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Rainier Mesa/Shoshone Mountain CAU Technical Basis Agreement Document: Hydrologic Source Term

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2.3. Hydrologic Source Term

2.3.1 Background: The Hydrologic Source Term (HST) represents the transient release of residual radioactivity into groundwater associated with an underground nuclear test. An HST *model* seeks to quantitatively calculate these releases from a mathematical representation of release processes and physical and chemical data related to the test and the altered test environment. The development of an HST model requires a **phenomenological understanding** of underground detonation effects and their role in altering the physical and chemical environment surrounding a test, an estimate of the abundance, physical form, and spatial distribution of radioactivity in the post-test environment – the **radiologic source term** (RST), and consideration of **mechanisms and processes** that serve to transfer radioactive compounds into groundwater following a detonation. Simplified representations of the HST model are required for use in populating individual source regions in larger scale models of groundwater flow and contaminant transport within the sub CAU and CAU scale models. By necessity, such models must abstract and generalize many of the complicated release mechanisms over the large number of tests encountered in the CAU.

2.3.2 Test, Tunnel, and Pond Sources: Within the Rainier Mesa/Shoshone Mountain (RM/SM) CAU, a total of 61 underground tests (involving 62 unique detonations) occurred at Rainier Mesa proper between 1957 and 1992 (Fig. 1; DOE, 2000). All but 2 were conducted in horizontal tunnel complexes built into the mesa, and the remaining 2 were conducted in vertical shafts located on top of the mesa. At Shoshone Mountain, 6 other underground tests (associated with 6 detonations) were conducted in tunnels. The 2 shaft tests, WINESKIN (U12r) and CLEARWATER (U12q), are the largest tests conducted and comprise 25% of the total announced test yield in the RM/SM CAU.

All tests at Rainier Mesa and Shoshone Mountain were conducted above the regional water table. Because of this, specific consideration must be given to the effects of variably saturated conditions on the migration of radionuclides (RNs), particularly those with medium to high volatilities. Tests conducted in E-, N-, and T-tunnels occurred under zones of perched water that tended to perennially leak into the drifts and drain into constructed ponds or impoundments beyond the tunnel portals. The effluent entrained test-related RNs that later appeared over time in the ponds. The N-, and T-tunnels were sealed and plugged in 1993. This effectively ended pond discharges but led to the creation of flooded and contaminated conditions in the tunnel systems behind the plugs. The E-tunnel complex was unsuccessfully plugged and continues to drain water and RNs today. Both WINESKIN (U12r) and CLEARWATER (U12q) are situated close to the saturated RVA aquifer and are presumed to readily contribute RNs into it (see §3.3.4).

