The Waste Isolation Pilot Plant Transuranic Waste Repository: A Case Study in Radioactive Waste Disposal Safety and Risk

Leif G. Eriksson, Director, Nuclear Waste Management
GRAM, Inc..
8500 Menaul Boulevard NE, Suite B-335, Albuquerque, New Mexico 87112, USA

Abstract

The Waste Isolation Pilot Plant (WIPP) deep geological defense-generated *transuranic radioactive waste*[a] (TRUW) repository in the United States of America (USA) (Figure 1) was certified on the 13th of May 1998 and opened on the 26th of March 1999. Two sets of safety/performance assessment (PA) calculations supporting the certification of the WIPP TRUW repository [1] show that the maximum annual individual committed effective dose (CED) will be 32 times lower than the regulatory limit and that the cumulative amount of radionuclide releases will be at least 10 times, more likely at least 20 times, lower than the regulatory limits. Yet, perceptions remain among the public that the WIPP TRUW repository imposes an unacceptable risk.

---

a TRUW is a man-made, mainly alpha-emitting, radioactive waste category containing transuranic isotopes (atomic weights/numbers greater than uranium [No. 92]) having more than 3,700 becquerels per gram (Bq/g) of waste, with half-lives greater than 20 years. The maximum surface dose rate for TRUW is 10 sieverts per hour (Sv/h). A total of 175,584 cubic meters (m^3) of TRUW may be disposed of in the WIPP TRUW repository. At least 168,504 m^3 of this waste will have a surface dose rate below 0.002 Sv/h , 7080 m^3 will have a surface dose rate between 0.002 Sv/h and 10 Sv/h, but only 354 m^3 may have a surface dose rate above 0.1 Sv/h.

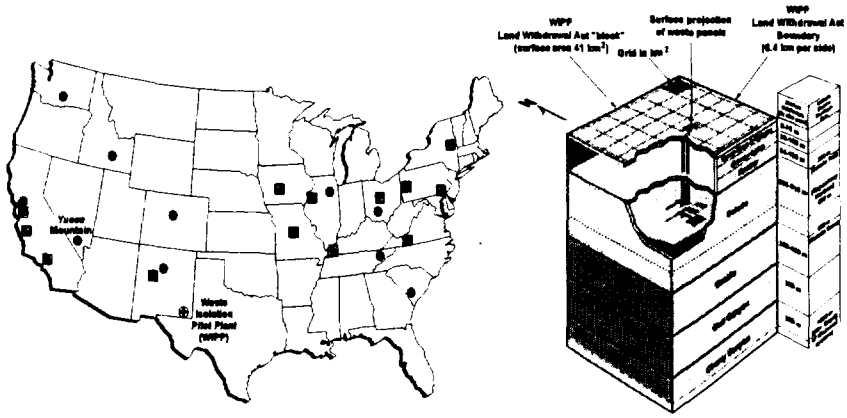

Figure 1. Locations of the WIPP and Yucca Mountain sites and 10 large- (circles) And 13 small-quantity (squares) TRUW generator/storage sites, and a schematic illustration of the main stratigraphic formations and units at the WIPP site.

1. Introduction

On the 13th of May 1998, the U.S. Environmental Protection Agency (EPA) certified that the WIPP TRUW repository complied with all applicable TRUW disposal regulations [1]. The first shipment of TRUW from Los Alamos National Laboratory arrived at four o'clock in the morning on the 26th of March 1999, crowning 25 years of joint U.S. Department of Energy (DOE) and Sandia National Laboratories (SNL) efforts. These first-of-a-kind events corroborate a long-standing global scientific consensus and demonstrate de facto to the world that: *Disposal of long-lived radioactive waste may be safely done in a carefully selected, designed, constructed, and operated deep geological repository.* To ensure the continued safe operation, the WIPP TRUW repository must be recertified by the EPA at least every fifth year after commencement of operations throughout the 35-year disposal phase, i.e., seven recertifications; the first one by the 26th of March 2004.

The WIPP success story is summarized below in three main sections. Section 2 contains brief background descriptions of the legal and regulatory frameworks for the safe disposal of long-lived radioactive waste in the USA. It also provides brief summaries of the WIPP site, the baseline layout of the WIPP repository, and key elements of the DOE's path forward for demonstrating to the regulators and other affected or interested parties that the WIPP TRUW repository is safely and cost-effectively operated throughout the disposal phase and the ensuing 10 year decommissioning and closure period. Section 3 describes and discusses the two key sets of PA calculations and results presented in and in support of the WIPP compliance certification application (CCA) [2], respectively. Section 4 contains a summary of the author's main observations and conclusions. Indeed, this entire text

is attributable to the author alone unless otherwise indicated by bracketed numerical references in the text. References are listed in a separate section following the main text. Select key words, terms, concepts, and statements are highlighted in *Italics*.

