

Appendix 1

**“Dose Calculations Supporting Irrigation with Tritiated
Water”**

by A. A. Simpkins and P. L. Lee

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**WESTINGHOUSE SAVANNAH RIVER COMPANY
INTER-OFFICE MEMORANDUM**

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(original initialed)
Technical Reviewer

TO: G.C. BLOUNT, 730-2B
ER ENGINEERING

FROM: A. A. SIMPKINS, 773-42A (original initialed by PL for AS)
P.L. LEE, 773-42A (original initialed by PL)
ENVIRONMENTAL ANALYSIS

**DOSE CALCULATIONS SUPPORTING IRRIGATION WITH
TRITIATED WATER - FINAL**

At your request, potential doses from the evaporation of tritiated water have been estimated in support of the irrigation of tritiated water project near the Old Radioactive Waste Burial Ground (ORWBG). This irrigation project has been proposed as a relatively low-cost way of lowering tritium concentrations in Four Mile Creek. Previous calculations for this project were performed by Jannik (2000a, 2000b) and these have been refined using detailed input.

Detailed discussions are provided on how each of the doses were determined as well as the risks that are associated with each of the estimated doses.

The following topics are discussed: 1) comprehensive dose and risk analysis for aqueous release of tritium, 2) comprehensive dose and risk analysis for atmospheric release of tritium, 3) resolution of comments by E. Rollins on previous work, 4) relative differences between aqueous and atmospheric pathways, and 5) discussion of overall uncertainty associated with the dose and risk calculations.

EXECUTIVE SUMMARY

Doses to offsite and onsite individuals and populations were calculated for the release of 3,000 curies of tritiated water to 1) the atmosphere (via irrigation and evaporation) and 2) the Savannah River (via groundwater migration). These doses are summarized in Table 1a.

As shown in Table 1a, the potential, maximally exposed individual (MEI) offsite dose from the liquid release of 3,000 curies of tritium (0.015 mrem) is more than twice the offsite MEI dose from an airborne release of 3,000 curies of tritium (0.0067 mrem). However, the potential dose to an onsite, collocated worker from this airborne release would be 0.063 mrem, which is more than 4 times the liquid pathway offsite MEI dose. The total liquid pathway population dose of 0.51 person-rem is slightly more than, but essentially the same as, the total airborne pathway population dose of 0.50 mrem. The airborne pathway population dose includes the dose to the onsite workers and to the 80-km offsite population. It was assumed that there is no liquid exposure pathway to onsite workers.

Table 1a. Comparison of Doses from the Direct Release of 3,000 Curies of Tritium to the Savannah River versus the Atmosphere

Receptor	Tritium Released to the River	Tritium Released to the Air (Irrigation)
Onsite Worker	NA	0.063 mrem
Onsite Population	NA	0.20 person-rem
Offsite MEI	0.015 mrem	0.0067 mrem
Offsite Population	0.51 person-rem	0.30 person-rem
Total Population	0.51 person-rem	0.50 person rem

Preliminary uncertainty estimates indicate that the MEI dose estimates in Table 1a could range from 0.0026 to 0.038 mrem due to tritium released to the river and 0.00091 to 0.035 mrem due to tritium released to the atmosphere. These preliminary estimates indicate that offsite atmospheric doses could potentially be lower than those due to liquid pathway releases. However, both pathways potentially result in the same dose given the uncertainty in the dose estimates.

In addition, a comparison was made of doses determined using 1) the liquid and atmospheric source terms reported in the SRS Environmental Report for 1999 (WSRC 1999) and 2) revised 1999 SRS source terms. The revised source terms included an additional release of 3,000 curies of tritium to the air and

a reduction of 3,000 curies of tritium from the liquid pathway. This comparison is shown in Tables 1b and 1c.