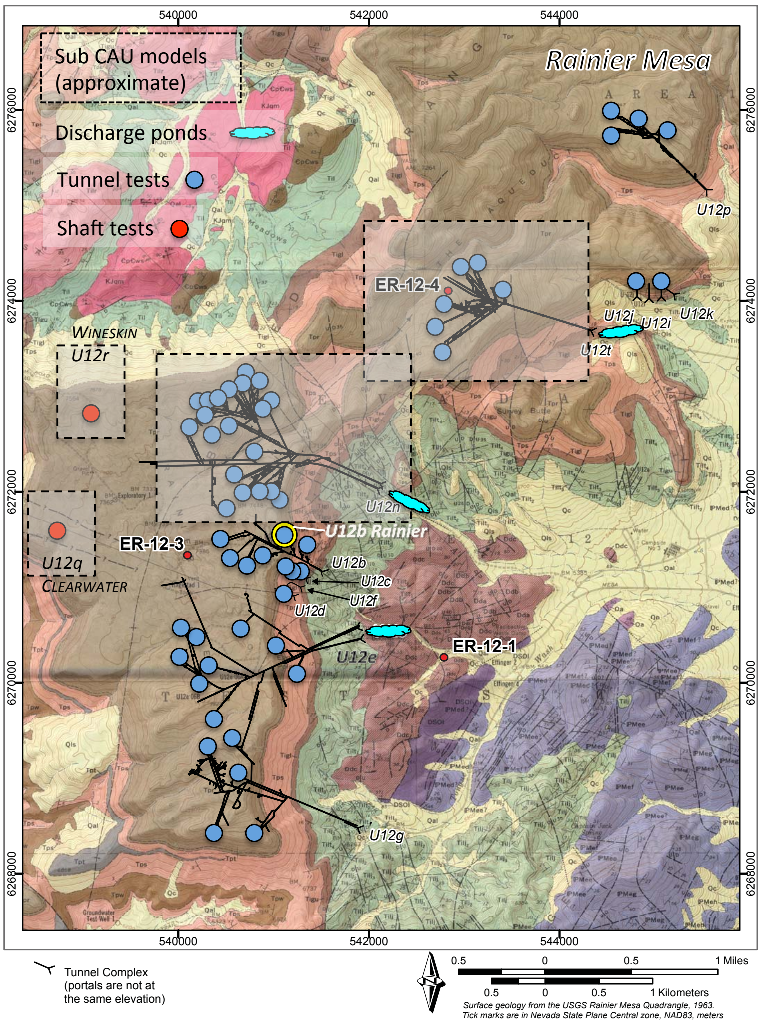
2.3.3 HST Models: Collectively, the test cavities, ponds, and flooded tunnels all comprise potential sources of RNs to the hydrologic system that must be addressed by the HST models (Fig. 1). Phase I of the models involved the assembly and interpretation of components that *inform* the HST, including a myriad of test related observations, radiochemical data, and physical parameters (Tompson et al., 2011). It also involved the development of a simplified tunnel system model and a detailed model-based analysis of the RAINIER (U12b) test. Phase II involved the assembly of components that *define* and *simplify* the HST for use in sub CAU and CAU scale models. Phase III involved an application to the WINESKIN (U12r) and CLEARWATER (U12q) tests (see §3.3.4).

2.3.3.1 Data: Significant data were available to support the identification of the RST, tunnel system model, RAINIER test model, and the WINESKIN (U12r) and CLEARWATER applications. Useful phenomenological data include the Bowen et al. (2001) unclassified RST for the RM/SM CAU (with associated uncertainties), reentry data from the RAINIER cavity (thermal conditions, altered physical characteristics, chemical properties, rubble and glass material, RN levels and distributions; Fig. 2), and new interpretations on melt glass composition from recent CHANCELLOR (U-19ad) drill-back investigations. Geologic information includes borehole core measurements of matrix, thermal, sorption, and rock saturation properties, the fracture database, and scattered water level data. Numerous observations of the tunnel flow, pond, and radiologic conditions were available, including portal discharge and concentration data and tunnel and pond concentration data, both during and after testing, and both before and after tunnel plugging.

2.3.3.2 Tunnel Model: A simplified model was developed for the E-, N-, and T-tunnel networks to link estimates of infiltration to measured tunnel water discharges, pond water accumulations, and tunnel flooding as a function of time and detonation sequence (Fig. 3). The primary objectives were to estimate the fractions of the RST associated with test cavities in the tunnels that were lost to the tunnel drifts and pond system over time. Models were calibrated to reproduce tunnel discharge history, calculate RN fluxes in tunnels and to ponds, estimate pond losses into subsurface, and address both the open and plugged periods of the N- and T- tunnels. Although evapotranspiration (ET) is a key factor in establishing pond water balances (higher ET can force dry ponds for extended periods), the majority of water discharged to ponds was lost to seepage rather than evaporation. Vertical seepage of water through tunnel walls is small compared to losses through portals. An end to the transient tunnel refilling is suggested by 2020. With the exception of a small number of tests in T tunnel (e.g., with stemming failures, as in MIGHTY OAK), most test inventories remain confined within the test cavities (Fig. 4). That said, the proportion of the overall T-tunnel RST discharged to the tunnel and ponds through 2020 is appreciable (~1/3 of the T tunnel RST). ^{3}**H** and $^{238+239+240}$**Pu** are the only species that appear above MCL in tunnels and ponds, and, thus, comprise *the relevant RN list* for pond sources.

