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Addendum to the Z-Area
Radiological Performance Assessment

WSRC-RP-98-00156
Revision 0

ADDENDUM TO THE RADIOLOGICAL PERFORMANCE ASSESSMENT FOR THE Z-AREA SALTSTONE DISPOSAL FACILITY AT THE SAVANNAH RIVER SITE

Additional Information Supplied to the
DOE Performance Assessment Peer Review Panel and
DOE Headquarters in Support of Review, 1993-1997

Prepared by

WESTINGHOUSE SAVANNAH RIVER COMPANY
Aiken, South Carolina

April 1998

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1.0 Summary

The Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility (Z-Area RPA) at the Savannah River Site (SRS) was prepared and submitted to the Department of Energy (DOE) for approval in December 1992 (Ref. 1).

A listing of formal reports issued between December 1992 and December 1997 that contain information pertinent to the Z-Area Saltstone disposal facility are listed in Appendix A. These are public documents, some of which are quite lengthy, that are already available to any interested party. Brief annotations describing these reports are provided, rather than including these documents in this addendum.

As stated in a memorandum from DOE-HQ, the Z-Area RPA is conditionally accepted upon meeting five specified conditions (Ref. 2). This addendum addresses the first two conditions specified in this memorandum, namely:

> "1. The site is to address the requirement for an as low as reasonably achievable analysis in accordance with the latter part of DOE Order 5820.2A, Chapter III, 3.a.(2). The detail of this analysis should be commensurate with the calculated doses."
>
> "2. An addendum to the performance assessment, or a revised performance assessment, is to be issued by June 30, 1998. The addendum is to include the additional information developed by the site in response to number one above and the supplemental information provided subsequent to submittal of the performance assessment (e.g., in response to requests from Headquarters and the PRP). The addendum must be distributed to all known holders of the performance assessment. The purpose of this condition is to ensure that the documentation that was the basis for Headquarters' acceptance is readily available to any party interested in the performance assessment."

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The requirement for an "as low as reasonably acheivable" (ALARA) analysis is addressed in Section ~~3~~ 2 of this Addendum. Based on the combined calculated maximum dose of 1.8 mrem/yr estimated at the SRS boundary for the composite analysis for the Z-Area and E-Area low-level waste (LLW) disposal sites (Ref. 3), a quantitative ALARA analysis for the Z Area saltstone LLW disposal site is neither necessary nor financially justified, based on guidance provided by DOE (Ref. 4).

2.0 ALARA Analysis

6/24/98

As noted in the RPA for Z Area (Ref. 1), groundwater is the only significant pathway for the public to be exposed to contaminants placed in Z Area. Groundwater beneath Z Area is virtually isolated from all other potential sources of radioactive contamination from other facilities at the SRS, by virtue of being on the highest topographical location within the boundary of the SRS. A separate composite analysis specific to Z Area is deemed unnecessary, since interaction with releases to groundwater from "upstream" facilities within the SRS is not credible. However, releases from Z-Area vaults could impact the dose to the public when combined with releases from other facilities within the SRS, such as the E-Area LLW vaults or other facilities after they are decommissioned. Accordingly, a combined composite analysis was completed for all facilities within the central part of the SRS, designated as the General Separations Area (GSA). The GSA is located geographically between Upper Three Runs Creek and Four Mile Branch, and includes Z Area, S Area, H Area, E Area and F Area (Ref. 3).

Groundwater aquifers beneath Z Area are incised by nearby flowing streams, which restrict the extent of any radioactive contamination in groundwater to the seep line at the streams. Because the aquifers are incised, possible groundwater contamination beyond the existing SRS boundary is eliminated. Releases from Z Area vaults into underlying groundwater are directed to Upper Three Runs or McQueens Branch, a smaller tributary of Upper Three Runs (Ref. 1). The mouth of Upper Three Runs at its juncture with the Savannah River is therefore the appropriate point to assess the potential effect of radioactive releases from Z-Area.

In the composite analysis that includes all potential sources within the GSA (Ref. 3), the calculated maximum dose is 1.8 mrem/yr to a hypothetical member of the public located at the mouth of Upper Three Runs, the point of assessment that includes releases from the Z Area and E Area LLW vaults. Two closed LLW disposal facilities within the GSA, the Mixed Waste Management Facility and the Old Burial Grounds, are the major sources of the radioactive isotopes contributing to the calculated doses at the mouths of Upper Three Runs and Four Mile Branch, most of which reach the Savannah River via Four Mile Branch. Releases from the Z Area and E Area LLW disposal sites contribute only a small fraction of the projected 1.8 mrem/yr release to Upper Three Runs from the GSA. The calculated maximum dose of 1.8 mrem/yr from <u>all</u> sources within the GSA that could interact with releases from ZArea is well below the DOE primary dose limit of 100 mrem/yr specified in DOE Order 5400.5. This maximum dose is also well within the dose constraint of 30 mrem/yr for any single source, practice or pathway, as specified in DOE guidance (Ref. 4). Quantitative ALARA analysis for alternative disposal options is deemed unnecessary for any of the facilities within the GSA at the SRS that release contaminants to Upper Three Runs. The added expense of a quantitative ALARA analysis certainly cannot be justified for either the E-Area LLW disposal vaults or the Z-Area saltstone disposal vaults.

Note also that the method of production for saltstone, the design of the disposal vaults and the closure plan for the Saltstone Disposal Facility incorporates ALARA principles throughout. Placing the waste within a surrounding vault constructed of clean concrete provides shielding during active disposal operations, and waste placement is monitored by a remote closed-circuit television system, rather than direct visual observation. The final closure plan for the disposal site, which includes placement of a clean concrete cap provides an engineered barrier to mitigate direct intrusion into the waste at some future date.

6/24/98

3.0 References

1. *Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility*, WSRC-RP-92-1360, Rev. 0, Westinghouse Savannah River Company et al., Aiken, SC (December 1992).
2. **DOE Memorandum,** Mark W. Frei, DOE-HQ (EM-30) to Frank M. McCoy, Acting Deputy Manager, DOE-SR, *SUBJECT: Conditional Acceptance of the Saltstone Disposal Facility Performance Assessment*, February 18, 1998.
3. *Composite Analysis, E-Area Vaults and Saltstone Disposal Facilities,* **WSRC-RP-97-311,** Rev. 0, Westinghouse Savannah River Company (September 1997).
4. *Guidance for Composite Analysis of the Impact of Interacting Source Terms on the Radiological Protection of the Public from Department of Energy Low-Level Waste Disposal Facilities,* U. S. Department of Energy (April 1996).

Prepared by: ______________________ Date: 4/30/98

J. R. Fowler, Editor
Sr. Fellow Scientist
Westinghouse Savannah River Company
High Level Waste Engineering

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APPENDIX A

OF THE

ADDENDUM TO THE RADIOLOGICAL PERFORMANCE ASSESSMENT FOR THE Z-AREA SALTSTONE DISPOSAL FACILITY AT THE SAVANNAH RIVER SITE

Listing of Reports and Correspondence Issued between December 1992 and December 1997 Pertinent to the Z-Area Performance Assessment

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Appendix A.
Reports and Correspondence Issued between December 1992 and December 1997 Pertinent to the Z-Area Performance Assessment

An annotated listing of documents and correspondence pertinent to the Z-Area Radiological Performance Assessment (RPA) is shown below. Copies of items A1. through A5., some of which are quite lengthy, are not included as a part of this addendum, since these reports are available to the public either in reading rooms or as part of permit applications. Correspondence and supplemental information provided to the Peer Review Panel and the Department of Energy in conjunction with review and approval of the RPA are included (items A6. through A19.) and follow the listing below.

A1. *Final Supplemental Environmental Impact Statement Defense Waste Processing Facility*, **DOE/EIS-0082-S**, U. S. Department of Energy, Savannah River Site, Aiken, SC (November 1994).

A supplement to the original EIS issued in 1982 for the Defense Waste Processing Facility used to vitrify HLW and solidify and dispose of decontaminated salt solution. The supplement reflects the current vault disposal of saltstone formulated with cement, fly ash and slag, as described in the RPA, as opposed to trench disposal of a saltcrete waste form prepared using cement and fly ash that was the basis for the original EIS. These changes in waste form formulation and method of final disposal were made to further reduce the potential impact to the environment from groundwater contamination, and are consistent with the ALARA principal for disposal of LLW, as specified in DOE Order 5820.2A, Chapter III, 3.a.(2).

A2. *Addendum to the Permit Application for the Z-Area Saltstone Disposal Facility - Z-Area Closure Plan, Savannah River Site, Aiken, South Carolina*. General Engineering Laboratories Inc, 2040 Savage Road, Charleston, SC (August 1995).

A study validating the engineering feasability and projected functionality of the site closure plan described in the Z-Area RPA. This addendum to the permit application was prepared and submitted to the South Carolina Department of Health and Environmental Control (SCDHEC) to fulfill changes and conditions of permit requirements imposed by the state.

A3. *Savannah River Site Future Use Project Report - Stakeholder Recommendations for SRS Land and Facilities*, Savannah River Operations Office, U. S. Department of Energy, Aiken, SC (January 1996).

A summary of stakeholder recommendations for the long-term use of the Savannah River Site. If these recommendations are enacted, the long-term risk from LLW disposal within the boundaries of the Savannah River Site is further reduced by virtue of minimizing or eliminating activities and use of the closed disposal sites that could compromise the effectiveness of engineered barriers that are described in the RPA for both the E-Area and the Z-Area disposal facilities. These engineering barriers are designed to prevent intrusion within the waste by humans, plants, animals or infiltrating water. This report recommends that the SRS be designated as a National Environmental Research Park, thus retaining Federal ownership in perpetuity. The report also recommends that access by the general public to the General Separations Area (GSA), within which these disposal sites are located, be restricted and that the GSA itself be designated as suitable for industrial use only.

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A4. *Saltstone and EAV Composite Analysis Residual Radionuclide Inventory Report*, DCN: 5112-013-FD-BFQV, CDM Federal Programs Corporation, 1359 Silver Bluff Rd., Suite G-20, Aiken, SC (September 1996).

A compilation of the residual radionuclides projected for the various facilities located within the General Separations Area (GSA) at the SRS, which includes two separations facilities (F Area and H Area canyons) and waste management facilities (F Area HLW tank farm, H Area HLW tank farm, S Area HLW vitrification canyon, E Area LLW disposal site, Z Area saltstone disposal site and other facilities projected to contain minor quantities of residual radionuclides). Data in this report served as input data to establish potential interactions of contaminant releases from other facilities within the GSA with projected releases from the LLW disposal sites located in Z Area and E Area.

A5. *Composite Analysis, E-Area Vaults and Saltstone Disposal Facilities,* WSRC-RP-97-311, Rev. 0, Westinghouse Savannah River Company (September 1997).

The calculated maximum dose to a hypothetical member of the public located at the confluence of Upper Three Runs Creek with the Savannah River (the point of compliance for releases from the Z Area and E Area LLW vaults) is 1.8 mrem/yr. The calculated maximum dose at Four Mile Branch is 14 mrem/yr. These doses are based on projected releases from all potential sources within the GSA. Two closed LLW disposal facilities within the GSA, the Mixed Waste Management Facility and the Old Burial Grounds, are the major sources of the radioactive isotopes contributing to the calculated dose at the mouth of Four Mile Branch. Releases from the Z Area and the E Area LLW disposal sites are prevented from reaching Four Mile Branch by a groundwater divide that lies between the facilities and Four Mile Branch. The calculated maximum dose from all sources within the GSA is well below the DOE primary dose limit of 100 mrem/yr and also well within the dose constraint of 30 mrem/yr for any single source, practice or pathway.

A6. Letter, W. E. Kennedy, Jr., to Performance Assessment Peer Review Panel Members and Advisors, *Peer Review Panel Minutes - 3/23-24/93,* April 28, 1993 (1 page with 3 attachments).

att. i. Meeting Minutes Performance Assessment Peer Review Panel, Kansas City, Kansas, March 23-24, 1993 (11 pages).

att. ii. Letter (with comments attached), Stan Neuder to Bill Kennedy, Review Comments on the Savannah River Site Saltstone Facility, March 22, 1993 (6 pages).

att. iii. Member List, Performance Assessment Peer Review Panel, April 8, 1993 (3 pages).

Attachments i. and ii. contain comments generated from the review of the draft RPA final report by the Peer Review Panel and Advisors, listed in Attachment iii.

A7. Letter, James R. Cook and John R. Fowler to William E. Kennedy, Jr., *Summary of Information Developed for the Saltstone RPA (U),* SRT-WED-93-203, Westinghouse Savannah River Company, July 8, 1993 (10 pages with 4 attachments).

att. i. Models used to Estimate Release from Fractures (11 pages).

att. ii. Sensitivity/Uncertainty of Z-Area Radiological Performance Results with Respect to K_d

att. iii. Errata for Radiological Performance Assessment for the Z-Area saltstone Disposal Facility (U), WSRC-RP-92-1360, Rev. 0, 12/18/92 (8 pages with 6-page Attachment: Porflow-3 Input File Upper Moisture Barrier Simulation).

att. iv. Response to Request of Peer Review Panel for Additional Information on the SRS Saltstone RPA, 5/17/93 (24 pages with a 14-page attachment: Project Summary of Physical Properties Measurement Program, Core Laboratories Report DRES-92119, performed by Core Laboratories, Carrollton, Texas).

This letter and attachments are a compilation of responses to comments and additional supporting information provided to the PRP and DOE-HQ in support of the review of the Z-Area RPA report.

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A8. **Letter**, David W. Layton to William E. Kennedy, Jr., July 13, 1993 (with 5-page Enclosure: Review of Exposure Scenarios, Pathways, and Associated Doses for the Performance Assessment of the Z-Area Saltstone Disposal Facility dated July 1993).

The enclosure to this letter contains the final set of comments on the Saltstone RPA from David W. Layton, a member of the PRP.

A9. **Letter**, D. B. Amerine, WSRC to Clyde W. Terrell, DOE-SR, *Subject: Request DOE-HQ Request for Paper on Saltstone Disposal at SRS (u)*, **OPS-DTZ-94-0001**, Westinghouse Savannah River Company, February 18, 1994 (1 page with 11-page attachment: Basis for Saltstone Disposal Operations at the Savannah River Site).

At the request of EM-343, the technical, regulatory and cost basis for Saltstone disposal at the SRS is summarized. Similarities and differences relative to grout disposal at Hanford are compared.

A10. **DOE Memorandum**, Raymond P. Berube to Jill E. Lytle, *Subject: SRS Saltstone Performance Assessment and Implementing Order DOE 5820.2A at LLW Disposal Facilities*, March 25, 1994 (3 pages with 3-page enclosure: Review of PA for SRS Saltstone Disposal Facility).

The enclosure to this memorandum contains review comments on the Z-Area RPA from the Office of Environment, DOE-HQ (EH-20).

A11. **DOE Memorandum**, Raymond F. Pelletier to Joseph A. Coleman, *SRS Saltstone Performance Assessment*, September 20, 1994 (2 pages with 3 page attachment: Additional EH-23 Comments on the Savannah River Site (SRS) Saltstone Performance Assessment (PA)).

The attachment to this memorandum contains additional review comments on the Z-Area RPA from the Office of Environmental Guidance, DOE-HQ (EH-23).

A12. **Letter**, D. G. Thompson, WSRC, to M. S. Glenn, DOE-SR, Response to DOE-HQ Comments on Z-Area Performance Assessment (u), **OPS-DTZ-95-0001**, Westinghouse Savannah River Company, January 10, 1995.

WSRC response to DOE-SR to the comments in attachments to items A10. and A11. above.

A13. **DOE Memorandum**, Charles E. Anderson to Director, High Level Waste Division, Office of Waste Management, HQ, Headquarters Review of the "Radiological Performance Assessment (RPA) for the Z-Area Saltstone Disposal Facility," and Request for Additional Information, August 30, 1996 (1 page with 3 attachments).

att. i. Response to Questions from EM-35 for DOE-SR (3 pages).

att. ii. Support for Answer to Question 4 on "NORM" (1 page).

att. iii. **Letter**, Robert L. Gill, SCDHEC, to Larry C. Haney, WSRC, RE: Modified SRS Z-Area Saltstone Industrial Solid Waste Permit, # 025500-1603 (Formerly IWP-217), Aiken County (1 page with 8 page attachment: Industrial Solid Waste Permit # 025500-1603).

DOE-SR's response to questions from DOE-HQ on (1) the effect of the use of enhanced Naturally Occurring Radioactive Materials (NORM) in flyash and slag that is used in the production of saltstone, and (2) whether the groundwater standards includes or excludes existing radioactivity already present before contaminants from the landfill site enter the groundwater. The current operating permit for saltstone disposal describing groundwater monitoring requirements imposed by SCDHEC, which the site must follow as a condition of the operating permit, is included as part of this response (Attachment iii.).

A14. **Letter**, Howard B. Gnann, DOE-SR, to Rodney M. Satterfield, WSRC, Saltstone Disposal Facility Radiological Performance Assessment, June 6, 1997 (1 page with 2-page attachment: NORM Screening Calculation)

Request from DOE-SR to WSRC for additional supporting information and/or calculations from WSRC on the effect of enhanced NORM in Saltstone and its impact on long-term performance.

A15. **DOE Memorandum**, Roy J. Schepens to Mark W. Frei, *Additional Analysis in Support of the Saltstone Radiological Performance Assessment (Your Letter dated 5/16/97)*, June 18, 1997 (1 page with 2 attachments).

A16. **Letter**, R. M. Satterfield, WSRC, to H. B. Gnann, DOE-SR, *Contribution of NORM to Projected Dose from Saltstone (U)*, June 16, 1997.

A17. **Letter**, J. R. Fowler to R. M. Satterfield, *Screening of NORM Nuclides in Saltstone (U)*, **OPS-DTZ-97-0018**, Westinghouse Savannah River Company, June 13, 1997 (8 pages).

DOE-SR response to a DOE-HQ request for additional analysis to establish if NORM in saltstone is significant in the long-term performance and environmental impact for Z Area. Includes attachments provided by WSRC to DOE-SR in response to item 8. Based on screening calculations, long-term doses are controlled by radioactive contaminants in salt solution, not the dry materials. The contribution from NORM radioisotopes in dry materials is negligible.

A18. **E-mail Message**, Kirk Owens, SAIC, to John Fowler, WSRC, Saltstone Magic Reduction Factors, September 30, 1997 (1 page).

Request for clarification on the source of factors used in screening calculations to establish that the contribution of naturally occurring radium isotopes in NORM is negligible, as stated in Attachment ii. of 9. above.

A19. **E-mail Message**, John Fowler, WSRC, to Kirk Owens, SAIC, Re: Saltstone Magic Reduction Factors, October 1, 1997 (2 pages).

Response to request for clarification of factors used in the calculations shown in ~~10~~ A18. above.

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R0
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Battelle
Pacific Northwest Laboratories
Battelle Boulevard
P.O. Box 999
Richland, Washington 99352
Telephone (509) 375-3849

April 28, 1993

To: Performance Assessment Peer Review Panel Members and Advisors

From: W. E. Kennedy, Jr., Acting Chairman

PEER REVIEW PANEL MINUTES - 3/23-24/93

Attached are the minutes of the thirteenth meeting of the U.S. Department of Energy Performance Assessment (PA) Peer Review Panel.

Thank you for your participation in another excellent meeting. I believe that we conducted a thorough review of the final Savannah River Saltstone Facility PA and that our decision to proceed with a timely final review is well justified.

I have sent our requests for additional information to Elmer Wilhite with a copy to Joe Coleman, EM-35. The completion of our final review depends, in part, on satisfactory responses to our requests; however, please keep working on your final review so that we can bring this issue to a close.

As you know, we will meet in Savannah River to conduct a preliminary review of the E-Area Vaults PA and discuss our progress toward completion of the final Saltstone PA during the week of May 24, 1993.

Finally, I would like to thank each of you again for your contributions to the review of the completeness of the final Saltstone PA and I look forward to seeing you again in May.

Sincerely,

W. E. Kennedy, Jr.

W. E. Kennedy, Jr., Technical Group Leader
Occupational and Environmental Health Protection Section
HEALTH PHYSICS DEPARTMENT

WEK:caw

Attachment

Meeting Minutes
Performance Assessment Peer Review Panel
Kansas City, Kansas
March 23-24, 1993

This was the thirteenth meeting of the Department of Energy (DOE) Performance Assessment Peer Review Panel (PRP). F. W. Ross, Nuclear Regulatory Commission (NRC), J. M. Gruhlke, Environmental Protection Agency (EPA), D. J. Barnes, Environmental Restoration and Waste Management (EM), and J. A. Coleman, DOE Headquarters (HQ) point of contact, were unable to attend. S. M. Neuder, Battelle - DC Office, was also unable to attend. The attendees were:

W. E. Kennedy	Pacific Northwest Laboratory, Acting PRP Chairman
R. U. Curl	Radioactive Waste Technical Support Program, EG&G Idaho
R. L. Dodge	Nevada Test Site
W. R. Hansen	Los Alamos National Laboratory
D. W. Layton	Lawrence Livermore National Laboratory
D. W. Lee	Oak Ridge National Laboratory
S. J. Maheras	Idaho National Engineering Laboratory
K. W. Owens	Science Applications International Corporation (EM-351)
E. L. Wilhite	Savannah River Site
D. E. Wood	Chairman, Performance Assessment Task Team

Also in attendance were Jeff Perry, DOE Idaho Field Office (ID), Jim Cook, Savannah River Site (SRS), and Lisa McDowell-Boyer, Oak Ridge Grand Junction.

This meeting was held to conduct the completeness review of the final Savannah River Site Z-Area (Saltstone) performance assessment (PA). Prior to the meeting, Bill Kennedy, Jr. was elected acting PRP Chairman by the Panel members. Elmer Wilhite and Steve Maheras were disqualified from participating as Panel members due to their involvement in preparation of the Saltstone PA. Jim Cook and Lisa McDowell-Boyer were present to assist Elmer Wilhite and Steve Maheras in discussing the Saltstone PA and responding to the Panel's questions. Jeff Perry was invited to observe the meeting process in order to assist ID in its review of the Idaho National Engineering Laboratory final PA. Panel members discussed the PA, identified areas where additional information is needed, and provided detailed comments pertaining to the document. Following the completeness review, the Panel accepted the Saltstone PA for detailed final review with a request for SRS to provide specific additional information.

SRS Z-Area Completeness Review

Elmer Wilhite, Steve Maheras, and Lisa McDowell-Boyer remained out of the meeting until the Panel had an opportunity to discuss its initial thoughts. Bill Kennedy, Jr. opened the meeting by defining the process for a completeness review and asking the Panel their initial reaction to the Saltstone PA. The Panel felt there were no major flaws; however, there were a number of areas requiring clarification and concerns about presentation.

The Panel addressed Savannah River's response (Appendix G) to their comments from the preliminary review of the Saltstone PA. Preliminary review comments requiring SRS response started with comment No. 4.

4. The Panel's review suffered from the lack of completeness of the preliminary PA draft and the absence of "all pathway" results.

   Response satisfactory

5. The preliminary PA draft lacks synthesis and integration of the components into a fully-described and defendable PA.

   Response satisfactory

6. The PRP recommends a better analysis of seismic events and the potential impacts of stress cracking on waste form performance.

   Response satisfactory

7. The PA model selection was not well defined and the use of complex models was not justified.

   Response not satisfactory - SRS does not justify the use of more complex models. There is no rationale given for jumping directly into 3D. Why does SRS need to use complex models and how does the site data relate to them?

8. SRS should explore available data to ensure that the models that are selected and developed are representative of the site behavior.

   Response not satisfactory - Savannah River has expanded the text to include additional data, but they did not provide a clear evaluation of how the data was used or how it relates to the justification of the models selected.

9. By separating barrier (i.e. cap) from vault simulations, there is a potential difficulty of integration of the component results that makes an analysis of the total system difficult. Artificial and potentially contradictory boundary conditions seem to be imposed.

   Response not satisfactory - The coupling of the models to get system results is not well treated or justified. What happened to atmospheric coupling? The response concentrates on the components of the system and not on an integral system.

10. Transient rainfall-driven events (storms) are not well accounted for in the simulations.

    Response not satisfactory - There is no discussion of the effect or importance of transient rainfall events. If the uncertainty associated with transient events is too great to deal with now, Savannah River should slate these for consideration in future revisions of the PA.

11. The scenarios and results must be put into context in an interpretation section to ensure that proper risk management decisions can be made.

    Response satisfactory

12. The effect of the cover at site closure may elevate the water table. The consequences of this potential rise in the water table are appropriate to consider in the PA.

    Response not satisfactory - Mounding at site closure will cause the water table to raise. Although the facility does retard local recharge, it does not have a retarding effect on the regional water table. This is not well discussed and there is no justification provided for Savannah River's dismissal of the problem.

13. The effect of the bamboo cover on evapotranspiration and consequent desiccation of the cap or increased infiltration should be evaluated.

    Response satisfactory - However, bamboo is not a native species and may not be a climax species. Over time, it may go to a climax forest of oak. Does the 40 cm/yr infiltration case bound the analysis for a climax rain forest cover? More discussion is needed.

14. A plan for long-term, near-field monitoring during the control period, to confirm PA assumptions and data, should be presented.

    Response not satisfactory - Savannah River says they do not plan to conduct long-term, near-field monitoring. This response does not address the validation or verification of the models. While there are programmatic considerations to place the resources elsewhere, there needs to be some baseline monitoring in place to monitor the near-field performance of the facility.

15. Consideration of all disposal practices in the saltstone vaults, including the existing materials in vaults 1 and 4 should be included in the PA.

    Response satisfactory

16. The PRP supports expanded efforts to reevaluate the waste inventory in light of recent mission-related production changes at the Savannah River Site.

    Response satisfactory

The Panel began general discussion of the PA and identified 4 major issues to be discussed with the PA Preparers. Bill Kennedy reminded the Panel that this review is to center on big issues and detailed comments should be reserved for the detailed final review.

- The properties of the waste form and engineered system components seem to be unrealistic (Table 3.3.1)
- There is no program for long-term, near-field disposal facility monitoring to verify and validate the models.
- The dose analysis was done as an upper bound with no base case presented. This leads to confusion and could lead to the conclusion that the dose objectives have been exceeded.
- The response to the initial comments were not all adequate.

The preparers were asked in at this point. Bill Kennedy expressed appreciation for the completeness and thoroughness of the PA and the great amount of work performed in a short time. There was considerable discussion of the above 4 issues, which included discussion of the inadequate SRS responses to the Panel's comments on the preliminary Saltstone PA. This discussion resulted in the Panel's requesting Savannah River to provide five items of additional information, which are presented later in these minutes.

Elmer Wilhite discussed the Saltstone PA and noted several corrections to the text. He also passed out supplemental information for the Panel's consideration. He noted that the uncertainty analysis for Kd was omitted and will be included in a future revision.

Next, the Panel reviewed the PA section by section to identify issues or concerns. The comments Stan Neuder provided before the meeting are attached.

- Executive Summary - There are a number of general modifiers that lead to ambiguity. The summary is not well written.
- Introduction - The neutralized aqueous recycle mentioned in Figure 1.2.1 is not mentioned in the text.

PAGE NO.	
1-8	The interpretation of the performance objective for protection of groundwater is in response to state, not DOE, requirements.
1-9	There are three EPA standards cited that are not consistent.
2-1	Second paragraph, last sentence, "(chemical, radiochemical)" should be removed. It is confusing.
2-3	Section 2.2.1 and the chart on page 2-5 do not appear to be consistent. Perhaps demography should be removed.

2-40 The phrases "the 1978 reactor production forecast and the projected production mix for the years 1988-1990" seem strange since they have already occurred. Also, how were the uranium, plutonium, and mixed fission product inventories developed.

2-52 There are a lot of subjective modifiers used that are not quantifiable. This is a general concern.

2-66 There needs to be a date associated with Table 2.6-2. What point in time is the zero timeframe and to when is it projected?

2-75 The conductivity values used in Table 2.7-1 are not consistent with section 3. This table should not be here.

3-7 The term "slumping" in cover degradation is not realistic. Is the soil erosion rate consistent with the SRS site?

3-9 The last paragraph should not be in the document. There will be very little sulfate attack of the waste form.

3-10 How does the 10,000 year timeframe relate to calculations to peak dose? There is no discussion of the timeframe used.

3-15 Justify the remark "saltstone degradation."

3-16 Figures 3.1-6 and 3.1-7 have no label on the Z axis. Also, the differences in shading are not meaningful.

3-18 The .005 cm cracks are micro. Are they significant and will they grow over time?

3-19 There should be some discussion justifying the use of an immersion leach rate.

3-20 The discussion of TCLP testing is omitted here. Table 3.1-1 concentration limits are derived and there should be a discussion of what they are and what they mean.

3-29 Biointrusion is not important for the intruder, but is it important for the offsite all-pathways? There is no discussion or justification.

3-33 There is more current thinking on the Baes and Sharp equation presented in 1990 by Sheppard.

3-35 Rain splash is not considered. Should it be, in this application?

3-43 Where is the well? It is critical but not defined. The degradation of the facility and closure cap is not treated the same in the all-pathways and intruder scenarios. There should be some discussion of what the results mean and why the different degradation scenarios were used.

3-42 More text is needed to explaining the agriculture scenario assumptions. SRS needs to justify the scenarios not included.

3-48 Drilling is excluded from saltstone due to the hardness of the drill bit, but the hardness of the concrete or saltstone is not specified.

3-58 The assumption that escaping contaminants do not escape upward needs more justification, especially with a bamboo cover.

3-59 The statement that solubility considerations are not explicitly addressed is highly conservative, especially for tin.

3-61 How does the fractured monolith get integrated with PORFLOW-3D? The integration should be fully and completely discussed (integration of intact and degraded models).

3-63 The assumption, in section 3.3.2.1, that natural conditions preclude the deeper migration of contaminants holds true if the geology is regionally extensive. There needs to be more discussion of this point.

A number of assumptions are made in section 3.3.2.3 with no support. Perhaps some of the Appendix A discussion should be here.

3-64 The three zones for the groundwater model are considered homogeneous, when earlier the zones were considered heterogeneous. How do you get from the heterogeneous to the homogeneous regime?

The statement that recharge under the facility is estimated to be 0.2 cm/year from near-field analysis should be removed since it is discussed in detail later.

3-65 The longitudinal dispersivity given in Table 3.3-3 needs to be set at zero.

3-77 There is an apparent conflict between the last paragraphs of pages 3-77 and 3-63. A figure should be added and the two paragraphs in question should be more clearly written.

3-85 The term "annual dose" is not consistent with "committed effective dose". The author should define the term as "committed effective dose equivalent for one year" and be consistent throughout the document.

4-2 The clay/gravel drain system which overlies the vaults is assumed to work forever. It will not. There needs to be a strong justification if this assumption is retained. There should also be a failure scenario calculated to determine the importance of the drain system. Its continued function may or may not be

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1/31/05

important. Sensitivity analysis says it is not important for the intact case, but the degraded case is not addressed.

4-5 There is an error in the tritium values in Table 4.~~2~~4-3. There are a number of other errors throughout the document. There needs to be an errata sheet given to the Panel for final review.

The flux values for the two cases are very close but not the same. They should be the same since, in each case, 2 cm/year passes through the saltstone.

4-33 There is a statement that "The reference run does not include the clay/gravel drain over the vaults", however; there is no presentation of this run or the data from it.

4-34 The text in the third paragraph on page 4-33 does not agree with Table 4.2-2 on page 3-34.

5-3 The third paragraph statement about "over design" may not be over design if the drain field deteriorates.

A-61 There needs to be an explanation of why "weeks" was selected for clearance class for Pu-238, Pu-239, and Am-241, in Table A.4-3. Years appears more appropriate.

B-19 The use of the Picard method can be a weakness. Most modelers now use the NEK method.

This completed the section by section review. At this point the Panel excused the Savannah River support personnel and deliberated on the path forward. Elmer Wilhite and Steve Maheras remained as resources to the Panel, but were precluded from exercising their opinions or affecting the Panel's decisions.

The Panel once again discussed the major issues and noted that there were no fatal flaws in the PA. However, there are a number of minor comments that need resolution. After considerable discussion, the Panel voted to accept the PA for final detailed review with a request to Savannah River for additional information. The requested additional information is:

- Explain the long-term viability of the clay/gravel drainage layers incorporated into the closure cap. Specifically:
    1. Provide justification that clay layers can be constructed with an in-place hydraulic conductivity of 10^{-9} cm/second.
    2. Provide justification for the 0.5 cm/second gravel layer.
    3. Provide an analysis of how long the clay/gravel layers will remain operative and what their conductivities will be after they degrade.

4. How much water infiltrates to the waste vaults when the drainage layers degrade?

5. What is the sensitivity of the source term to the increased/decreased water infiltration rate that occurs when the drainage layers degrade?

6. What effect does the degradation of the drainage layers have on the system performance?

- Expand the sensitivity analysis to include degradation of saltstone and concrete hydraulic conductivities for long-term conditions. This would apply to the fractured concrete and flow through the bulk unfractured saltstone blocks. The suggested increase in conductivity is several orders of magnitude.

- Provide data to support the hydraulic properties of the clay, concrete, and saltstone as identified in the PA. Provide a description of and justification for the long-term behavior of these properties and the effect they might have on the performance of the disposal facility.

- The chemical form of technetium affects its transport in the environment and its bioavailability. These parameters, in turn, directly affect potential human exposure and radiation doses. To further analyze the dose assessment for Tc, the PRP requests that additional analyses/information be provided on the following:

  1. The likely chemical form of Tc, based on measurements and/or geochemical modeling, and the associated solubilities in water, along with any available soil-water partitioning data.

  2. A review of the plant-uptake studies reported in the literature (including those published after the cited reviews) and the chemical forms of Tc used in these studies.

  3. An analysis of the basis of the dose conversion factor for Tc, with particular reference to the technical basis for the gut uptake factor used to determine the dose conversion factor. If the uptake factor is based on a soluble form of Tc, please determine whether data are available in the literature that could be used to estimate or infer the gut uptake factor for insoluble species and, if such data are available, derive an estimate for insoluble TC.

  4. An estimate of the amount of Tc on crops derived from rain splash, using available studies.

- In the area of validation and verification of model results, the Panel requests:

  1. Supplemental information that outlines and describes current efforts to compare modeling assumptions or results with field data
  2. A description of near-field monitoring programs or validation exercises that may provide data to confirm PA assumptions and results (TDR probes and suction lysimeters).

The requested information is to be provided to the Panel for inclusion in their final review. However, the detailed review will be undertaken without awaiting the data. Bill Kennedy, Jr. assigned each Panel member areas of responsibility for conducting the detailed review, as follows:

• Bob Dodge	Behavior of closure cap and engineered systems
• Wayne Hansen	Scenarios, pathways, dose, and inventory and source term
• Bill Kennedy, Jr.	Scenarios, pathways, dose, and concrete
• Dave Layton Don Lee	Scenarios, pathways, and dose
• Don Lee	Groundwater
• Stan Neuder	General integration
• All	General review and comment

Bill Kennedy will prepare a letter to Elmer Wilhite (cc: to Joe Coleman and Greg Duggan) identifying the request for additional information and that the Panel is proceeding with the final review.

Bill asked the Panel if they wished to meet for a day during the SRS E-Area Vault PA preliminary review to status their progress with the Saltstone detailed review and the SRS response to the information request. The Panel agreed that it would be a good idea. The next meeting will be May 25-27, 1993, in Augusta, Georgia. May 25 will be devoted to the Saltstone status review.

PRP Business Meeting

The Panel held its business meeting Tuesday evening, May 23, 1993. Elmer Wilhite opened the meeting by passing out the current PA review schedule (this is the same schedule that was attached to the Nevada Test Site Area-5 PA minutes). He asked the Panel's opinion about having representatives from other sites in attendance. The Panel felt it is acceptable, but not for the final review.

Prior to the meeting, Greg Duggan asked Elmer Wilhite to mention the need for FY 1993 funding additions and budget projections for FYs 1994 and 1995. The Panel felt the 1993 funding is adequate. Since the Panel will be doing more final reviews and more time and matrix resources will be required, the FY 1994 and 1995 budget should be 20% over 1993.

Elmer mentioned that Greg Duggan also asked if the PRP should consider the Nevada Test Site Greater Confinement Disposal (GCD) PA. The GCD performance assessment is being done to justify near-surface disposal of Greater-Than-Class C like waste (TRU over 100 nci/g).

The Panel believed they could do the review, but DOE-HQ needs to provide direction to the Panel to perform the review as an exception to its charter under DOE Order 5820.2A. If the Panel were to review the PA, they would require the same level of analysis as for low-level PAs. Elmer felt that before giving a response to Greg Duggan, he needs more information about what DOE expects.

The next PA is the preliminary PA for the SRS E-Area Vaults. The PA will be sent to the Panel on April 12, 1993. The review is scheduled for May 26-27, 1993, in Augusta, Georgia.

Elmer noted that DOE-HQ is in the process of requesting comments on the Performance Assessment Task Team's (PATT) closed issues as reported in the September 1992 PATT progress report. Elmer asked the Panel to review the document and provide all comments to him. He will merge the comments, send them back to the Panel for review, and transmit them to Greg Duggan.

Elmer asked the Panel its feelings about conducting a Fall workshop. The Panel felt there is no time or energy for one at the present time. However, there could be a session in the DOE Low-Level Waste Conference devoted to PA lessons learned from Panel reviews. There could also be a joint PRP/PATT meeting to discuss comments on the PATT closed issues and the 5820.2A revision progress.

The Panel would still like to have all its review comments consolidated and grouped by category. Robert Curl will look into having this done.

Summary of Action Items

- Panel members will initiate the detailed final review of the SRS Z-Area (Saltstone) PA, concentrating on the areas assigned them.
- ~~Bill~~ Kennedy, Jr. will prepare a letter to Elmer Wilhite (cc: to Joe Coleman and Greg Duggan) identifying the Panel's request for additional information and that the Panel is proceeding with the final review.
- Panel members are to review the closed issues contained in the September 1993 PATT Progress Report, DOE/LLW-157, and provide comments to Elmer Wilhite.

- Elmer Wilhite will consolidate the Panel's comments on the PATT closed issues and transmit them to Greg Duggan, EM-351.
- Elmer Wilhite will send Panel members a copy of the SRS E-Area Vault PA by April 12, 1993.
- Robert Curl will look into having the Panel's comments from prior PA reviews consolidated into one document.

<u>Post Meeting Notices</u>

- None

Attachments:

Comments from Stan Neuder

Peer Review Panel member list

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TO: Bill Kennedy, Acting Chairman
Peer Review Panel

FROM: Stan Neuder, Reviewer
Peer Review Panel

SUBJECT: Review Comments on the Savannah River Site
Saltstone Facility

Battelle

Pacific Northwest Laboratories
P.O. Box 999
Richland, Washington U.S.A. 99352
Telephone (509)

Bill-

I have found no major flaws with the SRS Saltstone PA document. My review comments are of a nature that would require relatively minor fix-ups. The documentation is well-written and fairly complete in all categories. My recommendation is for the preparers to move into the draft final stages.

Stan Neuder

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Pg. xxii Indicate the period of time over which the radionuclide concentrations and nitrate concentrations are calculated.

Pg. 1-9 Cite EPA reference for proposed revisions of the drinking water standards for radionuclides.

Pg. 2-4 The E-Area and the Hazardous Waste/Mixed Waste Disposal Facility should be shown on the facilities map of the SRS. Are they sufficiently far apart to be considered separate facilities? No

Pg. 2-9 The potential impacts of an MMI of VII at the Z-Area, with a recurrence interval of about 1,000 years, is not fully discussed in paragraph 2.1.4.3. The historic high water table at Z-Area is 5 feet so that the liquifaction potential may not be low. Dismissing these potential impacts requires further justification.