If, during 1999, the SRS liquid tritium source term was reduced by 3,000 curies and the airborne tritium source term was increased by 3,000 curies, the changes in potential doses would be as follows:

- the total offsite MEI dose would be about 7% less (0.28 mrem vs. 0.26 mrem)
- the total population dose would be about 5% less (9.9 person-rem vs. 10.4 person-rem)
- the total maximum onsite worker dose would be about 8% more (1.3 mrem vs. 1.2 mrem)

Table 1b. Doses Based on the Source Terms Documented in the SRS Environmental Report for 1999

Receptor	Doses Based on the 1999 SRS Source Terms		
	Liquid	Air	Total
Onsite Worker	NA	1.2 mrem	1.2 mrem
Onsite Population	NA	3.8 person-rem	3.8 person-rem
Offsite MEI	0.22 mrem	0.057 mrem	0.28 mrem
Offsite Population	4.0 person-rem	2.6 person-rem	6.6 person-rem
Total Population	4.0 person-rem	6.4 person-rem	10.4 person-rem

Table 1c. Doses Based on the 1999 SRS Revised Source Terms (3,000 curies of tritium subtracted from the liquid pathway and 3,000 curies of tritium added to the air pathway)

Receptor	Doses Based on the Revised SRS Source Terms		
	Liquid	Air	Total
Onsite Worker	NA	1.3 mrem	1.3 mrem
Onsite Population	NA	4.0 per-rem	4.0 person-rem
Offsite MEI	0.20 mrem	0.060 mrem	0.26 mrem
Offsite Population	3.0 person-rem	2.9 person-rem	5.9 person-rem
Total Population	3.0 person-rem	6.9 person-rem	9.9 person-rem

1. Comprehensive Dose And Risk Analysis For A Liquid Release Of Tritium

LADTAP XL[©] Spreadsheet (Hamby 1991) is used to calculate dose to the maximally exposed offsite individual (MEI) and to the downriver population from routine releases of radionuclides to the Savannah River. LADTAP XL[©] uses a simple volumetric dilution model to predict downriver concentrations and calculates dose for the following pathways: ingestion of water, fish, and invertebrates and external exposure resulting from recreational activities on the river. The model does not take into account dilution in the streams, but assumes the entire source term is deposited into the Savannah River. For the MEI, maximum usage parameters are used and for the population dose, average usage parameters are used.

Using the 30-y average Savannah River Mile 120 flow rate of 10,500 cfs and the assumed release of 3,000 curies of tritium, the dose to the MEI was estimated to be 0.015 mrem. The downriver population dose was estimated to be 0.51 person-rem.

It should be noted that in recent years the average tritium concentration measured in Savannah River water near River Mile 120 has been about 1 pCi/mL, which is 5% of the EPA drinking water standard for tritium of 20 pCi/mL. However, measured tritium concentrations in some Four Mile Creek seep lines near the ORWBG have been as high as 15,000 pCi/mL, which is 3 orders of magnitude more than the drinking water standard.

The potential risk, representing the probability of a latent cancer fatality, was estimated using the ICRP 60 risk factor of $5.0E-07/\text{mrem}$ for a member of the offsite population (ICRP 1991). The MEI dose of 0.015 mrem corresponds to an individual risk of $7.5E-09$. The population dose of 0.51 person-rem corresponds to a risk of $2.6E-04$.

2. Comprehensive Dose And Risk Analysis For Atmospheric Releases Of Tritium

Tritium is assumed to enter the atmosphere via evaporation from the irrigated area. A maximum of 3,000 curies is assumed to enter the atmosphere in a year. Initially, 30 acres will be irrigated south of the burial grounds. An area source such as this can be treated as a point source when the distance at which the receptor is located is greater than two-and-one-half times the diameter of the source (ORNL 1979.)

For 30 acres, the diameter is approximately 400 m. Therefore, at distances greater than 1,000 m it is appropriate to assume the source originated from a point. The MEI located at the site boundary and the offsite population are a

minimum of 10 km from the source, which qualifies for assuming a point source. In the future, the size of the irrigated area may be increased by as much as 10 to 20 times. This would negate the point source assumption and require an assessment as a diffuse source, which would lead to greater atmospheric dispersion and potentially lower offsite doses.

