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Radioactive Waste Isolation in Salt: Peer Review of the Office of Nuclear Waste Isolation's Report on Functional Design Criteria for a Repository for High-Level Radioactive Waste

D. F. Hambley, J. E. Russell, J. S. Busch,
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RADIOACTIVE WASTE ISOLATION IN SALT:

PEER REVIEW OF THE OFFICE OF NUCLEAR WASTE ISOLATION'S REPORT ON FUNCTIONAL DESIGN CRITERIA FOR A REPOSITORY FOR HIGH-LEVEL RADIOACTIVE WASTE

by

D.F. Hambley, J.E. Russell,* J.S. Busch,**
W. Harrison, D.E. Edgar, and M.W. Tisue

Energy and Environmental Systems Division
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*Texas A&M University
**Raymond Kaiser Engineers, Oakland, Calif.

Department of Energy
Chicago Operations Office
Salt Repository Project Office
505 King Avenue
Columbus, Ohio 43201-2693

NOTICE TO READERS

At the request of the Salt Repository Project Office (SRPO), Argonne National Laboratory conducted a peer review of the report entitled "Functional Design Criteria for High-Level Nuclear Waste Repository in Salt," prepared by the Office of Nuclear Waste Isolation (ONWI). (A microfiche copy of the reviewed document is attached to the inside back cover of this report.) A review of this type was required because according to SRPO's Quality Assurance Procedure No. 7.1 (paragraph 3.3), this document could significantly affect program objectives.

The reviewed report contains basic information defining the starting point for the design of a repository in salt and will be used primarily by the architect/engineer responsible for the conceptual design.

The peer review panelists were asked to consider whether the design criteria were technically sound; whether the criteria precluded development of the best possible design features by not taking advantage of site-specific geotechnical characteristics; and whether the criteria represented a realistic set of parameters. This review report prepared by Argonne will contribute significantly to improving the criteria and has been transmitted to ONWI for its consideration and implementation.

RCWunderlich

R. C. Wunderlich
Deputy Project Manager
Salt Repository Project Office

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FOREWORD

Documents are being submitted to the Salt Repository Project Office (SRPO) of the U.S. Department of Energy (DOE) by Battelle Memorial Institute's Office of Nuclear Waste Isolation (ONWI) to satisfy milestones of the Salt Repository Project of the Civilian Radioactive Waste Management Program. Some of these documents are being reviewed by multidisciplinary groups of peers to ensure DOE of their adequacy and credibility. Adequacy of documents refers to their ability to meet the standards of the U.S. Nuclear Regulatory Commission, as enunciated in 10 CFR Part 60, and the requirements of the National Environmental Policy Act and the Nuclear Waste Policy Act of 1982. Credibility of documents refers to the validity of the assumptions, methods, and conclusions, as well as to the completeness of coverage.

Since late 1982, Argonne National Laboratory has been under contract to DOE to conduct multidisciplinary peer reviews of program plans and reports covering research and development activities related to siting and constructing a mined repository in salt for high-level radioactive waste. The present report summarizes Argonne's review of ONWI's draft report entitled *Functional Design Criteria for High-Level Nuclear Waste Repository in Salt*, dated January 23, 1984.

On February 7, 1984, DOE requested that Argonne review the report (see App. A), and the peer review panel met at Argonne on March 5, 1984. The review procedure involved obtaining written comments on the report from two extramural and three Argonne experts in relevant research areas. Reviewer comments were integrated into the present report by the review session chairman, with the assistance of Argonne's core peer review staff. All of the peer review panelists concurred in the way in which their comments were represented in this report (see App. B), a draft of which was sent to SRPO on March 12, 1984.

PREVIOUSLY PUBLISHED REPORTS IN THE SERIES

"RADIOACTIVE WASTE ISOLATION IN SALT"

ANL/EES-TM-242	Peer Review of the Office of Nuclear Waste Isolation's Geochemical Program Plan (Feb. 1984)
ANL/EES-TM-243	Peer Review of the Office of Nuclear Waste Isolation's Socioeconomic Program Plan (Feb. 1984) (revised July 1984)
ANL/EES-TM-246	Peer Review of the Office of Nuclear Waste Isolation's Plans for Repository Performance Assessment (May 1984)
ANL/EES-TM-254	Peer Review of the Office of Nuclear Waste Isolation's Reports on Preferred Repository Sites within the Palo Duro Basin, Texas (April 1984)
ANL/EES-TM-256	Special Advisory Report on the Status of the Office of Nuclear Waste Isolation's Plans for Repository Performance Assessment (Oct. 1983)
ANL/EES-TM-258	Peer Review of the Office of Nuclear Waste Isolation's Plan to Decommission and Reclaim Exploratory Shafts and Related Facilities (July 1984)
ANL/EES-TM-259	Peer Review of the Office of Nuclear Waste Isolation's Report on the Organic Geochemistry of Deep Groundwaters from the Palo Duro Basin, Texas (Aug. 1984)
ANL/EES-TM-260	Peer Review of the Texas Bureau of Economic Geology's Report on the Petrographic, Stratigraphic, and Structural Evidence for Dissolution of Upper Permian Bedded Salt, Texas Panhandle (Aug. 1984)

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TABLES

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A microfiche copy of the following unpublished report is attached to the inside back cover of this report: Office of Nuclear Waste Isolation, *Functional Design Criteria for High-Level Nuclear Waste Repository in Salt*, Battelle Memorial Institute, Columbus, Ohio (Jan. 23, 1984).

RADIOACTIVE WASTE ISOLATION IN SALT:

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SUMMARY OF RECOMMENDATIONS

The following recommendations have been abstracted from the body of this report. The Office of Nuclear Waste Isolation's report outlining functional design criteria for a mined repository in salt for high-level radioactive waste should:

1. State clearly the precise purpose and scope of the report, preferably under an appropriate heading at the beginning.

2. Discuss design more comprehensively, particularly in the areas of waste handling and packaging, underground openings, ventilation systems, hoist systems, placement of waste packages, and quality assurance.

3. Address in much greater detail how the design will meet applicable federal, state, and local laws and regulations.

4. Provide an appendix containing complete citations for all relevant regulations and design standards, including those found in industrial and technical society publications.

5. Use terminology consistent with 10 CFR Part 60.* For example, the term "decommissioning" should be replaced by "permanent closure," unless the dismantling and decontamination of surface facilities is being addressed.

