Enclosure 7

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INDEPENDENT COMPARATIVE ASSESSMENT OF HLW REPOSITORY SITES

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however, it would be useful to provide a more detailed description of the quantitative comparisons performed, and to present the actual numerical calculations which support DOE's conclusions that the site rankings are insensitive to all but extreme values of weighting factors for different sets of guidelines. This material could be set forth in an Appendix to the EA or in a separate document referenced in the EA.

In this latter connection, as mentioned in the body of the letter transmitting our comments, The Analytic Sciences Corporation ("TASC") has performed an independent comparative evaluation for EEI/UNWMG based on the system guidelines, extrapolations from existing data, and vulnerability to disruption. This analysis, which is described in a separate report included with these comments, confirms DOE's identification of the Hanford, Yucca Mountain, and Deaf Smith sites as preferred locations, distinctly ranked higher than either Richton or Davis Canyon when considered under both the preclosure and the postclosure guidelines.

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EXECUTIVE SUMMARY

This document reports methods and results for comparative assessments of the Davis Canyon, Deaf Smith, Hanford, Richton, and Yucca Mountain candidate HLW repository sites. TASC performed these assessments at the request of the Utility Nuclear Waste management Group (UNWMG) to support the UNWMG comments on the Department of Energy's draft Environmental Assessments. The objectives of the work were to assess independently the candidate repository sites by (1) critically reviewing DOE's site ranking methodology; (2) developing an approach to site ranking taking into account the anticipated performance of the overall system and obtaining rankings based on this new approach; and (3) comparing and analyzing all DOE and TASC results.

TASC used two comparative assessment approaches. Both take into account the anticipated performance of the overall system -- which DOE did not do. One TASC approach involved assessment of expected overall system performance after uncertainty of relevant performance parameters has been reduced by acquisition of additional site data. In contrast, DOE's rankings were based on use of available data, conservative analyses, and evaluation of subsystem performance.

The other TASC approach involved an evaluation of the vulnerability of repositories at the candidate sites to occurrence and effects of processes and events that could disrupt waste isolation performance. The DOE assessments did not consider disruption scenarios.

The DOE and TASC site ranking results relative to the postclosure guidelines were found to be compatible. This implies that DOE's judgments and methods for site evaluations relative to the postclosure guidelines did not bias their ranking results. The DOE methods also did not produce results substantially different from those that would have been obtained if DOE had used the system guidelines.

The DOE and TASC assessments using the postclosure guidelines indicate that all five candidate repository sites are technically acceptable and not clearly distinguishable on the basis of postclosure gidelines alone. Thus, the TASC analysis established that the preclosure gidelines (not considered in the TASC work) are the principal determinant of DOE's finding that the Yucca Mountain, Hanford, and DEAF Smith sites are top-ranked. When the preclosure guidelines are taken into account, TASC confirmed that Hanford, Yucca Mountain, and Deaf Smith are virtually indistinguishable from each other but distinctly higher-ranked than Richton and Davis Canyon within the ranking framework.

INDEPENDENT COMPARATIVE ASSESSMENT OF HLW REPOSITORY SITES

1. INTRODUCTION

In Chapter 7 of the Draft Environmental Assessment (EA) documents, the U.S. Department of Energy (DOE) reported methods and results for comparative evaluation of five candidate high-level waste (HLW) repository sites proposed for nomination as suitable for detailed site characterization. Each of the five sites -- Davis Canyon, Deaf Smith, Hanford, Richton, and Yucca Mountain -- is a preferred site within a geohydrologic setting. The comparative evaluations were performed to satisfy requirements of Section 112(b)(E)(iv) of the Nuclear Waste Policy Act of 1982, and of the DOE's 10 CFR Part 960 siting guidelines (Ref. 1).

The DOE found that the Hanford, Yucca Mountain, and Deaf Smith sites "...offer, on balance, the most advantageous combination of characteristics and conditions for the successful development of a repository and should therefore be recommended for characterization" (Ref. 2). The three ranking methods used by DOE -- averaging, pairwise comparison, and utility estimation -- all showed these three sites to be higher-ranked than the Richton and Davis Canyon sites.

As part of their review of the EA documents, the Utility Nuclear Waste Management Group (UNWMG) requested The Analytic Sciences Corporation (TASC) to perform the independent, comparative site assessment reported herein. TASC has been a participant in projects concerned with HLW disposal for nearly a decade, and has a total of nearly 100 person-years of experience relevant to this assessment. Under sponsorship of the Electric Power Research Institute, TASC has developed and applied methods for performance assessment of HLW repositories. TASC's previous assistance to the UNWMG includes support of comments concerning the NRC Waste Confidence Proceedings, proposed rule-making by the NRC (10 CFR Part 60), and the EPA (10 CFR Part 191). Appendix A presents a bibliography of relevant TASC publications, a description of relevant TASC experience, and resumes of key staff.

Chapter 2 of this report outlines concepts and techniques involved in these assessments; it is intended to serve as a primer for readers who are not familiar with the subject. Chapter 3 describes the methods used by TASC, compares them to those used by DOE, and presents the TASC results. Chapter 4 compares and discusses all TASC and DOE results.

2. HLW REPOSITORY PERFORMANCE ASSESSMENT

This chapter describes in overview the principles, purposes, and practice of HLW repository performance assessment (PA). Application to the TASC and DOE assessments for the draft EAs is emphasized.

Repository PA is basically evaluation of the repository's ability to isolate radionuclides from the human environment. In future years, such evaluations will be performed in accordance with repository licensing requirements. At present, for purposes of the Environmental Assessments, PA can be used to help determine if sites are suitable for repositories and to compare candidate sites.

Two types of PA -- preclosure and postclosure -- can be distinguished. Preclosure PA is concerned with the hands-on aspects of a repository; e.g., construction, operation, and closure. Principles and practice for this type of PA have been well-established through experience with other nuclear facilities; preclosure PA is not addressed here.

Postclosure PA -- the subject of these assessments -- is concerned with the ability of the repository to maintain radionuclides in isolation for periods of thousands of years. Over such time periods, engineered features of a repository can degrade significantly (e.g., by corrosion of the waste canister), and natural processes and events, such as erosion and earthquakes, can change the waste isolation capability of the site, i.e., of the "geologic setting". The repository licensing process will be aimed at establishing, with reasonable assurance, that waste isolation will be maintained in the long term as needed. The draft EAs are a step in the process of selecting preferred site(s) for repositories that will be subject to licensing reviews.

