Performance Confirmation Strategies for the Waste Isolation Pilot Plant – A Historical Perspective from an Operating Disposal Facility - 12248

Steve Wagner
John Hart and Associate for Sandia National Laboratories, Carlsbad, New Mexico 88220

ABSTRACT

Performance confirmation is an important element of the Waste Isolation Pilot Plant (WIPP) program. Performance confirmation was first used during the early WIPP site-characterization phase to focus experimental activities that address the development of probabilistic repository performance models and to address stakeholder assurance needs. The program is currently used to analyze the conditions of the repository and its surroundings to ensure that the basis for the repository's long-term radioactive waste containment predictions is valid. This basis is related to the parameters, assumptions, conceptual and numerical models that are used to predict or validate the potential radioactive waste containment performance of the system. The concept of performance confirmation for the WIPP is one that has evolved since the first repository work was initiated decades ago and plays an important role in assuring adequate repository performance both now and in the long-term. The WIPP mission has progressed from a pilot project to an operational disposal facility and will progress to eventual site closure when disposal operations are completed. Performance confirmation is an important part of each of these progressions.

INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is a U.S. Department of Energy deep geologic repository sited in salt beds in Southeast New Mexico for the permanent disposal of defense-generated transuranic waste (see Figure 1). Performance confirmation is an important element of the WIPP project. The performance confirmation program is used to analyze the current conditions of the repository and its surroundings to ensure that the basis for the repository's long-term radioactive waste containment predictions is valid. This basis is related to the parameters, assumptions, conceptual and numerical models that are used to predict or validate the potential radioactive waste containment performance of the system. The concept of performance confirmation for the WIPP is one that has evolved since the first repository work was initiated decades ago and has played an important role in assuring adequate repository performance both now and in the long-term. The WIPP mission has progressed from a pilot project to an operational disposal facility and will progress to eventual site closure when disposal operations are completed. Performance confirmation is an important part of each of these progressions.

There are several drivers for the WIPP's performance confirmation program that will be discussed along with a description of the program, its operation and important findings.