6. Define the architect/engineer's responsibility with respect to design of waste packages and seals.

7. Be reviewed by a technical editor to correct the numerous spelling, grammatical, and syntax errors.

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*U.S. Nuclear Regulatory Commission, *Disposal of High-Level Radioactive Wastes in Geologic Repositories; Licensing Procedures*, Code of Federal Regulations, 10 CFR Part 60 (June 30, 1983).

8. Include a table that divides the repository into four to six regions, defines those regions in terms of occupancy by personnel, and specifies maximum permissible radiation doses for each region.

9. Contain brief summaries of the main characteristics of each of the seven salt sites still under consideration.

10. Provide a glossary of technical and specialized terms.

1 INTRODUCTION

The Office of Nuclear Waste Isolation (ONWI) report entitled *Functional Design Criteria for High-Level Nuclear Waste Repository in Salt* should contain the basic information needed to start designing a repository in salt. It will be used primarily by the architect/engineer responsible for the conceptual design.

The peer review conducted by Argonne National Laboratory involved obtaining written critiques of the report from two extramural and three Argonne experts in relevant research areas. Panelists did not contact ONWI personnel, and none of the panelists have been involved in any programs sponsored by the U.S. Department of Energy (DOE) or directed by ONWI such that their participation in the review could be construed as a conflict of interest.

No specific guidance was provided to Argonne by DOE on how to conduct the review. However, DOE did provide the following questions (see App. A) to serve as a framework for peer review activities:

1. How does the RFDC [repository functional design criteria report] constrain the salt repository project design efforts?

2. Does it preclude SRPO [Salt Repository Project Office] from developing the optimum combination of design features which could result from taking advantage of salt site-specific geotechnical characteristics?

3. Does the RFDC adequately represent a realistic set of requirements? That is, should SRPO identify additional requirements?

4. What will be the schedule, cost, and technical impacts of this [*sic*] criteria?

5. Are the requirements, criteria, and planning bases technically sound or too constraining?

6. What information, specifications, or requirements should be added or deleted from the RFDC?

2 REGULATORY REQUIREMENTS

Applicable guidelines, regulations, and standards must be adhered to in the design of a mined repository in salt. Such compliance must be demonstrated to the U.S. Nuclear Regulatory Commission (NRC) before a license and a construction authorization will be issued. Therefore, much more information and guidance should be provided to the architect/engineer than the list of federal regulations and standards, federal statutes, DOE orders, and program guidance documents on pages 18-19 of the ONWI report and the almost casual references to selected parts of the Code of Federal Regulations scattered sparsely through the text. On the other hand, detailed descriptions of the thousands of individual requirements relevant to the total design concept cannot and should not be presented in the report.

On page 1, the report states that "groundrules and instructions are given and repository functions are described" and that "this document establishes the functional criteria...to design the repository." The report further states that "future design efforts, and the ultimate performance of the repository, will be measured against these criteria." If such is indeed the case, the amount of information on applicable regulations and guidelines is inadequate. Although the report provides the necessary general background on repository facilities and their operation, it will be of limited utility as a source of information on the regulations to be adhered to during design, construction, operation, and permanent closure.

Tables 1 and 2 list the DOE orders and the parts of the Code of Federal Regulations that are applicable to repository design, construction, operation, and permanent closure. Although these lists are long, it is very probable that additional regulations could have been included. Comparing these entries with those on pages 18-19 indicates the cursory treatment of the subject by the authors of the report. In addition to the federal statutes listed on page 19, portions of the Energy Reorganization Act of 1974 and the Resource Conservation and Recovery Act of 1976 are also applicable. Furthermore, at this stage of the Civilian Radioactive Waste Management (CRWM) Program, the applicable regulations and standards in effect in Louisiana, Mississippi, Texas, and Utah should also be listed.

TABLE 1 U.S. Department of Energy Orders Pertinent to Repository Design

1130.4	3771.1	5500.2
1130.5	3790.1	5500.3
1240.1	3791.1	5500.4
1240.1A	4200.3	5610.1
1260.2	4210.3A	5610.3
1300.2	4200.3A	5630 Series
1323.1	4320.1	5631 Series
1324.2	4330.4	5631.1
1325.1A	5031.1	5632 Series
1330.1	5100.1	5633.1
1340.1	5300 Series	5635.1
1350.1	5420.1	5636.2
1540.1	5431.1A	5636.3
16[illegible]0 Series	5432.1A	5650.2
1700.1	5434.1	5700.1C
1800.1	5434.2	5700.2B
2100.4	5440.1B	5700.3B
2200.1	5480.1	5700.4
2250.1A	5480.1A	5700.5
3220.1	5481.1A	5700.6A
3220.2	5482.1A	5700.7
3230.2A	5483.1	5900.1
3304.1	5484.1	5900.2
3400.1	5484.2	6430.1
3410 Series	5500.1	6480.1A
3710.1		

The following revisions should improve the utility of the report. First, the treatment of federal and state statutes should be expanded, perhaps in an appendix. The appendix should be organized so that pertinent guidance on regulations is correlated with specific design requirements. Second, the repository system should be subdivided into its major elements (e.g., transportation facilities, storage and handling, administration and quality control, and excavation) and the corresponding regulations and guidelines as well as key design and performance requirements carefully identified. Alternatively, regulatory authorities could be identified and the appropriate regulations keyed to design elements or functions. Although adding this information would be a major undertaking, the value of the report will remain less than adequate without it.

TABLE 2 Parts of the Code of Federal Regulations Pertinent to Repository Design

10 CFR 20	40 CFR 81	40 CFR 165
10 CFR 60	40 CFR 112	40 CFR 167
10 CFR 71	40 CFR 116	40 CFR 190
10 CFR 73	40 CFR 117	40 CFR 191
10 CFR 960	40 CFR 120	40 CFR 201
10 CFR 961	40 CFR 121	40 CFR 204
	40 CFR 122	40 CFR 240
29 CFR 19	40 CFR 123	40 CFR 241
	40 CFR 125	40 CFR 256
30 CFR 57	40 CFR 129	40 CFR 257
	40 CFR 133	40 CFR 260
40 CFR 50	40 CFR 141	40 CFR 261
40 CFR 51	40 CFR 142	
40 CFR 52	40 CFR 143	49 CFR 173
40 CFR 60	40 CFR 149	
40 CFR 61	40 CFR 162	

3 TECHNICAL ISSUES

The architect/engineer will require much more information and guidance, particularly on the following major topics:

- Quantity of radioactive material,
- Waste packages,
- Underground openings,
- Underground ventilation systems,
- Hoist systems,
- Placement of waste packages,
- Radiation levels,
- Seals,
- Shaft misalignment, and
- Extraction ratios.