2.1 RELEVANT SITING GUIDELINES

The DOE Siting Guidelines, 10 CFR Part 960, define and classify all guidelines involved in site suitability evaluation. Some of the guidelines are concerned specifically with long-term repository performance; i.e., those concerned with geohydrology, geochemistry, rock characteristics, climate, erosion, dissolution, tectonics, natural resources, and site ownership and control. These are the guidelines listed in Table B-2, Appendix B, of each draft EA; they are the guidelines of concern to the assessments reported here.

2.2 PERFORMANCE ASSESSMENT METHODS AND THEIR USE

The practice of PA can be described as conversion of the qualitative requirements of the siting guidelines into quantitative predictions of long-term repository performance with respect to waste isolation capability. Quantitative predictions can be made using values for physical properties such as rock strength and for the effects of occurrences such as earthquakes and well-drilling; PA uses the quantitative information in mathematical models which predict performance.

There are many specific PA models and methods. They differ in characteristics such as primary function and level of detail. A variety of models is necessary; for example, modeling of repositories in salt and in basalt differs in detail.

Personnel in DOE, NRC, and the extra-agency peer technical community are working interactively to develop models that are soundly-based, meet user needs, and can be shown to function correctly. The NRC has published guidance on PA models for the repository licensing process (Ref. 3).

In the draft EAs, the DOE used PA models and available data to evaluate the candidate sites relative to the individual suitability guidelines. For example, waste package performance -- evaluated in terms of expected lifetime -- was estimated for each site using appropriate models and conservative assumptions. The DOE specifically did not evaluate and compare the sites relative to the system guidelines. The distinctions between assessments based on the individual guidelines and assessments based on the system guidelines, and the role of uncertainty in assessment methods and results, are significant to the distinction between TASC's independent assessments and DOE's assessments reported in the EAs. The TASC and DOE methods are compared in Chapter 3.

PA methods used for assessments relative to the individual suitability guidelines (which can be called subsystem assessments) are relatively narrow in function (e.g., elapsed time for penetration of a waste canister wall by corrosion will be estimated). In contrast, system PA requires coupling of the individual models* to produce assessments of overall system performance. There are many technical issues associated with subsystem/system assessment relationships, but for EA purposes, one issue is key: uncertainty in results.

*"Coupling" may be accomplished either by linking individual subsystem models or by using other models with broader scope (and, perhaps, less detail).

Estimates of sources and magnitudes of uncertainty in system PA results are difficult to make and to justify, especially when data are incomplete as they are at present. In addition, system PA requires consideration of processes and events that can disrupt the waste isolation capability of the repository. Selection of the "disruption scenarios" and estimation of their effects relies heavily on expert judgment and involves uncertainties that cannot be reduced or resolved by data acquisition. The DOE apparently based its position that "...the evidence is not adequate to compare or rank the site for any of the system guidelines..." (EA Chapter 7, p. 7-4) on these uncertainty and judgment characteristics of system PA. TASC believes, however, that preliminary evaluation of overall system performance is possible.

2.3 THE ROLE OF JUDGMENT AND UNCERTAINTY

Judgment and uncertainty play key, interactive roles in repository PA and in the DOE and TASC comparative assessments of the candidate sites. Detailed discussion of these roles is beyond the scope of this report; this section identifies key principles and briefly describes their significance.

Two concepts provide a framework for this discussion:

1. "Mathematical uncertainty" is concerned with uncertainty in the outputs of the mathematical models used in PA. It can be quantified, analyzed, and affected by factors such as characteristics of the model iself and uncertainty in data inputs. Site characterization is aimed at reducing uncertainty in PA results by reducing uncertainty in data for physical properties that can be measured.

2. "Judgment uncertainty" involves the conventional issues associated with exercise of expert judgment. It can be linked to mathematical uncertainty through use of judgment to select models and to estimate numerical values of model parameters. "Pure" judgment (i.e., not subject to verification or modification through experiment) also enters the mathematical aspects of PA through selection of disruption scenarios and estimation of their probabilities.

At present, because site-specific data are relatively sparse, judgment plays a large role in PA and mathematical uncertainty is relatively large. Site characterization and in-situ testing are expected to reduce uncertainty through expansion of the data base (see, for example, Ref. 4). There will always be, however, a "residual uncertainty" associated with predictions of waste isolation capability and, as indicated above, there will always be an element of judgment in the prediction results. The licensing process will take into account residual uncertainty in making judgments regarding the ultimate safety of the repository.

Although uncertainty levels are currently large relative to levels for the licensing process, the present situation is not highly open-ended or unbounded. The scientific principles for waste isolation PA are well understood, and representative values for relevant physical properties are well known. Predictions of waste isolation performance have been made for nearly a decade (Ref. 5), and there is consensus that quantitative results for these predictions are representative and generally conservative; i.e., it is likely that actual performance will be better than predicted. Such predictions provide the technical basis for NRC's 10 CFR Part 60 technical criteria and EPA's 40 CFR Part 191 nuclide release limits.

The DOE limited their use of PA in the draft EAs to subsystem evaluations. They could have performed system performance assessments (the Hanford draft EA did so to a limited extent, but results were not a basis for suitability assessments); their judgment not to do so can be attributed to the fact that the limited data allow the possibility that site-specific characterization could disclose "surprises" (e.g., a presently-unknown fault) that would negate system PA results, and to the large mathematical uncertainty that would be associated with current "best-value" system PA results.

TASC's approaches to exercising judgment and dealing with uncertainties differed from those of DOE. Key elements of the TASC approach can be briefly summarized as follows:

- Available data were taken to be representative; i.e., it was predicted that detailed site characterization will reduce uncertainty in current parameter values without changing them significantly and will not encounter surprises
- Projections of isolation capability were based on overall system performance rather than subsystem performance
- Judgments were made concerning the possible occurrence of disruption scenarios and their effect on system performance.

This approach is less conservative than that used by DOE. It can generally be characterized as a logical but unconfirmed extrapolation of available information, using the principles and generic information that underly the HLW disposal regulations.

2.4 COMPARATIVE ASSESSMENT METHODS

Performance assessment methods such as outlined above are used to evaluate a specific site and repository system. To compare sites or systems, other methods must be used.

The DOE used three site comparison methods in the draft EAs: averaging, pairwise comparison, and utility estimation. The documents outline the characteristics of each technique and identify references which can provide more detailed information on the techniques themselves. TASC reviewed DOE's use of the methods; to the extent possible with the information provided in the draft EAs, DOE's results were confirmed.

