

Selection of Hydrological Model for Waterborne Release

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T.I. Brown Jr., D.R. Marx

March 1999

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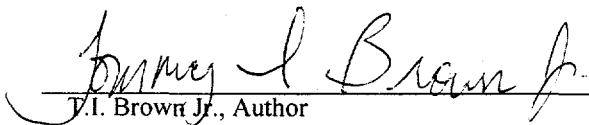
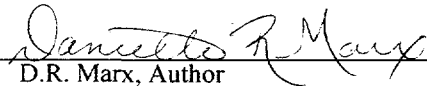
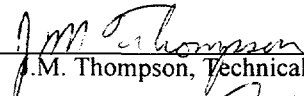

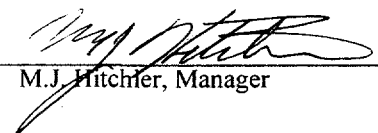
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EXECUTIVE SUMMARY

The Savannah River Site (SRS) evaluated and tested its hydrological dose codes. The testing determined the appropriate model for use in future modeling regarding the effects of hydrological releases to the Savannah River on downstream populations. Testing and evaluation of the SRS hydrological dose codes included identification of constraints, assessment of code flexibility, and total cost consideration. Evaluation of postulated releases, in a manner consistent with that of DOE/EH-0173T and DOE Orders 5400.1 and 5400.5, provides a perspective on the potential consequences that aqueous releases from SRS facilities may have on downstream users of the Savannah River. Guidelines for evaluation of contaminant concentration levels in water are the Environmental Protection Agency Safe Drinking Water Standards (EPA 1998) and the Food and Drug Administration Derived Intervention Levels for Accidental Radioactive Contamination of Human Food and Animal Feeds (FDA 1998).

Presented are the criteria used to select codes that model surface water release of contaminants to the environment. Two liquid release scenarios were analyzed to perform a comparison between the SRS hydrological dose codes STREAM2 and LADTAP XL. The releases are assumed to be introduced into the Savannah River via an accidental spill of contaminated water. The entire contents of the spill are assumed to reach the river. Based on an analysis of the radionuclide water concentrations reported by the two codes and the aspects desired in the code for the future study, STREAM2 is recommended for use.

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1.0 INTRODUCTION

Following a request from the States of South Carolina and Georgia, downstream radiological consequences from postulated accidental aqueous releases at three Savannah River Site (SRS) nonreactor nuclear facilities will be examined. This evaluation will aid in determining the potential impacts of liquid releases to downstream populations on the Savannah River.

Two SRS surface spill runoff hydrological dose codes are currently available. These two codes, LADTAP XL and STREAM2, are both maintained by Savannah River Technology Center (SRTC) personnel. A prerequisite for examining the SRS accidents is determination of the appropriate code for use in the evaluation. The decision on which hydrological modeling code to use will be based upon testing and evaluation that includes identification of constraints, assessment of code flexibility, and total cost consideration. Evaluation of postulated releases, in a manner consistent with that of DOE/EH-0173T (DOE 1991) and DOE Orders 5400.1 and 5400.5 (DOE 1990, DOE 1993), provides a perspective on the potential consequences that aqueous releases from SRS facilities may have on downstream users of the Savannah River. The purpose of this report is to evaluate the two available models and determine the appropriate model for use in following waterborne release analyses. Additionally, this report will document the accidents to be used in the future study.

2.0 BACKGROUND

Evaluation of SRS accidents involving waterborne releases requires the use of a hydrological model. Two SRS aqueous modeling codes, LADTAP XL and STREAM2, will be analyzed for applicability to the future study. For comparison of the models, two accident scenarios have been identified in Section 3.1 and will be modeled with each code. For acute waterborne releases, immersion and consumption of contaminated fish are beyond the present design parameters of the two hydrological dose codes. The ingestion pathway modeling in acute waterborne releases is expected to be dominant, thus decreasing the importance of including other pathways within the models. The issue of including immersion and consumption of contaminated fish pathways following an acute release could be explored under a separate project. A discussion of LADTAP XL and STREAM2 follows.