Pg. 2-13 Zones 2 and 3 and Zones 5 and 6 are identified as the important sources of water. (Pg 2-13). Pg 2-30 states that groundwater in zones 5 through 8 are not pumped from Z-Area. Section A.2.1.2. (Pg. A-39) identifies zones 6,7,8, and 5/6 as the units included in the groundwater conceptual model. Appendix E discusses the hydrology of Z-Area in great detail. It is not clear which hydrologic units, and why those units, are most important for dose considerations. Doses would likely depend on which aquifer is supplying the water. Clarify which aquifers are used for which scenarios and whether radionuclide concentrations differ in the different zones. Also discuss whether doses are calculated at the times of peak radionuclide concentrations in the various hydrologic zones.

Pg. 2-13 Discuss the long-term behavior and ultimate disposition of Par Pond, and the potential impact, if any, on Z-Area.

Pg. 2-27 There are several conflicting statements in the text regarding the distance to the water table in Zone 8. Text states that under Z-Area, the minimum depth to the water table from the ground surface is estimated to be 13 meters. "This minimum depth...corresponds to the historic high water table." Text (P. 2-9) states that "At Z-Area, the water table occurs at no less than 2.3 meters..." Text (P. 2-58) states that "The bottom of the saltstone monoliths will be at least 8 meters above the historic high water table..." Fig. 2.7-1 (P. 2-72) indicates 5 feet from the vault to the historic high water table. Discuss the possibility for the water table to reach the vaults and the potential impact of such an event.

Pg. 2-32 As with a previous question regarding clarification on the use of various aquifers in the pathway analysis and their peak concentrations at various times, provide a similar classification for the surface waters of nearby creeks.

Pg. 2-32	Explain the fluctuations of radiological constituents in groundwater wells, and how these fluctuations are factored into the dose calculations.
Chpt. 2-4	Although there is some discussion of temperature controls (thermal limit of 90 degrees celsius), the issue of proper curing and stability of saltstone when radioactive heat production is present should be clearly addressed.
Pg. 2-52	Several statements in the text such as "...leaching of chromium and technetium was <u>effectively</u> reduced" (p. 2-52) and, "...insoluble species that <u>are not readily leached</u> from the saltstone..." (p. 2-58), and "These less soluble forms <u>effectively fix</u> these contaminants..." (P. 2-58) would benefit from some degree of quantification.
Pg. 2-64	Justify the choice of a radionuclide inventory cut-off of 10^{-15} Ci/L. Relate this number to dose or drinking water concentration limits.
Pg. 2-66	The repetition of specific numbers in Table 2.6-2 seems to indicate an estimation and round-off procedure used to quantify the radionuclide inventory. For example, in the Ci/L column, the numbers 8.9 and 2.7 appear in about 20% of the entries. Explain. Also, discuss uncertainties.
Pg. 2-71	Discuss the origin of perched water above the vaults.
Pg. 2-71	Describe the assumed lifecycle of the revegetative bamboo and whether the bamboo remains in place during the post-closure and institutional control period. (According to Pg. 3-7, all bamboo is cleared after 100 years?) If bamboo cleared, discuss the impact of increased infiltration.
Pg. 2-72	According to the diagram, the gravel drainage ditches are not lined and so would allow a considerable amount of water to seep through the sides and bottom areas and infiltrate the backfill soil around the vaults.
Pg. 3-3	The reference to "Sect. 1.2", in the fourth paragraph, should be changed to Sect. 1.3.
Pg. 3-6	Assuming equation 3.1 to be a vector equation, the vector notation appears faulty.

Pg. 3-7	Justify the statement (paraphrased here) that the net flux through the degraded cover area would approach the limiting value of 40 cm/yr. It seems that the backfilled media would be more porous than the surrounding undisturbed soils so that infiltration would exceed 40 cm/yr.
Pg. 3-7	Change reference to "Sect. 2.1.7" to Sect. 2.1.8.
Pg. 3-15	Justify the statement that "The bulk of the saltstone is expected to last...in excess of 10,000 years."
Pg. 3-18	The one bullet that appears <u>not</u> to be conservative is that "the crack spacing is 3m." Perhaps observations of the saltstone vault no. 4 can confirm this assumption.
Pg. 3-25	Pathway 14 description is unclear as to whether wind erosion is or is not the cause of the resuspension.
Pg. 3-25	The pathway--resuspension of contaminated soil from irrigation--does not appear to be included in the list of pathways. The sixth bullet on pg. 3-31 does describe this pathway. Perhaps some of the descriptions in list of 47 the pathway are incomplete.
Pg. 3-27	The pathway, biosintrusion -resusupension- <u>offsite</u> inhalation, does not seem to be included. (perhaps in pathway 43?)
Pg. 3-30	The significance of pathway no. 14 (p. 3-25) doesn't seem to be addressed in the discussions of section 3.2.2.2. It is not included in the four pathways of consequence. (P. 3-30)
Pg. 3-36	The Kd values listed on P. 3-35 are described as "do not necessarily apply to the SRS but are expected to be reasonably represented." This statement does not provide the reader with much comfort in the selected values. Justify/quantify the "reasonableness" of these numbers.
P. 3-40	Explain the difference between this equation and the equation on p. A-21. Provide a reference for these equations.

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April 8, 1993

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SRT-WED-93-203

July 8, 1993

William E. Kennedy, Jr.
Technical Group Leader
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P.O. Box 999 MS: K3-54
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Dear Mr. Kennedy:

SUMMARY OF INFORMATION DEVELOPED FOR THE SALTSTONE RPA (U)

During the Peer Review Panel (PRP) meeting on May 25, 1993, you requested that SRS prepare a summary that integrates and interprets the additional information that SRS has developed for the Saltstone Radiological Performance Assessment (RPA) with the information contained in the RPA. The requested summary follows; it indicates that the summarized documentation provides reasonable assurance that the Saltstone Disposal Facility will comply with the performance objectives of DOE Order 5820.2A.

We acknowledge the efforts of Laura McDowell-Boyer and Elmer Wilhite in preparing the summary.

If you have questions, or if we can help further, please call.

Sincerely,

James R. Cook
Principal Geologist
803-725-5802

John R. Fowler
Fellow Scientist
803-557-2293

Att.

CC: Peer Review Panel Members and Advisors
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Introduction

The Peer Review Panel (PRP), in its meeting on May 25, 1993, requested SRS to provide a summary that integrates and interprets the results presented in the Saltstone Radiological Performance Assessment (WSRC-RP-92-1360, Rev. 0, 12/18/92) and those presented in subsequent information developed to aid the PRP's review. The subsequent information is:

1. *Models Used to Estimate Release from Fractures.*

   An expanded discussion of the methodology used to analyze releases from fractures in the RPA.

2. *Sensitivity/Uncertainty of Z-Area Radiological Performance Results with Respect to K_d.*

   An analysis of the sensitivity and uncertainty of the RPA results as a function of K_d; this analysis was not done for the RPA.

3. *Errata for Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility (U), WSRC-RP-92-1360, Rev. 0, 12/18/92.*

   A listing of typographical and other errors, and their corrections, in the RPA.

4. *Response to Request of Peer Review Panel for Additional Information on the SRS Saltstone PA, 5/17/93.*

   Information developed in response to questions from the PRP at their 3/23/93 meeting.

We have attached each of these items. Items 1 and 2 were distributed to the PRP during their meeting on March 23, 1993. Items 3 and 4 were distributed to the Panel on May 17, 1993.

Summary

Results of the Saltstone Radiological Performance Assessment (RPA), revised in accordance with the information presented in items 1 through 4, are shown in Table 1. The results for the intact saltstone/vault scenarios in Table 1 are the same as those in the RPA (Table 5.1-1 on page 5-2). Results for the degraded saltstone/vault scenarios have been revised based on information presented in item 4. The revision to the inadvertent intruder dose reflects a different plant-to-soil concentration ratio for Tc-99 (part 4 of item 4); the

revision of the dose from groundwater reflects an increase in the hydraulic conductivity of clay overlying the vaults (from 7.6×10^{-9} cm/s to 10^{-7} cm/s), and in hydraulic conductivity of saltstone and concrete (part 1 of item 4).

The results in Table 1 are clearly in compliance with the performance objectives of DOE Order 5820.2A. We believe that these results, and sensitivity studies discussed below, provide reasonable assurance that the Saltstone Disposal Facility (SDF) at the Savannah River Site will meet the performance objectives of DOE Order 5820.2A, for radionuclides.

For nitrate, the results for the degraded saltstone/vault analysis in the RPA indicate a peak groundwater concentration of 53 mg/L, when corrected according to the errata (item 3), compared to a performance objective of 45 mg/L. This value does not reflect an increase in the clay conductivity over that used in the RPA. Increasing the conductivity of clay overlying the vaults increases the peak groundwater concentration of radionuclides by a factor of about 13 (Table 2 of item 4). A similar increase is expected for nitrate. This increase can be attributed to the increased flow through the fractures predicted by the fracture flow analysis (Table 1 of item 4). Therefore, improvements in the closure concept to reduce the amount of water available for infiltration through fractures, and improvements in the overly conservative method of predicting flow through fractures, are warranted and are expected to reduce the calculated concentrations of contaminants in groundwater (RPA, pp. 2-60, 2-61, and 3-61).

Performance assessment for nitrate, or other chemicals, is not required under DOE Order 5820.2A. However, the Saltstone Disposal Facility is permitted as an industrial solid waste landfill with the State of South Carolina. Under this permit, potential nitrate concentrations in groundwater are of concern. Thus, continued development of the performance assessment will be necessary to show compliance for nitrate.

DISCUSSION

In the Saltstone Disposal Facility Radiological Performance Assessment, doses resulting from activities of inadvertent intruders and chronic ingestion of contaminated groundwater were estimated. The purpose of the following discussion is to: 1) discuss the RPA results in terms of additional information obtained since the RPA was presented to the Peer Review Panel, and in doing so, clarify exposure and degradation scenarios developed in the RPA; 2) discuss the implications of these updated results in terms of compliance with performance objectives; and 3) briefly discuss needs for further research and data collection to continue the RPA process.

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In the RPA, exposure analyses for inadvertent intruders and consumption of contaminated groundwater considered both intact and degraded engineered barriers (moisture barriers and saltstone/vaults). Degradation of barriers is treated differently for the inadvertent intruder and the groundwater analyses.

Degradation of the upper moisture barrier in the groundwater analysis in the RPA was simulated by using the normal infiltration rate of 40 cm/yr. (i.e., by assuming the barrier was not present). Degradation of the lower moisture barrier was not considered in the RPA; degradation of this barrier was assessed in part 1 of item 4 by assigning the hydraulic properties of backfill soil to the barrier (i.e., by assuming the barrier was not present). For the intruder analysis, the moisture barriers were not considered. In the intact saltstone/vault case, this provides a conservative upper bound. In the degraded saltstone/vault case, because of the very long time required for degradation of the concrete vaults and saltstone, it was judged reasonable to assume that erosion would have removed the moisture barriers.

In the groundwater analysis in the RPA, degradation of saltstone and vaults considered fracturing of the concrete materials, as this was considered the most likely and earliest form of degradation to potentially take place, and the groundwater analysis was very sensitive to the presence of cracks or fractures. In part 2 of item 4, a different form of degradation was simulated by increasing the hydraulic and diffusive properties of concrete and saltstone. For the intruder analysis, the presence of cracks or fractures in the saltstone/vaults would have little, if any, impact on the ability of the saltstone/vaults to deter an intruder. Therefore, the degraded case for inadvertent intruders considered the loss of physical integrity of the vaults and saltstone, which is estimated to occur very long after fracturing initially occurs.

1. Inadvertent Intruders

In considering doses to an inadvertent intruder, two cases were analyzed. In the intact case, the concrete vaults are assumed to serve as viable barriers to intrusion. In the degraded case, after several thousands of years, the concrete vaults and saltstone are assumed to have become largely indistinguishable from soil; thus, intrusion into the waste is possible. Each case is discussed below.

1.1 Intact Case

For the inadvertent intruder, the massive presence of the saltstone/vault, with properties very different from soil, is assumed to effectively deter intrusion into the waste. This assumption is based on the fact that excavation and well-drilling techniques employed in the SRS vicinity presume that sandy-clay soil will be encountered, rather than some harder material (RPA, pp. 3-41, 3-48 and A-58). Thus, encountering harder material would result in the activity (well drilling or basement excavation) being relocated. However, contaminants will migrate from saltstone to the surrounding soil, where they could be contacted by an intruder. In this case, two scenarios were assessed; an alternative agricultural scenario involving excavation of contaminated soil above the saltstone vaults (RPA, pp. 4-19 to 4-21) and a residential scenario where the intruder is assumed to reside in a home located immediately on top of the concrete roof of an intact vault (RPA, p. 4-21). In both of these scenarios, the dose calculation was done assuming only 100 years of decay. Therefore, no credit was taken for the presence of the upper moisture barrier to deter intrusion. These scenarios are intended to be "worst case" scenarios to illustrate the very low doses expected. In the RPA, the dose from the agriculture scenario is about 10^{-5} mrem/year (RPA, p. 4-21), while that from the resident scenario is 0.6 mrem/year (RPA, p. 4-24). None of the information developed in items 1 through 4 has impacted the results from the analysis of this scenario. Thus, the result of 0.6 mrem/year presented in Table 1 is unchanged from that presented in the RPA in Table 5.1-1 on page 5-2 and Table 4.1-13 on page 4-24.

1.2 Degraded Case

Resident and agriculture scenarios were also analyzed for the degraded case, where it is assumed that the concrete and saltstone have become largely indistinguishable from soil. In these scenarios, because of the considerable time required for degradation of the concrete and saltstone, it is assumed that the moisture barriers have eroded to expose the vaults. The dose from the resident scenario is not affected by the information developed in items 1 - 4; thus, the dose from this scenario is 10 - 70 mrem/year (RPA, Table 4.1-15, p. 4-27). However, the dose from the agriculture scenario depends significantly on the dose from Tc-99; and, as indicated in the response to the PRP's question 4 (item 4, p. 18), the analysis of technetium uptake by plants in the RPA (RPA, pp. 4-47 and A-69) is now believed to be unnecessarily conservative. Using the more reasonable value of the plant-

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to-soil concentration ratio for technetium from saltstone, the dose from technetium in the degraded case for the agriculture scenario becomes 5 mrem/year instead of 40 (RPA, Table 4.1-11 on p. 4-20). Thus, the dose from all radionuclides in the agriculture scenario becomes 16 to 76 mrem/year, and this value is presented in Table 1. The dose range computed in these scenarios results from the uncertainty in the amount of shielding that should be considered in estimating the dose from ^{126}Sn. The larger values presented above reflect the assumption of no shielding (an upper bound); the smaller values reflect the assumption of 30 cm of soil as shielding (a more reasonable estimate).

2. Groundwater

Scenarios for both intact and degraded engineered barriers were analyzed in the RPA (RPA, p. 3-19) to assess their effect on groundwater contamination. As discussed in the RPA (RPA, p. 3-38), the performance objective of 4 mrem/year for drinking water is more restrictive than the 25 mrem/year all pathways performance objective. Thus, only doses from direct consumption of 2 liters of groundwater per day are discussed further.

2.1 Moisture Barrier Degradation

Degradation of the upper moisture barrier (cover) was represented in the RPA by analyzing two infiltration rates for both intact and degraded saltstone and vaults; an infiltration rate representing an intact upper barrier (2 cm/yr.), and an infiltration rate representing a completely degraded upper moisture barrier (40 cm/yr.). However, degradation of the lower clay/gravel drain was not analyzed in the RPA (RPA, p. 3-7). In response to a PRP request, additional information was developed addressing the impact of: 1) a higher hydraulic conductivity for the clay layer in both moisture barriers; and 2) degradation of the lower clay/gravel drain (part 1 of item 4).

The effect of assigning a value of 1×10^{-7} cm/sec to the hydraulic conductivity of clay in the upper moisture barrier, rather than the value of 7.6×10^{-9} cm/sec that was used in the RPA, is to increase the average infiltration through the upper barrier by a factor of 2 (from 2 cm/year to 4 cm/year, see item 4, p. 3). This increase in infiltration is insignificant in the analysis of both intact and degraded saltstone and vault scenarios and is bounded by the analysis of a totally degraded upper moisture barrier that results in an infiltration rate of 40 cm/year.

The effect of assigning a value of 1×10^{-7} cm/sec to the hydraulic conductivity of clay in the lower clay/gravel drain, rather than the value of 7.6×10^{-9} cm/sec that was used in the RPA, is insignificant for the intact scenario (item 4, p. 4). However, as discussed below, it is significant for the degraded (fractured) scenario. Similarly, degradation of the lower clay/gravel drain (simulated by assigning a value of 1×10^{-5} cm/sec to the hydraulic conductivity) does not affect the intact scenario, but does affect the degraded (fractured) scenario.

2.2 Intact Saltstone/Vault Scenario

In the intact case presented in the RPA, the hydraulic conductivities of the concrete vault and saltstone were assigned values of 1×10^{-10} cm/sec and 1×10^{-11} cm/sec, respectively (RPA, Table 3.3-1, p. 3-60). These values are supported by recent data obtained from Core Laboratories (item 4, p. 13). The source term from the intact saltstone/vault scenario is insensitive to infiltration rate because the low hydraulic conductivities of the concrete vault and saltstone limit water flux through the vault to much less than the infiltration rate (item 4, p. 4). Thus, the dose from the intact scenario presented in Table 1 is the same as that presented in the RPA (RPA, Table 5.1-1 on page 5-2).

2.3 Degraded Saltstone/Vault Scenario

In the RPA, degradation of the concrete vault and saltstone was assessed (RPA, pp. 3-7 to 3-19); it was concluded that the most likely, and earliest, degradation mode is development of cracks. Thus, degradation of the vault and saltstone in the RPA was treated by analyzing flow of water from overlying material into cracks, and migration of contaminants through saltstone to the cracks (RPA, pp. 3-59 to 3-61, and item 1).

The analysis of release from fractured saltstone and vaults is very conservative. Each of the vaults is assumed to develop cracks simultaneously at closure. Cracks in every vault are assumed to be spaced only three meters apart. All cracks are assumed to fully penetrate the vault and saltstone. Self-healing mechanisms such as carbonation or infiltration of soil fines are not considered (RPA, p. 3-18). Additionally, as pointed out in the RPA (RPA, pp. 3-59 to 3-61, p. 4-40, p. 5-4, and p. A-26), the methodology available at this time to analyze the performance of fractured saltstone/vaults incorporates multiple conservatisms; thus,

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when improved methodology is available, it is expected to show lower concentrations of contaminants in groundwater from fractured saltstone/vaults.

The effect of the hydraulic conductivity of clay in the lower clay/gravel drain on the fractured saltstone/vault scenario was investigated in item 4. Using a more realistic value of $1\text{x}10^{-7}$ cm/sec rather than the RPA value of $7.6\text{x}10^{-9}$ cm/sec results in a peak dose of 0.6 mrem/year (item 4, p. 8, assuming that the doses from ^{79}Se and ^{129}I are additive, because they are calculated to occur at similar times) compared to the RPA value of 0.03 mrem/year (RPA, p. 5-2). Thus, the result for the degraded saltstone/vault scenario in Table 1 is 0.6 mrem/year.

The sensitivity of the fracture scenario to the hydraulic conductivity of clay in the lower clay/gravel drain was tested by assigning a value of $1\text{x}10^{-5}$ cm/sec (typical of backfill soil) to simulate the total failure of the drain (item 4, page 8). The resultant dose from this sensitivity run was 80 mrem/year. Rather than indicating non-compliance, this run illustrates the necessity of designing the closure to mitigate migration from cracks. As discussed below, development of a detailed closure design is required.

2.4 Sensitivity of Results to Hydraulic Conductivities of Saltstone and Vaults

In part 2 of item 4, the sensitivity of the intact scenario to changes in concrete and saltstone hydraulic conductivity and effective diffusivity was assessed. The results (item 4, p. 12) show that with the hydraulic conductivity of the concrete and saltstone assigned a value of $1\text{x}10^{-8}$ cm/sec and the effective diffusivity assigned a value of $1\text{x}10^{-7}$ cm^2/sec, the maximum dose is 0.1 mrem/year compared to 0.001 mrem/year in the intact scenario. This result demonstrates that the hydraulic and diffusion properties of concrete and saltstone are less important in assessing performance than is consideration of fractures, according to the presently very conservative fractured saltstone/vaults scenario and conservative fracture analysis methodology.

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3. Comparison of Updated Results to Performance Objectives

The results from the SDF RPA were compared to performance objectives in Sect. 5.1 of the submitted report. The comparison indicated, we believe, that the results provide reasonable assurance that the SDF complies with all of the performance objectives in DOE Order 5820.2A. The information provided in the attached items does not change that conclusion, but strengthens it by more clearly defining the sensitive parameters in the supporting analyses

Table 1 provides a comparison of the results incorporating the additional information provided in items 1 through 4 to the relevant performance objectives. The revised dose estimates incorporate a higher hydraulic conductivity of clay, degraded concrete and saltstone properties, and a lower plant-to-soil concentration ratio for Tc-99. The additional sensitivity analyses that were conducted (parts 1 and 2 of item 4) on the degradation of the engineered features of the SDF indicate that fractures are a potential concern for the facility performance, but that control of water flow to and through fractures will alleviate the concern.

4. Data and Research Needs

In our view, the data developed in the RPA and in items 1 through 4 provide reasonable assurance that the Saltstone Disposal Facility will meet the performance objectives of DOE Order 5820.2A; however, additional work on the RPA is needed.

As stated in the RPA (RPA, pp. 5-3 to 5-5), development of a detailed closure design must be completed to provide assurance that the closure assessed in the RPA can be constructed. Also, improvement in the methodology used to assess the fractured vault/saltstone scenario is needed to reduce conservatism in the RPA and to provide reasonable assurance of compliance for nitrate.

In item 4 (item 4, p. 24), it is acknowledged that technology for near-field measurements must be developed so that environmental monitoring at the Saltstone Disposal Facility will provide data for validating the models used in the RPA.

Table 1. Summary of Revised RPA Results Compared with Performance Objectives

Inadvertent Intruder (chronic exposure)

Performance Objective: 100 mrem/yr.

Intact Saltstone/Vault		Degraded Saltstone/Vault	
Dose, mrem/yr.[a]	Time of Occurrence, yr.	Dose, mrem/yr.[b]	Time of Occurrence, yr.
0.6	> 100	16 to 76	> 1,000

Groundwater

Performance Objective: 4 mrem/yr.

Intact Saltstone/Vault		Degraded Saltstone/Vault	
Dose, mrem/yr.[c]	Time of Occurrence, yr.	Dose, mrem/yr.[d]	Time of Occurrence, yr.
0.001	> $2.5\text{x}10^6$	0.6	15,000

a. Dose resulting from resident scenario involving home on top of intact concrete roof above disposal unit (RPA, p. 4-24). Dose is calculated at 100 years after disposal, to represent an upper bound for this scenario.

b. Dose resulting from agriculture scenario involving direct intrusion into disposal units [RPA, p. 4-20, adjusted by using a more reasonable plant-to-soil concentration ratio for Tc-99 (part 4 of item 4)]. The dose calculation does not consider the effect of radioactive decay and migration from the disposal facility.

c. Dose resulting from groundwater ingestion at the time of maximum predicted groundwater concentration (RPA, p. 4-12).

d. Dose resulting from groundwater ingestion at the time of maximum predicted groundwater concentration (RPA, p. 4-12); dose reflects increased hydraulic conductivity of clay overlying the vaults (to 10^{-7} cm/s, see part 1 of item 4) and increased hydraulic conductivity and effective diffusivity of concrete and saltstone (see part 2 of item 4).

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Models Used to Estimate Release from Fractures

Overall Approach

The approach adopted to estimate the release rate of radionuclides from fractures relied on two separate analyses: one by Yates (1988), to approximate the flow of water into each fracture: and one by Rasmuson and Neretnieks, to estimate the concentration resulting from diffusion of contaminants from saltstone into the fracture through which the water is flowing. The analysis adapted from Yates considered two-dimensional flow into the fracture from the clay above the vaults. The results of this analysis provided the ratio of the flow through the clay above the fractured vaults to the flow through the clay as if there were not vault below, but another soil layer. The hydraulic conductivity of the clay is considered when the results of the non-dimensionalized flow analysis is multiplied by the flow through the clay alone. The flow into the fractures, assumed to be saturated, is used in the Rasmuson and Neretnieks analysis of mass transport from the unfractured saltstone to the fracture.

Adaption of Yates (1988) Solution

The "Yates (1988) solution" is an analytical solution to a system of two-dimensional equations describing steady-state flow through a stratified saturated aquifer (Fig. 1.). Three stratified regions were considered in Yates' solution: 1) a middle aquifer region; and 2) two aquitard regions on either side. Adaptions were made to allow this solution (Fig. 2) to be used to estimate flow into a fracture from clay above by: 1) rotating Yates' model 90°, 2) assuming the column of clay directly above the fracture (that is, the .005 cm wide column of clay) is Yates' aquifer, and that clay on either side of this thin column takes the place of Yates' aquitards; 3) assuming that the problem is symmetric around the fracture; and 4) non-dimensionalizing the results by dividing the flow through the column of clay above the fracture by the flow through clay without a fracture beneath. The resulting non-dimensional value represents the reduction in flow through the clay due to the presence of the fractured concrete. The assumption is made that the hydraulic head across the top of the clay overlying the fractured vault is constant laterally, due to the overlying gravel layer above.

The equation from the Yates' solution describing hydraulic head as a function of distance in the aquifer (eqn. 29 in Yates 1988) was applied to the problem domain shown in Fig. 2. This equation is reproduced here as Eq. 1.

$$\begin{aligned} H_2(x,z) = {} & B_e - q_e x/K_{2x} - q_e z/(2K_{2z}) \\ & + q_e[x^2/K_{2x} - z^2/K_{2z}]/(4a) - (\alpha_2/K_{2z}) \\ & \times \sum_{n=1}^{\infty} \cos(kx)[V_n \cosh(kz/\alpha_2) \\ & + W_n \sinh(kz/\alpha_2)], \quad (cm) \end{aligned} \tag{1}$$

Yates' Model

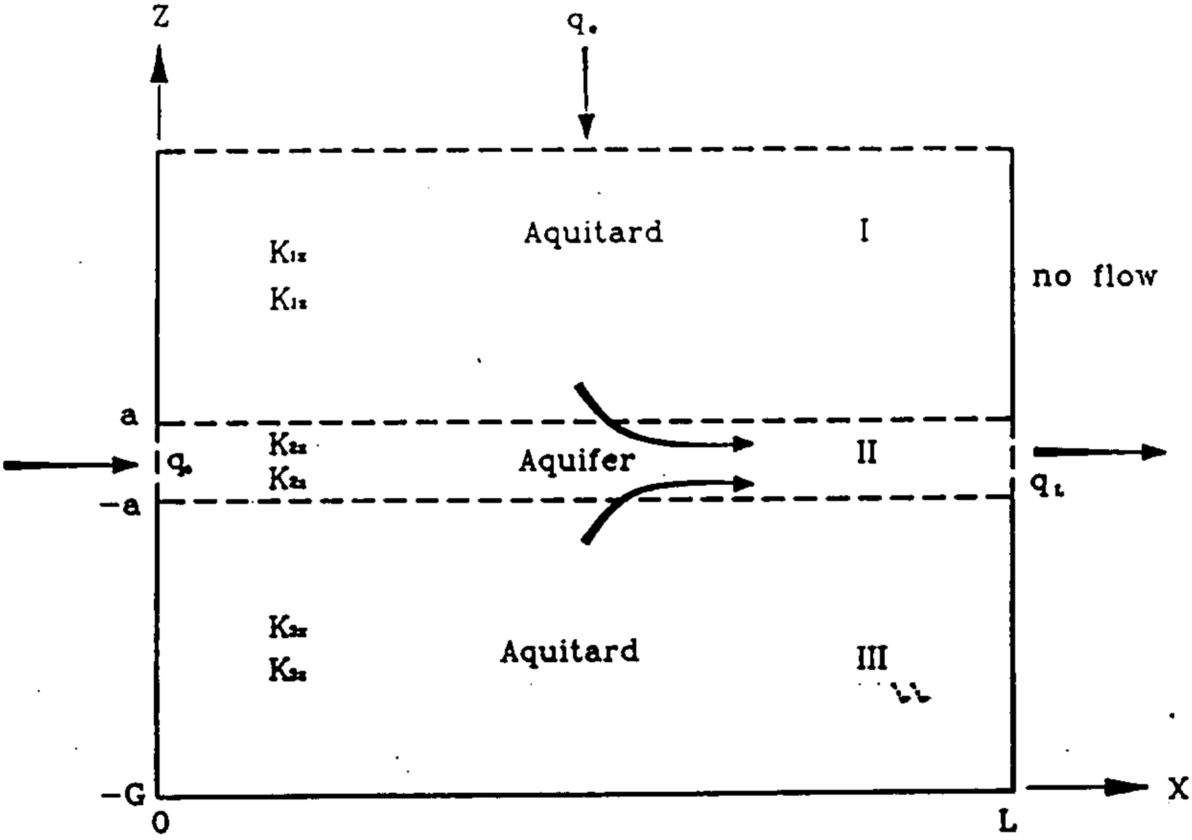

Fig. 1. Conceptual drawing of Yates model

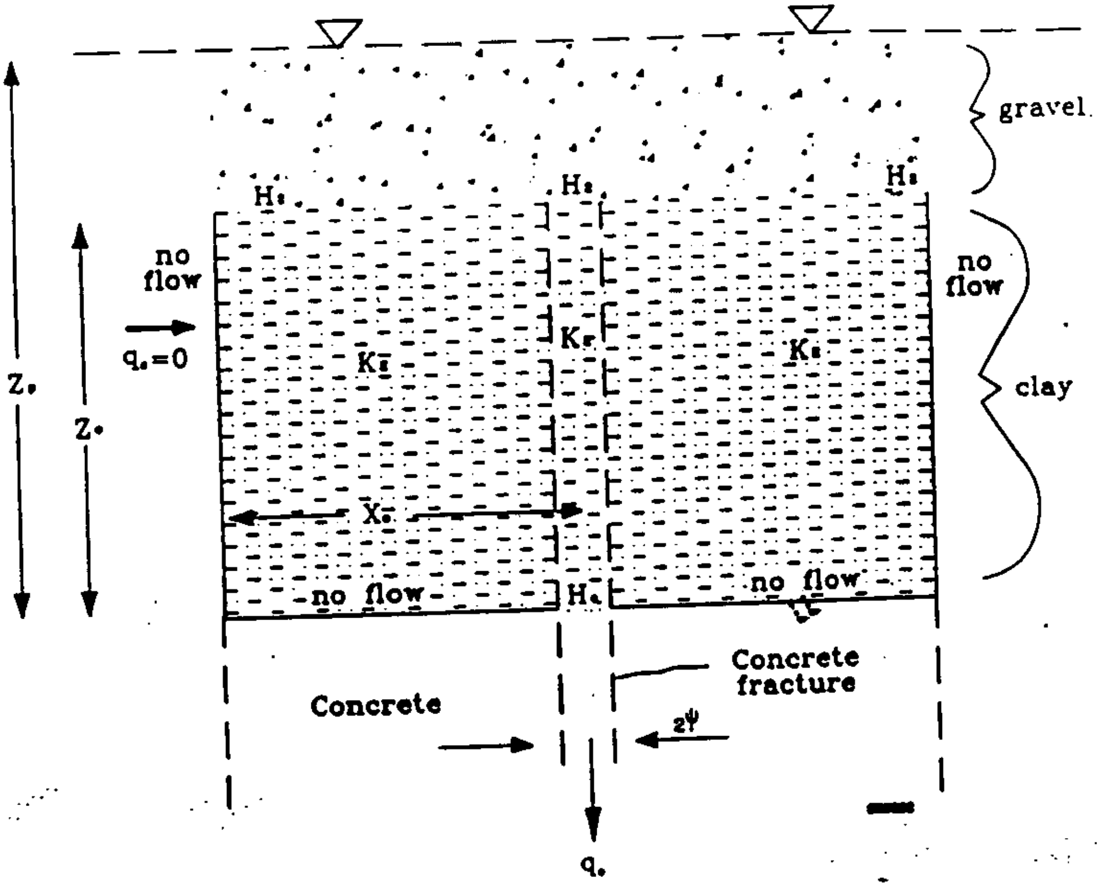

Fig. 2 Conceptual drawing of fracture flow analysis domain, adapted from Yates' model

where

$$B_o = H_o + (\alpha_2/K_{2z})\sum_{n=1}^{\infty} V_n,$$

$$V_n\ ,\ W_n = f\,(\lambda_n, P_i, k, \Psi, \alpha_2, \zeta_n),$$

$$\lambda_n = f\,(\alpha_2, q_o, q_e, L, \Psi, k),$$

$$\zeta_n = f\,(P_i),$$

$$P_i = f\,(K_i, X_e, \Psi, \alpha_1),$$

and $H_o = H_2(0,0)$. This equation is modified in the following manner. First, the x-direction of Yates' corresponds to the height of the clay zone above the fracture, and L/2 is assumed equal to the height of this zone, Z_o. The z-direction from Yates' is now the horizontal direction across the top of the vaults in the fracture application. Second, the q_e term, corresponding to recharge at the upper boundary of Region I (Fig. 1), in the above equation is equal to zero in the fracture application. This is because this boundary is now the half-distance between cracks, or the "flowdivide" between cracks. Eq. 1 from Yates' now simplifies to

$$\begin{aligned} H_2(x,z) = H_o &+ (\alpha_2/K_{2z})\sum_{n=1}^{\infty} V_n - q_e x/K_{2x} \\ &- (\alpha_2/K_{2z})\sum_{n=1}^{\infty} \cos(kx)[V_n \cosh(kz/\alpha_2) \\ &+ W_n \sinh(kz/\alpha_2)]. \quad (cm) \end{aligned} \tag{2}$$

Since x is assumed to be L/2, and k = nπ/L, the summation term becomes zero because Σcos(nπL/2L) is zero. Therefore, $H_2(Z_o, 0)$, where Z_o is the thickness of the clay layer and X_o is the half-spacing between fractures, is simplified to:

$$H_2(Z_o,0) = H_o + (\alpha_2/K_{2z})\sum_{n=1}^{\infty} V_n - q_e Z_o/K_{2x} \quad (cm). \tag{3}$$

Since $\alpha_2 = (K_{2z}/K_{2x})^{1/2}$, and K_{2z} is assumed equal to K_{2x}, then α_2 is equal to unity. Therefore, the final simplification to Yates' equation results in

$$K_2(H_2 - H_o) = \sum_{n=1}^{\infty} V_n - q_e Z_o\ , \quad (cm^2/yr) \tag{4}$$

or

$$K_2 \frac{(H_2 - H_o)}{Z_o} = \sum_{n=1}^{\infty} \frac{V_n}{Z_o} - q_o\,, \quad (cm/yr) \tag{5}$$

or

$$K_2 \frac{(H_o - H_2)}{Z_o} = q_o - \sum_{n=1}^{\infty} \frac{V_n}{Z_o}\,. \quad (cm/yr) \tag{6}$$

The last equation describes the darcy flow in the clay zone above a crack as a function of hydraulic conductivity of the clay (K_2), thickness of the clay zone (Z_o), and flow velocity in the crack (q_o). Solving for q_o, the flow through the clay into the crack:

$$q_o = \frac{K_2\,(H_o - H_2)}{Z_o\left(1 - \sum_{n=1}^{\infty} \frac{V_n}{Z_o q_o}\right)} = \frac{K_2\,(H_o - H_2)}{\left(Z_o - \sum_{n=1}^{\infty} \frac{V_n}{q_o}\right)}\,. \quad (cm/yr) \tag{7}$$

Averaging this flow into the crack across the distance between cracks, $2X_o$, q_{avg} becomes:

$$q_{avg} = \frac{2\Psi}{2X_o} \frac{K_2(H_o - H_2)}{\left(Z_o - \sum_{n=1}^{\infty} \frac{V_n}{q_o}\right)}\,. \quad (cm/yr) \tag{8}$$

where 2Ψ is the crack aperture. To obtain a dimensionless flow rate, q_{avg} is divided by the flow across the clay with the same head loss gradient, assuming soil, not a fractured vault, underlies the clay. The flow through the clay without the underlying vault, according to Darcy's law, is:

$$q_{clay} = \frac{K_2(H_o - H_2)}{Z_o}\,. \quad (cm/yr) \tag{9}$$

To fully nondimensionalize the problem, the height of the clay and half-distance between cracks is divided by one-half the crack aperture, Ψ:

$$z_o = \frac{Z_o}{\Psi}; \quad x_o = \frac{X_o}{\Psi}$$

The dimensionless flow rate, ζ_3, becomes:

$$\zeta_3 = \frac{q_{avg}}{q_{clay}} = \frac{z_o}{x_o(z_o - \sum_{n=1}^{\infty} \frac{V_n}{q_o \Psi})} \qquad (10)$$

The q_o in the denominator of the summation expression cancels out because the expression for V_n contains a q_o in the numerator.

Equation 10 is the final adaptation of Yates' (1988) solution that was used to determine the flow rate in the fracture. Because ζ_3 represents the ratio of darcy flow into the fracture from the overlying clay, averaged over the distance between fractures, to the darcy flow in the clay as if there were not underlying fractured vault, the ratio must be multiplied by this latter value to obtain the actual flow into the fracture. The darcy flow in the overlying clay material, assuming no underlying fractured vault, or q_{clay}, may be calculated knowing the head loss gradient across the clay and the saturated hydraulic conductivity of the clay:

$$q_{clay} = \frac{K_2 \times Z_p}{Z_o} \quad (cm/yr) \qquad (11)$$

The head loss gradient across the clay is the ratio of the height of perched water, Z_p, to the thickness of the clay layer, Z_o. This is true if the perched water overlying the clay zone experiences essentially no resistance to flow relative to the resistance in the clay layer. The value of q_{avg} is computed from:

$$q_{avg} = \zeta_3 \times q_{clay} \, , \qquad (12)$$

and is used in the mass transport simulations.

Adaptation of the Rasmuson and Neretnieks Solution

The "Rasmuson and Neretnieks (1981) solution" adapted for this analysis is a solution of a one-dimensional convection/diffusion equation describing transport of potentially-sorbing radionuclides through fissures in bedrock. This solution describes the concentration in the fissures, or fractures, resulting from the introduction of water containing radionuclides at the top of the fissures, accounting for accumulation of radionuclides in the rock by applying Fick's law of diffusion for radial movement of a solute from the fissures to microfissures. The semi-analytical solution was modified to consider the inverse problem of diffusion from microfissures in bedrock to fissures as a result of input of uncontaminated water at the top of the fissure. The microfissures in this application are assumed to be the pores of saltstone, and the fissures are represented by the 3 m-spaced fractures.

The solution from Rasmuson and Neretnieks which is modified for the fractured saltstone analysis is represented by Eq. 31 in their article, and is reproduced below.

$$\frac{C_f}{C_o} = \frac{1}{2} + \frac{2}{\pi}\int_0^{\infty} \exp(-\delta H_1)\sin(\sigma\theta\lambda^2 - \delta H_2)\frac{d\lambda}{\lambda}, \qquad (13)$$

where

C_f = fracture concentration, mol/m^3,
C_o = inlet concentration of the fracture, mol/m^3,
$\delta = \gamma\ z\ /\ m\ U_f$,
$\gamma = 3\ D_a\ K\ /\ r_o^2$, s^{-1},
D_a = apparent diffusivity for microfissures, m^2/s,
K = volume equilibrium constant, m^3/m^3,
r_o = effective radius of fissure, m,
z = distance along flow direction, m,
$m = e_f/(1 - e_f)$,
e_f = porosity of fissures,
H_1 = (seeEq.13),
H_2 = (seeEq.14),
$\sigma = 2\ D_a\ /\ r_o^2$, s^{-1},
$\theta = t - (z/U_f)$,
λ = variable of integration.