2. Background

Pursuant to current U.S. laws [3] [4], the DOE is responsible for the safe disposal of both TRUW and spent nuclear fuel and other high-level radioactive wastes (HLW) in deep geological repositories in compliance with applicable federal and state regulations and standards. However, the development and operation of the related repositories are the responsibility of two separate and essentially autonomous DOE offices/programs. The Carlsbad Area Office (CAO) is responsible for the safe disposal of the nation's TRUW at the WIPP site. The Office of Civilian Radioactive Waste Management (OCRWM) is responsible for the development and operation of a safe repository for the nation's HLW at the Yucca Mountain site (Figure 1), if it is found suitable. Similarly, the legal and regulatory frameworks and independent regulatory oversight organizations for these programs are distinctly different as are their evolutionary status. Whereas the EPA is the main independent federal regulator for safe disposal of TRUW, the U.S. Nuclear Regulatory Commission (NRC) is the main independent regulator for safe disposal of HLW. Also, whereas WIPP is in operation, the potential opening of a HLW repository at the Yucca Mountain site is more than 10 years away. Thus, the subsequent text only addresses TRUW disposal.

About 60 percent of the nation's existing TRUW is mixed with regulated hazardous constituents (mixed TRUW). Thus, in order for the DOE to dispose of this mixed TRUW at the WIPP site, it must obtain both a certification from the EPA that the TRUW contained in the *mixed and non-mixed TRUW* may be safely disposed of at the WIPP site, and a permit, also referred to as the Resource Conservation and Recovery Act (RCRA) Part B Permit, from the New Mexico Environment Department (NMED) that the regulated hazardous constituents contained in the *mixed TRUW* may be safely received, handled, stored, and disposed of at the WIPP site. The certification (and pending recertifications) of WIPP is governed by two federal regulations, 40 CFR 191 [5] and 40 CFR 194 [6]. The permitting is governed by three federal regulations, 40 CFR 261 [7], 264 [8], and 268 [9], which in the case of WIPP are implemented by the NMED as are state regulations pertaining to hazardous waste operations in New Mexico. A federal court decision on the 22nd of March 1999 granted the WIPP repository "interim status" to dispose of hazardous waste pending the NMED's long overdue issuance of the RCRA Part B Permit. As indicated by this decision, the disposal of hazardous waste presents a much lower risk to the public and the environment than disposal of non-mixed TRUW. Thus, the focus in Section 3 is on the inherent safety/risks of the WIPP TRUW repository relative to 40 CFR 191 and 194.

The WIPP Land Withdrawal Act (LWA) [3] sets aside a 41.6 square kilometer (km^2) land parcel from public use for the WIPP site in a sparsely populated, arid area in the southeastern portion of New Mexico (Figure 1). The closest major city, Carlsbad, has about 25,000 residents and is located about 42 kilometers (km) northwest of the

WIPP site. Less than 100,000 people reside with an 80-km radius and less than 30 people reside within a 10-km radius of the WIPP site. The prevailing geology comprises an about 6,000-m thick evaporitic rock sequence overlying the crystalline basement rock. As schematically illustrated in Figure 1, a 600-m thick (250-million-year old, regionally extensive, virtually impermeable, and seismically and tectonically undisturbed) bedded rock salt formation, the Salado Formation, hosts the repository. Potable water is scarce and natural hydrological pathways occur mainly above and below the repository host rock.

The WIPP repository baseline layout comprises eight main panels covering a horizontal area of about 0.5 km^2. Each panel is divided into seven waste disposal/emplacement rooms measuring 4-m in height, 10-m in width, and 91-m in length. Only one panel has been excavated to date and the shortest distance from the perimeter of the repository/waste to the accessible environment is 2.4 km. The emplaced TRUW will be surrounded by magnesium oxide (MgO) backfill to ensure a stable chemical disposal room environment (pH) during the 10,000-year regulatory period, and to minimize water movements, gas generation, and radionuclide solubility in the disposal rooms. One of the favorable characteristics of the repository host rock is that rock salt deforms with time (creeps) at very low deviatoric stresses and thereby will gradually close all underground openings within 500 years and encapsulate the emplaced waste into an impermeable monolith.

