**U.S. Department of Energy Experience in Creating and
Communicating the Case for the Safety of a Potential
Yucca Mountain Repository**

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Abstract. Experience gained by the U.S. Department of Energy (the Department) in making the recommendation for the development of the Yucca Mountain site as the nation's first high-level waste and spent nuclear fuel repository is useful for creating documents to support the next phase in the repository program, the licensing phase. The experience that supported the successful site-recommendation process involved a three-tiered approach. First, was making a highly technical case for regulatory compliance. Second, was making a broader case for safety in an Environmental Impact Statement. And third, producing plain language brochures, made available to the public in hard copy and on the Internet, to explain the Department's action and its legal and scientific bases. This paper reviews lessons learned from this process, and makes suggestions for the next stage of the repository program: licensing.

INTRODUCTION

On July 23, 2002, the President of the United States signed into law House Joint Resolution 87 a bill passed by both houses of Congress. The law designated the Yucca Mountain site as the nation's first spent nuclear fuel and high-level radioactive waste repository, and allowed the process to now move forward into the licensing phase. Getting to this milestone required the characterization of the Yucca Mountain site, the study of materials to be used in building the repository, an appropriate level of design, and a host of other scientific, engineering, computer analysis, and document preparation work. The next challenge, the licensing process, will be very demanding on both the Department and its regulator, the U.S. Nuclear Regulatory Commission.

One of the lessons learned in the process leading to the successful site recommendation to the President is that we need to be able to show that the work supporting a claim for repository safety is competent and credible. This needs to be done to satisfy a very technical regulatory and oversight body audience. This audience is empowered by law to stand in judgment of the project and evaluate whether or not there is sufficient confidence in the safety argument to allow the project to move forward to its next phase. There are, however, other audiences, ranging from the general public through elected officials to the non-participant scientific and engineering communities from which the Department's experts have been drawn. Without general support from at least some of these important segments of society, it may be difficult to move forward with this technical, but Congressionally controlled program.

This paper will discuss what was done for these various audiences in preparation for the site recommendation decision, and suggest that the Department's approaches and actions might be improved upon, and might usefully be emulated to some extent by repository programs in other nations. It is recognized that each nation has a cultural and legal/regulatory setting that makes it unique. However, the need to communicate very technical materials at several levels for audiences differing in scientific or technical expertise is universal.

This paper explores the lessons learned from the site recommendation process and suggests applications of those lessons during the licensing process. This paper makes suggestions, not policy. The first priority for the Department is to produce a comprehensive, high-quality license application

for the Nuclear Regulatory Commission to review. But the need exists to explain the content of this application, and the process of which it is a part, to a variety of other, non-regulatory, audiences.

THE 2002 CASE FOR YUCCA MOUNTAIN SAFETY

1. The tiers of documents supporting the site recommendation decision

A highly technical document was produced that demonstrated that the applicable regulation, the Department's Siting Guidelines, published in the Code of Federal Regulations at Title 10 Part 963 (hereafter 10 CFR 963 or simply Part 963), was met [1]. This regulatory compliance document is the *Yucca Mountain Site Suitability Evaluation* [2]. In turn, this document was supported by a more comprehensive document, the *Yucca Mountain Science and Engineering Report* [3] giving the scientific foundations for its compliance arguments. Thus, two documents were prepared. One was to show compliance, the other to show the science underlying that compliance. The *Yucca Mountain Science and Engineering Report* was supported by many analysis and model reports. There are too many to list here, but they are generally available on the Internet at <http://www.ocrwm.doe.gov/technical/index.shtml>.

A third document, required by law, was a *Final Environmental Impact Statement* [4]. It is a comprehensive discussion of safety and other potential impact items required by the National Environmental Policy Act, (NEPA). It is generally readable by non-specialists, with more detailed treatments of certain issues, and discussions of data and calculations, available in more technical appendices. In addition, it has a "Readers Guide" and a "Summary" document, both of which are designed to be readable by non-specialists.

Finally, to convey the decision being made (the site recommendation to the President) and give an indication of its basis to the general public, a two-part brochure was produced and made available on the Internet [5]. The first part is *Why Yucca Mountain?*, the second part is *Why Yucca Mountain? Frequently Asked Questions*.