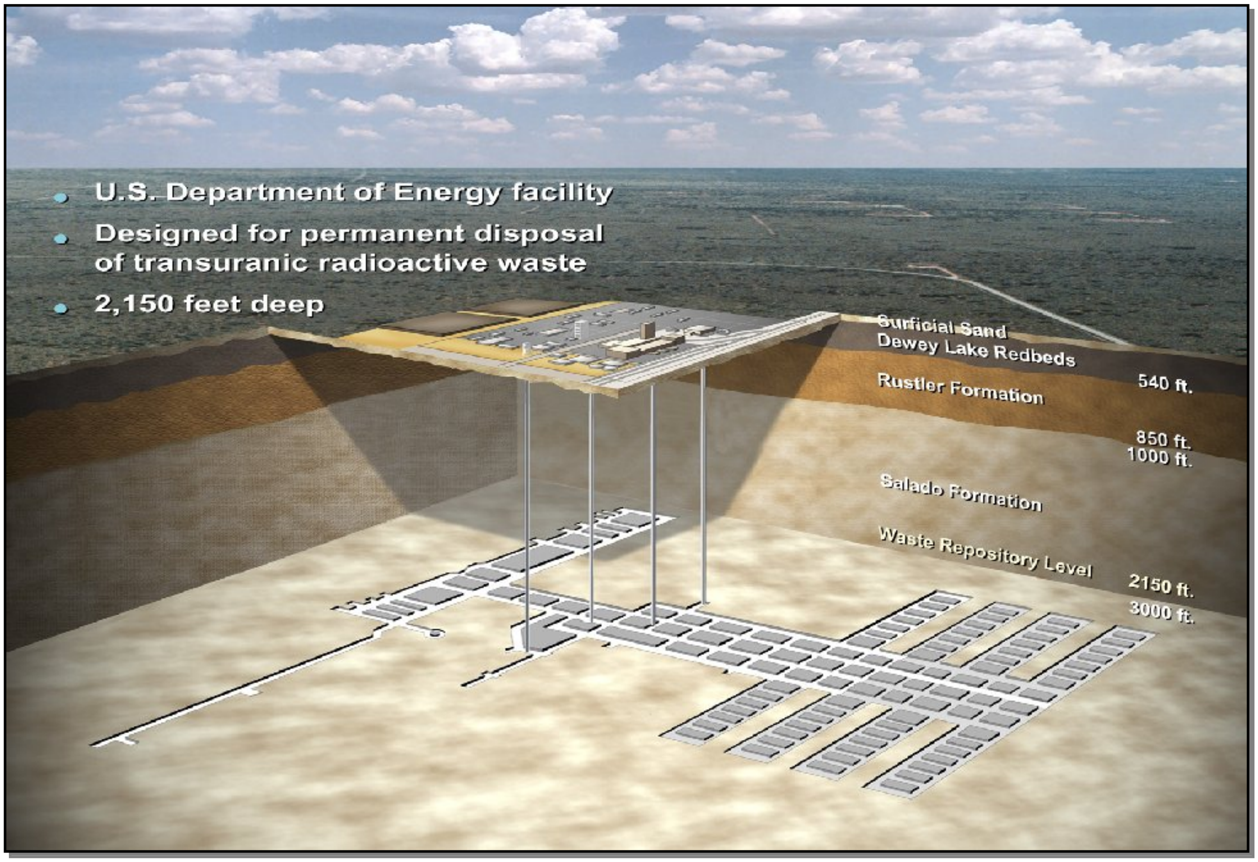

Figure 1. WIPP Underground Layout

EARLY WIPP HISTORY

Early radioactive materials research and defense activities generated the first radioactive waste in the U.S. Since these wastes comprised a small volume of hazardous radioactive materials, their disposal was not given much thought. Most waste was disposed in canyons, shallow near-surface landfills or stored in underground tanks[1]. After time, the problem of what to do with radioactive waste gained notice. The Atomic Energy Commission (AEC), the agency in charge of U.S. nuclear activities, commissioned the National Academy of Science (NAS) to investigate disposal options in 1955. Due to defense priorities at that time, waste disposal did not receive much attention until the late 1960s.

The first radioactive waste disposal proposal in Southeast New Mexico occurred in the early 1970s after the AEC abandoned an attempt to site a radioactive waste disposal facility in bedded salt near Lyons, Kansas. The disposal concept was based on the 1957 recommendations from the NAS which determined that geologic disposal of radioactive waste in salt was the most promising method for disposal [1]. Experimental work and a high-level waste disposal demonstration at Lyons concluded that radioactive

[1] The definition of waste used here does not consider used nuclear fuel as waste.

waste disposal in salt was feasible [2]. However, the discovery of previously unknown boreholes and nearby solution mining led to a search for other suitable bedded salt formations. In the early 1970s, Southeast New Mexico was chosen for a pilot disposal project. The first site characterization work started in 1974 with the drilling of two exploratory boreholes. The first shaft was constructed in 1981 with experimental rooms mined shortly thereafter. These activities generated valuable data that would be used to determine the site's suitability for long-term radioactive waste containment. Most of the data was developed to support the building of probabilistic computer models that were to predict the probability and consequence of long-term radionuclide releases away from the disposal system.

It is important to note that at the time the WIPP was sited, the intent was to dispose of both low-level and high-level waste. The predecessor agency for the Department of Energy, the AEC, was in charge of the project and gave Sandia National Laboratories the role of Scientific Advisor in 1974. Also, the project was self-regulating; there were no independent regulators or licensor. There were no specific regulations outlining radioactive waste containment performance criteria, necessary design elements or if additional measures were needed to address post-closure safety. Stakeholder involvement later changed these conditions.

WIPP IS REGULATED

At the time WIPP was originally sited it was believed that site characterization and a technical performance demonstration would provide most of the answers needed and would ensure stakeholders that the repository would be safe. However, political factors about what type of waste would be disposed in WIPP and a general mistrust of the implementing agency resulted in the U.S. Congress giving regulatory authority over the radioactive components of the waste to the Environmental Protection Agency (EPA). The EPA was also tasked to publish WIPP-specific certification criteria. The EPA had previously been given the task to write generic radioactive waste disposal standards for a radioactive waste disposal facility in 1975 which were not finalized until 1985 [3]. Additionally, stakeholder and state authorities wanted to be involved in the project and negotiated a formal agreement between the DOE and the State of New Mexico in 1981. These agreements included, among other things, a list of experimental activities, waste limitations and monitoring requirements that were to become elements of a performance confirmation program [4].

Once finalized, the EPA standards included radioactive containment requirements that were to be demonstrated through a probabilistic performance assessment (PA). The standards also included a requirement for multiple "assurance measures" that were intended to add confidence the repository would perform as predicted, as well as other requirements relating to disposal operations. Monitoring was included as one of these assurance measures. The monitoring requirements also became elements in the WIPP's performance confirmation program. The EPA standards that apply to WIPP are,

- *40 CFR 191: Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Waste* [5] and
- *40 CFR 194: Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Standards* [6].

WIPP STUDIES, PERFORMANCE PREDICTIONS AND PRE-OPERATIONAL PERFORMANCE CONFORMATION

As discussed above, regulations and state agreements both became drivers for PA and a performance confirmation program. However, there were other internal drivers.