A geologic condition at the WIPP site of particular significance to the certification and pending recertifications of the WIPP TRUW repository is local occurrences of economic natural resources, mainly potash and hydrocarbons. These resources, in combination with local over-pressurized brine reservoirs below the repository, form the bases for the most adverse features, events, and processes (FEPs) affecting the long-term safety/performance of the WIPP TRUW repository. By regulatory mandate [5], these FEPs are combined into scenarios that largely drive the PA calculations and consume the majority of the project's scientific and financial resources. They are also the feedstock for concerns and propaganda about to the long-term risks imposed by the WIPP TRUW repository.

In preparation for the first recertification of the WIPP TRUW repository, the CAO, supported by its two main contractors (SNL and Westinghouse), is continuously assessing and implementing means and measures to simplify and reduce uncertainties in the PA calculations presented in the CCA and operational measures improving safety and cost. For example, SNL conducted one near-field system analysis and one set of sensitivity and PA calculations during 1998 to address and help formulate the CAO's recertification strategy. Furthermore, a fundamental component of the CAO's recertification strategy is to monitor and participate in foreign and international programs and projects, with the main objectives being to cost-effectively:

1. Expand the current database and in-house knowledge relevant to the recertification of the WIPP TRUW repository;
2. Make the existing knowledge (e.g., data, models, and scientists) and facilities (e.g., laboratories and the WIPP site) available to others because many of the scientific/engineering challenges faced and successfully resolved by the CAO

and its contractors are common to any deep geological disposal program; and
3. Dispel the anti-nuclear movement's propaganda myth that long-lived radioactive waste cannot be safely disposed.

The underlying fundamental principle for the CAO's participation in foreign and international radioactive waste management and disposal projects, programs, and events is that the safe disposal of long-lived radioactive waste is more than a national challenge, it is a global challenge that is best met by international collaborations.

3. Description and Discussion of the Inherent Safety/Risks of the WIPP TRUW Repository

Figuratively speaking, the applicable law, i.e., the LWA [3], defines the playing field, 40 CFR 191 [5] provides the (very narrow) goal posts and 40 CFR 194 [6] provides (a very low) cross bar for the certification of the WIPP TRUW repository. Thus, in order to understand the long-term risks and fully appreciate the inherent safety of the WIPP TRUW repository, it is imperative that the special public health and environmental radiation protection requirements defined in 40 CFR 191 and 194 be addressed.

The two fundamental safety cases defined in 40 CFR 191 pertain to (1) *undisturbed* and (2) *disturbed* (repository system) *conditions*. Undisturbed conditions refer to natural FEPs affecting the repository during the 10,000-year regulatory period. Disturbed conditions add hypothetical inadvertent human intrusion FEPs. The key 40 CFR 191.15 [5] safety requirement for *undisturbed conditions* reads:

> "Disposal systems for waste and any associated radioactive material shall be designed to provide reasonable expectation that, for 10,000 years after disposal, undisturbed performance of the disposal system shall not cause the annual committed dose received through all pathways from the disposal system, to any member of the public in the accessible environment to exceed 15 millirems (150 microsieverts)."

The key 40 CFR 191.13 [5] safety requirements for *disturbed conditions* read:

> "Disposal systems for spent nuclear fuel and high-level and transuranic wastes shall be designed to provide a reasonable expectation, based on performance assessment (PA), that the cumulative releases of all radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall: (1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A); and (2) have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A)."

The DOE is required to demonstrate compliance with the above requirements using probabilistic-based calculations presented in the form of *mean complementary cumulative distribution functions* (CCDFs) [5]. These calculations must include all

scenarios with a probability of occurrence greater than one chance in 10,000 during 10,000-years regulatory period, i.e., the probability has to be greater than 10^{-8}. Two related compliance criteria [6], i.e., 40 CFR 194.34(d) and (f), respectively, further specifies:

> "(d) The number of CCDFs shall be large enough such that, at cumulative releases of 1 and 10, the maximum CCDF generated exceeds the 99th percentile of the population of the CCDFs with at least a 0.95 probability"; and
> "(f) Any compliance application shall provide information, which demonstrates that there is at least a 95 percent level of statistical confidence that the mean of the population of CCDFs meets the containment requirements of Sec. 191 of this chapter."

