LADTAP XL: AN IMPROVED ELECTRONIC SPREADSHEET VERSION OF LADTAP II

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MASTER

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SUMMARY

An electronic spreadsheet has been developed to estimate the maximum individual and population dose from chronic liquid releases occurring at the Savannah River Site. Environmental pathways include external exposure resulting from recreational activities on the Savannah River and ingestion of water, fish, and invertebrates of Savannah River origin. Quality assurance principles are applied by protecting the spreadsheet from unauthorized change and providing version number, time and date on each page of output.

Improvements have been made to LADTAP II's fish and invertebrate consumption pathway model used to estimate population dose. Build-up of shoreline sediments is assumed to have occurred over the past 40 years, the approximate operating time of the Savannah River Site. Additionally, the swimming dose model has been improved by considering tritium absorption through the skin during submersion. Given a typical annual release, the skin absorption dose dominates the swimming and boating dose to both the maximum individual and population.

Comparisons of LADTAP II and LADTAP XL output show that these enhancements result in an insignificant increase in predictions of total dose to the maximum individual and a 10% increase in total dose to the Savannah River user population.

INTRODUCTION

The radiological consequences to users of the Savannah River are estimated annually from chronic aqueous discharges to streams on the Savannah River Site (SRS). In the past, the LADTAP II computer program, resident on the unclassified IBM mainframe, has been used for such dose assessments[1]. An EXCEL spreadsheet has been created to predict the

radiologicai dose to a hypothetical maximum individual and affected populations from chronic liquid releases at the SRS. The "LADTAP XL" spreadsheet, its assumptions, and its mathematical models are described in this report. A copy of the benchmarking output is given in Appendix A. Verification of each calculation has been carried-out by hand and can be found in Appendix B.

The LADTAP XL transport model estimates river concentrations assuming a continuous and constant release over a period of one year. Nuclide concentrations are determined by simple volumetric dilution without taking into account nuclide depletion except through radioactive decay. Additional dilution in the Savannah River estuary is further accounted for in the use of a dilution factor. Water, fish, and invertebrate consumption can be specified by the user as none, average, or maximum use. River recreational doses are predicted assuming the maximum individual participates in shoreline, swimming, and boating activities for given periods of time during the release year.

The shoreline dose estimates of LADTAP XL assume a long-term, constant buildup of radionuclides in river sediments. Predictions of dose from swimming and boating are determined using identical models. However, as with aquatic ingestion, the usage factors describing the average and maximum individual's habits are user specified. The assumptions incorporated into LADTAP XL have the maximum individual boating and swimming for a user-specified fraction of the year with the dose rate from boating being half the dose rate from swimming.

DETERMINATION OF NUCLIDE CONCENTRATIONS

As mentioned above, the annual average concentration of nuclide i in the Savannah River, C_i^r, is estimated by volumetric dilution. The river concentration at the receptor location is given by,

$$C_i^r = \frac{1.12 \times 10^{-6} \ A_i}{F_r}$$

(1)

where,

C_i^r = river concentration of nuclide i, $[\mu Ci \ ml^{-1}]$;

1.12×10^{-6} = conversion factor, $[\mu Ci \ ft^3 \ yr \ Ci^{-1} \ ml^{-1} \ sec^{-1}]$;

A_i = activity of nuclide i released, $[Ci \ yr^{-1}]$; and

F_r = assumed river flow rate at one of four locations, [ft^3 sec^{-1}].

Since the released radioactivity is being dispersed as it travels down the river, the simple dilution model results in a conservative concentration estimate. When assessing dose in a retrospective study, river flow rates are measured at Highway 301 and the estuary; flow rates at Beaufort-Jasper and Port Wentworth are estimated based on measured concentrations of tritium in the domestic water supplies. For prospective dose assessments historical flow rates are utilized to determine daily and annual average flows. Appendix C contains a copy of the summary to "Historical River Flow Rates for Dose Calculations".[2] Recommended flow rates for prospective studies are given in Table 1.

Table 1. Assumed Savannah River Flow Rates for Prospective Dose Assessments.

	Flow Rate (cfs) at Specified Location	
Assessment (flow avg.)	Hwy 301	Beaufort-Jasper and Port Wentworth
Routine (annual avg.)	10,500	13,000
Minimal Flow (annual avg.)	5,300	6,600
Accident (daily avg.)	3,900	4,900

Equation 1 does not include radioactive decay since transit times differ when estimating maximum individual and population dose. Radioactive decay occurring between release and exposure is accounted for in the individual pathway models that follow. Concentrations appearing in the spreadsheet are those calculated before decay has been considered.

LIQUID PATHWAY DOSIMETRY MODELS

The pathways considered in LADTAP XL include ingestion of river water; ingestion of fish and invertebrates of Savannah River origin; and swimming, boating, and recreational shoreline activities. The maximum individual is assumed to reside on the Savannah River at a downstream location where complete mixing occurs. This individual consumes untreated water and fish taken from the river; invertebrate consumption is only considered

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in the estimation of population dose. The maximum individual is also assumed to swim in and boat on the Savannah River during the course of the release year. Exposure to shoreline sediments also occurs during the year.

Dose to the population is calculated by summing average doses to the following receptors: (1) drinking water users at Beaufort-Jasper and Port Wentworth, (2) recreational users of the Savannah River, (3) consumers of fish from the Savannah River, and (4) consumers of invertebrates from the Savannah River estuary. The pathway models used in LADTAP XL are given below and are similar to those described in Regulatory Guide 1.109.[3]

Water Ingestion

The nuclide-specific dose to an individual from the ingestion of river water is given by,

$$D_i^W = U_W \; t^I \; C_i^r \; DF_i \; e^{-\lambda_i t_w} \tag{2}$$

where,

D_i^W = individual drinking water dose from nuclide i, [mrem];

U_W = water consumption rate, [L yr^{-1}];

t^I = intake duration, [yr];

C_i^r = concentration of nuclide i in river water, [μCi L^{-1}];

DF_i = ingestion dose factor for nuclide i, [mrem μCi^{-1}];

λ_i = radioactive decay constant for nuclide i, [d^{-1}]; and

t_w = transit time between release and consumption, [d].

The NRC Regulatory Guide 1.109[3] or the current SRS usage survey[4] should be consulted for appropriate usage and consumption rates. Drinking water population doses are estimated for Beaufort-Jasper (BJ) and Port Wentworth (PW) consumers by multiplying the consumer population times the average individual drinking water dose determined using BJ and PW water concentrations and Equation 2. Water ingestion pathway dose models in LADTAP II and LADTAP XL are identical.

Aquatic Foods Ingestion

The nuclide-specific dose to an individual from the consumption of contaminated aquatic foods is estimated by,

$$D_i^F = U_F \ t^I \ C_i^r \ DF_i \ B_i \ e^{-\lambda_i t_f} \tag{5}$$

where,

D_i^F = individual dose from consumption of aquatic foods, [mrem];

U_F = aquatic foods consumption rate, [kg/yr];

t^I = intake duration, [yr];

C_i^r = maximum nuclide concentration in river water, [$\mu Ci \ L^{-1}$];

DF_i = ingestion dose factor, [mrem μCi^{-1}];

B_i = bioaccumulation factor, [L kg^{-1}];

λ_i = radioactive decay constant, [d^{-1}]; and

t_f = transport time between harvest and consumption, [d].

Equation 5 is used to calculate dose from both fish and invertebrate consumption. Fish and invertebrates are assumed to be in equilibrium with nuclide concentrations in the Savannah River. Except for a site-specific factor of 3000 L/kg for cesium accumulation in freshwater fish, bioaccumulation factors for freshwater fish and saltwater invertebrates were obtained from reference 1. Maximum individual dose estimates generated by LADTAP XL are the same as those calculated using LADTAP II.

The assumption is made in LADTAP II that commercial fish and saltwater invertebrates harvested from the Savannah River are consumed by the entire U.S. population, effectively reducing the 50-mile population dose. More conservatively, the 50-mile population dose is determined in LADTAP XL assuming that the total harvest is consumed by the population. The consumption rate and intake duration in equation 5 are replaced by the annual amount of aquatic foods harvested (in kg). If, in the case of a small population or large annual harvest, some of the harvested seafood is exported from the 50-mile region, only the aquatic foods needed to support the population are assumed to be consumed.

In Appendix D a comparison is shown between LADTAP II and LADTAP XL dose estimates by nuclide resulting from the consumption of commercial fish and invertebrates.

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Dose predictions using LADTAP XL are larger because the total commercial harvest is assumed to be ingested by the 50-mile population.

Shoreline Activities

The LADTAP XL spreadsheet uses a model developed by Soldat, et al.[5] to obtain an estimate of the sediment concentration resulting from the deposition of waterborne radionuclides. The model was developed using data collected over several years and is said to produce an "order of magnitude estimate". The model does not consider removal of surface contamination by weathering. The "effective" surface contamination, S_i, in units of activity per unit area, is estimated by,

$$D_i^{SH} = 100 \ U_{SH} \ 0.2 \ C_i^r \ \tau_i \ DF_i^G \left\{1 - e^{-\lambda_i t_b}\right\} \tag{6}$$

where,

D_i^{SH}	=	individual dose from exposure to shoreline sediments, [mrem];
100	=	water-to-sediment transfer coefficient, [L m^{-2} day^{-1}];
U_{SH}	=	time exposed to shoreline annually, [yr];
0.2	=	shore width factor, [unitless];
C_i^r	=	concentration of nuclide i in river water, [μCi L^{-1}];
τ_i	=	radiological half-life of nuclide i, [day];
DF_i^G	=	ground-shine dose factor, [mrem m^2 yr^{-1} μCi^{-1}];
λ_i	=	radioactive decay constant of nuclide i, [yrs]; and
t_b	=	time sediment is exposed to contaminated water, [40 yrs].

