



# Site characterization of the Yucca Mountain disposal system for spent nuclear fuel and high-level radioactive waste



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## ABSTRACT

This paper summarizes the investigations conducted to characterize the geologic barrier of the Yucca Mountain disposal system. Site characterization progressed through (1) non-intrusive evaluation and borehole completions to determine stratigraphy for site identification; (2) exploration from the surface through well testing to evaluate the repository feasibility; (3) underground exploration to study coupled processes to evaluate repository suitability; and (4) reporting of experimental conclusions to support the repository compliance phase. Some of the scientific and technical challenges encountered included the evolution from a small preconstruction characterization program with much knowledge to be acquired during construction of the repository to a large characterization program with knowledge acquired prior to submission of the license application for construction authorization in June 2008 (i.e., the evolution from a preconstruction characterization program costing  $< \$0.04 \times 10^9$  as estimated by the Nuclear Regulatory Commission in 1982 to a thorough characterization, design, and analysis program costing  $\$11 \times 10^9$ —latter in 2010 constant dollars). Scientific understanding of unsaturated flow in fractures and seepage into an open drift in a thermally perturbed environment was initially lacking, so much site characterization expense was required to develop this knowledge.

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## 1. Introduction

In 1987, Congress selected Yucca Mountain as the sole location to be characterized for a potential disposal site for high-level radioactive waste (HLW), commercial spent nuclear fuel (SNF), and SNF owned by the US Department of Energy (DOE-owned SNF or DSNF) [1]. 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),<sup>1</sup> had been under consideration for a repository since 1978. In 2008, DOE submitted the Safety Analysis Report for the construction License Application (SAR/LA) to the Nuclear Regulatory Commission (NRC) (Fig. 1). DOE had spent  $\$15 \times 10^9$  (in 2010 US dollars) since site selection began in 1983 [2, p.10]. This cost included all waste management program costs required by the *Nuclear Waste Policy Act of 1982* (NWPA) [3] such as the Yucca Mountain Project (YMP) cost of  $\$11 \times 10^9$ . Although the Obama Administration and Congress brought a *de facto* halt to YMP by a lack of funding in 2010 and

began the process of formulating new policy, much can be learned from the past scientific challenges encountered<sup>2</sup>.

This paper summarizes information on site characterization 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* [4]. In keeping with the intended audience, this special issue devotes much to modeling and results; however, characterization of the natural barrier consumes much of the time and resources required to evaluate a geologic disposal system. Site characterization is at the heart of understanding the current behavior of components of the disposal system. Certainly, a description of the final understanding of the behavior of the Yucca Mountain disposal system is most satisfying academically, but re-examining the progression of this understanding, although somewhat tedious, provides a means for a future repository program to perceive the technical uncertainty that will exist at various phases of the project. The uncertainty that will exist cannot be grasped solely by examining the progression of characterization conducted at Yucca Mountain, but it provides a good starting point that can be enhanced by reading companion

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<sup>1</sup> 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.

<sup>2</sup> At the time of submittal of the SAR/LA, DOE reported spending  $\$13.5 \times 10^9$  with  $\sim \$9.9 \times 10^9$  spent by YMP (in 2007 dollars) [4, Table, ES-1]. Most of the costs reported herein are for the year reported and have not been converted to a constant US dollar basis by accounting for inflation.