As described in Chapter 7 of the draft EAs, the DOE applied the three comparative ranking methods to their assessment results for both the preclosure and the postclosure guidelines. In contrast, TASC addressed only the postclosure guidelines (cf. Section 2.1) and used only the utility estimation technique for site comparisons. The utility estimation technique is the only one of the three that DOE used that is appropriate for TASC's assessment methods. Both DOE and TASC used utility estimation without applying weighting factors to the individual postclosure guidelines listed in Table B-2 of Appendix B of the draft EAs.

As indicated by DOE in Appendix B of the draft EAs, use of utility estimation requires use of expert judgment to rate each site for each of the guidelines. In terms of performing a judgment-based comparative rating of sites, DOE and TASC therefore did the same thing. However, as outlined above in Section 2.3 and detailed in Chapter 3, the bases for the DOE and TASC utility ratings differed.

3. TASC ASSESSMENT METHODS AND RESULTS

As noted in Chapter 2, DOE did not use the system guidelines and system PA as bases for site rankings because the data base is incomplete. Uncertainty was judged by DOE to be too large at this time to obtain reliable results from a systems approach; DOE therefore took a conservative approach to interpretation and use of available information.

As explained in Section 2.3, TASC believes uncertainty -- although relatively large -- is sufficiently bounded to use system-based concepts and to apply the results in site rankings. For the same reasons as cited by DOE, TASC did not quantitatively assess system performance. Instead, as detailed below, TASC exercised judgment to select site ratings for the postclosure guidelines based on expected evolution of the data base.

Two fundamental judgments underlie the TASC approach: (1) expansion of the data base for each site, through characterization and testing, will narrow mathematical uncertainty (cf. Section 2.3) and establish physical parameters essentially at "typical" values for the geologic medium; and (2) characterization will not disclose surprises such as currently-unknown aquifers or faults that would make the site unacceptable.

The current status of information necessitates the judgments stated above. The TASC methods described in Sections 3.1 and 3.2 are the same as DOE might use later in the OCRWM program when more information is available, or might have used in the draft EAs under a less conservative approach.

3.1 EXTRAPOLATION OF EXPECTED SYSTEM PERFORMANCE

A key element of performance assessment is evaluation of the "expected" or "design" performance of the repository system. Each of the postclosure siting guidelines is related to parameters such as permeability that will ultimately be involved in evaluation of expected system performance. At present, uncertainty in the values of these parameters (and, therefore, in expected performance) is relatively high. In addition, uncertainty differs from site to site because of differences in the quantity of data available and in the apparent effects of geologic complexity and inhomogeneity on capability to reduce uncertainty through acquisition of additional data.

TASC established utility ratings for the candidate sites by judging the site ratings for the postclosure guidelines at the conclusion of site characterization, i.e., for a status in which expected system performance would be assessed on the basis of an essentially complete data base. In other words, ratings such as those exhibited in Table B-2 of Appendix B of the draft EA were selected, with the TASC ratings being directed by prediction of ratings after data uncertainty has been reduced.

The core feature of this rating approach is its focus on expected system performance after reduction of mathematical uncertainty as a result of expansion of the data base. This focus differs from DOE's focus on use of conservative PA models and assumptions to estimate <u>subsystem</u> performance relative to the individual guidelines. The TASC approach requires consideration of how the guidelines listed in Table B-2 of the draft EAs apply interactively to the natural and engineered barrier subsystems and to compliance with EPA and NRC performance criteria.

Utility ratings obtained by TASC using this approach are shown in Table 3.1-1, which can be compared to Table B-2 of the draft EAs. TASC's use of judgment can be illustrated by comparing the TASC and DOE ratings for the geohydrology and rock characteristic guidelines.

In TASC's judgment, additional data for the Hanford site will not significantly reduce uncertainty in Hanford

TABLE 3.1-1

TASC RATINGS BASED ON EXTRAPOLATION OF SYSTEM PERFORMANCE

TECHNICAL GUIDELINE	RATING									
	1	2	3	4	5	6	7	8	9	10
Geohydrology					H			Y	DS R DC	
Geochemistry						R	DC DS		H,Y	
Rock Characteristics					H		Y		DS,R	DC
Climate									All	
Erosion									All	
Dissolution							R	DC DH		Y,H
Tectonics					Y	H			R,DC	DS
Natural Resources								DC DS R	H	Y
Ownership										All

H - Hanford　　DS - Deaf Smith　　DC - Davis Canyon
Y - Yucca Mountain　　R - Richton

geohydrology because of the complexity of the geologic setting. The contribution of geohydrology to uncertainty in repository system performance at Hanford will, therefore, be high relative to the contribution for salt sites. In contrast, additional data for the salt sites are extrapolated to confirm a strong contribution of geohydrology to performance of a repository in salt. Hence, TASC's rating for the Hanford site for this guideline is lower than DOE's, and the TASC and DOE ratings for the salt sites are the same.

For the rock characteristics guideline, TASC projects that additional data will reduce Hanford's relative rating and will confirm the superior qualities of the Davis Canyon site that are suggested by available data. Hence, TASC's rating for the Hanford site for this guideline is again lower than DOE's; TASC's rating for the Davis Canyon site is higher than DOE's.

Similar statements concerning TASC's use of judgment can be made for the other ratings shown in Table 3.1-1 except for the climate, erosion and ownership guidelines, for which TASC accepted and used DOE's ratings.

3.2 EXTRAPOLATED VULNERABILITY TO DISRUPTION

In addition to evaluation of expected system performance, a significant element of performance evaluation for licensing purposes is to evaluate the probability and consequences of future events and processes that could disrupt the repository's waste isolation capability. For example, earthquakes or human action such as drilling could create new pathways for nuclide transport to the human environment. Such unexpected, improbable-but-possible scenarios were the subjects of these TASC assessments. Degradation phenomena such as waste canister corrosion and plastic deformation of salt are aspects of expected performance and are not considered here.

As stated in Section 2.3, selection of disruption scenarios and estimation of their probabilities are exercises in "pure" judgment; i.e., choices cannot be tested or verified through acquisition of data. Peer reviews and group efforts can be used to establish consensus that choices made are reasonable, but "proof" of results is not possible.

The DOE could have used vulnerability-to-disruption evaluations in their draft EA suitability assessments since these judgments and ratings are not dependent on site characterization data. The DOE did not, however, make this type of evaluation, possibly because of the generally conservative DOF approach and because these evaluations are inherently associated with system PA (e.g., coupled effects for the waste package and the geologic setting have to be considered). These TASC assessments therefore have no parallel in the draft EA's.

TASC established these ratings by using judgment to rate the sites in terms of their <u>resistance</u> to disruption by events and processes associated with each postclosure guideline. In other words, a site will have a high utility rating under this approach if events and processes related to the guideline do <u>not</u> have a high potential to disrupt the repository from its expected performance. In previous work, TASC applied the term "repository robustness" to this concept (Ref. 6).

