# PRINCIPLES OF, AND LESSONS FROM, THE WIPP

REMPE, NORBERT T., WIPP-Westinghouse, Carlsbad, NM, U.S.A.

**Summary**

Applying the lessons of geology and its affiliated sciences, as well as those of long-lived feats of engineering, we can confidently design, build, operate, close, and decommission repositories deep in the earth's crust that permanently contain dangerous materials. Geologically old, bedded salt is a particularly suitable host medium. Its continued presence is evidence of long-term regional stability. Salt is easy and safe to mine. Deep excavations in salt close gradually by viscoplastic deformation (creep), encapsulating and isolating anything emplaced within. But the one indispensable corollary to all those favorable technical and scientific aspects is the well-informed and voluntary consent of the people affected most by a frequently controversial repository. The people of Carlsbad, New Mexico (NM), and the Waste Isolation Pilot Plant (WIPP) have forged such a relationship, resulting in the world's first operating deep geologic repository for transuranic (TRU) and TRU mixed waste. Emulating the best the WIPP has to offer will benefit deep geologic isolation elsewhere.

**Introduction**

Deep geologic waste isolation is the environmentally appropriate final destination for some of the byproducts of modern science and technology, of population growth, and of the concomitant global rise in the standard of living. To permanently isolate one category of intermediate-level, radioactively contaminated waste deep underground, the U.S. Department of Energy (DOE) has built and is operating the WIPP, 42km east of Carlsbad, NM. The U.S Congress (Congress) authorized the WIPP to accept TRU waste resulting from U.S. defense activities only. This material (ranging from unprocessed laboratory trash, such as tools, glassware, and gloves, to solidified sludge from wastewater treatment) contains more than 3 700Bq of alpha-emitting transuranic isotopes (radionuclides with atomic weights greater than uranium) per gram of waste, with half-lives greater than 20 years. The highest permissible activity, averaged over the volume of a waste container, is $851 \times 10^9$Bq per liter, and the maximum surface dose rate is 10Sv per hour. In a more global classification system, this waste would be labeled intermediate, long half-life, and alpha-emitting waste. During the next 35 years, the WIPP will accept 175 000$m^3$ of that waste, delivered in drums and other steel containers, and emplace it 655m deep in rooms specifically excavated for that purpose in the middle of a 600m thick series of Upper Permian salt beds. The particular project site was selected because it features among its other technically favorable characteristics a local and regional geological environment that is fairly straightforward, robust, and well understood. As the only functioning deep geologic disposal facility for radioactive waste in salt worldwide, the WIPP sets an example for conscientious environmental management through the judicious application of geoscientific principles and methods. Virtual elimination of the threat of natural hazards and a very low risk of accidental human intrusion ensure permanent and safe isolation from the easily accessible biosphere. Further, the WIPP demonstrates the technical and ecological feasibility of reconciling environmental protection with sustainable technological development.

**Previous Work**

National treasures and other items of value have been temporarily sheltered in deep salt mines for centuries, waste rock and mill tailings from a variety of mining operations have been permanently stowed deep underground for many decades, and chemically hazardous wastes have been placed into underground potash mines since 1972. Recognizing the advantages of one potential host lithology in particular, the U.S. National Academy of Sciences (NAS) in 1957 recommended the study of rock salt formations for final disposal of radioactive wastes. Salt is impermeable and easy to mine. Furthermore, the persistence of thick and geologically old, bedded salt is clear evidence for long-term tectonic stability, structural integrity, and an absence of significant contact with moving ground water. Centuries of mining experience have also verified that salt under thick overburden heals temporary fractures and gradually closes excavations by creep.

Pursuant to the NAS recommendation, the U.S Atomic Energy Commission (AEC) first investigated an old salt mine in Lyons, Kansas, (Project Salt Vault) in the late 1960s and early 1970s for its suitability to permanently isolate high-level radioactive waste. When that project faltered due to unresolved technical issues and political attacks, a renewed nationwide search eventually focused on southeastern New Mexico.

Meanwhile, other countries also advanced the technology of radioactive waste disposal in salt. The Federal Republic of Germany operated the experimental Asse repository from 1967 to 1978, and East Germany brought the Morsleben repository fully on line in 1978. In a related, but politically separate and more favorable arena, the major German potash producer commenced deep geologic disposal of chemically toxic waste in mined-out sections of an operating potash mine in 1972.