3.1 QUANTITY OF RADIOACTIVE MATERIAL

Table 3.1, together with the data on waste receipts given in Sec. 3.3, not only defines the quantity of radioactive material to be handled, but also the rate at which it will need to be handled. The equivalent metric tons of uranium and the kilowatts of decay heat of each type of waste package must be specified.

The authors should develop a table that lists, for each waste package type:

- Dimensions and weight,
- Decay heat produced,
- Radiation dose produced,
- Quantity (in equivalent metric tons of uranium),
- Receipt rate,
- Thermal limits, and
- Shipping mode and packages per shipment.

If the revised report does not contain such a table, the architect/engineer should develop one. The tabulation should include an estimate of all unknowns. No design freedom should be permitted in developing the tabulation, which would be a necessary design input. This tabulation, whether already in the report or to be developed by the architect/engineer, should be revised as necessary.

3.2 WASTE PACKAGES

The report should clearly define the architect/engineer's responsibility with respect to waste packages, including information on which wastes, as received, are ready for placement and what additional processing (e.g., disassembly) and packaging will be required for wastes not ready for placement. The architect/engineer will likely know that the program has already invested in designs and studies of waste packages for use in the salt environment.

Waste canisters are discussed in Table 3.1, and the surface temperature limits for the waste packages are discussed on page 16. Backfilling around the canisters to help inhibit migration of nuclear material after canister failure should be discussed.

3.3 UNDERGROUND OPENINGS

The fourth paragraph on page 31 paraphrases 10 CFR Part 60.133(e)(2), which states that "openings in the underground facility shall be designed to reduce the potential for deleterious rock movement or fracturing of overlying or surrounding rock" (U.S. Nuclear Regulatory Commission, 1983). Openings in salt behave plastically, even at shallow depths, so that time-dependent strain, or creep, must be considered. Creep is a complex phenomenon that results in highly site specific pillar behavior. Creep has traditionally been considered to occur in three phases: (1) primary (or transient) creep, which is characterized by an initially high creep strain rate that decays with time; (2) secondary (or steady state) creep, which is characterized by a constant creep strain rate under given loading conditions; and (3) tertiary creep, which is characterized by a creep strain rate that increases rapidly with time. This characterization, which is based on laboratory testing of small-scale samples, can be misleading when used to predict underground pillar behavior.

Baar (1977) states that tertiary creep does not occur underground, and detailed case histories from Saskatchewan and the Werra district in Germany tend to support this conclusion. These data also indicate that deformation rates are quite site specific and depend on the loading history of the particular opening or pillar. Hence, in situ measurements must be taken at a given site for a period of several years to confirm predictions of computer models using constitutive laws based on laboratory studies. More basically, researchers and practitioners disagree on a realistic criterion for determining the stress state at which salt yields. Baar (1977) used the maximum shear stress (or Tresca) criterion, while others have used maximum octahedral shear stress. Yet others, such as workers at RE/SPEC, Inc., have derived more complicated relationships based on laboratory testing.

Given such controversy, it is prudent not to specify a formula for creep. However, it is necessary to specify that creep deformation be allowed for, to some extent, in specifying the dimensions of the storage rooms.

3.4 UNDERGROUND VENTILATION SYSTEMS

The criteria provided for design of the underground ventilation systems are incomplete. For example, no mention is made of the requirement in 10 CFR Part 60.133(g)(3) that the ventilation systems for development and storage operations be kept separate. Furthermore, where airways of the two systems are adjacent, the static pressures at prospective leakage points must be such that any leakage occurs from the development ventilation system toward the storage, or confinement, ventilation system.

To guide the architect/engineer, the following air volume and velocity requirements should be specified:

- Minimum air volume per person -- 200 standard cubic feet per minute (scfm),
- Minimum air volume per diesel brake horsepower (BHP) -- 100 scfm,
- Minimum air volume per electric BHP -- 20 scfm,
- Maximum air velocity for shafts other than personnel shafts -- 3000 feet per minute (fpm),
- Maximum air velocity for personnel shafts -- 2000 fpm, and
- Recommended range of air velocities for main entries and haulages -- 800-1500 fpm.

After emplacement of waste packages, room temperatures will rise as a result of heat conduction. Cooling of rock surrounding the openings will be required before unprotected personnel can retrieve canisters. If a repository is sited in a salt dome, cooling of the rock will also be required during development operations. Unprotected personnel should not be allowed to enter openings unless the wall rock temperature in the opening is less than 125°F. Further, the threshold limit values for moderate exertion in hot environments recommended by the American Conference of Governmental Industrial Hygienists should be employed. These values are based on the Wet Bulb Globe Temperature Index (WBGT), which is determined as follows:

$$WBGT = 0.3\ t_{wb} + 0.7\ t_g$$

where t_{wb} = wet bulb air temperature and t_g = globe temperature.

The surface temperature of the wall rock, which represents radiated heat, can be taken as the globe temperature. The WBGT index for the worst condition to which unprotected personnel can be exposed during an emergency must not exceed 106°F at 100% humidity. Threshold limit values for various work conditions are given in Table 3. To maximize cooling efficiency, intake air to storage rooms should be cooled as necessary so that the wet bulb temperature does not exceed 65°F. Air flow requirements for cooling can be calculated using Starfield's (1966) tables.