2.1 LADTAP XL

LADTAP XL is an electronic EXCEL spreadsheet designed to model chronic aqueous releases and is based on U.S. Nuclear Regulatory Guide 1.109 (USNRC 1977a). LADTAP XL can be used to predict the radiological consequences to the maximum offsite individual (MOI) and affected populations following postulated chronic aqueous discharges to streams on SRS. Environmental pathways incorporated in LADTAP XL include external exposure resulting from recreational activities on the Savannah River and ingestion of water, fish, and invertebrates of Savannah River origin (Hamby 1991).

LADTAP XL assumes a constant release over a period of one year. Nuclide concentrations in the Savannah River are estimated by diluting annual releases in a volume of water equal to the total annual river flow without taking into account nuclide depletion other than radioactive decay

(Simpkins 1998). Dose predictions are calculated assuming constant annual intake and usage rates for water consumption, fish consumption, and other river activities.

To use LADTAP XL for acute releases, a minimum daily flow rate is used which serves to minimize dilution and maximize concentration. The only pathway appropriate for use with acute releases is the ingestion water pathway. The fish ingestion pathway assumes that the concentration in the fish is in equilibrium with the water concentration. In an accident situation, this would not be the case and is thus not appropriate for inclusion in acute release scenarios. Recreational pathways are not considered for acute releases (Simpkins 1998).

2.2 STREAM2

STREAM2 is the SRS Weather Information and Display System (WINDS) emergency response hydrological dose code (Chen 1995, Chen 1996a, Chen 1996b). STREAM2 is an aquatic response computer program designed to model the transport of pollutants from a release point within SRS to various points downstream on the Savannah River. STREAM2 is a modified version of STREAM. STREAM uses an algebraic equation to approximate the solution of the one dimensional advective transport differential equation. To correct the problem of spurious oscillations in the concentration profile when modeling long duration releases in STREAM, STREAM2 incorporates the U.S. Environmental Protection Agency (EPA) WASP5 code to replace the transport and diffusion module of STREAM (Chen 1998a). The WASP5 code is a water quality analysis program that simulates one-dimensional pollutant transport and fate through surface water. Additional input files describing the geometry of the pollutant pathway from the release point to the coastal area and the stream/river flow conditions are used in STREAM2 for simulations (Chen 1998b).

STREAM2 is composed of three modules: the calculation, pre-processor, and post-processor modules. The pre-processor module user interface consists of the time, date, type, location, calculation units, amount, and duration of the release. The input data from the user is transferred from the pre-processor to the calculation module, which calculates the pollutant concentrations and transport time at downstream locations. The post-processor module displays the output data from the pollutant concentrations and transport times on the computer screen in graphical and tabular form.

STREAM2 is conservative in its modeling approach and does not include physical factors that would reduce actual downstream concentrations. Two parameters currently under consideration for potential inclusion in STREAM2 are dilution and deposition. Preliminary examination has indicated that incorporating dilution into the model is unnecessary since the additional dilution provided by other sources is relatively insignificant (i.e., 10%). However, incorporation of deposition changes may be of benefit and should be examined further. Modeling deposition in STREAM2 may reduce the downstream radionuclide by as much as a factor of 2 for certain radionuclides, such as cesium and plutonium, based on information in the RAP Radiological Assessment Program (RAP) reports (Carlton et. al. 1992a, 1992b). Incorporation of either of these two physical factors, if deemed appropriate for STREAM2, will occur at a later date.

