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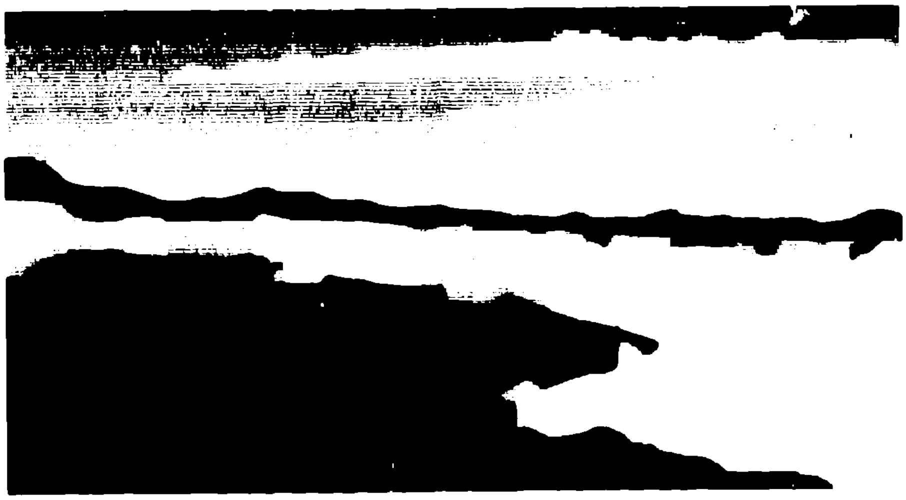

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The Nevada Test Site: An Analog for a Nuclear Repository

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Nuclear waste storage, radionuclide migration

Abstract

The United States proposes to store high level nuclear wastes underground; a site at Yucca Mountain in southern Nevada is currently under evaluation. A major concern is that radioactive materials may dissolve in the groundwater and be transported to the accessible environment. At the Nevada Test Site (NTS) adjacent to Yucca Mountain underground nuclear tests have been conducted for over 30 years. Radionuclides (unreacted fissile material, activation products, fission products) from these tests remain underground with no confinement by engineered barriers. The US Department of Energy has supported studies since 1973 designed to measure the distribution of these radionuclides and to evaluate the processes by which they might be transported by groundwater. We describe here some of what we have learned about how radionuclides are distributed around nuclear test cavities and how they interact with groundwater.

I. Introduction

The disposal of high level radioactive waste is an unresolved problem in the United States. We favor placing these wastes in an underground repository, and are currently evaluating the suitability of a site in southern Nevada for underground disposal. The proposed repository at Yucca Mountain would be in a thick horizon of zeolitized tuff well above the water table. Part of the site evaluation is an attempt to forecast what would happen if climatic changes allowed groundwater to reach the stored wastes. Would radionuclides be transported to the accessible environment as dissolved or colloidal species? What are the natural barriers to such transport? There are only a few known sites in the world that could serve as natural analogs for this situation, providing information on the large scale movement of radionuclides through the underground environment. Fortuitously, immediately adjacent to Yucca Mountain is the Nevada Test Site (NTS) where underground nuclear tests have been conducted since 1962. Over 600 nuclear devices have been exploded, leaving a residue of radionuclides -- fission products, unreacted fissile material and neutron activation products -- most of which are still in the vicinity of the explosion cavity. About a third of these tests were below the water table and the cavities created by the explosions have since filled in with water. The other tests were in the vadose zone, so we can study radioactive residues in both saturated and unsaturated hydrologic environments. The form of residual material is varied: most is incorporated in melt glass, some is a surface deposit on rocks in the cavity and rubble chimney, and some (e.g., tritium and gaseous species) is dispersed in the groundwater . Although the times since these tests were conducted are short compared to the expected lifetime of the repository, they are long enough to begin to see the effects of the environment on residue materials. For example, we may observe degradation and leaching of melt glass by the groundwater. Although it was never planned for this purpose, the NTS can serve as an enormous natural laboratory in which we may study the behavior of radionuclides in the same environment as that of the proposed repository. In this paper we outline what is known about radionuclide migration underground at the NTS and suggest further research that will be useful for the evaluation of the Yucca Mountain site.