Utility ratings obtained by TASC using this approach are shown in Table 3.2-1. The judgments used to produce these results are illustrated by consideration of the ratings for the rock characteristics and tectonics guidelines. The salt

TABLE 3.2-1
TASC RATINGS BASED ON VULNERABILITY TO DISRUPTION

TECHNICAL GUIDELINE	RATING									
	1	2	3	4	5	6	7	8	9	10
Geohydrology							H		DS R DC	Y
Geochemistry							DS R DC	H	Y	
Rock Characteristics							H		Y	DS R DC
Climate										All
Erosion										All
Dissolution							R	DS DC		H,Y
Tectonics							Y	H		DS R DC
Natural Resources							R	DS DC		Y,H
Ownership										All

H - Hanford DS - Deaf Smith DC - Davis Canyon
Y - Yucca Mountain R - Richton

sites are in areas of low seismic activity; they were therefore judged to have equal, top-level ratings. In addition, plastic deformation of salt will tend to heal fractures and therefore eliminate fracture-flow pathways caused by any natural or human-induced disruption scenarios. The three salt sites therefore also have equal, top-level ranking for the rock characteristic guidelines.

Similar statements concerning TASC's use of judgment in this assessment approach can be made for the other ratings shown in Table 3.2-1. In these assessments, TASC did not accept and use DOE's ratings for the climate, erosion, and ownership guidelines. All sites were given a rating of 10 for the climate and erosion guidelines because the depths of the repositories were considered to render them insensitive to disruption scenarios in these categories. All sites were given a rating of 10 for the ownership guideline because long-term controls and markers will limit scenarios for inadvertent human intrusion.

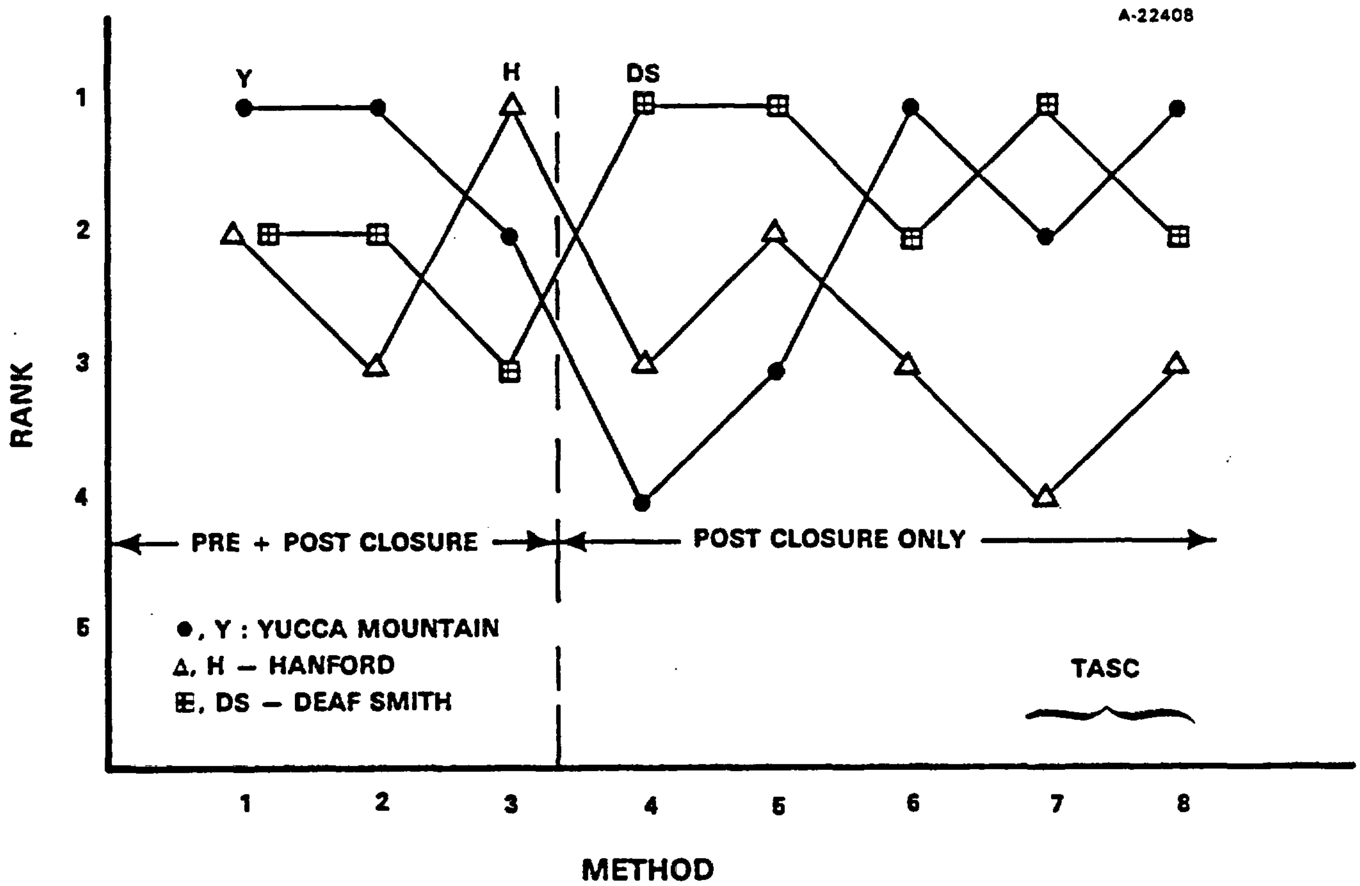
4. COMPARISON AND DISCUSSION OF TASC AND DOE RESULTS

TASC's ratings presented in Tables 3.1-1 and 3.2-1 were used to establish comparative site rankings under the same procedures that DOE used for the utility estimation ranking method. Thus, although the TASC and DOE approaches used to establish the utility ratings are different, the site rankings are comparable.

