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DEEP GEOLOGIC DISPOSAL OF MIXED WASTE IN BEDDED SALT: THE WASTE ISOLATION PILOT PLANT

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ABSTRACT

Mixed waste (i.e., waste that contains both chemically hazardous and radioactive components) poses a moral, political, and technical challenge to present and future generations. But an international consensus is emerging that harmful byproducts and residues can be permanently isolated from the biosphere in a safe and environmentally responsible manner by deep geologic disposal. To investigate and demonstrate such disposal for transuranic mixed waste, derived from defense-related activities, the U.S. Department of Energy has prepared the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico.

This research and development facility was excavated approximately at the center of a 600 m thick sequence of salt (halite) beds, 655 m below the surface. Proof of the long-term tectonic and hydrological stability of the region is supplied by the fact that these salt beds have remained essentially undisturbed since they were deposited during the Late Permian age, approximately 225 million years ago.

Plutonium-239, the main radioactive component of transuranic mixed waste, has a half-life of 24,500 years. Even ten half-lives of this isotope - amounting to about a quarter million years, the time during which its activity will decline to background level - represent only 0.11 percent of the history of the repository medium. Therefore, deep geologic disposal of transuranic mixed waste in Permian bedded salt appears eminently feasible.

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Weapons Site Cleanup

Environmental cleanup of the U.S. Department of Energy's (DOE) weapons complex is projected to be the most costly engineering project in U.S. history. Research for and production of nuclear weapons proceeded for decades, with protection of the environment being assigned a relatively low priority. Wastes were discarded with little thought given to long-term environmental consequences. The total cost of the requisite environmental remediation effort is estimated by some independent observers to be about $250 billion.

Rationale for the WIPP

Nuclear weapons facilities contain both chemically hazardous and radioactive waste. Plutonium processing operations generate laboratory and production trash contaminated with traces of radioactive materials. This waste includes: cloth, rubber, polyethylene, paper, wood, metals, glass, resins, graphite, oils, solvents, alcohols, and sludges. Decontamination and decommissioning activities at DOE installations result in additional contaminated items that require proper disposal. To investigate and demonstrate the safe and environmentally responsible deep geologic disposal of one category of such waste-so-called transuranic (TRU) mixed waste, derived from only defense-related activities - the DOE has constructed the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico.

Waste in the WIPP

Design and construction of the WIPP had to take into account the nature and the relevant characteristics of the waste destined to be disposed in the facility. In order to know how the waste may interact with the repository, characteristic properties of the waste needed to be investigated in great detail.

TRU Waste

TRU waste is defined by the DOE as waste that is contaminated with radionuclides that exhibit the following characteristics:

- Possess an atomic number greater than 92;

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- Be alpha-emitting;
- Have a half-life greater than 20 years;
- Exist in concentrations greater than 3700 Bq per gram.

Contact-handled (CH) TRU waste is handled in closed steel containers (drums). The maximum external dose rate of the container surface is less than 2 mSv per hour. Remote-handled (RH) TRU waste is handled in specially designed shielded casks. The external dose rate of the container surface is greater than 2 mSv per hour, but less than 10 Sv per hour. Plutonium-239, the main radioactive component of TRU waste, is an alpha emitter with a half-life of 24,500 years.

Mixed Waste

TRU mixed waste is any TRU waste that is co-contaminated with wastes defined and regulated as chemically hazardous. The TRU mixed waste destined for shipment to the WIPP is generated and/or stored by ten DOE national defense facilities engaged in plutonium processing, defense-related research and development programs, and decontamination and decommissioning operations.

Chemically Hazardous Constituents

Chemically hazardous constituents in the TRU wastes destined for disposal at the WIPP consist largely of the following:

- Toxic metals, e.g., cadmium, chromium, lead, mercury, selenium, and silver.
- Halogenated organic compounds, e.g., tetrachloroethylene, trichloroethylene, methylene chloride, 1,1,1-trichloroethane, carbon tetrachloride, and 1,1,2-trichloro-1,2,2-trifluoroethane.
- Nonhalogenated organic compounds, e.g., xylene, methyl alcohol, and butyl alcohol.