Indications are that these documents served their various purposes. A recommendation was made to the President, by the Secretary of Energy, via a letter [6]. In that letter, mention is made of a peer review by an international group of experts with International Atomic Energy Agency (IAEA) involvement. The letter, in turn, transmitted a more substantial explanation of the Secretary's decision to recommend the site [7] and makes clear that the IAEA review referred to in the letter is the joint review performed and published by the IAEA with the Organization for Economic Co-Operation and Development's Nuclear Energy Agency [8] (referred to hereafter as the NEA-IAEA review).

2. Making the case for long-term repository safety

The NEA-IAEA review, in Section 2.5, indicated that the safety evaluations that were the subject of the review were found to be "*soundly based and implemented in a competent manner,*" and provided "*an adequate basis for supporting a statement on likely compliance within the regulatory period of 10 000 years, and, accordingly, for the site recommendation decision.*" (Emphasis in original.) However, the NEA-IAEA review also made critical observations about the work being too narrowly focused on regulatory compliance and not making a broader case for showing the level of understanding reflected in these safety evaluations. The review made a number of observations about the approach being conservative in some key respects, and for not making a case for the intrinsic robustness of the proposed repository system. In its Section 3.1 the review makes clear that what was looked for and found wanting was a "Safety Case."

A Safety Case should be developed as a higher level document, and include the articulation of a strategy to achieve safety as distinct from the strategy for demonstrating compliance, with an emphasis on obtaining and communicating understanding and facilitating dialogue with the relevant stakeholders.

The tiers of documentation described above, taken as a whole, make a comprehensive case for safety and demonstrate understanding of the system to a wide range of potential stakeholder audiences

(interpreted to mean all interested parties including the public). However, they do not quite answer all of the suggestions for improvement provided by the NEA-IAEA review. Making a comprehensive case for system safety is not a trivial undertaking, and the definition of what a safety case is has changed since 2002.

3. The safety case as a concept

The IAEA and NEA are jointly promulgating an international document titled *Safety Requirements for Geological Disposal* (currently in draft [9], as cited in an NEA publication [10]) that defines the safety case as . . . “an integration of arguments and evidence that describe, quantify and substantiate the safety, and the level of confidence in the safety, of the geological disposal facility.” That publication has a Figure that explains the safety case concept (Figure 1).

It is the Department's contention that the tiered document structure created to support the site recommendation process collectively addresses all of the elements of a safety case mentioned in Figure 1. Is a hierarchy of documents the best way to make a multiple-audience case for safety? Perhaps it is not. The Swiss National Cooperative for the Disposal of Radioactive Waste (Nagra) is getting international praise for its *Project Opalinus Clay Safety Report* [11], a single volume English language report addressing every aspect of a safety case as defined by IAEA and NEA. However, the Swiss authorities are receiving three documents from Nagra, two comprehensive technical reports synthesizing the geological investigations and engineering underlying the above-cited safety assessment. So, a hierarchy of documents may be necessary even when a comprehensive single-volume safety argument has been produced.

The Nagra *Project Opalinus Clay Safety Report* is an exemplary multi-audience, one-volume case for safety, suitable to the stage of the Swiss repository program (the feasibility-of-siting stage, in this case). Creating a similar document for the Department's licensing phase would be challenging, but worthwhile in terms of being able to explain the content of the massive, highly focused license application to more general (non-specialist but still technically astute) audiences. Producing such a multi-audience document is under consideration.

CRITICAL OBSERVATIONS ON THE 2002 YUCCA MOUNTAIN SAFETY EVALUATION LEADS TO A CHALLENGE OF THE REGULATIONS

4. An administrative challenge to the Nuclear Regulatory Commission's regulation

The State of Nevada sought to re-open the regulation to be addressed by the Department for its Yucca Mountain license application by requesting a formal rulemaking to change the NRC's regulation [12] in several ways. The one portion of the request that is of interest here is for the Nuclear Regulatory Commission to address the NEA-IAEA review observations on the Department's interpretation of the Nuclear Regulatory Commission's [then draft] regulation [8] in its conduct of the safety assessment supporting the site recommendation. The Nuclear Regulatory Commission pointed to the words of the NEA-IAEA review in supporting its denial of the request [13].

