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Site selection and regulatory basis for the Yucca Mountain disposal system for spent nuclear fuel and high-level radioactive waste

Rob P. Rechard [a,*], Thomas A. Cotton [b], Michael D. Voegele [c]

[a] Nuclear Waste Disposal Research & Analysis, Sandia National Laboratories, P.O. Box 5800, Albuquerque 87185-0747, NM, USA
[b] Complex Systems Group, 4429 Butterworth Place, NW, Washington DC 20016, USA
[c] 7404 Oak Grove Avenue, Las Vegas 89117, NV, USA

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ABSTRACT

This paper summarizes the historical events from the identification of the Yucca Mountain site in southern Nevada in 1978 to its selection by the US Congress as the sole site to characterize for a repository for spent nuclear fuel and high-level radioactive waste in 1987. Coincident with this selection process and later site characterization, the US spent from 1977 to 2009 establishing long-term, radiation protection standards and a regulatory framework for demonstrating compliance. When first promulgated, the US Environmental Protection Agency's radiation protection standards limited cumulative release of radionuclides at a boundary ≤5 km from the edge of a generic repository over a 10^4-year regulatory period. But in 2001, site-specific standards for a repository at Yucca Mountain were promulgated to limit the dose to an individual at a point ≤~18 km from the repository edge in the predominant direction of groundwater flow over a 10^6-year period. Also during the 33-year effort, the regulatory framework of the US Nuclear Regulatory Commission, which implemented the radiation protection standards, changed from setting performance criteria on barrier subsystem components in 1983 to the identification and technical justification for barrier performance based on a performance assessment. Also, reasonable expectation as the standard of proof for evaluating compliance was clarified.

1. Introduction

In 2002, 15 years after selection by the US Congress for characterization, President Bush recommended and Congress authorized the US Department of Energy (DOE) to seek a license from the US Nuclear Regulatory Commission (NRC) to construct a repository at Yucca Mountain (YM). The repository, located on the western border of the Nevada National Security Site (formerly known as the Nevada Test Site or NTS), was intended for disposal of commercial spent nuclear fuel (CSNF),[1] high-level radioactive waste (HLW),[2] and DOE-owned spent nuclear fuel (DSNF) [4] (Fig. 1). In 2008, DOE submitted the License Application, including the Safety Analysis Report, for construction authorization (SAR/LA). The SAR/LA represented a significant milestone in the effort to implement nuclear waste policy in the US that had been in place since 1983 [5].

A major portion of the SAR/LA for Yucca Mountain depends upon a compliance analysis called a performance assessment (PA), which is described in this special issue of *Reliability Engineering and System Safety*. To present a historical perspective on the PA, this paper discusses selection of the site (Section 2) and the lengthy development of performance measures and corresponding limits for the YM repository specified by NRC and the US Environmental Protection Agency (EPA) (Section 3). The political forces and personalities that have influenced the Yucca Mountain Project (YMP) are of great interest and much has been written about them [6–11]. Yet, the corresponding scientific and engineering issues that YMP faced are also important if the US is to improve upon the technical implementation of nuclear waste policy in the future.[3] Although some of these scientific and engineering issues

* Corresponding author. Tel.: +1 505 844 1761; fax: +1 505 844 2348.
E-mail address: rprecha@sandia.gov (R.P. Rechard).

[1] Spent nuclear fuel (SNF) is "…fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing [1, Section 2(23)]".

[2] As used here, high level waste (HLW) is "…the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations…" [1, Section 3 (12)]. Although not used in this manner here, HLW also refers to a category of radioactive waste by the International Atomic Energy Agency (IAEA), which requires disposal in a deep, geologic repository to protect humans from exposure over the long-term and, thus, collectively includes SNF and material from reprocessing SNF. The NRC uses HLW similar to IAEA in its implementing regulations, 10 CFR 60 and 63 [2, Section 60.2; 3; Section 63.2].

[3] The names for the DOE Nevada office were Nevada Nuclear Waste Storage Investigations (NNWSI) Office in 1978, Yucca Mountain Site Characterization Office (YMSCO) after passage of *Nuclear Waste Policy Amendments Act* [1] and later office reorganization in 1991; and, finally, Yucca Mountain Project (YMP) Office after passage of the *Yucca Mountain Development Act* in 2002 [4].

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Fig. 1. View looking southeast at central portion of Yucca Mountain in southern Nevada.

have recently been summarized [11–13], this paper provides further background and historical context at the interface between site selection and the regulatory basis.

As the performance criteria solidified, the PAs evolved from using simple models for evaluating performance measures in 1984, to using numerous mathematical models for the SAR/LA in 2008. The PA iterations provide convenient points to discuss the status of YMP over the years. Although many iterations have occurred, seven PAs serve to demarcate the historical events presented herein.