The H_1 and H_2 in this equation are represented by:

$$H_1 = \lambda\left(\frac{\sinh 2\lambda + \sin 2\lambda}{\cosh 2\lambda - \cos 2\lambda}\right) - 1 \quad ; \qquad (14)$$

and

$$H_2 = \lambda\left(\frac{\sinh 2\lambda - \sin 2\lambda}{\cosh 2\lambda - \cos 2\lambda}\right) \quad . \qquad (15)$$

This solution provides the concentration in the fracture, relative to the concentration entering the fracture at the top, as a function of time, assuming no dispersion in the fissure, a semi-infinite media, and no radioactive decay. To consider radioactive decay, the value of C_f/C_o should be multiplied by $\exp(-\lambda_d t)$. It was necessary to look at the reverse of this problem, and solutions to heat conduction problems were consulted because of the similarity between heat conduction equations and diffusion equations.

According to Carslaw and Jaeger (1959), the solution of the problem describing heat conduction to a semi-infinite solid of initial temperature zero from a boundary at a constant temperature, V, is:

$$\frac{v(x,t)}{V} = erf\frac{x}{2\sqrt{(kt)}} \tag{16}$$

where $v(x,t)$ is the temperature at distance x from the boundary at time t. This problem is similar to the diffusion problem addressed by Rasmuson and Neretnieks. The solution to the problem describing heat conduction *from* a semi-infinite solid at a constant temperature, V, to a boundary at initial temperature zero is simply the complement of Eq. 16, or:

$$\frac{v(x,t)}{V} = 1 - erf\frac{x}{2\sqrt{(kt)}} \quad . \tag{17}$$

Therefore, by analogy, the solution describing diffusion from saltstone to fractures can be expressed as the complement of the equation describing diffusion from fractures into microfissures (Eq. 13) or:

$$\alpha\frac{C_f}{C_{t_0}} = 1 - Y\,[\exp(-\beta)] \;, \tag{18}$$

where

$$Y = \frac{1}{2} + \frac{2}{\pi}\int_0^{\infty}\exp(-\delta H_1)\sin(\sigma\theta\lambda^2 - \delta H_2)\frac{d\lambda}{\lambda} \;,$$

and C_{t_0} = total concentration in the waste form, α = volumetric distribution coefficient (= K in Eq. 13), and $\beta = \lambda_d t$. Equation 18 is the analytical solution applied to estimate fracture concentration as a function of time in the Z-Area RPA.

Example Calculation

To demonstrate implementation of the fracture flow and mass transport analysis described above, the method is applied to an example problem. Determination of the flow rate into the fracture, applying the adapted Yates' analysis, and calculation of the release rate from fractured saltstone according to the adaqpted Rasmuson and Neretnieks analysis are considered below. The example problem is identical to that addressed in the Z-Area RPA for nitrate.

For the analysis of flow into a fracture from the overlying clay layer, a FORTRAN code was written solving Eq. 10, above, for ζ_3. Required input for this code consists of the nondimensionalized height of the clay layer over the fractured vaults, or Z_0/Ψ, and the nondimensionalized half-spacing between cracks, or X_0/Ψ. The parameter Ψ represents that crack half-width, or .0025 cm in the Z-Area RPA. The thickness of the clay layer is 50 cm, and the crack spacing ($2X_0$) is 300 cm in the Z-Area RPA. Therefore, for the example problem,

$$z_0 \quad = \quad Z_0/\Psi \quad = 50\text{ cm}/.0025\text{ cm} \quad = 1.0 \times 10^4\text{, and}$$

$$x_o \quad = \quad X_o/\Psi \quad = 150\ \text{cm}/.0025\ \text{cm} \quad = 6.0 \times 10^4 .$$

The input file is named "finput", and the two input values are simply separated by commas. After running the FORTRAN code with this input, the output appears in a file named "foutput". This output file contains three values: the value of z_o, x_o, and ζ_3. The value of ζ_3 is 4.697389×10^{-2} for these input values.

The next step in the analysis is to convert this ζ_3 value to a darcy velocity, in the appropriate format for use in the analysis of mass transport from the saltstone to, and through, the fractures. The mass transport analysis requires input of the darcy velocity through a fracture, averaged across the distance between fractures, or q_{avg}. This darcy velocity is the product of ζ_3 and the darcy velocity through the clay, q_{clay}, in the absence of underlying fractured concrete (Eq. 12 above). The value of q_{clay} is a function of the hydraulic conductivity of the clay (K_2) and the head gradient across the clay (Z_p/Z_o), where Z_p is the height of perched water on top of the vault. The value of q_{clay} is obtained from Eq. 11 above:

$$q_{clay} = \frac{K_2 \times Z_p}{Z_o} = \frac{0.24 cm/yr \times 61 cm}{50 cm} = 0.2928\ cm/yr .$$

Therefore, the value of q_{avg} is:

$$q_{avg} = \zeta_3 \times q_{clay} = 4.697389 \times 10^{-2} \times 0.2928 cm/yr = 1.37 \times 10^{-2} cm/yr$$

In order the implement the semi-analytical mass transport solution based on the Rasmuson and Neretnieks analysis, the following parameters must be given values:

DARV = the average darcy velocity in the vaults, or q_{avg}, (cm/yr),
CRACK = fracture porosity, or Ψ/X_o,
Z = thickness of the vault, or length of fractures, (cm),
SPACE = fracture spacing, or $2X_o$, (cm),
ALPHA = volumetric distribution coefficient, equal to saltstone porosity $\times (1.+K_d)$,
and RLDEC = radioactive decay constant, yr^{-1}.

Values of these parameters are placed in an input file named "minput", for use with a FORTRAN code implementing the analysis. In this example, the following values are input:

DARV = 1.37×10^{-2} cm/yr,
CRACK = .0025/150, 1.67×10^{-5},
Z = 730 cm,
SPACE = 300 cm,
ALPHA = 0.46 (K_d = 0), and
RLDEC = 0.

```
$DEBUG
C Analytical solution to the flow through cracks probelm by S. R. Yates
C Soil Sci Soc, Am J., 52:356-363, 1988.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      PARAMETER (PI = 3.141592654)
      OPEN(6,FILE='FOUTPUT')
      OPEN(5,FILE='FINPUT')
      WRITE(*,*) 'INPUT X, Z0'
      READ(5,*) X, Z0
      IF(Z0.LT.100) THEN
        NSUM = 200
      ELSE
        NSUM = 2.*Z0
      END IF
      SUM = 0.0
C
C BOOKKEEPING FOR FASTER SPEED
C
      IF(NSUM.LE.2000) THEN
        N1 = 2000
        N2 = 0
        N3 = 0
      ELSE IF((NSUM.LE.10000).AND.(NSUM.GT.2000))  THEN
        N1 = 2000
        N2 = NSUM
        N3 = 0
      ELSE
        N1 = 2000
        N2 = 10000
        N3 = NSUM
      END IF
      WRITE(*,*) 'N1,N2,N3 = ', N1, N2, N3
C
C  FIRST 2000 INTERATIONS - BY ONES
C
      DO 100 N = 1, N1
C  J = (2*N)-1
C  RK = DFLOAT(J)*PI/(2.*Z0)
        RK = DFLOAT(2*N-1)*PI/(2.*Z0)
        RLAM = 2*(1-(-1)**(2*N-1))/(2*Z0*RK*RK)
C  RLAM = 2./(Z0*RK*RK)
        TST = RK*(X-1.)
        IF (TST.GT.10000.) TST = 10000.
        P1 = DTANH(TST)
        P3 = P1
        P2 = DTANH(RK)
        ZETA = (P1+P3)*(1.+P2**2)+2.*P2*(P1*P3+1.)
        V = RLAM*(P1+P3+2.*P1*P2*P3)/(DCOSH(RK)*ZETA)
        SUM = SUM + V
C  WRITE (*,*) N,SUM
  100 CONTINUE
C
C  NEXT 8000 INTERATIONS - BY TENS
C
      DO 200 N = 2005, N2, 10
        RK = DFLOAT(2*N-1)*PI/(2.*Z0)
        RLAM = 2*(1-(-1)**(2*N-1))/(2*Z0*RK*RK)
        TST = RK*(X-1.)
        IF (TST.GT.10000.) TST = 10000.
```

```
        P1 = DTANH(TST)
-      WRITE (*,*) P1
        P3 = P1
        P2 = DTANH(RK)
        ZETA = (P1+P3)*(1.+P2**2)+2.*P2*(P1*P3+1.)
C  WRITE(*,) N, V, SUM
        V = RLAM*(P1+P3+2.*P1*P2*P3)/(DCOSH(RK)*ZETA)
        SUM = SUM + V * 10.
  200 CONTINUE
C
C  ALL THE REST - BY HUNDREDS
C
        DO 300 N = 10100, N3, 200
          RK = DFLOAT(2*N-1)*PI/(2.*Z0)
          RLAM = 2*(1-(-1)**(2*N-1))/(2*Z0*RK*RK)
          TST = RK*(X-1.)
          IF (TST.GT.10000.) TST = 10000.
          P1 = DTANH(TST)
          P3 = P1
          P2 = DTANH(RK)
          ZETA = (P1+P3)*(1.+P2**2)+2.*P2*(P1*P3+1.)
          V = RLAM*(P1+P3+2.*P1*P2*P3)/(DCOSH(RK)*ZETA)
C  WRITE(*,*) N, V, SUM
        SUM = SUM + V * 200.
  300 CONTINUE
      RH2 = SUM - Z0
      ZETA3 = (-2./RH2)*Z0/(2.*X)
      WRITE(6,1000) X, Z0, ZETA3
 1000 FORMAT(1X,3(1PE12.6, 5X))
      STOP
      END
```

Sensitivity/Uncertainty of Z-Area Radiological Performance Results with Respect to K_d

The groundwater concentrations predicted in the Z-Area Radiological Performance Assessment (RPA) (*Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility*, 1992) are a function of the values assumed for the distribution coefficient, K_d, in the various materials present in the facility and subsurface environment. The purpose of this report is to investigate the relationship of predicted groundwater concentrations to K_d, to consider the sensitivity of the results to K_d, and to address the uncertainty in the Kd's used in the RPA by providing some bounding-type calculations.

The distribution coefficient is used in the assessment of groundwater concentrations in the Z-Area RPA in two ways: 1) it is used to estimate the initial pore concentration in saltstone, which is input into the contaminant transport code PORFLOW-3D; and 2) it is used to evaluate retardation due to sorption in saltstone, concrete, and soil in the contaminant transport equations inherent in PORFLOW-3D. Initial pore concentrations are calculated for the RPA according to the equation found on p. A-21 of Rev. 0 of the RPA. This equation is reproduced below:

$$C_{pore} = C_{block} \,/\, (\theta + \rho_m K_d (1-\theta)) \tag{1}$$

where

C_{pore} = pore fluid concentration (Ci/L),
C_{block} = concentration of the saltstone block (Ci/L),
θ = porosity of the saltstone (0.46),
ρ_m = matrix density (2.07 g/cc), and
K_d = nuclide distribution coefficient in saltstone (cc/g).

Equation 1 indicates that the initial pore solution concentration is inversely related to the saltstone K_d; for K_d's much larger than the porosity of saltstone, or 0.46, the relationship is approximately linear. The flux to the water table, predicted in the near-field analysis of the Z-Area RPA, is a function of the initial pore solution concentration, and the transit time of contaminants through the saltstone, the concrete vaults, and the surrounding soil. The transit time is important in determining the time of arrival at the water table of contaminants leaving the vaults, and in determining how much decay may occur before contaminants reach the water table. Sorption, accounted for with the distribution coefficient, in effect retards the movement of contaminants through the various materials. The transit time of a particular contaminant, t_c, is related to the transit time of water, t, by:

$$t_c = t\left(1 + \frac{(1-\theta)}{\theta}\,\rho_m K_d\right), \tag{2}$$

As the transit time of the contaminant increases, or as K_d in saltstone, concrete, and soil increases, the flux to the water table may decrease due to decay during transit.

Therefore, the flux to the water table decreases as saltstone K_d increases, due to decreased initial pore fluid concentration and possibly due to the additional time for decay during transit out of the vaults and through the soil. As the saltstone K_d decreases, the flux to the water table increases due to the higher initial pore fluid concentration predicted, and due to the shorter transit times through the vaults. For shorter-lived radionuclides, the retardation phenomenon has a more profound effect on the flux to the water table. For radionuclides with half-lives very long relative to even the retarded transit time, retardation has little effect on the ultimate flux, other than to delay arrival at the water table.

The relationship between the flux to the water table and the value of K_d used for saltstone and other materials is not readily expressed analytically. However, it is apparent that the flux to the water table is very sensitive to K_d, because a lower saltstone K_d will not only increase the initial pore solution concentrations, but also decrease the transit time from the vault, such that less radioactive decay occurs before release. Flux to the water table is less sensitive to soil K_d than saltstone K_d since the soil Kd only affects the transit time, but soil K_d may be important for shorter-lived radionuclides such as H-3, Cs-137, or Sr-90.

The problem can be bounded on the upper end by considering the results for a non-sorbing and non-decaying species such as nitrate. The results of the RPA indicate that the peak fractional flux for nitrate in the intact case occurs at the water table at 7500 years, and is on the order of 4.2×10^{-6} (Fig. C.4-11). This peak release is defined as the fraction of the original inventory in saltstone released to the water table in one year. For nitrate, it can also be interpreted to be the fraction of the initial pore solution released in one year, because all of the nitrate in saltstone is assumed to be in the pore solution (i.e., the K_d is zero). If retardation and decay are neglected for the radionuclides, the peak fractional flux of radionuclides to the water table can likewise be expected to be on the order of 4.2×10^{-6}, if the fractional release is interpreted to be the fraction of the amount in the initial pore solution that is released in one year. The maximum pore solution concentration of the radionuclides is the initial pore fluid concentration, as application of Eq. 1 assumes equilibrium partitioning of the radionuclides between the pore fluid and the solid surfaces. Making this comparison to nitrate flux, it is possible to determine a conservative peak fractional flux as a function of saltstone K_d for each radionuclide.

In Table 1, peak fluxes are given for a minimum and maximum K_d for each radionuclide not screened from consideration in the Z-Area RPA. The ranges in saltstone K_d's selected were obtained from ranges of experimentally-obtained values noted in Allard (1985), and represent somewhat broader ranges than are considered "probable" ranges by the author for a standard cement environment. The peak fluxes were determined assuming no retardation or decay, as described in the above paragraph, according to:

$$Flux(pCi/yr) = 4.2\times10^{-6} \times C_{pore} \times 5.29\times10^{8} \tag{3}$$

where

5.29×10^{8} = total volume of pore solution in the facility, L,
$4. \times 10^{-6}$ = fractional flux to the water table, and
C_{pore} = initial pore solution concentration.

The initial pore fluid concentration, C_{pore}, was determined according to Eq. 1. It is important to remember that these are fluxes which ignore retardation and radioactive decay, which has a large impact on the fluxes estimated for the RPA. The transit times out of the saltstone are extremely long, and thus considerable decay occurs within the vaults for many of the radionuclides.

The implications of the fluxes supplied in Table 1 can be best understood in terms of the impact on groundwater concentrations at the compliance point for groundwater protection. Because this concentration is directly proportional to the flux at the water table, an increase in the K_d in saltstone will result in an decrease in the groundwater concentration. For a given K_d in the three hydrologic units considered in the RPA, the resulting compliance point concentration is linearly proportional to the flux at the water table. For nitrate, the K_d in soil is zero, representing no sorption. Comparing the peak flux of nitrate to the water table in Table 4.1-3 of the Z-Area RPA to the peak groundwater concentration at the compliance point for nitrate (Table 4.1-5), a multiplier can be derived that allows estimation of the peak compliance point groundwater concentration as a function of peak flux to the water table. This multiplier, when based on the nitrate values, is pertinent to a non-sorbing, non-decaying species, and thus would add another dimension of conservatism when coupled with the bounding flux values in Table 1 for the radionuclides of concern.

The multiplier obtained is:

$$\begin{aligned} Multiplier &= 5.2 mg/L + 5.5\times10^{8} mg/yr \\ &= 9.5\times10^{-9}\ yr/L\ . \end{aligned} \tag{4}$$

Using this multiplier and the bounding peak fluxes in Table 1 for the radionuclides of interest in the Z-Area RPA, bounding groundwater concentrations can be estimated for the minimum saltstone K_d's assumed. These are presented in Table 2, along with the allowable groundwater concentration for compliance, for comparison. It is readily apparent that even under these unreasonable assumptions, only Cs-137 threatens the groundwater protection standard. Given the short half-life of Cs-137 (30 yr) with respect to transit times through the vault and soil, this radionuclide is not a problem in the final analysis documented in the Z-Area RPA.

Allard, B. 1985. *Radionuclide Sorption on Concrete*, NAGRA-NTB-85-21, November, 1985.

Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility, 1992. WSRC-RP-92-1360, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC, December 18, 1992.

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Table 1. Estimated upper-bound peak fluxes to the water table, neglecting decay during transit out of the saltstone vaults and through the unsaturated soil zone.

Radionuclide	Saltstone Kd (cc/g)	Calculated C_{pore}[a] (pCi/L)	Upper Bound Flux to Water Table[b] (pCi/yr)
H-3	Max = 2 Min = 0	1.2×10^6 6.8×10^6	2.6×10^9 1.5×10^{10}
C-14	Max = 15000 Min = 1500	0.33 3.3	7.4×10^2 7.4×10^3
Se-79	Max = 50 Min = 0	5.0×10^3 6.1×10^5	1.1×10^7 1.4×10^9
Sr-90	Max = 200 Min = 1	1.3×10^3 1.8×10^5	2.9×10^6 4.0×10^8
Tc-99	Max = 1500 Min = 100	3.3×10^4 5.0×10^5	7.3×10^7 1.1×10^9
Sn-126	Max = 1000 Min = 10	9.8×10^1 9.5×10^3	2.2×10^5 2.1×10^7
I-129	Max = 200 Min = 4	7.6×10^1 3.4×10^3	1.7×10^5 7.6×10^6
Cs-137	Max = 1000 Min = 1	7.6×10^3 5.4×10^6	1.7×10^7 1.2×10^{10}
Pu-238	Max = 15000 Min = 1000	2.0 3.0×10^1	4.4×10^3 6.7×10^4
Am-241	Max = 50000 Min = 2500	1.9 3.8×10^1	4.2×10^3 8.4×10^4

[a] Eq. 1, assuming 30 years of decay of inventory

[b] Eq. 3

Table 2. Bounding groundwater concentrations based on minimum saltstone K_d's and assuming no decay in transit from the waste form and through the environment to the compliance point

Radionuclide	Upper-bound groundwater concentrations at compliance point (pCi/L)	Concentration necessary for compliance with groundwater protection standards (pCi/L)
H-3	140	90.000
C-14	7.0×10^{-5}	3.000
Se-79	13	700
Sr-90	3.8	40
Tc-99	10	4,000
Sn-126	0.2	300
I-129	7.2×10^{-2}	20
Cs-137	110	100
Pu-238	6.4×10^{-4}	1
Am-241	8.0×10^{-4}	1

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Errata for
Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility (U),
WSRC-RP-92-1360, Rev. 0, 12/18/92

- On page *v*, for Sections 4.1.3 and 4.1.4, "Doses" should be "Dose".
- On page *vii*, for Appendix F, insert "QA" after "SOFTWARE".
- On page *x*, for C.2-4, close the parenthesis at the end of the second line.
- On page *xvii*, for D.3-1, replace "formation" with "formulation".
- On page *xx*, insert the following after "SSHT Salt Solution Hold Tank": "TDS Total Dissolved Solids".
- On page *xxii*, in the eleventh line, replace "complies with" with "exceeds"; in the thirteenth line, replace "38 mg/L" with "53 mg/L"; in the fourteenth line, replace "approaches" with "exceeds".
- On page 1-8, in the first paragraph after the performance objectives, in the second line, delete "usually" and insert "at SRS" after "has been interpreted".
- On page 1-9, in the next-to-the-last paragraph, in the third and seventh lines, replace "effective dose equivalent" with "effective dose".
- On page 2-1, in the second paragraph, in the eighth line, omit "(chemical and radiochemical)".
- On page 2-7, in Section 2.1.4.1, in the second paragraph, in the fifth line, insert a comma before "the Pen Branch fault".
- On page 2-9, in Section 2.1.4.2, in the second paragraph, in the second line, "200 year" should be "200 years".
- On page 2-13, in Section 2.1.6, in the last sentence of the last paragraph, replace "with an average velocity of approximately 3 $m\ s^{-1}$ corresponding to a flow of 1200 $m^3\ s^{-1}$" with "with an average flow of approximately 160 $m^3\ s^{-1}$".
- On page 2-17, in Section 2.1.10, in the first line of the second paragraph, replace "number" with "member".
- On page 2-30, in Section 2.2.4, in the first line of the first paragraph, replace "are" with "is".
- On page 2-33, in Table 2.2-3, the seventh Parameter listed should be "Suspended Solids" rather than "Suspended soils".
- On page 2-37, in Section 2.3.1.1, in the second paragraph, in the fifth line, replace "TBP" with "TPB".

- On page 2-41, insert an asterisk after the Table title. At the bottom of the page, insert the following before the list of footnotes: "* Density of solutions is 1.25 g/mL".

- On page 2-53, in Figure 2.4-1, in the legend for the two upper curves, "Ref" should be "non-slag".

- On page 2-54, in Figure 2.4-2, the legend for the solid circle symbol should be "No Cap non-slag Saltstone Lysimeter" rather than "No Cap Reference Saltstone Lysimeter". In the title for the figure, replace "Slag- and Cement-Based" with "Slag and non-slag".

- On page 2-60, in the fourth paragraph, in the seventh line, replace "composition of these steams" with "compositions of these streams".

- On page 2-64, in Section 2.6.4.1, in the sixth line, replace "1984" with "1983".

- On page 2-67, in Table 2.6-2, add the following to footnote b: "ITP waste was assumed to be aged 15 years".

- On page 2-70, in Table 2.6-4, the entry for Total alpha for Cell A should be "1.6×10^{-3}" rather than "2.5×10^{-5}".

- On page 2-71, in Section 2.7.1, in the first paragraph, in the eleventh line, replace "sysem" with "system".

- On page 2-75, in Table 2.7-1, the hydraulic conductivity of Backfill should be 1×10^{-4} cm/s.

- On page 3-3, in the third paragraph, in the third line, "(Sect. 1.2)" should be "(Sect. 1.3)".

- On page 3-5, in the second paragraph, in the fifth line, change "is" to "are".

- On page 3-9, under **Sulfate attack**, in the second paragraph, in the second and third lines, replace "groundwater" with "soil water".

- On pages 3-16 and 3-17, in Figures 3.1-6 and 3.1-7, the label for the vertical axis should be "Percent Rebar Remaining".

- On page 3-20, in the title for Table 3.1-1, replace "Langton (1989b)" with "(Langton 1989b)". In the heading for the second column insert "in salt solution" after "Concentration limit".

- On page 3-22, in the second paragraph, in the third line, change "indivi-dual" to "individual".

- On page 3-56, in Section 3.3.1, in the second paragraph, in t second line, insert "was" after "analysis".

- On page 3-58, in the first paragraph, in the fourth line, insert "out" after "carried".

- On page 3-59, in the second paragraph, in the last sentence, replace "assumed" with "used".
- On page 3-60, in Table 3.3-1, in the title, replace "assumed" with "used". In the heading of the second column from the left, insert "Saturated Hydraulic Conductivity" above K_s. In the fifth column from the left, the reference to footnote a should follow α rather than (cm^{-1}). Footnote c should be deleted.
- On page 3-61, in the second paragraph, in the eighth line, insert "vault" before "fractures"; in the tenth line, insert "saltstone" before "pours".
- On page 3-64, in the last sentences of the first and last paragraphs, replace "assumed" with "used".
- On page 3-65, in the heading for the second column, change "Assumed property value" to "Property value used".
- On page 3-86, in Section 3.4.4, in the fifth line, replace "DOE Order 5820.2a" with "DOE Order 5820.2A".
- On page 4-2, in the last line of the last paragraph, delete "Table".
- On page 4-5, in Table 4.1-3, the time of peak flux for tritium when infiltration is 2 cm/year should be "9.1×10^{1}" rather than "9.1×10^{-1}".
- On page 4-6, in Table 4.1-4, the peak flux for nitrate should be "4.9×10^{9}" rather than "3.4×10^{9}".
- On page 4-9, in Table 4.1-6, the peak concentration for nitrate should be "5.3×10^{1}" rather than "3.6×10^{1}". The peak concentration for C-14 should be "6.0×10^{-5}" rather than "6.0×10^{-6}".
- On page 4-26, in Section 4.1.4.3, in the fourth paragraph, in the third line, change "Sect. 4.1.4.2" to "Sect. 4.1.4.1".
- On page 4-35, in Section 4.2.1.2, in the second paragraph, in the seventh line, insert "and technetium" after "nitrate".
- On page 4-43, in the second paragraph, in the fourteenth line, delete "from"; in the fifteenth line, delete the first occurrence of "and the".
- On page 4-50, in Section 4.3.1, in the last sentence, change "(38 mg/L at 1400 years)" to "(53 mg/L at 1400 years)"; change "is close to" to "exceeds".
- On page 4-55, in Section 4.3.3, in the fourth line, change "are 84% of" to "exceeds".

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- On page 5-2, in Table 5.1-1, for the Degraded Saltstone/Vault Scenarios, the maximum predicted concentration for nitrate should be 53 mg/L rather than 38 mg/L. The column headings "Maximum predicted dose or concentration" under Intact Saltstone/Vault Scenarios and Degraded Saltstone/Vault Scenarios should be deleted. Insert new headings as follows: Insert "Best estimate dose" just above the dose results of "0.6 mrem per year" and "50 - 110 mrem per year" for the inadvertent intruder; Insert "Maximum predicted dose or concentration" just above the results for the groundwater pathway.

- On page 7-1, in the first reference, in the first line, replace "*Date*" with "*Data*". In the sixth reference, in the first line, replace "Celisum" with "Cesium".

- On page 7-2, in the seventh reference, in the first line, delete "24".

- On page 7-3, in the fifth reference, in the first line, change "S. T." to "S. J.".

- On page 7-4, in the ninth reference, in the second line, insert "DP-1493" after "*Ground.*".

- On page 7-8, in the sixth reference, in the second line, delete "2 before "*Savannah River Site*".

- On page 7-9, in the sixth reference, in the second line, change "DOE/E15/0082" to DOE/EIS/0082".

- On page 7-10, in the eighth reference, in the second line, insert "DPST-85-417" after "*Saltstone.*".

- On page 7-11, in the first reference, in the fourth line, replace "Chase T. Main" with "Chas. T. Main".

- On page A-9, in Figure A.1-4, the legend for the fourth set of values, denoted by triangles, should be "Coarse Sand" rather than "Course Sand".

- On page A-12, in the first paragraph, in the fifth line, insert "for" after "empirically". In the second paragraph, in the fourth line, change "assume" to "assumes".

- On page A-13, in Table A.1-2, in the Title, replace "assumed" with "used"; the entries for Nitrate under Clay and Gravel should be "0.".

- On page A-16, in the last sentence of the top paragraph, it is stated that a copy of the input file for the PORFLOW simulations of the upper moisture barrier is in Appendix C.2. This input file was inadvertently omitted from Appendix C.2. A copy is attached to th errata.

- On page A-19, in the fifth line of the top paragraph, change "all to" to "all of".

- On page A-22, in Table A.1-3, the initial pore concentration of Nitrate should be "2.3×10^5" rather than "1.6×10^5".

- On page A-29, in the definition of terms for the first equation, the last two terms Z_o and X_o should be upper case to refer to the numerators in the first two equations after "where". In the definition of λ_j, the "z_o" term should be lower case.

- On page A-33, in the second equation (which defines H_2 (λ)), in the numerator, the sign between the hyperbolic sine and the sine terms should be minus instead of plus. In other words, the equation should be:

$$H_2\ (\lambda) = \lambda\ \left(\frac{\sinh 2\lambda - \sin 2\lambda}{\cosh 2\lambda - \cos 2\lambda}\right)$$

  In the equation above "where the solution depends upon these dimensionless variables that follow:", the "aC_f" in the numerator should be "αC_f".

- On page A-35, in Table A.1-5, the value used for ϕ_f, the fracture porosity, should be "1.7×10^{-5}" rather than "1.0".

- On page A-39, in Section A.2.1.2, in the fourth line replace "Zone 5b (the Congaree Formation)" with "Zone 5a (the Congaree Formation)".

- On page A-40, in Table A.2-1, the values for vertical hydraulic conductivity for Zones 6/7/8 and 5b should be "4×10^{-6}" and "2×10^{-9}".In Section A.2.1.4, in the last paragraph, in the first line, the units for the effective diffusion coefficient should be "cm^2/s" rather than "cm/s".

- On page A-43, in Section A.2.2.2, in the first paragraph, in the seventh line, delete "of". In the second paragraph, in the last line, change "are" to "is".

- On page A-45, in the second paragraph, in the fourth line, delete "were obtained"; in the sixth line, change "setting" to "settings".

- On page A-47, in Section A.3.1, in the fourth line, insert "$/cm^3$" after "g". In Section A.3.1.1, in the second line, the reference should be to "Subpart Q", rather than to "Subpart O".

- On page A-48, equation A.3.1 should be written as follows:

$$J_s = 10^4 R\rho E\sqrt{\lambda D_s}\ \tanh\left[\sqrt{\frac{\lambda}{D_s}}\ (x_s)\right]$$

- On page A-49, in Section A.3.1.3, in the second line, the ^{222}Rn flux value should be 0.1 pCi m^{-2} s^{-1} rather than 7.3 x 10^{-1}.

- On page A-51, in Section A.3.2.3, in the first line, the reference should be to equation A.3.5, rather than to equation A.3.12. In the third line, the reference should be to equation A.3.6 rather than to equation A.3.13.

- On page A-52, In Section A.3.2.4, equation A.3.7 should be rewritten as follows:

$$Q_{ss} = \frac{\frac{R}{K_r + K_v}}{V_r}$$

$$R = J_i * A_b$$

Where

Q_{ss} = steady-state room concentration (pCi m^{-3})
R = radionuclide input rate (pCi s^{-1})
K_r = radionuclide decay constant (s^{-1})
K_v = room ventilation rate constant (s^{-1})
v_r = volume of room (m^3)
J_i = radionuclide flux (pCi cm^{-2} sec^{-1})
A_b = floor area of the room (cm^2)

In equation A.3.8 and in the following definition of terms, "Q" should be "Q_{ss}".

- On page A-60, in Table A.4-2, under the line containing "Sb-126", the following line should be inserted (this line should be indented just as the line for Sb-126):

Sb-126m	0.1	7.3 x 10^{-5}

- On pages C-2 through C-5, in Table C.1-1, each nuclide which is followed by "+ d" should have a reference to footnote d added. For example, "Ru-106 + d" should be "Ru-106 + d^{d}".

- On page C-5, the "Total Activity" entry should reference footnote e; i.e., the entry should be "Total Activity^{e}".

  The value for Total Activity of the Nominal Blend should be 2.90 x 10^{-4} Ci/liter rather than 2.81 x 10^{-4}.

- At the bottom of page C-5, in footnote c, the word "ration" should be "ratio".

  At the bottom of page C-5, the following two footnotes should be added:

  d "...+ d" indicates there are daughters in equilibrium. Activity reported is that of the parent.

  ● Total activity includes the activity of radioactive daughters in secular equilibrium with the parent (indicated by "...+ d").

- On page C-17, at the bottom of the page, in the second line of the caption, the parentheses should be closed at the end of the sentence.

- On page C-65, in the table at the bottom of the figure, the maximum concentration of 4.4 pCi/l, as a result of fractures, occurs at 1.5×10^4 years rather than 1.4×10^4 years.

- On page D-2, in Section D.1.2, in the first paragraph, in the last sentence, insert "the runs showed" after "Further,".

- On page D-5, in the Title for Table D.3-1, in the second line, change "formation" to "formulation". The second compound listed should be "$\mathrm{Al_2O_3}$" rather than "$\mathrm{A1_2O_3}$"; the eleventh compound listed should be "$\mathrm{SO_3}$" rather than "$\mathrm{So_3}$".

- On page D-10, in the top paragraph, in the fourth line, "cement ore fluids" should be "cement pore fluids".

- On page D-13, in the title of Table D.4-1, "interstitual" should be "interstitial".

- On page D-14, in Table D.4-2, in the left column, the first entry for Na species should be "$\mathrm{Na^+}$" rather than "Na"; the first entry for K species should be "$\mathrm{K^+}$" rather than "K"; the third entry for $\mathrm{SO_4{}^{2-}}$ species should be "$\mathrm{KSO_4{}^-}$" rather than "$\mathrm{KSO_4}$"; the first entry for $\mathrm{NH_4}$ species should be "$\mathrm{NH_4{}^+}$" rather than "$\mathrm{NH_4}$"; the entry for $\mathrm{NO_2}$ species should be "$\mathrm{NO_2{}^-}$" rather than "$\mathrm{NO_2}$". In the right column, the first entry for $\mathrm{NO_3}$ species should be "$\mathrm{NO_3{}^-}$" rather than "$\mathrm{NO_3}$"; the first entry for $\mathrm{CO_3{}^-}$ species should be "$\mathrm{NaHCO_3,aq}$" rather than "$\mathrm{NaHCO_3,aq^-}$"; the first entry for $\mathrm{Fe^{+3}}$ species should be "$\mathrm{Fe(OH)_4{}^-}$" rather than "$\mathrm{FeOH_4{}^-}$", the second entry should be "$\mathrm{Fe(OH)_2{}^+}$" rather than "$\mathrm{FeOH_2}$", the third entry should be "$\mathrm{Fe(OH)_3}$" rather than "$\mathrm{FeOH_3}$".

- On page E-1, in Section E.1.1, in the third paragraph, in the sixth line, "south-eastern" should be "southeastern".

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- On page E-9, in Section E.2.3, in the second line of the second paragraph, "are based" should be "is based". In the last line, delete the comma after "groundwater flow".
- On page E-13, in the top paragraph, in the second sentence, insert "adjacent" before "to Z-Area".
- On page E-16, in the top paragraph, in the fourth line, delete "Fig. E.2-4" just before "Zone 6".
- On page E-25, in Figure E.2-10, the x-axis label should say "moisture", rather than "moiture".
- On page F-2, under **PORFLOW-3D**, in the second line, replace "of" with "and". Under **SOFTWARE VALIDATION**, in the first line, replace "resting" with "testing".
- On page F-6, in Section 6.2.2, change the last line to read: "uniquely identifies each data set and corresponding simulation results."
- On page F-7, in Section 8.0, in the fourth line, replace "such and Idaho" with "such as Idaho".
- On page F-8, in the last reference, in the second line, repla "Mustifluid" with Multifluid".
- On page F-9, in the upper righthand corner of the page, replace "EGG-EELS-003" with "EGG-EELS-10666"; in the center of the page, replace "1992" with "March, 1993".
- On page H-2, in the caption for Figure H.1-2, replace "Fractionan" with "Fractional", and replace "of a function" with "as a function".
- On page H-3, in the titles for the first, third and fourth graphs, delete the first occurrence of "to".
- On page H-20, the last sentence of the footnote to Table H.2-1 should read: "To the right of the near-field uncertainty run number are thirteen numbers, representing the thirteen nitrate fractional fluxes at thirteen points in time, used for the saturated flow runs."