TABLE 3 Wet Bulb Globe Temperature Indexes for Various Work Conditions

Condition Each Hour	WBGT (°F)
Continuous work	80
75% work, 25% rest	82.4
50% work, 50% rest	84.9
25% work, 75% rest	88.0

3.5 HOIST SYSTEMS

The U.S. Nuclear Regulatory Commission requires compliance with Mine Safety and Health Administration (MSHA) regulations (10 CFR Part 60.132[b][9]). However, MSHA (1983, 30 CFR Part 57.19) regulations concerning hoisting apply only to the hoisting of personnel, although the preamble indicates that "where persons may be endangered,...the appropriate standards should be applied." Some requirements for shaft conveyances used in handling radioactive wastes are provided by NRC (10 CFR Part 60.132[b][10]), but these do not relate to hoist and hoist rope selection. To virtually preclude failure of hoist ropes and free fall of cages, thus satisfying 10 CFR Part 60.131(b)(10)(i), a multirope friction hoist system should be used for waste handling. At least four hoist ropes and two tail ropes are needed. Assuming that a friction hoist will be required, the following criteria are recommended:

- The hoist-drum-to-rope diameter ratio shall exceed 100:1.
- The factor of safety of tail or balance ropes shall not be less than 7.
- The factor of safety of a hoisting rope installation shall not be less than 5.5 or the factor obtained from the formula 8.0 minus 0.0005d, where d is the maximum length of the rope in feet in the shaft compartment below the hoist drum or head sheave, for a tower- or ground-mounted hoist, respectively.

These criteria are more stringent than those of MSHA and were obtained from the Ontario Ministry of Labour (1979). The Ontario standards have resulted from many years of hoist testing and inspection by the Mining Health and Safety Branch of the Ontario Department of Labour and its predecessors. However, if the suggested criteria are less stringent than those in a particular state, the report should specify that state regulations will prevail.

3.6 PLACEMENT OF WASTE PACKAGES

Cost will certainly be a factor in selecting the host medium for the first repository. Subsurface cost is the major component of total repository cost, with minimum medium extracted per unit of emplaced waste yielding the lowest subsurface cost. Waste emplacement in long horizontal holes probably results in the minimum medium extracted per unit of emplaced waste. Retrieval from long horizontal holes, however, remains to be demonstrated, even for host media whose rooms can remain open during the retrievability period. In the case of salt, the report indicates that rooms cannot remain open for the entire retrievability period. Therefore, waste retrieval from long horizontal holes in salt would probably be more difficult than from such holes in other geologic media because room reexcavation would be required.

If designers of repositories in media other than salt use long horizontal placement holes, while the designer of a repository in salt uses a different placement configuration, the salt option will be at a cost disadvantage. Also, for the same waste package configuration, the salt repository will be at a cost disadvantage compared with media that do not require reexcavation prior to retrieval. The architect/engineer will presumably be aware of the foregoing. However, the report should be more specific regarding placement of waste packages.

The report states on page 8 that "the selection of specific design options shall always consider cost efficiency." The report should also state that the design shall take advantage of whatever boring options are available to promote cost efficiency. On page 31, the following sentence should be added after the sentence that starts with "The emplacement configuration of the waste packages...": Alternative schemes for emplacing waste packages shall either involve individual packages or shall be restricted to configurations for which retrievability can be demonstrated.

3.7 RADIATION LEVELS

On page 16, the exposure of workers to radiation is limited to 750 mrem per year, and other radiation dose limits are referred to in Sec. 5.3 (Radiological Safety). The report should also include a table that divides the repository into four to six regions, defines those regions in terms of frequency of occupancy by personnel, and specifies maximum permissible radiation doses for each region.

3.8 SEALS

The architect/engineer will likely know that the CRWM Program has already invested in designs for seals for repository shafts and tunnels. Therefore, the report should clearly define the architect/engineer's responsibility with respect to seals.

3.9 SHAFT MISALIGNMENT

Shaft misalignment could conceivably occur if the shafts are not separated from the emplacement rooms by a sufficiently large shaft pillar. A requirement to this effect needs to be added.

3.10 EXTRACTION RATIOS

To minimize disturbance of the host rock and overlying rocks, the areal extraction ratio should be much lower than normally used in mining. Pillar width-to-height ratios should be at least 4:1 to preclude brittle fracture in pillars and to provide adequate support for overlying rocks. Such support is needed to inhibit eventual subsidence, which has the potential of fracturing aquitards and allowing intrusion of freshwater.

4 POTENTIAL CONSTRAINTS ON REPOSITORY DESIGN

4.1 RETRIEVAL BY REEXCAVATION OF EMPLACEMENT ROOMS

On page 4 the report implies that retrieval "would require re-excavation of emplacement rooms if they had been backfilled." Other schemes, including mining virgin rock below the canisters, have been proposed for retrieval.

4.2 CONFORMANCE WITH MINE SAFETY AND HEALTH ADMINISTRATION REGULATIONS FOR GASSY MINES

The report states on page 17 that the repository shall be designed to conform with MSHA regulations for gassy mines. For bedded salt, this requirement provides an unwarranted and significant constraint on design of the repository itself and of associated underground equipment, as well as on repository operations. It will also impact cost and schedules. Actually, three of the four active mines in salt domes on the Gulf Coast have been classified as gassy only since the methane explosion at the Belle Isle mine in Louisiana in 1979. (The Avery Island mine is not classified as gassy.) Because no site has yet been chosen, it may be prudent to ask the architect/engineer to provide gassy and nongassy alternative designs.

4.3 CHANGES IN SURFACE TEMPERATURE AND SURFACE ELEVATION

The report states that the maximum increase in temperature at the ground surface should be less than 4°C within 3 m of the surface and that displacement of the vertical surface over time be less than 3 m. Both of these requirements should be site specific. Judging from earlier conceptual designs, they can be easily met for a typical site.

The limitation on temperature derives from concern for the surface environment, particularly the vegetative cover and soil organisms. The limitation on surface uplift caused by thermal expansion is potentially much more serious; a limit of 3 m may be too high for some sites. The concern about thermally driven surface uplift relates to the possibility of uplift, or doming, causing fracturing in overlying aquitards. If fractures occur, groundwater may find its way to the burial horizon.

These criteria preclude taking advantage of the finite geometry of the repository. Considering the repository as a finite-plane decaying heat source and assuming either a constant temperature or a convective boundary at the surface, the transient temperatures in the medium between the repository and the land surface can be calculated. The vertical displacement of the medium can then be calculated based on these transient temperatures and the volumetric thermal expansion coefficient of the medium. The farther the repository from the surface and the smaller the area of the finite plane, the more heat will be dispersed outside the volume defined by vertically projecting the finite plane to the surface. Nevertheless, vertically above the center of the finite plane, the transient temperatures of the medium will approximate those from an infinite-plane decaying heat source.