It is assumed that the buildup (and decay) of nuclides, based on the current release, in Savannah River shoreline sediments has occurred for the past 40 years, the approximate operating period thus far of SRS facilities. The LADTAP II assumption of a 15 year buildup results in a lower dose from shoreline exposure for the longer-lived nuclides. Appendix D also contains a comparison of shoreline dose, assuming unit curie releases of each nuclide, using 40 and 15 year buildup times. Population dose estimates are determined by substituting individual shoreline exposure times with estimated population exposures times (in units of person-hrs).

Swimming and Boating

The maximum individual is assumed to participate in boating and swimming activities for a given period during the release year. The external dose received from swimming or boating is estimated for each nuclide by,

$$D_i^S = G \; t_s \; C_i^r \; DF_i \tag{9}$$

where,

D_i^S = individual dose from exposure while swimming, [mrem];

G = geometry factor (1 for swimming, 0.5 for boating);

t_s = time spent swimming or boating, [yr];

C_i^r = concentration of nuclide i in river water, [μCi m^{-3}]; and

DF_i = water submersion dose factor for nuclide i [mrem m^3 yr^{-1} μCi^{-1}].

Complete submersion is assumed while swimming (geometry factor = 1). While boating, the maximum individual is assumed to be on the surface of the contaminated water (geometry factor = 0.5). Minimal shielding, provided by the boat's hull, is not considered. Population doses are determined in a manner similar to that for shoreline exposure.

Tritium dose obtained via skin absorption while swimming has been considered in LADTAP XL since tritium concentrations in the Savannah River from chronic releases are potentially high enough for a significant skin absorption dose (relative to external swimming and boating doses). Tritium dose from skin absorption, D_T^{Skin}, is estimated in LADTAP XL using Equation 10.

$$D_T^{Skin} = t_s \; C_T^r \; DF_T \; I_T^{skin} \tag{10}$$

where,

t_s = time spent swimming, [hr];

C_T^r = concentration of tritium in river water [μCi/ml],

DF_T = ingestion dose factor for tritium [rem/μCi], and

I_T^{skin} = water absorption rate for total body submersion [35 ml/hr].

Tritium absorption through the skin has been studied for both air and water immersion.[6,7] Pinson and Langham[7] have studied the rate of water absorption through the skin while exposed to HTO in the vapor and liquid phases. Their data are used to determine water absorption via submersion assuming an average body area of 1.9 m[2].[6] Total water absorption as a function of submersion time is plotted in Figure 1.

A linear regression of the data shows that the absorption rate of water through the skin, in the vapor phase, is approximately 14 ml/hr in an atmosphere of 100% relative humidity and a temperature of 24°C.[7] Absorption through the skin while submersed in liquid water at the same temperature occurs at a rate two-and-one-half times faster, 35 ml/hr. This absorption rate is used in LADTAP XL to estimate the maximum individual's dose from absorption of tritium through the skin while swimming in the Savannah River.

ESTIMATING THE MAXIMUM INDIVIDUAL DOSE

Using the LADTAP XL Spreadsheet

LADTAP XL is an EXCEL spreadsheet (Version 2.2) developed on a Macintosh II. An IBM version is also available. A total of 37 nuclides can be included in the dose calculation. All nuclides known to have been released to aqueous streams from the SRS in forty years of operations are included in the list of available nuclides.

River flow rates at various downstream locations, pathway transport times, and all consumption and usage factors appear on the first page of the spreadsheet. The user is able to change only those values shown in red (on the monitor). The input parameters are checked at two validity levels. If an input value is outside the range of the first validity level the expected value and an asterisk appear to the right of the value indicating that the value is unexpected yet acceptable. If the input value is outside the second validity range the word "INVALID" appears in place of the asterisk indicating that the calculations of dose are highly questionable. In the second case the input value causing the INVALID statement should be replaced with an acceptable value. The water, fish, and invertebrate usage, or consumption, queries are answered with either "Avg", "Max", or "None" to indicate which preset consumption rates are to be used in the dose predictions. A response that is not recognized is treated as "None".

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The source term appears on the second page. Values of released activity, in curies per year, again, appear in red and are entered in the second column. The source term is checked for negative values and for values that are greater than the total activity released for a given nuclide in SRS history. The word "INVALID" appears to the right of the released activity value if it is negative; an asterisk appears for an unusually high value.

Average river concentrations at four downstream locations are calculated using the source term and the river flow rates entered by the user. The river concentrations are calculated as shown in Equation 1. These concentrations, which, as mentioned earlier, do not account for radioactive decay during transit, appear on page two. For purposes of quality assurance, only cells appearing on the spreadsheet in red can be changed by the user. The LADTAP XL version number along with the current time and date appear at the bottom of each printed page.

The third page contains decay constants; ingestion, ground-shine, and water immersion dose factors; and bioaccumulation factors for freshwater fish and saltwater invertebrates. The dose factors are taken directly from DOE/EH-0070 and DOE/EH-0071 (see references 8 and 9) with some modifications allowing for daughter ingrowth (see reference 10).

Page four shows estimates of fish ingestion, water ingestion, swimming and boating, and shoreline dose to the maximum individual by nuclide. A summary of the maximum individual dose is given at the top of the page.

Drinking water doses, both maximum individual and population, are given by nuclide on the fifth page. Dose estimates for users of domestic water from the Beaufort-Jasper and Port Wentworth water treatment facilities are determined using a maximum individual consumption rate (730 L/yr) and a population consumption rate (370 L/yr multiplied by the user population). A summary of individual and population dose is given at the top of the page. The total population dose via drinking water is the sum of the population doses from each of the two domestic water systems.

The last page provides dose estimates for the 50-mile population, centered on the SRS. This population is assumed to eat fish and invertebrates of Savannah River origin and participate in recreational activities on the river. Total fish and invertebrate consumption is calculated on the first page of LADTAP XL. This total is the average or maximum consumption rate (whichever is chosen by the user) multiplied by the 50-mile population.

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If the harvest exceeds the total consumption, food is exported out of the dose assessment region. In this case, the word "EXPORT" appears on the first page to the right of the total fish and invertebrate consumption values. If, however, total consumption exceeds the harvest, imported seafood is consumed. Population dose, by nuclide, is shown on page six with dose summed over all nuclides appearing at the top of the page.

A benchmark execution of LADTAP XL is given in Appendix A. The benchmarking scenario assumes one curie of each nuclide is present in the effluent. The maximum individual consumes average amounts of river water and maximum amounts of fish. The 50-mile population is assumed to consume average amounts of fish and invertebrates harvested from the Savannah River. River flow rates in the example are as follows: (1) Hwy 301 - 10,426 cfs; (2) BJ - 15,775 cfs; (3) PW - 12,958 cfs; and (4) Estuary - 13,270 cfs. All other parameter values are as specified in reference 3. Occasional execution of the benchmark scenario will ensure proper operation of LADTAP XL.

Input Parameters

The LADTAP XL spreadsheet is designed to give the user flexibility in setting input parameters to assess impacts of chronic releases under various conditions. Acceptable input ranges, however, have been placed on all of the input parameters to ensure valid interpretation of the results. Spreadsheet values appearing in RED (on the monitor) are those which are changeable by the user. Each value, once entered, is checked for validity. If an entered value is outside its pre-assigned range, a message will appear on the spreadsheet as discussed above. A description of each input parameter and its acceptable range is given below.

River Flow Rates [cfs]: The average annual Savannah River flow rate. Four values are requested: (1) measured flow at Highway 301, (2) "effective" flow at Beaufort-Jasper, (3) "effective" flow at Port Wentworth, and (4) estimated flow at the Savannah River estuary. Flow rates for prospective dose assessments are determined according to guidance provided in Reference 2. Estuary flow rates are estimated by increasing the measured flow at Highway 301 by 10%. The range is bounded by the lowest and highest recorded daily river flow rates at Hwy 301 since the construction of Thurmond Dam.
Expected Range: 5,300 - 25,000 cfs.
Valid Range: 3,900 - 77,000 cfs.

Recreation Usage [hr]:	Number of hours per year spent in a recreational activity on the Savannah River. ᵜ Shoreline Expected Value: 23.0 hrs. Swimming Expected Value: 8.9 hrs. Boating Expected Value: 21.0 hrs. Valid Range: 0 - 8,760 hrs.
MI Fish and Water Usage:	Fish and water consumption rates for the maximum individual dose estimation. This individual resides on the Savannah River at a point where complete mixing occurs. Fish Consumption Rates: 9 kg/yr avg.; 19 kg/yr max. Water Consumption Rates: 370 L/yr avg.; 730 L/yr max. Valid Response: "Avg", "Max", or "None".
Transport Time [days]:	Times used for radioactive decay between release and exposure or consumption. Times used for the maximum individual calculation. This value is only used to decrease the concentration of nuclides through radioactive decay. Recreation Expected Value: 1.0 day. Water Expected Value: 1.5 days. Fish/Invert Expected Value: 2.0 days. Valid Range: 0 - 10 days.
Populations [persons]:	Drinking water consumers on the Beaufort-Jasper and Port Wentworth domestic water systems and the population within 50-miles of the SRS geographic center. Beaufort-Jasper Expected Value: 50,000 persons Port Wentworth Expected Value: 15,000 persons 50-Mile Expected Value: 555,100 persons Valid Range: 0 - 1,000,000 persons
BJ/PW Travel Time [days]:	Time used for radioactive decay before consumption; includes transit down the Savannah River, water treatment, and system residence. Expected Value: 4.0 days. Valid Range: 0 - 10 days.
Population Usage [kg/yr]:	Water, fish, and invertebrate consumption rates used in calculating dose to the Beaufort-Japser and Port Wentworth water users and the 50-mile population. Water Consumption Rates: same as individual usage. Fish Consumption Rates: same as individual usage. Invertebrate Consumption: 2 kg/yr avg.; 8 kg/yr max. Valid Response: "Avg", "Max", or "None".
Total 50-Mile Consumption:	Values calculated by LADTAP XL indicating the maximum amounts of fish and invertebrates consumed by the 50-mile population. The values are determined by multiplying the 50-mile population by the consumption rates chosen above.

