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SAVANNAH RIVER LABORATORY

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March 17, 1983

MEMORANDUM

TO: T. V. CRAWFORD

FROM: M-D. S. TURCOTTE, C. M. KING

TIS FILE
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ENVIRONMENTAL IMPLICATIONS OF Tc-99 DWPF OPERATION AND SALTCRETE

SUMMARY

This paper presents the radiological effect on the offsite population from technetium-99 (Tc-99) releases associated with the disposal of the SRP high-level waste. Atmospheric releases from waste glass melting in the Defense Waste Processing Facility (DWPF) and liquid releases from leaching of saltcrete monoliths used to dispose of low level waste residues are both considered. In addition, the behavior of Tc-99 after leaching from DWPF glass waste forms in a geological repository is discussed.

For each of the possible release pathways, three process flowsheets were analyzed. The flowsheets represent different degrees of decontamination of the high level waste salt supernate and different methods for disposal of the Tc-99 recovered following glass melter off-gas treatment. These flowsheet analyses represent all currently identified potential pathways for offsite population exposure.

Atmospheric releases of Tc-99 from DWPF operations cause a negligible dose to the offsite population (80 km population). The total release of Tc-99 from the DWPF glass melter will represent 0.0009% of SRP operational releases of Tc-99 to the year 2000. The DWPF dose due to Tc-99 atmospheric releases could cause a potential 2.6E-11* fatal cancers during the assumed 30 year glass melter operation period. Natural background radiation over the same time period could cause a potential 4.7E+05 fatal cancers.

Saltcrete scenarios assume the depth of the monolith burial precludes uptake of Tc-99 by plants. The pathway of maximum potential population exposure from Tc-99 in saltcrete involves incorporation of decontaminated salt supernate directly into saltcrete (without ion exchange removal of Tc-99), and a 4% sediment retention of leached Tc-99 in the swamp area. A maximum population whole body dose of 1.4E-01 person-rem and associated organ exposures could cause a potential 2.3E-03 fatal cancers over 10,001 years in the population group considered. This number is only 0.001% of the calculated fatal cancer deaths caused by natural

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* Scientific Notation: 2.6E-11 = 2.6×10^{-11}.

radiation exposure to this same population group. From this analysis it is concluded that Tc-99 does not represent a significant hazard to the offsite population during DWPF operations and subsequent disposal of supernate in saltcrete monoliths.

The behavior of Tc-99 in the glass waste matrix in a geological repository will be dependent upon the oxidation-reduction conditions of the repository. Studies indicate a relatively high initial leach rate of Tc-99 from the glass waste followed by a period of pulses as the glass erodes and pockets of Tc-99 are reached. Movement of Tc-99 from the repository will be minimal if reducing conditions are maintained within the geological repository.

INTRODUCTION

The purpose of this study is twofold: to identify the escape routes of Tc-99 to the environment during the high-level waste disposal process, and to predict the probable behavior of Tc-99 after release to the environment.

There are no natural sources of Tc-99, which is a man-made fission product. It presents a potential health hazard to humans by localizing in the thyroid, stomach, and salivary glands. At the time the study began, the EPA draft guidelines for high level waste disposal (40CFR191) stated that the presence of fission products, such as Tc-99, in a waste would classify that waste as high-level waste. This definition implied that, even after decontamination,

the SRP salt supernate and saltcrete remained classified as as high-level waste and required disposal according to NRC procedures. Recently, this draft regulation has been changed to redefine high-level waste so as to exclude wastes containing radionuclides below certain concentration levels. For Tc-99, the proposed level was 30 μCi/g. This definition in effect removes salt supernate and saltcrete from the high-level waste classification; salt supernate has 30 nCi/g, while saltcrete has 20 nCi/g.[1] Additional Tc removal by ion exchange could decrease these values by a factor of 10 or more.

WASTE

The liquid high-level radioactive waste presently stored in SRP waste tanks consists of two parts: a sludge containing most of the radionuclides except Cs-137 and a salt supernate containing essentially all the Cs-137 and small amounts of other radionuclides. Based on measurements and calculations of waste stream composition, the sludge and supernate stored in the high-level waste tanks at SRP contain 1.45E-04 Ci Tc-99/L.[2] Assuming reactor operations continue until the year 2001, there will be a total of 100 million gallons of high-level waste, containing 56,000 Ci Tc-99, requiring disposal. Analyses indicate 30% of the Tc-99 is soluble and found in the salt supernate.[2] For comparison, in the Hanford waste tanks, 80% of the Tc-99 is present in a soluble form in the alkaline waste supernate.[3]

An in-tank treatment with sodium tetraphenylborate and sodium titanate is a current option for removing most of the radionulcides from the salt supernate. The resulting precipitate will be combined with the sludge fraction of the HLW and immobilized in borosilicate glass in the Defense Waste Processing Facility (DWPF). The glass waste forms will be disposed of in a geological repository.

The precipitation process removes little Tc from the supernate. Present calculations indicate the decontaminated supernate remaining after precipitation will contain 5.05E-5 Ci Tc-99/L solution, or 20% of its total activity.[2] The decontaminated salt supernate will also need disposal. The reference disposal method for the supernate is intermediate depth burial as saltcrete monoliths.

FLOWSHEETS

There are four process flowsheets considered in this analysis.

CASE 1: RECYCLE (Fig. 1).

The decontaminated salt supernate stream (DSS) flows through an ion exchange process with 90% removal of Tc-99. The polished stream (RSC) is then incorporated into saltcrete. The Tc-99 removed by ion exchange (IXR) is mixed with the sludge stream (S). The resulting stream (G) is introduced to the melter. The glass waste form (RGEO) will be stored in a geologic repository.

Clean up of the glass melter off-gas stream (MV) results in removal of most of the Tc-99 from the off-gas. From information on the chemistry of Tc-99, we can expect a large fraction of the Tc-99 removed from the offgas (OGB) to remain in a soluble form.[4] This removed Tc-99 is assumed soluble and recycled to the high-level waste tank farm. The remaining volatile Tc-99 is vented up the stack (RATM).

CASE 2: NO RECYCLE (Fig. 2)

This flowsheet is a modification of Case 1. The Tc-99 removed from the glass melter off-gas stream is put directly into saltcrete.

CASE 3: NO ION EXCHANGE (Fig. 3)

This case is included for comparison. The decontaminated salt supernate goes directly to saltcrete without an ion exchange step.

Table 1 presents the Tc-99 content of the various release streams. See Appendix A for information on flowsheet stream content calculations.