Attachment 1

PORFLOW-3

Input File

Upper Moisture Barrier Simulation

```
TITLE Two Moisture Barrier for Savannah River Site with two percent grade.
USER CS C.Smith
/
GRID   22 by  63
/
READ the 1 st record from 'start'
/
SCREen on
COORdinate  X:
/
/ non cover (1 - 10)
/
 -25.0   25.0  100.0  200.0  300.0  400.0  450.0  475.0  487.5  495.0
/
/ cover ( 11 - 22)
/
 505.0  515.0  530.0  555.0  580.0  630.0  725.0  825.0  925.0  970.0
 990.0  1010.0
/
COORdinate  Y:
/
/ backfill (1 - 23)
/
  -1.5    1.5    7.0   14.0   23.0   34.0   48.0   65.0   86.0  113.0
 143.0  180.0  220.0  257.0  287.0  314.0  335.0  352.0  366.0  377.0
 386.0  393.0  398.0
/
/ clay  (24 -  38)
/
                      402.0  410.0  417.0  424.0  431.0  438.0  445.0
 452.0  459.0  465.0  470.0  473.0  476.0  478.0  479.5
/
/ gravel ( 39 -  49)
/
                                                         480.5  482.0
 484.0  487.0  491.0  495.0  499.0  503.0  506.0  508.0  509.5
/
/ backfill ( 50 -  63)
/
                                                                510.5
 512.0  514.0  517.0  521.0  529.0  541.0  555.0  563.0  573.0  582.0
 591.0  597.0  603.0
/
/ Geometry  of system
/
ZONE  1 is from (  1,   1) to ( 22,  63) $ BACKFILL  soil layer
/
ZONE  2 is from ( 11,  39) to ( 22,  49) $ GRAVEL  soil layer
/
ZONE  3 is from ( 11,  24) to ( 22,  38) $ CLAY soil layer
/
DATUm  = 0. 0.
GRAVity  components  are: -0.02,-1.
/
DENSity of fluid is constant and equal to 1.0 gm/cubic meter
/
FOR zone 1   $BACKFILL
```

```
ROCK bulk den 1.60 gm/cc,  neff=.439, ntot=0.439 , ndif=0.439
HYDRaulic prop. ss = 1.e-3, Kx=332.6 Ky=332.6 cm/yr
MULTiphase flow: tabular option, 79 points
/ saturation matric potential in cm
      0.22   378.3312
      0.23   366.3198
      0.24   354.5856
      0.25    343.125
      0.26   331.9344
      0.27   321.0102
      0.28   310.3488
      0.29   299.9466
       0.3      289.8
      0.31   279.9054
      0.32   270.2592
      0.33   260.8578
      0.34   251.6976
      0.35    242.775
      0.36   234.0864
      0.37   225.6282
      0.38   217.3968
      0.39   209.3886
       0.4      201.6
      0.41   194.0274
      0.42   186.6672
      0.43   179.5158
      0.44   172.5696
      0.45    165.825
      0.46   159.2784
      0.47   152.9262
      0.48   146.7648
      0.49   140.7906
       0.5        135
      0.51   129.3894
      0.52   123.9552
      0.53   118.6938
      0.54   113.6016
      0.55    108.675
      0.56   103.9104
      0.57    99.3042
      0.58    94.8528
      0.59    90.5526
       0.6       86.4
      0.61    82.3914
      0.62    78.5232
      0.63    74.7918
      0.64    71.1936
      0.65     67.725
      0.66    64.3824
      0.67    61.1622
      0.68    58.0608
      0.69    55.0746
       0.7       52.2
      0.71    49.4334
      0.72    46.7712
      0.73    44.2098
      0.74    41.7456
      0.75     39.375
      0.76    37.0944
```

```
 0.77    34.9002
 0.78    32.7888
 0.79    30.7566
  0.8     28.8
 0.81    26.9154
 0.82    25.0992
 0.83    23.3478
 0.84    21.6576
 0.85     20.025
 0.86    18.4464
 0.87    16.9182
 0.88    15.4368
 0.89    13.9986
  0.9     12.6
 0.91    11.2374
 0.92     9.9072
 0.93     8.6058
 0.94     7.3296
 0.95      6.075
 0.96     4.8384
 0.97     3.6162
 0.98     2.4048
 0.99     1.2006
    1     0.0000
MULTiphase flow: COND tabular option, 79 points
/ saturation relative conductivity
     0.22 0.0000E+00
     0.23 2.7016E-08
     0.24 4.3226E-07
     0.25 2.1883E-06
     0.26 6.9161E-06
     0.27 1.6885E-05
     0.28 3.5013E-05
     0.29 6.4865E-05
      0.3 1.1066E-04
     0.31 1.7725E-04
     0.32 2.7016E-04
     0.33 3.9554E-04
     0.34 5.6020E-04
     0.35 7.7160E-04
     0.36 1.0378E-03
     0.37 1.3677E-03
     0.38 1.7705E-03
     0.39 2.2564E-03
      0.4 2.8360E-03
     0.41 3.5208E-03
     0.42 4.3226E-03
     0.43 5.2541E-03
     0.44 6.3287E-03
     0.45 7.5602E-03
     0.46 8.9633E-03
     0.47 1.0553E-02
     0.48 1.2346E-02
     0.49 1.4357E-02
      0.5 1.6606E-02
     0.51 1.9108E-02
     0.52 2.1883E-02
     0.53 2.4950E-02
     0.54 2.8328E-02
```

```
      0.55  3.2039E-02
      0.56  3.6102E-02
      0.57  4.0541E-02
      0.58  4.5377E-02
      0.59  5.0632E-02
       0.6  5.6332E-02
      0.61  6.2500E-02
      0.62  6.9161E-02
      0.63  7.6341E-02
      0.64  8.4066E-02
      0.65  9.2362E-02
      0.66  1.0126E-01
      0.67  1.1078E-01
      0.68  1.2096E-01
      0.69  1.3183E-01
       0.7  1.4341E-01
      0.71  1.5574E-01
      0.72  1.6885E-01
      0.73  1.8277E-01
      0.74  1.9753E-01
      0.75  2.1317E-01
      0.76  2.2972E-01
      0.77  2.4721E-01
      0.78  2.6569E-01
      0.79  2.8518E-01
       0.8  3.0573E-01
      0.81  3.2736E-01
      0.82  3.5013E-01
      0.83  3.7406E-01
      0.84  3.9920E-01
      0.85  4.2558E-01
      0.86  4.5325E-01
      0.87  4.8225E-01
      0.88  5.1262E-01
      0.89  5.4440E-01
       0.9  5.7764E-01
      0.91  5.1238E-01
      0.92  6.4865E-01
      0.93  6.8652E-01
      0.94  7.2602E-01
      0.95  7.6721E-01
      0.96  8.1012E-01
      0.97  8.5480E-01
      0.98  9.0131E-01
      0.99  9.4970E-01
         1  1.0000E+00
/
FOR  zone 2   $GRAVEL
ROCK  bulk den 2.60e6 gm/cub/me, neff=.380 , ntot=0.380 , ndif=0.380
HYDRaulic  prop. ss = 0.01 Kx*=1.577E+7 Ky*=1.577E+7 cm/yr Kz*=1.577E+7 cm/yr
MULTiphase  flow: VAN, n = 3.70, 0.0819 /cm, Swr = 0.0263
/
FOR  zone 3   $CLAY
ROCK  bulk den 2.60e6 gm/cub me, neff=.386, ntot=0.386, ndif=0.386
HYDRaulic  prop. ss = 6.E-4, Kx*=2.4E-1 Ky*=2.4E-1 cm/yr Kz*=2.4E-1 cm/yr
MULTiphase  flow: VAN, n = 1.33, 8.18E-4 /cm, Swr = 0.2974
/
/ assign initial conditions based upon unit gradient calculation with 38.1 cm/yr
/INIT P  -51.0   zone 1 3*0  (0,1)
```

```
/INIT P    0.0  zone 2 3*0  (0,1)
/INIT P    0.0  zone 3 3*0  (0,1)
/
BOUN  P -1 (S)  FLUX =    0.
BOUN  P  1 (N)  FLUX =    0.
BOUN  P -2 (E)  INTE =    0.
BOUN  P +2 (T)  FLUX =  -40.0 cm/yr
/
/ set code to determine flux for subsequent runs with saltstone
/
FLUX BALA for P ( 1,  63) to ( 22,  63) every 500 steps
FLUX BALA for P ( 1,  50) to ( 22,  50) every 500 steps
FLUX BALA for P ( 1,  49) to ( 22,  49) every 500 steps
FLUX BALA for P ( 1,  43) to ( 22,  43) every 500 steps
FLUX BALA for P ( 1,  39) to ( 22,  39) every 500 steps
FLUX BALA for P ( 1,  38) to ( 22,  38) every 500 steps
FLUX BALA for P (11,  24) to ( 22,  24) every 500 steps
FLUX BALA for P (15,  24) to ( 22,  24) every 500 steps
FLUX BALA for P ( 1,   1) to ( 22,   1) every 500 steps
/
/ OPERATIONAL  CONTROL
/
PROPerty  for P is HARM  mean
MATRIX  in X and Y directions for P in 4 sweeps using ADI
CONVergence  for P; LOCAl mode; value = 1.0e-05, max of 25 iterations
/
WINDow  from (2, 2) to (2,2)
DIAGnostic  node at (30,  40) every 1 steps
OUTPut  every 100000 steps
/RELAx for P 0.5 SE 0.5 KR 0.5 S 0.5
/RELAx for P 0.5
/
SOLVE  for 5.e-3 yr in steps of 1.e-3 increase by 1.0 max 100 min 1e-10
SAVE  U, V, P, S NOW  in 'end'
/
/SOLVE  for 2.e-1 yr in steps of 2.e-3 increase by 1.0 max 100 min 1e-10
/SAVE U, V, P, S NOW
/
/SOLVE  for 2.e-1 yr in steps of 3.e-3 increase by 1.0 max 100 min 1e-10
/SAVE U, V, P, S NOW
/
/SOLVE  for 5.e-1 yr in steps of 5.e-3 increase by 1.0 max 100 min 1e-10
/SAVE U, V, P, S NOW
/
/SOLVE  for 1.e-0 yr in steps of 7.e-3 increase by 1.0 max 100 min 1e-10
/SAVE U, V, P, S NOW  in 'end2'
/
/SOLVE  for 3.e-0 yr in steps of 9.e-3 increase by 1.0 max 100 min 1e-10
/SAVE U, V, P, S NOW
/
/SOLVE  for 5.e-0 yr in steps of 1.1e-2 increase by 1.0 max 100 min 1e-10
/SAVE U, V, P, S NOW
/
/SOLVE  for 10.0 yr in steps of 1.3.e-2 increase by 1.0 max 100 min 1e-10
/SAVE U, V, P, S NOW
/
/SOLVE  for 30.0 yr in steps of 1.5e-2 increase by 1.0 max 100 min 1e-10
/SAVE U, V, P, S NOW  in 'end3'
/
```

```
/SOLVE for 50.0 yr in steps of 2.e-2 increase by 1.0 max 100 min 1e-10
/SAVE U, V, P, S NOW
/
/SOLVE for 100.0 yr in steps of 2.5e-2 factor 1.0 max 100 min 1e-10 1.1 100000
/SAVE U, V, P, S NOW
/
/SOLVE for 200.0 yr by 3.e-2 factor 1.0 max 100 min 1e-10 1.1 100000
/SAVE U, V, P, S
/
END
```

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RESPONSE TO REQUEST OF PEER REVIEW PANEL FOR ADDITIONAL INFORMATION ON THE SRS SALTSTONE PA

5/17/93

Panel's question number 1

1. Explain the long-term viability of the clay/gravel drainage layers incorporated into the closure cap. Specifically:

   a. Provide justification that clay layers can be constructed with an in place hydraulic conductivity of 10^{-9} cm/sec.

   b. Provide justification for the 0.5 cm/sec gravel layer.

   c. Provide an analysis of how long the clay/gravel drainage layers will remain operative and what their conductivities will be after they degrade.

   d. How much water infiltrates into the waste vaults when the drainage layers degrade?

   e. What is the sensitivity of the source term to the increased/decreased water infiltration rate that occurs when the drainage layers degrade?

   f. What effect does the degradation of the drainage layers have on the system performance?

Response

Summary

Although the value for clay conductivity used in the RPA of 7.6×10^{-9} cm/s is arguable, using a value of 10^{-7} cm/s increases infiltration through the upper moisture barrier to 4 cm/yr, which is only a factor of two greater than that analyzed in the RPA. The value for hydraulic conductivity of gravel used in the RPA is only a factor of two greater than that recently measured. The rates of change of the hydraulic conductivities of clay and gravel as they degrade over time have not been determined; however, it is reasonable to expect that the limit of either of these conductivities is the conductivity of the native soil or backfill. Complete degradation of the drainage layers will make 40 cm/yr of infiltration available at the top of the vaults. The source term for intact vaults/saltstone is insensitive to infiltration rate; the source term for fractured vaults/saltstone is very sensitive to infiltration rate. For intact vaults/saltstone, system performance is not impacted by degradation of the drainage layers. However, for fractured vaults/saltstone, system performance is greatly affected.

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Discussion

a. The saturated hydraulic conductivity assumed in the Z-Area Radiological Performance Assessment (see p. A-7) was derived from laboratory data indicating a value of 7.6×10^{-9} cm/s (Wilhite and Wolf, 1986). This value is also supported by the recent laboratory data obtained by Core Laboratories (see response to question 3, and Attachment 1) on cores of two different clays being considered for use.

We acknowledge, however, that the value of 7.6×10^{-9} cm/s is arguable. Field values for constructed clay layers near Z-Area indicate saturated hydraulic conductivities on the order of 1.6×10^{-7} cm/s to 3.2×10^{-8} cm/s (Phifer, 1991). Daniel (1987) reviewed reported measurements of in-situ hydraulic conductivities of compacted clay liners ranging from 4×10^{-5} cm/s to 2×10^{-8} cm/s. Laboratory-measured values may differ from field-measured values as a result of difficulties encountered in constructing a fully-wetted and undisturbed layer of clay over a large area and difficulties in accurately measuring the field hydraulic conductivity for low-permeability materials. On the other hand, Gordon et al. (1989) report that field hydraulic conductivities of 10^{-7} cm/s or less can be achieved with thick clay liners which are constructed with standard compaction equipment in thin lifts. Given this information, a value of 10^{-7} cm/s would perhaps be more defensible for the conductivity of clay in the proposed moisture barriers.

To partially address the possibility that the in-place hydraulic conductivity of clay used in the Z-Area Saltstone Disposal Facility simulations is not adequately conservative, the infiltration analysis was repeated with a hydraulic conductivity of 10^{-7} cm/s for the clay in the upper moisture barrier, rather than 7.6×10^{-9} cm/s. Simulations with a higher value are not warranted as the Z-Area RPA already addresses the case where the clay has completely degraded, and the conductivity is on the order of that of the surrounding backfill or 10^{-5} cm/s. A complete analysis of the effect of changing the clay conductivity also requires considering the clay/gravel drain immediately above the vaults, in addition to the upper moisture barrier. The sensitivity of model results to changes in the conductivity of this lower clay layer is considered in Parts e and f below.

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With a clay conductivity of 7.6×10^{-9} cm/s, the average infiltration through the clay was calculated by PORFLOW-3D to be 0.5 cm/yr. A value of 2 cm/yr was used in the Z-Area RPA. This higher value was used because the infiltration under the clay is not uniform across the domain, with infiltration rates higher than 0.5 occurring near the edges of the clay, and rates lower than 0.5 occurring near the center of the clay. The value of 2 cm/yr used was conservative, however, because this value was used as the average over the whole of the moisture barrier (see pages 4-2 and A-3 of the RPA).

With a clay conductivity of 10^{-7} cm/s, the average infiltration through the clay is calculated by PORFLOW-3D to be approximately 4 cm/yr, which is only a factor of two greater than the value used in the RPA.

b. The saturated hydraulic conductivity of gravel used in the Z-Area RPA (0.5 cm/s, see p. A-7) was based on an analysis of coarse sand, glacial outwash, and stony soil by individuals at the University of Texas. The value obtained in recent laboratory experiments using gravel cores (0.15 to 0.16 cm/s) is somewhat lower than the value used in the RPA. Freeze and Cherry (1989) give a range of hydraulic conductivity for gravel of 0.1 to 100 cm/s. The evidence indicates that the hydraulic conductivity of gravel is not likely to be significantly less than 0.5 cm/s. If the field value were higher, the gravel drain would allow more drainage, and less water would flow through the facility. Therefore, it is likely that the value of 0.5 cm/s is fairly conservative.

c. The longevity of the clay and gravel layers is not known, especially over the long-term. Factors that affect the longevity of the clay (i.e., erosion, desiccation, biointrusion, settling, etc.) were noted on p. 3-7 of the Z-Area RPA. Likewise, the gravel layer may experience a decrease in conductivity over time as a result of plugging by soil particles entering the layer. The clay layer immediately above the vaults is supported by the vaults and monoliths, as is the perched water on the vaults. It is also lower in elevation than the upper barrier. Therefore, the rate of degradation of the lower drain system by the identified mechanisms is probably lower than for the upper moisture barrier.

Degradation will likely be a gradual process, with conductivity of the gravel decreasing and conductivity of the clay increasing over time. It is reasonable to expect that the limit of either of these conductivities is the conductivity of the native soil or overlying backfill.

d. When both clay/gravel layers degrade, the amount of water infiltrating to the waste vaults is controlled by the amount of infiltration below the root zone of the overlying soil. An infiltration analysis provided in Appendix A.1.1 of the RPA indicates that 40 cm/yr is a reasonable value to assume for areas of the SRS that are very nearly level, i.e., where lateral runoff is minimal. Therefore, complete degradation of both clay/gravel drain systems will likely result in the availability of 40 cm/yr infiltration to the top of the vaults.

e. The sensitivity of the source term, or rate of release of radionuclides from the wasteform, is addressed in the following manner.

First, the impact of a fully-degraded clay/gravel drainage layer on intact vaults and saltstone is considered. In the case where saltstone has a hydraulic conductivity of 10^{-11} cm/s, the flux of radionuclides from the saltstone is shown by numerical simulation to be due approximately equally to diffusive and advective mechanisms. Diffusive flux, which is driven by the concentration gradient, is not expected to be significantly impacted if the overlying clay/gravel drain degrades. The advective component of flux would increase if the movement of water through the wasteform were to increase as a result of the degradation of the clay/gravel drain system. However, in the case of intact vaults and saltstone, the movement of water through the vaults is not expected to significantly increase according to the following reasoning. The saturated hydraulic conductivities of intact saltstone (10^{-11} cm/s) and the concrete vaults (10^{-10} cm/s) used in the RPA are considerably lower than that of the overlying material, whether it be clay (10^{-7} cm/s) or backfill (10^{-5} cm/s). Because the overlying material remains saturated in the simulations (i.e., perching occurs with and without the clay/gravel drain), the rate of movement of water through the saltstone is controlled by the less permeable material, or saltstone. In other words, the rate at which water is delivered to the top of the vaults is fairly immaterial, as the saltstone can only transmit the water at a rate proportional to its hydraulic conductivity. The hydraulic gradient across the saltstone is also a factor in water movement, but in the case of a degraded clay/gravel drain, that gradient is expected to decrease due to the additional water in the system. By allowing more water into the system, the soil under the vaults becomes less dry, and thus the capillary pressures decrease (i.e., pressure becomes less negative). Some early simulations conducted in the Z-Area RPA indicated that the clay/gravel drain overlying the vaults was not a significant factor in determining the source term for intact saltstone, which lends support to the above discussion.

Second, the impact of a fully-degraded clay/gravel drain on the rate of radionuclide release from degraded vaults and saltstone is considered. Unlike the intact analysis, the fracture (degraded) analysis is very sensitive to the hydraulic conductivity of the material overlying the vaults. This sensitivity is due in part to the assumption that there is no resistance to flow in the fractures. The fracture analysis assumes that any water that makes it to the top of the vaults will be transmitted through the fractures. Computations were done using the semi-analytical approach for estimating release from fractures documented in the Z-Area RPA (see Section A.1.3). The range of hydraulic conductivity of material overlying the fractured vaults considered was 10^{-5} to 7.6×10^{-9} cm/s. For the case with "no clay/gravel", it was assumed that the gravel was not effective in limiting perched water, and the upper limit on perching was determined by the average infiltration rate of 40 cm/yr for the system. The amount of perching in the cases where clay was present was assumed to remain at 61 cm, as documented in the Z-Area RPA. Computations were carried out for four radionuclides, ^{79}Se, ^{99}Tc, ^{126}Sn and ^{129}I, which were identified as the significant contributors to dose from groundwater ingestion in the Z-Area RPA. The results of this sensitivity analysis are reported in Table 1. These results indicate that the estimated radionuclide release from fractures is very sensitive to the hydraulic conductivity of the clay overlying the vaults.

f. The effect of degradation of the lower clay/gravel drain on system performance was not addressed in the Z-Area RPA, and is addressed here. In part e above, it was noted that the source term for intact saltstone is very insensitive to the range of hydraulic conductivities associated with either intact or degraded clay. However, a degraded clay/gravel layer will allow more water into the system. Thus the water table would not be depressed under the facility, as occurs with an intact clay/gravel drain system. Earlier work on the RPA indicated, however, that this slight depression did not significantly affect the groundwater concentrations at the compliance point for groundwater protection. The regional flow system in effect "buffers" any minor depressions caused by the facility, and plume transport is not greatly affected by the presence or absence of moisture barriers.

able 1. Sensitivity of estimated release from fractures in saltstone as a function of hydraulic conductivity of material overlying vaults.

adionuclide	No Clay/Gravel K_{Clay} = 10^{-5} cm/s 150 cm perched water[a]		Clay/Gravel K_{Clay} = 10^{-7} cm/s 50 cm clay, 61 cm perched water		Clay/Gravel K_{Clay} = 7.6×10^{-9} cm/s 50 cm clay, 61 cm perched water	
	Darcy velocity through fractured saltstone[a] (cm/yr)	Peak fractional flux to water table[b, c] (/yr)	Darcy velocity through fractured saltstone (cm/yr)	Peak fractional flux to water table[b, c] (/yr)	Darcy velocity through fractured saltstone (cm/yr)	Peak fractional flux to water table[b, c] (/yr)
^{79}Se	40.	4.0×10^{-3}	.18	1.8×10^{-5}	.014	1.4×10^{-6}
^{99}Tc	40.	4.5×10^{-5}	.18	2.0×10^{-7}	.014	1.5×10^{-8}
^{126}Sn	40.	1.7×10^{-5}	.18	7.5×10^{-8}	.014	5.6×10^{-9}
^{129}I	40.	1.0×10^{-3}	.18	4.7×10^{-6}	.014	3.5×10^{-7}

[a] This is the maximum amount of perched water at this backfill conductivity that can be assumed. More perching gives a higher than 40 cm/yr darcy velocity.

[b] Assumes all of infiltrating water goes through fractures in the vaults.

[c] Peak is based on the flux from the fractured block when the fractures open.

For fractured saltstone, however, the system performance is affected greatly by the absence of the moisture barriers, due to the sensitivity of the release-from-fracture analysis to the hydraulic conductivity of the material overlying the vault. To evaluate these effects, computations were carried out for ^{79}Se, ^{99}Tc, ^{126}Sn and ^{129}I. The maximum doses for each radionuclide, along with the point in time at which they are predicted to occur, are shown in Table 2. Due to the different sorption coefficients and half-lives, the peak occurrences do not overlap, and thus the peak values in Table 2 are not strictly additive. These results show that the peak groundwater concentrations are of shorter duration when the releases are high, due to depletion of the source.

References for Response 1

Daniel, D. E., 1987, *Earthen Liners for Land Disposal Facilities*, in **Geotechnical Practice for Waste Disposal**, ASCE Specialty Conference, University of Michigan, Ann Arbor, Michigan, June 15-17, 1987.

Freeze, R. A. and J. A. Cherry, 1979, **Groundwater**, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Gordon, M. E., P. M. Huebner, and T. J. Miazga, 1989, *Hydraulic Conductivity of Three Landfill Clay Liners*, **J. Geotechnical Eng.**, 115(8), pp. 1148-1159.

Phifer, M. A., 1991, *Closure of a Mixed Waste Landfill - Lessons Learned*, in **Waste Management'91**, Vol. 1, pp. 517-525.

able 2. Peak dose from fractured saltstone/vaults for different hydraulic conductivities of clay overlying vaults.

adio-uclide	No Clay/Gravel $K_{Clay} = 10^{-5}$ cm/s			Clay/Gravel $K_{Clay} = 10^{-7}$ cm/s			Clay/Gravel $K_{Clay} = 7.6 \times 10^{-9}$ cm/s		
	Peak groundwater concentration (pCi/L)	Peak dose from groundwater (mrem/yr)	Time of peak dose (year)[a]	Peak groundwater concentration (pCi/L)	Peak dose from groundwater (mrem/yr)	Time of peak dose (year)[a]	Peak groundwater concentration (pCi/L)	Peak dose from groundwater (mrem/yr)	Time of peak dose (year)[a]
^{9}Se	1.3×10^{4}	80.	1.5E4	57.	0.4	1.5E4	4.4	0.03	1.5E4
^{9}Tc	3.3×10^{4}	30.	2.4E3 - 2.6E3	147.	0.1	2.4E3 - 3.9E3	11	0.01	2.4E3 -4.4E3
^{26}Sn+d	6.6	0.09	2.2E5	0.029	0.0004	2.2E5	0.0022	0.00003	2.2E5
^{29}I	2.1×10^{2}	40.	3.2E3	0.99	0.2	3.2E3 - >1E4	0.074	0.02	3.2E3 - 1E4

[a] Value in parenthesis is the time in years, or range of years, over which the peak groundwater dose is estimated to occur.

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Panel's question number 2

2. Expand the sensitivity analysis to include degradation of saltstone and concrete hydraulic conductivities for long-term conditions. This would apply to the fractured concrete and flow through the bulk unfractured saltstone blocks. The suggested increase in conductivity is several orders of magnitude.

Response

Summary

Degradation of saltstone and concrete, simulated by increasing hydraulic conductivity by three and two orders of magnitude, respectively, for non-fractured vaults/saltstone, resulted in decreased system performance. However, the resulting annual effective dose equivalent is less than 1 mrem/year.

Discussion

In the Saltstone Disposal Facility RPA, degradation of saltstone monoliths and concrete vaults was addressed by considering release from fractures in the concrete materials. What happens between fractures over time is a question that was not addressed, and it was assumed that the intact portions between fractures could be characterized by the initial hydraulic properties assigned to saltstone and concrete. In response to this question, a sensitivity analysis which focused on the potential effects of degradation of saltstone and concrete properties over time was conducted. This analysis addressed the potential effects of degradation of hydraulic and diffusive properties of these materials.

To conduct this sensitivity analysis, PORFLOW-3D runs were made to evaluate the advective and diffusive flux of radionuclides from saltstone. Because we were considering degraded materials, these runs were done assuming that both of the overlying clay/gravel drains had become nonfunctional, and were characterized by the hydraulic conductivity of backfill. Therefore, infiltration into the source region was assumed to be 40 cm/yr, or the average infiltration rate for the region.

Two additional simulations were carried out for four radionuclides: ^{79}Se, ^{99}Tc, ^{126}Sn and ^{129}I. These radionuclides were identified in the RPA as the significant contributors to dose from groundwater ingestion. The first simulation (Run 1) assumed that the concrete and saltstone were characterized by a hydraulic conductivity of 10^{-8} cm/s, which is two to three orders of magnitude higher than that assumed for the RPA simulations. Due to the difficulty in defining and simulating the time sequence of change in material properties, the hydraulic conductivity was simply assumed to be higher initially, and remain higher throughout the simulation.

The second simulation (Run 2) assumed a hydraulic conductivity of 10^{-8} cm/s for the concrete materials and also assumed that the effective diffusion coefficient had increased to 10^{-7} cm^2/s from $5x10^{-9}$ cm^2/s (see p. 2-56 of the RPA).

The results of these simulations are reported in Table 3 in terms of peak groundwater concentrations and time of occurrence of peak concentrations. Along with these results are the peak groundwater concentrations attributed to fractures and intact saltstone in the Z-Area RPA, for comparison. It is apparent from this sensitivity analysis that degradation of saltstone and concrete between fractures would significantly increase the release of radionuclides over that reported in the Z-Area RPA for intact saltstone and concrete, and would result in an earlier peak. Furthermore, consideration of the degraded saltstone conductivity would increase the predicted peak groundwater concentration over that attributed to fractures by up to a factor of forty. It should be noted, however, that the groundwater concentrations attributed to fractures in Table 3 are from the RPA; they do not consider degradation of the overlying clay layer, and thus are not strictly comparable to Runs 1 or 2 in Table 3. It should also be noted that the results appear to be insensitive to the effective diffusion coefficient, since the results of Run 1 and 2 are essentially the same. This indicates that at these higher hydraulic conductivities (that is, greater than 10^{-11} cm/s) the flux from the saltstone is advection-dominated.

Annual effective dose equivalents corresponding to the peak groundwater concentrations from Runs 1 and 2 were computed, and are listed in Table 4. For comparison, the results from the Z-Area RPA for the intact and degraded (i.e., fractured) vaults and saltstone are also shown. This table indicates that while there is a significant increase in predicted dose attributable to a higher conductivity of saltstone and concrete, the annual effective dose equivalent remains less than 1 mrem/yr.

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Table 3. Sensitivity analysis results for degraded material properties of unfractured saltstone and concrete.

	Peak Groundwater Concentration							
	Z-Area RPA Intact[a]		Z-Area RPA Fracture[b]		Run 1[c]		Run 2[d]	
	pCi/L	Time (yr)	pCi/L	Time (yr)	pCi/L	Time (yr)	pCi/L	Time (yr)
^{79}Se	$1.2x10^{-2}$	$2.1x10^{5}$	4.4	$1.5x10^{4}$	$2.0x10^{1}$	$8.0x10^{4}$	$2.1x10^{1}$	$8.0x10^{4}$
^{99}Tc	$6.7x10^{-7}$	$1.6x10^{6}$	$1.1x10^{1}$	$2.4x10^{3}$	$1.1x10^{2}$	$2.8x10^{5}$	$1.1x10^{2}$	$2.8x10^{5}$
^{126}Sn	$4.0x10^{-11}$	$9.2x10^{5}$	$2.2x10^{-3}$	$2.2x10^{5}$	$9.1x10^{-2}$	$3.0x10^{5}$	$9.1x10^{-2}$	$3.0x10^{5}$
^{129}I	$7.2x10^{-3}$	$>2.5x10^{6}$	$7.5x10^{-2}$	$3.2x10^{3}$	$1.6x10^{-2}$	$2.8x10^{5}$	$1.6x10^{-2}$	$2.8x10^{5}$

[a] Intact saltstone and concrete; $K_{sat} = 10^{-11}$ cm/s for saltstone and 10^{-10} cm/s for concrete; $D_{eff} = 5x10^{-9}$ cm^2/s. See RPA, p. 4-8.

[b] Fractured saltstone and concrete; $K_{sat} = 10^{-11}$ cm/s for saltstone and 10^{-10} cm/s for concrete; $D_{eff} = 5x10^{-9}$ cm^2/s. See RPA, p. 4-9.

[c] $K_{sat} = 10^{-8}$ cm/s for saltstone and 10^{-8} cm/s for concrete; $D_{eff} = 5x10^{-9}$ cm^2/s.

[d] $K_{sat} = 10^{-8}$ cm/s for saltstone and 10^{-8} cm/s for concrete; $D_{eff} = 10^{-7}$ cm^2/s.

Table 4. Peak annual effective dose equivalents for degraded saltstone and concrete.

Radio-nuclide	DCF[a] (mrem/yr per pCi/L)	Peak Annual Effective Dose Equivalent (mrem/yr)			
		Z-Area RPA Intact[b]	Z-Area RPA Fracture[c]	Run 1[d]	Run 2[e]
^{79}Se	$6.1\text{x}10^{-3}$	$7\text{x}10^{-5}$	$3\text{x}10^{-2}$	$1\text{x}10^{-1}$	$1\text{x}10^{-1}$
^{99}Tc	$9.5\text{x}10^{-4}$	$6\text{x}10^{-10}$	$1\text{x}10^{-2}$	$1\text{x}10^{-1}$	$1\text{x}10^{-1}$
^{126}Sn + d	$1.3\text{x}10^{-2}$	$5\text{x}10^{-13}$	$3\text{x}10^{-5}$	$1\text{x}10^{-3}$	$1\text{x}10^{-3}$
^{129}I	$2.0\text{x}10^{-1}$	$1\text{x}10^{-3}$	$2\text{x}10^{-2}$	$3\text{x}10^{-3}$	$3\text{x}10^{-3}$

[a] DCF = Dose conversion factor = Annual effective dose equivalent per unit concentration in drinking water. See RPA, p. 4-11.

[b] Intact saltstone and concrete; $K_{sat} = 10^{-11}$ cm/s for saltstone and 10^{-10} cm/s for concrete; $D_{eff} = 5\text{x}10^{-9}$ cm^2/s. See RPA, p. 4-12.

[c] Fractured saltstone and concrete; $K_{sat} = 10^{-11}$ cm/s for saltstone and 10^{-10} cm/s for concrete; $D_{eff} = 5\text{x}10^{-9}$ cm^2/s. See RPA, p. 4-12.

[d] $K_{sat} = 10^{-8}$ cm/s for saltstone and 10^{-8} cm/s for concrete; $D_{eff} = 5\text{x}10^{-9}$ cm^2/s.

[e] $K_{sat} = 10^{-8}$ cm/s for saltstone and 10^{-8} cm/s for concrete; $D_{eff} = 10^{-7}$ cm^2/s.

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Panel's question number 3

3. Provide data to support the hydraulic properties of clay, concrete, and saltstone as identified in the PA. Provide a description and justification for the long-term behavior of these properties and the effect they might have on the performance of the disposal facility.

Response

Summary

Recent laboratory measurements support the values used in the RPA for hydraulic conductivity of saltstone and concrete. However, the value for clay conductivity used in the RPA may not be supported. Recent sensitivity analyses indicate that degradation of the drainage layers has a greater impact on system performance due to release from fractures than degradation of the hydraulic conductivities of concrete and saltstone.

Discussion

To address the first part of this question, the Project Summary from the report on the recent laboratory analyses performed at Core Laboratories in Carrollton, Texas is attached. The complete report is not being provided because of its length (≈ 1,000 pages). Copies of the complete report can be made available, if desired. These analyses were conducted on clay, concrete, and saltstone materials representative of those that have been and will be used in the Saltstone Disposal Facility (SDF). We recognize that extrapolating from laboratory studies to the field is not wholly defensible, but believe that the laboratory results indicate the values used for the properties in the RPA are not without basis. From the table entitled Summary of Permeability to Liquid Test Results in the Project Summary, the hydraulic conductivity of saltstone is suggested to be on the order of 10^{-12} cm/s, while that for concrete from saltstone vaults is on the order of 10^{-9} to 10^{-10} cm/s. The corresponding values used in the RPA were 10^{-11} cm/s and 10^{-10} cm/s, respectively. The two different clay cores that were tested indicated conductivities on the order of $7x10^{-9}$ cm/s, while a value of $7.6x10^{-9}$ cm/s was used in the RPA. As discussed in the response to question 1, it is recognized that this clay value may not be representative of a field-achieved value, due to the difficulty in compacting clay over a large area to the degree achievable in the laboratory.

Because flux rates of radionuclides from saltstone are very small, and thus source depletion is very slow, it is reasonable to expect that degradation of the clay, saltstone and concrete will impact the source term at some time in the future. Various mechanisms of degradation were discussed in the RPA (Sect. 3.1.3). These mechanistic descriptions did not, however, specifically address the impact of degradation on hydraulic properties. In the responses to the previous two questions from the PRP, this latter concern has been addressed through the sensitivity analyses that were performed. Degradation of clay, resulting in increased hydraulic conductivity of the material overlying the vaults, is a potentially significant factor in increasing release from fractures (Table 1). Degradation of saltstone and concrete between fractures, resulting in increased hydraulic conductivity, also has a potentially significant impact on the estimated groundwater concentration attributable to releases from the porous materials (Table 3). In terms of compliance, a comparison of estimated doses resulting from degradation of hydraulic properties of clay and saltstone (Table 5) suggests that degradation of clay has a more serious impact on the facility performance than does degradation of saltstone or concrete. This conclusion may be a function of the perhaps overly-conservative assumption that all of the water infiltrating into the system flows through fractures.

Table 5. Comparison of peak annual effective dose equivalents for degraded clay and degraded saltstone and concrete.

Radionuclide	Peak annual dose equivalents (mrem/yr)	
	Fractures (degraded clay)	Intact (degraded saltstone and concrete)
^{79}Se	80	0.1
^{99}Tc	30	0.1
^{126}Sn + d	0.09	0.001
^{129}I	40	0.003

Panel's question number 4

4. The chemical form of technetium affects its transport in the environment and its bioavailability. These parameters, in turn, directly affect potential human exposure and radiation doses. To further analyze the dose assessment for Tc, the PRP requests that additional analyses/information be provided on the following:

   a. The likely chemical form of Tc, based on measurements and/or geochemical modeling, and the associated solubilities in water, along with any available soil-water partitioning data.

   b. A review of the plant-uptake studies reported in the literature (including those published after the cited reviews) and the chemical forms of Tc used in these studies.

   c. An analysis of the basis of the dose conversion factor for Tc, with particular reference to the technical basis for the gut uptake factor used to determine the dose conversion factor. If the uptake factor is based on a soluble form of Tc, please determine whether data are available in the literature that could be used to estimate or infer the gut uptake factor for insoluble species and, if such data are available, derive an estimate for insoluble Tc.

   d. An estimate of the amount of Tc on crops derived from rain splash, using available studies.

Response

Summary

SRS laboratory tests and geochemical modeling support the assumption that technetium in saltstone is in an insoluble form. A review of plant-uptake studies indicates that the radiological performance assessment (RPA) used a conservative basis to estimate the uptake of technetium from saltstone. The dose conversion factor for technetium that was used in the RPA is appropriate. Rain splash, which was not assessed in the RPA, will contribute less than 10% of the dose from technetium. In summary, the analysis presented in the RPA is unduly conservative. As the RPA is maintained, the information provided below will be incorporated in the next revision.

Discussion

a. The salt solution waste that will be made into saltstone contains high concentrations of hydroxide, nitrate and nitrite (RPA, page 2.41, Table 2.3-2). This oxidizing environment results in chromium and technetium being present in the waste in oxidized forms. Chromium is present as chromate (CrO_4^-). Technetium is present as pertechnetate (TcO_4^-). The distribution of technetium in the waste is discussed in the RPA on page 2-42. This discussion references the work of Fowler and Cook, 1984a. This study assessed the results of waste analyses and concluded that soluble technetium in SRS waste is in the pertechnetate form.

As the saltstone program evolved, several different wasteform compositions were considered (RPA, pages 2-46 to 2-55). The current saltstone composition, and that which is analyzed in the RPA, contains blast-furnace slag and is called "slag saltstone". An earlier composition that does not contain slag is called "non-slag saltstone".

Blast furnace slag contains ferrous iron and sulfur (RPA, page 2-52). As discussed in the RPA (pages D-7 to D-11), geochemical modeling results predict that technetium in slag saltstone is precipitated as the sulfide. This is also discussed in the RPA in Section 2.4.3.2 on pages 2-56 and 2-58.

Leaching tests at Savannah River, including the use of EPA tests to determine waste toxicity (EP- and TCLP tests), show that nitrate, technetium and chromium have similar leachabilities in non-slag saltstone. However, in slag saltstone, leachabilities of chromium and technetium are reduced compared to nitrate. These observations support the results of geochemical modeling that the technetium in slag saltstone is in a much less soluble form than in the salt solution. The pertinent Savannah River reports are listed and abstracted below.

b. We agree that further consideration of the plant uptake factor (B_v) for technetium is warranted. As stated in the RPA (page 5-4), experiments should be done to assess the uptake of technetium to plants from slag saltstone.

In the RPA, the generic value for B_v of 5, which was adopted by Ng (RPA, page 4-47 and A-69) was used as a basis to estimate root uptake of technetium. This value was reduced by a factor of 0.012 to represent the lower availability of technetium from slag saltstone.

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This analysis is conservative by about an order of magnitude. The value of 5 (wet weight) for food crops was assumed by Ng based on the soil to plant concentration ratio for forage (i.e., grasses) and, thus, would generally apply only to the vegetative parts of food crops and feed plants, such as leaves and stems. The concentration ratio for nonvegetative (reproductive) parts of the plant is usually much lower than that for vegetative parts. The study by Murphy cited in the RPA (WSRC-RP-90-421) found the technetium concentration ratio to be a factor of 200 to 500 less for nonvegetative plant parts than for vegetative. Also, only a small percentage of food crops consumed are vegetative parts (leafy vegetables). A survey by Hamby (1992) found that, in the vicinity of the Savannah River Site, only about 11% of all food crops consumed are leafy vegetables.

Baes et al. (1984) cite a value of 9.5 (dry weight) for the technetium soil to plant ratio for forage and a value of 1.5 (dry weight) for food crops. If the value of 1.5 is put on a wet weight basis using a wet to dry weight conversion factor of 0.43 (Baes, et al, Section 2.1), B_v becomes 0.64. If this value had been used as the basis for B_v in the RPA, calculated doses from technetium-99 would be reduced correspondingly by a factor of about 8. The dose from technetium-99 presented in the RPA on page 4-20 in Table 4.1-11 would be reduced from 40 to about 5 mrem/year. The sum of doses presented in this table to the inadvertent intruder from the agriculture scenario would be reduced from 50 - 110 mrem/year to 16 - 76 mrem/year.

c. The dose conversion factor used in the RPA is taken from DOE/EH-0071 "Internal Dose Conversion Factors for Calculation of Dose to the Public"; the gut uptake factor, f_1, used for technetium is 8E-1 (page 2.180 of DOE/EH-0071). These values are based on the recommendation in Publication 30 of the International Commission on Radiological Protection (ICRP). The value $f_1 = 0.8$ adopted by the ICRP was based on (1) measurements in humans administered technetium in pertechnetate form, which gave a value of about 0.95, and (2) measurements in rats administered technetium chloride, which gave a value of about 0.5. The assimilation of technetium in soluble form is not straightforward. A study by Hays (1973), which was noted by the ICRP, showed that the GI-tract absorption fraction could vary by an order of magnitude or more in the same patient when administration of technetium in the soluble pertechnetate form was repeated.

In the RPA, credit for the insoluble form of technetium in saltstone is taken by reducing the plant uptake factor (RPA, page A-69). Technetium taken up by plants must be in soluble form in order to be assimilated by the plant. Therefore, use of a relatively large f_1 in the dose conversion factor is warranted.

d. Rain splash can contaminate food crops with soil, thus resulting in a greater concentration of radioactivity in the plant than that arising from assimilation through the plant roots. Rain splash was not considered in the RPA. Thus, the analysis of dose in the RPA from the non-consumption of vegetation is potentially non-conservative. However, the following considerations indicate that rain splash is not significant in this RPA.

Pinder *et al.* (1990) studied the relative importance of resuspension and root uptake for plutonium in corn and other grains in field experiments at the Savannah River Site. This study found that resuspension (presumably including rain splash) transferred about 10 times more plutonium from surface soil to plants than did root uptake. The study noted that transfer of plutonium to plants by root uptake only (tests were conducted in a manner to prevent resuspension and rain splash) resulted in an uptake factor of about 3×10^{-4}. Thus, resuspension and rain splash would result in an uptake factor of about 0.003. Although this factor was determined for plutonium, it should be independent of radionuclide. As noted above, the plant uptake factor for technetium used in the RPA was 0.06. Also, as noted above, a more reasonable value is 0.008. Both of these values are greater than the estimated uptake caused by resuspension and rain splash, thus indicating that rain splash is relatively unimportant for technetium, even in an insoluble form.