To take advantage of the finite geometry of the repository, the report could be modified to read "...is less than 4°C at 3 m from the surface within 70% of the vertically projected repository area" and "to less than 3 m within 70% of the vertically projected repository area."

Even with the above modification, these far-field criteria cannot really be defended. For example, if the cost of the repository were reduced by, say, 30% when either the temperature criterion was increased from 4°C to 5°C or the vertical displacement criterion was increased from 3 m to 4 m, would ONWI continue to defend the original criteria? These measures are complex restatements of a former criterion that limited the initial kilowatts of decay heat per acre.

Changes in surface temperatures and surface elevations produced by the repository are anticipated to be relatively small. Therefore, these far-field limits should be deleted from the report. Far-field temperatures and vertical displacements will depend on the areal thermal loading. Therefore, as the design progresses, the architect/engineer should continue to calculate them to compare the results to known localized phenomena that have taken place over a comparable time period.

4.4 QUALITY ASSURANCE

Panelists presumed that any repository in salt will be designed, constructed, operated, and closed according to a quality assurance program complying with the requirements of American National Standards Institute/American Association of Mechanical Engineers (1983) and U.S. Nuclear Regulatory Commission (1979). If so, the report should include a section that classifies repository structures, systems, and components into the proper quality assurance levels related to nuclear safety. Section 8 (Quality Assurance) should be revised accordingly.

5 PRESENTATION

5.1 IMPROVING THE INTRODUCTORY MATERIAL

5.1.1 Purpose and Scope

The purpose of the report is not adequately stated. Section 2.2 (Purpose) deals not with purpose but with the types of radioactive waste to be received by the repository, with the ways in which such wastes will be handled and how they will be isolated, and with waste retrieval as well as permanent closure and decommissioning. In Sec. 1.0 (Preface), one gets a hint of the purpose from the following sentence: "This document establishes the functional criteria, defining how well the repository must work, for the architect/engineer to design the repository." However, this poorly structured sentence is clearly inadequate as a statement of purpose.

The purpose of the report should be stated at the outset, preferably under a heading entitled "Purpose and Scope." The following paragraph illustrates the type of material to be included in this section.

> The purpose of this document is to establish the basis for the conceptual design of a high-level radioactive waste repository in the bedded and domed salt formations currently under study by DOE. Fundamental considerations underlying the conceptual design effort, in order of importance, are:
>
> - Maximize worker and public safety,
> - Minimize environmental impact,
> - Minimize overall cost of repository construction, operation, and permanent closure and decommissioning, and
> - Use proven technologies, wherever practicable.

Once the authors define the purpose of their document, they will be able to outline it effectively, thereby helping to ensure that each topical area is adequately treated.

Equally important is an adequate statement of the scope of the document. With regard to scope, it is as important to know what is not going to be covered as it is to know what is going to be covered. The heading "Purpose and Scope" should follow Sec. 2.1 (Background).

5.1.2 Function of the Repository and Its Major Systems

The introductory material should conclude with a subsection describing the overall function of the repository and the various systems and facilities that will be treated in the text that follows (i.e., surface facilities, shafts, subsurface facilities, and waste-handling and service systems). Such information should be augmented by schematic diagrams easily understood by both concerned citizens and technical people.

5.2 SITE CHARACTERISTICS

In Sec. 4.2, design requirements are not specified because "the location of the salt repository is currently undetermined." However, because time is of the essence in the CRWM Program, it would be advisable to summarize the available data on the seven salt sites currently under consideration. Using the data base assembled for the seven site-specific environmental assessments, information for each site could be briefly outlined in an appendix. The following topics should be covered:

- Depth to emplacement horizon,
- Climatology,
- Geologic conditions,
- Hydrologic conditions,
- Geothermal gradient,
- Demography,
- Availability of utilities, and
- Thermomechanical properties of the salt.

Then, if leading candidate sites have been identified by the time of the next revision, the data base in the appendix could be expanded appropriately.

5.3 IMPROVING THE QUALITY OF THE WRITING

"Dispose of" connotes final disposition. Under the retrievability option, however, it is conceivable that much of the initial waste emplaced in a repository would be isolated only temporarily. Thus, it is desirable to avoid using the term "disposed of," when "isolated" is meant. For example, it is somewhat confusing on page 3 where it states that "...DOE has the responsibility to...dispose of, contain, and isolate nuclear waste in underground mined repositories." It would be better to say "to isolate,...with an option for mined retrieval at some time prior to final closure." An additional place in the text where "dispose" is unnecessary is in the last paragraph on page 3.

"Decommission" connotes taking specific steps and final safety precautions in terminating a nuclear reactor or waste-handling facility. The word implies mitigation of any hazardous radioactivity. With respect to a waste repository, the preferred term is "permanent closure," unless dismantling or decontamination of surface facilities is being discussed (10 CFR Part 60.132[e]).

Finally, the text should be edited by a competent technical editor. In addition to correcting numerous spelling, grammatical and syntax errors, the editor should recast illogical sentences like "The repository shall be responsible for all internal services which are required for operation" (lines 4-5 on p. 38).

6 PAGE-BY-PAGE COMMENTARY

Page(s)	Line(s)	Comment
3	1-29	Expand and rewrite Secs. 2.0 and 2.1.
3	13	Spell out the acronym "ERDA." The list of acronyms does not appear until page 5.
3	19-24	The entire paragraph is poorly written. The second sentence should be the first, the two other rock types should be mentioned, and the paragraph should not shift from discussing the rock types being considered for the first repository to the location of the second repository.
4	9	Insert "of" after "disposed."
4	15-16	Why is the depth given as "between 600 and 900 meters"? A minimum depth of 300 m is given in line 14 on page 16 and in 10 CFR Part 60.122(b)(5).
4	29	Delete "prior to permanent closure."
5	6	Insert "of" after "disposed."
7	17-26	Design of a waste package with a life of 300-1000 yr (p. 4) is not "current technology."
8	1-11	Section 3.1.2 is confusing. What does "technical conservatism" mean? In the second sentence, the word "conservative" is used to explain "conservatism." And, in the same sentence, what are the "residual uncertainties which could adversely affect performance"? And still further, performance of what?
10	25-26	This sentence states that "no radioactive waste in liquid form will be accepted at the repository." Yet on page 21, lines 8-10, the first functional requirement is that the facility should be "capable of receiving all forms of high-level nuclear waste."
11	10-16	Will defense wastes be excluded from the repository? What is an SST container?
11	20-21	A citation is needed for the *ONWI Technical Baseline Manual*.