The NEA-IAEA review suggested in its Sections 2.1 and 2.2 that the Department was too focused on showing quantitative regulatory compliance with the Nuclear Regulatory Commission's regulation (as it was in turn reflected in the DOE's own regulation, the 'Siting Guidelines' [1]). This observation from the review was overlooking the fact that the regulation also requires demonstration of understanding in support of the compliance calculation, and that the regulation left the approach to showing compliance to the Department. The NEA-IAEA review also suggested the Department ought to construct a safety case within which to place the regulation-driven safety assessment.

The State of Nevada challenged the Nuclear Regulatory Commission regulation in part to request it explicitly include a requirement for the Department to do as the NEA-IAEA review suggested: to construct a comprehensive safety case within which to place its safety evaluation.

Figure 1: An overview of the relationship between the different elements of a safety case [10]

The Nuclear Regulatory Commission denied this particular request on the grounds that the Department is free to construct a case for the repository however it may wish, and the requirement already exists to show understanding as part of the basis for compliance (quotations selected from Pages 32-33 of Attachment 2 [13]):

Petitioner [State of Nevada] believes that DOE must be required to present "an affirmative safety case" which demonstrates an understanding of repository performance. To ensure

demonstration of an affirmative safety case, petitioner has proposed a new regulation (proposed § 63.21(c), *supra*) which is based on, but not identical to, recommendations made by the Peer Review with respect to DOE's TSPA-SR. Although the Peer Review focused on DOE's TSPA-SR, it did make a few observations on NRC's proposed Part 63:

The regulations require that a risk-informed approach should be adopted in demonstrating compliance with the dose limit, in recognition of the uncertainties inherent in making assessments over long time frames in the future. It is also required that the assessment should reveal an understanding of the relationship between the performance of the repository subsystems and the total system performance. Nevertheless despite the prescriptive nature of the regulations, the I[n]ternational R[eview] T[eam] notes that the proposed licensing regulation 10 CFR 63 states that "consistent with a performance based philosophy, the Commission proposes to permit DOE the flexibility to select the approach for demonstrating this relationship that is most appropriate to its analysis."

The Commission then cites two paragraphs from the NEA-IAEA review and observes (Pages 33-35 of [13]):

Thus, the Peer Review acknowledged the importance of DOE presenting, in its TSPA, an in-depth understanding of the performance of the repository system and recognized that demonstration of safety is more than numerical compliance with the proposed regulatory requirements. As a matter of record, a similar concern was raised during the public comment period on the proposed regulation (i.e., can performance assessment be relied on as the sole quantitative technique for evaluating compliance with the postclosure safety requirements). The Commission, in response to this concern, explained that the regulations contained a number of requirements directed at DOE's demonstrating an in-depth understanding of the repository system:

Although repository postclosure performance is evaluated with respect to a single performance measure for individual protection, the NRC considers a broad range of information in arriving at a licensing decision. In the case of the proposed repository at Yucca Mountain, Part 63 contains a number of requirements (e.g., qualitative requirements for data and other information, the consideration and treatment of uncertainties, the demonstration of multiple barriers, performance confirmation program, and QA program) designed to increase confidence that the postclosure performance objective is satisfied.

The Commission will rely on the performance assessment as well as DOE's compliance with these other requirements in making a decision, if DOE submits a license application for disposal of HLW at Yucca Mountain.

The Commission response continues, but the important point is that, in essence, the Commission agrees with the NEA-IAEA review and says it is up to the Department to demonstrate that it knows its system and have evaluated its uncertainties. Whether or not this broad demonstration of understanding, evaluating uncertainty, and showing compliance is called a safety case is up to the Department to determine.