Site-specific codes, MAXDOSE-SR (Simpkins 1999) and POPGASP (Hamby 1992 and Bauer 1991a) were used to determine the dose to the MEI and the 80-km population dose, respectively, resulting from routine atmospheric releases. MAXDOSE-SR and POPGASP both access XOQDOQ (Sagendorf 1976), which is based on USNRC Regulatory Guide 1.111 (USNRC 1977b). The XOQDOQ module calculates the relative concentration and relative deposition at specific downwind locations for both individual and population doses. Both codes utilize the GASP module which is documented by the USNRC (Eckerman et al. 1980). The GASP module calculates the atmospheric concentrations, deposition rates, concentrations in foodstuffs, and radiation dose to individuals and populations resulting from chronic releases of radionuclides to the atmosphere. The basis for GASP is USNRC Regulatory Guide 1.109 (USNRC 1977a). Both GASP (Hamby 1992) and XOQDOQ (Bauer 1991a) have been verified for use at SRS.

The assumed release location was N75100, E54900 which corresponds to approximately the center of the area that is initially proposed to be irrigated. Meteorology for the period of 1992 to 1996 was used and the release was assumed to originate from ground level. Onsite worker doses were estimated for the collocated worker assumed to be working in 235-F. This dose was hand calculated using air concentrations determined by MAXDOSE-SR.

The resulting doses and risks are shown in Table 2. The risk represents the probability of a cancer fatality using ICRP 60 risk factors of 4.0E-07/mrem for workers and 5.0E-07/mrem for members of the public (ICRP 1991).

It should be noted that 3,000 curies of tritium is less than 10% of the 1999 SRS atmospheric tritium oxide source term of 33,900 curies. This relatively small additional amount would be difficult to observe in the average tritium-in-air concentrations measured at the site boundary.

Table 2. Doses and Risks from the Airborne Release of 3,000 Curies of Tritium

Receptor	Location	Dose	Risk
MEI	SW 11.7 km	0.0067 mrem	3.4E-9
Offsite Population	Within 50 miles	0.30 person-rem	1.5E-4
Onsite Worker	NW 1000 m	0.063 mrem	2.5E-8

3. Resolution Of Comments By E. Rollins On Previous Work

Attachment 1 shows comments by E. Rollins that were provided at the public comment session. Each of these comments are discussed in detail below.

- 1) For this assessment, the liquid pathway maximally exposed individual was assumed to reside near Savannah River Mile 120. This location, which is the one used in the SRS Annual Environmental Report, was originally chosen because it assures 1) inclusion of all SRS liquid releases and 2) complete mixing of contaminants in the river. In addition, the River Mile 120 location, which is near the US Hwy 301 bridge, is a convenient sampling location. The Port Wentworth Water Treatment Facility, SCDHEC, GDNR, and SRS all have sampling stations at this location.
- 2) For this assessment, only the SRS environmental surveillance and effluent monitoring data for 1999 was used.
- 3) When CAP88 was executed in Jannik's memo (Jannik 2000a) the assumed release was from the center of the site using H Area meteorology. Using the center of the site, the receptor was assumed to be 16 km away in the SW sector. The dose release factor referred to by Rollins is for F Area where the MEI is 11.5 km to the SW and F Area meteorology is used. The differences in meteorology between F Area and H Area can account for almost a factor of two difference in relative air concentrations when all other inputs are identical. This combined with the closer distance accounts for the large difference between the CAP88 and MAXDOSE-SR.
- 4) The model was executed for a ground-level release originating from a point source. The annual-average relative air concentration is calculated using the following equation (Simpkins 1999):

$$annual \left(\overline{\chi/Q} \right) = \sum P_i \left(\frac{\chi}{Q} \right)_i$$

where

P_i = probability of a given set of meteorological conditions occurring

$(\chi/Q)_i$ = sector arc average relative air concentration associated with the given set of meteorological conditions

Relative air concentrations averaged over a wind-direction sector are determined using the following equation:

$$\left(\frac{\chi}{Q}\right)_i = \frac{2.032 e^{-\left(\frac{h_e}{2\sigma_z}\right)^2}}{\sigma_z U x}$$

where

χ/Q =sector arc average relative air concentration ($s\ m^{-3}$)

x =downwind distance (m)

h_e =effective release height (m)

U =wind speed ($m\ s^{-1}$)

σ_z =standard deviation of the concentration distribution in the vertical direction (m)