Three potential routes for environmental release of Tc-99 during high-level waste disposal were identified:

- volatilization during glass vitrification
- leaching of glass waste in repository
- leaching from saltcrete monoliths

VITRIFICATION

Immobilization of sludge in glass will lead to Tc-99 volatilization during glass formation. Research has been conducted at Battelle Northwest Laboratory on the volatilization of radionuclides during preparation of a full-level radioactive borosilicate glass waste form.[5] Calcination results in 0.005% volatilization, melting results in 2.89% volatilization of Tc-99. The SRP design basis assumptions used to calculate releases from the DWPF glass melter are 5% volatilization of Tc-99, and 1% entrainment in the melter.[6] These assumptions are in close agreement with the measured data.

Volatilization of 3% represents a potential loss of 1,200 to 1,700 Ci Tc-99 during glass formation (Fig. 1, 2, 3; Table A1). The most likely Tc-99 compound to volatize during vitrification will be Tc_2O_7.[4] This dioxide is water soluble and converts to $HTcO_4$ after contact with water vapor. Most of the Tc-99 volatized during vitrification will be removed from the off-gas stream during passage through the water quench, the deep bed filters and the sand filter.[6] The design basis decontamination factors for treatment of the melter off-gas stream are approximately DF=4.0E+10.[6] This decontamination factor results in a total release of 30 to 40 nCi Tc-99 from the glass melter stack.

A rough estimate of the total amount of Tc-99 released through the year 2001 from SRP operations (other than the DWPF) can be made to compare to the potential Tc-99 releases from the melter off-gas

stream. The results from a grab sample of the SRP F Area stack off-gas stream indicate the SRP reprocessing facilities release about 0.1 mCi/yr.[7] During 46 years of operation, SRP will have released about 4.6 mCi Tc-99. Releases of Tc-99 from the melter off-gas will contribute 0.0006 - 0.0009% to SRP releases to the year 2000, and are therefore negligible.

The revised GASPAR code was used to calculate the population dose from the melter stack releases.[8] The off-gas release of 30 to 40 nCi over a 30-year period results in a whole body dose of 4.2E-08 person-rem to the population within 50 miles. For comparison, the population whole body dose from natural background radiation is 2.2E+09 person-rem to the same affected population over a 30-year period. The calculated population and associated organ doses, combined with fatal cancer risk factors, was used to calculate potential fatal somatic effects from Tc-99.[9] The potential fatal cancers caused by whole body and organ dose from off-gas melter releases of Tc-99 numbers 2.6E-11 fatalities for the 30-year operational period. During the same period, natural background whole body and organ doses will have resulted in a potential 4.7E+05 fatal cancers. It may be concluded from this that the effects of Tc-99 volatilized during vitrification are negligible. See Appendix B for more details on the GASPAR code.

REPOSITORY

The borosilicate glass waste forms produced by the DWPF are to be disposed of in a geological repository. Leaching of the glass following water intrusion into the repository may cause loss of Tc-99 and can be considered as a potential pathway to the environment. The borosilicate glass waste will contain a total of 38,000 to 54,000 Ci Tc-99, or approximately 3.8 to 5.4 Ci per glass cylinder depending on the flowsheet followed (Table 1).

Technetium-99, as TcO_4^-, is phase separated in glass.[10] It accumulates at the internal pore surfaces (or bubbles) during glass formation.[11] Technetium exhibits glass leaching behavior much different than that of Cm-144, U-233, Am-243, Np-237 or Pu-239. The leach rates of these radionuclides studied decrease a factor of 10 in the first 10 to 20 days of leaching. The leach rate for Tc-99 is a factor of 1,000 higher initially, and decreases a factor of 1.0E+04 within 4 days (Fig. 4). The researchers suggest this drastic drop in leach rate is related to the accumulation of Tc-99 on the pore surfaces close to the outside surface of the glass. The cumulative leach rate of Tc-99 is relatively flat, and the study predicts the silicate leach rate crosses the Tc-99 leach rate after four years (Fig. 5). Following the four year period, Tc-99 will leach in pulses as the glass erodes and bubbles are reached.

Once leached from the glass, the movement of Tc-99 will be dependent upon the oxidation-reduction status of the geological repository. Deep underground sediments and geological repositories

tend to have an oxidation-reduction potential that favors Tc(IV) over Tc(VII). The reduced form of Tc-99, Tc(IV), is considered relatively immobile. Studies conducted with rock media under the conditions representative of a geological repository indicate that most of the water-soluble Tc-99 is removed from solution rather quickly.[4] The technetium precipitates as the insoluble oxide ($TcO_2:2H_2O$) and sulfides (Tc_2S_7 or TcS_6), or complexes with organic material and is immobilized. The reducing conditions present within the repository should result in long-term retention of leached Tc-99 as the insoluble oxide or sulfide. The reduced or precipitated form of Tc-99 will rapidly reoxidize if the environment becomes oxidizing. Therefore, assuring reducing conditions in the repository is of primary importance in controlling Tc-99 movement after disposal.

SALTCRETE

Intermediate depth burial of saltcrete is the reference case for disposal of the decontaminated salt supernate. Decontaminated salt supernate is mixed with cement to form a saltcrete product of relatively low leachability and good dimensional stability. Saltcrete design is based upon a controlled rate of nitrate leaching over a period of 10,000 to 50,000 years.

Results of field lysimeter tests to determine the rate of Tc-99 leaching from saltcrete are inconclusive.[12] The rate of

Tc-99 leaching is assumed similar to that of nitrate, which is assumed to leach as quickly as tritium.

The most likely transport medium for leached Tc-99 will be the groundwater. The burial depth of the saltcrete should preclude root uptake of Tc-99. Tests reporting Tc-99 holdup on soil generally predict little holdup on soils with low organic content such as those found at SRP.[4,13,14,15] Ongoing studies at SRL are determining the behavior of pertechnetate, the most likely form of Tc-99 in the environment, in both batch and soil column systems. Batch K_d (distribution coefficients) tests on four soils originating near the burial ground have resulted in K_d measurements of 0.10 - 1.32 mL/g.[16] These are all very low results and predict Tc-99 moves at approximately the rate of groundwater.

The groundwater containing leached Tc-99 will eventually reach the Savannah River. Results from both freshwater and seawater aquatic investigations indicate Tc-99 remains predominantly in the water column. Uptake of Tc-99 from the water is highest for fast-growing species such as phytoplankton. Larger species — fish, red abolone, mollusks — accumulate Tc-99 primarily by ingestion. Based on the one available field study, uptake by freshwater plants and animals should be low. This fresh water study indicates approximately 4% Tc-99 precipitation to the sediments. There is some evidence suggesting additional Tc-99 precipitates under reducing water conditions such as are found in

bogs, marshes and swamps. This behavior suggests a potential site for holdup or accumulation of Tc-99 in the Savannah River.