In 1982, the dose of a volcanic eruption through the repository and in 1984, the consequence of an undisturbed scenario class were evaluated for the draft and final Environmental Assessments (EA) required by the *Nuclear Waste Policy Act of 1982* (NWPA) [1]. These deterministic analyses, collectively designated herein as PA–EA [14–16], provide the initial marker for the paper. The first stochastic PA, conducted by Sandia National Laboratories (SNL) in 1991 (PA-91) [17], serves as the second marker. PA-91 was followed by two assessments in 1993: one conducted by the recently awarded management and operator (M&O) contractor, TRW (PA-M&O-93) [18]; and one conducted by SNL (PA-93) [19, Fig. 1-1]. The latter PA-93 serves as the third marker. Another major PA was conducted in 1995 (PA-95) by the M&O contractor and serves as the fourth marker [20]. In 1997, Congress asked for a viability assessment of the proposed YM repository, which was completed the following year (PA–VA) and serves as the fifth marker [21]. An analysis in late 2000 for the site recommendation (PA–SR) serves as the sixth marker [22]. A licensing case (PA–LA), which became the basis for the 2008 SAR/LA, serves as the final marker.

Besides the task of developing performance measures (as discussed in this paper), six additional tasks are conducted in iterations of the PA [23, Fig. 1; 24]. Companion papers describe these remaining tasks such as characterization of disposal system, identification of hazards, evolution of the modeling system, and sensitivity analysis [23,25–32].

2. Site selection

2.1. Institutions and roles at YMP

The US legal framework is similar to other international programs in many aspects (e.g., the government defines the policy and approach), but differences are evident [12; 33, Section 3]. One difference is that regulatory responsibility for CSNF is divided among several agencies in the US.[4] EPA sets pre- and post-closure radiation protection standards for repositories for HLW and SNF and NRC implements those standards. NRC also sets and implements standards for storage of waste and transportation casks for radioactive waste. The US Department of Transportation (DOT) regulates the carriers and transportation routes for the radioactive waste. For the disposal of defense transuranic (TRU) waste at the Waste Isolation Pilot Plant (WIPP) in southern New Mexico, EPA sets and also implements the radiation protection standards (Table 1).

Another difference in the US is that a government agency, DOE, is responsible for siting, building, and operating repositories for SNF, HLW and TRU waste. Except for Germany, other countries have set up a public company (e.g., Belgium, France, Japan, Spain, and the United Kingdom), or electric utilities have set up a separate private entity (e.g., Canada, Finland, Sweden, and Switzerland) to site, build, and operate a SNF/HLW repository, somewhat similar to the situation for low-level waste (LLW) in the US [39].[5] This public or private entity in other countries may also be more closely integrated with the storage and transportation operations than in the US.

2.2. Site selection and national policy

2.2.1. Search for permanent disposal

The search for permanent disposal for radioactive waste began in 1955 when the Atomic Energy Commission (AEC), formed in 1946, asked the National Academy of Sciences (NAS) to examine the disposal issue.[6] In 1957, NAS reported that deep salt formations were promising for disposing of HLW [43]. With the technology available in the 1950s and 1960s, the AEC gave mined disposal in salt priority. However, AEC was slow to implement a solution [6,10].

Then in May 1969, the Rocky Flats Plant, built by AEC in 1951 to produce plutonium (Pu) components for nuclear weapons, caught fire. Located only 26 km from Denver, the fire attracted much public attention. The press reported that radioactive waste debris was to be sent to the Radioactive Waste Management Complex (RWMC), built in 1952 on the Idaho National Laboratory (INL) reservation near the Snake River and its associated aquifer. Because of its less than ideal location for long-term storage of radioactive waste, AEC promised Senator Church of Idaho that the waste would be moved to a more suitable site. In June 1970, AEC tentatively selected the abandoned Carey salt mine near Lyons, Kansas, the site of an underground research laboratory (URL) on heat dissipation managed by Oak Ridge National Laboratory (ORNL) between 1963 and 1968 [44, Chapter 4; 45, p. 10]. As part of the selection process, AEC funded cooperative studies with the Kansas Geologic Survey.

By 1971, a large number of boreholes for mineral exploration had been identified and loss of fluids from some solution mining had been reported near the mine. After much controversy, the AEC abandoned the Lyons Project and announced to Congress in May 1972 plans for what was later called a Retrievable Surface Storage Facility (RSSF), in which waste could be stored “a minimum of 100

[4] A similar situation once existed in Sweden where the Swedish Radiation Protection Institute (SSI) developed radiation protection standards and the Swedish Nuclear Power Inspectorate (SKI) handled implementation; however, in 2009 these two functions were merged into the Swedish Nuclear Power Authority (SSM) [34].

[5] In the US, the categories of radioactive waste were defined for the *management* of the waste. Using the source of the waste to designate SNF and HLW was a simple approach and related indirectly to some of the important radionuclide constituents. Waste that was not SNF, HLW, TRU waste, or byproduct material (as defined in the *Atomic Energy Act of 1954* [40]) was designated as LLW. For LLW, Congress assigned the disposal responsibility to the states in 1980, except for the NRC greater-than-class C category (GTCC). GTCC, which is similar to the EPA TRU waste category, remained the responsibility of the federal government [41,42].

[6] Many of the early events that preceded the selection of Yucca Mountain are associated with the handling of defense related radioactive waste, which was produced earlier than commercial SNF, and discussed when reviewing events related to the disposal of TRU waste at WIPP [38].