Vegetables are usually washed before being consumed. Washing would tend to reduce contamination on the plants resulting from rain splash. Also, in the scenarios involving consumption of contaminated plants that were analyzed in the RPA, any technetium present in the plants as a result of rain splash would be in the insoluble form. If this technetium was not removed from the plants by washing, it would likely not be as readily assimilated in the human gut as the technetium taken up by the plant through its roots. This consideration would also tend to mitigate the effect of rain splash.

References for Response 4

Baes et al., 1984, *A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture*, ORNL-5786, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Hamby, D. M, 1992, *Site-Specific Parameter Values for the Nuclear Regulatory Commission's Food Pathway Dose Model*, **Health Physics**, Vol. 62, p. 136.

Hays, M. T., 1973, *^{99m}Tc-Pertechnetate transport in man: absorption after subcutaneous and oral administration: secretion into saliva and gastric juice*, **J. Nucl. Med.** Vol. 14, p. 331.

Pinder, J. E., K. W. McLeod, and D. C. Adriano, *Atmospheric Deposition, Resuspension, and Root Uptake of Pu in Corn and other Grain-Producing Agroecosystems near a Nuclear Facility*, **Health Physics**, Vol. 59, p. 853.

<u>SRS Reports supporting the insoluble form of Tc in Saltstone</u>

Oblath, S. B. 1984, *Relative Release Rates of Nitrate, Tc, Cs, and Sr from Saltstone*, DPST-84-620, Savannah River Laboratory, E. I. du Pont de Nemours & Co., Inc.

> Samples of non-slag saltstone were leached in distilled water according to a modified ANS 16.1 procedure. Results show equal leachability for nitrate and technetium. Cesium-137 is leached at 70% and strontium-90 at 4% of the nitrate leach rate.

Oblath, S. B. and C. A. Langton 1985, *Comparison of Leach Results from Field and Laboratory Prepared Samples*, DPST-85-261, Savannah River Laboratory, E. I. du Pont de Nemours & Co., Inc.

> Samples of non-slag saltstone were prepared in the laboratory and in the field. Field prepared samples were obtained from batches of non-slag-saltstone produced for the large-scale saltstone lysimeters. These samples were made from actual decontaminated salt solution. The laboratory prepared samples used the same formulation, but were made with simulated salt solution. Leach rates for nitrate for the field and laboratory prepared samples were the same. The leach rate of cesium was about 70% less than that for nitrate in both sets of samples. In the field prepared samples, the leach rate of antimony-125 was about an order of magnitude less than that of cesium-137. The leach rate of ruthenium-106 was estimated to be at least an order of magnitude less than that of cesium-137.

Oblath, S. B. 1986, *Leach Test of 107 Liter Saltstone Blocks at Brookhaven National Laboratory*, DPST-86-442, Savannah River Laboratory, E. I. du Pont de Nemours & Co., Inc.

> Samples of non-slag and slag saltstone, prepared in the field (as described in Oblath and Langton, 1985) were formed in 107 liter (28-gallon) containers. These samples were leached according to the ANS 16.1 procedure at Brookhaven National Laboratory. Observed leach rates are the same as smaller-scale samples reported in Oblath and Langton, 1985. For non-slag saltstone, leach rates of nitrate, chromium and technetium were the same. Leach rates from slag saltstone for chromium and technetium were at least an order of magnitude lower than for nitrate.

Langton, C. A. 1986a, *Reduced Technetium Leaching in Slag - Class F Fly Ash Saltstone Formulations*, DPST-86-551, Savannah River Laboratory, E. I. du Pont de Nemours & Co., Inc.

> Samples of non-slag and slag saltstone made from simulated salt solution spiked with technetium-99 were leached in distilled water according to a modified ANS 16.1 procedure. Nitrate and technetium leach rates were determined. For the non-slag saltstone, nitrate and technetium leach rates were similar. For the slag saltstone, technetium leach rates were an order of magnitude less than those for nitrate.

Langton, C. A. 1986b, *Reduced Chromium Leaching in Slag-Based Saltstone Formulations*, DPST-86-863, Savannah River Laboratory, E. I. du Pont de Nemours & Co., Inc.

> Samples of non-slag and slag saltstone made from CrO_4^- simulated salt solution spiked with chromium as were leached in distilled water according to a modified ANS 16.1 procedure. Nitrate and chromium leach rates were determined. The chromium leach rate was at least an order of magnitude lower than the nitrate leach rate in the slag saltstone while in the non-slag saltstone, the leach rates were similar.

Langton, C. A. 1987, *EP Toxicity and TCLP Results for Cr-Doped Slag-Based Saltstone*, DPST-87-467, Savannah River Laboratory, E. I. du Pont de Nemours & Co., Inc.

> Samples of non-slag and slag saltstone made from CrO_4^- simulated salt solution containing chromium as were tested according to the EP-Toxicity and TCLP tests. Results show that up to 5000 ppm chromium in salt solution can be tolerated in slag saltstone without exceeding the non-hazardous criterion of the tests. For non-slag saltstone, only about 680 ppm chromium can be tolerated. These results were presented in the RPA on page 2-53 in Figure 2.4-1.

Clark, S. B. and E. L. Wilhite 1991, Low-Level Liquid Waste Disposal at the Savannah River Site: A Large Scale Demonstration of Saltstone. *Waste Management'91*. Vol. II, edited by R. G. Post, University of Arizona, Tucson, Arizona, pp. 603-609.

Results of field lysimeter experiments were analyzed. One experiment contains three 30-ton monoliths of non-slag saltstone. The other contains a 55-gallon sized monolith of slag saltstone. Ratios of nitrate and technetium in the sump water of the lysimeters varied as a function of the type of saltstone. For non-slag saltstone, nitrate and technetium concentrations were strongly correlated. For slag saltstone, technetium concentrations in sump water were always much lower than the nitrate concentration. Samples of soil moisture, collected just below the monoliths, showed the same trend.

These results are presented in the RPA on page 2-54 in Figure 2.4-2. They are also discussed in the RPA on page A-69.

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Panel's question number 5

5. In the area of validation and verification of model results, the Panel requests:

   a. Supplemental information that outlines and describes efforts to date to compare modeling assumptions or results with field data.

   b. A description of near-field monitoring programs or validation exercises that may provide data to confirm PA assumptions and results (TDR probes and suction lysimeters were previously suggested).

Response

Summary

The flow and transport code used in the RPA has been validated by comparison with field data at the Las Cruces Trench in New Mexico, and at Z-Area. SRS is seeking appropriate near-field monitoring technology to validate models and assumptions used in the RPA and will implement such technology as it becomes available.

Discussion

a. The PORFLOW-3D computer code has been minimally validated in an application at Las Cruces, NM (Rockhold and Wurstner, 1991). This application involved a two-dimensional simulation of unsaturated flow and transport. The results of the comparison of model simulation results to field data indicated reasonably good agreement with respect to water content changes in response to input of water to the system. Only fair (i.e., qualitative) agreement was obtained between simulated and observed solute concentrations. The investigators believed that although they attempted to create a two-dimensional flow regime in the field experiment, three-dimensional flow and edge effects were significant factors in impacting the validation results.

   Field measurements of base flow in the three streams in the vicinity of Z-Area were made in the course of completing the Radiological Performance Assessment. The purpose of these measurements was to test the validity of the discharge rates predicted by saturated flow application of the PORFLOW-3D code. The data collected are provided in Appendix C.3 of the RPA. In Sect. 3.4.2.1, the comparison of the stream flow data to predicted discharge rates to streams is discussed. The conclusions of this water balance exercise were that the flow model reasonably simulated the amount of discharge occurring to these streams from groundwater.

b. We agree that near-field monitoring is necessary to validate the predicted performance of the SDF. However, technology for accomplishing near-field monitoring, especially in terms of in-situ monitoring of non-volatile contaminants, is in a developmental stage. SRS will continue to seek appropriate near-field monitoring technology for the SDF and implement such technology as it becomes available. Suction lysimeters and time-domain resistometer (TDR) probes will be considered for use in monitoring the region immediately adjacent to, or underneath, vaults. The longevity of these in-place monitoring techniques must be evaluated before a decision as to their potential efficacy can be made. Such in-place procedures have the potential for providing information on moisture profiles and plume movement, or lack thereof, that can be used to provide validation of predictions provided in the Z-Area RPA.

Meanwhile, SRS will continue to collect data from the saltstone lysimeters located in the low-level waste burial grounds at SRS (E-Area). The lysimeter program will be continued for one or two more years until closure of the burial grounds takes place.

Reference for Response 5

Rockhold, M. L. and S. K. Wurstner, 1991. *Simulation of Unsaturated Flow and Solute Transport at the Las Cruces Trench Site Using the PORFLO-3 Computer Code*, PNL-7562, Pacific Northwest Laboratory, Richland, Washington, March, 1991.

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Attachment 1

Project Summary

Physical Properties Measurement Program

Core Laboratories Report
DRES - 92119

Performed by
Core Laboratories,
Carrollton, Texas

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but included

PROJECT SUMMARY

Background

The testing program was designed to measure the fluid flow and mechanical properties of various materials utilized in the construction of waste fluid confinement vaults. All testing was performed at the minimum confining stress possible to model the field conditions. The ten supplied materials were as follows:

<u>Unconsolidated Materials</u>

- Top Soil
- Gravel
- Dixie Clay
- Grace Clay
- Sand
- Burma Road Backfill
- Turner Road Backfill

<u>Consolidated Materials</u>

- Concrete from the Saltstone Vault
- Concrete from the E-Area Vault
- Saltstone

The first seven materials, which are unconsolidated, were provided to Core Laboratories in labeled one gallon metal containers. The Concrete from the E-Area vault material was a 1ft x 1ft x 1ft block, the Concrete from the Saltstone Vault was a 3 ft x 1 ft cylinder, and the Saltstone was contained in several one gallon plastic jugs. Test samples of each material were prepared as described in the test protocols for each type of measurement.

Specific Permeability to Liquid and Effective Porosity

Specific permeability to liquid and effective porosity were determined for two samples of each unconsolidated material and three for each of the consolidated materials using the procedures described in Section 2. The tests were performed with no confining pressure to model the field conditions of the materials as closely as possible. The unconsolidated materials were tightly packed in stainless steel tubes with screens on each end. The consolidated materials were mounted in an epoxy coating. A test concrete sample, whose specific permeability to liquid had been previously determined at minimal confining stress in a coreholder, was mounted in epoxy and permeability remeasured, as a quality control check of the epoxy seal. The pre- and post-mounting permeability to liquid for this sample were equivalent, confirming the sealing of the epoxy to the sample.

Specific permeability to liquid and effective porosity test results are presented in summary form on Pages 1 and 2, and in detailed format in Section 2. The duplicate measurements were in excellent agreement for all materials. The calculated hydraulic conductivity was in the expected range for samples of this type.

Unsteady-State Gas-Water Water-Gas Relative Permeability

Unsteady-state tests were performed to determine the gas-water and water-gas relative permeability relationships on one sample of each material following the specific permeability to brine determinations using the procedures described in Section 3. The unsteady-state method was utilized due to the nature of the samples and the low permeability values of the consolidated samples.

The displacements were generally piston-like in both directions, resulting in end-point determinations only for the majority of the tests (gas-water curves were determined for only the Top Soil, Sand, Burma Road Backfill, and Turner Road Backfill samples). Gas-Water Water-Gas relative permeability test results are presented in summary form on Pages 3 and 4, and in graphical and tabular formats in Section 3. Where incremental two-phase data was not available, curves were extrapolated from the end-points.

The Top Soil, Gravel, and Sand samples demonstrated gas-water relative permeability characteristics typical of clean water-wet unconsolidated materials. The Dixie Clay, Grace Clay, Burma Road Backfill, and Turner Road Backfill samples showed evidence of drying during the gas injection, which apparently caused cracking or shrinkage of the clay materials in these samples. The effective permeabilities to gas at residual water saturation and to water at trapped gas saturation were higher for each of these five samples than the corresponding specific permeability to brine.

The Concrete samples demonstrated expected behavior, however, the throughputs on these samples were less than a pore volume due to their low permeability. The Saltstone sample exhibited an effective permeability to gas at residual water saturation 32400 times higher than the specific permeability to brine and an effective permeability to water at trapped gas saturation 157 times higher. These data can be explained by drying of the Saltstone during the gas injection, or the presence of a trapped gas saturation in the original preparation of the material. The observed increase in permeability is not due to bypassing around the epoxy seal as the absolute permeability measurements are low (effective permeability to gas at residual water saturation - 1.2e-01 md, effective permeability to water at trapped gas saturation - 5.8e-04 md).

Air-Brine Capillary Pressure

Air-brine drainage capillary pressure curves were determined on two samples of each of the unconsolidated materials using the procedures described in Section 4. The water saturation at a capillary pressure of 35 psi for the Top Soil, Sand and Gravel, ranged from 8.4 to 21.8 percent pore space. These values are in the expected range for samples of this type. The clay containing samples (Dixie Clay, Grace Clay, Burma Road Backfill, and Turner Road Backfill) ranged from 71.2 to 94.1 percent pore space water saturation at 35 psi capillary pressure.

Air-brine imbibition capillary pressure curves were determined on one sample of each of the consolidated materials using the procedures described in Section 4. The samples were first desaturated with air at 35 psi capillary pressure, then allowed to imbibe water at pressures up to 35 psi. These tests indicated that less than while ten percent pore space water will be removed by air at 35 psi capillary pressure, the displaced fluid will re-imbibe to resaturate the pore space.

The end-point saturations for all materials are in good agreement with those determined in the gas-water relative permeability tests. The duplicate measurements were in good agreement for all materials. Air-Brine Capillary Pressure test results are presented in summary form on Pages 5 and 6, and in graphical and tabular format in Section 4.

Acoustic Velocity

Dynamic Moduli and Poisson's Ratio were determined on two samples of each material by measuring acoustic velocity as outlined in Section 5. Gravel, Burma Road Backfill, and Turner Road Backfill were retested for quality control purposes. An Ottowa Sand sample was prepared and tested as a check plug in addition to the normal aluminum standard. These samples were tested at three overburden pressures in 500 psi increments beginning with 300 psi. Net stress was held constant by increasing the overburden and pore pressures on the samples at the same rate. Overburden pressure variation was used to determine if improper transducer seating was occurring at low pressures causing inaccurate travel times. A saltstone vault concrete sample (2-B), was also re-tested for confirmation of the data.

The data demonstrate that measured travel time increases gradually with increasing overburden pressure. The lack of erratic or excessive changes in travel times indicates that transducer seating at low pressures is effective. Retested backfill samples are in close agreement to the original data as is the saltstone vault concrete sample.

The gravel samples, however, show a significantly higher shear velocity over the original test data. In order to verify this finding, another set of gravel samples was prepared and tested with similar results. The original data files were reviewed in an attempt determine a reason for the variance. Original data acquisition work sheets indicate that first arrival times for the shear waves were very difficult to determine which resulted in a reported shear velocity which was too low. The cause of this weak shear signal in the original test was probably due to loose screens on the samples. The original data has been revised for the final presentation.

Acoustic velocity test results are presented in summary form on Pages 7 and 8, and in graphical and tabular format in Section 5.

Pore Volume Compressibility

Pore Volume Compressibility was measured on two samples of each material using the procedures described in Section 6. The pore volume reduction at 200 psi applied stress for the unconsolidated materials ranged from 23.95 to 38.53 percent. The consolidated materials demonstrated much lower reductions in pore volume, ranging from 0.98 to 5.21 percent. These test results are as expected for these materials. The duplicate measurements were in good agreement for all samples. Pore Volume Compressibility test results are presented in summary form on Page 9, and in graphical and tabular format in Section 6.

Quality Control

All equipment was calibrated and standards evaluated as described in the individual test protocols. Copies of all records of pertinent information regarding the performance of each type of test are included at the end of each Section. The main tool for assessing the quality of the data set was duplicate measurements. In all cases, the duplicate measurements were in good agreement. In general, the data was within the expected ranges for the types of materials tested.

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SUMMARY OF PERMEABILITY TO LIQUID TEST RESULTS

Westinghouse Savannah River Company

Sample I.D.	Cumulative Test Time, days	Length, cm	Area, cm^2	Viscosity, cp	Delta Pressure, psi	Incremental Flow Rate, cc/sec	Permeability to Liquid, millidarcies	Hydraulic Conductivity, cm/sec (Q/A)	Porosity, percent
Top Soil - 1	3.0	7.59	11.76	0.988	0.050	0.017	3120	3.06e-03	40.5
Top Soil - 2*	3.0	7.59	11.76	0.988	0.049	0.017	3190	3.13e-03	38.8
Gravel - 1	3.0	30.48	5.07	0.988	0.029	0.050	151000	1.48e-01	38.0
Gravel - 2*	3.0	30.48	5.07	0.988	0.027	0.050	162000	1.59e-01	38.6
Dixie Clay - 1	11.0	7.59	11.76	0.988	50.0	5.1e-05	9.5e-03	9.4e-09	54.1
Dixie Clay - 2*	11.0	7.59	11.76	0.988	50.0	3.9e-05	7.3e-03	7.1e-09	57.7
Grace Clay - 1	17.8	7.59	11.76	0.988	50.0	3.4e-05	6.4e-03	6.3e-09	54.8
Grace Clay - 2*	17.8	7.59	11.76	0.988	50.0	4.2e-05	7.9e-03	7.7e-09	57.6
Sand - 1	2.5	7.59	11.76	0.988	0.100	0.033	3120	3.06e-03	39.9
Sand - 2*	2.5	7.59	11.76	0.988	0.055	0.017	2840	2.79e-03	34.8
Burma Road Backfill - 1	36.8	7.59	11.76	0.988	50.0	2.1e-03	4.0e-01	3.9e-07	47.5
Burma Road Backfill - 2*	35.8	7.59	11.76	0.988	50.0	4.3e-03	8.1e-01	8.0e-07	51.6

*Sample selected for Gas-Water Relative Permeability Tests

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SUMMARY OF PERMEABILITY TO LIQUID TEST RESULTS

Westinghouse Savannah River Company

Sample I.D.	Cumulative Test Time, days	Length, cm	Area, cm^2	Viscosity, cp	Delta Pressure, psi	Incremental Flow Rate, cc/sec	Permeability to Liquid, millidarcies	Hydraulic Conductivity, cm/sec (Q/A)	Porosity, percent
Turner Road Backfill - 1	36.8	7.59	11.76	0.988	50.0	1.6e-03	3.1e-01	3.0e-07	45.5
Turner Road Backfill - 2*	35.8	7.59	11.76	0.988	50.0	2.6e-03	4.8e-01	4.7e-07	42.7
Concrete from Saltstone Vault-1B	24.0	6.24	11.05	2.39	50.0	5.3e-07	2.1e-04	1.1e-10	17.4
Concrete from Saltstone Vault-5B	37.7	5.77	11.13	0.988	50.0	1.6e-05	2.4e-03	2.3e-09	18.9
Concrete from Saltst. Vault-7B*	38.0	5.05	11.10	0.988	50.0	9.9e-06	1.3e-03	1.3e-09	16.8
Concrete from E-Area Vault-2E	36.9	5.46	10.76	0.988	50.0	5.0e-09	7.4e-07	7.2e-13	18.1
Concrete from E-Area Vault-4E	37.5	5.35	10.68	0.988	50.0	8.3e-09	1.2e-06	1.2e-12	19.3
Concrete from E-Area Vault-7E*	37.5	4.44	10.72	0.988	50.0	1.0e-08	1.3e-06	1.2e-12	18.6
Saltstone - 1	16.0	4.29	11.07	2.39	50.0	2.4e-08	6.6e-06	3.4e-12	44.6
Saltstone - 3A	16.0	4.35	11.26	2.39	50.0	2.0e-08	5.4e-06	2.8e-12	41.6
Saltstone - 4*	12.0	4.74	11.30	2.39	50.0	1.3e-08	3.7e-06	1.9e-12	40.6

*Sample selected for Gas-Water Relative Permeability Tests

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SUMMARY OF GAS-WATER RELATIVE PERMEABILITY TEST RESULTS

Westinghouse Savannah River Company

Sample I.D.	Porosity, percent	Initial Conditions: Water Saturation, percent pore space	Initial Conditions: Specific Permeability to Water, millidarcies	Terminal Conditions: Water Saturation, percent pore space	Terminal Conditions: Effective Permeability to Fluid, millidarcies	Terminal Conditions: Relative Permeability to Fluid,+ millidarcies	Fluid Recovered: percent pore space	Fluid Recovered: percent fluid in place
Top Soil 2	38.8	100.0	3190	12.5	189	0.059*	87.5	87.5
		--	--	64.1	1340	0.420**	51.6	59.0
Gravel 2	38.6	100.0	162000	4.3	15500	0.096*	95.7	95.7
		--	--	15.5	34800	0.214**	11.2	11.7
Dixie Clay 2	57.7	100.0	7.3E-03	96.7	17.4	2380 *	3.3	3.3
		--	--	98.6	1.2e-02	1.64**	1.9	57.6
Grace Clay 2	57.6	100.0	7.9e-03	93.8	0.391	49.4*	6.2	6.2
		--		95.1	3.1e-02	3.92**	1.3	21.0
Sand 2	34.8	100.0	2840	22.0	326	0.115*	78.0	78.0
		--	--	65.7	188	0.066**	43.8	56.2
Burma Road Backfill 2	51.6	100.0	0.812	76.6	3.51	4.32*	23.1	23.1
		--	--	80.8	8.58	10.6**	4.1	17.8

* to Gas
** to Water
\+ Relative to the specific permeability to water

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SUMMARY OF GAS-WATER RELATIVE PERMEABILITY TEST RESULTS

Westinghouse Savannah River Company

Sample I.D.	Porosity, percent	Initial Conditions		Terminal Conditions			Fluid Recovered	
		Water Saturation, percent pore space	Specific Permeability to Water, millidarcies	Water Saturation, percent pore space	Effective Permeability to Fluid, millidarcies	Relative Permeability to Fluid,+ millidarcies	percent pore space	percent fluid in place
Turner Road Backfill 2	42.7	100.0	0.478	75.2	1.30	2.70*	24.8	24.8
		-	-	86.0	1.90	4.02**	10.8	43.6
Concrete from the Saltstone Vault 7B	16.8	100.0	1.3e-03	85.4	7.9e-06	0.0061*	14.6	14.6
		--	--	87.0	2.0e-04	0.154**	1.5	10.3
Concrete from the E-Area Valt 7E	18.6	100.0	1.3e-06	100.0	4.6e-08	0.035**	--	--
		--	--	98.7	5.4e-07	0.415**	1.3	--
Saltstone 4	40.6	100.0	3.7e-06	99.3	1.2e-01	32400*	0.7	0.7
		--	--	99.3	5.8e-04	157**	--	--

* to Gas
** to Water
\+ Relative to the specific permeability to water

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SUMMARY OF AIR-BRINE CAPILLARY PRESSURE

Drainage Test

Sample ID	Pressure: 1	2	4	8	15	35
Top Soil						
TS-1	39.7	32.8	29.8	25.7	24.1	20.4
TS-2	34.1	29.4	26.6	23.9	23.0	20.8
Gravel						
GL-1	39.7	30.9	27.0	23.2	19.4	16.9
GL-2	36.9	26.8	19.1	14.0	11.3	8.4
Dixie Clay						
D-1 100.0	100.0	100.0	97.3	94.3	92.0	
D-2 100.0	100.0	98.7	97.7	96.3	95.1	
Grace Clay						
GE-1	100.0	100.0	99.3	97.3	95.1	93.5
GE-2	100.0	100.0	98.8	97.7	95.8	94.1
Sand						
S-1 35.8	29.7	25.8	21.9	19.9	19.2	
S-2 41.3	33.1	29.1	25.6	24.6	21.8	
Burma Road Soil						
BRS-1	97.7	97.2	96.6	91.5	87.8	85.3
BRS-2	96.2	95.2	92.3	88.0	85.6	82.7
Turner Road soil						
TRS-1	96.5	94.4	84.1	78.4	74.1	71.8
TRS-2	96.5	93.8	83.3	78.3	74.5	71.2

Initial Condition: 100 percent water saturated

File: DRES-92119

SUMMARY OF AIR-BRINE CAPILLARY PRESSURE

Imbibition Test

Sample ID	Pressure: 1	2	4	8	15	35
E Area Concrete						
1E	97.5	98.7	99.0	99.2	99.4	99.8

Initial Conditions: 94.3 percent water saturated

Sample ID	Pressure: 1	2	4	8	15	35
Saltstone Concrete						
3B	92.6	93.0	94.0	94.9	96.9	99.3

Initial Conditions: 91.0 percent water saturated

Sample ID	Pressure: 1	2	4	8	15	35
Saltstone Concrete						
1	96.7	97.3	97.8	98.2	98.6	99.7

Initial Condition: 88.0 percent water saturated

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ULTRASONIC VELOCITY AND DYNAMIC MODULI

Westinghouse Savannah River Company

SAMPLE ID	NET STRESS	BULK DENSITY	VELOCITY COMP	VELOCITY SHEAR	BULK MODULUS	YOUNG'S MODULUS	SHEAR MODULUS	POISSON'S RATIO
	psi	gm/cc	ft/sec	ft/sec	psi	psi	psi	
				Top Soil				
TS-1	100	2.04	6100	3037	6.85e+05	6.78e+05	2.54e+05	0.335
TS-2	100	1.99	6035	2994	6.57e+05	6.44e+05	2.41e+05	0.337
				Gravel				
GL-1	100	2.04	6655	2967	8.87e+05	6.64e+05	2.41e+05	0.375
GL-2	100	2.05	6973	3361	9.32e+05	8.43e+05	3.12e+05	0.349
				Dixie Clay				
D-1	100	1.93	6562	2894	8.27e+05	5.99e+05	2.17e+05	0.379
D-2	100	1.95	6471	2962	7.93e+05	6.31e+05	2.31e+05	0.367
				Grace Clay				
GE-1	100	1.89	4277	1972	3.34e+05	2.70e+05	9.90e+04	0.365
GE-2	100	1.83	4078	1975	2.82e+05	2.60e+05	9.63e+04	0.347
				Sand				
S-1	100	1.92	5766	2659	6.17e+05	5.00e+05	1.83e+05	0.365
S-2	100	1.96	5707	2601	6.21e+05	4.88e+05	1.78e+05	0.369

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ULTRASONIC VELOCITY AND DYNAMIC MODULI

Westinghouse Savannah River Company

SAMPLE ID	NET STRESS	BULK DENSITY	VELOCITY COMP	VELOCITY SHEAR	BULK MODULUS	YOUNG'S MODULUS	SHEAR MODULUS	POISSON'S RATIO
	psi	gm/cc	ft/sec	ft/sec	psi	psi	psi	
Burma Road Backfill								
BRS-1	100	2.06	6555	2384	9.84e+05	4.50e+05	1.58e+05	0.424
BRS-2	100	1.98	6757	2630	9.73e+05	5.21e+05	1.85e+05	0.411
Turner Road Backfill								
TRS-1	100	2.01	6593	2908	8.71e+05	6.31e+05	2.29e+05	0.379
TRS-2	100	1.99	6689	2878	9.03e+05	6.16e+05	2.22e+05	0.386
E-Area Vault Concrete								
3-E	100	2.25	13494	5657	4.23e+06	2.71e+06	9.71e+05	0.393
5-E	100	2.29	13287	5607	4.16e+06	2.70e+06	9.72e+05	0.392
Saltstone Vault Concrete								
2-B	100	2.39	16394	7937	5.95e+06	5.46e+06	2.03e+06	0.347
6-B	100	2.37	16432	7453	6.26e+06	4.86e+06	1.77e+06	0.370
Saltstone								
3	100	1.78	9682	5050	1.43e+06	1.61e+06	6.12e+05	0.313
4	100	1.78	9849	5086	1.50e+06	1.64e+06	6.22e+05	0.318

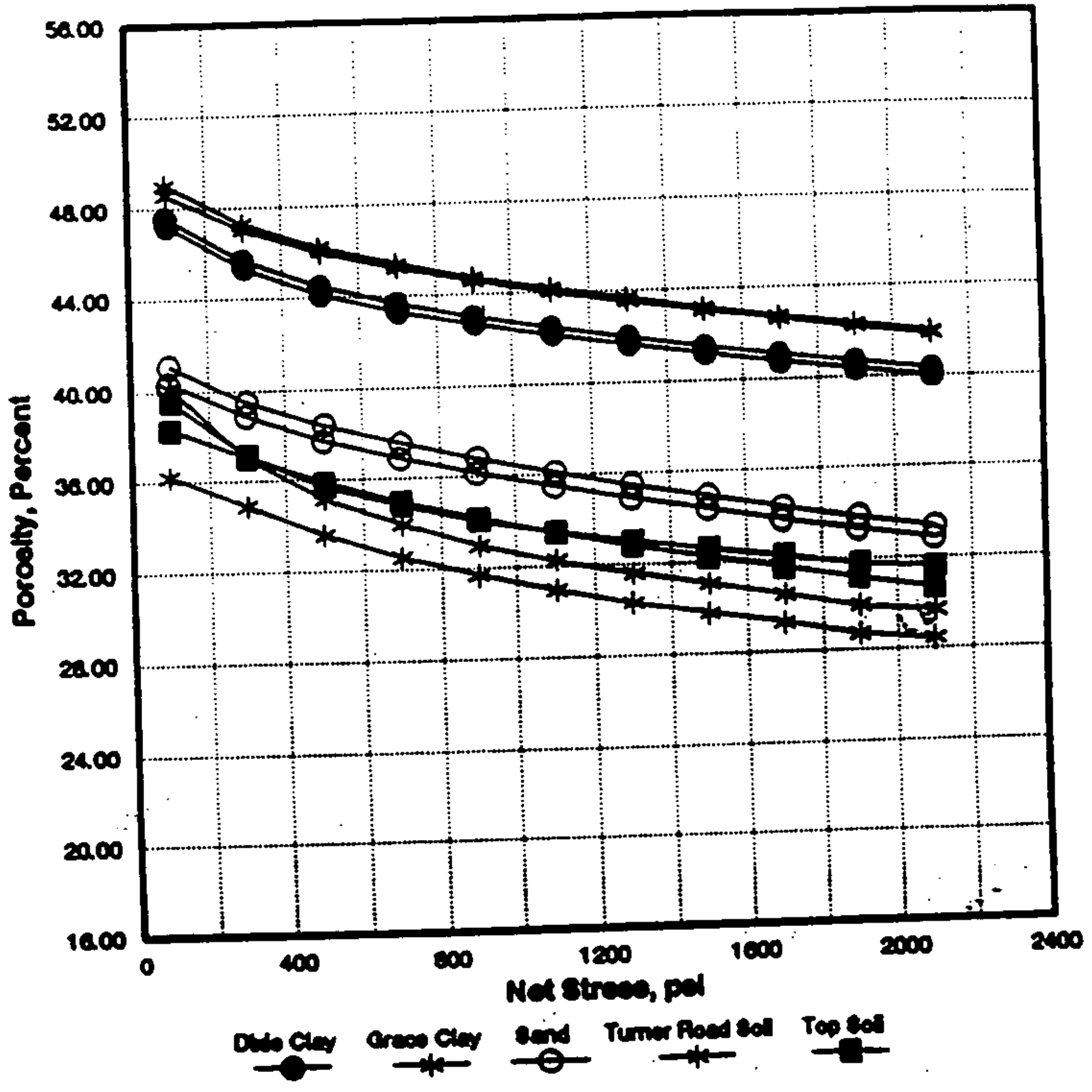
Porosity Versus Net Stress

Constant Pore Pressure - Changing Confining Pressure

WESTINGHOUSE
SAVANNAH RIVER COMPANY

SAMPLE ID: COMPOSITE

JOB FILE: DRES-92119



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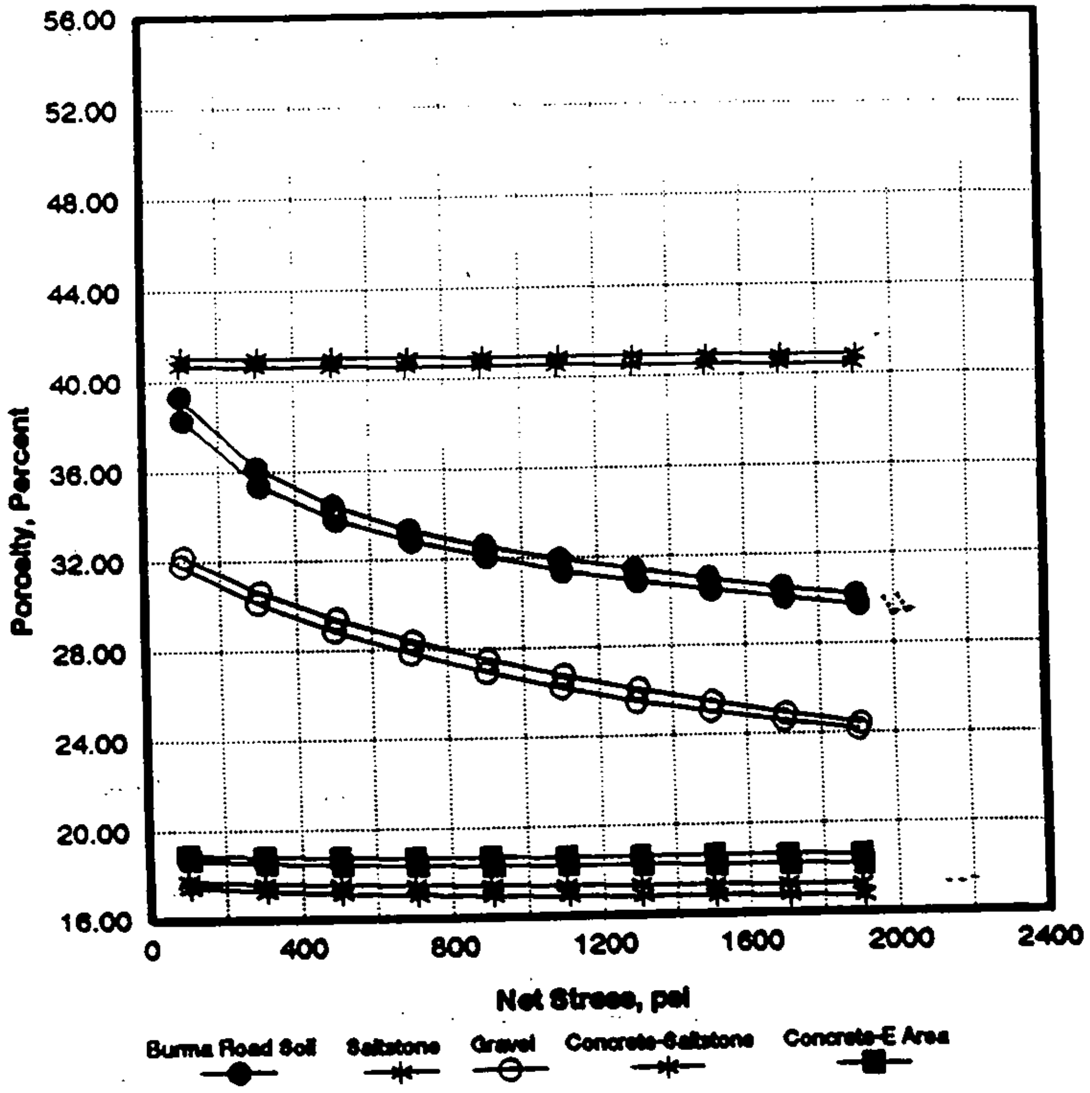
Porosity Versus Net Stress

Constant Pore Pressure - Changing Confining Pressure

WESTINGHOUSE
SAVANNAH RIVER COMPANY

SAMPLE ID: COMPOSITE

JOB FILE: DRES-92119



Core Laboratories

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Lawrence Livermore National Laboratory

HEALTH AND ECOLOGICAL
ASSESSMENT DIVISION

July 13, 1993

William E. Kennedy, Jr.
Battelle-Pacific Northwest Lab
P.O. Box 999
Richland, WA 99352

Dear Bill,

I regret that I will not be able to attend the next meeting of the Peer-Review Panel. Enclosed you will find my final set of comments on the Saltstone PA.

Sincerely,

Dave Layton

David W. Layton
Group Leader
Exposure Assessment

DWL:jg

Enclosure

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Review of Exposure Scenarios, Pathways, and Associated Doses for the Performance Assessment of the Z-Area Saltstone Disposal Facility

David W. Layton
Health and Ecological Assessment Division
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Livermore, CA 94550

July 1993

Comment #1

The performance assessment (PA) evaluated the potential doses to members of the public who do not intrude onto the saltstone disposal facility and to potential intruders who occupy the site at some time after institutional controls are assumed lost. To ensure that potentially important exposure pathways were not omitted in the dose assessment for off–site individuals, a conceptual model was developed outlining 47 different exposure mechanisms. An analysis of those pathways showed that only the ground–water–based pathways are important. A more detailed analysis of those pathways showed that the direct consumption of well water dominates the doses via water–based pathway (other exposures were associated with the consumption of crops/animal products supported with well water and contacts with contaminated garden soil). Additional screening–level analyses were performed to identify the radionuclides that may contribute the most to doses via consumption of well water and ten radionuclides were selected for further analysis.

Similar screening–level analyses were performed for chronic and acute exposures for potential intruders at the site. Chronic exposures were assumed to result from agricultural and residential landuses directly on top of the disposal units. Acute exposures were assumed to occur as a result of onsite construction, attempts to dig a foundation, and the installation of a well. However, it was shown that the chronic exposure scenarios will always produce the highest doses to individuals, and so the acute–exposure scenarios were not considered in the dose assessment. A subsequent screening–level analysis was then conducted to identify the radionuclides that should be included in the more detailed dose assessments. I did not identify any other exposure mechanism or radionuclides that should have been considered for more detailed analyses.

I was impressed with the approach that was taken to identify the important exposure scenarios and radionuclides. The principal benefit of this approach was the elimination of unproductive analyses of minor exposure mechanisms and radionuclides.

Comment #2

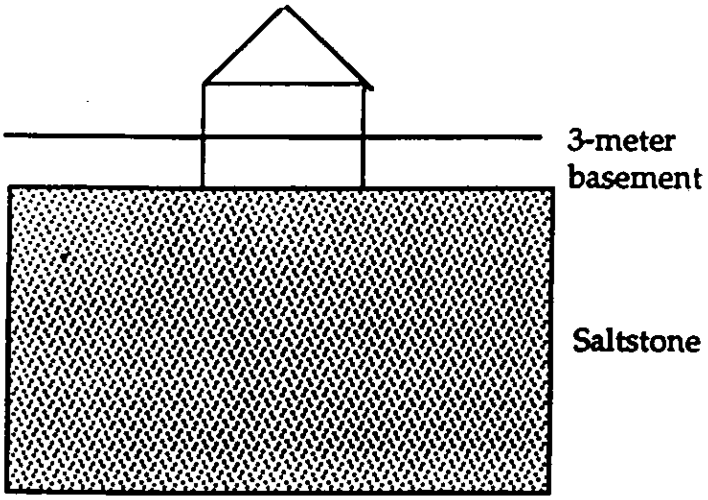
In order to predict the doses to offsite residents, as well as resident farmers and occupants of houses without gardens at the site, a series of dose–conversion factors were developed in Appendix A that translated radionuclide concentrations in environmental media to effective dose equivalents for relevant exposure pathways. A single dose–conversion factor could then be computed for each radionuclide associated with a given scenario (see, for example, Table 4.1-9). The development of scenario– and radionuclide–specific dose conversion factors simplifies the dose assessment and assists in the early identification of key radionuclides. I did not find any exposure–related parameters that could be considered unreasonable for the purposes of the present dose assessment. The 50-y committed effective dose equivalents per unit activity inhaled or ingested that were used to determine the dose–conversion factors were derived from an existing DOE compendium.

