WHAT IS THE ECONOMIC IMPACT OF 40 CFR 197 ON YUCCA MOUNTAIN?

C. Elliot Foutes
Dr. Kenneth Czyscinski
USEPA
John Bartlett
S. Cohen and Associates, Inc.
Matt Kozak
Monitor Scientific, Inc.

ABSTRACT

In this paper, DOE's strategy for development of a proposed repository at Yucca Mountain is reviewed to determine the impact of EPA's 40 CFR 197 rule making on the repository. This review is conducted through two major, converging perspectives. The first, an historical perspective, traces the evolution of the repository design from principal reliance for safety on natural barriers to a design having principal reliance on engineered barriers. This perspective demonstrates that this change evolved as a result of site characterization findings and their resulting impact on repository design, together with criticism and recommendations from external reviews of the DOE program. The second perspective, performance assessment, traces the evolution of strategy to achieve current performance, i.e., no expected radionuclide releases and no potential for radiation doses for more than 10,000 years. Together, these perspectives lead to the conclusion that the Yucca Mountain Repository has evolved in such a way that EPA's 40 CFR Part 197 standards have had and will have no impact on the costs of repository program development.

INTRODUCTION: THE RULE AND THE REPOSITORY

The Rule

Pursuant to Section 801 of the Energy Policy Act of 1992, the U.S. Environmental Protection Agency (EPA) has issued a rule to ensure protection of public health and the environment from releases of radioactive material from a deep geologic repository to be built at Yucca Mountain **(1)**. The rule, 40 CFR Part 197, contains standards for the protection of the public from releases of radioactive materials stored or disposed of in the potential repository **(2)**. The rule contains three principal standards: an Individual-Protection Standard (IPS) of 15 mrem/yr CEDE (or equivalent), a Human-Intrusion Standard (HIS), and a Ground Water Protection Standard (GWS) derived from the Safe Drinking Water Act **(3, 4)**.

This document describes, in detail, the basis for, and results of, the assessment of economic impacts of the proposed standards on the costs of storage and disposal of radioactive wastes at Yucca Mountain. This assessment was performed pursuant to Agency policy on the use of cost-benefit analysis and to determine the application of Executive Order 12866 to this rule making **(5)**.

The Yucca Mountain Repository

The Nuclear Waste Policy Amendments Act of 1987 designated the Yucca Mountain site in Nevada as the only location to be evaluated as a possible place for disposal of spent nuclear fuel and high-level radioactive wastes **(6)**. The site is located about 90 miles north of Las Vegas, Nevada. The climate is semi-arid and was originally selected because it was expected that there would be limited potential for water to enter the repository and subsequently to transport radionuclides to distant locations. The Department of Energy (DOE) owns, constructs and will operate the site, should it be approved.

The Yucca Mountain Repository would dispose of spent fuel from nuclear power reactors and high-level wastes from the reprocessing of spent fuel from commercial and naval nuclear power reactors and reactors used in DOE research and weapons development programs. Other radioactive materials that could be disposed of in the Yucca Mountain repository include highly radioactive low-level waste, known as greater-than-Class-C waste, and excess plutonium resulting from the dismantlement of nuclear weapons.

The basic concepts for radioactive waste disposal into geological formations were set forth by the National Academy of Sciences in the 1950's and have been embodied in repository design concepts and regulatory concepts ever since then. The wastes are to be emplaced in deep geological formations, which isolate them from the human environment with a combined system of engineered and natural barriers to provide containment and isolation.

MAJOR ECONOMIC PERSPECTIVES

Two major, converging perspectives were utilized in the Economic Impact Analysis (EIA) for the rule to support the contention that the EPA Yucca Mountain Standards do not impose additional costs on the DOE program. The first, an historical perspective, traces the evolution of the repository design from principal reliance for safety on natural features to principal reliance on engineered features and the factors that influenced the change. The second, a performance assessment perspective, traces the evolution of the safety strategy, the evolution of identification and characterization of factors that contribute to performance, and the approach to identifying and reducing uncertainties that are important to demonstration of compliance with standards. Both of these perspectives are briefly summarized in this paper.