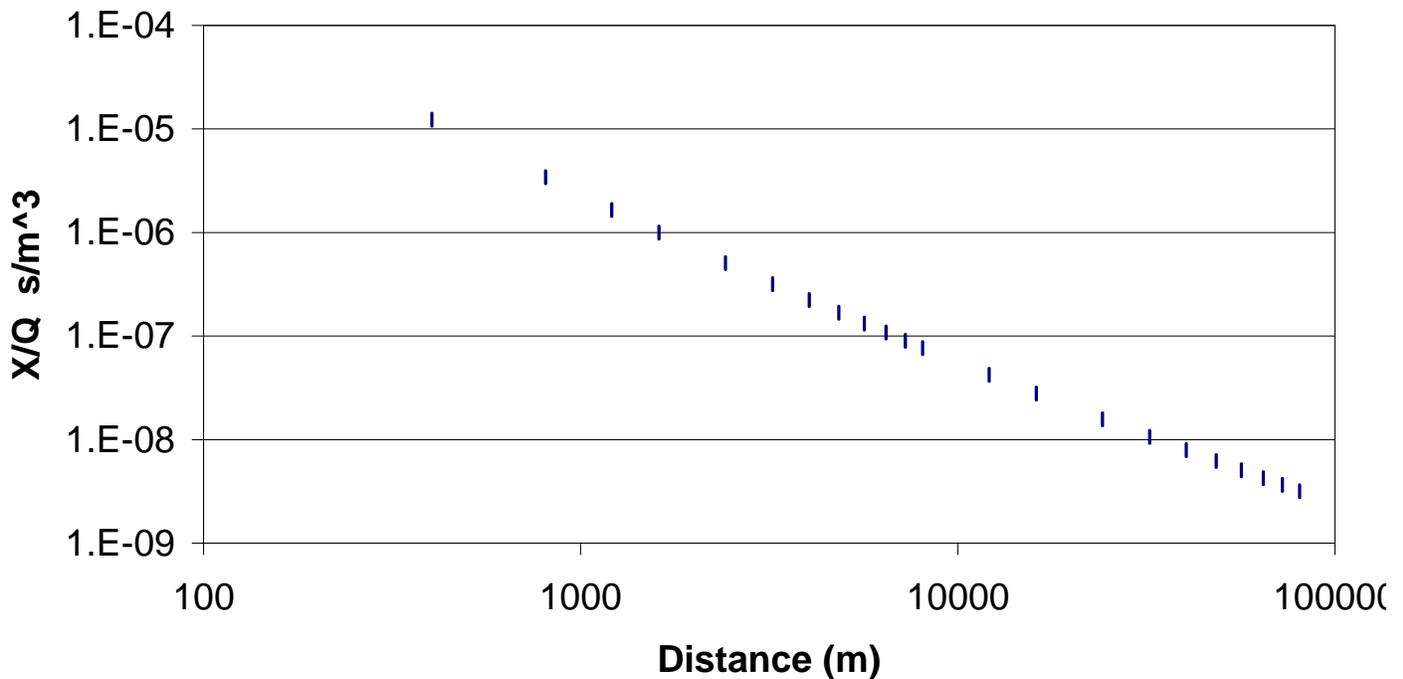
While the equations used by CAP88 and MAXDOSE-SR as shown above are identical, the values that are used within the equations can be different. For more details on the differences in the models refer to Simpkins (1997).

Relative air concentrations are shown for various distances and models in Table 3 for the SW Sector. Looking at any given location using different meteorological data can result in a factor of two difference in the relative air concentrations which is directly proportional to dose. Using MAXDOSE-SR, the relative air concentrations are plotted as a function of distance for the SW sector and the results are shown in Figure 1.

Table 3. Relative Air Concentrations Using CAP88 and MAXDOSE-SR

Model	Meteorology	Downwind Distance	
		15,200 m	16,200 m
CAP88	F	2.88E-08	2.66E-08
CAP88	H	1.53E-08	1.41E-08
MAXDOSE-SR	F	6.06E-08	5.53E-08
MAXDOSE-SR	H	3.02E-08	2.76E-08

Figure 1. Relative Air Concentration vs Distance



- 5) The fifty-mile population dose calculated in the annual environmental report uses the computer model POPGASP whereas the Jannik memo (Jannik 2000a) referred to used CAP88. This alone can provide nearly a factor or three difference due to the same reasons discussed above concerning the individual dose differences. The fact that the releases are from different heights would also contribute to the differences.
- 6) As discussed in Section 2, for the distances and areas involved, a point source is appropriate. When the irrigation area is increased to 800 acres this will not be the case and an area source will need to be considered.
- 7) Collective dose to the onsite population is calculated in the following section.