The effects of Tc-99 leaching from saltcrete were estimated by using the LADTAP II code.[17] Two modes of transport after release from saltcrete are considered.

MODE 1: It is assumed that Tc-99 leaches out of the saltcrete over a period of 10,000 years. It travels via the groundwater to the Savannah River.

MODE 2: The leaching for this scenario is the same as Mode 1. It is also assumed 4% of the Tc-99 is held up in the Savannah River swamp sediments. At the year 10,0001, a flood resuspends all of the swamp-held Tc-99 and flushes it down the Savannah River. The dose from the 96% that is not held up is assumed similar to Mode 1.

The calculated population dose was used to calculate potential fatal somatic effects from Tc-99. Table 2 presents the fatal cancers resulting from all scenarios considered. Both yearly and total fatal cancers over the 10,001 year period are a small fraction of those caused by background radiation. See Appendix C for more information on the LADTAP II code and Appendix D for information on calculation of somatic (cancer) effects.

The flood scenario using a NO ION EXCHANGE flowsheet results in the maximum number of potential fatal cancers over the 10,001 year period — 2.3E-03 fatalities. Background radiation during the same period causes 1.71E+08 fatal cancers to the same

affected population. The effects of Tc-99 (leached from saltcrete) upon the downstream population is negligible compared with background effects.

The effects of Tc-99 leaching from saltcrete were also estimated using the SRL DOSTOMAN code[20] based upon the measured bulk leachability of saltcrete[12] and the measured soil retention properties of Tc-99 for SRP burial ground soils.[16] Using as input basic information on Z area dimensions, monolith properties, percolating rainwater rates, burial ground geologic data, and nuclide data (source term, leach rate, soil to water distribution coefficient, and decay constant), the code has been used to project the Tc-99 flux (Ci/yr) to the hydrological system below and contiguous to the proposed Z area landfill. Groundwater, tributary and Savannah River concentrations are then converted to drinking water dose, as summarized in Table 3, based upon ICRP 30 dose factors. For the reference process (saltcrete monolith plus clay liner), concentrations of Tc-99 in the hydrological system near the proposed Z area never exceed the EPA standard for Tc-99 of 900 pCi/L[21] for public water supplies. The groundwater calculations are based upon the premise that groundwater volume is supplemented annually by infiltrating rainwater. The horizontal flow of the groundwater aquifer — which would further dilute contaminated rainwater — is not included. Hence, the calculations represent an upper limit for Tc-99 contamination of the groundwater. Only in the extreme example of saltcrete leachability

exceeding the measured values by a factor of ten, is the projected Tc-99 groundwater concentration greater than the EPA guideline. The Upper Three Runs tributary and Savannah River concentrations are well within the EPA standard for this extreme case, illustrating the dilution effect with subsequent transport to outlying streams. For the reference process, the projected drinking water dose is well below the EPA standard of 4 mrem/person, independent of source of water or of body organ. The basic input for the DOSTOMAN calculation of hydrological transport is summarized in Appendix E.

Based upon the premise that water, contaminated by infiltrating rainwater leaching of Tc-99 from saltcrete, could be used for offsite irrigation of crops; a five-vector foodchain analysis was conducted to extend the basic DOSTOMAN results to additional foodchain pathways to man. The basic methodology is U. S. Nuclear Regulatory Commission Regulatory Guide 1.109[22] with the drinking water consumption pathway extended to four additional vectors: fish caught from contaminated water (tributary and Savannah River), crops irrigated with contaminated water, and cow's milk and meat from herbivore's consumption of contaminated crops and water. Since the original data base for Tc-99 transfer coefficients to foodchain pathways in Regulatory Guide 1.109 were based upon anologies to SR-90, more recent information on vegetative uptake factors, based on the work of Hoffman, et al.[23] and herbivore's milk and meat, based on the work of Till, et al.[24] have been used in this

analysis. Till, et al.[24] well illustrated the need for updated, preferably site specific, information on foodchain transfer coefficients for Tc-99. Fifty-year integrated dose commitments increased by about 140 (i.e., thyroid: 0.60 to 80 mrem/person) for ingestion pathways by use of more recent Tc-99 transfer data in the Till, et al., analysis.[24] This work further illustrated the need for extending the original DOSTOMAN liquid effluent analysis to foodchain vectors other than drinking water. Basic input to the NRC foodchain calculation is given in Appendix F.

For the reference process, saltcrete plus clay liner, results of extending the DOSTOMAN projections on hydrological contamination (Table 3) to food chain pathways are presented in Table 4. For the Maximum Exposed Individual (MEI), the 50-year integrated dose commitment is 50 mrem/person to the critical organ (stomach wall). This is a worst case calculation assuming the use of contaminated groundwater for offsite crop irrigation. The individual at the site boundary (tributary water) and the average exposed individual (Savannah River water) would receive a dose at least two orders of magnitude less. The dose to the Beaufort/Jasper/Port Wentworth population (Appendix C), assuming the Savannah River water is used for crop irrigation, is still several orders of magnitude less than the population dose associated with natural background radiation. The population dose via the DOSTOMAN/food chain projections are comparable in magnitude to the LADTAP II projections (Appendix C, Table C3) on population dose for potable water, aquatic food and

recreation pathways. Hence, the somatic effects analysis and conclusions, as presented in Table 2, would be analogous.

The significance of the dose commitments resulting from the aqueous release of Tc-99 to the biosphere can be put into perspective to standards promulgated by the U. S. Environmental Protection Agency in 40 CFR 190.[25] These standards recommend 25 mrem/person as the maximum dose to the whole body and other organs except the thyroid; the standard for the thyroid is 75 mrem/person. Our analysis indicates that average individual and site boundary exposure would be <u>well within</u> those guidelines. Only in the <u>hypothetical case</u> of groundwater use for offsite agricultural purposes - an extremely low probability event - would those guidelines be exceeded for one organ: the stomach wall, the critical organ under ICRP 30 dose methodology.

From the study conducted here, Tc-99 alone does not present a high degree of risk from releases to the environment. However, it is necessary that three important assumptions in design criteria are met:

1) Decontamination factor for Tc-99 from off-gas stream = 4.0E+10;
2) Reducing conditions in geological repository be maintained;
3) Leach rate of Tc-99 from saltcrete be no greater than that of nitrate.