CONSTRUCTING THE CASE FOR REPOSITORY SAFETY FOR THE LICENSE APPLICATION

5. Documents in preparation to support the license application

As in the case of the site recommendation process, the licensing process is also being approached in a multi-tiered fashion. Two tiers are currently being developed. The lower tier provides the technical and scientific basis for the data, and the models used to interpret that data at the detailed as well as subsystem and system levels. The higher tier is the license application itself, which refers to the lower tier of documents as needed, and makes the case for compliance, shows understanding of the system,

evaluates uncertainty, and lays out plans for continuing or new investigations as part of a Performance Confirmation Plan.

5.1. The safety evaluation, the heart of the license application

Designs and scientific information are brought together in an evaluation of the way the total system performs after final closure. That evaluation is called the Total System Performance Assessment (TSPA) and it constitutes the heart of the case for safety as well as the central exhibit in the compliance demonstration. The NEA-IAEA review observed concerning the 10,000-year compliance calculations required in regulations at that time (page 24 of [8]):

Finally it is noted that the U.S. regulations are currently the subject of legal challenges. Thus it would be prudent to ensure that any TSPA is robust to possible regulatory changes, such as the 10,000-year compliance period.

The U.S. Circuit Court of Appeals in Washington, D.C. did, in fact, invalidate just that part of the regulations applicable to Yucca Mountain [14], and the U.S. Environmental Protection Agency (EPA) is revising its standard, to be followed by the implementing regulation being revised by the Nuclear Regulatory Commission (NRC). In particular, the court addressed the lack of specific compliance criteria for peak dose. The regulations considered in the court case have always required for the calculations to be taken to the time of peak dose, or up to the period of geologic stability, which is considered to be a million years by the EPA [15], citing the National Academy of Sciences [16]. The results were to be described and reported in the Environmental Impact Statement. However, the TSPA that was critiqued by the NEA-IAEA reviewers did not have a longer term component; it aimed only at showing compliance with the 10,000-year regulation, as has been noted.

The proposed revised draft EPA standard [17] currently out for comment as part of the formal rulemaking process, lets stand the 10,000-year portions of the former Part 197 standard [15] and gives a preferred approach and several options for the standard that is to be addressed for time period beyond 10,000 years and up to a million years. Regardless of the outcome of the rulemaking process, the work that the Department needs to do to show compliance will involve extending calculations out in time that the previously EPA standard characterized as very uncertain:

... the peak dose within 10,000 years after disposal must comply with the individual-protection standard. In addition, we require calculation of the peak dose within the period of geologic stability. The intent of examining the disposal system's performance after 10,000 years is to project its longer-term performance. We require DOE to include the results and bases of the additional analyses in the EIS for Yucca Mountain as an indicator of the future performance of the disposal system. The rule does not, however, require that DOE meet a specific dose limit after 10,000 years. We have concerns regarding the uncertainties associated with such projections, and whether very long-term projections can be considered meaningful; however, existing performance assessment results indicate that the peak dose may occur beyond 10,000 years . . . Such results may, therefore, give a more complete description of repository behavior. We acknowledge, however, that these results, because of the inherent uncertainties associated with such long-term projections, are not likely to be of the quality necessary to support regulatory decisions based upon a quantitative analysis and thus need to be considered cautiously. In any case, these very long-term projections will provide more complete information on disposal system performance. [15]

In its proposed draft standard, the EPA acknowledges that it still believes this. However, given the decision by the U.S. Circuit Court of Appeals, the proposed longer term standard accommodates the higher uncertainty that goes with calculating for the longer term by specifying a higher numerical limit for the assigned performance measure, and specifying that for these longer term calculations the median, rather than the mean, is to be used. Its numerical performance goal is a number shown to be safe from a population dose perspective, based on regional differences in background radiation. That number, based on the difference between background doses near the proposed repository and Colorado, is a median dose of 3.5 milliSieverts (350 millirem) per year. This is a larger value than the

0.15 milliSievert (15 millirem) per year mean dose specified for the 10,000-year portion of the standard, when uncertainties also exist, but are generally significantly less.