2.3.3.3 Detailed RAINIER (U12b) Analysis: The RAINIER reentry data are seminal for understanding underground test phenomenology at the NNSS. Hence, a detailed model-based analysis of the RAINIER (U12b) test was developed to characterize early-time processes that affect RN redistribution near tests and understand the effects of variably saturated conditions on migration of medium to high volatility RNs. Simulation results focused on migration of ^{3}H, ^{14}C, and Noble gas precursors to ^{90}Sr and ^{137}Cs in gas and liquid phases. Results were consistent with observations and conceptualization of RN distributions around tests. Early migration patterns of ^{3}H and ^{14}C were influenced affected by thermal buoyancy effects, geology and fracture-matrix interactions, and RN-specific gas phase partitioning effects. Above MCL concentrations of both ^{3}H and ^{14}C were shown to reach the perched water below RAINIER.

2.3.3.4 Simplified HST: Operational specifications for a simplified HST have been developed. These involve definitions for the yield-weighted allocation of the RST among the RM/SM tests, guidelines for partitioning the RST between the cavity and tunnel environments (as above) and among the melt glass, water, rubble, and gas phases (for portions in the cavity), and rules for distributing RN mass within RN-specific exchange volumes. Altered zone specifications were based upon RM-specific observations and models. Release mechanisms related to glass dissolution, sorption effects, hydrologic flow, pond and tunnel losses, and gas phase redistribution issues were considered. Recommendations for addressing combined aqueous and colloidal Pu species were provided. Model initialization and fracture/matrix RN assignments took into account the more transient nature of early RN distributions (see also §3.3.4), gaseous distributions, and tunnel and pond behavior. A screening and uncertainty analysis was developed to identify a subset of the 43 RNs in the unclassified Bowen et al. (2001) inventory anticipated to have regulatory impact on groundwater contamination. Uncertainties in the RST, partitioning fractions, exchange volume diameter, glass dissolution rate, initial fracture/matrix RN distribution, and sorption Kd value were considered to identify a *relevant RN list for cavity sources*: ^{3}**H,** ^{14}**C,** ^{36}**Cl,** ^{90}**Sr,** ^{99}**Tc,** ^{129}**I,** ^{238}**U,** ^{238}**Pu,** ^{239}**Pu,** ^{240}**Pu,** and ^{241}**Am.** Gaseous RNs were not considered, except ^{14}C, as specifically motivated by results in the detailed RAINIER model. These analyses serve as input into larger-scale models and are available in spreadsheet form.



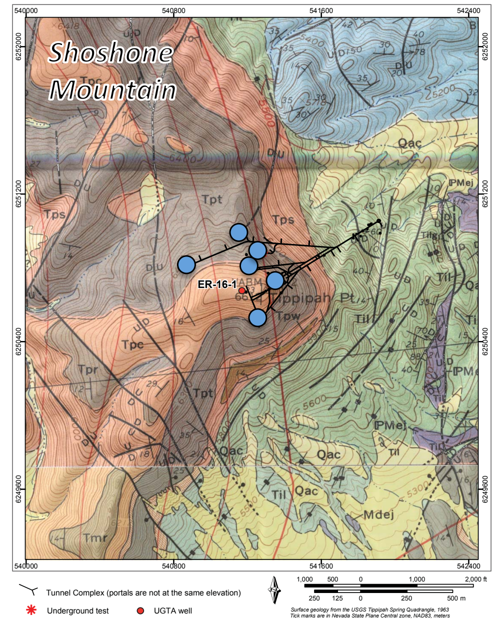


Figure 1. **Locations of tunnel complexes, tunnel tests (blue) and shaft tests (red) in the RM/SM CAU. Approximate locations of discharge ponds associated with drainage from the E-, N-, and T-tunnel complexes are shown in light blue. The dotted boxes correspond approximately to domains of the Sub-CAU scale models.**