4. Relative Differences Between Aqueous And Atmospheric Pathways

Each year offsite doses are estimated based on releases to the environment from various facilities. These doses are reported in the Annual Environmental Report. For 1999, the estimated doses to the maximally exposed offsite individual from operations at SRS were 0.057 mrem and 0.22 mrem for atmospheric and aqueous releases, respectively (WSRC 1999). For

compliance purposes, SRS conservatively combines these two doses even though the two doses are calculated for hypothetical individuals residing at different geographic locations. The combined dose would be 0.28 mrem.

For comparison, since the irrigation of tritiated water would in theory remove 3,000 curies from the aqueous pathway and add 3,000 curies to the atmospheric pathway dose estimates were made with the respective changes. Using this revised 1999 source term, the new atmospheric and aqueous doses would be 0.060 mrem and 0.20 mrem, respectively, for a total of 0.26 mrem. This dose is approximately 7% less than the dose reported in the 1999 Environmental Report. However, during 1999 the average annual flow for the river was low (5,920 cfs as opposed to the 30-y average of 10,500 cfs) which in turn leads to a higher liquid pathway dose.

The offsite population doses reported in the SRS Environmental Report for 1999 were 4.0 person-rem from liquid releases and 2.6 person-rem from airborne releases. Though not documented in the SRS Environmental Report for 1999, the onsite population dose would have been 3.8 person-rem. Therefore, the total population dose from the 1999 source term was 10.4 person-rem.

Using the revised 1999 SRS source term, the offsite population dose would be 3.0 person-rem from liquid releases and 2.9 person-rem from airborne releases. The onsite population dose would have been 4.0 person-rem. The total population dose using the revised 1999 source term would have been 9.9 person-rem, which is about 5% less than the total dose using the reported 1999 source term.

For an alternate comparison, one can look at the dose for a typical year (flow rate 10,500 cfs at Highway 301) releasing 3,000 curies to the river and comparing this to a release of 3,000 curies to the atmosphere. Using the average flow rate the dose would be 0.015 mrem. The dose from an atmospheric release discussed in a previous section was 0.0067 mrem. Therefore, for a typical year at the site, the dose to the MEI from the release of 3,000 curies of tritium would be reduced by a factor of about 2 using the irrigation process as opposed to releasing it directly to the river.

For another comparison, the population dose can be compared for both irrigation and direct release to the stream. For direct release to the stream and hence the river, as discussed in Section 1, the population dose would be 0.51 person-rem. For the atmospheric release, the 80-km offsite population dose was estimated to be 0.30 person-rem in Section 2. The onsite population dose is hand calculated using sector arc concentrations calculated by MAXDOSE-SR and onsite population distributions (East 1993). The onsite population used was developed in 1993 when the site population was

considerably higher, so this calculation is conservative. The supporting spreadsheet for this calculation is shown in Attachment 2. The onsite population dose was estimated to be 0.20 person-rem. This leads to a total population dose of 0.50 person-rem from the atmospheric pathway, which is slightly less but essentially the same as the liquid pathway population dose.

5. Discussion Of Overall Uncertainty Associated With The Dose And Risk Calculations

The overall uncertainty associated with dose and risk calculations is discussed and preliminary estimates have been made for potential doses from the evaporation of tritiated water and routine releases to the Savannah River. Dose uncertainty quantifies the lack of confidence that MAXDOSE-SR, POPGASP, and LADTAP XL[©] are truly predicting the dose given the uncertainty in the models' input parameters and the uncertainty in the models assuming no uncertainty in the input parameters. Parameter uncertainties are estimated by developing a distribution for each input parameter and using Monte Carlo sampling to estimate a range of doses that quantify possible interactions between inputs. The model uncertainty can be estimated by comparing model predictions with measured values. Previous estimates of parameter and model uncertainties for MAXDOSE-SR and LADTAP XL[©] are discussed and used in the preliminary uncertainty estimates for the MEI doses estimated in this document. Risk uncertainty can be estimated from uncertainties in dose and the risk factors used to calculate risk.