TABLE 1

Amount of Tc-99 in DWPF Output Streams

Ci			
Case	RATM	RGEO	RSC
Recycle	40	54000	1800
No Recycle	40	53000	3300
No Ion Exchange	30	38000	18000

TABLE 2

Potential Fatal Cancers from Saltcrete Leaching*

	Yearly Fatal Cancers		Total Fatal Cancers**	
Case	number	% of bckgrnd	number	% of bckgrnd
Leach Recycle	2.2E-08	0.0001	2.2E-04	0.0001
Leach No Recycle	4.0E-08	0.0002	4.0E-04	0.0002
Leach No Ion Exchange	2.2E-07	0.001	2.2E-03	0.001
Flood Recycle	8.9E-06†	0.04	2.3E-04	0.0001
Flood No Recycle	1.6E-05†	0.07	4.2E-04	0.0002
Flood No Ion Exchange	8.6E-05†	0.40	2.3E-03	0.001
Background††	1.7E+04	-	1.7E+08	-

* Based on LADTAP calculated doses and fatal cancer risk factors.

** Calculated over 10,001 years.

† The year following the flood.

†† From BEIR III, Table III-4.

TABLE 3

Hydrological Contamination as Projected by the DOSTOMAN Code

Saltcrete Leachability	Tc-99 Conc pCi/L			
	Tc-99 Flux Ci/yr	Groundwater	Tributary	Savannah River
Monolith + Clay Liner	10^{-2}	60.	0.6	2×10^{-3}
Monolith (Meas.)	10^{-1}	600.	5.6	2×10^{-2}
10 X Monolith	1	6000.	56.	2×10^{-1}

NOTE: EPA Drinking Water Standard for Tc-99 is 900 pCi/L[21]

Drinking Water Dose (mrem/p/50 yr) for the Saltcrete Reference Process (Monolith + Clay Liner)

Organ	Source of Drinking Water		
	Groundwater	Tributary	Savannah River
Whole Body	2×10^{-3}	2×10^{-5}	6×10^{-8}
Stomach Wall	6×10^{-1}	5×10^{-3}	1×10^{-5}
GI-LLI	2×10^{-1}	2×10^{-3}	4×10^{-6}
Thyroid	3×10^{-1}	2×10^{-3}	6×10^{-6}
GI-ULI	7×10^{-2}	6×10^{-4}	2×10^{-6}

NOTE: The EPA Drinking Water Standard is 4 mrem/person[21]

TABLE 4

Saltcrete Reference Process
DOSTOMAN/Foodchain Projections*
50 Year Dose Commitment/ICRP 30

	Water Source for Crop Irrigation				
	Groundwater	Tributary	Savannah River		Natural Background
Organ	MEI** Dose mrem/p	Individual at Site Boundary mrem/p	Individual mrem/p	Population Dose person-rem	Population Dose person-rem
Stomach Wall	50.	4×10^{-1}	2×10^{-3}	1.4×10^{-1}	7×10^{3}
Bone	0.6	5×10^{-3}	2×10^{-5}	1.4×10^{-4}	7×10^{3}
Liver	0.8	6×10^{-3}	3×10^{-5}	2.1×10^{-4}	5.6×10^{3}
Whole Body	0.2	2×10^{-3}	7×10^{-6}	4.9×10^{-4}	6.5×10^{3}
Thyroid	23.	2×10^{-1}	1×10^{-3}	7×10^{-2}	6.5×10^{3}
Kidney	10.	8×10^{-2}	4×10^{-4}	2.8×10^{-2}	6.5×10^{3}
Lung	0.1	1×10^{-3}	4×10^{-6}	2.8×10^{-4}	1.4×10^{4}
GI/LLI	16.	1×10^{-1}	5×10^{-4}	3.5×10^{-2}	5.6×10^{4}

* Foodchain pathways:
Drinking water, fish, crops, cow's milk, cow's meat

** MEI, Maximum Exposed Individual assumed to receive dose by ingestion of foodstuffs from offsite crop irrigation using Tc-99 contaminated groundwater as irrigation source.

APPENDIX A

ASSUMPTIONS

1) T = 56,000 Ci
2) Tc-99 decontamination factor for off-gas treatment = 4.0E+10.
3) Off-gas treatment bottoms are soluble.

TABLE A1
Tc-99 MATERIAL BALANCE
curies

STREAM	CASE 1	CASE 2	CASE 3
DSS	18500	16800	18000
G	55800	54300	39200
IXR	16600	15100	-
MV	1670	1630	1180
OGB	1670	1630	1180
S	39200	39200	39200
RATM	40nCi	40nCi	30nCi
RGEO	54100	52700	38000
RSC	1850	3310	18000

APPENDIX B

GASPAR DOSE CODE

The revised GASPAR[18] code calculates population dose from atmospheric releases of radionuclides. The code implements the dose model from NRC Regulatory Guide 1.109 (Rev. 1). An indepth description of SRP revision of the code and the corresponding dose factor library will be issued.[8] For the purpose of this investigation, some changes have been made in both the parameters of the code and in the dose factor library. The transfer factor for soil to vegetation is based upon findings of a literature review.[4]

Veg/soil 2.0E+01 g/g

The adult organ dose factors are based on ICRP 30 dose factors.

Thyroid	5.9E-06 mrem/pCi
GI-LLI	4.1E-06 mrem/pCi

The affected population for the GASPAR code is 721,000 people.

The input for the GASPAR code is in curies of radionuclide released per year. It was assumed the glass melter would operate for 30 years for the purposes of this study.

TABLE B1
INPUT TO GASPAR

CASE	RELEASE* Ci	INPUT TO CODE Ci/yr
RECYCLE	40E-09	1.3E-09
NO RECYCLE	40E-09	1.3E-09
NO ION EXCHG	30E-09	1.0E-09

* Total release over 30 years.

APPENDIX B (Contd)

The population doses calculated by GASPAR are shown in Table B2 for a constant population of 7.21E+05 over the 30 year release period.

TABLE B2
POPULATION DOSES
person-rem/yr

Organ	Recy/No Recy	No Ion Exchg	Background
Whole Body	1.40E-09	1.40E-09	7.3E+07
GI-LL	8.89E-08	8.89E-08	6.2E+07
Bone	3.50E-09	3.50E-09	8.9E+07
Liver	4.72E-09	4.72E-09	-
Kidney	5.83E-08	5.83E-08	-
Thyroid	9.02E-08	9.02E-08	-
Lung	5.19E-10	5.19E-10	4.1E+07
Bone Marrow	-	-	6.2E+07

APPENDIX C

LADTAP II DOSE CODE

The LADTAP II code calculates the dose to the downstream population from aqueous releases by SRP. The code implements the radiation exposure models of Regulatory Guide 1.109. The aqueous pathways considered result in organ doses from potable water, aquatic foods, shoreline deposits, swimming, boating and irrigated foods.[18] Specific modifications of the code were made for this application. The vegetation to soil transfer factor and the organ dose factors were changed as in the GASPAR code.