4.1 COMPARISON OF DOE AND TASC RESULTS

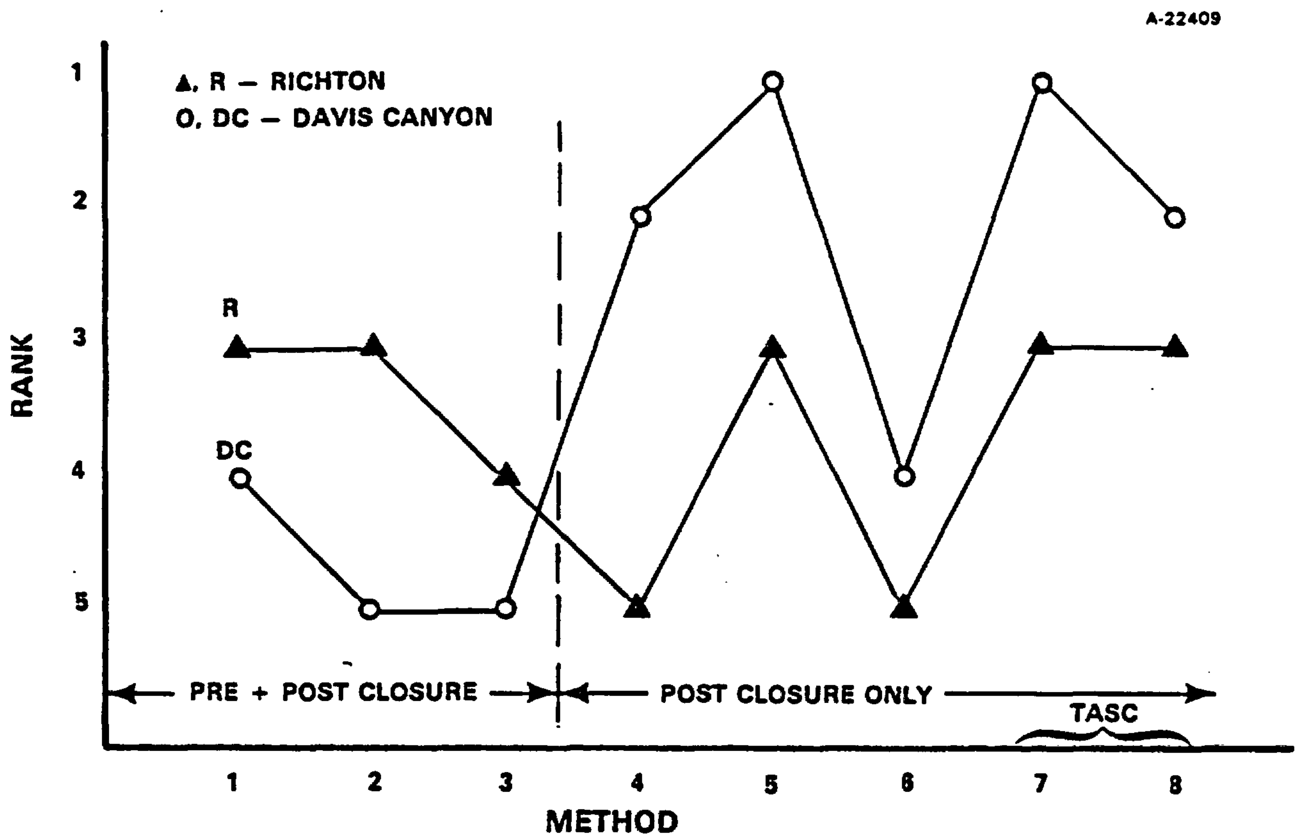
TASC's ranking results are compared to DOE results in Figs. 4.1-1 and 4.1-2. Figure 4.1-1 shows results for the Yucca Mountain, Hanford, and Deaf Smith sites; Fig. 4.1-2 shows results for the Richton and Davis Canyon sites. This separation of results avoids exessive clutter on one figure and puts all results for DOE's three top-ranked sites (Yucca Mountain, Hanford, and Deaf Smith) together.

As noted in the legends for the figures, results for Methods 1, 2, and 3 were obtained by DOE through consideration of both the preclosure and the postclosure guidelines. Methods 4, 5, and 6 show DOE's results from consideration of only the postclosure guidelines for the averaging, pairwise comparison, and utility estimation ranking methods, respectively. DOE's Method 6 results and TASC's results (Methods 7 and 8) are therefore directly comparable in that they were all obtained under consideration of only the postclosure guidelines using the utility-estimation ranking method. Note that sites can be, and in some cases are, equally ranked.



METHOD 1 – EA, POST- PLUS PRE-CLOSURE, UTILITY ESTIMATION
2 – EA, POST- PLUS PRE-CLOSURE, AVERAGING
3 – EA, POST- PLUS PRE-CLOSURE, PAIRWISE COMPARISON
4 – EA, POSTCLOSURE, AVERAGING
5 – EA, POSTCLOSURE, PAIRWISE COMPARISON
6 – EA, POSTCLOSURE, UTILITY ESTIMATION
7 – TASC, POSTCLOSURE, EXPECTED PERFORMANCE, UTILITY ESTIMATION
8 – TASC, POSTCLOSURE, DISRUPTION SCENARIOS, UTILITY ESTIMATION

Figure 4.1-1 Comparison of DOE and TASC Results Yucca Mountain, Hanford, and Deaf Smith



METHOD 1 — EA, POST- PLUS PRE-CLOSURE, UTILITY ESTIMATION
2 — EA, POST- PLUS PRE-CLOSURE, AVERAGING
3 — EA, POST- PLUS PRE-CLOSURE, PAIRWISE COMPARISON
4 — EA, POSTCLOSURE, AVERAGING
5 — EA, POSTCLOSURE, PAIRWISE COMPARISON
6 — EA, POSTCLOSURE, UTILITY ESTIMATION
7 — TASC, POSTCLOSURE, EXPECTED PERFORMANCE, UTILITY ESTIMATION
8 — TASC, POSTCLOSURE, DISRUPTION SCENARIOS, UTILITY ESTIMATION

Figure 4.1-2 Comparison of DOE and TASC Results Richtón and Davis Canyon

4.2 DISCUSSION OF RESULTS

The results shown in Figs. 4.1-1 and 4.1-2 can be interpreted to show that:

- DOE and TASC ranking results relative to the postclosure guidelines both show that consideration of the postclosure guidelines alone does not clearly distinguish the comparative rankings of the five sites
- Consideration of the preclosure guidelines in addition to the postclosure guidelines does distinguish Hanford, Yucca Mountain, and Deaf Smith as the top-ranked sites for all three comparative ranking methods used by DOE.

With respect to the final ranking results obtained by DOE in Chapter 7 of the draft EA's, these results imply that (1) the preclosure guidelines apparently are the principal determinant for DOE's finding that the Yucca Mountain, Hanford, and Deaf Smith sites are top-ranked, and (2) DOE's judgments and methods for evaluations relative to the postclosure guidelines did not bias their ranking results. When the preclosure guidelines are taken into account, TASC confirmed that Hanford, Yucca Mountain, and Deaf Smith are virtually indistiguishable from each other but distinctly higher ranked than Richton and Davis Canyon within the ranking framework.