Design Evolution Perspective

The Yucca Mountain repository design has evolved dramatically since the Site Characterization Plan (SCP) was published in 1988 **(7, 8)**. Several external events and DOE's response indicate that the evolution of the repository design was driven not by the EPA rule, but rather by a number of other influences, as listed below.

- Increased understanding of the expected natural barrier performance gained through site characterization studies;
- An iterative total system performance assessment analyses used to direct site characterization and repository design efforts, and **(9, 10, 11)**;
- External reviews of DOE's program, which repeatedly recommended more a robustly designed Engineered Barrier System (EBS) be pursued to reduce uncertainties in projected performance.

These design changes were largely precipitated by decreasing expectations for the natural barrier's contribution to performance, and an engineering approach to minimize the uncertainties in projecting performance. From this is can be said that the EPA standards played little or no part in the design evolution.

The original SCP reference repository design concept involved vertical emplacement of small thin-walled waste canisters, with a design lifetime on the order of 300-1,000 years, into the floor of emplacement tunnels excavated in Yucca Mountain. The SCP waste package conceptual design was driven by two principal considerations; the requirement in 10 CFR Part 60 that the package provide "substantially complete" containment for not less than 300 years to a maximum of 1000 years, and the anticipated long ground water travel times through the unsaturated zone (UZ)**(12)**. **Table I** contrasts the estimated ground water travel times from the SCP time frame and the more recent estimates produced for the DOE Viability Assessment and subsequent assessments supporting the Site Recommendation decision **(13, 14**). In 1988, ground water travel times through the UZ were believed to be extremely long, requiring only a minimal contribution from the disposal system's engineered components to meet the most restrictive regulatory requirements. Long UZ travel times were due to the belief at the time that flow in fractures was negligible. However, subsequent site characterization studies revealed that fast flow paths along fractures do occur and projections of UZ flow times have been greatly reduced to reflect the current understanding of the UZ flow system **(15)**. With combined UZ and saturated zone (SZ) travel time estimates well below 10,000 yrs., uncertainties in projecting natural barrier performance became a limitation in developing a robust compliance demonstration. More highly engineered waste package designs were a direct consequence of decreasing expectations for the natural barrier's performance contribution. By 1993, the dual-wall, corrosion resistant waste container was the focus of total system performance assessments (TSPA), signaling the abandonment of the original SCP design.

Table I. Ground Water Infiltration and Ground Water Travel Time Estimates * for the Yucca Mountain Site - during the SCP and the DOE/VA Time Frames

Hydrologic Characteristics	**1988 (SCP)**	**1998 (DOE/VA)**	**2001 (SR)**
Infiltration Rate into Yucca Mountain (current climate)	0.2- 0.5 mm/yr. max. estimate - 4.5 mm/yr.	7 mm/yr. max.- 23 mm/yr.	4.6 mm/yr. max. - 11.1 mm/yr. **(See ref. 16)**
Ground Water Travel Time through the UZ (from repository level downward)	min.- 1,345 yrs. mean - 43,265 yrs. max. - 80,095 yrs.	min. < 10 yrs. median - 5,000 yrs. max. - ~ 10,000 yrs.	min. ~ 2,500 yrs. mean ~ 5,300 yrs. max. ~ 11,500 yrs.** **(See Ref. 17)**
Ground Water Travel Time through the SZ	ave.- 1,700 yrs. (5 km distance from the repository)	min. ~ 300 yrs.** median/mean ~ 2,000 yrs. max. ~ 4,000 yrs.	low - 1200 yrs.*** high - 600 yrs* **(See Ref. 18)**

*Travel time estimates vary significantly depending on modeling assumptions. Values given in this table are for approximate comparisons only and should not be considered as absolute values.
** Travel times are for a 20 km distance rather than 5 km for the 1988 travel times estimate.
*** Travel times are for the 18 km distance from the repository location.