The populations used as the downstream water users is assumed constant at the projected year 2000 population.

TABLE C1
POPULATION FOR LADTAP CODE

Beaufort/Jasper	40300
Port Wentworth	29200
50 mile radius	781000

Six cases were considered. Table C2 shows the input data to the code for each case. For the three flood cases, the dose resulting from the 96% of the Tc-99 which is not deposited is assumed equal to the dose in the three non-flood cases.

APPENDIX C (Contd)

TABLE C2
INPUT DATA FOR LADTAP II

Case	Release* Ci	Input to Code Ci/yr
Recycle	1850	1.85E-01
No Recycle	1680+1630	3.31E-01
No Ion Exchange	18000	1.80
Flood- Recycle	(1850)(0.04)	7.40E+01
Flood- No Recycle	(1680+1630)(0.04)	1.30E+02
Flood- No Ion Exchg	(18000)(0.04)	7.20E+02

* For non-flood cases, total release over 10,000 years.
For flood cases, release in the one flood year.

Table C3 presents the population dose results for all six cases.

TABLE C3
POPULATION DOSES
person-rem/yr

Organ	Recycle	No Recycle	No Ion Exchange	Flood Recycle*	Flood-No Recycle*	Flood-No Ion Exchg*
Bone	8.63E-05	1.56E-04	8.52E-04	3.51E-02	6.15E-02	3.42E-01
Liver	1.17E-04	2.15E-04	1.17E-03	4.82E-02	8.44E-02	4.70E-01
Body	3.42E-05	6.27E-05	3.42E-04	1.41E-02	2.47E-02	1.37E-01
Thyroid	2.65E-03	4.85E-03	2.64E-02	1.09	1.91	1.06E+01
Kidney	1.46E-03	2.67E-03	1.42E-02	5.99E-01	1.05	5.82
Lung	1.02E-05	1.86E-03	1.02E-04	4.18E-03	7.36E-03	4.06E-02
GI-LLI	2.28E-03	4.18E-03	2.28E-02	9.37E-01	1.65	9.12

* For the one year following the flood.

APPENDIX D

FATAL CANCERS

A comparison of radiation effects may be best achieved by computing the potential number of fatal cancers resulting from exposure to a radionuclide. Calculation of fatal cancers can be made by incorporating fatal cancer risk factors with the dose. The calculation of fatal cancer risk factors is based on BEIR III and an indepth explanation of the methodology is found elsewhere.[9,19] Table D1 presents the fatal cancer risk factors for organs based on BEIR III.

TABLE D1
RADIATION DOSE-EFFECT RISK FACTORS

Organ	Risk Factor/Million person-rem
Red bone marrow	20
Bone	0.4
Lung	34
Thyroid	0*
Breast	13
Liver	7.9
Kidney	4.0
GI tract	6.4**
Whole body	0.32
Remainder	34

* Although radiation can induce thyroid cancer, the type of cancer induced is rarely fatal.

** Not including stomach or esophagus.

The fatal cancers to the downstream population resulting from normal background doses based on BEIR III are presented in Table D2.

TABLE D2
NATURAL BACKGROUND RADIATION

Organ	Total mrem/yr	Pop. Dose person-rem	Fatal Cancers fatalities/yr
Whole Body	93	7.3E+07	2.34E+01
Lung	180-530	4.1E+08	1.39E+04
Bone Surfaces	115	8.9E+07	3.56E+01
Bone marrow	80	6.2E+07	1.24E+03
GI tract	80	6.2E+07	3.97E+02

Fatal cancers from atmospheric releases are calculated over a 30 year period. Fatal cancers from saltcrete over the 10,001 year period for the non-flood cases are calculated by simply multiplying 10,001 by the fatal cancers per year. For flood cases, fatal cancers for the first 10,000 years are assumed the same as the non-flood cases. To these are added the fatal cancers for year number 10,001.

APPENDIX E

BASIC INPUT FOR DOSTOMAN PROJECTIONS OF Tc-99 MIGRATION FROM SALTCRETE

Z Area Dimensions

Area	100 Acres 40.5 Hectares 4.5×10^5 M^2
Landfill to Groundwater Distance	25 feet
Surface to Monolith Distance	20 feet
Groundwater to Tributary Distance	980 feet

Meteorology

Average Annual Rainfall	120 cm/yr
Runoff	40 cm/yr
Evapotranspiration	40 cm/yr
Infiltrating Rainwater	40 cm/yr
Rainfall Volume	
- SRP site	9.6×10^{14} ml/yr
- 100 Acre Z Area	4.8×10^{11} ml/yr
- Infiltration to Groundwater	1.6×10^{11} ml/yr

Geology

Groundwater Flow Rate	40-80 ft/yr
Tributary Flow Rate	20 ft^3/sec
	1.8×10^{13} ml/yr
Savannah River Flow Rate	7500 ft^3/sec
	6.7×10^{15} ml/yr
Nearest Outcrop	980 feet
Rainwater Flow Rate	7 ft/yr
Landfill Soil Bulk Density/Porosity	6.4
Barnwell Aquifer Bulk Density/Porosity	4.0
Landfill Soil Permeability	2×10^{-6} m/yr
Landfill Hydrostatic Gradient	0.01 m/m
Landfill Soil Porosity	0.25

Saltcrete

Bulk Leachability	1×10^{-5} g/cm^2·day
Fraction of $NaNO_3$	6×10^{-2}
Bulk Density	1.89 g/cc
Monolith Dimensions	
Trapazoidal Face	30' x 20' x 10'
Length	135'
Max Cross Sectional Area	4×10^3 ft^2

APPENDIX E (Contd)

Saltcrete (Contd)

Monolith Weight	3×10^{9} gms
Tc-99 Concentration	20 nCi/g Saltcrete
Fraction of Tc-99	2×10^{-10}
Release Rate Transfer Coefficient	5×10^{-6} Yr^{-1}
Clay Permeability	10^{-8} cm/sec

Nuclide Data

Radio. Half-Life	2.13×10^{5} yrs
Radio. Decay Constant	3.3×10^{-6} yr^{-1}
Saltcrete Concentration	20 nCi/g
Source Term	22,000 Ci
Distribution Coefficient	1.5×10^{-1} ml/g - 1.3 ml/g
Landfill Retardation Factor	0.11 to 0.51
Barnwell Aquifer Retardation Factor	0.16 to 0.63

Dosimetry Data

Drinking Water Rate (Adult)	730 L/yr
50 yr Dose Commitment Factors (mrem/pCi)	
- Whole Body	5×10^{-8}
- Stomach Wall	1.3×10^{-5}
- GI/LLI	4.1×10^{-6}
- Thyroid	5.9×10^{-6}
- GI/ULI	1.5×10^{-6}