**Community Commitment**

Carlsbad is the first community worldwide to actively solicit, support, and promote a radioactive waste repository in its neighborhood. City and county leaders took the initiative by actually volunteering their town and its environs, provided the project would not endanger the health and safety of people or the environment. This hospitality toward a controversial project, quite in contrast to the widespread NIMBY (Not In My Backyard) attitude toward anything related to mining, waste, and radioactivity, was not based on uncritical acceptance of government and industry assurances. Nor was it a desperate attempt to lure economic development into a remote desert area, regardless of the environmental consequences. Carlsbad's positive attitude is, instead, the result of:

1) More than a century of regional geologic reconnaissance (aiding in the establishment of two nearby national parks), 2) Close to a century of hydrocarbon exploration and production (resulting in thousands of drill holes in the Permian Basin), 3) Six decades of potash mining experience (establishing a detailed regional knowledge base about, and practical experience with, the behavior and safe management of excavations in salt, 4) Trivial consequences of a 3kt nuclear underground blast in salt (Project Gnome, the first shot of the Plowshare series), 360m below the surface and about 40km southeast of the city, on

December 10, 1961, and 5) Complete and timely sharing of information with, and continuous active participation by, community leaders, citizens, and other project stakeholders. More than once, local citizen support proved crucial to the survival of the project during site characterization, construction, and licensing. Recently, political obstacles were thrown into the path of some other nations' (Switzerland, Great Britain, Germany) radioactive waste management programs. Those experiences emphasize yet again that unwavering socio-political support, as demonstrated by Carlsbad in such an exemplary fashion, is the sine qua non of lasting repository success.

**Analogues**

Widespread public acceptance of permanent deep geologic waste isolation depends fundamentally on the scientific community's ability to identify, study, and correctly interpret repository analogues. There are several excellent natural analogues at and near the WIPP. Hydrocarbon reservoirs below the Upper Permian evaporites reinforce the well- established proposition that nature, with no need for human assistance, is perfectly capable of isolating highly volatile and flammable fluids underground for hundreds of millions of years. Carbon dioxide, trapped in close association to a vertical igneous dike of Tertiary age that is exposed not in the WIPP but in two neighboring potash mines, demonstrates the impermeability of rock salt even to gas for at least 30 million years. Very small intracrystalline inclusions and small intercrystalline reservoirs in WIPP salt at the disposal level, as well as limited open fractures in anhydrite 300m below, contain saturated brines, each with a different chemical composition, a unique isotopic ratio, and a distinct and specific pressure. These discrete brine occurrences constitute convincing evidence for the tightness of a formation that has not been homogenized by internal or external forces and has therefore remained essentially static and stable for at least 200 million years. By demonstrating the long-term impermeability of repository rocks to fluids, local natural analogues eliminate any reasonable doubt in the ability of the same rocks to permanently confine solid waste. This site-specific confidence is a welcome addition to our general assurance of very little, if any, migration of dangerous materials from other well-studied natural analogues, including uranium deposits, e.g., Cigar Lake, and even one natural nuclear reactor site (Oklo).

While natural analogues instill confidence in long-term repository safety over geologic spans of time, our confidence in satisfactory short-term operational and intermediate-term post-closure performance is bolstered by engineered analogues. Examples include geologic repositories in salt in Germany for chemically hazardous waste (Herfa, Heilbronn, Zielitz) – with a successful operating record of several decades, centuries-old underground mines (Wieliczka, Hallstatt), and millennia-old public works (Rome) and monuments (Egypt). Additional confidence can be gained by comparing the miniscule hypothetical release potential of radioactive waste repositories with the negligible actual consequences of worst-case engineered analogues such as underground nuclear detonations.

**Principal Safety Features**

Key characteristics of the WIPP encompass both those that are more or less generic to all deep geologic repositories, and those that are highly specific to the WIPP site. The WIPP's principal line of defense against release of contaminants to the easily accessible environment is its basic natural barrier. The host rock, Permian Salado salt, is impermeable. Salt at the disposal horizon has not been affected by groundwater in 250 million years. More than 300m rock salt and an additional 300m non-salt overburden separate the repository from the surface. Under the weight of the combined cover of 655m, the salt surrounding the excavations gradually creeps or flows (at a vertical closure rate of 7-8cm per year) into the openings and encapsulates the waste. Four well-engineered and maintained shafts form the only (temporary) connections between the surface and the repository level. All shafts will be plugged with state-of-the-art multi-component seal systems (engineered barriers) when the repository is full. In addition, panel closure systems divide the disposal area into separate cells, minimizing the already low-consequence potential hazard resulting from the very unlikely worst-case scenario of inadvertent human intrusion. Bags of chemical backfill (MgO) are added to each stack of waste containers, so that postulated, but highly unlikely, brine inundation in the wake of inadvertent repository penetration does not result in meaningful dissolution and mobilization of radionuclides.