3.0 SELECTION CRITERIA

Several technical factors enter into the selection of hydrological dose codes. The code must be able to give temporal information, specifically time-to-impact outputs with varying flow rates and transport times to downstream receptors, and perform instantaneous release calculations. Ideally, the code should be flexible enough to calculate concentration following both chronic and acute aqueous releases to the environment. The model should be among, or consistent with, those models that will actually be used or available following a release and should have adequate documentation. The model should have low costs associated with acquisition, training, execution, and minimal constraints. Calculation of contaminant concentration and radiological dose downstream are important outputs. Calculation of radiological doses to the public resulting from the ingestion of contaminated water must be consistent with guidance DOE/EH-0071 (DOE 1988) for Internal Dose Conversion Factors for Calculation of Dose to the Public. All individual and population doses are based on the assumption that liquids discharged from SRS facilities are completely mixed in the river before reaching the potential pathways. The dose calculations are also based on the assumptions that all radionuclides are conserved during transport except for radiological decay of target isotopes. Therefore, factors such as hold up time and/or biological filtration in the intervening wetland during transport to the Savannah River are not incorporated. Guidelines used for evaluation of contaminant concentration levels in water are the Environmental Protection Agency Safe Drinking Water Standards (EPA 1998) and the Food and Drug Administration Derived Intervention Levels for Accidental Radioactive Contamination of Human Food and Animal Feeds (FDA 1998).

If both models are found to meet the technical factors, preference will be given to the simplest model(s), in accordance with scientific consensus (NCRP 1996). Choosing the least complex model has several advantages. In general, the time needed to construct input files and run a simple model is shorter. Fewer input parameters reduce the likelihood of a transcription error. Additionally, the results from simple models may be more easily verified by hand calculations than calculations from complex models. In summary, the selection of the hydrological modeling code for acute surface water releases must consider the capabilities, availability, familiarity, simplicity, and cost of the code. The model selection criteria listed above are summarized in Section 6.0, Table 4.

4.0 SCENARIOS USED FOR MODEL TESTING

In order to determine the appropriate code for use in the hydrological modeling examination, aqueous release scenarios for D-Area and H-Area were analyzed by both the STREAM2 and LADTAP XL codes. Bounding source terms from current facility Authorization Basis documents were used in selection of the two scenarios (Hope 1998). Radionuclide concentrations at three locations on the Savannah River – the river outfall, the intersection with Highway 301, and the Savannah, GA, water supply – were calculated using both modeling codes and compared. For both releases it was assumed that the radionuclides are introduced into the Savannah River via an accidental spill of contaminated water and that the entire contents of the spill reach the river. The D and H area accident scenarios used for model testing are described below.

In D-Area, the bounding radiological hazard is stored reactor moderator that is contaminated with tritium oxide. For the D-Area Heavy Water Facility accidental release scenario, the source term is assumed to be $2.58 \times 10^{+6}$ Ci of tritium oxide (HTO). Using the given concentration of 11 curies per liter, the release would be $6.24 \times 10^{+4}$ gallons of moderator.

The second scenario is an assumed release from the H-Area Tank Farm resulting from an evaluation basis earthquake event. The source term for the liquid surface water release is $1.6 \times 10^{+6}$ gallons of dilute supernate. The isotopic composition of the dilute supernate at five years maturity is given in Table 1.

Table 1 Isotopic Composition of the Dilute Supernate at five year Maturity

Isotope	Ci/Gallon
Sr-90	1.3E-03
Ru-106	1.8E-01
Cs-134	7.2E-01
Cs-137	5.0E+00
Pu-238	6.5E-03

The duration of release for D-Area is assumed to be instantaneous. Both an instantaneous release and a 24- hour release are assumed for H-Area incidents.

The aqueous release scenarios that will be modeled following determination of the appropriate modeling code are located in the Appendix.

5.0 RESULTS

Radionuclide concentrations were calculated using both LADTAP XL and STREAM2. Table 2 presents the calculated concentrations at the Highway 301 intersection and the Savannah, GA, water supply for the H-Area Tank Farm release. The LADTAP XL results used a 24-hour release duration, while the STREAM2 results were calculated for both an instantaneous and a 24-hour release. Flow rates in the STREAM2 calculations were assumed to be constant at both Highway 301 and Savannah, GA, while LADTAP calculations used a varying flow rate at the two points. The LADTAP XL 24-hour adjusted flow rate column uses the STREAM2 flow rate for ease in comparison.