External Reviews

As early as 1990, the National Research Council urged DOE to "make greater use of conservative engineering design instead of using unproven engineering design based on scientific principles" **(19),** a comment aimed at the "above boiling point" strategy and the uncertainties involved. In this vein, the Nuclear Waste Technical Review Board consistently recommended DOE consider more robustly engineered repository designs to deal with the uncertainties in projecting disposal system performance **(20, 21, 22, 23, 24, 25)**. Their reviews also highlight the difficulty in characterizing the natural barrier variability and assessing its performance confidently. DOE's independent peer review of the TSPA/Viability Assessment (VA) also critically highlighted the uncertainties in projecting repository in the absence of sound information on the coupled thermal effects on repository performance, the heterogeneity of the natural barrier, and the lack of detailed understanding of near-field processes **(26)**. In response, DOE recently completed a design alternatives study which culminated in the new EDA II design with its features intended to eliminate uncertainties, including a titanium drip shield intended to reduce the importance of reliably predicting ground water seepage into emplacement drifts and waste package containment lifetimes, and the elimination of concrete drift liners. With significantly extended waste package lifetime expectations for the new design, uncertainties in modeling contaminant dispersion in the UZ and SZ also becomes much less important for dose assessments within the regulatory time period **(27)**. In none of these external reviews and recommendations were the EPA standards a point of contention. Technical uncertainties and the anticipated difficulties in carrying the DOE safety case through NRC licensing in the face of these uncertainties were the issues.

In summary, increasing understanding about the expected characteristics and potential performance of the natural barrier system led to less reliance on its contribution to the disposal system's total performance. Persistent criticism of the early SCP safety strategy that relied on very limited ground water access to the wastes, long ground water travel times and a "hot repository" design that would further limit water access, led to a greatly enhanced role for the engineered barrier in the safety strategy. The SCP design gave way to the current design concept calling for in-drift horizontal emplacement of large, highly corrosion-resistant double-walled waste packages, with a design lifetime of significantly more than 10,000 years, with titanium drip shields over the waste packages to prevent ground water seepage into the emplacement drifts from directly contacting packages **(28)**. This new EBS design (also termed the EDA II design) clearly signaled a much greater reliance on the repository's engineered components to provide waste containment and isolation over the regulatory period. Limiting uncertainties in projecting performance, rather than EPA standards, drove the Yucca Mountain repository design and development program.

Iterative Performance Assessments

DOE's program of site characterization and engineered barrier design are linked through the use of total system performance assessment modeling. In this iterative process, current information about site characteristics and EBS performance are used to make projections of repository performance, and to examine the uncertainties in these projections as well as identify weaknesses in modeling capabilities. Through this iterative loop, a repository safety strategy evolved wherein the repository design evolved to reflect increased understanding of natural barrier performance and the capability of performance modeling to bound uncertainties in projecting performance. After the SCP publication in 1988, TSPAs were conducted in 1991, 1993, 1995, and 2000 for conceptual repository designs, culminating in the TSAP/VA and TSPA/SR, which examined actual proposed designs **(29, 30)**.

A consistent design case in these assessments, as well as the original SCP design, was a high repository thermal loading intended to drive water away from the wastes for a significant period of time to prolong waste package containment lifetime (the "above boiling point" repository concept). The uncertainties in predicting the coupled effects of heat on ground water flow and chemistry, as well as the interaction with waste packages, remained a contentious question in all the TSPA assessments as pointed out by external review of DOE's efforts. Repository design decisions were influenced by these uncertainties, but also by the effect of conservative assumptions in other areas of the assessments as discussed below.

Performance Assessment Perspective

Critically examining the assumptions and uncertainties in repository performance assessments supports the contention that overly conservative assumptions in the performance scenarios drove the Yucca Mountain repository EBS engineering development efforts, rather than the specific exposure limits in the EPA standards. Neither the individual nor ground water protection exposure limits drove the move to a more highly engineered EBS for the Yucca Mountain site.

Individual and ground water protection standards are fundamental to health and safety protection for deep geologic disposal. The economic issue is the relative cost of potential alternative levels of protection, more specifically an exposure level of 15 vs. 25 mrem/yr., or higher levels. The incremental cost for a more stringent standard can be addressed by determining if there are data collection requirements or design improvements imposed by the more stringent protection level. A perspective on cost implications of the lower protection level can be obtained by examining the two total system performance assessments (TSPA) published for actual engineered barrier designs for the Yucca Mountain site. The first was performed to support the site viability assessment, in the 1998 time frame (referred to here as TSPA/VA), and the recent TSPA (referred to here as TSPA/SR) in support of the site recommendation **(31, 32)**. The TSPA/VA addressed an earlier EBS design, while the latter (TSPA/SR) examined the current more highly engineered EDA II design.