At the WIPP, inadvertent intrusion by drilling is the only credible scenario that could potentially cause the release from the repository of waste constituents in concentrations of regulatory concern. The likelihood of that scenario becoming a reality is reduced to an almost negligible chance by a variety of preventive administrative, institutional, and engineering measures. The U.S. government owns the surface and essentially all mineral rights in the so-called WIPP Land Withdrawal Act Area (LWAA), a square tract of land encompassing $42km^2$. No drilling or mining is permitted there in perpetuity. In about the center of the LWAA lies the disposal area proper, measuring less than $0.5km^2$. The disposal area footprint consists of rooms about 90m long and 10m wide, pillars between rooms 30m wide, and pillars between panels (each made up of seven rooms and six pillars in parallel) 60m wide. These dimensions result in an aggregate extraction ratio of less than 25 percent. Thus, even if some future explorer, ignorant of the WIPP, were to drill not only within the forbidden LWAA, but in the much smaller disposal area, the risk of penetrating anything but (pillar) salt would be less than one chance in four. It warrants repeating that underground isolation is in any case much safer in the long run than storage at and near the surface with all of its attendant risks of exposure to the elements and human interference.

Other protective measures against unintentional WIPP penetration include the placement of project records into local, state, national, and international archives, as well as the construction of permanent surface markers. These will be massive monuments, engineered to last thousands of years, and inscribed with messages in symbols and several languages. Future generations will therefore be able to decipher these "Rosetta Stones" even if all knowledge of one or more of the languages used becomes lost.

**Natural Resources versus Permanent Isolation**

The choice of a site appropriate for deep geologic isolation may be influenced by natural resources in two opposite ways. On the one hand, former mines and the mined-out portions of still active mines provide infrastructure and abundant underground space. On the other, mining obviously presupposes natural resources. The potential future exploration for, and production of, these resources are popularly assumed to increase the risk of eventual inadvertent breaching of the repository. U.S. regulations try to address this conundrum by requiring that other favorable characteristics must outweigh the perceived weakness of a site containing known natural resources.

The WIPP disposal area consists of dedicated excavations, 655m deep, that are not part of an active or former mine. But the facility is nevertheless situated in an area rich in a variety of natural resources. These range from near-surface caliche, through potash seams 420 to 540m deep, to hydrocarbon reservoirs 1 400 to more than 7 000m deep. To mitigate concerns expressed by regulators and oversight groups, the DOE has prohibited any mining and drilling within the WIPP LWAA.

An alternative response to the perceived conflict between waste isolation and the potential for resource extraction might be to actually encourage carefully controlled drilling and mining before repository closure, in order to reduce the incentive for future intrusion. Oil and gas below the disposal horizon could be reached by inclined drilling from outside the LWAA. Mining of the potash seams above the disposal horizon now would, besides eliminating the incentive for later mining, provide underground space for emplacement of warning markers, disincentives, and possibly even obstacles to repository penetration.

But even this eminently rational alternative to the currently mandated approach could not possibly address one characteristic that is generic to any repository site, be it located in an area of presently known natural resources or not: We are in no position to even guess the kind of materials future generations will consider valuable natural resources. Neither hydrocarbons, nor potash, nor caliche were considered natural resources as few as 200 years ago. WIPP performance assessment, by comparison, tries to look 10 000 years into the future. In light of our fundamental ignorance about the material needs of our descendants, it is impossible to try to predict the likelihood of human intrusion into any one particular site compared with any other.

**Regulatory Framework**

Congress specifically exempted the WIPP itself from regulation by the U.S. Nuclear Regulatory Commission (NRC). Only the design for the waste transportation containers needed NRC certification before industrial production could begin. Nevertheless, the WIPP is subject to two very different and separate sets of fundamental standards and rules. The reason for this complicated regulatory environment is that most of the waste destined for the WIPP contains not only radioactive (potentially radiotoxic), but also chemically hazardous (potentially chemotoxic) constituents, categorizing it as "mixed" waste under U.S. law. The U.S. Environmental Protection Agency (EPA) is responsible for regulating radioactive waste, while the New Mexico Environment Department (NMED) has the responsibility for implementing regulations and issuing permits for hazardous waste.

In the early stages of the project, the DOE largely regulated itself, assisted by numerous independent oversight groups (without enforcement authority) such as the NAS, the Defense Nuclear Facilities Safety Board (DNFSB), and New Mexico's Environmental Evaluation Group (EEG). This relatively simple regime ended in late 1992 when Congress passed the so-called WIPP Land Withdrawal Act (LWA) which, among other provisions, directed the EPA to issue final regulations for deep geologic isolation of radioactive waste and to enforce them. By this action, Congress broke an extended impasse caused by legal challenges to the EPA standards for radioactive waste disposal that were first proposed in 1985. Current EPA regulations include requirements for containment, assurance, individual protection, and ground water protection, all seeking a reasonable degree of certainty for a period of 10 000 years. In May 1998 the EPA determined, after a careful review of the DOE's voluminous compliance certification application and numerous public hearings, that the WIPP will safely contain TRU waste, and that it complies with the agency's disposal standards. After some additional legal hurdles (temporary injunctions imposed at the behest of anti-nuclear activists) were cleared, the first non-mixed TRU waste finally arrived at the WIPP in the early morning of March 26, 1999.