Aquatic Harvests [kg/yr]:	Total amounts of edible fish and seafood harvested from the Savannah River in an average year. Sport Fish Expected Value: 35,000 kg/yr. Commercial Fish Expected Value: 2,700 kg/yr. Invertebrate Expected Value: 390,000 kg/yr. Valid Range: 0 - 1,000,000 kg/yr.
Travel Times [days]:	Time used for radioactive decay before consumption of sport fish and commercial fish/invertebrates. These values are used when calculating dose to the 50-mile population. Sport Fish Expected Value: 10 days. Commercial/Invertebrate Expected Value: 13 days. Valid Range: 0 - 30 days.
Estuary Dilution Factor:	Unitless factor accounting for increased dilution in the Savannah River estuary. Nuclide concentrations in the estuary are calculated using volumetric dilution (determine by the average annual flow rate) and the dilution factor. The estuary concentrations are used to estimate concentrations of nuclides in the saltwater invertebrates consumed by the 50-mile population. Expected Value: 3 Valid Range: 1 - 10
Recreation Usage (per-hrs):	Recreational usage of the Savannah River and its shoreline in units of total person-hours per year. These values are used to calculate dose to the 50-mile population. Shoreline Expected Value: 960,000 person-hrs. Swimming Expected Value: 160,000 person-hrs. Boating Expected Value: 1,100,000 person-hrs. Valid Range: 0 - 1,500,000 person-hrs.
Released Activity [Ci/yr]:	Total activity of specified nuclide reaching the Savannah River over the course of one year. This activity is assumed to be released at a constant and continuous rate. The valid range is any non-negative number that is no larger than the maximum amount released from the SRS between 1954 and 1988. Valid Range: 0 - MAX (varies among nuclides).

Summary of Assumptions

The following is a composite list of assumptions used in the LADTAP XL spreadsheet calculations of maximum individual and population dose from normal operating aqueous releases.

- River concentrations determined by volumetric dilution.
- Nuclide depletion only through radioactive decay.

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- Aquatic life is in equilibrium with river concentrations.
- Sport and commercial fish are harvested in freshwater while invertebrates are harvested in saltwater.
- Shoreline width factor is 0.2 (see reference 4).
- Water-to-sediment transfer coefficient equals 100 [L m^{-2} day^{-1}] (see reference 4).
- Swimming dose is calculated assuming complete submersion.
- Skin aborption rate of tritium during submersion is 35 ml/hr (reference 7).
- Boating dose is one-half of swimming dose assuming half immersion and no shielding.

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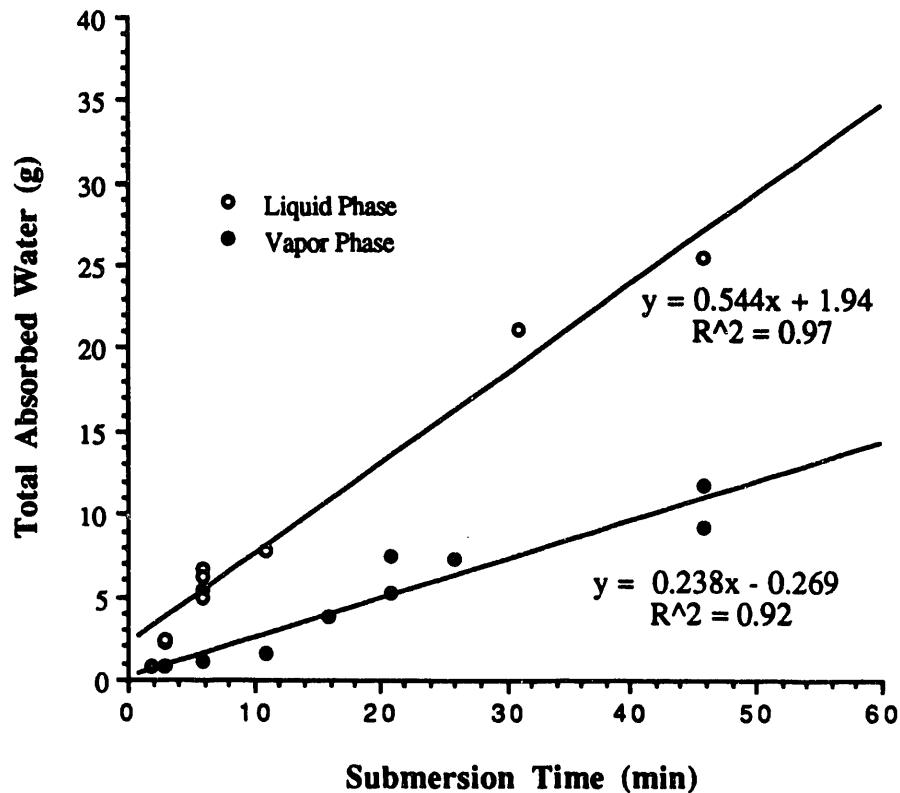
Figure 1. Water absorbed through the skin while exposed to HTO in the vapor and liquid phases as a function of time. Calculated from data of Pinson and Langham (ref. 7).

APPENDIX A
LADTAP XL Benchmark

LADTAP XL

Version 2.0

Benchmarking Run

FLOW & EXPOSURE PARAMETERS

Measured River Flow Rate (Hwy 301):	10,426	(cfs)	
Flow Rate at Beaufort-Jasper:	15,775	(cfs)	
Flow Rate at Port Wentworth:	12,958	(cfs)	
Flow Rate at the Estuary:	13,270	(cfs)	
Annual Max. Ind. Shoreline Usage:	23.0	(hr)	
Annual Max. Ind. Swimming Usage:	8.9	(hr)	
Annual Max. Ind. Boating Usage:	21.0	(hr)	
Max. Ind. Fish Usage (Avg, Max, None):	max		19 (kg/yr)
Max. Ind. Water Usage (Avg, Max, None):	Avg		370 (L/yr)
Recreation Transport Time:	1.0	(d)	
Water Transport Time:	1.5	(d)	
Fish/Invertebrate Transport Time:	2.0	(d)	
Beaufort-Jasper Population:	50000	(persons)	
Port Wentworth Population:	15000	(persons)	
50-Mile Population:	555100	(persons)	
BJ/PW Travel Time:	4.0	(d)	
Pop. Water Usage (Avg, Max, None):	Avg		370 (L/yr)
Pop. Fish Usage (Avg, Max, None):	Avg		9 (kg/yr)
Pop. Invertebrate Usage (Avg, Max, None):	Avg		2 (kg/yr)
Total 50-Mile Fish Consumption:	5.0E+06	(kg/yr)	
Total 50-Mile Invertebrate Consumption:	1.1E+06	(kg/yr)	
Annual Sport Fish Harvest (edible):	3.5E+04	(kg/yr)	
Annual Commercial Fish Harvest (edible):	2.7E+03	(kg/yr)	
Annual Invertebrate Harvest (edible):	3.9E+05	(kg/yr)	
Sport Fish Transport Time:	10.0	(d)	
Commercial/Invertebrate Transport Time:	13.0	(d)	
Estuary Dilution Factor:	3	(unitless)	
Population Shoreline Usage:	9.6E+05	(person-hrs)	
Population Swimming Usage:	1.6E+05	(person-hrs)	
Population Boating Usage:	1.1E+06	(person-hrs)	

SOURCE TERM AND RIVER CONCENTRATIONS

Nuclide	Released Activity (Ci/yr)	AVERAGE UNDECAYED CONCENTRATIONS (uCi/ml)			
		Hwy 301 Flow Rate (cfs) 10,426	BJ Flow Rate (cfs) 15,775	PW Flow Rate (cfs) 12,958	Estuary Flow Rate (cfs) 13,270
H-3	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
P-32	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
S-35	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Cr-51	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Mn-54	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Co-58	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Co-60	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Zn-65	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Sr-89	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Sr-90	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Y-91	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Zr-95†	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Nb-95	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Mo-99	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Ru-103	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Ru-106†	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Sb-124	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Sb-125	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
I-129	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
I-131	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Cs-134	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Cs-137	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Ba-140	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
La-140	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Ce-141	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Ce-144†	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Pm-147	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Th-232	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
U-234	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
U-235†	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
U-237	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
U-238	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Np-239	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Pu-238	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Pu-239	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Am-241	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11
Cm-244	1.00E+00	1.07E-10	7.10E-11	8.64E-11	2.81E-11

†Denotes preferred isotope when isotopic breakdown is not available.
* Denotes value is either negative or above overall SRS release for that nuclide.