Waste Acceptance Criteria

Prior to shipment to the WIPP, the contents of each waste container must conform to a set of strict waste acceptance criteria (WAC). These criteria specify limits to the physical, chemical, and radiological characteristics of the waste in order to ensure safe emplacement in the repository. One such criterion precludes liquid wastes from being accepted at the WIPP. All sites sending waste to the WIPP have to prove compliance with the WAC, as well as with transportation requirements in addition to all applicable environmental regulations.

Waste Characterization

In preparation for testing, and to ensure conformance to the WAC and the other requirements, representative samples of the TRU mixed waste inventory are being characterized at the generator and storage sites through a multi-stage process using existing data, knowledge of the various processes that generated the waste, and analytical methods. The latter consist of real-time radiography (RTR), radioassay (RA), visual examination, analysis of gases in the headspace of the waste container, and flammability testing.

Analytical Methods

RTR consists of the qualitative and semi-quantitative evaluation of radiographic images of the interior of containers filled with waste. RA is a quantitative measurement of key radioactive constituents in a waste container. Visual examination includes weighing some or all of the contents of a waste container. Samples of gases taken from waste container headspaces are analyzed for chemically hazardous constituents to determine whether their concentrations are within specified regulatory limits. Flammability testing provides an evaluation whether headspace gas samples are potentially flammable. Using an extremely conservative approach, a flammable mixture is defined as either a binary mixture with concentrations of hydrogen and methane exceeding 50% of the theoretical lower explosive limit or a mixture of volatile organic compounds in air that propagates a flame during a laboratory test.

WIPP Location

The WIPP is located in one of the thickest, least disturbed sections of bedded salt in the U.S., at 32° 22' 30" north latitude and 103° 47' 30" west longitude, in southeastern New Mexico. Therefore, the site is part of the Pecos River Valley section of the Great Plains physiographic province. Surface elevations within the 41.5 km^2 site range from 1000 m to 1085 m. The town of Carlsbad, New Mexico, lies 42 km west of the WIPP. Fewer than 30 permanent residents live within a 16 km radius of the WIPP. Cattle ranching is the major land use in the general vicinity. Ground water quality is inherently so poor that drinking water for people and most of the livestock is supplied by pipeline. The Carlsbad region is the center of the U.S. potash mining and refining industry. Southeastern New Mexico also contributes significantly to the hydrocarbon production of the prolific Permian Basin. The closest potash mine lies 8 km west-southwest of the site, and the closest gas well lies 3 km south-southwest of the waste disposal area.

Site Geology

Geologically, the WIPP is situated in the northern Delaware Basin which constitutes the western part of the larger Permian Basin. In it, almost 4000 m of Permian-age rocks represent the most complete Permian record in North America. Part of this record is a 1100 m thick sequence of bedded evaporites, primarily halite and anhydrite. These evaporites are overlain by other Late Permian rocks, i.e., interbedded evaporites, carbonates, and clastics. Younger formations are either relatively thin or absent.

Tectonic activity since the Permian, i.e., for about 250 million years, has been minimal. About 3.5 to 1 million years ago, faulting elevated the Guadalupe and Delaware mountains along the western edge of the basin. An igneous dike intruded about 35 million years ago into the evaporites, approximately 16 km northwest of the WIPP. Regional and local seismic data indicate a 1000 year acceleration of 0.06 g or less and a 10,000 year acceleration of 0.1 g or less. There is no evidence for large magnitude earthquakes in the area within the recent geologic past.

Repository Design

The repository horizon lies 655 m below the surface, slightly below the center of the so-called Salado formation, a 600 m thick series of salt beds. Four vertical shafts connect the surface to the underground, intersecting the top of the salt about 255 m below the surface. Shafts range from 3 m to 6 m in diameter, the largest being the waste shaft. The underground disposal area comprises 40.5 ha, consisting of eight panels with seven rooms each. The rectangular rooms are 4 m high, 10 m wide, and 91 m long. Pillars between rooms are 30 m wide. Total waste disposal capacity amounts to 175,000 m^3.