Although the performance period in the USA is shorter, the regulatory definition and required implementation of the undisturbed conditions are largely consistent with international recommendations and praxis, the definitions and the required implementation if the disturbed conditions are globally unique both in terms of concepts and stringency. Other unique regulatory concepts and requirements of 40 CFR 191 [5] are:

- The safety basis for the disposal regulations is 1,000 cancer deaths during 10,000 years among a global population of 10 billion people, i.e. *the repository-induced cancer-death risk is* 10^{-11};
- The controlled area comprising a surface area and the directly underlying rock mass, may neither exceed a 100 km^2 horizontal surface area projection nor may the lateral distance between the emplaced waste and the accessible environment exceed 5 km;
- CEDs are calculated no closer than at the boundary between *the controlled area* (hosts the repository) shown on Figure 1 and *the accessible environment*; and
- The amount of radionuclides that may be released to the accessible environment is directly proportional to the amount of radioactive material emplaced in the repository.

Four specific conditions of importance to the subsequent discussion of the inherent safety/risks of the WIPP TRUW repository are:

- The controlled area at the WIPP site (Figure 1), is only 41 km^2, whereas the allowable controlled area under 40 CFR 191 is 100 km^2;
- The shortest lateral distance at the WIPP site between the TRUW and the accessible environment is 2.4 km, whereas the allowable distance under 40 CFR 191 is 5 km;
- Excepting the shaft and panel seals and the chemically buffered disposal rooms, the WIPP TRUW repository does not rely on any engineered barrier, i.e., long-term radionuclide containment and isolation are provided solely by the prevailing natural barriers (the geologic setting) only; and
- The WIPP TRUW repository's compliance with the 40 CFR 191.15 CED limit is based on *undisturbed conditions*, whereas the compliance with the 40 CFR 191.13 radionuclide release limit is based on *disturbed conditions*.

The current regulatory, political, scientific/engineering, and broad public acceptance of and confidence in the safety of the WIPP TRUW repository are largely based on:

1. The long-term (post-closure) conceptual and numerical models, FEPs, and PA calculations and results presented in the October 1996 WIPP CCA [2],and
2. The subsequent PA validation test (PAVT) calculations and results requested and analyzed by the EPA before certifying the WIPP TRUW repository in May 1998 [1].

The aforementioned two sets of PA calculations demonstrate beyond any reasonable doubt that all pertinent regulatory long-term public health and environmental radiation protection criteria applicable to the WIPP TRUW repository are readily satisfied. Specifically:

1. The annual CED to the maximally exposed individual *under undisturbed conditions* will be at least 32 times lower than the regulatory limit and at least 768 times lower than the average annual natural background radiation in the USA; and
2. The cumulative radionuclide releases *under disturbed conditions* (Figure 2) will be lower than 1/10th of the related regulatory limits for the bounding mean PAVT CCDFs and lower than 1/20th of the regulatory limits for the mean CCA CCDFs.

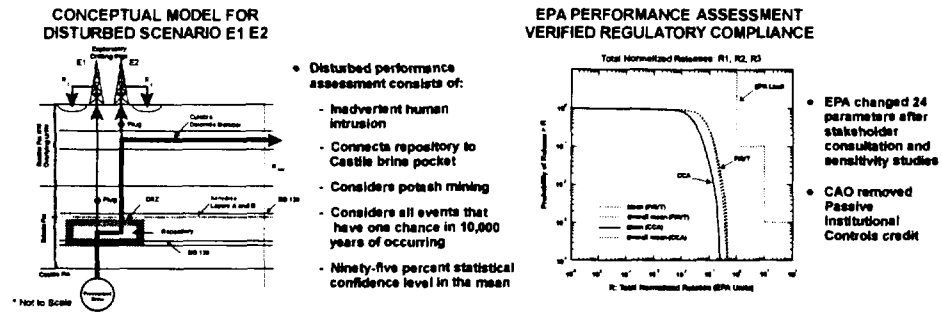

Figure 2. Schematic illustration of the "highest consequence disturbed scenario" and the *mean CCA and PAVT CCDFs* for radionuclide releases from the WIPP TRUW repository *during the 10,000-year regulatory period.*

The National Academy of Sciences Committee on WIPP has monitored the WIPP project since 1978. It has published ten related reports and the last report states [10]:

> "For a repository disturbed by human intrusions, when evaluated on the basis of reasonable expectation of intrusive activities and their consequences, and using models that would implement available engineering features and do not make overly conservative assumptions, the consensus of the committee is that the WIPP repository could be shown to comply with the EPA standard."

Implicit in this statement are: (a) that the DOE has to implement regulatory-driven [5] [6] unreasonable expectations of intrusive activities, i.e., human-induced disturbances; and (b) that the assumptions used by the DOE in the CCA [2] are overly conservative.