Page(s)	Line(s)	Comment
12		Table 3.1 does not provide adequate guidance to the architect/ engineer. For example, a waste package may contain more than one spent fuel assembly. Also, is the architect/engineer expected to redesign waste packages? Should the paired numbers under the heading "Received by Truck/Rail (%)" total 100%?
12	26	Replace "decommissioning" with "permanent closure." This change should be made throughout the report.
16	14-16	The area over which surface penetrations should be limited should be extended to provide a buffer zone around the underground operations area.
17	1-3	The end of this sentence should be revised to read "than 4°C at 3 m from the surface, within 70% of the vertically projected repository area." Or, the paragraph could be deleted.
17	4-6	Because salt domes must be assumed to be gassy, repository designs should conform with 30 CFR Part 57.21. However, this requirement is overly restrictive in the case of repositories sited in bedded salt, which is not necessarily gassy.
17	10-12	The meaning of this sentence is unclear.
17	13-14	Add "within 70% of the vertically projected repository area." Or, delete the paragraph.
18	8-12	An appendix listing applicable codes and standards would be useful.
18	15	Delete the words "or omission."
21		The words "facility" or "facilities" appear several times on this page (lines 3, 8, 14, 15, 20, and 24). In each case, the author might have chosen a better word that would have described more precisely what is to be designed -- building, structure, plant, complex, etc.
21	2-4	This sentence is confusing.
22	1	"Will be functional" should be changed to "will be designed to be functional."

Page(s)	Line(s)	Comment
24	22-25	This paragraph implies that construction of the repository may occur before in situ characterization is complete. The U.S. Nuclear Regulatory Commission is unlikely to give construction authorization before the site has been shown with "reasonable assurance" to be suitable. Hence, site characterization will need to be substantially complete before such authorization. The exploratory shaft area will probably be used to demonstrate storage and retrieval.
26	20-21	Extensive work on waste package design and processing facilities has already been completed. Is the architect/engineer expected to repeat this work?
28	24-26	Mine Safety and Health Administration requirements for hoist rope safety factors apply strictly to conveyances for personnel. Similar criteria should be provided for conveyances that will be handling wastes.
29	4-6	A requirement should be added that the shafts be isolated from the storage rooms by a pillar sufficiently large to minimize deformation of the shaft caused by room construction.
29	25-27	Separate ventilation circuits for development and emplacement activities are required by 10 CFR Part 60.133(g)(3). In other words, at least two shafts must be used for air intake.
30	6-7	Since MSHA gassy mine regulations require that the main intake and exhaust currents be carried in separate shafts (30 CFR Part 57.21-22), delete "(in shafts or compartments)."
30	25-27	Note that MSHA gassy mine regulations require cross-cuts between openings on 100-ft centers (30 CFR Part 57.21-46).
31	17-20	Insufficient attention is paid to ground support. The statement that time-dependent rock movement shall be minimized is rather simplistic. Creep closure must be considered.
31	24-25	This sentence should read: "Following emplacement and with the approval of NRC, the room will be backfilled with compacted, crushed material."
31	26	Revise the sentence to begin: "In such case, retrieval, if necessary, will..."

Page(s)	Line(s)	Comment
33	7-11	Revise the sentence to read: "During permanent closure, seals of a different nature will be constructed so that once the repository has been backfilled and closed, the seals (especially in the shafts) will help prevent migration of radionuclides to the accessible environment."
33	18	Change "that contact" to "that the contact."
33	22	Revise the sentence to begin: "Before closure, prevent water inflow from..."
33	25	Revise the sentence to begin: "Before and after closure, preserve the integrity of the site geology so that..."
35-36		Many of the listed functions could take place in a single building. As it now reads, each function is to take place in its own building.
37	4-5	A requirement so obvious need not be stated.
37	19	Change "for" to "from."
37	20	Change "shipping casks" to "shipping cask transporters."
37	26-27	This sentence needs to be rewritten.
41	8-12	Is the disposal capacity to be "sufficient" or "excess"? If excess, how much excess is to be provided? One shift? One day? One week?
43	4-5	Delete the sentence beginning "The repository shall be as safe as..."
43	12	Delete the words "or omission."
43	14	Change "that" to "their."
46-47	28-30; 1-13	"Dynamic Effects of Equipment Failure" and "Falls" should be treated in separate subsections.
47	14-23	The following bullet should be added: "o Separate ventilation circuits for development and emplacement activities." In addition, temperature limits should be given for personnel occupancy and work.

Page(s)	Line(s)	Comment
50	1	The title for Sec. 7.0 should read "Retrievability and Permanent Closure."
50	6	Change "decommissioned" to "permanently closed."
50	12	Change "established performance objectives" to "performance objectives established."
50	27	Add "under repository temperature conditions" to the end of the sentence.
51	1-3	Retrieval may be required for other reasons.
51	6-8	This requirement is designed to satisfy 10 CFR Part 60.142(C), which states that a backfill test section must be constructed to test placement and compaction procedures before permanent backfilling is begun. This intent needs to be clear.
51	21-27	Change "decommissioning" to "permanent closure."

REFERENCES

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Ontario Ministry of Labour, *Ontario Regulations 660/79, Mines and Mining Plants*, Queen's Printer, Toronto, Ontario, Canada (1979).

Starfield, A.M., *Tables for the Flow of Heat into a Rock Tunnel with Different Surface Heat Transfer Coefficients*, J. South African Institute of Mining and Metallurgy, *66*(12):692-694 (July 1966).

U.S. Nuclear Regulatory Commission, *Disposal of High-Level Radioactive Wastes in Geologic Repositories: Licensing Procedures*, Code of Federal Regulations, 10 CFR Part 60 (June 30, 1983).

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PEER REVIEW PANEL MEMBERS

Dr. Joseph S. Busch
Raymond Kaiser Engineers
Oakland, California

*Dr. Dorland E. Edgar
Geoscience and Engineering Group
Energy and Environmental Systems Division
Argonne National Laboratory

‡Mr. Douglas F. Hambley
Geoscience and Engineering Group
Energy and Environmental Systems Division
Argonne National Laboratory

**Dr. Wyman Harrison
Associate Director for Geoscience and Engineering
Energy and Environmental Systems Division
Argonne National Laboratory

Dr. James E. Russell
Texas A&M University
College Station, Texas

Ms. Mary W. Tisue
Geosciences Editor
Energy and Environmental Systems Division
Argonne National Laboratory

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*Member of core peer review staff.