APPENDIX F

BASIC INPUT FOR NRC REGULATORY GUIDE 1.109 FOODCHAIN ANALYSIS/ SALTCRETE REFERENCE PROCESS

Drinking Water Pathway	
Groundwater Tc-99	60 pCi/L
Tributary Tc-99	0.6 pCi/L
Savannah River Tc-99	2×10^{-3} pCi/L
Water Consumption	730 L/yr
Fish Pathway	
Uptake Factor	100 $\frac{\mu Ci/g \text{ fish}}{\mu Ci/ml \text{ water}}$
Consumption	6.9 kg/ Fish/yr·Person
Vegetative Pathway	
Tc-99 Buildup	1 year
Irrigation:	
Time Period	6 months
Rate	8.3 inches/mo
	0.29 $l/m^2 \cdot hr$
Surface Density	240 kg/m^2
Net Rate	5.3×10^3 ml/kg Soil
Plant Uptake Factor	20 g/g
Weathering:	
Fraction Retained	0.25
Half-life	14 days
Rate Constant	2.1×10^{-1} hr^{-1}
Agricultural Productivity	2 kg/m^2
Weathering Constant	2.3×10^4 $\frac{ml}{kg \text{ crop}}$
Plant Consumption Rate	240 kg/yr·person
Milk Pathway	
Cow's Crop Intake	50 kg/day
Cow's Water Intake	60 L/day
Tc-99 Transfer Coefficient to Milk	9.9×10^{-3} $\frac{\mu Ci/L}{\mu Ci/day}$
Man's Milk Consumption	200 L/yr·person

APPENDIX F (Contd)

Meat Pathway

Cow's Daily Intake of Tc-99 from Water and Crops	8.3×10^{-1} µCi/day
Tc-99 Transfer Coefficient to Meat	8.7×10^{-3} $\frac{\mu Ci/kg}{\mu Ci/day}$
Man's Meat Consumption	95 kg/yr·person

Sum of All Exposure Pathways (pCi/yr)

	Groundwater	Tributary	Savannah River
Water	5×10^4	4×10^2	2×10^0
Fish	-	4×10^2	2×10^0
Crops	1.4×10^6	1.1×10^4	4.6×10^1
Milk	1.6×10^6	1.3×10^4	5.3×10^1
Meat	6.8×10^5	5.5×10^3	2.2×10^1
Total	3.8×10^6	3.1×10^4	1.3×10^2

Fifty Year Integrated Dose to the Individual

Critical Organ (ICRP 30)	Stomach Wall
Dose Commitment Factor	1.3×10^{-5} mrem/pCi

Source of Water:

	Groundwater	Tributary	Savannah River
Dose $\left(\frac{\text{mrem}}{\text{p·50 yr}}\right)$	49	4×10^{-1}	2×10^{-3}

Population Data

Exposed Population	70,000
Five Vector Pop. Dose from Savannah River (person-rem)	1.4×10^{-1}
Background Radiation (rem)	0.1
Background Pop. Dose (person-rem)	7×10^3