However, notwithstanding these very compelling safety arguments, a broad range of fears and concerns remain among the public that need to be addressed. Three common public fears and concerns associated with any radioactive waste disposal project are:

- Any concept including the word *nuclear* or *radioactive conveys a stigma* dating back 50 years to the infamous mushroom clouds over Hiroshima and Nagasaki and the related human, material, and environmental devastation;
- The project typically presents an *involuntary risk* and *is* thus *not looked upon favorably or objectively*; and
- The *disposal of radioactive wastes involves state-of-the-art knowledge and analyses in a broad range of sciences and technologies not readily understood outside the group of specialists directly involved in the analyses.*

In addition to public health and environmental protection concerns, there seems to be an abundant fear around the world about proliferation associated with plutonium. In the case of the *filled* WIPP TRUW repository, it will contain a total of about 12,000 metric tons of plutonium, which equates to a volume of less than 1 m^3. This small volume of plutonium will be dispersed in 175,584 m^3 of TRUW of which at least 96 percent will have a surface dose rate equal to or below 0.002 Sv/h (see footnote to Abstract). Consequently, the WIPP TRUW is neither a potential proliferation threat because the plutonium in the TRUW is not readily accessible or conducive to separation or partitioning for nuclear weapons production nor a major disposal phase nor post-closure threat to public health or the environment. Hence, the CAO's near-term disposal-phase strategy focuses on:

- Enhancing the realism, reducing the uncertainties, and simplifying the conceptual and numerical models used in the WIPP PA;
- Responding to public concerns in terms that are more readily understood; and
- Actively encouraging, seeking, and participating in joint international collaborative efforts in the USA and abroad.

4. Summary of Observations and Conclusions

The 1998 certification and the 1999 opening of the WIPP TRUW repository are domestic milestones that were achieved by state-of-the-art means and measures. Indeed, the March 1999 opening of the WIPP TRUW repository commenced a new DOE era facilitating significant national risk reduction and environmental improvement by:

- Safe disposal of long-lived radioactive waste currently stored in temporary surface and near-surface structures, several of which are located adjacent to population centers; and

- Accelerated clean up of radioactively contaminated sites.

The certification, opening, and safe operation of the WIPP TRUW repository also signal a new era for enhanced acceptance and credibility of deep geological disposal of long-lived radioactive waste both in the USA and abroad. Intrinsically, perhaps ultimately, they also support the continued use of peaceful industrial, medical, agricultural, and research nuclear applications, because they demonstrate de facto to the world that deep geological disposal of long-lived radioactive waste can be safely done at a carefully selected site in a specially designed repository. Indeed, one of the most apparent and inescapable conclusions is that if primary reliance for the containment and isolation of long-lived waste is placed on the natural barriers rather than specially designed engineered barriers, rock salt is a very, if not the most, suitable geologic medium.

References

1. U.S. Environmental Protection Agency. Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance with the Disposal Regulations: Certification Decision; Final Rule, Federal Register, Volume 63, pp. 27354-27406, May 1998, Radiation Protection Division, Washington, D.C.
2. U.S. Department of Energy Carlsbad Area Office. Waste Isolation Pilot Plant Compliance Certification Application, Oct 1996.
3. U.S. Congress. The WIPP Land Withdrawal Act of 1992, Public Law 102-572.
4. U.S. Congress. The Nuclear Waste Policy Act of 1982, Public Law 97-425.
5. U.S. Environmental Protection Agency. Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, Code of Federal Regulations, Title 40, Part 191, Dec 1993.
6. U.S. Environmental Protection Agency. Criteria for Certification of the Waste Isolation Pilot Plant's Compliance With the 40 CFR 191 Disposal Regulations, Code of Federal Regulations, Title 40, Part 194, Feb 1996.
7. U.S. Environmental Protection Agency. Identification and Listing of Hazardous Waste, Code of Federal Regulations, Title 40, Part 261.
8. U.S. Environmental Protection Agency. Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities, Code of Federal Regulations, Title 40, Part 264.
9. U.S. Environmental Protection Agency. Land Disposal Restrictions, Code of Federal Regulations, Title 40, Part 268.
10. Committee on the Waste Isolation Pilot Plant, Board on Radioactive Waste Management, Commission on Geosciences, Environment, and Resources, National Research Council. The Waste Isolation Pilot Plant-A Potential Solution for the Disposal of Transuranic Waste, National Academy Press, Washington, D.C., ISBN 0-309-05491-5 (1986).