It is now widely acknowledged, even by some voices usually critical of the WIPP, that the already very low risk stemming from the radioactive waste constituents outweighs by orders of magnitude the risk from chemotoxic constituents such as volatile organic compounds (VOC) or heavy metals, e.g., lead shielding. Just the same, the WIPP also needed to demonstrate compliance with the so-called Resource Conservation and Recovery Act (RCRA) which governs the management and disposal of hazardous (chemotoxic) waste. For New Mexico (and therefore the WIPP, too) the EPA delegated regulatory authority concerning the RCRA to the NMED. That agency conducted extensive and formal public hearings on its proposed decision in favor of the DOE's application, and by the time of this conference, the permit shall have been issued. By the time this abstract was submitted, only non-mixed TRU waste had been disposed of at the WIPP,

**Conceptual Challenges and Responses**

Regulatory, judicial, and administrative hurdles aside, the very concept of waste isolation in general, and of disposal in the WIPP in particular, did encounter several technical and scientific arguments that, at one time or another, appeared to place final mission success in jeopardy. Most of these concerns involved the role of water and its effect on the host rock.

Small volumes of saturated brine squeeze out of the salt and seep into the excavations for a few months to, at most, 2-3 years following mining. They created in some critics' minds colorful images of underground streams carrying radioactive slurry to the surface. Apart from the fact that such a horror scenario must suspend the law of gravity, short-term brine weeps are a feature commonly observed in salt and potash mines. A detailed and very careful WIPP brine sampling and evaluation program of several years' duration allayed the fear by concluding that brine seeps only from the excavation-disturbed zone (EDZ) immediately surrounding the excavations, with no practical evidence for far-field flow. Carefully evaluating and thereby eliminating the issue of brine inflow also reduced another related issue, that of gas generation, to insignificance. Theoretically, radioactive waste and its containers in a closed repository could slowly decompose by microbial decay of organic materials, anoxic corrosion of metals, and radiolysis. Such processes would produce gases that, if generated in sufficient quantity and accumulated under sufficient pressure, might induce fractures in the surrounding rock. These in turn might allow waste constituents to migrate beyond the repository boundary and eventually return to the easily accessible biosphere. Practically, however, microbial degradation and anoxic corrosion require a moist to wet environment to become feasible. That condition will not be fulfilled because individual WIPP panels are open to mine ventilation for at least five years. Ventilation therefore removes substantially all available moisture long before even partial repository closure. The rate of radiolysis of WIPP waste is inherently too low to be of practical concern.

Karst became another contentious topic. Some WIPP opponents still portray the WIPP site as potentially riddled with karst conduits through which fresh water could attack and dissolve the salt. That line of reasoning conveniently overlooks the fact that dozens of drill holes and four shafts revealed no karst features in the LWAA. Besides, ordinary karst is a surface- and near-surface phenomenon that could not threaten isolation 655m deep for millions of years even if karst features were detected right above the WIPP.

Finally, underground stability has been a recurring theme of some critics during the life of the WIPP excavations (since 1982). Project delays (more than 10 years) caused some excavations to remain open far longer than originally intended. Some of those creep close at vertical rates of up to 9cm per year, and ground support requires continuous effort. But these conditions are similar to those in any salt or potash mine and are likewise managed routinely and safely. Beyond standard mining practice, however, the WIPP has installed more than 1 000 geotechnical instruments to monitor rock behavior and to indicate deteriorating conditions sufficiently early to implement remedial measures. Here, as in all other aspects of the WIPP, safety is always the first priority and is never compromised.

**Conclusions**

The first deep geologic repository in salt for TRU and TRU mixed waste has proven to regulators, oversight groups, critics, and neighbors that it effectively protects people and the environment from some deleterious byproducts of nuclear activities. Functioning as a genuine pilot project, yet at a fully operational scale, the WIPP offers a model for future efforts to safely isolate other dangerous wastes deep in the earth's crust.

**Further Information Sources**

Web sites:
www.wipp.carlsbad.nm.us
www.epa.gov/radiation/wipp
www.nsc.org/ehc/wipp.htm
www.rt66.com/~eeg/

E-mail:
infocntr@wipp.carlsbad.nm.us