Comment #3

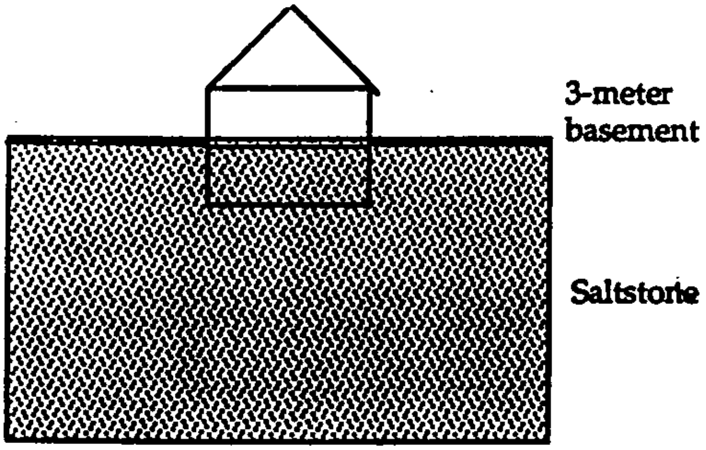
The results of the dose assessment for offsite residents (given in Table 4.1-8) indicate that the doses from the drinkingwater pathway will be far below the 4 mrem/y limit. However, the result of the dose assessments for on–site intruders showed that external exposure to gamma radiation from ^{126}Sn in contaminated soil or saltstone could be as high as 390 mrem/y, while the ingestion of crops contaminated with ^{99}Tc could reach 57 mrem/y. These estimates, though, were not adjusted to account for the fact that there is not an infinite horizontal source of unshielded saltstone containing ^{126}Sn. Also, there was no adjustment to account for the possibility that a house would be completed into the uncontaminated areas between the saltstone units at the disposal facility. Once adjustments were made for these factors, the total doses decreased to about the 100 mrem/y level.

Because the adjusted doses are still relatively close to the 100 mrem/y limit, it would have been useful to do a more realistic analysis of the external radiation doses to resident intruders. For example, it was never really clear what geometry was used to determine the external doses. Specifically, was the basement situated on top of the saltstone units or completed into the degraded units? According to Appendix A, external exposures were based on radionuclides that are uniformly distributed in a slab of infinite thickness that is made up of soil–equivalent material. A shielding factor of 0.7 is used to reduce exposures because of the protection afforded by floors and walls. Exposures are determined for an individual that is 1 m from the source region. But does that mean an individual living in a basement? Figure 1 depicts two types of basement completions that are possible. The first one (Fig. 1a) has the basement on top of the saltstone, with the barrier gone or degraded. In this case little on no contaminated material has been excavated and mixed with surface soils. In the second case, though, excavated materials are likely to contaminate surface soils. But, as was noted in the text, the saltstone could not support vegetation so clean soils would have to be brought in? Yet would the contaminated materials from the excavation of the foundation be mixed with the imported topsoil? Note that the garden scenario assumes that contaminated soil/saltstone is mixed with uncontaminated topsoil in a ratio of 1:5. Thus, the garden scenario is implicitly tied to some sort of saltstone excavation.

Figure 2 depicts the placement of houses with concrete slabs onto the saltstone units. It would appear that these types of houses come closer to matching the source–receptor geometry that is being assessed in the PA. However, a lot less soil/saltstone is removed with the excavation associated with a concrete slab. For example, the average house in the U.S. has about 150 m^2 of floor space, and thus with a 3 m basement, 450 m^3 of material would be excavated. By comparison, the excavation for a house on a slab might only remove 0.3 m of soil, producing only a tenth as much material. This means that there would be substantially less material to contaminate a home garden or imported topsoil. As a matter of fact, the most prevalent foundations in the South are concrete slabs and perimeter foundations (crawl space). Only about 20% of the houses have full or partial basements (see Fig. 3). Thus, a more realistic assessment would focus on the external radiation exposures for individuals living in houses that are more representative of those build in the South.



a.



b.

Figure 1. Alternative scenarios for completing houses with basements in saltstone disposal facility with degraded barriers, (a) foundation is situated on top of saltstone and (b) foundation is excavated into the degraded, weathered saltstone. In the excavation case contaminated materials are assumed to be spread in surficial soils around the house.

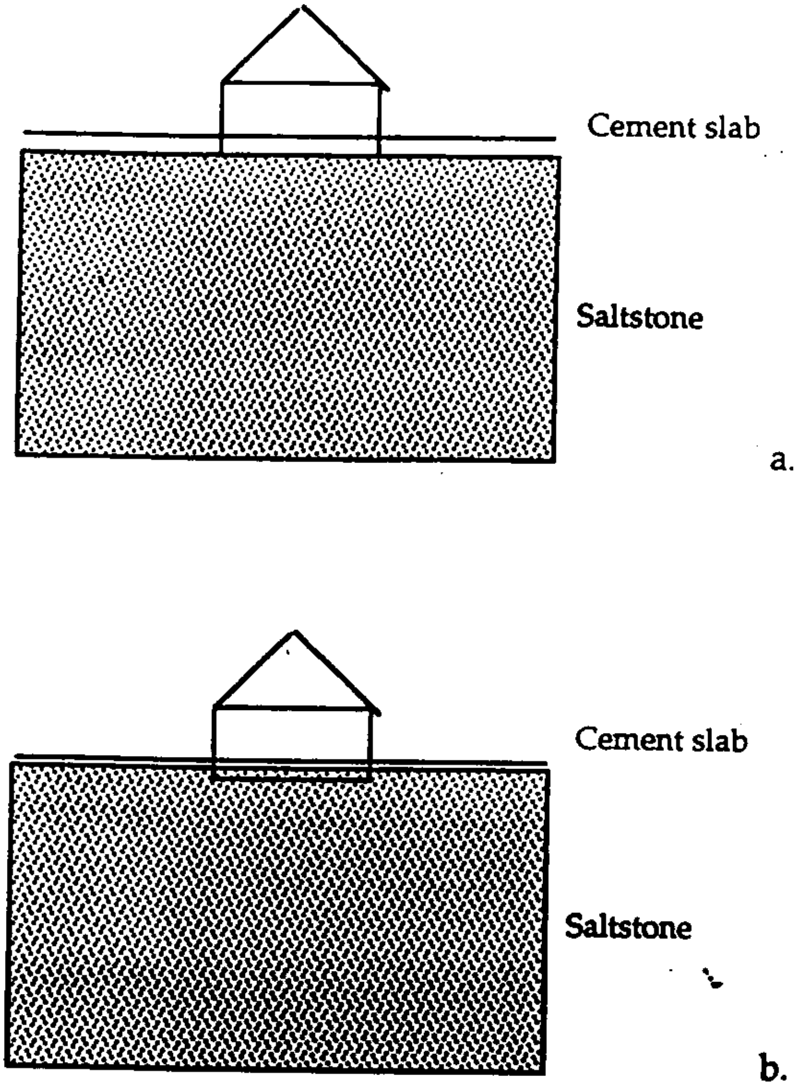


Figure 2. Alternative scenarios of completing houses with concrete slab foundations onto saltstone units with degraded barriers, (a) slab is situated on top of the saltstone and (b) the slab is poured into a shallow foundation penetrating the saltstone.

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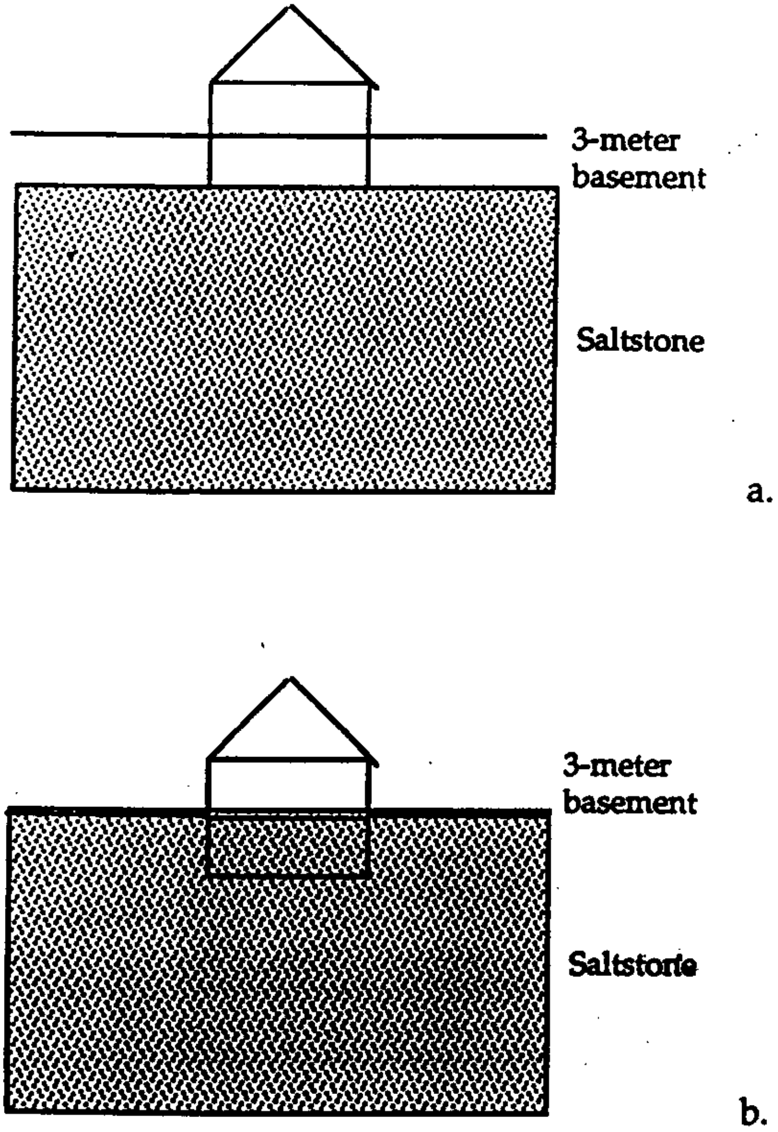

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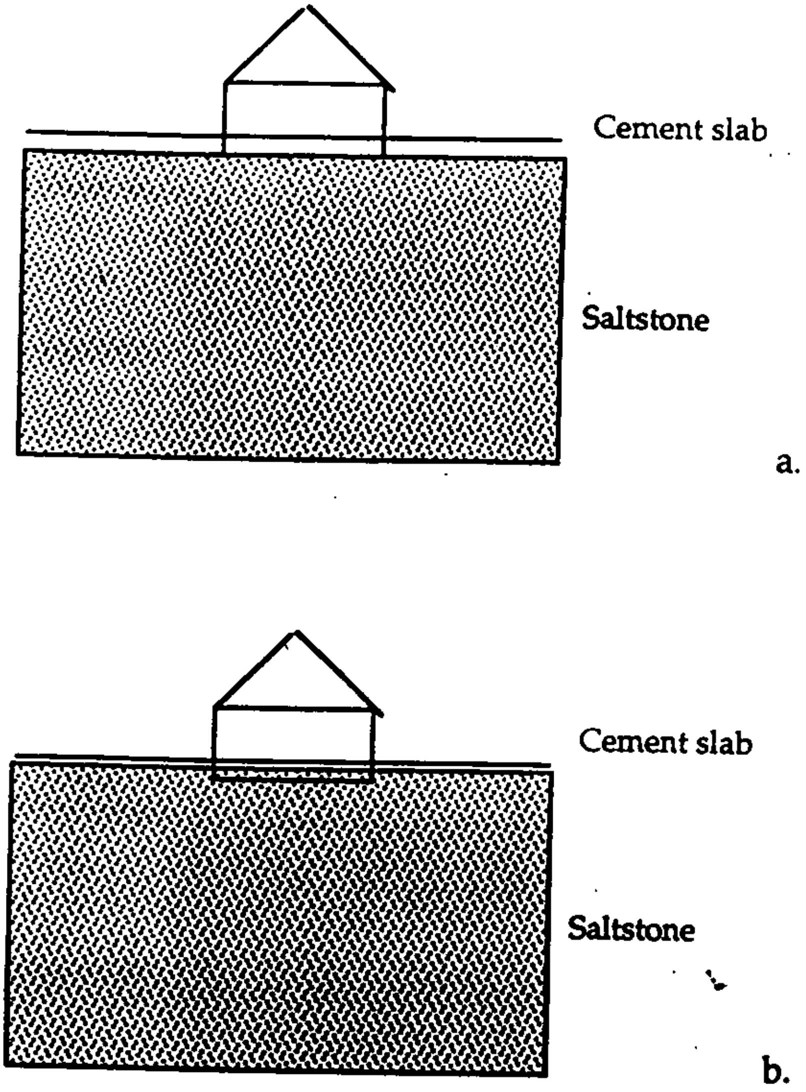

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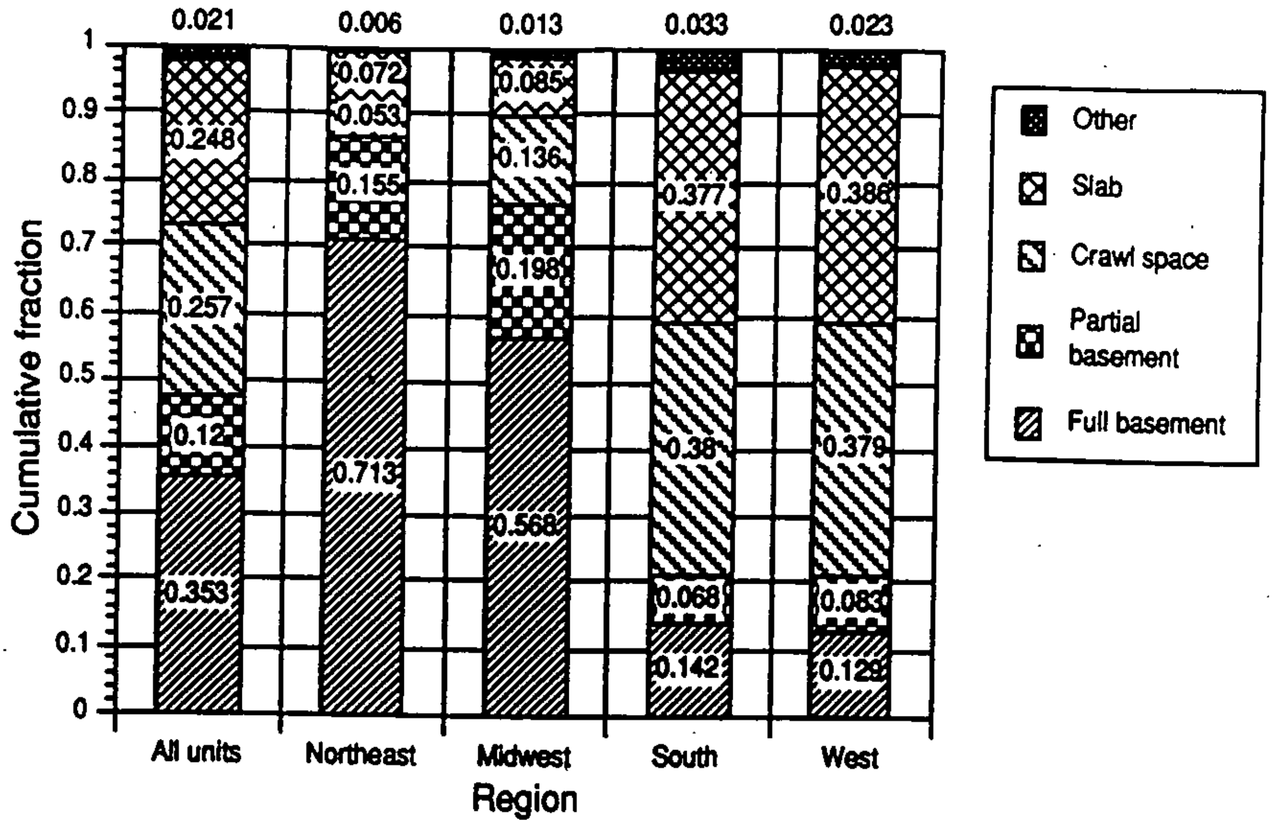

Figure 3. Breakdown of foundation types of houses in different parts of the U.S.

OPS-DTZ-94-0001

February 18, 1994

Mr. Clyde W. Terrell
Defense Waste Processing Division
Savannah River Field Office
U. S. Department of Energy
Aiken, SC 29802

Dear Mr. Terrell:

Subject: DOE-HQ Request for Paper on Saltstone Disposal at SRS (u)

Ref. 1. Telefax from Ha Vu, Department of Energy, Germantown, MD (EM-343) to Jim Lockridge, SWEC, Savannah River Site, dated 27-Oct-1993.

2. Verbal Requests from M. S. Glenn to W. T. Goldston and J. R. Fowler, 11-Nov-1993 and 10-Jan-1994.

3. Telefax from Ha Vu, op cit., dated 18-Dec-1993 (comments on draft from EM-343).

In response to a request from EM-343 for a paper describing the technical, regulatory and cost basis for Saltstone disposal at SRS, Sam Glenn of your staff requested assistance in preparing a suitable response. Dr. J. R. Fowler of our technical staff provided a draft in early December for review and comment. As requested in January, he has now incorporated comments from EM-343, resulting in the attached document. We believe this should fulfill the request from EM-343.

Any questions you may have should be directed to W. T. Goldston or Dr. Fowler of our staff.

Sincerely,

[original signed by D. B.
Amerine]

D. B. Amerine, Manager
Defense Waste Processing Facility

Attachment (1)

/jrf

CC: M. S. Glenn, DOE-SR, 704-S
R. M. Satterfield, 719-4A
J. F. Ortaldo, 704-S
J. R. Fowler, 704-Z
D. G. Thompson, 704-Z

BASIS FOR SALTSTONE DISPOSAL OPERATIONS AT THE SAVANNAH RIVER SITE

SUMMARY

Recently, the Richland Operations Office (DOE-RL), with DOE-HQ participation, selected vitrification technology instead of grout to immobilize the low-activity aqueous fraction that will be generated from pretreatment operations on Hanford's high-level aqueous waste (HLW). This decision was reached during the renenogiation of the Tri-Party Agreement among DOE-RL, the Environmental Protection Agency (EPA) and the Washington State Department of Ecology (WSDE). Contributing factors to this decision were the requests by certain segments of the public in the Pacific Northwest to immobilize this waste in a form that would produce less waste volume and could be placed in storage for possible retrieval at some future date.

The principal differences between the design and disposal costs for SRS Saltstone and Hanford grout are dictated by the different regulatory interpretations imposed by the State of Washington and the State of South Carolina to establish if waste is deemed hazardous. The South Carolina Department of Health and Environmental Control (SCDHEC) permits a disposal site based on the properties of the waste that is actually placed in a site. The WSDE classifies solid waste based on the waste characteristics at the point of its generation, rather than the final waste form that is placed in a disposal site.

Saltstone production and disposal in Z-Area at the Savannah River Site (SRS) is similar in concept to grout production and disposal at Hanford. The technical, regulatory and economic justification to retain treatment and disposal of the low-activity soluble waste generated at the Savannah River Site (SRS) as Saltstone is summarized in this report. At the SRS, production and disposal of LLW saltstone is preferred over LLW vitrification and storage for these reasons:

(1) final disposal of LLW waste, consistent with environmental regulations and minimum risk to the public, is preferred over long-term storage;

(2) Saltstone production and disposal is well within safety and regulatory requirements imposed by the EPA, SCDHEC, and DOE Orders for treatment and near-surface disposal of LLW;

(3) production and disposal of Saltstone must continue if aqueous HLW is to be converted to glass and thus eliminate the storage of HLW in older waste tanks at SRS in a timely manner;

(4) Saltstone production and disposal facilities are not included in the compliance and waste removal schedule for the Federal Facility Agreement for SRS, since it is an operating facility that SCDHEC and EPA deem to be in compliance with applicable regulations (a change in the treatment and disposal method for the aqueous waste would adversely impact the proposed schedule that is a part of the FFA);

(5) Saltstone is classified as non-hazardous waste by SCDHEC, eliminating the stringent RCRA requirements imposed by the WSDE for treatment and disposal of grout at Hanford;

(6) as a result of pretreatment of salt waste in the In-Tank Precipitation process, Saltstone meets the definition of Class A radioactive waste, as defined by NRC;

(7) South Carolina and the SCDHEC have extensive experience in regulating a LLW disposal facility at Barnwell and have high credibility with the general public in SC.

DISCUSSION

1.0 Alternatives Considered for Aqueous HLW and LLW at the SRS

In the Final Environmental Impact Statement (FEIS) for the Defense Waste Processing Facility (DWPF), several alternatives to immobilize aqueous HLW presently stored at the SRS are summarized (Ref. 1). As part of the Record of Decision for the DWPF that is based on the FEIS, decontamination of the salt and disposal as a cement-based LLW solid in an engineered landfill was selected. This decision was based on the demonstrated technology, regulatory requirements, and regulatory guidance at the time of the decision. The evolution of both the production of the Saltstone waste form and the landfill design is described in the Radiological Performance Assessment (RPA) for disposal of Saltstone in Z-Area (Ref. 2). Interactions with the EPA, SCDHEC and the public show continued acceptance of the product and disposal site.

2.0 Overview of the HLW Treatment and Disposal System at SRS

Saltstone production and disposal is one part of an integrated storage, treatment and disposal system being put in place at the Savannah River Site (SRS) to convert aqueous HLW into solid HLW and LLW waste forms suitable for final disposal. The integrated HLW treatment and disposal system is designed to remove the HLW from storage tanks, pretreat the HLW to minimize the volume and mass of HLW glass that must be produced, vitrify the high-activity fraction of HLW after pretreatment, store the HLW glass that is produced, and treat and dispose of the low-activity aqueous fraction that is generated from other treatment operations. A flow diagram of the integrated aqueous HLW system is shown in Figure 1.

Canisters of HLW waste glass and LLW Saltstone are the final solid waste forms generated by this system. The canisters of glass will be stored in the DWPF located in S-Area until they can be shipped to the Federal Repository. Saltstone is produced in Z-Area and placed in large concrete vaults for final disposal. The disposal vaults are also located in Z-Area.

Principal components of the integrated HLW treatment and disposal system are:

(1) the Tank Farms located in the Separations Areas (F-Area and H-Area) where aqueous HLW is generated and stored;

(2) HLW pretreatment (also done within the Tank Farms) that uses HLW evaporators, the In-Tank Precipitation Process (ITP) equipment, and Extended Sludge Processing (ESP) equipment to prepare feeds for other waste treatment facilities;

(3) the Effluent Treatment Facility (ETF) located in H-Area that purifies water containing very low concentrations of chemical and radioactive contaminants to allow release of the water to the environment;

(4) the DWPF Vitrification Facility located in S-Area that converts HLW slurries from ITP and ESP pretreatment operations in the Tank Farms into HLW waste glass; and

(5) the DWPF Saltstone Production and Disposal Facilities located in Z-Area that converts low-activity salt solution from ITP and ETF to Saltstone and disposes of the Saltstone in vaults also located in Z-Area.

At the SRS, the soluble salt portion of stored HLW is processed through ITP, resulting in the separation of a relatively small volume of a HLW precipitate slurry and a large volume of low-activity salt solution. The HLW precipitate slurry from ITP and sludge slurry from ESP will be sent to S-Area for vitrification, while the salt solution from ITP will be transferred to Z-Area for treatment and on-site disposal as Saltstone. Pretreatment in

ITP significantly reduces the radiological hazards associated with this waste during subsequent treatment operations in Z-Area. Hanford does not currently pretreat the salt solution to reduce the concentration of Cs-137 or Sr-90 in their grout containing salt waste.

The ETF, one waste tank (Tank 50H), a waste transfer line to Z-Area, the Saltstone Production Facility (SPF) and the Saltstone Disposal Facility (SDF) comprise a treatment and disposal sub-system that treats the large volume of aqueous low-activity waste that is (or will be) generated from treatment operations (see Figure 1). The ETF treats aqueous streams containing very low concentrations of contaminants (usually less than 1 wt% of the total waste stream) to purify the water and release it to a permitted outfall on the site. Soluble contaminants removed from the water are combined and concentrated into an aqueous solution that is also transferred to Z-Area (via Tank 50H) for treatment and disposal as Saltstone. Disposal of the concentrated aqueous waste from ETF as Saltstone is an integral part of the continued operation of the ETF process.

Pretreatment of the existing HLW inventory presently stored in the Tank Farm at the SRS will generate about 750,000 cubic meters of LLW Saltstone contained in 110-120 vault cells.

3.0 Saltstone Production and Disposal

The SDF, located in a 650,000-square meter area of the SRS designated as Z-Area, is a near-surface disposal facility that will receive low-level radioactive waste generated at the SRS and incorporated into a cement-based waste form called Saltstone. Important characteristics of Z-Area that led to its selection as the site for the SDF include a considerable depth to the water table under the site (7-18 meters) and its proximity to the waste generation site (H-Area). An underlying aquitard and nearby streams that almost entirely surround Z-Area virtually isolate groundwater under the site, further supporting this choice of location.

Saltstone grout is produced in Z-Area by mixing an aqueous LLW/MW stream containing copious amounts of sodium salts with a dry blend of furnace slag, fly ash and cement. The LLW Saltstone grout is pumped into concrete vaults where it hardens and cures into a monolithic solid waste form with low water conductance properties and high retention properties for radioactive waste constituents of concern. Extensive leach tests have been, and continue to be, performed on Saltstone that demonstrate the ability of the waste form to retain contaminants within the solid waste form. The Saltstone monoliths are resistant to degradation, and thus are expected to stabilize the LLW for thousands of years.

The recently completed radiological performance assessment for Z-Area (Ref. 2) has been reviewed and approved by the Peer Review Panel appointed by DOE-HQ. WSRC has issued a DOE Review Draft of the Safety Analysis Report for Z-Area that shows Z-Area operations to be a low-hazard facility that can be operated without undue risk. The draft SAR has been independently reviewed by the Technical Review Group (TRG) appointed by DOE-HQ. Comment resolution between WSRC and the TRG is underway and will be completed in 1994. Results from the RPA and a description of Z-Area facilities are briefly summarized below. For a complete description of the process, product and disposal site, see the SAR and RPA. (Ref. 2, 3)

3.1 Long-Term Performance Assessment

Based on results and associated uncertainties presented in the RPA for Z-Area (Ref. 2), reasonable assurance is provided that the disposal of Saltstone will meet the long-term radiological goals specified for LLW disposal in DOE Order 5820.2A. Even if the facility degrades at some time in the future, calculated doses from estimated radionuclide concentrations in the groundwater are at least two orders of magnitude below the 4 mrem per year limit for the maximally exposed individual for groundwater resource protection established in the Order. In five exposure scenarios considered for inadvertent intruders, estimated doses are all less than 100 mrem per year, also specified in the Order.

3.2 Saltstone Production Facility (SPF)

The Saltstone Production Facility (SPF) is permitted by the SCDHEC as a totally enclosed wastewater treatment plant that treats hazardous aqueous waste and converts it to a non-hazardous solid. The facility is exempted from RCRA Part A and Part B permitting under the exemption section for totally enclosed treatment plants (no liquid effluents are released directly to the environment). Operation of the Saltstone Production Facility (SPF) is described in detail in the draft Z-Area SAR. The low concentrations of radioactive contaminants enable contact operation and maintenance in Z-Area. Accident analyses in the SAR clearly show that Z-Area operations are low hazard, with minimal impact either on or off the SRS site.

The SPF began radioactive operations in 1990. Approximately 4 million liters (over 1 million gal) of aqueous waste have been treated to produce and dispose of about 7000 m^3 of Saltstone in a Z-Area Vault. A flow diagram of the SPF process is shown in Figure 2. In the SPF, fly ash (41.5 wt %), slag (41.5 wt %), and cement (17 wt%) are blended to prepare a mixture of dry materials called premix. When Saltstone is being produced, this dry mixture is fed to a mixer normally at a rate of 35 metric tons per hour to a mixer where it is combined with aqueous LLW/MW salt solution (23,000 liters per hr) to produce LLW Saltstone grout at a rate of about 38-39 cubic meters per hour (10,200 gal/hr). The generation rate of aqueous waste in other treatment operations will normally only require Saltstone production during a single shift each day (6-10 hrs), resulting in a daily production rate of about 350 cubic meters per day.

Saltstone grout, which has the consistency of latex paint, is pumped directly to a cell in a vault where it self-levels to fill the area of the cell. The Saltstone grout sets and hardens into a solid monolithic layer in the cell with a compressive strength of at least 300 psi (generally in excess of 1000 psi). Subsequent production is simply pumped onto previous production until the height of the waste monolith reaches 7.3 meters (24 feet). After a cell is filled, production shifts to another cell in the vault. After a vault is completely filled, interim closure of the vault is completed, and production moves to another vault.

As part of interim vault closure operation, 15 to 30 centimeters (6 to 12 inches) of clean (non-radioactive) grout is poured on top of the Saltstone monolith contained in a cell to completely fill the vault and eliminate any voids in the vault between the waste and a reinforced concrete roof that is installed on the vault. The clean grout layer also serves to further isolate the waste from the general environment until interim vault closure is completed by sealing openings in the roof that enabled placement of the waste.

3.3 Saltstone Disposal Facility

The Saltstone Disposal Facility (SDF) is permitted as a landfill for the disposal of solid industrial waste by the SCDHEC. The facility is designed as a "controlled-release" landfill. Since Saltstone is classified as non-hazardous industrial waste by SCDHEC, the SDF is not required to meet RCRA land disposal requirements. This is a significant factor in the overall cost of vault construction and disposal costs, especially when compared to the grout facility at Hanford.

As presently planned, the SDF will contain up to 15 large concrete vaults divided into cells. Fourteen of these vaults will each have dimensions of approximately 60 m wide by 180 m long by 7.6 m high (200 feet wide by 600 feet long by 25 feet high). The other vault (Vault 1) is about 30 m wide by 180 m long by 7.6 m wide. Each of the larger vaults will be divided into 12 cells that are approximately 30 m long by 30 m wide by 7.6 m high (100 feet by 100 feet by 25 feet). Vault 1 is divided into 6 cells with the same physical dimensions as the larger vaults. The disposal capacity of a vault cell in the SDF is comparable to the capacity of an entire vault used to dispose of Hanford grout. This seeming disparity in vault design is due to the different regulatory requirements imposed by the State of Washington because Hanford grout is classified as "Dangerous Waste" by the state regulatory agency. Hanford vaults were therefore required to meet RCRA requirements for the disposal of hazardous waste.

Approximately 3 to 4.5 meters of overburden have been removed at the SDF to prepare and level the site for vault construction. All vaults will be built at or slightly below the grade level that exists after the overburden

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and leveling operations are complete. The bottom of the Saltstone monoliths (LLW solid waste) will be at least 8 meters above the historic high water table beneath the Z-Area site, thus avoiding disposal of waste in a zone of water table fluctuation. Runoff and runon controls have been installed to minimize site erosion during the operational period.

When all the vaults are filled, individual vaults will be covered with a clay cap and a gravel drainage layer to reduce infiltration through the SDF. Additional fill will be placed over this drainage layer prior to installing a second clay/gravel drainage layer over the disposal site. Fill will then be placed over the second drainage layer, the site will be graded and drainage ditches will be installed to control runoff and minimize erosion after site closure. Topsoil will be added, and bamboo will be planted on the site. Bamboo is a shallow-rooted terminal vegetation that has been selected for the closure to minimize intrusion of deeper-rooted vegetation such as pine trees. This closure design is expected to reduce infiltration through the SDF to less than 1 cm/year.

Based on projected operations of the integrated HLW treatment and disposal system at the SRS, about 450 million liters (120 million gallons) of aqueous LLW/MW salt solution will be generated for disposal in Z-Area. Treatment of this waste will require 110-120 cells in the SDF, corresponding to about 725,000 cubic meters of LLW Saltstone contained in concrete vaults. This volume corresponds to about 1.2 million metric tons of Saltstone. If the entire permitted capacity of Z-Area (174 cells) is filled with Saltstone of comparable composition to that projected from the existing inventory, a total of 732 million liters (192 million gal) of waste could be treated to yield 1.14 million cubic meters of LLW Saltstone (about 2 million metric tons).

3.4 Estimated Cost for 30-Year Life of the Z-Area Project

At the request of DOE-HQ, a rough estimate of the total cost for Saltstone production and disposal of LLW/MW generated from the existing HLW inventory has been made. Cost figures shown below are based on 1993 dollars, and are meant to provide an estimate that is only an approximate order of magnitude for the life-cycle cost of the project. These numbers are suitable for planning purposes to compare against other disposal options, but they are not suitable for detailed budget calculations, nor should they be used for long-term forecasts.

<u>SPF + Vault 1 and 4</u> (18 cells)	$ 47 M
<u>Cost of Future Vaults</u> (8 @ $17 M ea)	$136 M
<u>Process Raw Materials</u> (@ $50/ton for 114 cells)	$ 35 M
<u>Operating Costs</u> (20 yrs @ $7 M/yr)	$140 M
<u>Total for Site Closure</u> (3-5 yrs)	$ 75 M
<u>Regulatory and Order Compliance</u> (25 yrs @ $2M/yr)	$ 50 M
<u>Long-Term Surveillance</u> (100 yr @ $100 K/yr)	$ 10 M

Based on these cost estimates, the life cycle cost for the Z-Area Saltstone production Site is projected to be between $500 million to $600 million (1993 dollars). This projection assumes loss of administrative control and/or responsibility after 100 years, leaving the facility in a "walk-away" condition.

4.0 Similarities and Differences between Saltstone and Hanford Grout

Both the Hanford grout and the SRS Saltstone disposal systems are designed to meet federal and the respective state regulations for protection of the environment. The ultimate goal of both systems is to protect groundwater resources to assure primary drinking water standards are not exceeded.

Chemically, the cement-based waste forms at Hanford and the SRS are very similar. The wastes at each site are mixed with dry blends composed of slag, flyash and cement. Hanford also includes limestone in their dry blend to reduce the heat generated during setting and curing of the grout and a pottery clay to reduce leaching of Cs-137 and Sr-90. Waste forms at both sites were developed to meet the same criteria – produce a solid that is resistant to leaching and has sufficient compressive strength to be self-supporting (at least 60 psi is required, but higher strengths are specified at both sites).

As noted above, Hanford does not pretreat salt solution to reduce the level of radioactive contaminants prior to disposal. The concentration of various components in salt solutions to be treated for disposal in Z-Area at the SRS and in the grout facility at Hanford are tabulated below for comparison. The presence of radioactive contaminants, chromium(VI) and the high pH due to hydroxide require these solutions to be classified as aqueous mixed waste (MW). Both SRS and Hanford convert the aqueous waste to a solid for final disposal, in accordance with the requirements of DOE Order 5820.2A.

A COMPARISON OF AQUEOUS MW FEEDS AT SRS AND HANFORD

Component	SRS concentration	Hanford Concentration
Sodium	117 g/L	100 g/L
Nitrate	103 g/L	78 g/L
Nitrite	30 g/L	34 g/L
Hydroxide	20 g/L	27 g/L
Chromium	0.2 g/L	0.3 g/L
Sr-90	**0.5 nCi/ml**	**6600 nCi/ml**
Tc-99	**65 nCi/ml**	**77 nCi/ml**
Cs-137	**12 nCi/ml**	**310,000 nCi/ml**
Total Alpha	**1.1 nCi/ml**	**1.5 nCi/ml**
Total Activity	**200 nCi/ml**	**320,000 nCi/ml**

4.1 Regulatory

Although grout and Saltstone are similar in form and composition, regulatory requirements imposed by the SCDHEC and the WSDE differ. Although the Nuclear Regulatory Commission (NRC) has no regulatory authority at the SRS, Saltstone would be classified as Class A LLW by the NRC. Based on projected compositions, Hanford's grout would be classified as Class C LLW by the NRC.

4.1.1 South Carolina Regulations

Waste disposal regulations for the State of South Carolina are essentially identical to EPA regulations. The SCDHEC regulates waste disposal based on the properties of a final waste form to assure that groundwater quality and the general environment are not compromised as a result of waste disposal. Saltstone is well within the requirements for non-hazardous industrial waste, as defined by SCDHEC, and is suited for disposal in a near-surface industrial waste landfill. Unset Saltstone grout is also considered to be non-hazardous by SCDHEC. The ratio of dry material to water is carefully controlled during the production of Saltstone to assure that no significant quantities of free liquids that would be considered hazardous waste are sent to a disposal vault. The SDF is thus designed as a "controlled release" industrial waste disposal site that prevents rapid release of waste contaminants to the general environment.

4.1.2 Washington Regulations

The State of Washington Department of Ecology (SWDE) classifies salt solution used to produce Hanford's grout as Dangerous Waste, since the salt solution used to produce the waste is hazardous due to its high pH. Because the characteristics of the waste used to produce grout is classified as Dangerous Waste, the grout is also classified as dangerous waste.

The SWDE imposes similar requirements for the treatment, storage and disposal of Dangerous Waste that are imposed by the EPA on Hazardous Waste. Such waste requires disposal in an engineered facility with double containment and leachate collection systems, as specified by RCRA and implementing EPA regulations. Stringent requirements on releases from hazardous waste sites are also imposed by SWDE and EPA, and generally are required to be "no-release" facilities for the life of a permit (30-years under RCRA). Any leachate that collects must also be handled as Dangerous Waste until tests confirm that the leachate has no hazardous characteristics. Neither the EPA nor the SWDE have addressed action to be taken at the end of a 30-year permit period for a permitted hazardous waste storage or disposal site.

A significant quantity of excess contaminated water with a high pH is also placed in the Hanford vault during grout production. Because of the excess water, the grout vaults at Hanford must also function (and be permitted) as a surface impoundment for Dangerous Waste until the grout sets. After the grout sets, the excess water is removed and returned to a waste tank.

4.2 Climate, Geology, Hydrology

Climate, geology and hydrology are key factors that control both the concentration of contaminants in the soil pore water and velocity at which they are transported to the groundwater after they are released from a vault. Annual rainfall at Hanford averages about 16 cm/yr, of which about 1 cm/yr infiltrates through the soil to the water table. Annual rainfall at SRS averages about 110 cm/yr. About 38 cm/yr infiltrates through the soil to the water table. Thus the downward velocity of contaminants would be expected to be somewhat higher due to increased infiltration at the SRS. However, the higher infiltration rate also reduces the concentration of any released contaminants, since not all of the infiltrating water contacts the waste. As noted above, barriers to divert infiltration from the vicinity of the vaults will be installed in Z-Area to reduce the infiltration through the waste to less than 1 cm/yr at the SDF.

4.3 Long-Term Radiological Impacts

Based on analysis presented in the RPAs for the individual sites, both the Hanford grout disposal site and the Saltstone disposal site at SRS will meet the long-term radiological goals specified in DOE Order 5820.2A for LLW disposal sites. As noted earlier, the Peer Review Panel (PRP) has recommended that DOE-HQ formally issue the Z-Area RPA. The final RPA for Hanford grout disposal is expected to undergo review in 1994 by the PRP.

The principal radionuclides and the projected overall inventory at the time of closure of the SDF and the Hanford grout facility are compared in the following table. Ranges are provided because of the uncertainty associated with future operations at both sites.

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Radionuclide	SDF at SRS, Ci	Hanford Grout, Ci
Total activity	100,000 - 200,000	13,000,000 - 21,000,000
Cs-137	5,000 - 10,000	12,000,000 - 13,000,000
Sr-90	200 - 1,000	1,000,000 - 10,000,000
Tc-99	30,000 - 40,000	15,000 - 30,000
I-129	20 - 30	30 - 40
total alpha	500 - 1,000	500 - 1,000

The lower activity in the SRS waste has a significant impact on facility safety, design and operating costs. Saltstone is produced in a radiologically controlled area (RCA) which permits contact maintenance, while Hanford grout is produced remotely in a shielded facility that requires remote maintenance. Based on the level of radioactive contaminants projected for treated salt solution at SRS, Saltstone would be classified as "Class A" waste by the Nuclear Regulatory Commission (NRC) if Saltstone were subject to NRC regulations. SCDHEC views Saltstone to be similar to the LLW waste sent to the disposal facility at Barnwell, SC that has operated since the 1960's and is licensed by the NRC and SCDHEC for the disposal of commercial nuclear LLW. The use of vaults instead of clay-lined trenches for disposal is generally viewed by both SCDHEC and the public in South Carolina as a proactive approach to improved disposal practices for LLW.