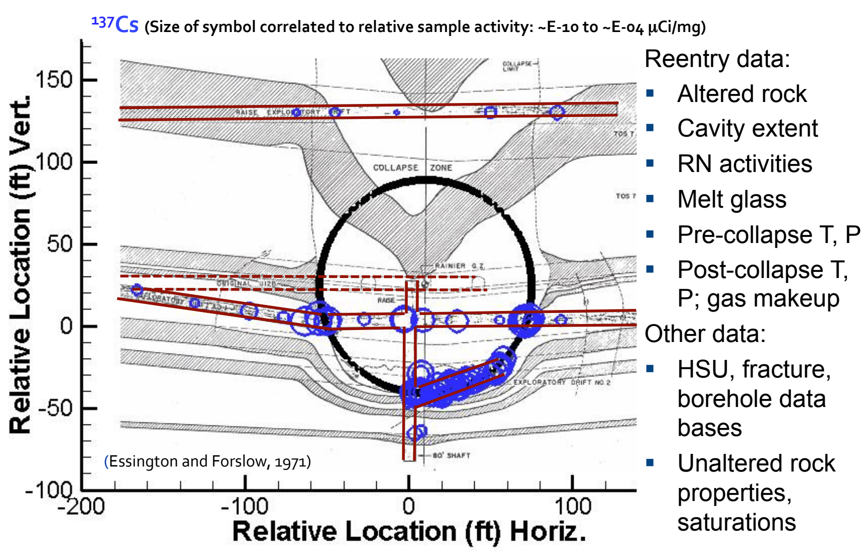


Figure 2. **Measured ^{137}Cs from samples collected in the RAINIER (U12b) cavity (microcuries/mg; Essington and Forslow, 1971). Data decay corrected to t_0 (September 19, 1957). Pre- (dotted) and post-test drifts shown in red. Reentry and other geologic data relevant to the HST model are itemized.**