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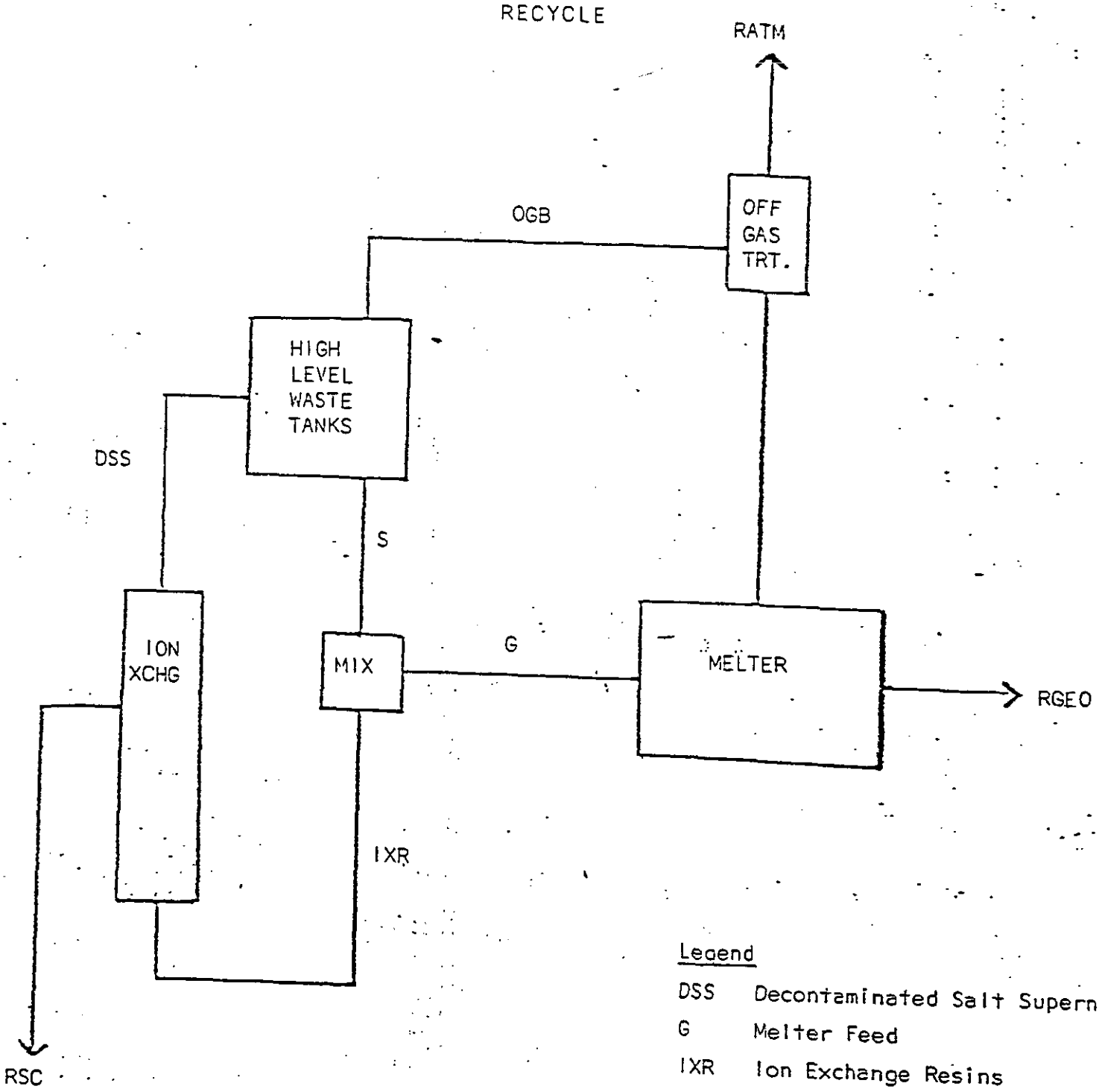
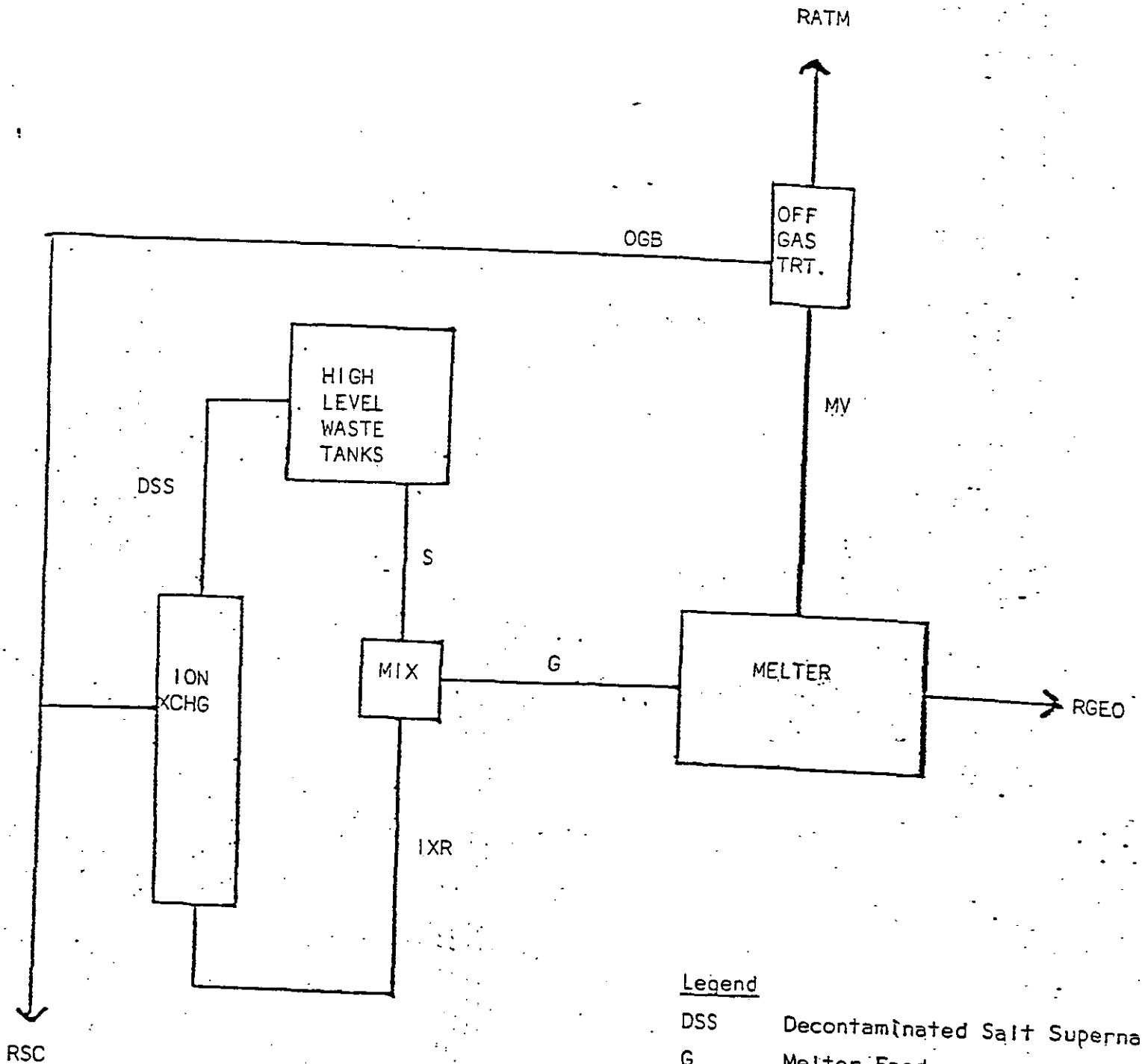
FIGURE 1: CASE 1
RECYCLE



Legend

DSS	Decontaminated Salt Supernate
G	Melter Feed
IXR	Ion Exchange Resins
MV	Melter Volatilized
OGB	Off Gas Treatment Bottoms
S	Sludge
RATM	To atmosphere
RGEO	To geological repository
RSC	To saltcrete