For licensing, demonstrating compliance with the standards requires detailed characterization of the engineered and natural barriers, a TSPA that offers a reasonable degree of confidence in the calculated results, and preferably assessments that indicate projected performance is substantially better than required considering the uncertainties inherent in long time frame performance projections. Uncertainties in TSPAs arise from two sources: the parameter value variations included in the calculations and the fundamental assumptions used to frame the performance scenarios analyzed. The former uncertainties generate dose rate variations calculated from statistically sampling the parameter value distributions, and are reflected in the dose rate vs. time graphs shown in **(33, 34)**. The latter uncertainties can displace the dose rate vs. time results band upward or downward depending on the degree of conservatism in framing the scenarios.

In developing the repository EBS, an iterative approach is employed linking TSPAs, design efforts, as well as site characterization. If the TSPAs show unsuitable performance, the repository developer must determine if enhancements in engineered components are the best solution, or if the deficiencies are better removed by improved understanding of barrier performance or more realistic modeling of the disposal system. These decisions have program cost implications, which directly reflect the uncertainties in the disposal system TSPAs and in turn the assumptions inherent in the performance scenarios analyzed. A more stringent exposure limit standard can drive program costs by forcing more robust design and increased site characterization studies. However, excessively conservative assumptions in framing TSPA performance scenarios can have the same effect by driving design and characterization efforts in response to TSPA assessments that are in reality unrealistic "worst case" situations rather than realistic performance projections. Without critically examining the assumptions made in framing these scenarios and their effects on the dose assessments, repository development decisions can be made that drive program costs not as a direct consequence of the regulatory exposure limits, but rather reflecting the underlying assumptions in the performance scenarios. The text below examines some of the assumptions in the TSPA/VA and TSPA/SR analyses and their implications for compliance demonstrations and repository design choices.

TSPA/VA results show an average individual dose at the 20 km downgradient distance as 4×10^{-2} mrem/yr, with dose estimates spanning approximately 5-6 orders of magnitude **(35)**. This uncertainty reflects the parameter distribution data after 10 years of characterization studies and a program cost of several billion dollars. Examination of the assumptions within the TSPA/VA scenarios however, reveals that very conservative assumptions were made to simplify the assessments. For example, all seepage water into emplacement drifts was assumed to contact the waste packages, although the diameter of the waste package is only about one-third that of the emplacement drift; immediately after corrosion breaches the container an exit hole in the container was assumed to exist and releases instantaneously calculated using solubility limits; all the surface area in a failed fuel rod was assumed available for reaction with intruding ground waters; among other assumptions **(36)**. These assumptions are in the TSPA/VA "base case" which, due to their high and arguably unrealistic conservatism, is actually an extreme performance case. More realistic assumptions would dramatically increase the time to failure for the waste packages, lower release rates, and displace the band of dose rate assessments in the TSPA/VA three to four orders of magnitude lower than the results published **(37)**. This added margin could easily compensate for other uncertainties in the assessments. Even with these assumptions, releases over 10 K yrs are dominated by an assumed early container failure from manufacturing defects (juvenile failures). This failure mode assumed 1.25% of the spent fuel cladding was also prematurely failed at emplacement, but data for "in-service" cladding failure rates are about an order of magnitude lower **(38)**. Here again for the "off-normal" situation of a manufacturing failure, unrealistic assumptions in the TSPA give results orders of magnitude higher than realistically anticipated.

