

## Lessons Learned from WIPP Site Characterization, Performance Assessment, and Regulatory Review Related to Radionuclide Migration through Water-Conducting Features

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### *Abstract*

Many lessons have been learned over the past 24 years as the Waste Isolation Pilot Plant (WIPP) project has progressed from initial site characterization to final licensing that may be of relevance to other nuclear-waste-disposal projects. These lessons pertain to the manner in which field and laboratory investigations are planned, how experiments are interpreted, how conceptual and numerical models are developed and simplified, and how defensibility and credibility are achieved and maintained. These lessons include: 1) Site characterization and performance assessment (PA) should evolve together through an iterative process, with neither activity completely dominating the other. 2) Defensibility and credibility require a much greater depth of understanding than can be represented in PA models. 3) Experimentalists should be directly involved in model and parameter abstraction and simplification for PA. 4) External expert review should be incorporated at all stages of a project, not just after an experiment or modelling activity is completed. 5) Key individuals should be retained for the life of a project, or a process must be established to transfer their working knowledge to new individuals. 6) An effective QA program needs to be stable and consistent for the duration of a project and focus on best scientific practices. All of these lessons relate to the key point that consideration must be given from the earliest planning stages to maximizing the defensibility and credibility of all work.

### **Introduction**

Over the past 24 years, the WIPP project has moved from site characterization to performance assessment to regulatory review to final licensing. Evaluation of radionuclide migration through water-conducting features has been a key concern throughout the history of the project, and has been an area in which many lessons have been learned that may be of relevance to other nuclear-waste-disposal projects. These lessons pertain to the manner in which field and laboratory investigations are planned, how experiments are interpreted, how conceptual and numerical models are developed and simplified, and how defensibility and credibility are achieved and maintained.

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## Lesson 1: Site characterization and PA should evolve together.

In the early stages of a project, a broad-based approach to site characterization must necessarily be adopted. The conceptual models that led to selection of the site for characterization in the first place must be tested and refined. As knowledge is improved, probabilistic PA modelling can be performed to identify the uncertainties in features and processes most relevant to safety, which then become the subject of additional characterization. This process continues until a set of conceptual and mathematical models is developed that is defensible, with uncertainties low enough to support a licensing decision.

As one example from WTPP of this process working well, a localized zone of relatively high transmissivity was discovered in the Culebra dolomite that models showed would be the dominant groundwater pathway for off-site transport. Accordingly, considerably more effort went into quantifying the hydraulic properties of the Culebra in this region than in other regions. Then, as matrix diffusion was found to be an important process affecting contaminant transport in this region of the Culebra, a great emphasis was placed on field and laboratory testing and model development to understand the process in depth and reduce the uncertainty in its effectiveness.

Early PA results should not be used to terminate experimental programs on the grounds that safety can be adequately demonstrated without invoking the process or mechanism to be studied. Early understandings of the relative importance of different processes sometimes change as a project progresses, and no real barrier to radionuclide migration should be ignored simply because it "isn't needed", if for no other reason than that it provides additional confidence in a site. In the late 1980's, studies related to chemical retardation (sorption) in the Culebra were terminated because physical retardation alone was thought to be adequate to demonstrate compliance with regulations. As our understanding of the features, events, and processes (FEPs) that needed to be considered changed in subsequent years, however, chemical retardation was found to be important in some scenarios. As a result, the experimental programs were hastily resumed and had to make up for lost time.

Likewise, early site-characterization data should not overly bias continued characterization until PA has established the importance of the data to compliance. Scientists involved in site characterization always have a conceptual model of the system they are studying, even if this model resides only in their heads. In the case of the Magenta dolomite at the WIPP site, this conceptual model led to a conclusion early in the project's history that because the Magenta was everywhere found to be less permeable than the Culebra, it was unimportant as a potential radionuclide transport pathway relative to the Culebra. Accordingly, considerably less effort was devoted to characterizing the Magenta even though no numerical modelling had been performed that demonstrated the unimportance of transport through the Magenta. In fact, PA models prior to 1993 arbitrarily precluded Magenta transport [1]. During the final technical review process leading up to the WIPP Compliance Certification Application (CCA) [2], some reviewers thought the Magenta had not been adequately characterized to make the case that transport through it could not affect compliance under any scenario. (They agreed, however, that the relative lack of characterization of the Magenta did not affect the finding that it was unimportant in the specific scenarios considered in the CCA [3].) In this instance, site characterization did not provide PA with enough data for detailed modelling because of a preconceived notion of unimportance. This example illustrates that "less likely" transport pathways should not be incompletely characterized simply because a dominant pathway is thought to exist.

These examples illustrates a key lesson, that site characterization and PA should evolve together through an iterative process, with neither activity dominating the other. For experimental

guidance, PA should use reasonable estimates of parameter and conceptual uncertainty and not "conservative" assumptions that may bias results towards preconceived notions. Site characterization should be cautious about focusing attention on assumed dominant processes or pathways before PA modelling is performed. Throughout, experimentalists should seek to define and reduce uncertainties, while PA modellers should seek to determine the effects and importance of uncertainties.

### **Lesson 2: Defensibility and credibility require more knowledge than PA.**

Although PA models may represent some processes in a simplified fashion, a detailed understanding of those processes, requiring detailed models, is also necessary. Performing experiments and developing models for test interpretation that are more detailed than those that will ultimately be used in PA serve two important functions. First, they allow a detailed understanding of a process to be developed and, just as importantly, demonstrated. Second, they provide a defensible basis for model simplification as the scale under consideration increases. The detailed understanding allows convincing demonstration of the adequacy of the simplified PA approach.