FIGURE 2: CASE 2
NO RECYCLE

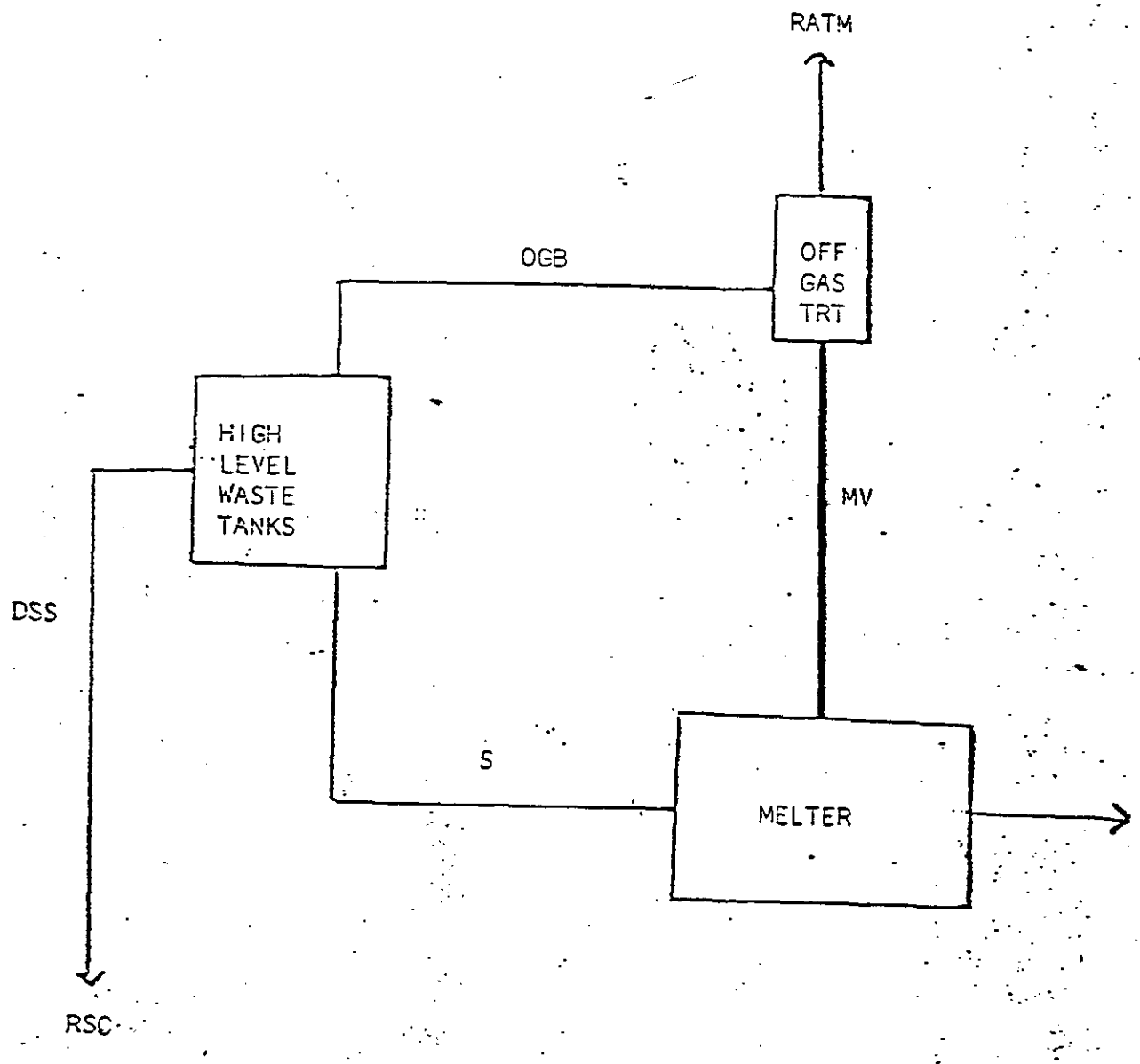


Legend

DSS	Decontaminated Salt Supernat
G	Melter Feed
IXR	Ion Exchange Resins
MV	Melter Volatilized
OGB	Off Gas Treatment Bottoms
S	Sludge
RATM	To atmosphere
RGEO	To geological repository
RSC	To saltcrete

FIGURE 3: CASE 3

NO ION EXCHANGE



Legend

DSS	Decontaminated Salt Supernate
MV	Melter Volatilized
OGB	Off Gas Bottoms
S	Sludge
RATM	To atmosphere
RGEO	To geological repository
RSC	To saltcrete

FIGURE 4

LEACH RATE OF RADIONUCLIDES FROM SIMULATED WASTE GLASS (11)

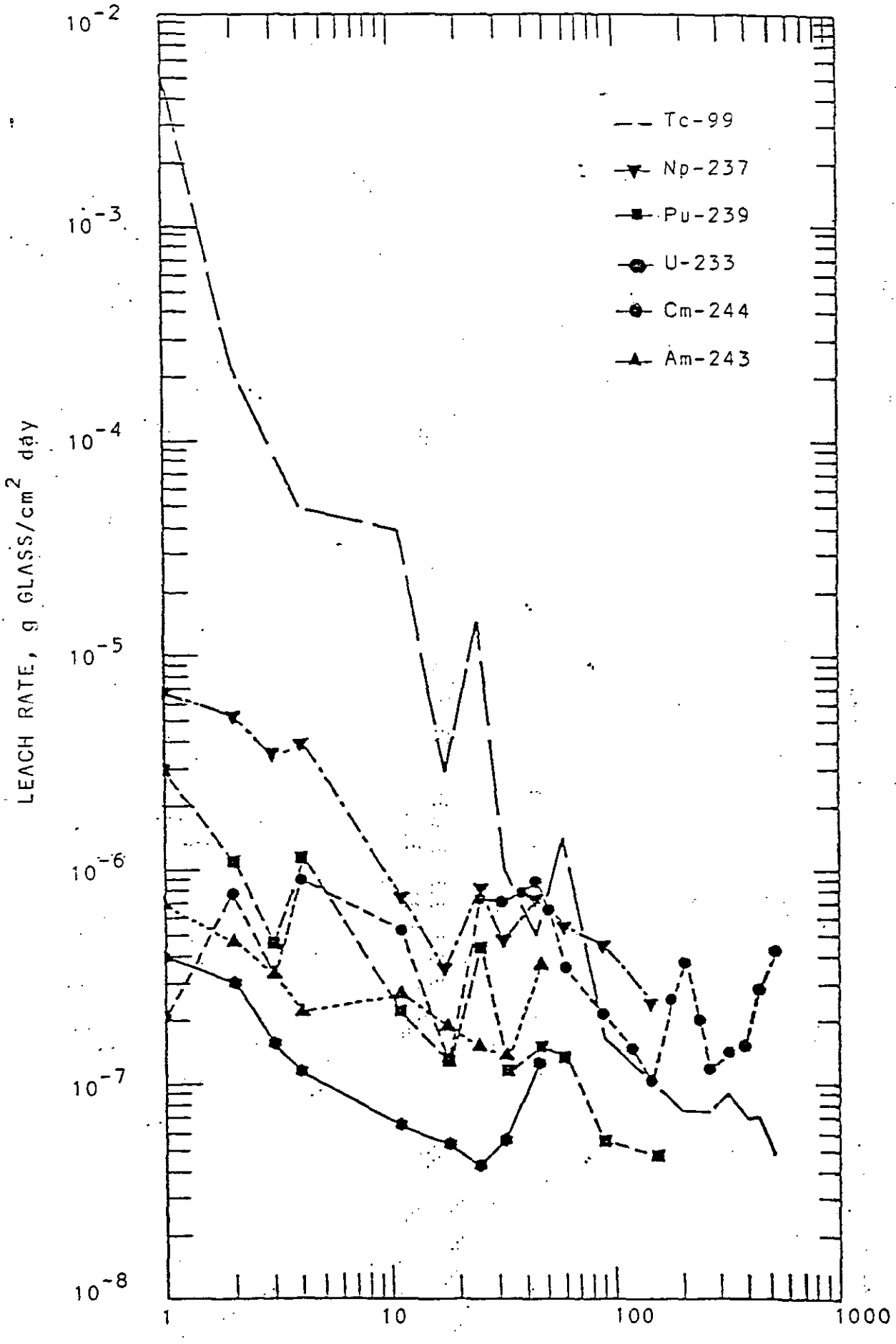


FIGURE 5

CUMULATIVE FRACTIONS OF Tc-99 AND SILICA RELEASED FROM SIMULATED WASTE GLASS (11)