DOSE SUMMARY REPORT

Dose to a Hypothetical Individual Living on the Savannah River
50-year CEDE (mrem)

Fish Ingestion	Water Ingestion	Shoreline Exposure	Swimming and Boating	TOTAL
3.0E+00	7.6E-01	7.3E-03	4.7E-05	3.7E+00

Total Dose to the 50-Mile Population
50-year CEDE (person-rem)

Aquatic Foods Consumption	River Recreation	BJ Water Consumption	PW Water Consumption	TOTAL
1.7E+02	3.1E-01	2.5E+01	9.2E+00	2.0E+02

CONVERSION FACTORS

Nuclide	Decay Constant (1/day)	Ingestion EDE Dose Factor (rem/uCi)	Grd Shine DF (mrem sq m) (yr uCi)	Water Im DF (mrem cu m) (yr uCi)	Freshwater Fish Accum. Factor (L/kg)	Saltwater Invert Accum Factor (L/kg)
H-3	1.54E-04	6.3E-05	0.00E+00	0.00E+00	9.0E-01	9.3E-01
P-32	4.85E-02	7.7E-03	0.00E+00	0.00E+00	1.0E+05	3.0E+04
S-35	7.95E-03	6.5E-04	0.00E+00	0.00E+00	7.5E+02	4.4E-01
Cr-51	2.50E-02	1.3E-04	3.41E+00	3.47E-01	2.0E+02	2.0E+03
Mn-54	2.22E-03	2.7E-03	8.41E+01	9.42E+00	4.0E+02	4.0E+02
Co-58	9.80E-03	3.5E-03	9.87E+01	1.09E+01	5.0E+01	1.0E+03
Co-60	3.60E-04	2.6E-02	2.27E+02	3.78E+01	5.0E+01	1.0E+03
Zn-65	2.84E-03	1.4E-02	5.48E+01	6.56E+00	2.0E+03	5.0E+04
Sr-89	1.37E-02	8.7E-03	1.36E-02	1.55E-03	3.0E+01	2.0E+01
Sr-90	6.64E-05	1.3E-01	0.00E+00	0.00E+00	3.0E+01	2.0E+01
Y-91	1.18E-02	8.9E-03	3.31E-01	4.06E-02	2.5E+01	1.0E+03
Zr-95	1.08E-02	3.4E-03	1.52E+02	8.21E+00	3.3E+00	8.0E+01
Nb-95	1.98E-02	2.2E-03	7.76E+01	8.56E+00	3.0E+04	1.0E+02
Mo-99	2.52E-01	4.4E-03	2.91E+01	3.05E+00	1.0E+01	1.0E+01
Ru-103	1.76E-02	2.7E-03	5.01E+01	5.26E+00	1.0E+01	1.0E+03
Ru-106	1.88E-03	2.1E-02	2.10E+01	2.28E+00	1.0E+01	1.0E+03
Sb-124	1.15E-02	9.3E-03	1.76E+02	2.15E+01	1.0E+00	5.0E+00
Sb-125	7.01E-04	2.6E-03	4.48E+01	4.63E+00	1.0E+00	5.0E+00
I-129	1.21E-10	2.8E-01	2.20E+00	1.07E-01	1.5E+01	5.0E+01
I-131	8.62E-02	5.3E-02	4.04E+01	4.17E+00	1.5E+01	5.0E+01
Cs-134	9.21E-04	7.4E-02	1.58E+02	1.73E+01	3.0E+03	2.5E+01
Cs-137	6.29E-05	5.0E-02	5.78E+01	6.22E+00	3.0E+03	2.5E+01
Ba-140	5.42E-02	8.4E-03	2.33E+02	2.87E+01	4.0E+00	1.0E+02
La-140	4.13E-01	7.7E-03	2.13E+02	2.66E+01	2.5E+01	1.0E+03
Ce-141	2.13E-02	2.6E-03	8.78E+00	8.71E-01	1.0E+00	6.0E+02
Ce-144	2.44E-03	2.0E-02	5.10E+00	5.89E-01	1.0E+00	6.0E+02
Pm-147	7.24E-04	9.5E-04	4.10E-04	4.15E-05	2.5E+01	1.0E+03
Th-232	1.35E-13	2.8E+00	6.66E-02	2.26E-03	3.0E+01	2.0E+03
U-234	7.77E-09	2.6E-01	8.07E-02	1.86E-03	2.0E+00	1.0E+01
U-235	2.70E-12	2.5E-01	1.71E+01	1.72E+00	2.0E+00	1.0E+01
U-237	1.03E-01	2.7E-03	1.61E+01	1.53E+00	2.0E+00	1.0E+01
U-238	4.25E-13	2.3E-01	6.46E-02	1.29E-03	2.0E+00	1.0E+01
Np-239	2.95E-01	2.9E-03	1.92E+01	1.89E+00	1.0E+01	1.0E+01
Pu-238	2.16E-05	3.8E+00	8.58E-02	1.12E-03	3.5E+00	2.0E+02
Pu-239	7.87E-08	4.3E+00	3.78E-02	9.74E-04	3.5E+00	2.0E+02
Am-241	4.39E-06	4.5E+00	2.99E+00	2.33E-01	2.5E+01	1.0E+03
Cm-244	1.05E-04	2.3E+00	8.29E-02	1.07E-03	2.5E+01	1.0E+03

Dose to a Hypothetical Individual Living on the Savannah River
50-year CEDE (mrem)

	Fish Ingestion	Water Ingestion	Shoreline Exposure	Swimming	Boating	EDE (mrem) Summed Over All Nuclides
	3.0E+00	7.6E-01	7.3E-03	2.1E-05	2.5E-05	3.7E+00

Nuclide	Fish Ingestion Dose (mrem)	Water Ingestion Dose (mrem)	Shoreline Dose (mrem)	Swimming Dose (mrem)	Boating Dose (mrem)	Nuclide Dose All Pathways (mrem)
H-3	1.2E-07	2.5E-06	0.0E+00	2.1E-09	0.0E+00	2.6E-06
P-32	1.4E+00	2.8E-04	0.0E+00	0.0E+00	0.0E+00	1.4E+00
S-35	9.8E-04	2.6E-05	0.0E+00	0.0E+00	0.0E+00	1.0E-03
Cr-51	5.0E-05	5.0E-06	5.2E-07	3.7E-08	4.4E-08	5.6E-05
Mn-54	2.2E-03	1.1E-04	1.5E-04	1.0E-06	1.2E-06	2.5E-03
Co-58	3.5E-04	1.4E-04	3.9E-05	1.2E-06	1.4E-06	5.3E-04
Co-60	2.7E-03	1.0E-03	2.5E-03	4.1E-06	4.9E-06	6.1E-03
Zn-65	5.7E-02	5.5E-04	7.5E-05	7.1E-07	8.4E-07	5.7E-02
Sr-89	5.2E-04	3.4E-04	3.8E-09	1.7E-10	2.0E-10	8.6E-04
Sr-90	8.0E-03	5.2E-03	0.0E+00	0.0E+00	0.0E+00	1.3E-02
Y-91	4.4E-04	3.5E-04	1.1E-07	4.4E-09	5.2E-09	7.9E-04
Zr-95	2.2E-05	1.3E-04	5.4E-05	8.9E-07	1.0E-06	2.1E-04
Nb-95	1.3E-01	8.5E-05	1.5E-05	9.2E-07	1.1E-06	1.3E-01
Mo-99	5.4E-05	1.2E-04	3.5E-07	2.6E-07	3.1E-07	1.7E-04
Ru-103	5.3E-05	1.0E-04	1.1E-05	5.6E-07	6.7E-07	1.7E-04
Ru-106	4.3E-04	8.3E-04	4.4E-05	2.5E-07	2.9E-07	1.3E-03
Sb-124	1.9E-05	3.6E-04	5.9E-05	2.3E-06	2.7E-06	4.5E-04
Sb-125	5.3E-06	1.0E-04	2.5E-04	5.0E-07	6.0E-07	3.6E-04
I-129	8.6E-03	1.1E-02	1.3E-04	1.2E-08	1.4E-08	2.0E-02
I-131	1.4E-03	1.9E-03	1.7E-06	4.2E-07	4.9E-07	3.2E-03
Cs-134	4.5E-01	2.9E-03	6.7E-04	1.9E-06	2.2E-06	4.6E-01
Cs-137	3.1E-01	2.0E-03	2.2E-03	6.8E-07	8.0E-07	3.1E-01
Ba-140	6.2E-05	3.1E-04	1.6E-05	3.0E-06	3.5E-06	3.9E-04
La-140	1.7E-04	1.6E-04	1.3E-06	1.9E-06	2.3E-06	3.4E-04
Ce-141	5.1E-06	1.0E-04	1.6E-06	9.3E-08	1.1E-07	1.1E-04
Ce-144	4.1E-05	7.9E-04	8.1E-06	6.4E-08	7.6E-08	8.4E-04
Pm-147	4.8E-05	3.8E-05	2.2E-09	4.5E-12	5.3E-12	8.6E-05
Th-232	1.7E-01	1.1E-01	3.8E-06	2.5E-10	2.9E-10	2.8E-01
U-234	1.1E-03	1.0E-02	4.6E-06	2.0E-10	2.4E-10	1.1E-02
U-235	1.0E-03	9.9E-03	9.8E-04	1.9E-07	2.2E-07	1.2E-02
U-237	9.0E-06	9.2E-05	5.5E-07	1.5E-07	1.8E-07	1.0E-04
U-238	9.4E-04	9.1E-03	3.7E-06	1.4E-10	1.7E-10	1.0E-02
Np-239	3.3E-05	7.4E-05	1.9E-07	1.5E-07	1.8E-07	1.1E-04
Pu-238	2.7E-02	1.5E-01	4.2E-06	1.2E-10	1.4E-10	1.8E-01
Pu-239	3.1E-02	1.7E-01	2.2E-06	1.1E-10	1.3E-10	2.0E-01
Am-241	2.3E-01	1.8E-01	1.7E-04	2.5E-08	3.0E-08	4.1E-01
Cm-244	1.2E-01	9.1E-02	2.4E-06	1.2E-10	1.4E-10	2.1E-01