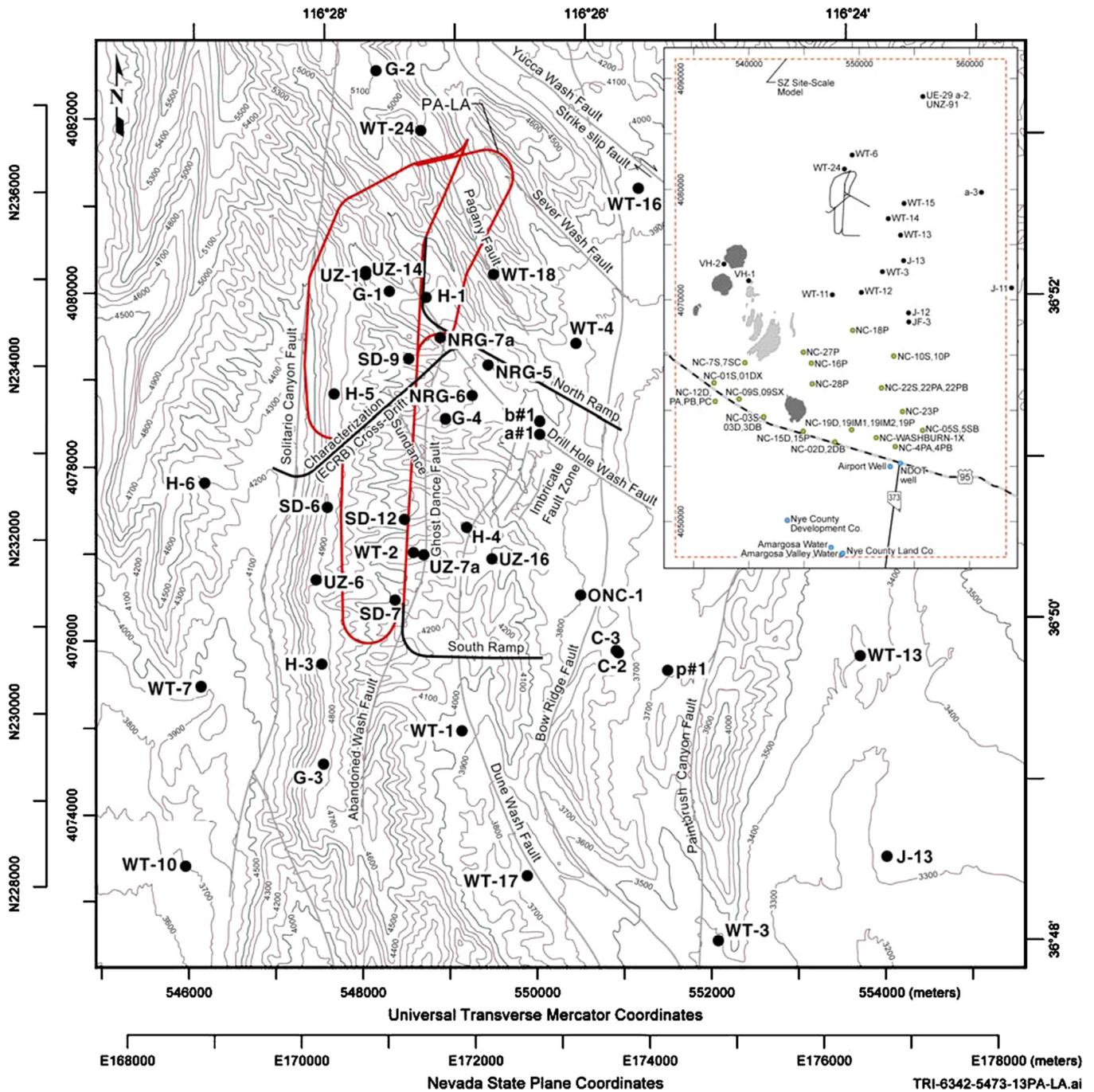


Fig. 1. Pertinent characterization wells at Yucca Mountain, Nevada in relation to repository for PA-LA.

papers, which describe the site selection, repository design, and evolution of the modeling system for the PA [5–13]. Some of the scientific issues encountered at Yucca Mountain have been summarized (e.g., [14–17]); however, this series of papers provides more background and historical context in order to examine potential technical implications for future repository programs.

As understanding of the disposal system has increased through characterization, the PAs have evolved from initial assumptions for site selection used in 1984, to extensive mathematical models used in the site recommendation (SR) in 2001, and finally to the partially validated mathematical models used in the SAR/LA in 2008. Seven PA iterations provide convenient points to discuss the status of YMP over the years.

In 1982 and 1984, deterministic calculations, designated collectively herein as PA-EA [18–20], were conducted for the draft and final Environmental Assessments (EA) required by NWP [3].

PA-EA provides the initial marker for the paper. The first stochastic PA, conducted in 1991 (PA-91) [21], 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 [22, Fig. 1-1; 23]. The Congressionally requested viability assessment (PA-VA), completed in 1998, serves as the fifth marker [24]. The conclusion of site characterization culminated with an analysis in late 2000 for the site recommendation PA-SR and serves as the sixth marker [25]. PA-LA, which forms the basis of the SAR/LA, serves as the final marker.

## 2. Characterization of geologic barrier

After the United State's commitment to geologic disposal in 1980, the formal steps of selecting a site as outlined in NWP were

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