Table 3 presents the results for the postulated release from D-Area. STREAM2 calculations are shown for peak concentrations at three downstream locations and LADTAP calculations are for the 24-hour concentrated release duration. Since LADTAP XL is not designed to handle releases of such a short duration, results less than a 24-hour release duration are not reported for this scenario. LADTAP XL results could be modified using calculation data from U.S. Nuclear Regulatory Commission Regulatory Guide 1.113 (NRC 1977b) to give results for instantaneous releases, but this development work is beyond the scope of this project.

Table 2 Water Concentration for H-Area Release

Radionuclide	Highway 301 conc. Ci/L			Savannah, GA, conc. Ci/L			
	LADTAP XL	STREAM2		LADTAP XL	STREAM2		
	24-hr	Inst. Peak	24-hr Peak	24-hr	24-hr Adjusted Flow	Inst. Peak	24-hour Peak
Sr-90	1.20E-07	1.90E-07	1.14E-07	9.60E-08	1.20E-07	1.74E-07	1.12E-07
Ru-106	1.70E-05	2.64E-05	1.58E-05	1.30E-05	1.63E-05	2.42E-05	1.55E-05
Cs-134	6.60E-05	1.05E-04	6.32E-05	5.30E-05	6.63E-05	9.65E-05	6.17E-05
Cs-137	4.60E-04	7.33E-04	4.39E-04	3.70E-04	4.63E-04	6.71E-04	4.29E-04
Pu-238	6.00E-07	9.52E-07	5.71E-07	4.80E-07	6.00E-07	8.72E-07	5.58E-07

Table 3 Water Concentration for D-Area Release

	LADTAP conc. (Ci/L)	STREAM2 conc. (Ci/L)		
Radionuclide	24hr	B. Dam Inst. Peak	Hwy 301 Inst. Peak	Savannah Inst. Peak
H-3	1.50E-04	1.44E-03	9.76E-04	6.30E-04

6.0 DISCUSSION

Based on the concentration data provided in Section 5.0 and the selection criteria described in Section 3.0, a hydrological modeling code for use in future waterborne release modeling must be chosen. Table 4 presents a listing of the selection criteria used to compare LADTAP XL and STREAM2.

Both LADTAP XL and STREAM2 are capable of calculating radionuclide concentrations following chronic (1 year) and acute (24-hour) releases. However, only STREAM2 is capable of calculating concentrations following an instantaneous release. The concentration values calculated within the codes are average values for LADTAP XL and peak values with STREAM2. LADTAP XL is capable of calculating both concentration and dose while STREAM2 only calculates concentration. Documentation comparing the modeling code to actual measurements on the Savannah River is available for STREAM2 but not for LADTAP XL. Additionally, STREAM 2 is more flexible than LADTAP XL and also includes temporal data while LADTAP XL is more simplistic. There is not a substantial difference in costs associated with acquisition, training, and execution for the two models. Both models are consistent with DOE guidelines.

The one-dimensional diffusion modeled in STREAM2 provides more realistic values, especially for short duration releases. The lack of temporal information in LADTAP XL precludes calculation of time-to-impact values. Considering the importance of these values and the comparison of the models provided in Table 4, it is recommended that STREAM2 be used in future waterborne release modeling and examination.