‡Review session chairman and member of core peer review staff.

**Review panel chairman and member of core peer review staff.

APPENDIX A

U.S. DEPARTMENT OF ENERGY LETTER REQUESTING PEER REVIEW

Department of Energy
National Waste Terminal
Storage Program Office
505 King Avenue
Columbus, Ohio 43201

February 7, 1984

Wyman Harrison
EES-362
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

Dear Mr. Harrison:

SUBJECT: PEER REVIEW OF THE REPOSITORY FUNCTIONAL DESIGN CRITERIA (RFDC)

The DOE-Salt Repository Project Office (SRPO) received the above document from ONWI on January 25, 1984.

We are requesting that ANL perform a peer review which should be documented and formally transmitted to this office by March 9, 1984.

This Functional Design Criteria contains basic information defining the starting point for the design of the repository in salt, and will be used primarily by the architect/engineer (Fluor) who is responsible for the conceptual design.

This review should, as a minimum, address the following:

1. How does the RFDC constrain the salt repository project design efforts?

2. Does it preclude SRPO from developing the optimum combination of design features which could result from taking advantage of salt site-specific geotechnical characteristics?

3. Does the RFDC adequately represent a realistic set of requirements? That is, should SRPO identify additional requirements?

4. What will be the schedule, cost, and technical impacts of this criteria?

5. Are the requirements, criteria, and planning bases technically sound or too constraining?

Wyman Harrison
Page 2

6. What information, specifications, or requirements should be added or deleted from the RFDC?

In addition, any other comments pertaining to this document that are deemed appropriate will be considered.

Enclosed are five copies of the subject criteria.

Your interest and cooperation are appreciated.

Sincerely,

R. C. Wunderlich
Chief
Engineering and Technology
Salt Repository Project Office

SRPO:DKR:1168A

Enclosure:
As Stated

cc: T. Baillieul, SRPO, without enclosure
J. Fitch, Fluor/Columbus, without enclosure

ST#270-84

APPENDIX B

CONCURRENCE SHEET

APPENDIX B

CONCURRENCE SHEET

I concur that the Argonne National Laboratory review of ONWI's report entitled *Functional Design Criteria for High-Level Nuclear Waste Repository in Salt* fairly represents my comments, where incorporated, to the peer review panel.

Joseph S. Busch

Wyman Harrison

Dorland E. Edgar

James E. Russell

Douglas F. Hambley

APPENDIX C

CREDENTIALS OF PEER REVIEW PANEL MEMBERS

Joseph S. Busch

Northwestern University: B.S., Chemical Engineering (1949)
Johns Hopkins University: M.S., Chemical Engineering (1953)
Carnegie Mellen University: Ph.D., Chemical Engineering (1960)

Dr. Busch is a Principal Engineer with Raymond Kaiser Engineers, Oakland Calif. He has 32 years of experience working on nuclear and chemical engineerin projects for both government and industry. He has supervisory and design experienc with solid, liquid, and gas processing systems for nuclear and nonnuclear facilities. Hi nuclear experience includes work on both fast reactors and light-water reactors.

Dr. Busch participated in the National Waste Terminal Storage Program b working on a conceptual design for a mined repository in salt for highly radioactiv waste. He was assistant project manager in charge of underground technology and als served as head of the thermal analysis group. As such he directed the work of mining rock mechanics, heat transfer, and ventilation engineers and consultants, and coordinate the design of subsurface systems with that of surface facilities.

Dr. Busch also served as manager of a preconceptual design of an incinerato facility to be constructed at Idaho National Engineering Laboratory. He has als participated in the Basalt Waste Isolation Project and the Nevada Nuclear Waste Storag Investigation.

Dr. Busch is a registered chemical engineer in Pennsylvania, Michigan Mississippi, and New York. He has published numerous papers on heat transfer, nuclea systems, and pollution abatement.

Dorland E. Edgar

Central Missouri State University: B.S., Geology (1968)
Colorado State University: M.S., Geology (1973)
Purdue University: Ph.D., Geology (1976)

Dr. Edgar joined the Geoscience and Engineering Group of the Energy and Environmental Systems Division of Argonne National Laboratory in 1978. Since that time he has worked as a geologist and hydrologist on programs related to waste management and energy and mineral resources development. From 1981 through 1983, he participated in studies of the geologic setting of crystalline rocks of the northeastern and Lake Superior regions of the United States for the purpose of assessing their suitability as sites for a high-level radioactive waste repository. His primary areas of responsibility on this project were surface-water and groundwater hydrology, geomorphology, and surficial geology.

From 1978 to 1981, Dr. Edgar was affiliated with Argonne's Land Reclamation Program and Environmental Control Technology Program, where he studied the relationships between surface mining and reclamation activities, and geomorphic processes, hydrology, water quality, and erosion and sedimentation. Dr. Edgar also served as a U.S. Department of Energy representative to an interagency group that reviewed comments and drafted revised regulatory guidelines for the U.S. Office of Surface Mining.

Before coming to Argonne, Dr. Edgar was employed at Oak Ridge National Laboratory, where he conducted research on surface and subsurface hydrologic and geologic conditions, and their relationship to the shallow land disposal of low-level radioactive waste. One project involved the study of the hydrologic and geomorphic processes involved in transporting radionuclides from burial sites through an instrumented watershed. Dr. Edgar's graduate research was directed primarily toward the relationships between hydrology and the geomorphic processes operating within alluvial stream channels and drainage basins.

Dr. Edgar has published approximately 25 scientific and technical publications, and is a member of two professional societies.

