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Evolution of repository and waste package designs for Yucca Mountain disposal system for spent nuclear fuel and high-level radioactive waste

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ABSTRACT

This paper summarizes the evolution of the engineered barrier design for the proposed Yucca Mountain disposal system. Initially, the underground facility used a fairly standard panel and drift layout excavated mostly by drilling and blasting. By 1993, the layout of the underground facility was changed to accommodate construction by a tunnel boring machine. Placement of the repository in unsaturated zone permitted an extended period without backfilling; placement of the waste package in an open drift permitted use of much larger, and thus hotter packages. Hence in 1994, the underground facility design switched from floor emplacement of waste in small, single walled stainless steel or nickel alloy containers to in-drift emplacement of waste in large, double-walled containers. By 2000, the outer layer was a high nickel alloy for corrosion resistance and the inner layer was stainless steel for structural strength. Use of large packages facilitated receipt and disposal of high volumes of spent nuclear fuel. In addition, in-drift package placement saved excavation costs. Options considered for in-drift emplacement included different heat loads and use of backfill. To avoid dripping on the package during the thermal period and the possibility of localized corrosion, titanium drip shields were added for the disposal drifts by 2000. In addition, a handling canister, sealed at the reactor to eliminate further handling of bare fuel assemblies, was evaluated and eventually adopted in 2006. Finally, staged development of the underground layout was adopted to more readily adjust to changes in waste forms and Congressional funding.

1. Introduction

In 2008, the US Department of Energy (DOE) submitted the Safety Analysis Report for a License Application (SAR/LA) to the US Nuclear Regulatory Commission (NRC) in order to construct a repository at Yucca Mountain for high-level radioactive waste (HLW), commercial spent nuclear fuel (CSNF), and DOE-owned SNF (DSNF). Yucca Mountain (YM), located at the boundary between the Nellis Air Force Range and the Nevada National Security Site (formally known as the Nevada Test Site or NTS),[1] had been under consideration for a radioactive waste repository since 1978 (Fig. 1).

While many of the scientific characterization issues related to Yucca Mountain have been discussed in the literature over the years, much of the technological and engineering designs are in project reports. Hence, this paper presents the evolution of the repository and engineered barrier design in order to provide a historical perspective on the performance assessment (PA) underlying the SAR/LA described in this special issue of *Reliability Engineering and System Safety*. Companion papers describe the site selection, site characterization, and evolution of the modeling system for the PA [1–9]. Although part of the engineering strategy for the YM repository was recently summarized [10,11], this paper provides further background and historical context.

Seven PA iterations provide convenient points to discuss the status of Yucca Mountain Project (YMP) over the years. In 1982 and 1984, deterministic analyzes of volcanic eruptive doses and undisturbed groundwater releases, collectively designated herein as PA-EA [12,13], were conducted for the draft and final Environmental Assessments (EA) required by the *Nuclear Waste Policy Act of 1982* (NWPA) [14]. PA-EA provides the initial marker for the paper. The first stochastic PA, conducted in 1991 (PA-91) [15], serves as the second marker. PA-93 and PA-95, which serve as the third and fourth markers, respectively, provided preliminary guidance on site characterization and repository design [16, Fig. 1-1,17]. The Congressionally requested viability assessment (PA-VA), completed in 1998, serves as the fifth marker [18]. The conclusion of site characterization culminated with an analysis in late 2000 for the site recommendation (PA-SR) and serves as the sixth marker [19]. PA-LA, which forms the basis of the SAR/LA, serves as the final marker.

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[1] Because the area was known as the Nevada Test Site during most of the disposal system characterization of Yucca Mountain, this paper and companion papers use NTS rather than the current NNSS acronym.

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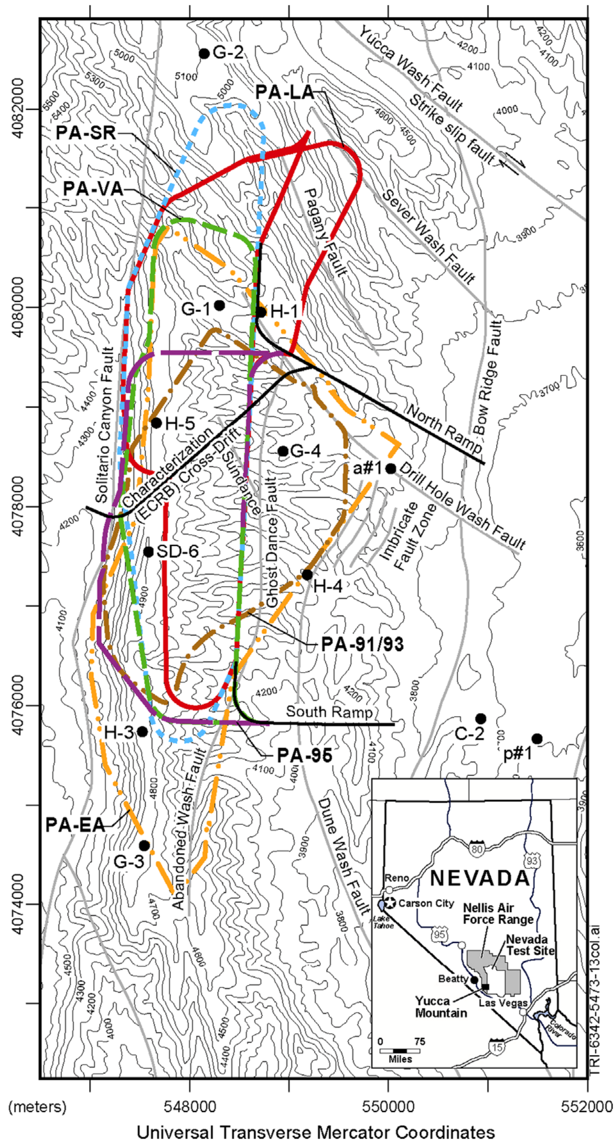