Information was needed to build a robust and defensible PA model. Site characterization included in-situ and laboratory experiments on the disposal system's host rock, geologic structure, hydrology, seals designs, actinide chemistry, gas generation and many other aspects of the system. The State of New Mexico requested specific hydrologic studies to confirm parameters that were to be used in PA [4]. These activities created varying amounts of valuable information. As with all large projects, resources and timelines limit the depth that scientific research can investigate a particular aspect of the system. A decision-analysis tool called the "Systems Prioritization Methodology (SPM) was used to help prioritize the important parameters and experiments needed for PA and the compliance demonstration. The results led the DOE to select activities to pursue because they provided the optimal combination of information that had a high likelihood of demonstrating compliance with the EPA standards while assuring cost-effective use of limited resources. The SPM multi-attribute analyses used knowledge of existing experimental programs, existing models and sensitivity analyses to determine what elements were the most uncertain and sensitive to demonstrating compliance with the EPA standards. The SPM involved stakeholders, oversight groups and regulator's input and used this information within the prioritization. The final results were used by DOE to prioritize ongoing site characterization experiments and analyses [7]. The important elements identified for further study included:

- Concentrations and Transport of Colloid Carriers
- Culebra[2] Fracture/Matrix Flow Laboratory Studies
- Multi-Well Tracer Test
- Rock Mechanics
- Studies of Short and Long-Term Shaft Seal Components
- Blowout Releases
- Dissolved Actinide Solubilities for Oxidation States +III to +VI
- Chemical Retardation for Th, Np, Pu, U and Am

[2] The Culebra Member of the Rustler Formation is the most transmissive water bearing zone above the repository. The Culebra is one of the transport pathways modeled in the WIPP PA.

These activities were the basis for the performance confirmation program that pushed the project past the site characterization stage of the repository's life cycle. The program produced important data and confirmatory information that was used to finalize conceptual models, parameter ranges and numerical model implementation in a compliance PA that ultimately demonstrated the repository would meet EPA's disposal standards. Disposal of transuranic waste was initiated shortly thereafter in 1999. Performance confirmation activities did not stop with this accomplishment.

OPERATIONAL-PHASE PERFORMANCE CONFIRMATION

The EPA included requirements in its disposal standards for a monitoring program that met the common definition of Performance Confirmation. The intent of such a program was to use various techniques that continually challenge the basis used to satisfy the safety case for a repository. The purpose of the program is to provide additional assurance that the repository will safely isolate waste from the biosphere as predicted. For WIPP, EPA stated:

"Assurance requirements were included in the disposal regulations to compensate in a qualitative manner for the inherent uncertainties in projecting the behavior of natural and engineered components of the WIPP for many thousands of years." [8]

The EPA included six assurance measures to be applied to the disposal system. Specifically one measure applies to performance confirmation. EPA stated:

"[The] Disposal systems shall be monitored after disposal to detect substantial and detrimental deviations from expected performance. This monitoring shall be done with techniques that do not jeopardize the isolation of the wastes and shall be conducted until there are no significant concerns to be addressed by further monitoring."[5]

EPA further outlined how such a program was to be developed.

"The Department shall conduct an analysis of the effects of disposal system parameters on the containment of waste in the disposal system and shall include the results of such analysis in any compliance application. The results of the analysis shall be used in developing plans for pre-closure and post-closure monitoring...." [6]

The DOE qualitatively and quantitatively analyzed potential PA parameters to determine what aspects of the system could be monitored to meet the EPA's requirements. DOE used EPA guidance in the standard to develop the following criteria to assess these parameters [7].

- Addresses significant disposal system parameters defined by their:
  - effect on the system's ability to contain waste.
  - effect on the ability to verify predictions about the performance of the disposal system.
- Addresses an important disposal system concern,

- Obtains meaningful data in a short time period,
- Will not violate disposal system integrity, and
- Complements other existing environmental monitoring programs.

The results of the analysis identified ten parameters that met the criteria. The analyses were documented in the DOE's Compliance Certification Application to the EPA [9]. The parameters chosen relate to human activities in the surrounding area, groundwater hydrology, geotechnical performance, waste activity and overburden subsidence. The specific parameters are:

- Creep Closure and Stresses - The closure rate of the mined openings
- Extent of Deformation – Fracture propagation in rock surrounding drifts
- Initiation of Brittle Deformation - Qualitative parameter related to rock behavior.
- Displacement of Deformation Features - Lateral displacement of drift boreholes
- Culebra Ground Water Compositions - Relates to flow, transport and solubility assumptions
- Change in Culebra Ground Water Flow – Relates to transmissivity model and the groundwater basin model
- Drilling Rate – Exploratory drilling human activity used in PA intrusion scenario
- Probability of Encountering a Castile Brine Reservoir[3] - Exploratory drilling activity used in PA intrusion scenarios
- Subsidence Measurements – Ground movement response from mining repository
- Waste Activity – Curies of ten important radionuclides

The confirmation program using these ten monitoring parameters has been in operation since 1999 and the results reported annually. The program has been verified by the EPA to meet their assurance requirements and is reassessed at each five-year recertification cycle. The program has proven beneficial in identifying conditions that are outside PA expectations. Specific changes have been made to PA models as a direct result of this performance confirmation monitoring program (an example will be discussed in the next section).