Hanford grout has significantly higher concentrations of Cs-137 and Sr-90, and the grout waste would be classified as "Class C" LLW by the NRC, if the Hanford grout facility were subject to NRC regulations. Although vault disposal at SRS and Hanford is consistent with the requirements of the NRC for Class C LLW disposal, disposal of waste in Z-Area that is consistently above Class A limits would likely jeopardize continued disposal operations at Z-Area. Accordingly, the goal for SDF disposal is to maintain the overall average composition of the waste at or below Class A limits.

5.0 Vitrification of LLW as an Alternative to Saltstone

The Minimum Additive Waste Stabilization (MAWS) technology has been proposed as an alternative treatment process for LLW/MW to replace cement-based solidification processes at DOE sites. The technology appears to be especially promising if a significant quantity of contaminated soil must be treated at a site (Ref. 3). The use of this technology at Fernald to minimize the waste volume generated from basin closures appears to be especially promising, compared to solidifying contaminated soil in a cement-based waste form. Issues and possible impacts of LLW vitrification as an alternative to production and disposal of Saltstone are discussed below.

5.1 Issues Related to Vitrification of SRS Salt Waste

The high sodium, nitrate and nitrite content of the low-activity aqueous waste that is presently being sent to Z-Area for disposal as Saltstone would present special challenges for the production of solid LLW using a vitrification process. Leach-resistant glasses are generally limited to a total sodium oxide content of about 20 wt%, as noted in the present information available on MAWS. (Ref. 4)

Environmental impacts would shift from long term concerns about potential contamination of groundwater to near term issues related to on-site and off-site atmospheric releases, if a vitrification process were adopted at the SRS to replace disposal as Saltstone. Special attention in off-gas treatment for a vitrification process would be required to minimize emissions of oxides of nitrogen.

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The potential volatility of various radionuclides at high temperature is also of concern. For example, the volatility of technetium from the oxidizing environment of a melter processing high nitrate waste may require pretreatment to reduce the concentration of Tc-99 in the waste, and would generate a secondary waste stream that must be stored or further treated for disposal. Alternatively, the off-gas and condensate from the melter must be treated prior to release to the general environment. Although its concentration in the SRS waste is low, any carbon-14 contained in the waste would eventually be evolved as carbon dioxide. Saltstone has been shown to effectively immobilize technetium-99 as an insoluble sulfide and carbon-14 as an insoluble carbonate within the Saltstone matrix, eliminating the need for further pretreatment prior to processing into Saltstone for disposal.

A silica source would be needed for a vitrification process, preferably soils that have been contaminated and are also considered to be a waste. Seepage basins are targeted as a primary source of such wastes at other sites. However, large volumes of contaminated soil are not available at the SRS because the seepage basins that contained significant concentrations of radioactive and/or hazardous contaminants have already been remediated at the SRS. The cost advantage of using a waste stream as a raw material for the vitrification process, especially with the high volume of salt waste that must be processed, is precluded. Unlike other DOE sites, closure and remediation of basins is not presently an issue at SRS.

Energy requirements for a vitrification process would be higher than a process that produces a cement-based waste form such as Saltstone. Just on the basis of the water content (60-80 wt %), significantly more energy would be needed to vitrify the waste compared to simply mixing the aqueous waste with dry materials. Maintenance and process safety, compared to the Saltstone process, would also be compromised if a vitrification process were adopted due to the high-temperature nature of the process. The cost of conversion to a vitrification process must also be considered, including all the regulatory and safety requirements that must be redone (SAR, RPA, EIS, FFA, etc.).

5.2 Comparison of Estimated Waste Volumes - Saltstone vs. Glass

As noted above, the projected capacity of the SDF (174 cells) could contain about 2 million metric tons of Saltstone with a volume of about 1.14 million cubic meters. Based on the projected salt composition (Ref. 2), the sodium content of the waste would determine the quantity of glass that would be produced, since a vitrification process would thermally decompose most of the anionic waste constituents and convert them to oxides. Up to 1.2×10^{10} moles of sodium could be sent to Z-Area for treatment and disposal in the low-activity aqueous waste. Using this projected quantity of sodium and the nominal limit of 20 wt % sodium oxide in glass, the projected mass of glass generated by this waste can be calculated:

$$(1.2 \times 10^{10} \text{ mol Na})(1 \text{ mol Na}_2\text{O}/2 \text{ mol Na}) = 6.0 \times 10^{9} \text{ mol Na}_2\text{O}$$

$$(6.0 \times 10^{9} \text{ mol Na}_2\text{O})(0.062 \text{ kg Na}_2\text{O}/\text{mol Na}_2\text{O}) = 3.7 \times 10^{8} \text{ kg Na}_2\text{O}$$

$$(3.7 \times 10^{8} \text{ kg Na}_2\text{O})(1 \text{ kg glass}/0.20 \text{ kg Na}_2\text{O}) = 1.9 \times 10^{9} \text{ kg glass}$$

$$(1.9 \times 10^{9} \text{ kg glass})(1 \text{ met. ton}/10^{3} \text{ kg}) = 1.9 \times 10^{6} \text{ met. ton glass}$$

The mass of glass waste is not significantly different than the mass of Saltstone that would be generated from the same waste inventory. The density of glass (2600 kg/m^3) is higher than Saltstone (1700 kg/m^3), so the volume physically occupied by a glass is lower:

$$(1.9 \times 10^{9} \text{ kg glass})/(2600 \text{ kg/m}^3) = 730{,}000 \text{ m}^3$$

This physical volume of glass is only about 64 % of the physical volume of Saltstone that would be produced. However, producing large monoliths such as will be done with Saltstone is not possible for glass

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produced in a high temperature process, so the reduction in waste volume will be offset by voids in secondary containers used to hold the glass waste. In HLW glass waste forms, glass occupies only 85-90 % of the internal volume of the canisters. The container would also occupy physical space. Thus, careful design of packaging is required to avoid eliminating the seeming advantage of lower waste volume offered by a glass waste form.

5.4 Regulatory Impact of Shifting from Saltstone

A change in the treatment and disposal method for the low-activity waste stream sent to Z-Area would adversely impact the proposed compliance schedule for other facilities that are addressed in the Federal Facility Agreement (FFA) for SRS. Neither Z-Area nor the ETF are considered in the FFA schedule, since these are operating facilities that other regulatory agencies deem to be in compliance with applicable regulations. Continued operation of both facilities is needed to support the ITP and ESP operations that will pretreat stored HLW before it can be transferred to S-Area for vitrification.

Several permits would be needed to build and operate a vitrification facility for the treatment of LLW/MW. However, if a vitrification process for the salt waste presently stored in the HLW waste tanks could be developed, disposal at the SRS may be precluded. The lower volume of waste (about 64 % of the Saltstone volume as a waste form) would likely yield a final waste form that exceeds Class A waste, as defined by the NRC (Ci/cubic meter specifications). This higher activity could lead SCDHEC to require the waste to be shipped elsewhere (outside SC) for final disposal. The cost of containers and handling before and after filling must also be considered. Containers must meet Department of Transportation regulations for off-site shipments, and such requirements are also imposed at SRS for on-site shipments.

Final disposal may either require qualification of the container for simple trench burial or the construction of a vault to provide secondary containment. Shifting from vault disposal to trench disposal may not be possible, since vault disposal has been reviewed and generally accepted as the desirable method of disposal by the NRC, various state regulatory agencies and DOE sites.

A shift to LLW/MW vitrification technology for salt solution waste at the SRS would require extensive documentation, experimentation and demonstration before it could be adopted. The preparation of an EIS, SAR, permit applications and other supporting documents would be required, since this method of treatment and disposal of the LLW/MW stream has not been included in prior studies.

6.0 References

1. **Final Environmental Impact Statement, Defense Waste Processing Facility, Savannah River Plant, Aiken, S. C., DOE/EIS-0082, U. S. Department of Energy, February 1982.**
2. **Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility**, WSRC-RP-92-1360 (rev. 0), Westinghouse Savannah River Company, Aiken, S. C., December 18, 1992.
3. **Safety Analysis Report - Z-Area, Savannah River Site, Saltstone Facility**, WSRC-SA-3 (DOE Review Draft), Westinghouse Savannah River Company, September 1992.
4. Telefax from Ha Vu, Department of Energy, Germantown, Md (EM343) to Jim Lockridge, SWEC, Savannah River Site, dated 27-Oct-1993. [Contained charts and report discussing development of "Minimum Additive Waste Stabilization (MAWS)" at Fernald.]

United States Government Department of Energy

memorandum

DATE: March 25, 1994

REPLY TO
ATTN OF: Office of Environment:Berube:X65680

SUBJECT: SRS Saltstone Performance Assessment and Implementing Order DOE 5820.2A at LLW Disposal Facilities

TO: Jill E. Lytle
Associate Director
Office of Waste Operations

By January 14, 1994 memorandum, your office requested our review of the Savannah River Site (SRS) radiological performance assessment (PA) for its saltstone disposal facility. Although we found the PA to be a technically sound document, we have enclosed comments on the document that primarily address questions of compliance with Order DOE 5820.2A.

Our review concentrated on the radiological aspects of Section III.3.a, Performance Objectives. Although additional work must be done to address uncertainties (see below), we believe that the saltstone facility will likely perform in compliance with these performance objectives. Nonetheless, clarification is needed regarding Section III.3.a.4 of the Order which requires protection of ground water resources "consistent with Federal, State and local requirements."

For this performance objective the critical determination appears to be compliance with those groundwater protection requirements that have been promulgated by the State of South Carolina. (In effect, the Order incorporates the State requirements by reference.) Because the State groundwater standards are imprecise, SRS should, among other things, provide some assurance that the State agrees with SRS's interpretation of the State requirements.

In addition, information should be provided about how SRS proposes to "maintain releases...as low as reasonably achievable" in compliance with paragraph III.3.a.2 of the Order. SRS could accomplish this requirement by describing, and implementing, a structured program of PA maintenance that is integrated into the site waste management plan. This PA maintenance program should include continued experimental and computational work, as well as near-field monitoring in compliance with paragraph III.3.b.3. The PA acknowledges the uncertainties in predicting disposal facility performance, and points out that should moisture barriers fail, and should the saltstone degrade extensively, then the facility might not be in compliance with the Order. There is a related question about the long-term release of nitrates.

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We believe that PAs for DOE disposal facilities must truly be "living documents," and that PA maintenance programs should be considered a necessary operational requirement in the same way that an environmental monitoring program is a necessary operational requirement. Besides directing preparation of design and waste acceptance criteria for low-level waste (LLW) disposal facilities, PAs should be used to direct research meant to validate assumptions and values for critical modeling parameters. Research and PA development should continue in an iterative manner over the life of the disposal facility.

But without an uncompromising mandate from DOE headquarters, such research and verification activities might be discontinued as economy measures. Such economy would be shortsighted, however. There are a number of uncertainties associated with predicting the long-term behavior of LLW disposal facilities, and many of the experimental programs that have been conducted to obtain parameter values for models are of a short-term nature. Continued research and PA maintenance are needed to ensure the credibility of DOE's LLW management efforts. In any case, we expect that technical questions will continue to arise, and it would certainly seem more efficient and timely to respond to these questions using ongoing research programs rather than proceeding by fits and starts. Cost savings would result if research and verification activities were coordinated among DOE sites and disposal facilities.

We also continue to have a general concern about the process by which DOE ensures that the requirements of DOE 5820.2A are met. Although a PA may provide a promise of action, it doesn't by itself cause the action to happen. In my April 14, 1992, memorandum, we suggested establishment of a formal, regulatory-type review and authorization mechanism that functions in an analogous manner to a commercial licensing program. We again urge such a program, including issuance of a "design and operating plan" against which facility design and operation can be inspected.

For operating facilities such as SRS Saltstone, one could consider a phased approach, whereby the design and operating plan would initially focus on compliance with those design and operating features important to the PA, including the PA maintenance program. The plan would prohibit operators from changing, without approval, facility design and operations in ways that are inimical to the PA conclusions. Thereafter, other provisions of the Order could be considered for inclusion in the design and operating plan, such as facility closure plans. For new facilities, where construction and operation should be contingent on EM approval, one could prepare a more initially complete design and operating plan based on a facility "application" as suggested in my April 14, 1992, memorandum.

operation. The schedules for preparation of the PAs have shown a propensity for slippage. We believe that additional efforts should be made to encourage the sites to complete these PAs. To do this, we recommend prompt issuance of an EM policy that first, would require approval of a PA before construction and operation of any new LLW disposal facility, and second, would require, as a condition of continued operation, completion of PAs for all existing disposal facilities by a specified date.

Finally, we see a need to develop a firmer policy for managing LLW disposed before September 26, 1988, the effective date of DOE 5820.2A, and addressing the long-term impacts that may be associated with this LLW. As a first step, we suggest a program to characterize former waste disposals and assemble data, such as groundwater monitoring data, that can be used to help assess alternative policies. We suggest such a program in any case, for both former and existing LLW disposal facilities, to allow timely consideration of possible difficulties with complying with future standards for LLW disposal issued by the Environmental Protection Agency (EPA).

In a Federal Register notice dated December 20, 1993, EPA promulgated a general environmental standard, 40 CFR Part 191, for disposal of high-level waste, transuranic waste, and spent nuclear fuel (58 FR 66398). Among other things this notice indicates that EPA plans to issue a general environmental standard for disposal of LLW.

We can neither predict nor prejudge the content of EPA's planned LLW standard, although we expect that EPA may consider, as an alternative, a groundwater protection requirement similar to that promulgated for 40 CFR Part 191. This groundwater protection requirement is linked to drinking water concentration limits, and background levels of radionuclides must be included when determining compliance with the standard.

We would appreciate receiving your thoughts about these suggestions, particularly those concerning the completion of PAs for new and existing disposal facilities. The staff points of contact in the Office of Environmental Guidance are G. Roles (586-0289) and E. Regnier (586-5027).

Raymond P. Berube
Deputy Assistant Secretary
for Environment

Enclosure

Review of PA for SRS Saltstone Disposal Facility

1. One of the performance objectives in Order DOE 5820.2A indicates that groundwater resources are to be protected, "consistent with Federal, State and local requirements" (Section III.3.a.4). We are unaware of any Federal requirements for protection of groundwater at LLW disposal facilities, although 40 CFR Part 193, under development by EPA, may contain such requirements when eventually promulgated. We are also unaware of any local groundwater protection requirements. However, groundwater protection requirements have been promulgated by the State of South Carolina. The PA does not specify these requirements but does indicate, on page 1-8, that "compliance...usually has been interpreted as meaning that concentrations of chemical and radioactive contaminants at any points of compliance should not exceed standards for public drinking water supplies established by the EPA," and that "such a requirement is included in the SCDHEC regulations and permits for the Z-Area disposal facility." Later on page 1-8, the PA indicates that the point of compliance assumed for the PA is "consistent with the SCDHEC regulations and permits."

   The PA should clarify the actual State requirement, and assess the possible release of radionuclides from the saltstone facility against this requirement. We understand that the State standard, among other things, addresses "man-made" radionuclides, that are "not to exceed concentrations or amounts such as to interfere with use, actual or intended, as determined by the Department [of Health and Environmental Control]." Because this standard is imprecise, SRS should provide some assurance that the State agrees with SRS's interpretation of the State requirements.

2. Section III.3.b requires that PAs should not only be maintained, but that "monitoring should be used to validate or modify the models used in performance assessments." Clear plans and schedules should be provided for doing so, in coordination with other studies and work conducted as part of the PA maintenance program. (See comments 3 and 4.) We note that on page 24 of the 5/17/93 response to a request for information from the PRP, the preparers of the PA addressed possible monitoring programs. This response, however, is insufficient.

3. The PA properly identifies uncertainties in the performance of the saltstone facility over the long term. The primary uncertainties appear to relate to the question of the long-term performance of moisture barriers and drains, and the extent to which the saltstone may degrade. Additional plans and schedules should be provided for the follow-up work proposed to address these and other major uncertainties as

they are identified. In addition, we note that releases from the saltstone facility have been projected from relatively short-term lysimeter and laboratory studies. As part of the PA maintenance program, these studies should be continued to provide greater assurance that the performance objectives will be met over the long-term. (Also see comment 4.)

4. In compliance with paragraph III.3.a.2 of the Order, the PA should more clearly indicate how SRS proposes to "maintain releases of radioactivity in effluents to the general environment as low as reasonably achievable." We suggest that SRS could accomplish this requirement by describing, and implementing, a structured program of PA maintenance leading to final development and implementation of a facility closure plan. The PA maintenance program would be integrated into the site waste management plan discussed in Chapter VI of the Order and in proposed 10 CFR Part 834.

We draw an analogy to the as low as reasonably achievable (ALARA) programs implemented by DOE sites for compliance with DOE 5400-series orders. By March 14, 1991, memorandum, EH issued guidance for implementation of ALARA programs established to control exposures to the public from normal operations and in development of authorized limits for the release of DOE property (lands, buildings, equipment, and so forth) containing residual radioactive material. As used in this guidance, ALARA is an approach to radiation protection to manage and control exposures (both individual and collective) to the work force and to the general public, and releases of radioactive material to the environment, at levels as low as practicable, taking into account social, technical, economic, practical, and public policy considerations. ALARA is not a dose limit, but rather a process.

Although the guidance was not specifically prepared with the intent of addressing the question of possible releases of radioactive materials from LLW over thousands of years, we believe that the guidance contains a number of principles that would be applicable. One would develop and implement a program that sets forth a structured approach to decisionmaking. One would identify those aspects of the site design and waste characteristics that are significant for minimizing long-term releases, and consider alternatives. One would estimate the performance of the different alternatives and select the preferred alternative from those considered. One would then implement the alternative, maintaining an audit trail.

In the case of the Saltstone facility, the PA would outline an iterative process to optimize facility design and waste acceptance criteria over the life of the facility. It would be used to provide structure to the PA maintentence program, with the intent of resolving major uncertainties, and working toward developing and implementing a facility closure plan. The PA maintenance program would be addressed in the site waste management plan and would identify activities intended to resolve these uncertainties, where the activities could include experimental efforts (e.g., infiltration experiments, lysimeter studies) and model improvement. The PA maintenance program would also become more refined based on feedback from these efforts. Experimental data, model refinement, and analyses of alternatives would provide a basis for identifying any needed changes in facility design and operation, or waste acceptance criteria, to reduce possible environmental releases to levels as low as reasonably achievable, and to provide support for developing and implementing an approved facility closure plan.

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United States Government Department of Energy

memorandum

DATE: SEP 2 0 1994

REPLY TO ATTN OF: Office of Environmental Guidance:Wallo:X64996

SUBJECT: SRS Saltstone Performance Assessment

TO: Joseph A. Coleman, Director
Office of Eastern Waste
Management Operations
Environmental Management

By March 25, 1994, memorandum, we provided comments on the Savannah River Site (SRS) radiological performance assessment (PA) for its saltstone disposal facility, and also raised concerns about related issues including DOE's process for ensuring compliance with DOE 5820.2A. We subsequently received your June 30 memorandum that provided the SRS response to our saltstone comments. We then met with EM-30 and SRS staff on August 16.

Based on this August 16 meeting, we believe that there is an improved understanding of EH expectations for operation of the saltstone disposal facility. We are satisfied with the June 30 response regarding protection of groundwater consistent with State requirements. However, we are not satisfied with the June 30 response to our other comments. As we indicated in the August 16 meeting, SRS needs to set forth and implement specific programs to resolve major PA uncertainties, to validate PA models, and to maintain the PA according to a schedule. SRS staff agreed to provide additional plans to conduct these activities, and to clarify plans for closure and operation of old and new lysimeter systems. SRS staff also agreed to provide documentation that addresses compliance with Section III.3.a.2 of DOE 5820.2A with respect to reducing release of effluents to the environment to levels as low as reasonably achievable.

Furthermore, we presented SRS staff with additional comments on the PA. We expect that SRS will provide us with a written response that will be subsequently incorporated into the next revision to the PA. (We expect that PA revisions will occur periodically throughout facility operation.) These comments were provided at the meeting in a draft form; we have finished them and have attached them to this memorandum.

Some of the comments will require guidance from EM for resolution. We noted similar concerns as part of our review of the PA for the E-Area Vault disposal facility, where clearer policy needs to be provided for issues such as assumptions about future ownership of DOE LLW disposal facilities and the purpose of analyses for protection of an inadvertent intruder.

We also discussed the expected Environmental Protection Agency (EPA) standard for low-level waste disposal, 40 CFR Part 193. Although EPA staff have not provided us with the details of this standard, they have communicated its major themes. For example, EPA staff plan to include a groundwater protection requirement that would be linked to drinking water maximum concentration limits (MCLs), where background levels of radionuclides would be included when determining compliance. We plan to provide EM with an outline of these major themes, and will request that EM help us to begin a process of working with Field Offices to obtain their assessments of the likely costs, benefits, and impacts (program changes or disruptions) of the standard on their activities. We will use the responses to continue to work with EPA staff as they develop the standard.

In the case of the saltstone facility, although limited data is presented in the PA, it does indicate that background levels of radium-226 may occasionally approach or exceed drinking water MCLs. This may cause problems for operation of the saltstone facility in compliance with the expected standard. Limited quantities of waste containing Ra-226 precursors have been disposed in the saltstone facility. In addition, the saltstone formulation includes coal combustion slag which should contain enhanced concentrations of Ra-226 as well as other naturally occurring radionuclides.

We look forward to resolving these issues. The staff points of contact in the Office of Environmental Guidance are G. Roles (586-0289) and E. Regnier (586-5027).

Raymond F. Pelletier
Director
Office of Environmental Guidance

Attachment

cc. R. Berube, EH-20
J. Lytle, EM-30

Additional EH-23 Comments on the Savannah River Site (SRS)

Saltstone Performance Assessment (PA)

1. Order DOE 6430.1A, General Design Criteria.

   SRS needs to address the applicability of and compliance with Order DOE 6430.1A, General Design Criteria, particularly in reference to Sections 1324-5 and 1324-6. This order was issued on 6 April 1989.

2. Future land use for Saltstone Site.

   The PA discusses the Saltstone facility as if SRS expects that after the end of institutional control, access to the site will be completely unrestricted. Although we aren't sure of SRS plans for future site use, we believe that the PA needs to clarify this issue. Completely unrestricted release strongly implies an end to site ownership and other passive institutional controls. We believe that the intent, rather, is to retain ownership of the disposal site after the active institutional control period, and to apply passive institutional controls.[1]

   Provided that an assumption is made of disposal facility land ownership, then after the 100-year active institutional control period, SRS could characterize future land use as being under the control of relatively strong passive institutional control measures. It is possible that nonintrusive surface use of disposal facility land might be allowed (e.g., for grazing or for a park). In this case, inadvertent intrusion into the waste can be envisioned as an "accident," a hypothetical event. An inadvertent intruder is then an abstract entity, a mechanism applied to guard against the potential for humans to receive very large radiation doses in the event of "catastrophy," recognizing that it is impossible to reliably predict human actions and the radiation doses that might occur.

   But if the intent is to release the land for completely unrestricted use, then by definition, no passive institutional controls are imposed. Intrusion into the waste looks less like an accident and more like a probable event, and an inadvertent intruder looks less like an abstract entity and more like a real person. In any case, one may be compelled to consider decommissioning criteria

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[1] Passive institutional controls can include measures such as land ownership, covenants in deeds, markers, and so forth, and can last long after active institutional control measures (fences and guards, monitoring and maintenance activities, etc.) are presumed to be effective. The 100-year limit on institutional controls should only apply to active institutional controls.

rather than LLW disposal criteria. More restrictive dose limits or calculational assumptions may be applicable.

We believe that a clearer statement of DOE policy is needed on land ownership of LLW disposal facilities. The policy should be such that preparers of LLW PAs may assume that DOE ownership of LLW disposal facility land (and other passive institutional control measures) will continue indefinitely beyond the active institutional control period.

3. Biointrusion.

On page 3-29 of the PA, a discussion is provided about the potential for biointrusion, which can result in surface contamination of the disposal facility. Doses are calculated to an inadvertent intruder. However, persons receiving radiation doses might not be intruders depending on assumptions about future ownership and use of disposal facility land. If the intent after the active institutional control period is to authorize the surface use of the site by individuals, then persons potentially exposed would not be intruders. A more restrictive annual dose limit than 100 millirems would be appropriate.

4. Intruder well-water calculations.

In the PA, an argument is made that because annual doses from release to groundwater are considerably less than 100 millirems, it is not necessary to consider doses from well water to an inadvertent intruder. This is illogical, because the doses projected to meet the all-pathways and groundwater protection performance objectives are calculated under the assumption of undisturbed performance of the saltstone facility by humans. But the intruder, by definition, intrudes into the disposal facility and therefore, in theory, changes its performance (e.g., disrupts barriers to infiltration of water into waste).

There is a need for clearer guidance from DOE on the purpose of the inadvertent intruder analyses. If the intent of the analyses is to protect a real person, then intruder doses associated with use of well water must logically be performed under the assumption that the disposal facility is disrupted by the intruder. The results of such calculations would be difficult to justify, however, because they would be artifacts of assumptions about intruder actions. But if the intent is to treat inadvertant intrusion as a hypothetical event, as a mechanism to help determine waste acceptance and design and operating criteria, then a case can be made that doses from use of well water need not be considered for purposes of intruder protection. Protection of the environment and human health and safety from possible release of contamination to groundwater is already ensured through compliance with other performance objectives.

5. 40 CFR Part 141.

As a minor point, the PA occasionally references 40 CFR Part 141 as if it is in terms of effective dose equivalent (EDE). This is incorrect. The current version of 40 CFR Part 141 uses older dosimetry models, although the revised Part 141 rule proposed by EPA on 18 July 1991 (and not yet promulgated) is in terms of EDE.

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Westinghouse
Savannah River Company

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OPS-DTZ-95-0001

JAN 10 1995

To: M. S. Glenn
DOE-SR, 704-S

From: D. G. Thompson
Manager, Saltstone Facility

RESPONSE TO DOE-HQ COMMENTS ON ZAREA PERFORMANCE ASSESSMENT (u)

References:

1. USDOE Memorandum, R. P. Berube to J. E. Lytle, "SRS Saltstone Performance Assessment and Implementing Order DOE 5820.2A at LLW Disposal Facilities," March 25, 1994.
2. USDOE Memorandum, R. F. Pelletier to J. A. Coleman, "SRS Saltstone Performance Assessment," September 23, 1994.
3. Letter, H. F. Daugherty to V. W. Sauls, "Response to DOE-HQ on EAV Radiological Performance Assessment Comments," SWE-SWD-94-0247, September 30, 1994.

Dr. J. R. Fowler of our staff has the primary technical responsibility for the Z-Area Radiological Performance Assessment (RPA). As you requested, he has prepared responses to the comments from DOE-HQ (Ref. 1, 2) to assist you in the preparation of responses to EM-323.

Reference 3 provides information on programs funded at SRS relative to the E-Area vaults (EAV). Some of these programs are purposely designed to apply to any disposal or remediation site at the SRS (e.g., infiltration studies). Note that any committments by Saltstone Operations, relative to maintenance of the Radiological Performance Assessment for Z-Area, presumes adequate funding will be provided by the Department of Energy to support this activity.

A. Response to Comments from R. P. Berube (Reference 1)

1. **Compliance with Section III.3.a.(4): Comment on providing assurance that state agrees with SRS's interpretation of State requirements.**

   A statement will be added in the summary of the RPA that notes SCDHEC has issued operating permit for the disposal site and thus agrees that Z-Area disposal site complies with state requirements when the RPA is revised to incorporate the errata provided to the Peer Review Panel.

2. **Compliance with Section III.3.b. [NOTE: Only paragraphs (1) and (3) of this section apply to a PA for a specific disposal site, such as Z-Area. This section requires field organizations with disposal sites to <u>prepare and maintain</u> a site specific PA for disposal of waste and to <u>monitor and/or test</u>, <u>as required</u>, to evaluate actual and prospective performance and to validate or modify models used in PAs. EH felt that clear plans and schedules should be included for active programs as part of the maintenance of the RPA.]:**

   The requirements specified in this section of the Order are first addressed.

4. Compliance with III.3.a.2: "Clearly indicate how SRS proposes to maintain releases to the environment to be ALARA."

   ALARA analysis was suggested for the site waste management system plan or system PA, rather than in a facility specific PA. A facility-specific PA simply provides technical support for the waste management plan and system PA. These principles should be applied even if waste disposal is not a part of a site's overall mission.

   Present guidance for 5820.2A does not require an ALARA analysis for a PA covering a specific disposal site such as ZArea. This type of analysis and comparison is more appropriately done in conjunction with Environmental Assessments or Environmental Impact Statements as a part of selecting the preferred method of treatment and final disposal.

   Please note, however, that ALARA has been used as a guiding principle throughout the evolution of the SRS HLW waste treatment, storage and disposal system, of which Z-Area is only one component. The decision to remove cesium and strontium from soluble waste at the SRS was included as a part of HLW treatment and disposal to adhere to the ALARA principle. Likewise, the historical evolution from saltcrete in trenches to saltstone in vaults was a direct result of applying the ALARA principle. The DWPF vitrification facilities, the saltstone facilities, in-tank treatment operations, the glass and saltstone waste forms, and the selected method of saltstone disposal are designed, controlled and operated with the ALARA principle as a guide. We agree that ALARA is a process and we have applied it at the SRS.

B. Response to Comments from R. F. Pelletier (Reference 2)

1. Order DOE 6430.1A, General Design Criteria: This comment requested that SRS address the applicability and compliance with 6430.1A, particularly sections 1324-5 and 1324-6.

   ZArea facilities are low-hazard (category III) nuclear facilities. The design and construction of existing Z-Area facilities were completed prior to the issuance of 6430.1A. Since 6430.1A did not exist, ZArea facilities were designed and constructed to meet or exceed the specifications of 6430.1 for a low hazard facility.

   Conformance with DOE requirements, including 6430.1A, is specifically addressed in the SAR for ZArea (WSRC-SA-3). Any future significant additions or modifications (i.e., future vaults) will comply with 6430.1A.

   When 6430.1A was issued, WSRC contracted with United Engineers and Constructors (UE&C) to perform a compliance review of the design data for ZArea facilities against the requirements of 6430.1A to confirm that non-compliances, if any, would not impact safety or the environment. The review was completed in September 1990 (WSRC Report No. 864962). ZArea facilities meet or exceed the requirements for a low-hazard (category III) nuclear facility. One non-compliance with ANSI standard C21981 requirement for electrical panels was identified, but was determined not to be considered a deficiency for ZArea, since the design and installation of these panels were consistent with standard industrial practice, and the deviation did not impact safety or the environment.

   Z-Area storage and treatment facilities comply with or exceed the requirements in 1324-5 and 1324-6 that are applicable to present operations. Storage tanks, transfer lines into the facility, and saltstone production equipment are doubly contained, as required by this section. Criticality is not credible in Z-Area, due to the low concentration of fissile materials in solutions processed and the saltstone produced. In the event of a DBE, complete failure of all containment facilities would have local consequences only, consistent with the requirements for a category III facility.

   In terms of confinement systems, the monolithic saltstone waste form provides primary containment; the vault and temporary cover provide secondary containment until a layer of nonradioactive concrete is installed to provide permanent secondary containment during active disposal operations in Vault 1. Vault 4 will be retrofitted with a permanent roof structure and future vaults will be constructed with permanent roof structures prior to filling with saltstone to provide secondary containment. The change to a permanent roof prior to filling has been made to simplify interim vault closure operations and will significantly reduce the volume of job-control waste generated from continuing operations (ALARA), based on operating experience related to disposal operations in Vault 1. This change in vault construction and operations has been reviewed against the RPA, and does not require a revision of the RPA.

Final closure (clay layer, backfill, etc.) will provide the tertiary containment specified for disposal sites. The closure concept presented in the Z-Area RPA complies with applicable specifications in 1324-5.3 and all of 1324-6, including the specification of ongoing site maintenance.

2. Future land use for Saltstone site.

Minimal assumptions were made in the RPA for both Z-Area and EAV regarding future land use. Active institutional control of 100 yrs is specified in the Order. In these RPAs, we assumed the most conservative case -- release of the site for general public use. This is not meant to imply that the facility will actually be released for general, unrestricted use. Passive control (i.e., continued ownership and occasional inspection by the U.S. government) is more likely to be the case. This is a DOE policy issue that we cannot address in the context of the RPA, beyond calculating the potential impact to an intruder, as if he had free access to the site.

If guidance from DOE Headquarters' changes to include application of the public performance objective to persons conducting activities within the disposal facility, the RPA can be revised accordingly.

3. Biointrusion.

See response to B2.

4. Intruder well water calculations.

We concur with the comment. Better guidance is needed on the intruder analyses to be done. If passive administrative controls are maintained in perpetuity, then the need for these calculations are eliminated. However, the calculations do show that even if this activity is assumed, the dose to the resident intruder is still quite small. The principal concern in Z-Area, if a well were drilled that compromised the closure cap, would be an increase in nitrate concentration in the underlying groundwater. Radioactive species would not increase significantly, even if the cap integrity or the vault integrity is compromised.

If guidance from DOE Headquarters changes to include application of the public performance objective to persons conducting activities within the disposal facility, the RPA will be revised accordingly.

40 CFR Part 141.

We agree with the observation. On page 1-9 and 1-10 of the Z-Area RPA, the more-modern method of dose calculation was described, and the proposed regulation was used as the basis for calculation. As noted in the discussion, using a single dose limit for all radionuclides provides a consistent and transparent regulatory approach.

DGT/jrf

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Distribution for OPS-DTZ-95-0001:

J. W. Wilson, 210-S
J. R. Fowler, WSRC, 704-Z
R. M. Satterfield, 719-4A
J. F. Ortaldo, 704-S
R. Schwamberger, 704-Z
D. G. Thompson, 704-Z
E. L. Wilhite, WSRC, 773-A
J. R. Cook, WSRC, 773-A
A. Yu, WSRC, 773-A
Records

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pg. ~~142~~ 147 R.0

DOE F 1325.8 (Rev 11-12-91)

United States Government — Department of Energy (DOE)

memorandum

Savannah River Operations Office (SR)

DATE AUG 3 0 1996

REPLY TO ATTN OF PD (Hannah/803-208-1541)

SUBJECT Headquarters Review of the "Radiological Performance Assessment (RPA) for the Z-Area Saltstone Disposal Facility", and Request for Additional Information

TO Director, High Level Waste Division, Office of Waste Management, HQ

Attached is SR's response to your request for additional information regarding the groundwater protection section of the subject RPA. The responses were discussed with Virgil Lowery of your staff, and an attempt was made to address his concerns and incorporate comments.

Any questions may be directed to me or Ray Hannah at 803-208-1541.

Charles E. Anderson, Director
Programs Division

PD:ALT:eeh

PB-96-0174

Attachments
Response to Questions
from EM-35

cc w/attch:
P. Bubar, EM-323, HQ
M. Letourneau, EM-22, HQ

RESPONSE TO QUESTIONS FROM EM-35 FOR DOE-SR:

1. *(a) How are MCLs applied by the State of South Carolina?*

The state of South Carolina uses MCLs as the basis for regulation of public water supplies and as the standard for the quality of both surface and groundwater. They also apply MCLs to releases to surface waters and to groundwater monitoring analyses for proposed (i.e., baseline results before disposal begins) and active disposal sites. In both E-Area and Z-Area, the shallow aquifer beneath these disposal facilities are neither suitable nor adequate for drinking water supply due to its shallow depth and insufficient water supply capability. However, South Carolina Regulation 61-68 requires that drinking water standards be applied to all groundwater regardless of its intended use. As noted in a previous response relative to the conditional approval of the E-Area RPA, documented telephone discussions with the State Drinking Water Section and the Bureau of Solid and Hazardous Waste reaffirmed the applicability of the MCLs as the appropriate groundwater standard for disposal sites (Ref. 1).

(b) Are MCLs to be applied as an increment over what is already in the groundwater, or is it to be the total load in the groundwater from background, other contamination <u>and</u> the contribution of the disposal facility?

The total load of contaminants in the groundwater and surface water is compared against the MCLs to establish water quality. MCLs are thus used as the standard for comparison of monitoring results. For groundwater that could be impacted by a proposed disposal site, the existing water quality beneath a site is first established through groundwater monitoring upgradient, within and downgradient of a proposed site as a part of the background site characterization. After active disposal operations begin, continuing monitoring results from upgradient and downgradient wells are used to establish if contaminants found in monitoring wells are attributable to the disposal activities, to a failure of the disposal system used at the site, or to contamination from another source upstream of the disposal site. If MCLs are found to be exceeded in background characterization for a particular contaminant, then the facility waste form or disposal unit design must assure that the facility can make no statistically significant, incremental contribution of the contaminant that exceeds MCL in the background wells. For example, if the background concentration of copper exceeded the MCL for copper in the ground water, then either the disposal of leachable copper in the facility would either be excluded or the control of releases to statistically insignificant levels through either waste form design or disposal design would be required before an operating permit is issued.

2. *If the MCLs are applied to the total, how does the state view results of prospective analyses like the Saltstone PA relative to complying with the requirement of groundwater Protection?*

Results in the RPA are not considered in permitting by the state. The state permits disposal sites based on a review of the proposed design and supporting groundwater data obtained before, during and after waste disposal. Since the primary purpose of the RPA is to assess the long-term impact of radioactive contaminants, the state views this study as part of the regulatory control imposed by DOE in accordance with DOE's authority to regulate radioactive contaminants to assure that disposal activities at DOE sites do not pose any undue risk to public health or safety, or to the environment. The state relies on groundwater monitoring, as specified in facility permits, to determine if a state-permitted facility is protecting groundwater resources, in accordance with state regulations and operating permits. The groundwater monitoring plan for the site specifies contaminants of concern by the state. Specific monitoring requirements for each disposal facility for which the state has regulatory authority are specified in operating permits for each facility, consistent with the materials placed in the disposal facility. For facilities such as Z-Area, the operating permit specifies potential contaminants that must be tested for in upgradient and downgradient groundwater samples. The current Z-Area permit requires monitoring groundwater for pH, Specific Conductance, arsenic, antimony, barium, cadmium, chromium, lead, mercury, nitrate, nitrite, selenium, silver, benzene, toluene, the sum of Ra-226 and Ra-228, gross alpha particle activity, beta particle activity and proton (tritium) activity in upgradient and downgradient wells. Results are required to be reported to the state. (See permit for actions required, if a contaminant is found that exceeds MCLs.) Actual groundwater monitoring results during active disposal and for at least 30 years after closure serve as the basis to establish if a site is in compliance with state regulations.