Fig. 1. Location and extent of various proposed layouts for Yucca Mountain repository.

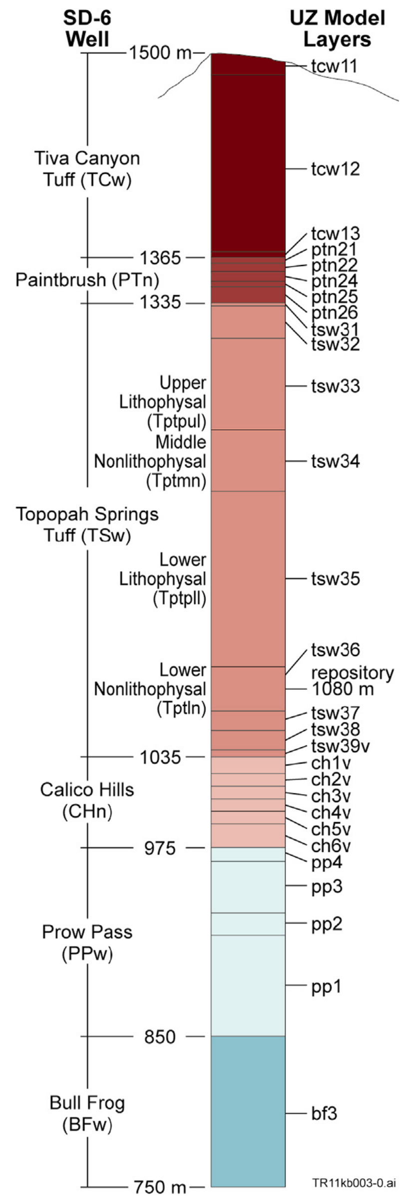

Fig. 2. General stratigraphy of Yucca Mountain at SD-6 borehole [16, Figs. 6 and 7, 25, Fig. 6.3.1-8].

2. Design of engineered system

The design of the repository has varied considerably over the life of YMP as the understanding of the geologic barrier has increased, the techniques for excavation have advanced, and desires for large containers for high throughput have been expressed (Fig. 1). Initially, the favored horizon for a repository at NTS was in the saturated zone (SZ), but the US Geological Survey (USGS) had suggested disposal of HLW in the UZ and alluvium in the 1970s. The USGS tentatively suggested the Topopah Spring welded tuff unit (TSw) in the unsaturated zone (UZ) in 1982 [1] (Fig. 2). That same year, Sandia National Laboratories (SNL) described a preliminary repository design [20]. However, a full evaluation of potential tuff units was not completed until 1983 and the report published a year later [21,22, p. 152]. Four units were formally evaluated: 2 units in the UZ (TSw and Calico Hills non-welded tuff or CHn) and 2 units in the SZ (Bullfrog and Tram welded tuff units or BFw and TRw, respectively) (Fig. 2). The report supported the selection of TSw for the repository.[2]

2.1. Engineered system in 1984 PA-EA

2.1.1. Repository design in 1984 PA-EA

In 1979, Congress decided to dispose only transuranic (TRU) radioactive waste generated from weapon production at the Waste Isolation Pilot Plant (WIPP) in bedded salt in southern New Mexico [26]. Congress stated in NWPA that remaining defense related DSNF should be disposed (presumably as defense HLW.[3]) with CSNF and the small amount of commercial HLW from the West Valley reprocessing plant closed in 1972 (Fig. A1), subject to

[2] A reference stratigraphy for thermal-mechanical modeling, published in 1985 [23], has been used by the project up through PA-LA and will frequently be used

(*footnote continued*)
herein since it generally corresponds to the major hydrologic modeling units. However, the formal stratigraphy and informal extensions developed by USGS in 1984 and revised in 1996 [24] are frequently necessary when discussing units of the repository horizon.

[3] President Ford delayed commercial reprocessing of CSNF in October 1976, and President Carter indefinitely delayed reprocessing in 1977. An important reason for the decisions was concern about proliferation of weapon material, based on the detonation of the Pu weapon by India in 1974 [1]; however, reprocessing of DSNF within the weapons complex continued until 1992 [27].