The operational monitoring program will be reassessed prior to site closure to finalize a post-closure performance confirmation program that is required by EPA and is expected to be maintained for at least 30 years and up to 100 years after site closure.

ACTIONS RESULTING FROM THE WIPP PERFORMANCE CONFIRMATION PROGRAM

One of the ten performance confirmation parameters involves the monitoring of a hydrological feature above the repository. Water levels in the Culebra formation are monitored in a well network over the site. Specifically, the assessment of the monitoring

[3] The Castile Brine Reservoir is a pressurized water bearing zone believed to be below the repository. The WIPP PA models drilling scenarios that intersect the Castile Brine Reservoir.

parameter “Changes in Groundwater Flow” involves trigger values derived from the steady-state freshwater heads estimated for the Culebra formation ground water flow model in the WIPP PA. A trigger value is a condition or value used to identify when a monitoring parameter is outside expected limits. The Culebra formation transmissivity (T) fields that were subsequently used to simulate the transport of radionuclides through the Culebra were considered calibrated when, among other things, the modeled heads at 32 monitoring wells fell within the ranges of uncertainty estimated for steady-state freshwater heads at those wells. If monitoring shows that heads at these wells are outside the ranges used for T-field calibration, the cause and ramifications of the deviations would need to be investigated. That was the case in 2000 when 17 wells were considered outside the expected range. The scientific advisor began a four-year investigation of possible causes for the unexpected conditions [10]. Additional geologic interpretations from borehole logs, new groundwater data and modeling led to a change in the PA groundwater conceptual model and the numerical implementation of that mode (see Figure 2)l. After the models passed a formal peer review, a new PA was run in 2009 that incorporated these changes into the WIPP baseline.

Figure 2 – WIPP Groundwater Investigations – Monitoring Well Drilling and Testing

A new method to assess “Change in Groundwater Flow” parameter was also developed that linked freshwater head data with modeled particle travel times. The travel time for a particle in the modeled flow field that uses the latest monitoring data is compared to the distribution of 100 travel times computed in the baseline PA to ensure it falls within the range of computed travel times. This method has been used to assess the current groundwater monitoring data for the last two reporting cycles. No further unexpected conditions have been observed.

This example shows how the WIPP performance confirmation program identified a condition outside PA expectations, researched the cause and effects and modified the modeling of the system to account for the new information. The result is a more robust understanding of the disposal system.

DISCUSSION

The concept of disposing radioactive waste in a geologic repository today involves a complete understanding of many technical, political, regulatory, societal and economic elements. Many of these elements overlap and solving all relevant issues necessary to site, operate and decommission a disposal facility should be done with knowledge of each element's requirements and impacts. Performance confirmation is one tool that can help to coordinate many of these elements into a program that actively investigates what is thought to be adequately understood about the system and what information is lacking. A performance confirmation program is used to determine ways to challenge and verify those areas that are thought to be understood and to find ways to understand those areas that are not well understood.

Performance confirmation programs have been used twice at WIPP, first during site characterization and PA development and later in a Compliance Monitoring program. At first, only certain technical aspects of the system were deemed important because it was a scientifically-based, government project. Early site characterization work was design to gather information about the geology and hydrology of the area and the mechanical properties of the natural barrier. The information would be used in a PA to determine the long-term containment performance of the disposal system. A performance confirmation element was used to identify the sensitive elements of the system that were certain, well understood or justified and those that were not. It identified experimental and analytical programs that could be used to reduce uncertainty, confirm sensitive assumptions and provide useful data. This performance confirmation program provided data to justify the adequacy of the information used in PA to demonstrate compliance with EPA's containment requirements.

Performance confirmation will continue to be used in the post-closure period for at least 30 years and likely up to the end of the 100-year institutional controls period. As the technical basis for the repository matures throughout the operational period, the currently planned post-closure monitoring program will need to be reassessed prior to implementation. However, the intent of the program will be the same as it was for the previous programs, to ensure the ultimate goal of the repository. This goal is to safely isolate waste from the accessible environment and ensure public and environmental safety.

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ACKNOWLEDGEMENT

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. This research is funded by WIPP programs administered by the Office of Environmental Management (EM) of the U.S Department of Energy