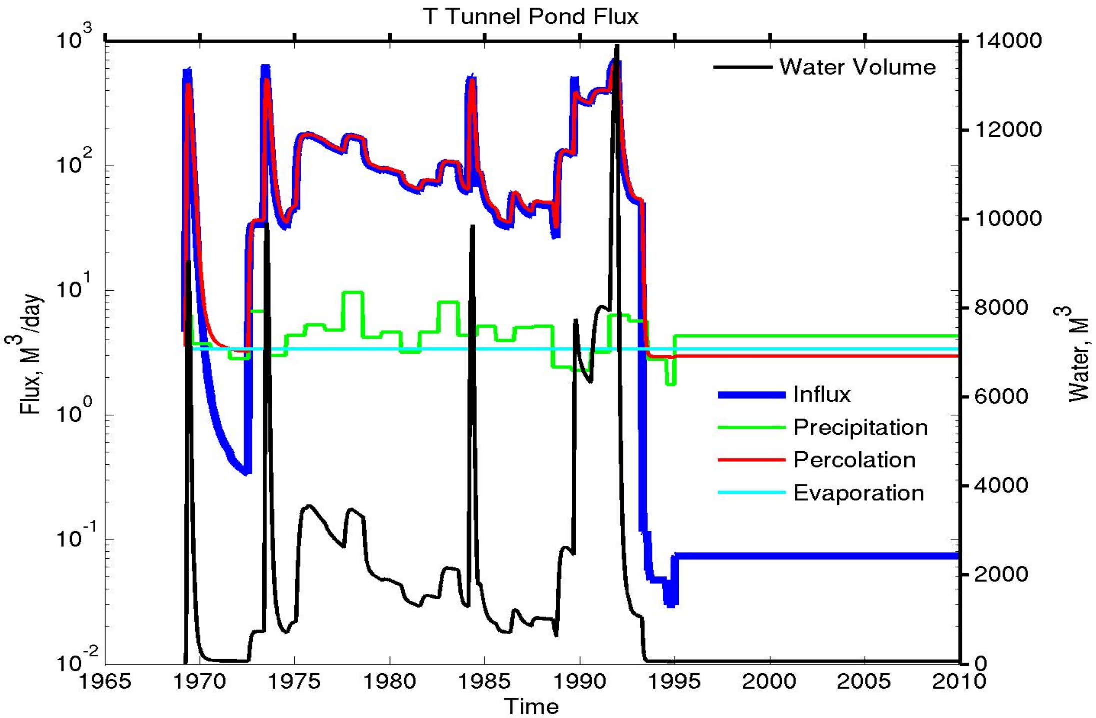


Figure 3. Simulated pond volume (m³) and water fluxes into and out of T-Tunnel pond system (m³/day) as a function of time, as determined by the simplified tunnel network model (Tompson et al., 2011). Percolation losses far exceed evaporative losses (here at 250 mm/y), even when the evaporation rate is raised to 2,500 mm/y.

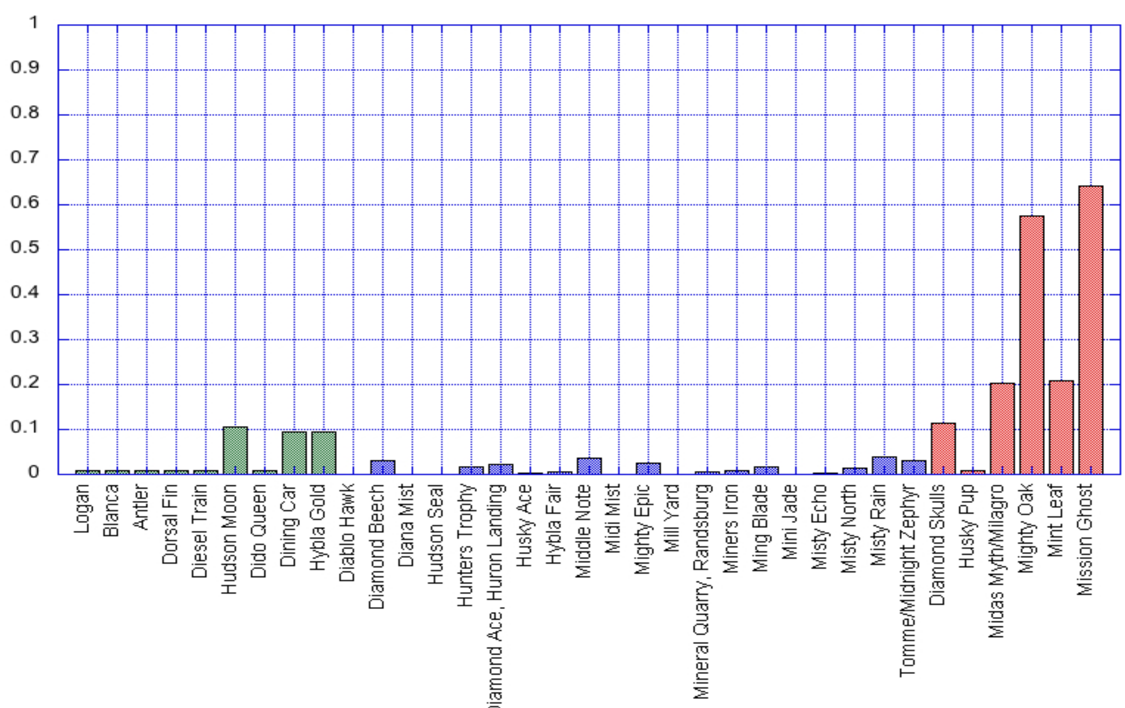


Figure 4. Simulated fraction of E- (green), N- (blue) and T-tunnel (red) tritium sources released to the relevant tunnel and pond systems as of the year 2020 (Tompson et al., 2011)

2.3.4 References:

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Essington, E.H. and E.J. Forslow (1971), Distribution of radioactivity in and near the Rainier rubble chimney. Teledyne Isotopes, Nevada Operations, Las Vegas, NV**:** NVO-1229-180, 81 p.

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