Drinking Water Dose to Persons Using the Beaufort-Jasper and Port Wentworth Domestic Water Systems
50-year CEDE

Max BJ User (mrem)	Max PW User (mrem)	BJ Users (per-rem)	PW Users (per-rem)	Pop. Dose (Per-rem) All Nuclides
9.9E-01	1.2E+00	2.5E+01	9.2E+00	3.4E+01

Nuclide	Max. Dose to BJ Users (mrem)	Max. Dose to PW Users (mrem)	BJ Users Pop. Dose (person-rem)	PW Users Pop. Dose (person-rem)	Total Water Pop. Dose (person-rem)
H-3	3.3E-06	4.0E-06	8.3E-05	3.0E-05	1.1E-04
P-32	4.0E-04	4.9E-04	1.0E-02	3.7E-03	1.4E-02
S-35	3.4E-05	4.1E-05	8.5E-04	3.1E-04	1.2E-03
Cr-51	6.7E-06	8.2E-06	1.7E-04	6.2E-05	2.3E-04
Mn-54	1.4E-04	1.7E-04	3.5E-03	1.3E-03	4.8E-03
Co-58	1.8E-04	2.2E-04	4.6E-03	1.7E-03	6.3E-03
Co-60	1.3E-03	1.6E-03	3.4E-02	1.2E-02	4.7E-02
Zn-65	7.3E-04	8.8E-04	1.8E-02	6.7E-03	2.5E-02
Sr-89	4.5E-04	5.5E-04	1.1E-02	4.2E-03	1.6E-02
Sr-90	6.7E-03	8.2E-03	1.7E-01	6.2E-02	2.3E-01
Y-91	4.6E-04	5.6E-04	1.2E-02	4.3E-03	1.6E-02
Zr-95	1.8E-04	2.1E-04	4.5E-03	1.6E-03	6.1E-03
Nb-95	1.1E-04	1.4E-04	2.9E-03	1.1E-03	3.9E-03
Mo-99	2.3E-04	2.8E-04	5.8E-03	2.1E-03	7.9E-03
Ru-103	1.4E-04	1.7E-04	3.5E-03	1.3E-03	4.8E-03
Ru-106	1.1E-03	1.3E-03	2.8E-02	1.0E-02	3.8E-02
Sb-124	4.8E-04	5.9E-04	1.2E-02	4.5E-03	1.7E-02
Sb-125	1.3E-04	1.6E-04	3.4E-03	1.2E-03	4.7E-03
I-129	1.5E-02	1.8E-02	3.7E-01	1.3E-01	5.0E-01
I-131	2.7E-03	3.3E-03	7.0E-02	2.5E-02	9.5E-02
Cs-134	3.8E-03	4.7E-03	9.7E-02	3.5E-02	1.3E-01
Cs-137	2.6E-03	3.2E-03	6.6E-02	2.4E-02	9.0E-02
Ba-140	4.4E-04	5.3E-04	1.1E-02	4.0E-03	1.5E-02
La-140	4.0E-04	4.9E-04	1.0E-02	3.7E-03	1.4E-02
Ce-141	1.3E-04	1.6E-04	3.4E-03	1.2E-03	4.7E-03
Ce-144	1.0E-03	1.3E-03	2.6E-02	9.6E-03	3.6E-02
Pm-147	4.9E-05	6.0E-05	1.2E-03	4.6E-04	1.7E-03
Th-232	1.5E-01	1.8E-01	3.7E+00	1.3E+00	5.0E+00
U-234	1.3E-02	1.6E-02	3.4E-01	1.2E-01	4.7E-01
U-235	1.3E-02	1.6E-02	3.3E-01	1.2E-01	4.5E-01
U-237	1.4E-04	1.7E-04	3.5E-03	1.3E-03	4.8E-03
U-238	1.2E-02	1.5E-02	3.0E-01	1.1E-01	4.1E-01
Np-239	1.5E-04	1.8E-04	3.8E-03	1.4E-03	5.2E-03
Pu-238	2.0E-01	2.4E-01	5.0E+00	1.8E+00	6.8E+00
Pu-239	2.2E-01	2.7E-01	5.6E+00	2.1E+00	7.7E+00
Am-241	2.3E-01	2.8E-01	5.9E+00	2.2E+00	8.1E+00
Cm-244	1.2E-01	1.5E-01	3.0E+00	1.1E+00	4.1E+00

Aquatic Foods Ingestion and Recreational Dose to the 50-Mile Population
50-year CEDE (person-rem)

Sport Fish Ingestion	Comm. Fish Ingestion	Invertebrate Ingestion	Shoreline	Swimming	Boating	50mi Pop Dose (Person-rem) All Nuclides
4.6E+00	3.3E-01	1.6E+02	3.0E-01	3.8E-04	1.3E-03	1.7E+02

Nuclide	Sport Fish Ingestion EDE	Comm Fish Ingestion EDE	Invertebrate Ingestion EDE	Shoreline Exposure EDE	Swimming EDE	Boating EDE
H-3	2.1E-07	1.6E-08	6.4E-07	0.0E+00	3.8E-08	0.0E+00
P-32	1.8E+00	1.2E-01	1.3E+00	0.0E+00	0.0E+00	0.0E+00
S-35	1.7E-03	1.3E-04	2.8E-06	0.0E+00	0.0E+00	0.0E+00
Cr-51	7.6E-05	5.4E-06	2.1E-03	2.2E-05	6.6E-07	2.3E-06
Mn-54	4.0E-03	3.0E-04	1.2E-02	6.2E-03	1.8E-05	6.3E-05
Co-58	6.0E-04	4.5E-05	3.4E-02	1.6E-03	2.1E-05	7.3E-05
Co-60	4.9E-03	3.8E-04	2.8E-01	1.0E-01	7.4E-05	2.5E-04
Zn-65	1.0E-01	7.8E-03	7.4E+00	3.1E-03	1.3E-05	4.4E-05
Sr-89	8.6E-04	6.3E-05	1.6E-03	1.6E-07	3.0E-09	1.0E-08
Sr-90	1.5E-02	1.1E-03	2.8E-02	0.0E+00	0.0E+00	0.0E+00
Y-91	7.4E-04	5.5E-05	8.4E-02	4.5E-06	7.9E-08	2.7E-07
Zr-95	3.8E-05	2.8E-06	2.6E-03	2.3E-03	1.6E-05	5.5E-05
Nb-95	2.0E-01	1.5E-02	1.9E-03	6.3E-04	1.6E-05	5.7E-05
Mo-99	1.3E-05	4.8E-07	1.8E-05	1.5E-05	4.7E-06	1.6E-05
Ru-103	8.5E-05	6.2E-06	2.4E-02	4.6E-04	1.0E-05	3.5E-05
Ru-106	7.7E-04	5.9E-05	2.2E-01	1.8E-03	4.5E-06	1.5E-05
Sb-124	3.1E-05	2.3E-06	4.4E-04	2.5E-03	4.2E-05	1.4E-04
Sb-125	9.7E-06	7.5E-07	1.4E-04	1.0E-02	9.1E-06	3.1E-05
I-129	1.6E-02	1.2E-03	1.5E-01	5.2E-03	2.1E-07	7.2E-07
I-131	1.3E-03	7.5E-05	9.5E-03	7.0E-05	7.5E-06	2.6E-05
Cs-134	8.3E-01	6.4E-02	2.0E-02	2.8E-02	3.4E-05	1.2E-04
Cs-137	5.6E-01	4.3E-02	1.4E-02	9.0E-02	1.2E-05	4.2E-05
Ba-140	7.3E-05	4.8E-06	4.6E-03	6.6E-04	5.3E-05	1.8E-04
La-140	1.2E-05	2.6E-07	3.9E-04	5.6E-05	3.5E-05	1.2E-04
Ce-141	7.9E-06	5.7E-07	1.3E-02	6.6E-05	1.7E-06	5.7E-06
Ce-144	7.3E-05	5.6E-06	1.3E-01	3.4E-04	1.2E-06	4.0E-06
Pm-147	8.9E-05	6.8E-06	1.0E-02	9.2E-08	8.1E-11	2.8E-10
Th-232	3.2E-01	2.4E-02	6.1E+01	1.6E-04	4.4E-09	1.5E-08
U-234	2.0E-03	1.5E-04	2.9E-02	1.9E-04	3.6E-09	1.3E-08
U-235	1.9E-03	1.4E-04	2.7E-02	4.1E-02	3.4E-06	1.2E-05
U-237	7.2E-06	4.1E-07	7.8E-05	2.3E-05	2.7E-06	9.3E-06
U-238	1.7E-03	1.3E-04	2.5E-02	1.5E-04	2.5E-09	8.7E-09
Np-239	5.7E-06	1.8E-07	6.9E-06	7.9E-06	2.8E-06	9.5E-06
Pu-238	5.0E-02	3.9E-03	8.3E+00	1.8E-04	2.2E-09	7.6E-09
Pu-239	5.7E-02	4.4E-03	9.4E+00	9.0E-05	1.9E-09	6.6E-09
Am-241	4.2E-01	3.3E-02	4.9E+01	6.9E-03	4.6E-07	1.6E-06
Cm-244	2.2E-01	1.7E-02	2.5E+01	1.0E-04	2.1E-09	7.2E-09