Uncertainty in Atmospheric Dose

Distributions for input parameters used in MAXDOSE-SR (the model used to estimate the atmospheric MEI dose) parameters have been quantified in Bauer 1991b and Hamby 1993. In Hamby 1993, sampling of distributions 1000 times for the 19 parameters yielded tritium doses ranging 87% lower to 400% higher than deterministic dose estimated without considering the uncertainty in the parameter values. This indicates that tritium doses estimated using MAXDOSE-SR could vary by a factor 400 given the uncertainties in the parameters contributing to the dose estimate. However, the median dose of the distribution is just 6% lower than the deterministic estimate.

The uncertainty in the atmospheric dose is almost completely driven by one highly variable parameter (i.e. the concentration of tritium in the atmosphere). Because the median of this parameters' distribution is close to the actual source term input for the deterministic estimate, the median dose is close to the deterministic dose. However, the dose distribution is relatively wide due to the high variability of this one parameter.

Simpkins 1997 established a level of model uncertainty in MAXDOSE-SR. A comparison was made between air concentrations estimated using MAXIGASP, a mainframe version of the PC based MAXDOSE-SR, and measurements taken at 13 offsite locations. The results indicated that the predicted concentration calculated by MAXIGASP on average is 1.7 times higher than the measured release. In addition, Simpkins 1999 verified that MAXDOSE-SR performance is similar to that of MAXIGASP. However, for certain conditions, the verification indicates a 2% difference between the results from the two versions of the model.

Uncertainty in POPGASP, the model used to estimate the atmospheric population dose, will be similar to that for MAXDOSE-SR with the addition of the uncertainty in the population size. The population values used in POPGASP are based on 1990 census numbers. However, new census numbers are currently being generated and the population is estimated to grow 14% per decade (Hamby 1990). This uncertainty must be considered to estimate uncertainty in the POPGASP dose estimate.

Uncertainty in Liquid Dose

Parameter uncertainties for the LADTAP XL[©] input parameters are quantified in Hyman 1995. Sampling of 45 parameter distributions yielded tritium doses ranging from 82% lower to 94% higher than the deterministic dose estimated with site-specific parameter values. The median dose of the distribution is 44% lower than the deterministic estimate. This indicates that MEI tritium doses estimated with LADTAP XL[©] could vary by a factor of 10 given the uncertainties in the parameters contributing to the dose estimate. The uncertainty in the population size would need to be evaluated to estimate the uncertainty in the population dose.

The uncertainty in the liquid dose is based on an almost equal contribution from several parameters that do not have much variability (i.e. water and food consumption rates). Because several parameters contribute equally to the distribution of doses, the sampling from these parameters leads to a median that is somewhat different than the deterministic value (about 44% lower). However, the dose distribution is relatively narrow due to the low variability in the contributing parameters.

No previous work was found to establish model uncertainty in LADTAP XL[©]. However, results from predicted values from the model can be compared to measured values at various locations on the Savannah River to quantify the model uncertainty.

Preliminary Uncertainty Estimates

The results of the uncertainty estimates from Hamby 1993 can be applied to the MEI dose estimates in Table 1a for a preliminary uncertainty estimate of dose due to parameter uncertainty. This yields doses ranging from 0.00091 to 0.035 mrem for the airborne pathway MEI and 0.0036 to 0.039 mrem for the liquid pathway dose. It must be noted that these uncertainty estimates are preliminary. However, they indicate that although doses due to irrigation of the tritiated water could potentially be lower than that from releases to the river, both pathways could potentially result in the same dose given the uncertainty in the dose estimates

To complete a true estimate of the uncertainty for the doses in Table 1a, all parameter and model uncertainties must be defined and propagated through the models to estimate a range in doses for SRS radioactive releases. An extensive effort to quantify these parameter and model uncertainties has been started by the Environmental Dosimetry Group and is projected to be completed by April 1, 2001.

cc: J. B. Gladden, 773-42A
G.T. Jannik, 773-42A
Dosimetry Files, 773-42A
J. Malanowski, 773-42A

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