Host Rock

Because the individual salt beds are almost horizonal, the repository could be excavated within just one stratigraphic horizon. Therefore, all rooms and panels within the storage/disposal area display the same stratigraphy. It consists of pure to muddy halite ($NaCl$) beds with accessory and thinly interbedded anhydrite ($CaSO_4$), clays, and polyhalite (K_2MgCa_2

$(SO_4)_4 \cdot 2H_2O$). In-situ rock permeabilities range from less than 10^{23} m^2 (0.01 nanodarcy) in pure salt beds to as high as 10^{18} m^2 (1 microdarcy) in some thin anhydrite interbeds

Excavation Response

The stress differential created by excavating the underground openings - 16 MPa in the undisturbed rock versus atmospheric pressure in the openings - causes the salt to deform in a plastic mode and to gradually creep into and fill any temporary opening. Observations and tests at the WIPP indicate that this process will be completed within 75 to 150 years. And that is, of course, the central idea behind the concept of the WIPP as a geologic repository: excavate underground openings, fill them with waste that cannot be disposed of safely at the surface, and then let the forces of nature enclose and encapsulate the waste, thereby fixing it in place and iso!~ting it permanently from the biosphere. The gradual stress redistribution during the period of salt deformation creates a near-field zone of disturbed rock that surrounds the excavations until the void is closed and the rock is repressurized. Within this zone, fracturing and dilation increase temporarily the original extremely low in-situ permeability by several orders of magnitude.

Brine

WIPP salt contains an average of about 0.55% moisture in the form of saturated brine, with most of it trapped in thin beds and intercrystalline accumulations of clay. Immediately upon mining a new opening, the resulting pressure differential, in conjunction with formation of the disturbed rock zone, mobilizes that brine. Wet patches, so-called weeps, appear on the freshly excavated surfaces a few days to weeks later. Evaporation of the weeps by circulating mine ventilation leads to the precipitation of salt crusts and the formation of "soda straw" salt stalactites. After several months of growth, these formations dry out and do not grow any further. The brine originally contained in the disturbed rock zone has been depleted, and continuing salt movement has closed the temporary fracture conduits.

Decommissioning

When the WIPP has been filled with waste, after about 25 years, it will be decommissioned. Underground rooms and access drifts will be backfilled with salt, and drifts and shafts will be sealed. Surface installations will be dismantled and removed, and permanent markers will be installed on the surface. Documentation about the location and nature of the WIPP will be placed in public records repositories and archives.

Waste/Repository Interactions

Because neither the wastes to be emplaced in the WIPP nor the repository medium are chemically inert, various reaction products may be generated by the following general processes:

- Corrosion of metals in wastes and containers;
- Microbial decomposition of organic waste components;
- Reactions between corrosion products and microbially generated gases;
- Reactions between backfill, gases, and brine;
- Radiolysis.

Gas Generation Potential

All of these processes individually or in various combinations may generate gases in sufficient quantity that the resulting pressures may prevent the waste-filled rooms from completely closing, may actually partially reverse the closure of the waste-filled rooms and drifts, and may even create fractures through which chemically hazardous and radioactive substances could migrate beyond the perimeter of the repository. A critical ingredient in all of these reactions is water, available from two principal sources: Traces of free liquids and moisture absorbed in the waste, and brine from the Salado formation. The amount of available water will affect amounts and types of the gases produced. If gas generation proves to be an obstacle to satisfactory repository performance, the project will evaluate various engineered modifications, either to the waste, or to the repository, or to both, in order to mitigate or to eliminate gas generation or its detrimental effects.

Performance Assessment

Determining the magnitude and significance of the gas generation issue provides just one input to a process called "Performance Assessment" (PA). PA is an assessment of compliance of a radioactive waste repository with environmental standards. The WIPP is required to demonstrate compliance with these standards on the basis of probabilistic risk assessment. One part of the standards specifies *maximum* allowable releases during management and storage of radioactive waste and applies to facilities designed for temporary storage of the waste. Another part of the standards aims to assure the *long-term (10,000 years)* integrity of a geologic repository for permanent disposal of nuclear waste. PA for compliance with both sets of standards requires an analysis that:

- Identifies processes and events that might affect the storage/disposal system;
- Examines the consequences of these processes and events for the performance of the storage/disposal system; and
- Estimates cumulative releases of radionuclides caused by all significant processes and events, taking into account their respective uncertainties.