This is an approach very similar to what is being considered or followed elsewhere in the world, and is, in the Department's opinion, in harmony with the DS-154 Draft IAEA/NEA [9] guidance on repository safety standards. The EPA makes clear in its discussions that it has given careful consideration to international precedents for its new approach. The Department will submit comments and suggestions on the details, as is proper for any stakeholder or interested party under the legally defined rulemaking process. According to law, there needs to be an NRC rulemaking to revise its 10 CFR Part 63 regulation to incorporate new requirements added to the EPA standard through the EPA's rulemaking process. It is currently not clear at what point the Department will be able to address the new 10 CFR 63 in a license application.

5.2. The supporting science and engineering documents, the circulatory system of the case for safety in the license application

If the TSPA is the heart, the scientific and engineering/design supporting documents are the circulatory system. Without feeds from that body of technical work the heart has nothing to bring to the discussion of safety. The best models in the world cannot yield credible output results unless they are firmly and properly based on science and engineering. For a long-term (whether 10,000 years or a million years) calculation to have credibility, it has to reflect and be consistent with what is known.

Part of the basis for the modeling is a reflection of what is known, because some models are calibrated against data and observations pertinent to the system being analyzed. However, to build a degree of confidence in the modeling, comparisons are also made against (1) data that is not used in the calibration process, (2) analogue systems if any are available, and (3) advance predictions of new tests if appropriate. Peer technical reviews of data and models also play an important part in the process of showing there is a basis for having confidence that the modeling that is done is fit for its intended purpose.

The intended purpose is to show that the planned system is expected to be safe. However, whether the demonstration of safety is sufficient or not at a given point in time may well depend on the stage or phase of the repository program. The licensing phase being entered into by the Department is one that seeks to gain an authorization from the NRC to construct a repository. Before the repository can receive waste and be operated, the NRC will have to make another finding that it is appropriate. Prior to allowing final repository closure, and undoubtedly at some points during the operational phase, other safety demonstrations will be required to show that all that was found to be important to safety is as it was assumed to be in the earlier safety assessments or has been properly evaluated.

Continuing science and engineering activities will reevaluate systems that are important to safety and efficiency during construction, operations and at closure. Upgrading the operational system in response to pertinent advances in technology may be expected, and should certainly not be precluded, during the decades of the operational phase. At final closure the efficacy of the sealing program will receive greater focus than prior to that time.

This look over the lifespan of a repository program underscores that such programs are very long term, active, and demanding societal commitments. This long term allows the case for safety to be periodically reevaluated. This means the level of confidence needed to support a decision can be time-phased. The question may be whether or not to go forward into a new phase (in the transitions from site selection to licensing, or in the transition from operations to closure, for two examples), to reverse a phase (retrieval of waste after the start of emplacement for example), or to continue the current phase after new information has been obtained for which the safety case needed to be reevaluated.

Not everything needs to be known at the start of a repository program. However, there needs to be a sufficient argument at the transition of one phase to the next to give participants, stakeholders and the public confidence that safety is very likely to be assured by carrying out the planned work. This point is made quite firmly in the U.S. by the NRC's *Yucca Mountain Review Plan* [18] which states in detail

what will be looked for in a license application to allow the start of repository construction at Yucca Mountain.

A REPOSITORY AT YUCCA MOUNTAIN: WHAT IS BEING PROPOSED?

6. Surface and subsurface facilities proposed for a Yucca Mountain repository

The concept of operations for a Yucca Mountain repository is to receive waste by rail, preferably, and also by truck. Spent fuel will be stored as necessary on the surface prior to repackaging for disposal. This storage facility provides the necessary opportunity to do thermal blending of fuel being placed into waste packages so as to achieve the desired thermal output from each waste package. The waste handling facilities will place spent fuel assemblies and high-level waste canisters into waste packages, and seal them by welding. Waste packages will then be moved underground and placed in emplacement drifts, end to end, with little separation. As a drift is filled, it is isolated from the rest of the repository.

Figure 2 shows the general layout of the repository and the location of surface facilities to be presented in the license application. Figure 3 shows a schematic of the proposed surface facilities and gives an indication of the process from waste acceptance to disposal. Figure 4 shows a larger version of a schematic cutaway of waste packages in a drift also shown on Figure 3. Figure 4 also shows the emplacement of the 'drip shield' over the containers in this drift. The drip shield is to guard against both rockfalls and dripping water. Rockfalls are expected in response to the cooling of the repository after the thermal period, with or without effects of earthquakes.