Table 4 Hydrological Dose Model Selection Criteria

Selection Criteria	STREAM2	LADTAP XL
Scenario Testing and Evaluation	✓	
Code Flexibility	✓	
1. Chronic (1yr) aqueous release	✓	✓
2. Acute (24hr)aqueous release	✓	✓
3. Instantaneous aqueous release	✓	
Provide Temporal Data	✓	
1. Transport Times	✓	
2. Time to Impact Data	✓	
Calculate		
1. Radiological dose		✓
2. Average concentration		✓
3. Peak concentration	✓	
4. Average flow rates	✓	✓
5. Minimum flow rates	✓	✓
6. Maximum flow rates	✓	✓
Low Costs associated with acquisition, training, and execution.	✓	✓
1. Model Familiarity	✓	✓
2. Model Simplicity	✓	✓
3. Model Availability	✓	✓
4. Adequate Model Documentation	✓	✓
5. Quality Assurance Capabilities	✓	✓
Available for use following a release to the environment	✓	✓
Consistent with DOE Guidelines	✓	✓

7.0 SUMMARY

Two SRS hydrological modeling codes, STREAM2 and LADTAP XL, have been examined for use in future waterborne release studies. STREAM2, the Weather Information and Display System (WINDS) emergency response hydrological code, is an aquatic response computer program designed to model the transport of pollutants from a release point within SRS to various points downstream on the Savannah River. STREAM2 has the flexibility to give outputs for instantaneous, chronic, and acute aqueous releases to the environment. LADTAP XL is a simplistic dilution model capable of calculating concentrations for chronic and 24-hour releases. A comparison of the two scenarios shows that the differences between the two codes for a 24-hour release are minimal. Considering the similarity in calculated concentrations and the temporal information available with STREAM2, it is recommended that STREAM2 be used for future waterborne release analysis.

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9.0 APPENDIX – SCENARIOS AND ANALYSIS PARAMETERS FOR THE FINAL WATERBORNE RELEASE EXAMINATION

After determination of the appropriate hydrological model, accident events for three aqueous outfalls will be examined. These SRS areas in which these outfalls are located – D-Area, H-Area, and TNX – were agreed upon jointly by Westinghouse Savannah River Company (WSRC), the Department of Energy (DOE) and the States of Georgia and South Carolina, and are documented in WSRC-TR-98-0411 (Clifton 1998). The D-Area outfall (D-03) was selected due to its proximity to the Savannah River and limitations in the ability to mitigate a release from the facility. H-Area contains H-Canyon wastewater and the risk of failure of the Tank Farm engineered berms and subsequent release into outfall H-12. These two aspects made H-Area a viable choice for selection in hydrological modeling. TNX was selected for hydrological modeling because of its close proximity to outfall X-08 and the risk of a potential chemical discharge. Authorization Basis (AB) documents will be used as references for determination of potential scenarios.

The output for the modeled scenarios will be examined for several parameters. Each scenario will be modeled using average, minimum, maximum, and median flow rates for the Savannah River. Time-to-impact values resulting from the multiple flow rates for two downstream locations - intersection of the Savannah River and Highway 301 and at the City of Savannah water treatment plant intake - will be examined. This will aid in determining the time urgency of an aqueous release. Peak and time-integrated radionuclide concentrations will be calculated for three locations, the entrance of the site stream to the Savannah River, the Savannah River and Highway 301 intersection, and the City of Savannah water treatment plant intake. These concentrations will be compared with regulatory limits (FDA 1998, EPA 1998). If necessary, ingestion dose resulting from the consumption of contaminated water may be calculated. The accident scenarios examined for each facility area are described below.

9.1 D – Area Scenarios

In the D – Area Heavy Water processing and drum storage facilities, tritium is the only hazardous and radiological material that has the potential to represent any threat of significance to the environment, general public, and onsite personnel. Buildings in the Heavy Water Facility are not seismically qualified or hardened to withstand the forces of high winds or tornadoes. Therefore, it is assumed that the buildings fail and result in a maximum release of tritium during the range of natural phenomena hazard (NPH) events. As such, only one accident event will be evaluated for D-Area. The aqueous release source term resulting from high winds, tornadoes, or earthquakes is $2.58 \times 10^{+6}$ curies of tritium and is assumed to be instantaneous.

