the most recent 5-year compilation period (Kabela and Weber 2007).

To show compliance with EPA regulations, only the H-Area database was used in the calculations because the EPA-required dosimetry code (CAP88, Mainframe version 1.0) is limited to a single release location

Meteorological data are input to the dose assessment codes as a joint frequency distribution (JFD) of wind speed and atmospheric stability. The meteorological data consist of the following:

- Wind direction frequency of occurrence determined for 22.5-degree sectors centered on 16 compass directions
- Atmospheric stability category (one of seven defined by σ_a)
- Categorization of windspeed into one of six speeds: 0-2, 2-4, 4-6, 6-8, 8-12, >12 m/sec

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