2. The Radiologic Source Term

If high level radioactive waste is stored at Yucca Mountain it probably will be in the form of a glass or cement encapsulated in a canister and surrounded by a backfill. Only after these engineered barriers are penetrated can groundwater begin to affect the waste itself. In contrast, the residues of nuclear tests are in contact with their environment, a situation analogous to a breached repository. The conditions of the nuclear test determine the form of the residual materials. In a typical test, the nuclear fuel, device construction materials, electrical cables, stemming materials, rock and anything else near the device is vaporized. Within a few minutes the vapor formed by the explosion cools so that liquid forms on the cavity walls and collects in the bottom, soon solidifying into melt glass containing a large fraction of the radioactive material. Some residues remain coated on the surfaces of the upper cavity, or on the rubble chimney that forms if the cavity collapses (as it usually does). The high pressure created by the explosion may drive vapor and gases through fractures for considerable distances out into the surrounding rock formations. The phenomenology of nuclear explosions underground is discussed in Ref. [1].

Our knowledge of the distribution of radionuclides in the postshot environment comes from drill backs conducted at the NTS immediately after the shot and from other drilling programs in NTS areas heavily used for testing [2]. Generally, we find that residues from nuclear tests are confined within the immediate vicinity of the test. An exception to this rule is that highly mobile species such as tritium may move with groundwater and be detected several hundred meters from the test site. There are a few instances in which vaporized radioactive material appears to have been injected through fractures at the time of the explosion and traveled hundreds of meters before being deposited [3]. Once the non-gaseous residue from a nuclear test is emplaced, it can move only through the influence of groundwater. This situation is analogous to a nuclear waste repository where vapor phase transport is not present. The hydrologic environment thus becomes critical in the conversion of the radiological source term to the hydrological (i.e., mobile) source term.

3. Test Residues in the Saturated Zone

From our studies of fresh debris acquired in drill backs at nuclear test sites, we have learned that groundwater dissolves these materials at rates that depend on the chemical element dissolving and on the physical form of the material [2]. The rates of dissolution of radionuclides incorporated in melt glass are slower than the rates of dissolution when the radionuclides were deposited as films on the rock surfaces. Dissolved species may not move far from their point of origin for they are subject to sorption on the tuffaceous rock, particularly if they are cations. For example, at the site of the Cambric test at the NTS, we pumped water from the vicinity of the cavity for seventeen years and observed the species that moved with the groundwater. Neutral species (tritium, ^{85}Kr) and anions ($^{36}Cl^-$, $^{99}TcO_4^-$) moved some ninety meters to the pumped well; cations ($^{137}Cs^+$, $^{90}Sr^{++}$) did not [4]. Some radioactive materials remaining after a nuclear test may be present as colloids. At the site of the Cheshire test a number of fission product radionuclides were found to be associated with colloids [5].

From such studies as those mentioned above we have a considerable body of experimental data about radionuclide behavior in the saturated zone at the NTS. This information should be directly applicable to modeling scenarios that seek to predict how the proposed Yucca Mountain repository would respond if breached by groundwater. The analogy to the NTS provides a realistic basis for predictive calculations since it is based on real time observations of field scale behavior.

4. Test Residues in the Unsaturated Zone

In contrast to saturated zone studies, nuclear test sites in the unsaturated zone have received little attention. It has been assumed that water movement in the vadose zone is insufficient to transport radionuclides any significant distance. There is a need to check this assumption, particularly for test sites that may be exposed to period pulses of water flow from rain or snowfall. We also need to examine the transport of volatile radionuclides such as tritium and ^{85}Kr through the vadose zone. Such studies, when they take place, should be particularly relevant to the proposed repository at Yucca Mountain, as it would be located in a thick layer of unsaturated tuff. Again, we have an opportunity to collect field data on which realistic models can be constructed

5. Conclusions

The NTS may be viewed as a well-developed laboratory for the study of radionuclide behavior in geologic media. The infrastructure needed for such research is already in place: there is institutional control of the area, personnel with drilling expertise and other technical skills are present, equipment and maintenance facilities are abundant. There is a long history of research on nuclear tests conducted in the saturated zone, and many sites are available in the unsaturated zone for study. The NTS could prove to be a valuable resource for the Yucca Mountain Project and could provide generic information for repository sites world-wide.

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