APPENDIX B
Hand Calculations of LADTAP XL Benchmark

LADTAP XL

Benchmarking Calculations

A   Total 50-Mile Fish Consumption   = (Pop Fish Usage) (50-Mile Pop)

$$= (9)(555,100) = 5.0 \times 10^6 \text{ kg/yr}$$

B   Total 50-Mile Invert. Consumption   = (Pop. Invert. Usage) (50-Mile Pop)

$$= (2)(555,100) = 1.1 \times 10^6 \text{ kg/yr}$$

C   River Concentration using given flow rate (μCi/ml):

$$301 \text{ CONC.} = \frac{\text{Unit Release}}{301 \text{ flow}} \; (1.12 \times 10^{-6} \text{ yr } \mu\text{Ci ft}^3/\text{sec Ci ml})$$

$$= (1/10426) \cdot (1.12 \times 10^{-6}) = 1.07 \times 10^{-10} \; \mu\text{Ci/ml}$$

D   River concentration at Beaufort-Jasper water intake (μCi/ml):

$$\text{BJ CONC} = \frac{\text{Unit Release}}{\text{BJ flow}} \; (1.12 \times 10^{-6} \text{ yr } \mu\text{Ci ft}^3/\text{sec Ci ml})$$

$$= (1/15775) \cdot (1.12 \times 10^{-6}) = 7.10 \times 10^{-11} \; \mu\text{Ci/ml}$$

E   River concentration at Port Wentwort water intake (μCi/ml):

$$\text{PW CONC} = \frac{\text{Unit Release}}{\text{PW flow}} \; (1.12 \times 10^{-6} \text{ yr } \mu\text{Ci ft}^3/\text{sec Ci ml})$$

$$= (1/12958) \cdot (1.12 \times 10^{-6}) = 8.64 \times 10^{-11} \; \mu\text{Ci/ml}$$

F   River concentration at the Savannah River estuary (μCi/ml):

$$\text{EST CONC} = \frac{\text{Unit Release} \; (1.12 \times 10^{-6} \text{ yr.}\mu\text{Ci.ft}^3/\text{sec Ci.ml})}{(\text{estuary flow}) \; (\text{dilution})}$$

$$= (1 \cdot 1.12 \times 10^{-6}) / (13270 \cdot 3) = 2.81 \times 10^{-11} \; \mu\text{Ci/ml}$$

G   Individual dose from fish ingestion:

Dose = (MI fish usage) (301 CONC) (ingestion DF) (FW fish accum.)
(transport decay) (10^6 ml mrem/L rem)

= 1.15×10^{-7} mrem (^{3}H)

H   Individual dose from water ingestion:

Dose = (301 CONC) (MI water usage) (ingestion DF) (10^6 ml mrem/L rem)
(transport decay)

= 2.49×10^{-6} (^{3}H)

I   Individual dose from shoreline exposure:

Dose = (water-to-sediment transfer coeff.) (MI shoreline usage)
(shorewidth factor) (301 CONC) (transport decay)
(nuclide half-life) (ground shine DF) (exponential buildup over
plant lifetime) / (8760 hrs/yr)

= (100 L/m^{2}day)(23 hrs)(0.2)(1.07×10^{-10}μCi/ml)

$\left(e^{-\left(6.29 \times 10^{-5} \right)\left(1\, day \right)} \right)$ (1000ml/L)($0.693/6.29 \times 10^{-5}$ day^{-1})

(57.8 mrem m^2/yr μCi) $\left[1 - e^{-\left(\left(6.29 \times 10^{-5} \right) 40 \cdot 365 \right)} \right]$

= 2.15×10^{-3} mrem (^{137}Cs)

J   Individual dose from exposure while swimming:

<u>All Nuclides Except Tritium:</u>
Dose = (301 CONC) (transport decay) (MI swimming usage) (water immer. DF)
(114.2 ml yr/m^3 hr) / (GEOM)

= (1.07×10^{-10} μCi/ml) $\left(e^{-\left(6.29 \times 10^{-5} \right)\left(1 \right)} \right)$ (8.9hrs) (622 mrem m^3/yr μCi)
(114.2) / 1

= 6.76×10^{-7} mrem (^{137}Cs)

<u>Tritium Only:</u>
Dose = (absorption rate) (ingestion DF) (submersion duration) (301 CONC)

= (1000 mrem/rem) (35 ml/hr) (6.3×10^{-5} rem/μCi) (8.9 hrs)
(1.07×10^{-10} μCi/ml)

= 2.10×10^{-9} mrem (^{3}H)

K   Individual dose from exposure while boating:

Dose = (301 CONC) (transport decay) (MI boating usage) (water immer. DF)
(114.2 ml yr/m^{3}hr) / (GEOM)

$$= (1.07 \times 10^{-10} \, \mu Ci/ml) \left(e^{-(6.29 \times 10^{-5})(1)} \right) (21 hrs)$$
(6.22 mrem m^3/yr μCi) (114.2) / 2

$$= 7.98 \times 10^{-7} \text{ mrem } (^{137}Cs)$$

L   Maximum dose to Beaufort-Jasper individual via water ingestion:

Dose = (BJ CONC) (transport decay) (max water consumption) (ingestion DF)
(10^6 ml mrem/L rem)

$$= (7.10 \times 10^{-11} \, \mu Ci/ml) \left(e^{-(1.54 \times 10^{-4})(4)} \right) (730 L/yr)$$
(6.3 x 10^{-5} rem/μCi) (10^6)

$$= 3.27 \times 10^{-6} \text{ mrem } (^3H)$$

M   Maximum dose to Port Wentworth individual via water ingestion:

Dose = (PW CONC) (transport decay) (max water consumption) (ingestion DF)
(10^6 ml mrem/L rem)

$$= (8.64 \times 10^{-11} \, \mu Ci/ml) \left(e^{-(1.54 \times 10^{-4})(4)} \right) (730 L/yr)$$
(6.3 x 10^{-5} rem/μCi) (10^6)

$$= 3.97 \times 10^{-6} \text{ mrem } (^3H)$$

N   Population dose to Beaufort-Jasper water users:

Dose = (BJ CONC) (transport decay) (avg water consumption) (ingestion DF)
(population) (10^3 ml/L)

$$= (7.10 \times 10^{-11} \, \mu Ci/ml) \left(e^{-(1.54 \times 10^{-4})(4)} \right) (370 L/yr)$$
(6.3 x 10^{-5} rem/μCi) (50,000 persons) (10^3)

$$= 8.28 \times 10^{-5} \text{ person-rem } (^3H)$$

O   Population dose to Port Wentworth water users:

Dose = (PW CONC) (transport decay) (avg water consumption) (ingestion DF) (population) (10^3 ml/L)

$$= (8.64 \times 10^{-11} \ \mu Ci/ml) \left(e^{-(1.54 \times 10^{-4})(4)} \right) (370 \ L/yr)$$
$$(6.3 \times 10^{-5} \ rem/\mu Ci) \ (15,000 \ persons) \ (10^3)$$

$$= 3.02 \times 10^{-5} \ person\text{-}rem \ (^3H)$$

P   Total population dose via drinking water:

Dose = BJ Dose + PW Dose

$$= 8.28 \times 10^{-5} + 3.02 \times 10^{-5} = 1.13 \times 10^{-4} \ person\text{-}rem \ (^3H)$$

Q   50-Mile population dose from sport fish harvest:

Dose = (301 CONC) (transport decay) (FW fish accum) (harvest) (ingestion DF) (10^3 ml/L)

$$= 1.07 \times 10^{-10} \ \mu Ci/ml \left(e^{-(1.54 \times 10^{-4})(10)} \right) (0.9 \ L/kg)$$
$$(3.5 \times 10^4 \ kg/yr) \ (6.3 \times 10^{-5} \ rem/\mu Ci) \ (10^3)$$

$$= 2.12 \times 10^{-7} \ rem \ (^3H)$$

Where HARVEST = The lesser of the actual Savannah River harvest and the total 50-mile fish consumption.

$$\therefore \ HARVEST = Min \ (3.5 \times 10^4; \ 5.0 \times 10^6)$$

R   50-Mile population dose from commercial fish harvest:

DOSE = (301 CONC) (transport decay) (FW fish accum.) (harvest) (ingestion DF) (10^3 ml/L)

$$= 1.07 \times 10^{-10} \ \mu Ci/ml \left(e^{-(1.54 \times 10^{-4})(13)} \right) (0.9 \ L/kg)$$
$$(2.7 \times 10^3 \ kg/yr) \ (6.3 \times 10^{-5} \ rem/\mu Ci) \ (10^3)$$

$$= 1.64 \times 10^{-8} \ rem \ (^3H)$$

Where HARVEST = the lesser of the actual Savannah River commercial harvest and the difference between the total 50-mile fish consumption and the actual sport harvest.

$$\therefore \ HARVEST = Min \ (2.7 \times 10^3; \ 5.0 \times 10^6 - 3.5 \times 10^4)$$

S   50-Mile population dose from saltwater invertebrate harvest:

Dose = (EST CONC) (transport decay)(SW invert. accum) (harvest)
(ingestion DF) (10^3 ml/L)

$$= (2.8 \times 10^{-11} \mu Ci/ml) \left(e^{-\left(1.54 \times 10^{-4}\right)(13)}\right) (0.93) (3.9 \times 10^5 \text{ kg/yr})$$
$$(6.3 \times 10^{-5} \text{ rem}/\mu Ci) (10^3)$$

$$= 6.42 \times 10^{-7} \text{ rem } (^3H)$$

Where HARVEST = the lesser of the actual Savannah River invertebrate harvest
and the total 50 mile invertebrate consumption.

$$\therefore \text{ HARVEST } = \text{Min} (3.9 \times 10^5; 1.1 \times 10^6)$$

T   50-Mile population dose from shoreline exposure:

Dose = (transfer coeff.) (pop shoreline usage) (shorewidth factor) (301 CONC)
(transport decay) (nuclide half-life) (ground shine DF)
(buildup over plant lifetime) / (8760 hrs/yr)

$$= (100 \text{ L/m}^2\text{day}) (9.6 \times 10^5 \text{ person hrs}) (0.2) (1.07 \times 10^{-10} \mu Ci/ml)$$

$$\left(e^{-\left(6.29 \times 10^{-5}\right)(1)}\right) (0.693/6.29 \times 10^{-5}d^{-1}) (57.8 \text{ mrem m}^2/\text{yr} \mu Ci)$$

$$\left[1-e^{-\left(6.29 \times 10^{-5}\right)40 \cdot 365}\right] / 8760$$

$$= 8.97 \times 10^{-2} \text{ person-rem } (^{137}Cs)$$

U   50-Mile population dose from exposure while swimming:

All Nuclides Except Tritium:

Dose = (301 CONC) (transport decay) (pop swimming usage) (water immer. DF)
(0.1142 ml yr rem/m^3 hr mrem) / (GEOM)

$$= (1.07 \times 10^{-10} \mu Ci/ml) \left(e^{-\left(6.29 \times 10^{-5}\right)(1)}\right) (1.6 \times 10^5 \text{ person hrs})$$
$$(6.22 \text{ mrem m}^3/\text{yr} \mu Ci) (0.1142) / 1$$

$$= 1.21 \times 10^{-5} \text{ person-rem } (^{137}Cs)$$

Tritium Only:

Dose = (absorption rate) (ingestion DF) (population usage) (301 CONC)

$$= (35 \text{ ml/hr}) (6.3 \times 10^{-5} \text{ rem}/\mu Ci) (1.6 \times 10^5 \text{ person-hrs})$$
$$(1.07 \times 10^{-10} \mu Ci/ml)$$

$$= 3.77 \times 10^{-8} \text{ person-rem } (^3H)$$

V 50-Mile population dose from exposure while boating:

Dose = (301 CONC) (transport decay) (pop boating usage) (water immer. DF)
    (0.1142 ml yr rem/m^{2}hr mrem) / (GEOM)

$$= (1.07 \times 10^{-10} \ \mu Ci/ml) \left(e^{-(6.29 \times 10^{-5})(1)} \right) (1.1 \times 10^6 \ per \ hrs)$$
$$(6.22 \ mrem \ m^3/yr \ \mu Ci)(0.1142) / 2$$

$$= 4.18 \times 10^{-5} \ person\text{-}rem \ (^{137}Cs)$$

APPENDIX C
Savannah River Flow Rates for Prospective Dose Assessments

WESTINGHOUSE SAVANNAH RIVER COMPANY
SAVANNAH RIVER LABORATORY

June 10, 1991

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HISTORICAL RIVER FLOW RATES FOR DOSE CALCULATIONS

SUMMARY

Annual average river flow rates are required input to the LADTAP Computer Code for calculating offsite doses from liquid releases of radioactive materials to the Savannah River. The source of information on annual river flow rates used in dose calculations varies, depending on whether calculations are for retrospective releases or prospective releases. Examples of these types of releases are:

Retrospective - releases from routine operations (annual environmental reports) and short term release incidents that have occurred.

Prospective - releases that might be expected in the future from routine or abnormal operation of existing or new facilities (EIS's, EID's, SAR's, etc.)

This memorandum provides historical flow rates at the downstream gauging station at Highway 301 for use in retrospective dose calculations and derives flow rate data for the Beaufort-Jasper and Port Wentworth water treatment plants. For prospective calculations, an average flow rate of 10,500 cfs is established for maximum individuals (Highway 301) and a derived flow rate of 13,000 cfs for the Beaufort-Jasper and Port Wentworth water treatment plants. Minimum annual flow rates, for maximizing doses from routine operations, are 5,300 cfs and a derived flow rate of 6,600 cfs for the maximum individual and water treatment plants, respectively. The minimum daily flow rates for calculation of prospective doses for short-term release incidents are 3,900 cfs and a derived flow rate of 4,900 cfs for the maximum individual and water treatment plants, respectively.

INTRODUCTION

The LADTAP computer code is used for calculating doses to individuals and population groups from routine and nonroutine releases of radioactive materials to the Savannah River. Annual river flow rate data is required input to the code in order to calculate dilution of the released materials. The source of information on annual river flow rates used in dose calculations varies, depending on whether calculations are for retrospective releases (i.e., releases have occurred in the past) or prospective releases (hypothetical releases that might be expected in the future). Examples of these types of releases are:

Retrospective - releases from routine operations (annual environmental reports) and short term release incidents that have occurred.

Prospective - releases that might be expected in the future from routine or abnormal operation of existing or new facilities (EIS's, EID's, SAR's, etc.)

Retrospective dose calculations require actual river flow rates that occurred during the period of release. These can be measured flow rates for the period, or adjusted-measured flow rates in which actual flow rates are adjusted to reflect measured dilution of tritium in the river. Adjusted flow rates are used in calculations for the annual environmental reports so that calculated doses accurately reflect measured concentration data in the river. Prospective dose calculations use flow rates based on historical average and minimum annual flow, adjusted for dilution of water between the river gauging station and the point of interest.

In the past, the source of information on flow rates was the U.S Geological Survey (USGS) gauging station at the SRS boat dock (one-half mile downstream from the mouth of Upper Three Runs, on the South Carolina side of the river). This gauging station is not calibrated at flow rates exceeding 22,000 cfs because the river profile (cross-section) is not defined at the higher flow rates. Historical data recorded by the Environmental Monitoring Section (EMS) was obtained from gauge readings by the SRS Power Department, using extrapolation of the flow curve above 22,000 cfs when needed. This usually underestimates high flow rates based on comparison with more accurate USGS flow rates at Augusta, GA (New Savannah Lock and Dam). Between 1954 and 1988 (35 years), annual flow rates at the SRS boat dock recorded by the EMS and USGS were lower than at the upstream Augusta gauging station for 19 years (Table 1).

The probable underestimation of flow rates at the SRS boat dock during some years did not cause any offsite doses to be underestimated. However, in the interest of obtaining more accurate flow rate data, flow rates were analyzed at the downstream USGS gauging station at Highway 301. This station is considered accurate at all flow rates by the USGS.

SOURCE OF FLOW RATE DATA

A summary of annual average Savannah River flow rates was prepared from USGS sources to provide a data set for use in dose calculations for SRS releases.

The USGS measures Savannah River flow at 4 locations below Augusta, GA, i.e., New Savannah Lock and Dam at Bush Field (Augusta), Savannah River near Jackson (SRS Boat Dock), Millhaven, Ga (Highway 301), and at Clyo, GA. The SRS Boat Dock gauging station is not calibrated for flows greater than 22,000 cfs and daily flow rates are not reported by the USGS when the flow exceeds 22,000 cfs.

The USGS flow data for all gauging stations are recorded in both paper and digital formats. The USGS office located in each state issues an annual "Water Resources Data Report" for that state and data are also stored in a digital format at USGS headquarters in Reston, VA (Daily Values File). The annual flow data for this summary were obtained from the USGS daily values file for the years from 1950 to 1986 and flows for 1987 and 1988 were obtained from USGS state reports.

Annual flow data were available for the period 1950 through 1988 at Augusta and Clyo. USGS did not start recording flow data for the SRS boat dock until 1972. Prior to 1972, data from the EMS records were used. Between 1972 and 1988, USGS boat dock data were incomplete for 12 of the years because flow rates exceeded 22,000 cfs during parts of these years. Highway 301 flows were not measured in the 1971-1981 time period. A comparison of the flows at Augusta and Highway 301 in the years when data were available (Figure 1) show that the average flows during the missing years at Highway 301

could be estimated from the flows at Augusta (shown in Figure 2). A correlation coefficient of 0.98 was obtained when the data(Figure 1) were fitted to a simple linear equation, y = mx + b; where y is estimated flow at Highway 301, x is the measured flow at Augusta, and m & b are coefficients obta:.;ed from the regression analysis. The values for the regression coefficients and their standard errors are: m = 1.1486 + -0.0330 and b = -202 + - 298. These coefficients and the Augusta flows were used to estimate the flow at Highway 301 for the 1971-1981 time period.

A summary of the flow rate data for 1950 - 1988 for the four gauging stations is shown in Table 1. A more detailed summary for each station is given by month and year in Appendix A. Detailed daily records are available from the Environmental Technology Section of SRL on compact disk and magnetic computer media. Table 1 includes a summary of maximum, average, and minimum annual flow rates and minimum and maximum monthly flow rates for the time period 1954 - 1988, the years of SRS operation. The Thurmond Lake Dam was in operation during this entire period.

SELECTED FLOW RATES FOR DOSE CALCULATIONS

During the period of SRS operation, the average annual flow rate for the period 1954 - 1988 was 10,500 cfs and the minimum annual average flow rate, which occurred in 1988, was 5,300 cfs at Highway 301 (Table 1 averages were rounded downward). These values will be used for prospective dose calculations for the maximum individual for annual releases. Previous values used were 10,400 cfs for average annual flow and 6,000 cfs for minimum annual flow. The minimum daily flow rate of 3960 cfs occurred on October 25, 1986. A value of 3,900 cfs will be used for prospective dose calculations for the maximum individual for short term releases, i.e., releases of one day or less.

River flow rates are not measured at the points where the water treatment plants pump water from the river. Beaufort-Jasper water is pumped from River Mile 39 into an eighteen-mile-long canal to the treatment plant. The Beaufort-Jasper treatment plant started operation in 1965. Port Wentworth water is pumped from Abercorn Creek at River Mile 29 and is piped about seven miles to the treatment plant. This plant was in operation before the startup of SRS operations. In order to develop flow rates for retrospective or prospective calculations of dose to customers of the two downstream water treatment plants, a relationship was developed for adjusting Highway 301 flow rates for additional dilution of non-river water to the river below Highway 301 and additional dilution in the pumping and transport system between the river and the water treatment plants. The method described in Hayes 1983, which is based on tritium concentrations at Highway 301 and at the water treatment plants, was used to develop percent dilution. It was necessary to update these data through 1990 to account for modifications to the water pumping and transport system put into effect at the Beaufort-Jasper water treatment plant in 1985. Table 2 shows the data for percent dilution for 1966 - 1990.