Douglas F. Hambley

Queen's University at Kingston: B.Sc., Mining Engineering (1972)
Lewis University: MBA candidate
Registered Professional Engineer, No. 18026014, Province of Ontario, and
No. 062-039201, State of Illinois

Mr. Hambley has more than 10 years experience in mining, tunneling, and underground construction. He joined the staff of the Geoscience and Engineering Group of the Energy and Environmental Systems Division of Argonne National Laboratory in 1984. Prior to working at Argonne, Mr. Hambley was employed as a Senior Mining Engineer for nearly four years by Engineers International, Inc., a mining/tunneling consulting firm located in Westmont, Ill. In addition to designing several large tunnels for various purposes, he spent over two years as Project Engineer on U.S. Nuclear Regulatory Commission contracts to assess retrievability from repositories for high-level radioactive waste and to provide technical assistance for repository design reviews.

Between 1972 and 1980, Mr. Hambley held various technical positions with major Canadian mining companies, including Denison Mines Ltd. and Falconbridge Nickel Mines Ltd. During his employment at Denison (1977-1980), he was responsible for several major projects, including (1) a tripartite (Denison/Rio Algom/CANMET) regional stability study; (2) investigation, specification preparation, and tender evaluation for Stanrock Mine dewatering and shaft rehabilitation; (3) design of the backfill system for a pillar recovery scheme; and (4) design of the underground garage and supply station for diesel fuel at No. 1 shaft.

Mr. Hambley has published on retrievability of high-level nuclear waste, design of shafts and tunnels, computer modeling of mine openings, and raise boring cost estimation. He is active in several technical societies.

Wyman Harrison

University of Chicago: S.B., Geology (1953), after three years of undergraduate work at Stanford University
University of Chicago: S.M., Geology (1954)
University of Chicago: Ph.D., Geology (1956)
Registered Geologist, No. 2476, State of California
Certified Professional Geologist, No. 134, American Institute of Professional Geologists, and No. 487, State of Virginia

Dr. Harrison is Associate Director for Geoscience and Engineering for Argonne National Laboratory's Energy and Environmental Systems Division. He directs a 25-person group that performs analytical and experimental studies related to management of energy and mineral resources and to development and deployment of related technologies. Major activities of the group include (1) acquisition of geophysical and geotechnical data bases, (2) analysis of the data of geoscience to support design and deployment of energy technologies, and (3) development of physical and mathematical models of geophysical/geotechnical systems.

Dr. Harrison's group recently completed comprehensive surveys of the geoscience data pertaining to crystalline rock complexes in the northeastern and Lake Superior regions of the United States to help assess their potential as possible sites for repositories for high-level radioactive waste. Dr. Harrison has conducted numerous other geological and geotechnical studies at Argonne, ranging from estimating the petroleum resources of selected basins in the Soviet Union to determining near-shore circulation in Lake Michigan.

From 1971 to 1975, Dr. Harrison was Professor of Geography (Associate Department Chairman) at the University of Toronto, where he specialized in geophysical studies related to slope stability in sedimentary terrains and the siting of supertanker ports. Prior to that, he was Associate Director for Physical, Chemical, and Geological Oceanography at the Virginia Institute of Marine Science and a Professor of Marine Science at the University of Virginia. Dr. Harrison was Director of Environmental/ Science Services Administration's (now National Oceanic and Atmospheric Administration's) Land and Sea Interaction Laboratory from 1964 to 1968. Before that he was on the faculty of Dartmouth College's Department of Geology and a geologist with the Indiana Geological Survey.

An author of over 100 papers, reports, reviews, and books, Dr. Harrison was made Senior Scientist at Argonne in 1976.

James E. Russell

South Dakota School of Mines and Technology: B.S., Civil Engineering (1963)
South Dakota School of Mines and Technology: M.S., Civil Engineering (1964)
Northwestern University: Ph.D., Theoretical and Applied Mechanics (1966)

Professor Russell joined the faculty of Texas A&M University in 1978 as Professor of Mining Engineering and Geophysics, and has been a Brockett Professor of Engineering since 1982. He has had extensive experience in the analytical/numerical, laboratory, and field rock mechanics aspects of mining, underground construction, and underground storage. Much of his research has involved in situ experiments related to waste repository design, radioactive waste isolation in salt, creep models for salt, thermal loading in waste repositories in salt, benchmark problems in salt using different numerical methods, coal gasification, and lignite mining.

Dr. Russell currently serves as rock mechanics consultant to ONWI and Oak Ridge National Laboratory; resource consultant for rock mechanics to the Overview Committee for the Basalt Waste Isolation Project; coinvestigator of an ONWI-sponsored project at Texas A&M University to develop constitutive equations for salt; and member of the Performance Constraints Working Group for RE/SPEC, Inc., and ONWI. During 1979 he served as a member of the Peer Review Group for DOE, Nevada Nuclear Waste Storage Investigations.

From 1972 to 1976, he was Vice President and Resident Consultant at RE/SPEC, Inc. From 1977 to 1978, just prior to accepting the position at Texas A&M, Professor Russell was the Project Manager for Rock Mechanics at the Office of Waste Isolation, Union Carbide Corporation. From 1967 to 1976, Dr. Russell served as Assistant Professor of Civil Engineering; Associate Professor of Civil Engineering, Mining and Civil Engineering, and Mining Engineering; and Professor of Mining Engineering at the South Dakota School of Mines and Technology. From 1966 to 1967, he was Senior Research Engineer at Southwest Research Institute.

Professor Russell has published extensively in the fields of rock mechanics, mining engineering, lignite mining, coal gasification, and waste isolation. He is a member of six professional and honorary societies, and has served on 11 national committees.

Mary W. Tisue

Beloit College: B.S., Geology (1961)
Yale University: M.S., Geology (1963)

Ms. Tisue has been employed since 1979 as a technical editor for the Energy and Environmental Systems Division of Argonne National Laboratory. From 1981 through 1983, she was part of a research team that gathered geologic information on the crystalline rocks of the northeastern and north-central United States, with a view to assessing their suitability as sites for repositories for high-level radioactive waste. Other projects have involved the editing of reports, journal articles, conference papers, and proposals on such topics as transportation, decision analysis, particulate control, industrial process energy conservation, economics of gasohol, chemistry of synthetic fuel process waters, environmental studies of ocean thermal electric conversion, recycling, petroleum geology and resource assessment, and socioeconomic impact of energy development.

Prior to accepting a position at Argonne, Ms. Tisue worked as a technical writer and marketing assistant for an instrument company and as an editor for the Metals Research Laboratory of what was then the Olin-Mathieson Chemical Corporation.

Ms. Tisue is a member of the Society for Technical Communication and the Association of Earth Science Editors.