As discussed previously, external review of the TSPA/VA results pointed out uncertainties not addressed in the assessments, specifically thermal effects. However these critiques proposed no estimates of the magnitude of the omitted effects on the TSPA dose assessments. Criticism about the incompleteness of an already highly conservative "base case" assessment made a very conservative analysis look less conservative. These external reviews were instrumental in moving DOE to the EDA II design with its enhanced engineering and higher costs. While more realistic assumptions for the performance scenario would increase the safety margin significantly, more modest design changes would also offer dramatic improvements in performance. For example, making the corrosion resistant alloy the outer waste container would increase waste package lifetime well beyond that projected in the TSPA/VA and lower doses accordingly, by eliminating the crevice corrosion mechanism and decreasing corrosion rates by about a factor of 25 times **(39)**.

TSPA/SR results for the EDA II repository design show no doses under the "nominal" scenario for in excess of 10,000 yrs., reflecting the enhanced engineering of the EDA II design, which is projected to resist corrosive breaching of the titanium drip shield and bi-metal waste container for these periods **(40)**. Only doses from the igneous intrusion scenario, analyzed outside the nominal case calculations, are projected within the regulatory time period (see Fig. 1). For TSPA/SR also, an examination of the assumptions in the performance scenarios shows that conservative assumptions were still used in framing the scenarios analyzed **(41)**. The following examples of conservative assumptions in the TSPA/SR are illustrative of the assumptions that result in higher dose estimates than realistically expected. For the TSPA/SR even higher cladding failure rates were assumed (8%) than in the TSPA/VA analyses, in contrast with actual "post-emplacement" failure expectations **(42, 43)**. With the drip shield added to the EDA II design, advective movement of radionuclides from a breeched waste container is severely limited in reality, but the assessments assume that a continuous diffusive transport pathway is available in spite of the physical conditions in the emplacement drift, which suggest that such pathways would not exist. Fuel element surface available after cladding failure is still over estimated by about four orders of magnitude giving unrealistically high release rates. Pumping dilution effects were not considered, which are commonly in the range of 10-50 fold dilution. For the igneous intrusion scenario, a strombolian eruption was assumed in contrast to the less explosive eruptions characteristic of basaltic igneous activity, along with other conservative assumptions about releases - resulting in greater radionuclide transport and consequent doses.

With respect to the ground water protection standard, the Yucca Mountain Draft Environmental Impact Statement presented assessments of the TSPA/VA design for ground water radionuclide concentrations at locations 5, 20, and 30 km downstream from the repository **(44)**. The assessments used the same assumptions as the individual dose assessments and were, as previously noted, highly conservative. The radionuclide concentrations were also dominated by the assumed early failure of a waste package from manufacturing defects. In spite of the conservative assumptions, the concentrations reported were well below the current MCL values in the standard **(45)**. For the EDA II design, TSPA/SR calculations showed no releases to the ground waters within the 10,000 year regulatory period - reflecting the enhanced EBS design which also essentially eliminated the potential for waste package failures from manufacturing defects such as weld failures **(46)**. Here also the conservative approaches taken to TSPAs indicate that ground water radionuclide MCL levels in the EPA standard are easily met by the VA design, with ample margin available if more realistic assumptions are used in the performance assessments. The ground water protection limits are clearly not the driver for the EBS enhancements of the EDA II design. The previous VA design was adequate to demonstrate compliance with the ground water protection requirements when more realistic assumptions were incorporated into the TSPA/VA calculations.

The need for excessively conservative approaches in assessing projected performance is not embodied in the EPA rule. In the rule (sec. 197.14), the principle of "reasonable expectation" was included (originating in the generic part 191 standard and applied by the Agency in the WIPP certification) to explain EPA's intent for demonstrating compliance with the standard (§197.14) **(47, 48)**. Under this approach, parameters difficult to quantify need not be excluded, or assumed to be at their most conservative values, as a means to simplify the analyses. Rather the inherent uncertainties in projecting performance should be explicitly recognized and cautious but reasonable values included in assessments, so that performance projections are as realistic as possible and not dominated by excessively conservative assumptions. Overly conservative assessments need not be used in making design choices and regulatory strategy development unless the designer deliberately chooses such a course. Under the reasonable expectation approach, the TSPAs for the VA repository design could have been framed less conservatively and better performance calculated. DOE made the management choice to move to the more costly EDA II design rather than defend more realistic assessments for the VA EBS design, or perform additional site characterization studies to reduce uncertainties associated with the natural system. This appears to have been a program management choice by the DOE and not driven by the EPA standard.