This analysis uses data collected from four principal areas of investigation:

- Interaction of the repository environment with waste, containers, and backfill;
- Methods for sealing discrete areas underground;
- Rates of salt and brine movement;
- Potential to retard the transportation of radionuclides by fluids moving through formations overlying the salt beds.

The present level of uncertainty about the understanding of the interactions of brine inflow, gas generation, and rates of various chemical and biological processes spans several orders of magnitude. That uncertainty notwithstanding, PA evaluations to date indicate no threat to the integrity of the repository from natural processes within the regulatory time frame of 10,000 years. But it cannot be assumed that institutional controls (guards, fences, etc.) will prevent or mitigate releases of radionuclides caused by inadvertent human intrusion, i.e., exploratory drilling for natural resources, subsequent to the first 100 years after decommissioning. The main focus of the *continuing PA investigations* is, therefore, the human intrusion scenario.

Test Phase Rationale

To reduce the level of uncertainty, tests with actual TRU mixed waste in the repository environment will precede the decision whether to commence waste disposal operations. Data gathered during the test phase, as well as other results of PA, will form the basis for the decision whether to proceed to the disposal phase. In the unlikely event of a negative decision, all waste emplaced for test purposes must be retrieved and placed elsewhere.

Test Program

Tests for gas generation potential will be conducted:

- on a small scale in laboratories outside the WIPP;
- on a medium scale in steel bins (boxes) in the WIPP underground; and
- on a large scale in underground rooms called alcoves, about one-fourth the size of a typical storage/disposal room at the WIPP.

The gas generation test program employs a phased approach. Small-scale and relatively simple tests are gradually scaled upward to larger and more complex ones. Laboratory tests are currently being conducted at four laboratories. The bin program is divided into tests with waste in an "as-received" condition, tests with waste and salt in a humid environment, and tests with waste and salt in bins inundated with brine. The alcove test program will provide data that are of interest during repository operation. A source-term test program investigates solubility, sorption, and colloid reactions of radionuclides in repository brine. Source-term data, i.e., concentrations and compositions as a function of time, are obtained from real waste inundated with brine. Test mixtures may be spiked with actinides, and chemical reactions may be accelerated to achieve steady-state conditions in a reasonable time. Bin-scale and source-term experiments may be continued for as long as practical, as long as they provide useful information to enhance safety or compliance with regulations.

International Comparison

The WIPP as the first geologic repository for TRU mixed waste is subject to more regulations because of the chemically hazardous constituents in the waste than because of the radionuclides. As a pilot project, the WIPP has no true analogue. There exists, however, a single operating hazardous waste repository in bedded salt, the Herfa-Neurode disposal facility (UTD) in Germany. The geologic setting is quite comparable to that of the WIPP. The UTD has accumulated a successful operating record of twenty years, disposing of inorganic, water soluble, hazardous wastes in mined-out sections of a still active potash mine. Because of the simpler nature of its waste, the UTD does not have to consider the issues of gas generation and potential overpressure, resulting in migration of hazardous constituents beyond the repository's boundary. As the WIPP's evaluation of these issues continues, their magnitude appears to diminish, though, and as it does, the analogy between the WIPP and the UTD improves. Lessons learned at the UTD should be applicable to the WIPP during the test phase, and possibly at least partially during the disposal phase.

Conclusion

The WIPP is designed to demonstrate the safe and permanent geologic disposal of TRU mixed waste in bedded salt. Existing wastes destined for the WIPP have been identified. The repository design has been validated. The WIPP is now ready to commence a test phase to investigate the interactions of actual

TRU mixed waste with the repository environment. Test results will support the determination whether to permanently emplace waste in the WIPP. Based on all the work accomplished to date, indications are that, indeed, deep geologic disposal of TRU mixed waste in bedded salt is today's environmentally most sound solution.

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Short Biography

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