Although not specifically addressed by either the DOE or TASC assessments, available data can be used to estimate how well the sites will perform on an absolute basis, i.e., with respect to regulatory requirements. TASC's review of the draft EA data and DOE's assessments indicated that in the absence of any surprises during site characterization, all five sites can be expected to meet regulatory requirements with significant margins. All five sites can therefore be judged to be acceptable for site characterization on the basis of anticipated long-term waste isolation capability.

APPENDIX A
RELEVANT TASC PUBLICATIONS AND EXPERIENCE

BIBLIOGRAPHY OF REPORTS PREPARED BY TASC FOR EPRI AND EEI

FORMAL REPORTS

"A status Report on Risk Assessment for Nuclear Waste Disposal," EPRI-NP-1197 (TR-1674-1), October 1979.

"Choosing Risk Assessment Methods for Nuclear Waste Disposal," TR-1674-3, December 1979.

"Status Report on Risk Assessment for Nuclear Waste Disposal, Supplements I and II," TR-336-1, October 1980.

"Status Report on Integrated Design and R&D Assessment of Nuclear Waste Disposal," EPRI-NP-1655 (TR-3336-3), December 1980.

"Integrated Technical and R&D Assessment of Nuclear Waste Disposal," TR-3336-2, May 1982.

Volume I: Summary and Overview: Repository System Performance Evaluation

Volume II: Methods for Repository System Performance Evaluation

Volume III: Repository Analyses

"Repository Design and Regulatory Guidance Issues Analyses," TR-3336-4, December 1982.

"Disposal of Large Power Plant Components and Fuel Assembly Waste," TR-3855-3, April 1983.

"Review of 40 CFR 191: Assessment of Technical Issues and Evaluation of Alternatives," TR-3336-5, June 1983.

"Retention Time Model for a Bedded Salt Repositiory," TR-3336-6, July 1983.

"A Sensitivity Model for Evaluating Repository System Performance," TR-3336-8, May 1984.

"Effects of Parameter Probability Distributions in Performance Assessment Models," TIM-3336-9, July 1984.

"Technical Assurance for HLW Disposal," TIM-3336-7, August 1984.

"Defense/Commercial Waste Integration," TIM-5143-1, November 1984.

INFORMAL REPORTS TO EPRI

"The EPRI High Level Waste Disposal Technology Program," Letter Report, 10 August 1983.

"KBS-3 Report Review," Letter Report, 25 November 1983.

"Alternatives for Disposal of Spent Fuel Hardware," Letter Report (J-3336-5), January 1984.

"Status Report: RP2511-1," February 1984.

"Comments on 40 CFR Part 191 - Working Paper no. 3 Dated February 1, 1984," Letter Report, 15 June 1984.

"Overview Comments on Volume I of the DOE Mission Plan," Letter Report, 18 January 1984.

"EPRI Detailed Comments on Chapter 2, Volume II, April 1984 Draft Mission Plan," and "Draft Text Chapter 2, Volume II of OCRWM Mission Plan," 1984.

"Criteria Assessment," Paper presented at Waste Management '84, 1984.

"Dose Rate Comparisons for EPA Limits," Letter Report, 16 August 1984.

Comments on USNRC Draft Technical Position on In Situ Testing, Letter Report, November 1984.

"Repository Program Assessment and Oversight Activity," White Paper, 1984.

"A Review of the WADCOM and WADCOM-MF Waste Disposal Cost Models," Letter Report (in preparation), 1985.

REPORTS TO EEI

"Long-Term Safety of Nuclear Waste Disposal: A Basis for Confidence," TR-3195-1, July 1980.

"Comments on EPA's Environmental Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," TR-4741-1, March 1983.

"Comment on 40 CFR Part 191 - Working Paper No. 3 Dated February 1, 1984," Letter Report, 23 February 1984.

"Draft Commentary on EPA SAB Subcommittee Report," May 1984.

Report on ANS Meeting, "Nuclear Waste Update," May 1984.

"Draft Mission Plan comments concerning Licensing," June 1984.

"Preliminary Assessment of Working Draft No. 4, Final 40 CFR 191 Dated May 21, 1984," Letter Report, 7 June 1984.

"UNWMG Comments on Proposed 40 CFR 191, Letter Report, 15 August 1984.

"Commments on NRC Technical Positions Concerning BWIP Hydrologic Testing and Generic Licensing Assessment Methodology," August 1984.

"Key Features of Proposed 40 CFR 191 (Working Draft No. 4, 21 May 1984) Potentially Having Adverse Implementation Impacts," letter Report, 7 September 1984.

"Analysis of WD-4, Comparison with December 1982 Version, and Proposed Draft of Subpart B," Letter Report, October 1984.

"Guidelines for Review of DOE Environmental Assessment Documents," November 1984.

"Comments on NRC Draft Tchnical Position on Waste Package Reliability," December 1984.

CHEMICAL TECHNOLOGY DEPARTMENT

TASC has seven years experience in nuclear waste management, principally in the areas of risk assessment, geohydrologic modeling and issues analysis. These activities are currently conducted by the Chemical Technology Department, managed by Dr. Thomas J. Kablele. Very closely affiliated with the Chemical Technology Department is the Office of Nuclear Technology directed by Dr. John W. Bartlett, which provides project management support. Both Dr. Kabele and Dr. Bartlett report directly to Dr. E. Wayne Vinje, Vice President. Key personnel within the Department reporting to Dr. Kabele are: Dr. Michael S. Guiffre, manager of the Process Engineering Section; Charles M. Koplik, manager of the Environmental Chemistry Section; and Dr. Steven G. Oston, Department Staff Analyst.

Chemical Technology Department personnel have backgrounds in applied mathematics and statistics, physics, chemistry, computer science, nuclear engineering, chemical engineering, mechanical engineering, operations research, systems and control sciences, and management. These diverse talents work effectively in teams to provide responsive, technically excellent support to clients.

Past and present waste management projects have been concerned with:

- Program planning
- Performance evaluation methods development

- HLW repositiory performance evaluations
- Policy, regulatory, and institutional issues
- Safety analysis for operations and transportation systems
- Repository design, including issues analysis and tradeoff evaluations
- Geological and hydrological factors in waste isolation
- Safety criteria development
- Geostatistics
- Life cycle costing and cost tradeoffs for waste management systems.