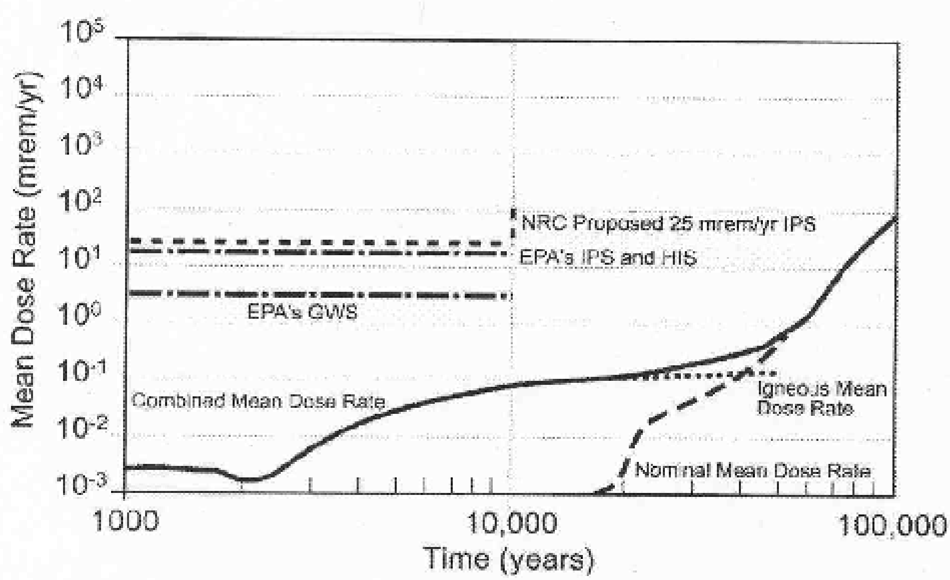

Fig. 1. Comparison of Radiation Protection Standards with Expected Values of TSPA-SR Calculations for a Repository at Yucca Mountain for Nominal and Igneous Scenarios.

As mentioned earlier, if the provisions of the proposed standard impose additional data requirements a cost impact would attach to the selection of alternative protection levels, or the inclusion of components of the standard, particularly the inclusion of ground water protection or the human intrusion standards. Examination of the data needs for assessing the ground water and human intrusion standards indicates that the same data and models used for compliance performance assessments for the individual protection standard would be used for these other two components of the rule **(49)**. Data and modeling capabilities necessary for compliance assessments for the individual protection standard are the same as required for ground water contamination assessments. The stylized framing of the intrusion scenario requires only assumptions about release mechanisms from a penetrated waste container, and these assumptions do not require additional data collection needs. Both the ground water and human intrusion standards therefore do not impose significant additional costs on the repository program.

SUMMARY AND CONCLUSIONS

This paper has demonstrated that the design and construction of the planned Yucca Mountain repository has progressed and been established independent of the proposed EPA standards. Specifically, regarding repository design, it has been shown that the DOE plans for repository design strategy, data acquisition, and budget allocations and requirements have been established independent of the proposed EPA standards. Moreover, they have evolved to the point and in such a way that EPA's 40 CFR Part 197 standards will have no impact on the total life cycle costs of the repository.

REFERENCES

1. "Energy Policy Act of 1992." Public Law 102-486, October 24, 1992.

2. "Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada; Final Rule, 40 CFR Part 197," U.S. Environmental Protection Agency, June 2001.

3. "National Interim Primary Drinking Water Regulations." EPA 50/9-76-003, U.S. Environmental Protection Agency, 1976.

4. 40 CFR Parts 141 and 142, Proposed Rule, National Primary Drinking Water Regulations; Radionuclides, Federal Register, 56 FR 33050, U.S. Environmental Protection Agency, July 18, 1991.

5. Executive Order 12866. Executive Office of the President of the United States, September 30, 1993.

6. "Nuclear Waste Policy Amendments Act of 1987", Public Laws 100-202 and 100-203, December 22, 1987.

