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THE PEÑA BLANCA NATURAL ANALOGUE PERFORMANCE ASSESSMENT MODEL

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The Nopal I uranium mine in the Sierra Peña Blanca, Chihuahua, Mexico serves as a natural analogue to the Yucca Mountain repository. The Peña Blanca Natural Analogue Performance Assessment Model simulates the mobilization and transport of radionuclides that are released from the mine and transported to the saturated zone. The Peña Blanca Natural Analogue Performance Assessment Model uses probabilistic simulations of hydrogeologic processes that are analogous to the processes that occur at the Yucca Mountain site.

The Nopal I uranium deposit lies in fractured, welded, and altered rhyolitic ash-flow tuffs that overlie carbonate rocks, a setting analogous to the geologic formations at the Yucca Mountain site. The Nopal I mine site has the following analogous characteristics as compared to the Yucca Mountain repository site.

- Analogous source: UO_2 uranium ore deposit = spent nuclear fuel in the repository
- Analogous geology: (i.e. Fractured, welded, and altered rhyolitic ash-flow tuffs)
- Analogous climate: Semiarid to arid
- Analogous setting: Volcanic tuffs overlie carbonate rocks
- Analogous geochemistry: Oxidizing conditionsAnalogous hydrogeology: The ore deposit lies in the unsaturated zone above the water table

The Nopal I deposit is approximately 8 ± 0.5 million years old and has been exposed to oxidizing conditions during the last 3.2 to 3.4 million years. The Peña Blanca Natural Analogue Performance Assessment Model considers that the uranium oxide and uranium silicates in the ore deposit were originally analogous to uranium-oxide spent nuclear fuel. The Peña Blanca site has been characterized using field and laboratory investigations of its fault and fracture distribution, mineralogy, fracture fillings, seepage into the mine adits, regional hydrology, and mineralization that shows the extent of radionuclide migration.

Three boreholes were drilled at the Nopal I mine site in 2003 and these boreholes have provided samples for lithologic characterization, water-level measurements, and water samples for laboratory analysis of the saturated zone water chemistry. The results of the field investigations and laboratory analyses of rock and water samples collected at Nopal

I are used to calibrate the Peña Blanca Natural Analogue Performance Assessment Model.

The Nopal I ore deposit was characterized during preliminary mining investigations in the 1980s. The information from the mine assays and other site investigations were used to develop the source term for the Peña Blanca Natural Analogue Performance Assessment Model. The exploratory mine showed that the ore deposit was an ovoid cylinder of uranium oxide, which was approximated as two waste packages, with a defined steady-state dissolution rate from the time when the ore body was exposed to oxidizing conditions at or near land surface. The Peña Blanca Natural Analogue Performance Assessment Model assumes that the Nopal I mine is in a recharge condition, relative to infiltration, with vertically downward flow through the unsaturated zone to the saturated zone. The model's unsaturated and saturated zones are divided into mixing cells to simulate groundwater flow and radionuclide transport. The radionuclide inventory for the model was developed using mineralogy of the ore deposit and other site investigations. The conceptual model for radionuclide transport assumes that ^{99}Tc is generated primarily by the spontaneous fission of ^{238}U based on the abundance of uranium species and an estimation algorithm to estimate possible ^{99}Tc production. The calculated radionuclide concentrations in the saturated zone beneath and downgradient from the Nopal I ore body using the Peña Blanca Natural Analogue Performance Assessment Model form the model's performance measure, and these results are compared to observed concentrations in groundwater samples obtained from wells at and near the Nopal I mine.

The model calculations show that the estimated radionuclide concentrations are dominated by ^{238}U, with lesser contributions from other uranium species. The range of calculated concentrations obtained from the model simulations brackets the observed concentrations in water samples obtained from boreholes completed beneath the ore deposit. The calculated results incorporate uncertainty through the use of distributions of the model's parameter values. The calculated concentrations are sensitive to the sorption coefficient (K_d) as corroborated by other site investigations that indicate that uranium in solution is apparently exchanging with minerals observed in fractures and the rock matrix in and around the Nopal I ore deposit.

Because the calculated values of uranium concentrations for groundwater beneath the Nopal I ore body are generally in agreement with observed concentrations, the Peña Blanca Natural Analogue Performance Assessment Model demonstrates the ability of the performance-assessment modeling to predict the mobilization of radionuclides and their transport in the unsaturated and saturated zones from a geologic source analogous to the nuclear material to be emplaced at the Yucca Mountain repository and through geologic materials also analogous to the Yucca Mountain site.