As part of these projects we have provided HLW site characterization evaluations for four disposal media: basalt, tuff, granite and bedded salt. Our customer base has included Rockwell Hanford Operations, the Department of Energy, Golder Associates, Lawrence Livermore Laboratory, the Nuclear Regulatory Commission, Sandia National Laboratories and the Electric Power Research Institute. Related to our HLW work are studies on low-level waste and subseabed disposal of nuclear wastes. TASC, in the conduct of this work, has assembled a wide variety of analytical techniques and computer models dedicated to data and repository performance assessment; most noteworthy is the NRC-benchmarked NUTRAN code.

In addition to its in-house expertise, TASC has formed working relationships with other companies in the Boston area and elsewhere to enhance the range of waste management capabilities. When needed, we are able to tap these resources on a consulting basis in such areas as hydrology, engineering geology, geochemistry, geophysics and licensing.

REPOSITORY SAFETY ASSESSMENT

The TASC approach to performance assessment is unique and, we believe, a highly effective one. Our experience is that prediction of repository performance involves large uncertainties. The uncertainties are due to extremely variable site geohydrologic data, the unknown capabilities of engineered barriers over long periods of time, and the possibility of future description changes in the containment ability of the host rock. We reflect such uncertainties in two ways. First, the analysis techniques employed are, in principle, simple. One-dimensional transport modeling is preferred over multi-dimensional, numerical transport codes. This approach can include more physical phenomena and without sacrificing accuracy considering the data input uncertainties. Second, we attempt to account for uncertainty quantitatively. The use of analytically based models allows for sensitivity (parameter variation) and Monte Carlo studies to describe the potential ranges of results, at reasonable cost to the client.

An important component of performance assessment is the NUTRAN code network, developed by TASC. Transport of radionuclides within the repository and in the geosphere is computed along a series of one-dimensional pipes representing preferred pathways of water flow. Many physical phenomena can be included in NUTRAN, for example:

- Waste package deterioration
- Waste form leaching
- Solubility limits

- Retardation due to radionuclide absorption on rock
- Buoyancy effects due to heating
- Longitudinal dispersion
- Diffusion through engineered barriers
- Changes in material properties or preferred pathways at times after emplacement
- Radioactive decay or build-up of radionuclides before and after emplacement (the ORIGEN code is an intrinsic part of NUTRAN)
- Modeling of shafts and boreholes
- Modeling of the extent (length and width) of the repository
- Prediction of water flows through the repository via a built-in hydraulic resistance network.

TASC has had extensive experience in assessing the performance of all major repository systems under serious consideration: basalt, bedded salt, tuff and granite. Consequently we have assembled a large set of recent site-specific data -- geologic, hydrologic and geochemical -- plus design-specific data such as initial fuel inventory and repository layout. This data bank is readily available for input to NUTRAN and is updated as new information becomes available.

NUTRAN is primarily based on analytical rather than numerical techniques; it is a "smart" code system that can be modified readily. Its modular construction allows for inclusion of new models when needed. For instance, a recent change to NUTRAN allows for use of 1D path segments that are very short compared to the diffusion length and for user-selected boundary conditions between path segments.

NUTRAN outputs are chosen to meet user requirements. For most systems analyzed, meeting EPA and NRC criteria is paramount. NUTRAN can calculate integrated releases of radionuclides to compare against EPA regulations; radionuclide flow rates can be determined for comparison with NRC requirements. This information can be obtained at any point in the repository system such as the "disturbed zone" and the "accessible environment" specified by Federal regulations. Both printed and automated plotter outputs are available.

In some cases it is desireable to estimate either individual or population doses resulting from disposal. The BIODOSE portion on NUTRAN, a complex biosphere compartment model, can be used for this purpose. Characteristics of any local ecosystem, including wells or surface bodies of water, are easily coded. The current library includes the Pecos and Columbia Rivers and a Swedish lake model, along with typical human dietary information and other food chain data.

Typical analyses with NUTRAN involve:

- Baseline cases (expected behavior of the system)
- Parameter variation studies exploring the effects of data ranges or results
- Monte Carlo analyses (by means of Latin Hypercube for efficiency) to obtain probability distribution functions
- Scenario studies to determine the importance of future disruptive events, e.g., seismic, on projected performance
- Analysis of scenarios and their probabilities necessary to meet EPA requirements on high consequence, low probability future events.

The NUTRAN code network has been a "workhorse" of TASC repository safety assessments since 1977. It is very well documented and has been successfully benchmarked as part of the NRC policy of code quality assurance. Other modeling techniques have, however, been developed by or are available to the staff for special purposes. These include:

- ORIGEN - an ORNL code for accumulation and depletion of radionuclide inventories in fuel and reactor components
- HEATING5 - an ORNL heat transfer code. It has capability for conduction, convection and radiation in 1, 2 or 3 dimensions
- SWIFT - a recently acquired Sandia code for 3D hydrology or waste transport calculations
- Retention Time - an analysis technique that describes the performance of engineered barriers and allows for design tradeoffs
- LOTRAN - a computer code similar to NUTRAN that assesses the safety of near-surface low-level waste disposal through a multi-pathway model
- MARINRAD - the TASC ocean radioisotope transport code employed for comprehensive safety assessment of disposal in subseabed sediments
- AIRSIM - a code developed by TASC to estimate the air transport of radionuclides particulates from puff (explosive) or plume (continuous) sources
- VRTECH - a cost analysis computer code used to evaluate the tradeoffs associated with low-level waste volume reduction
- SUMATRA and FEMWATER - finite element codes recently obtained for unsaturated medium transport; these codes are currently undergoing in-house testing and verification.

In summary, the TASC Chemical Technology Department has a wide variety of computer codes and analytical techniques that can be brought to bear to help clients solve waste management problems. Our forte is selecting reliable computational methods that are cost-effective because they are at a level of complexity compatible with current understanding of disposal sites and technology.

JOHN W. BARTLETT

Dr. Bartlett is manager of TASC's Office of Nuclear Technology. Since joining TASC in 1978, he has held management responsibility for all of TASC's HLW projects. Many of these projects were directly concerned with development and application of performance assessment methods.

For the four years prior to joining TASC, Dr. Bartlett was Manager of System Studies in PNL's Nuclear Waste Technology Program Office. In that role he developed and managed the projects that evolved into current ONWI programs to develop and apply performance assessment methods. While at PNL he also directed preparation of the five-volume Technical Alternatives Document, ERDA-76-43, and guided preparation of the DEIS for HLW management.

Before joining PNL, Dr. Bartlett was first associated with Knolls Atomic Power Laboratory and subsequently was a member of the chemical engineering faculty of the University of Rochester. His professional experience also includes service as a Fulbright Professor in Istanbul, Turkey, and work to develop a nuclear materials safeguards program for the National Bureau of Standards while serving as a Presidential Exchange Executive.