7. "Site Characterization Plan - Overview: Yucca Mountain Site, Nevada Research and Development Area, Nevada," DOE/RW-0198, U.S. Department of Energy, December 1988.

8. "Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada." DOE/RW-0199, U.S. Department of Energy.

9. "Total System Performance Assessment - 1993: An Evaluation of the Potential Yucca Mountain Repository," B00000000-0717-2200-0099-Rev. 01, Prepared by R.W. Andrews et al. INTERA, Inc., March 1994.

10. "Total System Performance Assessment - 1995: An Evaluation of the Potential Yucca Mountain Repository," B00000000-01717-2200-00136, Rev. 01, prepared by TRW Environmental Safety Systems Inc., November 1995.

11. "Yucca Mountain Science and Engineering Report, Technical Information Supporting Site Recommendation Consideration," DOE/RW-0539, U.S. Department of Energy, May 2001.

12. 10 CFR Part 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories," U.S. Nuclear Regulatory Commission, January 1, 1987.

13. "Viability Assessment of a Repository at Yucca Mountain, Volume 3 - Total System Performance Assessment," DOE/RW-0508, U.S. Department of Energy, December 1998.

14. "Yucca Mountain Science and Engineering Report, Technical Information Supporting Site Recommendation Consideration," DOE/RW-0539, U.S. Department of Energy, May 2001.

15. Fabryka-Martin, J. T., et al., "Distribution of Fast Hydrologic Paths in the Unsaturated Zone at Yucca Mountain, Proceedings of the Eight Annual Conference on High-Level Radioactive Waste Management", American Nuclear Society, May 11-14, 1998.

16. "Yucca Mountain Science and Engineering Report, Technical Information Supporting Site Recommendation Consideration," DOE/RW-0539, U.S. Department of Energy, May 2001.

17. "Yucca Mountain Science and Engineering Report, Technical Information Supporting Site Recommendation Consideration," DOE/RW-0539, U.S. Department of Energy, May 2001.

18. Eddebborh, Al.A. "What is the Mean and Variance of Transport Time of a Conservative Species in the SZ", Handout for Presentation to the Nuclear Waste Technical Review Board Meeting, January 30-31, Amargosa Valley, Nevada, 2001.

19. "Rethinking High-Level radioactive Waste Disposal", National Research Council, National Academy Press, Washington, DC (1990)

20. DOE Presentations to the Nuclear Waste Technical Review Board, June 29-30, 1999, Beatty, Nevada.

21. "NWTRB Special Report to Congress and the Secretary of Energy". Nuclear Waste Technical Review Board, March 1993, 2300 Clarendon Blvd, Suite 1300, Arlington, VA 22201-3367.

22. "Second Report to the U.S. Congress and the U.S. Secretary of Energy, Nuclear Waste Technical Review Board," November 1990, 2300 Clarendon Blvd, Suite 1300, Arlington, VA 22201-3367.

23. "Third Report to the U.S. Congress and the U.S. Secretary of Energy, Nuclear Waste Technical Review Board*,"* May 1991, 2300 Clarendon Blvd, Suite 1300, Arlington, VA 22201-3367.

24. "Report to the U.S. Congress and the Secretary of Energy," Nuclear Waste Technical Review Board*,* Jan-Dec., 1996, 2300 Clarendon Blvd, Suite 1300, Arlington, VA 22201-3367.

25. "Report to the U.S. Congress and the Secretary of Energy," Jan-Dec., 1998, 2300 Clarendon Blvd, Suite 1300, Total System Performance Assessment Peer Review Panel, Final Report, Nuclear Waste Technical Review Board, February 11, 1999.

26. "Repository Safety Strategy: Plan to Prepare the Postclosure Safety Case to Support Yucca Mountain Site Recommendation and Licensing Considerations," TDR-WIS-RL-000001 Rev 03, TRW Environmental Safety Systems, Inc., January 2000.

27. "Yucca Mountain Science and Engineering Report, Technical Information Supporting Site Recommendation Consideration," DOE/RW-0539, U.S. Department of Energy, May 2001.

28. "Yucca Mountain Science and Engineering Report, Technical Information Supporting Site Recommendation Consideration," DOE/RW-0539, U.S. Department of Energy May 2001.