For instance, double-porosity models incorporating multirate matrix diffusion were developed to represent WIPP tracer-test data on the scale of tens of meters, while site-scale modelling for the WIPP CCA used a simplified model with a single rate of diffusion. The simplified model used to represent matrix diffusion in the CCA has been accepted because of the detailed technical understanding of the process that has been developed through field tracer testing. In the case of anhydrite interbed fracturing, however, the simple model used in the CCA to represent fracturing as a function of imposed pore pressure was criticized because no detailed understanding of the phenomenon could be demonstrated [3]. The experiments that had been designed to provide that detailed understanding had been terminated as having "no performance effect" prior to completion [4].

These examples illustrate another key lesson, that the demands of defensibility and credibility require that a system or process must be understood to a much greater level of detail than the way in which it can be represented in PA models.

### **Lesson 3: Experimentalists should be involved in model/parameter abstraction.**

The scope of activities involved in characterizing groundwater flow and transport and building PA models to represent those processes creates the tendency for individuals to specialize in specific disciplines. Model simplification or abstraction, however, can be a complex process, requiring an understanding of how a process operates at both the small, experimental scale and at the large, PA scale. For this reason, the experimentalists responsible for developing the small-scale understanding of a process should also be directly involved in defining the simplification and associated parameter values that will be used for the PA models. For example, a parameter such as fracture spacing may have a range of values in modelling individual tracer tests, but be represented by a single value in PA models. Those most familiar with the range of values that a parameter takes and the effects of different values on behavior are best able to evaluate the effect that reducing the range to a single value will have on PA model results. Including experimentalists in the model-simplification process also avoids the awkward situation of experimentalists being unwilling to defend the models and/or parameter values used by PA.

#### **Lesson 4: External expert review should be incorporated at all stages.**

External expert review should be incorporated at all stages of a project. Test and analysis plans should be critiqued by the same experts whose support of the test results is desired. Responding to substantive criticisms is far easier while a test is still in the planning stages than after the test is complete. The plans for the recent WIPP tracer tests at the H-11 and H-19 hydropads were strengthened tremendously by reviews received through INTRAVAL and the WIPP Geostatistics Expert Group (GxG), as well as by critiques from the National Academy of Sciences WIPP Review Panel, the New Mexico Environmental Evaluation Group, and the Environmental Protection Agency. By being open about plans, publicly seeking out criticism from recognized experts, and being seen to be responsive to that criticism, both the defensibility and credibility of models are strengthened. If possible, the regulatory body with ultimate jurisdiction over licensing should also be included in the planning and analysis of experiments and modelling activities. This will ensure that their views are considered as the work proceeds and that they have a good understanding of, and confidence in, the final results.

#### **Lesson 5: Attention must be paid to maintaining project knowledge.**

Decades may elapse as a nuclear-waste-disposal project progresses from site characterization to licensing, during which individual scientists may come and go from the project. Having individuals knowledgeable about all aspects of a project can be critical during licensing hearings, in which questions may arise concerning work performed many years earlier. Therefore, either key individuals should be retained for the life of a project or, more realistically, a process should be established to ensure that the knowledge they possess is not lost to the project when they are no longer available. For example, new staff could be apprenticed to the more experienced staff on the project until they had mastered the historical concepts, experiments, models, and conclusions from earlier stages of the project. Having published reports on a topic is not adequate to establish credibility if no one is able to explain them and respond extemporaneously to questions about them.

#### **Lesson 6: An effective QA program needs to be stable and consistent, emphasizing best scientific practices.**

Defensibility of data depends in part on an effective quality assurance (QA) program. A QA program also needs to be stable and consistent throughout the duration of a project so that data collected that satisfied the standards in place when the project began are not found to be inadequate by the standards of a later time. Because of continuing changes in QA requirements, the WIPP project was forced to perform an extensive (and expensive) peer-review process to validate the use of existing data in the final PA. Some data that had been collected in accordance with the standards of the time were found to be unusable by current standards. This waste could have been avoided if the original QA program could have been designed to satisfy the ultimate licensing requirements. Unfortunately for WIPP, those requirements were not specified until 1996, 22 years after the project had begun.

Recognizing that regulatory environments and requirements are continually evolving in most countries and are, therefore, unpredictable decades into the future, QA programs should emphasize "best scientific practices" as recognized by scientists around the world. In judging the defensibility of data collected under early WIPP QA programs, the technical reviewers focused almost exclusively on the quality of the scientific practices followed (e.g., appropriate experiment designs, adequate

equipment, documentation of how the experiment was performed, and documentation of experimental results), and paid little attention to the detailed requirements of the old, or present, QA programs.

### Summary and conclusions

Nuclear-waste-repository programs should recognize the following lessons: 1) Site characterization and PA should evolve together through an iterative process, with neither activity completely dominating the other. 2) Defensibility and credibility require a much greater depth of understanding than can be represented in PA models. 3) Experimentalists should be directly involved in model and parameter abstraction and simplification for PA. 4) External expert review should be incorporated at all stages of a project, not just after an experiment or modelling activity is completed. 5) Key individuals should be retained for the life of a project, or a process must be established to transfer their working knowledge to new individuals. 6) An effective QA program needs to be stable and consistent for the duration of a project and focus on best scientific practices.

The overarching lesson learned from the WIPP experience is the need to view every experiment and model in the context of how it will be used and viewed during the licensing procedure. Consideration must be given from the earliest planning stages to maximizing the defensibility and credibility of all work. The role of individual scientists in providing that credibility should not be overlooked.

### References

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