From these data, a 121 percent average dilution was calculated for Beaufort-Jasper for 1966 - 1984 and 40 percent dilution for succeeding years. An average dilution of 26 percent was calculated for all years for the Port Wentworth plant. The higher dilution for the Beaufort-Jasper plant can be accounted for by additional dilution in the 18-mile canal system from rainfall (estimated at 4 percent) and ground and surface water. During the period 1965 - 1984, surface water was a large contributor to the dilution in the Beaufort-Jasper canal system. After 1984, surface water dilution was reduced by modifications to this system.

Table 3 shows the Highway 301 flow rate data for the period 1954 - 1988. Also shown are

derived flow rates to be used in retrospective dose calculation for Beaufort-Jasper and Port Wentworth, based on percent dilution of water downstream of Highway 301. It is emphasized that the derived flow rate data for Beaufort-Jasper and Port Wentworth are not true river flow rates but are numbers to be used in LADTAP computer code input to account for inflow to the river below Highway 301 and additional dilution in the pumping and transport system of the treatment plants. A summary of measured average and minimum flow rates at Highway 301 and derived values for the water treatment plants for prospective dose calculations is shown in Table 4.

REFERENCE

Hayes, D.W. 1983. "Examples of Savannah River Water Dilution Between the Savannah River Plant and the Beaufort-Jasper and Port Wentworth Water Treatment Plants", DPST-82-1076, January 12, 1983.

APPENDIX D

Comparison of Aquatic Foods Ingestion Dose Estimates
by LADTAP XL and LADTAP II

Table D-1. Population Dose via Aquatic Foods Ingestion (person-rem).

Nuclide*	Commerical Fish LADTAP II	Commerical Fish LADTAP XL	Saltwater Invertebrates LADTAP II	Saltwater Invertebrates LADTAPXL
H-3	1.8×10^{-9}	1.6×10^{-8}	8.5×10^{-10}	6.4×10^{-7}
P-32	1.3×10^{-2}	1.2×10^{-1}	1.8×10^{-3}	1.3×10^{0}
S-35	1.4×10^{-5}	1.3×10^{-4}	3.8×10^{-9}	2.8×10^{-6}
Cr-51	6.1×10^{-7}	5.4×10^{-6}	2.7×10^{-6}	2.1×10^{-3}
Mn-54	3.4×10^{-5}	3.0×10^{-4}	1.5×10^{-5}	1.2×10^{-2}
Co-58	5.0×10^{-6}	4.5×10^{-5}	4.5×10^{-5}	3.4×10^{-2}
Co-60	4.2×10^{-5}	3.8×10^{-4}	3.8×10^{-4}	2.8×10^{-1}
Zn-65	8.7×10^{-4}	7.8×10^{-3}	9.8×10^{-3}	7.4×10^{0}
Sr-89	7.0×10^{-6}	6.3×10^{-5}	2.1×10^{-6}	1.6×10^{-3}
Sr-90	1.3×10^{-4}	1.1×10^{-3}	3.8×10^{-5}	2.8×10^{-2}
Y-91	6.2×10^{-6}	5.5×10^{-5}	1.1×10^{-4}	8.4×10^{-2}
Zr-95	3.2×10^{-7}	2.8×10^{-6}	3.5×10^{-6}	2.6×10^{-3}
Nb-95	1.7×10^{-3}	1.5×10^{-2}	2.5×10^{-6}	1.9×10^{-3}
Mo-99	3.5×10^{-8}	4.8×10^{-7}	1.6×10^{-8}	1.8×10^{-5}
Ru-103	7.0×10^{-7}	6.2×10^{-6}	3.1×10^{-5}	2.4×10^{-2}
Ru-106	6.6×10^{-6}	5.9×10^{-5}	3.0×10^{-4}	2.2×10^{-1}
Sb-124	2.6×10^{-7}	2.3×10^{-6}	5.8×10^{-7}	4.4×10^{-4}
Sb-125	8.3×10^{-8}	7.5×10^{-7}	1.9×10^{-7}	1.4×10^{-4}
I-129	1.4×10^{-4}	1.2×10^{-3}	2.0×10^{-4}	1.5×10^{-1}
I-131	8.4×10^{-6}	7.5×10^{-5}	1.3×10^{-5}	9.5×10^{-3}
Cs-134	7.1×10^{-3}	6.4×10^{-2}	2.8×10^{-5}	2.0×10^{-2}
Cs-137	4.8×10^{-3}	4.3×10^{-2}	1.8×10^{-5}	1.4×10^{-2}
Ba-140	5.4×10^{-7}	4.8×10^{-6}	6.1×10^{-6}	4.6×10^{-3}
La-140	2.9×10^{-8}	2.6×10^{-7}	5.2×10^{-7}	3.9×10^{-4}
Ce-141	6.4×10^{-8}	5.7×10^{-7}	1.7×10^{-5}	1.3×10^{-2}
Ce-144	6.3×10^{-7}	5.6×10^{-6}	1.7×10^{-4}	1.3×10^{-1}
Pm-147	7.6×10^{-7}	6.8×10^{-6}	1.4×10^{-5}	1.0×10^{-2}
Th-232	2.7×10^{-3}	2.4×10^{-2}	8.2×10^{-2}	6.1×10^{1}
U-234	1.7×10^{-5}	1.5×10^{-4}	3.8×10^{-5}	2.9×10^{-2}
U-235	1.6×10^{-5}	1.4×10^{-4}	3.7×10^{-5}	2.7×10^{-2}
U-237	4.6×10^{-8}	4.1×10^{-7}	1.0×10^{-7}	7.8×10^{-5}
U-238	1.5×10^{-5}	1.3×10^{-4}	3.4×10^{-5}	2.5×10^{-2}
Np-239	2.1×10^{-8}	1.8×10^{-7}	9.3×10^{-9}	6.9×10^{-6}
Pu-238	4.3×10^{-4}	3.9×10^{-3}	1.1×10^{-2}	8.3×10^{0}
Pu-239	4.9×10^{-4}	4.4×10^{-3}	1.3×10^{-2}	9.4×10^{0}
Am-241	3.6×10^{-3}	3.3×10^{-2}	6.6×10^{-2}	4.9×10^{1}
Cm-244	1.9×10^{-3}	1.7×10^{-2}	3.4×10^{-2}	2.5×10^{1}
Total	3.7×10^{-2}	3.3×10^{-1}	2.2×10^{-1}	1.6×10^{2}

* source term is a one curie release of each of the nuclides listed.

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Table D-2. Maximum Individual Dose via Shoreline Exposure (mrem).

Nuclide*	15 Year Buildup LADTAP II	40 Year Buildup LADTAP XL
H-3	0.0×10^0	0.0×10^0
P-32	0.0×10^0	0.0×10^0
S-35	0.0×10^0	0.0×10^0
Cr-51	5.2×10^{-7}	5.2×10^{-7}
Mn-54	1.5×10^{-4}	1.5×10^{-4}
Co-58	3.9×10^{-5}	3.9×10^{-5}
Co-60	2.1×10^{-3}	2.5×10^{-3}
Zn-65	7.5×10^{-5}	7.5×10^{-5}
Sr-89	3.8×10^{-9}	3.8×10^{-9}
Sr-90	0.0×10^0	0.0×10^0
Y-91	1.1×10^{-7}	1.1×10^{-7}
Zr-95	5.4×10^{-5}	5.4×10^{-5}
Nb-95	1.5×10^{-5}	1.5×10^{-5}
Mo-99	3.5×10^{-7}	3.5×10^{-7}
Ru-103	1.1×10^{-5}	1.1×10^{-5}
Ru-106	4.4×10^{-5}	4.4×10^{-5}
Sb-124	5.9×10^{-5}	5.9×10^{-5}
Sb-125	2.4×10^{-4}	2.5×10^{-4}
I-129	4.7×10^{-5}	1.3×10^{-4}
I-131	1.7×10^{-6}	1.7×10^{-6}
Cs-134	6.7×10^{-4}	6.7×10^{-4}
Cs-137	1.0×10^{-3}	2.2×10^{-3}
Ba-140	1.6×10^{-5}	1.6×10^{-5}
La-140	1.3×10^{-6}	1.3×10^{-6}
Ce-141	1.6×10^{-6}	1.6×10^{-6}
Ce-144	8.1×10^{-6}	8.1×10^{-6}
Pm-147	2.2×10^{-9}	2.2×10^{-9}
Th-232	1.4×10^{-6}	3.8×10^{-6}
U-234	1.7×10^{-6}	4.6×10^{-6}
U-235	3.7×10^{-4}	9.8×10^{-4}
U-237	5.5×10^{-7}	5.5×10^{-7}
U-238	1.4×10^{-6}	3.7×10^{-6}
Np-239	1.9×10^{-7}	1.9×10^{-7}
Pu-238	1.7×10^{-6}	4.2×10^{-6}
Pu-239	8.1×10^{-7}	2.2×10^{-6}
Am-241	6.3×10^{-5}	1.7×10^{-4}
Cm-244	1.3×10^{-6}	2.4×10^{-6}
Total	5.0×10^{-3}	7.3×10^{-3}

* source term is a one curie release of each of the nuclides listed.

END

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