Dr. Bartlett holds a B.S. degree in chemical engineering from the University of Rochester and M.ChE. and Ph.D. degrees from Rensselaer Polytechnic Institute. He has authored over seventy journal articles, reports, book chapters, and speeches. He is a member of several technical honorary and professional societies.

THOMAS J. KABELE

Dr. Kabele is Manager of TASC's Chemical Technology Department. Projects under his direction include analyses of chemical and mechanical processes related to a wide variety of engineering problems. As part of his responsibilities, Dr. Kabele manages TASC's nuclear waste disposal work, which includes studies of risk to exposed populations from the transportation and pre-emplacement phases of nuclear waste disposal, the risks associated with the post-emplacement, long-term geologic phase and the resolution of institutional and repository licensing issues. Thermal analyses of nuclear waste canisters and waste repositories are included in this research area.

Dr. Kabele was previously affiliated with Battelle's Pacific Northwest Laboratories (PNL), where he was responsible for a variety of energy systems research projects. Among these were research related to hazardous emissions from electric power plants, transportation of fuels for energy production, rail-car design for transport of nuclear fuel, and cost-benefit analysis of options for decommissioning uranium mills and mill tailings. Prior to joining Battelle, Dr. Kabele was employed by Westinghouse-Hanford Company on the FFTF project where he was responsible for a wide variety of analytical and nuclear hardware development projects related to the control of hazardous materials and radiation safety. These projects included design of cover gas clean-up systems, analysis of radiation levels due to activated corrosion products and fission products, and estimation of the tritium releases from FFTF under various assumed operating conditions.

Dr. Kabele received a Bachelor of Chemical Engineering Degree from Rensselaer Polytechnic Institute in 1965. His post-graduate work was done at the University of Rochester, where he completed the requirements of a Ph.D. in Chemical Engineering in September, 1968. He is a member of the American Nuclear Society, the American Institute of Chemical Engineers, Tau Beta Pi, Phi Lambda Upsilon, and is a registered Professional Engineer in the State of California.

STEVEN G. OSTON

Dr. Oston is currently engaged in the systems analysis of risks to the public from various sources of radioactive materials associated with the nuclear fuel cycle. In addition to safety assessments of disposal methods, this work has included both policy and state-of-the-art technology evaluations. He is also involved with mathematical modeling of nuclide transport in porous media and with the thermal/chemical interactions of buried high-level wastes with geologic media. Dr. Oston has recently conducted analyses which supported the determination of performance criteria for high-level solidified nuclear waste. He has been responsible for evaluating the thermal and mechanical response of shipping casks to various types of transportation accidents; these studies led to estimates of the probability of release of radioactive nuclides as a function of accident conditions.

Previously, he was with Science Applications, Inc. where he was principally concerned with vulnerability of military systems to high-energy lasers and the interaction physics of intense laser beams with targets. Prior to that Dr. Oston was engaged in simulation of nuclear effects at the Ion Physics Corporation using relativistic electron beams. These experimental studies investigated impulse generation, shock propagation, and damage to target materials for comparison to underground nuclear test results. Previously Dr. Oston was employed at the Avco Corporation. As leader of the Radiation and Shock Physics Group, he directed computer and mathematical modeling efforts in a wide variety of radiation effects problems, primarily for the Air Force; this work included propagation of and shielding for x-rays, γ-rays, and neutrons, and response of structures to shock loadings. Prior employment in the field of chemical engineering involved research on fuel cells and solid propellant characteristics.

Dr. Oston received a B.S. degree in Chemical Engineering in 1959 and a Ph.D. degree in Nuclear Engineering in 1966, both from M.I.T. He obtained an M.S. degree in Engineering Management from Northeastern University in 1978. At M.I.T. he held AEC and NSF graduate fellowships and was a teaching assistant for courses in radiation detection and reactor safety. In addition, he was a summer research associate at Brookhaven National Laboratory studying light-water physics, and at the M.I.T. Reactor designing and constructing radiation shielding. Dr. Oston is a member of the American Nuclear Society, American Institute of Chemical Engineers, and Phi Lamda Upsilon; he is author or co-author of thirty publications.

MICHAEL S. GIUFFRE

As manager of TASC's Disposal Technology Application Section, Dr. Giuffre is responsible for a wide variety of projects dealing with the regulation, economics and technology of hazardous waste disposal. During his six years at TASC his principal research activities have emphasized problems attendent to nuclear waste management. He has led research teams which have examined many of the most pressing issues associated with high-level waste disposal. Included in these activities were ground-water transport modeling, and the evaluation and interpretation of studies which quantified uncertainties in future repository performance. He has also actively investigated low-level waste disposal issues. His work here has centered on economic analysis. He has investigated the economic ramifications of regulatory policy, burial site operations and the choice of waste management procedures for nuclear power plants. He is presently involved in a major EPRI-sponsored study of the long-range economic consequences of volume reduction strategies.

Dr. Giuffre received a B.A. in Physics from the University of California, Berkeley, and an M.A. and Ph.D. in Mathematics from the University of Rochester. Before joining TASC he served as an assistant professor of mathematics in the SUNY system and has also been employed in the aerospace industry where he specialized in electromagnetic problems, particularly those encountered in transmissions between space vehicles and the earth. Dr. Giuffre is a member of the American Mathematical Society, the Society of Industrial and Applied Mathematics, the American Nuclear Society and the AAAS. The results of his research have been published in various journals and reports, and have been presented at several technical meetings. Dr. Giuffre was an invited participant at the ONWI/INTERA workshop on uncertainty and a speaker at the NRC/ORNL uncertainty conference. He recently won the Best Paper Award of the Fuel Cycle Division of the American Nuclear Society.

REFERENCES

1. Draft Environmental Assessment, Chapter 7, Page 7-1.
2. Draft Environmental Assessment, Chapter 7, Page 7-132.
3. U.S. Nuclear Regulatory Commission, Draft Generic Technical Position on Licensing Assessment Methodology.
4. U.S. Nuclear Regulatory Commission, Draft Generic Technical Position on In Situ Testing During Site Characterization for High-Level Nuclear Waste Repositories.
5. Koplik, C.M., Kaplan, M.F., and Ross, B., "The Safety of Repositories for Highly Radioactive Wastes," The Analytic Sciences Corporation, Reviews of Modern Physics, 54, 1982, p. 269.
6. Oston, S.G., Giuffre, M.S., and Koplik, C.M., "Integrated Technical and R&D Assessment of Nuclear Waste Disposal," TR-3336-2, The Analytic Sciences Corporation, October 1983.