Figure 2. General layout of repository excavations, surface facilities for handling and packaging waste would be located at end of current North Ramp (drift length for disposal is 65 km).

Figure 3. Schematic of proposed waste forms, waste handling, packaging and disposal facilities.

Figure 4. Schematic of emplacement drift with drip shields over a portion of the waste packages (ground-support rock-bolts shown radiating from drifts).

The waste packages (Figure 5) are double-layered metal containers with a highly corrosion resistant alloy on its surface, and stainless steel on its interior to give strength to the whole structure. Different-sized packages are designed to accommodate the different types of expected waste forms.

Figure 5. Schematic of proposed spent nuclear fuel waste package.

7. A long-term safety evaluation outcome for the proposed Yucca Mountain repository

The Yucca Mountain repository will be able to substantially contain its radioactive inventory for many tens of thousands of years. Thereafter, the rate of waste package failure, together with the natural attributes of the system, will assure public safety is maintained even into the very distant future.

The reevaluation of the TSPA that is to support the license application is not yet complete. However, it is likely that its results may be roughly comparable to those published in the Final Environmental Impact Statement (FEIS) [4] that accompanied the Site Recommendation documents. Those FEIS results suggested that, over a million year time span, the highest potential doses from a Yucca Mountain repository would come at about a half million years. The FEIS also showed that if the more recent recommended dosimetry modeling data and approach from the International Commission on Radiological Protection (ICRP), and used by the IAEA in its safety guides, are used, the peak dose might be on the order of 30 to 40 millirem per year for the hypothetical individual defined as the potential dose-receptor by regulation.

This is a small fraction of U.S. and local background from all sources, which is about 360 millirem per year, and poses no concern in terms of significant adverse health impacts being likely. The 10,000-year doses calculated and shown in the FEIS as well as in the *Yucca Mountain Site Suitability Evaluation* [2] are a very small fraction of the allowable 15 millirem per year to this same hypothetical dose receptor.

CONCLUSIONS

8. A Yucca Mountain repository built, operated and closed as planned will not pose a significant risk to public health or safety

With robust waste packages, stable drifts, little water, and a mild chemical environment at depth, waste packages will last an extraordinarily long time within Yucca Mountain and will fail only after a very long time. At that point, the rate of waste package failure works in concert with the physical and geochemical characteristics of the host formation to continue to assure safety into the very distant future.

Worker safety will be assured throughout the construction and operational phases by following industry safety practices and specifications as well as site-, facility-, and even process-specific operating procedures. The NRC will have onsite inspectors at the Yucca Mountain facility to assure compliance with operating safety requirements.

Public risks from the proposed Yucca Mountain repository are expected to be non-radiological. Shipping the waste, according to the FEIS, presents the greater risk of all the risks evaluated for the system. Accidents are possible, but radiological releases from such traffic accidents are very unlikely.

Observations suggesting improvements based on review of earlier Yucca Mountain safety evaluations, such as those provided regarding the TSPA supporting the site recommendation process by the IAEA-NEA, have led to changes in the work done to demonstrate that safety is likely to be achieved by a Yucca Mountain repository in the very long term. Direct support of the license application safety case is provided through nearly a hundred technical documents. In addition, to give a broader overview of aspects of the scientific work described in these documents, two overview reports were prepared. One integrates all that is known about the site into a *Yucca Mountain Site Description* [19] document, the other integrates what was learned from various natural analogue studies concerning processes potentially operative in Yucca Mountain into a *Natural Analogue Synthesis Report* [20]. For a similar reason, the program created fourteen focused integrated scientific discussion documents readable by scientific experts who may not be specialists in the repository-development sense of being a

specialist [21]. Finally, as the licensing process begins it will be important to prepare materials that communicate the nature of this process, and the nature of the case being made for safety in that process, to a very broad audience. This was done for the site recommendation process. It is recommended that it be done again for the licensing process, for a public perhaps unaware of the rigorous, open, technical and legal process that is to be involved in licensing the first geologic repository for spent nuclear fuel and high-level radioactive waste in the U.S.

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