9.2 H – Area Scenarios

Two accident categories, natural phenomena hazards (NPH) and operational events, were considered for the H – Area releases. Examination of the Tank Farm NPH event scenarios was performed to determine the benefits of using an event precipitated by a natural phenomenon. The Tank Farm Safety Analysis Report (WSRC 1998b) indicates that the liquid pathway radiological dose for the volume of waste available for release following an evaluation basis earthquake (EBE) would greatly exceed evaluation guidelines. As a result, technical safety

requirement (TSR) controls are in place to mitigate accident consequences and reduce potential doses significantly. An unmitigated EBE event is less realistic than an operational event. For emergency preparedness issues, a realistic accident scenario is desired to determine the most likely consequences to downstream users of the Savannah River. Based on these factors, two operational H - Area accidents have been selected for modeling.

Information for the first event, the Coil and Tube Failure Scenario for H-Canyon, is taken from the H-Canyon BIO (WSRC 1998a). For the Coil and Tube Failure liquid pathway, the entire activity is released to Four Mile Creek. The release is assumed to be instantaneous. The radionuclide inventory resulting in the maximum release is shown in Table 5.

Table 5 Radionuclide inventory for the H-Canyon Coil and Tube failure event

Isotope	Curies	Isotope	Curies	Isotope	Curies	Isotope	Curies
Sr-89	1.35E+4	Ag-110	7.09E+1	Pr-144	3.75E+4	Pa-233	0.00E+0
Sr-90	6.79E+2	Sn-123	6.84E+1	Pm-147	3.76E+3	Pu-238	1.02E+2
Y-90	2.51E+2	Sb-125	7.76E+1	Pm-148m	1.03E+2	Pu-239	4.56E-1
Y-91	2.11E+4	Te-127	1.23E+2	Eu-155	4.18E+1	Pu-240	4.56E-1
Zr-95	2.7E+4	Te-129	1.05E+2	U-234	1.16E-1	Pu-241	1.32E+2
Nb-95	4.98E+4	Cs-134	1.68E+3	U-235	1.01E-3	Pu-242	1.47E-3
Ru-103	5.06E+3	Cs-137	2.04E+3	U-236	3.22E-2	Am-241	2.67E+0
Ru-106	2.6E+3	Ce-141	5.32E+3	U-238	8.65E-5		
Rh-106	2.6E+3	Ce-144	3.75E+4	Np-237	2.19E-2		

In the second event, the liquid leak and spill, 1,000 gallons of Slurry Sludge is released. The release is subject to runoff or is soaked into the surrounding soil. The total isotopic source term for the Tank Farm leak and spill event is listed in Table 6. The release is assumed to be instantaneous.

Table 6 Source Term for H-Area Tank Farm Leak and Spill Event

Isotope	Curie	Isotope	Curie
Sr-90	1.2E+5	Pu-238	4.2E+4
Ru-106	1.6E+2	Pu-239	3.5E+1
Cs-134	6.5E+2	Pu-240	2.6E+1
Cs-137	4.5E+3	Pu-241	4.7E+3
Ce-144	4.4E+3	Am-241	4.1E+1

9.3 TNX Scenarios

The only large amounts of radioactive materials at TNX are solutions of uranyl nitrate stored in two tanks in the vicinity of 677-T. The TNX EPHA (S-EHA-T-00001) has an inventory of less than 2 curies Uranyl nitrate solution. Within the EPHA the radionuclides were screened in accordance with the guidance of EMPP 6Q-001 where the threshold values of 10 CFR 30.72 are utilized. The total quantity of depleted uranium is 1569 kg. The Hazard Assessment Document (HAD) analyzed the solution as natural uranium (99.27% U-238, 0.72% U-235, and 5.5×10^{-3} % U-234). The total curie content of the two tanks is 1.08 Ci (0.52 Ci U-238, 0.02 Ci U-235, 0.54 Ci U-234). The TNX inventory is scheduled to be transferred to F or H-Area in the near future.