3. *If the MCLs are applied to the total, and if there is intent that a prospective analysis will demonstrate compliance at some future date, how does SR interpret the groundwater data, i. e., what is the background to which Saltstone will be adding activity?*

   MCLs are applied to the total, but the intent of the Z-Area radiological performance assessment is to provide reasonable assurance that the incremental impact of radioactive releases from the Z-Area Saltstone Disposal Facility do not exceed the radiological performance goals specified in DOE Order 5820.2A, with respect to protecting the health and safety of the public from a potential radiological dose, due to the disposal of saltstone at the Z-Area site located within the SRS. The projected peak releases and pathways are analyzed in the Z-Area RPA and the dose estimated for comparison to the goal. As noted in the Z-Area RPA (pp. 1-9, 1-10; cf. 4-50), using a single dose limit provides a consistent and transparent regulatory approach to all radionuclides that may or may not have MCLs specified in current regulations, and is actually more restrictive than the EPA's proposed (at the time the RPA was issued in 1992) revisions of the drinking water standard for radionuclides. Compliance with the conditions and groundwater monitoring requirements specified in the Z-Area operating permit issued by the SCDHEC meets the Order requirement to comply with applicable state and local regulations. Groundwater monitoring data is used and interpreted in accordance with the protocol specified in the permit issued by SCDHEC. (Ref. 2)

4. *What is the contribution to the dose or concentration in groundwater of technologically enhanced naturally occurring radioactive materials (NORM) in the saltstone admix? Higher than normal NORM may exist in the flyash and slag used in making vaults and saltstone due to the concentration of NORM that can occur in the burning of coal or the processing of metal ores. These quantities may require consideration from the standpoint of impact to groundwater in conjunction with the radioactive isotopes in the liquid waste.*

   NORM in the dry materials were not considered as part of the analysis in the RPA. The NORM from dry materials used in the saltstone and vaults is estimated to be about a factor of 5 greater than the 2 to 10 pCi/g found in the SRS soil from which the vaults and waste displace. U, Th and ^{40}K are the NORM in both the soil and these materials. The total activity in the saltstone waste is dominated by radioactive contaminants in the salt solution. The contribution of NORM in the dry materials to the total activity in saltstone is estimated to be less than 0.05 nCi/g, corresponding to about 0.06% of the projected average radioactivity in saltstone at the time of disposal (about 80-100 nCi/g total activity from salt solution), less than 0.1 % of total activity in saltstone at the time of closure, and less than 0.2 % of the 30 nCi/g of activity estimated 1100 years after disposal. Use of slag and fly ash to prepare saltstone converts these materials, normally considered a waste from other processes, places these materials in an environmentally better form for disposal.

REFERENCES

1. Letter, H. F. Daugherty to V. W. Sauls, Response to DOE-HQ on EAV Radiological Performance Assessment Comments (u), SWE-SWD-94-0247, September 30, 1994.

2. Z Area Permit (copy attached).

Alex Gabbard, Coal Combustion: Nuclear Resource or Danger.

SUPPORT FOR ANSWER TO QUESTION 4 ON "NORM"

A. SRS Soils

A study was completed on SRS soils to establish a baseline value for background radiation from SRS soils prior to startup of Plant Vogtle, a nuclear power plant operated by Georgia Power and Light directly across the Savannah River from SRS. Measured background radiation levels attributed to ^{40}K ranges from 0.5 to 10 pCi/g. For the Uranium decay series, background radiation ranges from 0.5 to 4.2 pCi/g. For the Thorium decay series, background radiation ranges from 0.4 to 2.1 pCi/g. Thus background radiation due to Normally Occurring Radioactive Materials in natural soils at the SRS would be expected to range from about 1.5 pCi/g to 16.2 pCi/g, the sum of the minimum and maximum values observed for these principal sources of background radiation.

B. Typical Construction Materials

Cement

In NCRP 94 (National Council on Radiation Protection, dated 1987) , typical cement is described as containing 6.4 pCi/g of ^{40}K , 1.2 pCi/g of U, and 0.57 pCi/g Thorium, corresponding to a total background activity of 8.2 pCi/g.

Fly Ash

Fly ash used in vault construction and in the Saltstone waste form is generated as a waste material from coal-fired power plants. Radioactivity has not been measured in flyash used at Saltstone. The NCRP estimates 4270 nCi/ton of coal, while the EPA (AP-42, as amended, October 1986) estimates 80 lbs. of ash is produced from the burning of 1 ton of coal. Based on these data, fly ash would contain no greater than 31 pCi/g.

Slag

In a typical blast furnace operation, about 500 lbs. of slag is produced from one ton of iron ore. Thus NORM in the ore would be about a factor of 4 higher than its concentration in the ore and flux materials. Assuming concentrations comparable to coal for NORM in the ores and flux materials, slag would be expected to contain 5-10 pCi/g of Norm from K, U, and Th impurities in the ores.

Concrete

In the same study done for the ultra-low level counting facility, the background radiation of normal structural concrete was as follows: ^{40}K = 15 pCi/g; Uranium decay series = 0.55 pCi/g; Thorium decay series = 1.5 pCi/g; Actinium decay series ≤ 0.32 pCi/g. Total "background" radiation for normal concrete is about 17 pCi/g.

Crush and Run

To support the construction of the ultra-low level counting facility located at SRTC, background radiation in several possible materials of construction were measured. "Crush and Run," a gravel mixture that is used throughout the region near the SRS for gravel roads and concrete construction, has been and will likely continue to be used within the Saltstone Disposal Facility and at the SRS as an ingredient in concrete, to construct gravel roads, and to line drainage ditches to minimize erosion. Background radiation levels in this material was measured: ^{40}K = 21 pCi/g; Uranium decay series = 1.4 pCi/g; Thorium decay series = 2 pCi/g; and Actinium decay series ≤ 0.5 pCi/g. Thus the total "background" activity for this commonly used material is about 25 pCi/g.

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South Carolina
DHEC
Department of Health and Environmental Control
2600 Bull Street, Columbia, SC 29201-1708

Commissioner: Douglas E. Bryant

Board: John H. Burriss, Chairman
William M. Hull, Jr., MD, Vice Chairman
Roger Leaks, Jr., Secretary
Richard E. Jabbour, DDS
Cyndi C. Mosteller
Brian K. Smith
Rodney L. Grandy

Promoting Health, Protecting the Environment

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APR 19 1996

CERTIFIED MAIL

April 16, 1996

Mr. Larry C. Haney
Westinghouse Savannah River Co.
P.O. Box 616, Building 742-A
Aiken, SC 29802

RE: Modified SRS Z-Area Saltstone Industrial Solid Waste Permit, # 025500-1603
(Formerly IWP-217)
Aiken County

Dear Mr. Haney:

Enclosed is a modified industrial solid waste permit for the SRS Z-Area Landfill. The Department has agreed to all the changes recommended in your letter of comment, dated February 22, 1996 (see attached).

Many changes are anticipated in State landfill requirements and at such time as the Department accomplishes the necessary regulatory changes, the Permittee will be required to comply with any applicable portions of such revisions.

The issuance of this permit marks the conclusion of regular activity with the Facility Engineering (Permitting) Section. However, should you have questions about the permit itself, please contact John Schnabel, P.E., (803) 896-4216. General Questions should be referred to Lower Savannah District consultant, Kurt Zollinger, (803) 641-7670.

Sincerely,

Robert L. Gill

Robert L. Gill, P.E., Manager
Facility Engineering Section
Division of Solid Waste Management
Bureau of Solid and Hazardous Waste Management

RLG/JJS/pej

cc: Kurt Zollinger, Lower Savannah District, EQC
John Schnabel, BSHWM
Eric Cathcart, BSHWM

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South Carolina
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Promoting Health, Protecting the Environment

OFFICE OF ENVIRONMENTAL QUALITY CONTROL
BUREAU OF SOLID AND HAZARDOUS WASTE MANAGEMENT
INDUSTRIAL SOLID WASTE PERMIT
025500-1603

Date of Original Issuance: May 19, 1986
Date of Modification: April 16, 1996
Effective Date of Modification: May 6, 1996

Permission is hereby granted to:

Name of Facility: Savannah River Plant Z-area Saltstone Disposal Facility
Permittee: U.S. DOE/Savannah River Site
Mailing Address: Post Office Box A
Aiken, SC 29802
Contact Person: A. B. Gould
Telephone: (803) 725-3969

for the operation of a industrial waste disposal facility located in Z-Area at the U.S. DOE/Savannah River Site, Aiken County.

This permit is modified pursuant to S.C. Code Ann. Sections 44-96-10 et seq. (Supp. 1995), Section 48-1-10 et. seq. (1987), and 25 S.C. Code Regs. 61-70 (1989). The authority granted below is subject to the requirements of the previously mentioned law and regulations and the attached conditions.

Patrick T. Walker
Patrick T. Walker, Director

Robert L. Gill
Robert L. Gill, P.E., Manager
Facility Engineering Section

Division of Mining and Solid Waste Permitting
Bureau of Solid and Hazardous Waste Management

If the permit is appealed, the effective date of the permit will be revised as necessary. Any request for review or appeal of this permit must be served in person or by mail within fifteen (15) days of the date of modification, on:

The Board of Health and Environmental Control
Office of the Commissioner
2600 Bull Street
Columbia, South Carolina 29201
(803) 734-4880

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SAVANNAH RIVER PLANT Z-AREA SALTSTONE DISPOSAL FACILITY
025500-1603

A. SPECIAL CONDITIONS

1. Site shall be constructed and operated in accordance with the permit application dated May 19, 1986, with revisions dated July 30, 1986 and December 12, 1995, unless permit conditions state otherwise.

2. The site is restricted to the disposal of saltstone generated by the Z-Area Industrial Wastewater Treatment Facility (Construction Permit #12,683) and saltstone failed equipment. It is the Permittee's responsibility to ensure that no other material is disposed at the site.

3. No hazardous waste as defined by the South Carolina Hazardous Waste management Regulations shall be disposed at this facility at any time. If it is determined that a hazardous waste has been disposed into this facility, all disposal activities should be stopped and this office notified immediately.

4. This office should be notified if the radioactive composition of the Z-Area Saltstone varies significantly from that identified in the application and subsequent permit modification applications.

B. GENERAL CONDITIONS

1. It is the Permittee's responsibility to adhere to all Federal, State and local zoning, land use and other applicable local ordinances and ensure all other necessary permits and/or approvals have been obtained prior to the receipt of any waste at the referenced facility.

2. It is the Permittee's responsibility to ensure that no other waste is disposed at this site. If the Permittee determines the need to dispose of any waste other than that listed in permit condition A.2, prior written approval must be obtained from the Bureau of Solid and Hazardous Waste Management. Each request shall be made in writing to the attention:

Director of Mining and Solid Waste Permitting
Bureau of Solid and Hazardous Waste Management
SC Department of Health and Environmental Control
2600 Bull Street
Columbia, South Carolina 29201

3. A minimum buffer zone of two (2) feet must be maintained between the seasonal high water table and/or bedrock and the lowest elevation of the disposal area. No material may be disposed into an area of standing water. If a disposal area should become inundated with water, steps must be taken to remove this water before continuing disposal of waste.

4. This permit will be subject to an environmental compliance review at least once every 5 years.

C. ENVIRONMENTAL MONITORING CONDITIONS

1) GROUNDWATER DETECTION MONITORING SYSTEM

The Permittee shall maintain a groundwater detection monitoring system consisting of a sufficient number of wells, installed at appropriate locations and depths to yield representative groundwater samples from the hydrologic units underlying the site.

a) Monitoring wells shall be installed hydraulically upgradient from the waste management area with numbers, locations, and depths sufficient to yield groundwater samples that are representative of background groundwater quality in the uppermost aquifer, and not affected by the facility.

b) Monitoring wells shall be installed hydraulically downgradient from the waste management area with numbers, locations, and depths sufficient to promptly detect any statistically significant degradation of groundwater quality in the uppermost aquifer.

c) The monitoring system shall be continuously maintained in such a manner as to yield samples representative of the quality of groundwater immediately upgradient and downgradient of the waste management area.

d) The Permittee shall construct monitoring wells and maintain monitoring well integrity in accordance with R.61-71 and the well construction specifications in the permit application. In addition, each monitoring well shall be properly labeled with a permanent identification plate constructed of a durable material secured to the well casing or surface pad where it is readily visible.

e) The Permittee shall maintain groundwater monitoring wells designated ZBG-1, ZBG-1A and ZBG-2. If the Permittee determines or is notified by the Department that the groundwater monitoring system no longer satisfies the minimum requirements for the number, location, construction, or integrity of wells, pursuant to groundwater permit condition 1, (e.g., structurally damaged wells, dry wells, wells no longer upgradient or downgradient, etc.) the Permittee shall:

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PG. 15b

i) Notify the Department in writing within seven (7) days of evaluating data, but no later than sixty 60 days after collecting groundwater monitoring data, that the monitoring system no longer satisfies permit conditions;

ii) Submit to the Department in writing a complete proposal to upgrade the monitoring well network within thirty (30) days of notification from the Department, but no later than ninety (90) days after collecting groundwater monitoring data; and

iii) Complete installation of additional well(s) necessary to achieve compliance with permit conditions within 60 days of receiving approval from the Department.

2) ROUTINE GROUNDWATER MONITORING

The Permittee shall perform routine monitoring of groundwater quality and elevation conditions to determine if waste disposal activities are affecting groundwater quality at the waste management area.

a) The Permittee shall perform groundwater monitoring according to the constituents in Attachment I for all wells that are determined to be components of the groundwater network and any other well(s) deemed necessary by the facility or the Department to uphold the intent of this permit. The permittee shall ensure that groundwater monitoring is conducted semi-annually in accordance with the schedule presented in section 6a of these permit conditions.

b) The Permittee shall perform groundwater monitoring according to the approved Groundwater Monitoring Plan dated February 15, 1995, and any subsequent modifications required by the Department.

c) The Permittee must determine during each sampling event the elevation of the groundwater surface in each well. Elevations must be determined on the same day that samples are collected.

d) The Permittee shall submit a revised Sampling and Analysis Plan. The revised plan should be submitted to the Department within sixty (60) days following reissuance of the permit.

3) DATA EVALUATION

The Permittee shall evaluate all groundwater quality and water level elevation data to determine if the waste management area is impacting groundwater.

a) The Permittee must ensure that a plan for statistically evaluating groundwater quality data is maintained.

b) The Permittee should ensure that the groundwater flow rate and direction are evaluated by a qualified professional each time the samples are collected. This evaluation should be used to determine whether the groundwater monitoring requirements under permit condition 1 continue to be met. A summation of the results of this semi-annual evaluation must be supplied in the annual report specified in permit condition 6b.

4) ASSESSMENT OF GROUNDWATER IMPACT

a) If statistical evaluation of the monitoring data indicates that a statistically significant change in groundwater quality has occurred, and said significant change has not been or currently is not being addressed through a condition of this permit, the Permittee shall,

i) Notify the Department within seven (7) days of making the initial determination that a significant trend or significant difference over background exists.

ii) Submit to the Department within thirty (30) days of notification, a preliminary report which addresses the potential for detrimental impact to human health and the environment as a result of the statistically significant change. The report should indicate whether additional assessment and\or corrective actions are warranted.

b) If routine monitoring indicates that a constituent exceeds the standards established in R.61-68 (Water Classifications and Standards System), or an attachment I parameter with no standard is measured above the detection limit, and said exceedance is not currently being addressed through a condition of this permit, the Permittee shall,

i) Notify the Department in writing within seven (7) days of making that determination.

ii) Immediately resample the monitoring well(s) in question to determine the validity of the data, and submit results no later than sixty (60) days after the date of the resampling event.

c) If a statistically significant change indicates that further assessment is warranted, as outlined in section a) of this permit condition, or an exceedance of a standard or the detection of an attachment I parameter with no standard is confirmed, as outlined in section b) of this permit condition, the Permittee shall,

i) Submit to the Department within ninety (90) days of verification of possible groundwater impact, a plan prepared by a qualified registered professional geologist or geotechnical engineer, to conduct a groundwater quality assessment. This initial assessment plan should, at a minimum, provide for the resampling of the well(s) in question for all attachment II constituents.

ii) Within ninety (90) days of approval of the assessment plan, initiate the first phase of the plan; submit a preliminary report identifying the source, migration rate, extent, and severity of the contaminant plume; and submit a plan for any additional assessment work required.

iii) Upon completion of the approved groundwater quality assessment, submit a report which details the findings of the groundwater quality assessment and makes recommendations toward further assessment and\or corrective action.

5) CORRECTIVE ACTION

Upon completion of the groundwater quality assessment and verification of groundwater contamination, the Permittee must submit a corrective action plan to address groundwater quality.

a) The Permittee must submit a plan for corrective action based on the findings of the groundwater quality assessment.

b) The Permittee must implement the corrective action plan within 90 days of approval by the Department. Additionally, the Permittee must establish and implement a groundwater monitoring program to demonstrate the effectiveness of the corrective action program.

c) The Permittee must continue corrective action measures to the extent necessary to ensure that the groundwater standards are not exceeded for a period of at least three consecutive years.

d) The Permittee must submit semi-annually to the Department a report which discusses the effectiveness of the corrective action program.

e) If the Permittee or the SCDHEC determines that the corrective action program no longer satisfies the requirements of groundwater permit condition 5, the

Permittee shall within 90 days of that determination submit a proposal to make appropriate changes to the program.

6) REPORTING

a) The Permittee shall analyze groundwater samples for the constituents in Attachment I and submit these groundwater data on a semi-annual basis in accordance with the following schedule:

Sampling Period	Submittal	Due Date
July-December	annual report with groundwater data	January 15
January-June	groundwater data	July 15

b) The Permittee shall submit an annual report signed by a qualified groundwater professional summarizing the semi-annual determinations of groundwater flow direction and rate as required by permit condition 3b. The annual report shall be submitted in accordance with the submittal schedule presented in Permit condition 6a. The annual report shall also include the groundwater monitoring data from both semi-annual monitoring events from the previous year and the semi-annual statistical analysis that has been performed on these data. In addition, the report shall make a determination as to whether the monitoring well network continues to meet the requirements of Permit Condition 1.

d) The established background values and the data collected by the implementation of the groundwater monitoring program as specified by this Permit shall be submitted to the SCDHEC, Bureau of Solid and Hazardous Waste Management, Division of Hydrogeology, Solid Waste Section and to the Regional Hydrogeologist in the Lower Savannah District Environmental Quality Control Office in Aiken, South Carolina.

D. CLOSURE/POST CLOSURE CARE CONDITIONS

1 The Permittee is responsible for submitting a closure plan within ninety (90) days of issuance of this permit, which outlines the activities necessary to close the landfill in a manner that minimizes the release of contaminants.

2. Post Closure Care shall be conducted for a period of thirty (30) years unless a variance is applied for and obtained by the Permittee. The Permittee is responsible for submitting a detailed Post Closure Care Plan, within ninety (90) days of the effective date of this permit, which outlines the activities to maintain a properly closed out landfill and includes, but is not necessarily limited to the following:

a. The Permittee is responsible for inspecting and maintaining an adequate cap and drainage system for the Post Closure Care Period. This plan shall provide a schedule indicating when the cap and drainage system will be inspected, a discussion about how each will be inspected, and a contingency plan that discusses what corrective action will be taken if failure occurs at any portion of the landfill.

b. The Permittee is responsible for inspecting and maintaining an adequate groundwater monitoring system for the Post Closure Care Period. This plan needs to describe in detail the activities to be performed to ensure that an adequate groundwater monitoring system is in place at the time of closure for post-closure monitoring of the waste management area. This plan shall specify the wells to be monitored, and the parameters to be monitored.

ATTACHMENT I

GROUNDWATER DETECTION MONITORING REQUIREMENT

DETECTION MONITORING PARAMETERS

pH (field & lab)
Specific Conductance (field)
Water level in M.S.L. (tenth/feet)
Arsenic
Antimony
Barium
Cadmium
Chromium
Lead
Mercury
Nitrate (as Nitrogen)
Nitrite (as Nitrogen)
Selenium
Silver
Benzene and Toluene
Radionuclides
    -Radium 226 and 228 (sum)
    -Gross alpha particle activity
    -Beta particle and proton radioactivity

Analyses of the metals should be performed on unfiltered groundwater samples.

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DOE F 1325.8 (Rev 11-12-91)

United States Government Department of Energy (DOE)

memorandum

Savannah River Operations Office (SR)

DATE: JUN 18 1997

REPLY TO
ATTN OF: PD (Hannah/803-208-1541)

SUBJECT: Additional Analysis in Support of the Saltstone Radiological Performance Assessment (Your Letter dated 5/16/97)

TO: Mark W. Frei, Acting Deputy Assistant Secretary for Waste Management (EM-30), HQ

Savannah River Operations Office was asked to provide the Office of Planning and Analysis (EM-35) technically-sound Naturally Occurring Radioactive Material (NORM) screening calculations, including documentation of key assumptions. Attached are the NORM screening calculations with assumptions for your review. This analysis concludes that the dose contribution of NORM radionuclides are insignificant with respect to the groundwater pathway for the Saltstone Disposal Facility.

Equations which your office provided in your memorandum plus additional screening criteria were used to accomplish this analysis. Appropriate values have been applied to equation variables for calculations. These values are based on site specific research and literature search conducted by the Westinghouse Savannah River Company technical staff.

The attached information is provided for your review and comments. Your efforts in the Saltstone Disposal Facility Performance Assessment process are appreciated.

Any questions may be directed to me or Ray Hannah at (803) 208-1541.

Roy J. Schepens
Acting Assistant Manager
for High Level Waste

PD:GRH:eeh

PB-97-0102

Attachment
NORM Calculations with
Assumptions

cc w/attach:
~~R. Hannah, PD, 704-S~~
H. Gnann, PD, 704-S
W. Smith, SWD, 703-A
R. Satterfield, WSRC,719-4A
S. Ayers, EM-32, HQ

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**Westinghouse
Savannah River Company**
Aiken, SC 29808

HLW-REG-97-0041
Keywords: Saltstone, NORM, Performance Assessment
Retention: Permanent, offer to NARA when file is inactive
Disposal Auth: DOE 14-2.d
Track #: 174

JUN 1 6 1997

Mr. Howard B. Gnann, Acting Director
Programs Division, High Level Waste
U. S. Department of Energy
Savannah River Operations Office
P. O. Box A
Aiken, SC 29802

Dear Mr. Gnann:

CONTRIBUTION OF NORM TO PROJECTED DOSE FROM SALTSTONE (U)

Ref: Letter, Gnann to Satterfield, "Saltstone Disposal Facility Radiological Performance Assessment" dated June 6, 1997

In response to the referenced letter, I am providing you an assessment of the effect of Naturally Occurring Radioactive Material (NORM) on the projected ground water dose from the Saltstone Facility. As documented in the attached report, the presence of NORM in Saltstone dry materials will have only a small impact on the Saltstone liquid pathway dose.

If you have any questions, please contact me (725-4651) or John Fowler (208-6929).

Sincerely,

RM Satterfield

R. M. Satterfield
Manager, Regulatory Programs
High Level Waste Management Division

RMS:cks
Attachment

CC: See attached distribution

OSR 25-621 (Rev 3-11-97)
Stores 25-15468.10

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WESTINGHOUSE SAVANNAH RIVER COMPANY

INTER-OFFICE MEMORANDUM

OPS-DTZ-97-0018

Retention: 10 years
Disposal Authority: 14-1.a.
Tracking #: 212

Key Words: Slag, Fly Ash, Groundwater, Z Area, Waste Disposal, Performance Assessment

June 13, 1997

To: R. M. Satterfield, 719-4A
High Level Waste Engineering

From: J. R. Fowler, 704-Z
High Level Waste Engineering

Screening of NORM Nuclides in Saltstone (U)

SUMMARY

In response to a recent request from DOE-SR (Ref. 6), additional calculations have been completed to bound the impact of "technologically enhanced" Naturally Occurring Radioactive Materials (NORM) that are present in dry materials used to produce saltstone. Based on the conservative assumptions used for these screening calculations, Ra, U and Th in the NORM in saltstone dry materials will not adversely impact the long-term performance of the Saltstone Disposal Facility. Conservative screening calculations show that all radioactive isotopes of these elements will be at least a factor of 25 below their concentration limits based on a 4 mrem/yr dose from the groundwater pathway.

BASES AND ASSUMPTIONS

For purposes of these screening calculation, the entire NORM radioactivity is attributed to U isotopes, Ra isotopes or to ^{232}Th. This approach assures NORM concentrations for these long-lived nuclides in dry materials are bounded, since all of these combine to yield the total alpha concentration in NORM. The approach used for screening in Ref. 7, is generally followed. However, the assumptions used were too conservative for known properties of cement waste forms in general, and for saltstone in particular. In fact, the initial screening used in the Z-Area Radiological Performance Assessment uses the bulk density of soil rather than the higher density of the cement matrix of saltstone, so it is also conservative relative to the known properties of saltstone. (Ref. 6, 7, 8) To be consistent with subsequent information provided to the Peer Review Panel (Ref. 2), appropriate distribution coefficients (K_d's) for these materials in a reducing cementitious environment and the higher matrix density consistent with saltstone properties have been used in these screening calculations. Key bases and assumptions for screening of NORM are summarized below:

- Principal long-lived NORM nuclides in slag and fly ash are natural uranium isotopes (^{234}U, ^{235}U, ^{238}U), ^{232}thorium and their radium decay daughters (^{226}Ra, ^{228}Ra). (Ref. 1)

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- NORM alpha concentration in saltstone is 2 x 10^{-5} Ci/m^3 (2 x 10^4 pCi/L) (Ref. 1)
- Concentration of NORM U in saltstone is assumed to be 2 x 10^{-5} Ci/m^3.
- Concentrations of U isotopes are calculated using natural isotopic abundances (Ref. 5)
- U distribution coefficient (K_d) between the solid matrix and the pore solution in saltstone is 5000 cc/g (5 m^3/kg); slag provides reducing environment in the matrix. (Ref. 3)
- Concentrations of ^{226}Ra and ^{228}Ra are calculated based on relative abundance to yield the molecular weight of 226.0254 (98.73% ^{226}Ra, 1.27% ^{228}Ra) (Ref. 5)
- Concentration of NORM Ra is assumed to be 2 x 10^{-5} Ci/m^3.
- Ra distribution coefficient (K_d) between the solid matrix and the pore solution in saltstone is 50 cc/g (0.05 m^3/kg) (Ref. 3)
- Concentration of NORM ^{232}Th is assumed to be 2 x 10^{-5} Ci/m^3 (Ref. 1)
- Thorium distribution coefficient (K_d) between the solid matrix and the pore solution in saltstone is 5000 cc/g (5 m^3/kg) (Ref. 3)
- Saltstone porosity is 0.46. (Ref. 2)
- Cementitious matrix density (ρ_m) in saltstone is 2.07 g/cc. (Ref. 2)
- Dose Conversion Factors are based on DOE guidance. (Ref. 9)
- Five year travel time is assumed to the compliance well located 100 meters from the point of entry into aquifer.

RESULTS

A. Radioactivity in Saltstone from NORM Radionuclides

The principal long-lived sources of radioactivity in nature are Ra, U and Th. For saltstone, NORM radioactivity from naturally occurring ^{226}Ra, ^{228}Ra, ^{232}Th, ^{234}U, ^{235}U, and ^{238}U is introduced from the use of fly ash and slag to convert salt solution to a stable solid. For purposes of screening calculations with respect to NORM in saltstone, total alpha activity of 34 pCi/g (3.4E-8 Ci/kg) for fly ash and 15 pCi/g (1.5E-8 Ci/kg) for slag was used. Based on saltstone composition, these concentrations yield a total NORM alpha activity in saltstone of 2.0 x 10^{-5} Ci/m^3 (2.0x 10^4 pCi/L). (Ref. 1)

B. Groundwater Limits for Nuclides in NORM

Groundwater limits calculated for naturally occurring ^{226}Ra, ^{228}Ra, ^{232}Th, ^{234}U, ^{235}U, and ^{238}U are based on an assumed dose limit of 4 mrem/yr from the groundwater pathway and an assumed consumption of 730 L of water per year. This is identical to the approach used in the Z-Area RPA and the screening calculation performed by DOE-HQ. (Ref. 6, 7, 8) The equation used for these calculations and results are shown in Table 1.

C. Bounding NORM Concentrations in Pore Solution of Saltstone

NORM radionuclide concentrations in the pore solution of saltstone are calculated to compare to the limits shown in Table 1. In these calculations, all NORM activity is assumed to be from the specific element being screened, and thus is conservative by at least a factor of 5. Except for radium, contributions to the alpha activity from other shorter-lived decay daughters is neglected, since these would be low in concentration and would decay before reaching the compliance well. Results are summarized in Table 2. Limits from Table 1 are also included for comparison to the projected maximum pore solution concentration. For all U isotopes and ^{232}Th, the concentration in the pore solution is below the groundwater concentration limit, and further calculations are unnecessary. The pore solution concentration for ^{238}U is about a factor of 25 below its limit; the rest are at least a factor of 3000 below their limits. Thus these radioactive species would not exceed the groundwater standard even if they were injected into the groundwater at their peak concentration in the pore solution. Dispersion and some dilution would occur as the solution migrates from the vault through the vadose zone, further reducing the actual concentration at the water table. Further screening calculations to reflect decay during transport are unnecessary for these four isotopes, since they do not exceed their respective groundwater limits in the pore solution in saltstone.

Based on the conservative concentration assumed for Ra in saltstone, the concentration of ^{226}Ra exceeds the groundwater concentration limit in the pore solution by about a factor of 8, while ^{228}Ra exceeds its limit by about a factor of 30. Accordingly, additional calculations are needed for Ra to reflect radioactive decay and interaction of the pore solution with underlying soil. The equation used for these calculations and results are shown in Table 3. Because of its short half-life, ^{228}Ra from NORM in saltstone would decay before reaching the compliance well. Concentration of the longer-lived ^{226}Ra would decay to a concentration that is no greater than a factor of about 25 below the concentration limit at the compliance well.

REFERENCES

1. J. R. Fowler to R. M. Satterfield, OPS-DTZ-96-0059, Screening of NORM for Saltstone Long-Term Performance Acceptance (u), Westinghouse Savannah River Company, Nov. 18, 1996. [cf. Diffuse NORM Wastes - Waste Characterization and Preliminary Risk Assessment, RAE-9232/1-2, Volume 1, prepared for the Environmental Protection Agency (April 1993).]

2. J. R. Cook and J. R. Fowler to W. E. Kennedy, Jr., SRT-WED-93-203, Summary of Information Developed for the Saltstone RPA (U), Westinghouse Savannah River Company, July 8,1993.

3. M. H. Bradbury and F-A Sarott, PSI Bericht Nr. 95-06 (ISSN 1019-0643), Sorption Databases for the Cementitious Near-Field of a L/ILW Repository for Performance Assessment, Paul Scherrer Institut, March 1995.

4. W. N. Jones, Jr., General Chemistry, The Blakiston Company (New York, 1954), page 844.

5. CRC Handbook, 72nd Edition, 1971-72.

6. H. B. Gnann, DOE-SR, to R. M. Satterfield, SUBJECT: Saltstone Disposal Facility Radiological Performance Assessment, Department of Energy, Savannah River Operations Office, June 6, 1997.

7. Attachment to Reference 6, NORM Screening Calculation.

8. Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility, WSRC-RP-92-1360, Westinghouse Savannah River Company, December 18, 1992.

9. Internal Dose Conversion Factors for Calculation of Dose to the Public, DOE/EH-0071, U. S. Department of Energy (1988).

10. Radiological Performance Assessment for the E-Area Vaults Disposal Facility (U), Appendix C, WSRC-RP-94-218, Westinghouse Savannah River Company, April 15, 1994.

Table 1. Calculation of Limits for Long-lived NORM Radionuclides in Saltstone (a)

NORM Alpha Activity = *2.00E-05* Ci/m^3

or *2.00E+04 pCi/L*

Bases for Limit in Groundwater at Compliance Well:

C_{limit} *= (4 mrem/yr) / [730 L/y)(DCF)]*

Calculated Concentration Limits for Natural U Isotopes, Ra-226 and Th-232

Nuclide	DCF (b), mrem/pCi	Groundwater C_{limit}, pCi/L
Natural U:		
U-234	1.1E-06	4981
U-235	2.1E-06	2609
U-238	2.3E-04	24
Natural Ra:		
Ra-226	1.1E-03	5
Ra-228	1.2E-03	5
Th-232	8.3E-07	6602

(a) Based on information and data in Ref. 1, 6, 7, 8.

(b) Ref. 9, (DOE/EH-0071); also shown in Appendix C of WSRC-RP-94-218. (Ref. 10)

Table 2. Calculation of Bounding NORM Concentrations in Saltstone Pore Solution (a)

$$C_{pore} = C(saltstone) / (\Theta + K_d \rho)$$

Where Θ = *saltstone porosity = 0.46*

K_d = *distribution coefficient between the solid matrix and pore solution (cc/g)*

ρ = *Saltstone matrix density = 2.07 g/cc*

Nuclide	Mass of Nuclide per g U	Specific Activity, Ci/g	Ci/g of U	Fraction of Total Activity	NORM C_{max} in Saltstone, pCi/L	Saltstone K_d (b), cc/g	Pore Solution C_{max}, pCi/L	C_{limit}, pCi/L
Natural U	1.0E+00		1.03E-06	1.0E+00	2.0E+04			
U-234	5.7E-05	6.2E-03	3.6E-07	5.1E-01	1.0E+04	5000	0.97	4981
U-235	7.2E-03	2.1E-06	1.5E-08	2.2E-02	4.4E+02	5000	0.04	2609
U-238	9.9E-01	3.4E-07	3.3E-07	4.7E-01	9.5E+03	5000	0.92	24
Natural Ra	3.3E-07		1.5E-06	1.0E+00	2.0E+04			
Ra-226 (d)		9.8E-01	3.2E-07	2.2E-01	4.4E+03	50	42	5
Ra-228 (d)		2.7E+02	1.2E-06	7.8E-01	1.6E+04	50	150	5
Th-232				1.0E+00	2.0E+04	5000	1.9	6602

(a) SRT-WED-93-203, Summary of Information Developed for the Saltstone RPA (U), July 8,1993. (Ref. 2)

(b) After Bradbury and Sarott, 1995. (Ref. 3)

(c) After Jones, 1954; maximum ratio of Ra to U in nature is no greater than 1 to 3,000,000. (Ref. 4)

(d) Isotopic ratios calculated based on a mol. wt. of 226.0254 (98.73% Ra-226, 1.27% Ra-228) (Ref. 5)

Table 3. Calculation of NORM Radium Concentrations at the Compliance Well (a)

$$C_{well} = C_{pore}\, e^{-[(Lamda)(Rf)(t)]}$$

Where

C_{well} = *concentration in groundwater at the compliance point*

C_{pore} = *NORM concentration in saltstone pore solution*

Lambda = *decay constant for specific nuclide*

Rf =*source reduction factor for travel through soil*

t = *aquifer travel time from beneath waste to compliance point (100 m)*

Nuclide	Saltstone C_{pore}, pCi/L	Lambda (1/year)	Rf	C_{well}, pCi/L	C_{limit}, pCi/L
Ra-226	4.2E+01	4.27E-04	2501	0.2	5
Ra-228	1.5E+02	1.21E-01	2501	0.0	5

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To: John Fowler at SRCCH02

Subject: Saltstone Magic Reduction Factors

Author: kirk_owens@ccmail.gmt.saic.com at Mailhub

Date: 9/30/97 3:18 PM

John,

Headquarters is attempting to closeout the review on the Saltstone PA. The most recent action on the PA was SRS submitting an analysis to support screening the NORM nuclides. In this analysis the U and Th were screened out based on their concentration in the Saltstone porewater being sufficiently low as to not cause doses in excess of 4 mrem/y at a consumption rate of 2 L/d. The screening analyses were well supported with a list of assumptions.

The analysis went on to use a more involved screening to justify Ra from consideration in the detailed analysis. In so doing, the scenario relies on travel time to the assumed point of compliance, and it appears it also relies on hold-up in the soil. In the Ra screening calculation there is a parameter RF that is a source reduction factor for travel through soil. However, no further information is provided for this factor. Can you explain what it is, how it is derived, and the justification for its selection?

Also, as a point of clarification, the factor t is the travel time to the well. Is this the travel time from the bottom of the Saltstone, through the vadose zone, through the saturated zone, to the well? Or is it the travel time from a point in the saturated zone beneath the Saltstone to the well?

Thank you for any assistance you can provide in answering these question.

Kirk out.

To: kirk_owens@ccmail.gmt.saic.com at Mailhub

Subject: Re: Saltstone Magic Reduction Factors

Author: John Fowler at SRCCH02

Date: 10/1/97 11:43 AM

The R_f isn't really magic, but reflects a standard (and relatively simple) technique used in hydrogeologic modeling to account for Kd and soil porosity for a waste disposal site. This technique was used to screen radionuclides for E-Area Vaults, as well. I've inserted my response [in red on my machine] to your specific questions into the text of your message below.

[Editor's note: In his reply, John Fowler inserted his responses to specific questions into the original e-mail request from Kirk Owens. These responses are italicized in the text that follows to distinguish them from the text of the original e-mail message]

____________________ Reply Separator ____________________

To: John Fowler at SRCCH02

Subject: Saltstone Magic Reduction Factors

Author: kirk_owens@ccmail.gmt.saic.com at Mailhub

Date: 9/30/97 3:18 PM

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The analysis went on to use a more involved screening to justify Ra from consideration in the detailed analysis. In so doing, the scenario relies on travel time to the assumed point of compliance, and it appears it also relies on hold-up in the soil. In the Ra screening calculation there is a parameter RF that is a source reduction factor for travel through soil. However, no further information is provided for this factor. Can you explain what it is, how it is derived, and the justification for its selection?

Additional screening calculations for Ra isotopes in NORM for the groundwater pathway followed the methodology used in the E Area RPA (WSRC-RP-94-218, rev. 0; section 3.2.3.4 (pp. 3-36 to 3-39), using the R_f of 2501 (shown in Appendix C, Table C.1-3 of WSRC-RP-94-218, rev. 0). In this screening, no credit is taken for the engineered barrier (vault), and the saltstone pore solution concentration shown in Table 2 of OPS-DTZ-97-0018 is used as the source term concentration in pore solution released from the waste.

If there is no distribution of isotopes between soil and infiltrating water or contaminated pore solution, then Rf is equal to 1 to avoid a "zero" term in the exponent for the decay calculation due to travel time from the point of entry into the aquifer to the compliance point. To establish the reduction factor for any species, the soil particle specific gravity (SGsoil) is divided by the soil Porosity (Psoil) to reflect the retardation of diffusion and flow through the porous media due to the presence of nonporous particles. This ratio is then multiplied by the Kd and added to 1 to obtain the Rf. This is a standard approach used in modeling for waste disposal (see for example "The PATHRAE-RAD Performance Assessment Code for the Land Disposal of Radioactive Waste"). Thus the source reduction factor for any contaminant that absorbs on the soil is determined as follows:

$$Rf = 1 + [Kd(soil) \times SGsoil/Psoil]$$

For soils at the SRS (mixtures of sands and clays), a soil particle specific gravity of 2.5 is used and the porosity is assumed to be 0.5. For Ra, Kd(soil) = 500 [Baes et al., ORNL-5786, "A Review and analysis of Parameters for assessing Transport of Environmentally Released Radionuclides through Agriculture" (1984)]. Thus the Rf for Ra is:

$$Rf(Ra) = 1 + [500 \times (2.5/0.5)] = 2501$$

Note that the Rf simply does a "physical/chemical" adjustment to account for soil adsorption and restriction of diffusion and flow due to the presence of solid particles. Travel time and corresponding radioactive decay through the vadose zone is ignored in this screening calculation (conservative).

Also, as a point of clarification, the factor t is the travel time to the well. Is this the travel time from the bottom of the Saltstone, through the vadose zone, through the saturated zone, to the well? Or is it the travel time from a point in the saturated zone beneath the Saltstone to the well?

As noted in Table 3 of OPS-DTZ-97-0018, the "t" used in the equation on the table is the aquifer travel time from beneath the waste to the compliance point. Time to release and travel time through the vadose zone is ignored, as noted above. Note also that this approach takes no credit for Kd within the soil layer containing the aquifer, which may or may not further retard transport with the water in the aquifer.

Thank you for any assistance you can provide in answering these question.

Kirk out.

Spock here. Beam me up, Scottie. Spock out.