29. "Viability Assessment of a Repository at Yucca Mountain, Volume 3 - Total System Performance Assessment," DOE/RW-0508, U.S. Department of Energy, December 1998.

30. "Yucca Mountain Science and Engineering Report, Technical Information Supporting Site Recommendation Consideration," DOE/RW-0539, U.S. Department of Energy, May 2001.

31. "Viability Assessment of a Repository at Yucca Mountain Total System Performance Assessment," DOE/RW-0508, Vol.3, U.S. Department of Energy, December 1988.

32. "Yucca Mountain Science and Engineering Report, Technical Information Supporting Site Recommendation Consideration," DOE/RW-0539, U.S. Department of Energy, May 2001.

33. "Viability Assessment of a Repository at Yucca Mountain Total System Performance Assessment," DOE/RW-0508, Vol. 3, U.S. Department of Energy, December 1988.

34. "Yucca Mountain Science and Engineering Report, Technical Information Supporting Site Recommendation Consideration," DOE/RW-0539, U.S. Department of Energy, May 2001.

35. "Viability Assessment of a Repository at Yucca Mountain, Total System Performance Assessment," DOE/RW-0508, Vol.3, U.S. Department of Energy, December 1988.

36. "Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada - Final 40 CFR Part 197 Evaluation of Potential Economic Impacts of 40 CFR Part 197," EPA 402-R-01-004, U.S. Environmental Protection Agency, June 2001.

37. "Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada - Final 40 CFR Part 197, Evaluation of Potential Economic Impacts of 40 CFR Part 197," EPA 402-R-01-004, U.S. Environmental Protection Agency, June 2001.

38. "Technical Support Document: Effectiveness of Fuel Rod Cladding as an Engineered Barrier in the Yucca Mountain Repository," U.S. EPA Air Docket, Docket # A-95-12, V-B-8 (40 CFR Part 197 rulemaking), U.S. Environmental Protection Agency, June 2001.

39. "Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada - Final 40 CFR Part 197 Evaluation of Potential Economic Impacts of 40 CFR Part 197," EPA 402-R-01-004, U.S. Environmental Protection Agency, June 2001.

40. "Yucca Mountain Science and Engineering Report, Technical Information Supporting Site Recommendation Consideration," DOE/RW-0539, U.S. Department of Energy, May 2001.

41. "Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada - Final 40 CFR Part 197 Evaluation of Potential Economic Impacts of 40 CFR Part 197," EPA 402-R-01-004, U.S. Environmental Protection Agency, June 2001.

42. "Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada - Final 40 CFR Part 197 Evaluation of Potential Economic Impacts of 40 CFR Part 197," EPA 402-R-01-004, U.S. Environmental Protection Agency, June 2001.

43. "Technical Support Document: Effectiveness of Fuel Rod Cladding as an Engineered Barrier in the Yucca Mountain Repository", U.S. Environmental Protection Agency, U.S. EPA Air Docket, Docket # A-95-12, V-B-8 (40 CFR Part 197 Rule Making), June 2001.

44. "Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Fuel and High-Level Radioactive Waste at Yucca mountain, Nye County, Nevada," DOE/EIS-0250D, U.S. Department of Energy, July, 1999.

45. "Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada - Final 40 CFR Part 197 Evaluation of Potential Economic Impacts of 40 CFR Part 197," EPA 402-R-01-004, June 2001, U.S. Environmental Protection Agency.

46. "Yucca Mountain Science and Engineering Report, Technical Information Supporting Site Recommendation Consideration," DOE/RW-0539, U.S. Department of Energy, May 2001.

47. "Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes; Final Rule," 40 CFR 191, U.S. Environmental Protection Agency, FR 66398-66416, Vol. 64, December 20, 1993.

48. "Criteria for the Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule", U.S. Environmental Protection Agency, FR 5224-5245, Vol. 61, No. 28, Friday 9, 1996.

49. "Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada - Final 40 CFR Part 197, Evaluation of Potential Economic Impacts of 40 CFR Part 197," EPA 402-R-01-004, U.S. Environmental Protection Agency, June 2001.