Guest Editorial: The 1996 Performance Assessment for the Waste Isolation Pilot Plant

The appropriate disposal of radioactive waste is a problem of great importance, wide-spread interest, and some controversy.[1-13] As part of the solution to this problem, the Waste Isolation Pilot Plant (WIPP) is under development by the U.S. Department of Energy (DOE) for the deep geologic disposal of transuranic (TRU) waste generated by defense programs in the United States.[14-16] The DOE submitted a Compliance Certification Application (CCA)[17] for the WIPP to the U.S. Environmental Protection Agency (EPA) in October 1996, and a positive certification decision for the WIPP was issued by the EPA in May 1998.[18] The first disposal of TRU waste in the WIPP took place in March 1999.

The 1996 CCA for the WIPP was supported by an extensive performance assessment (PA) carried out by Sandia National Laboratories (SNL), with this PA often designated the 1996 WIPP PA, the 1996 CCA PA, or simply the 1996 PA. In turn, the 1996 PA was supported by site characterization activities, experimental programs, model development programs, data development programs, uncertainty and sensitivity analyses, a dedicated computational environment, a rigorous quality assurance (QA) program, and a sequence of earlier PAs. Further, this PA was carried out in a regulatory environment defined by the following EPA regulations: *Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes* (40 CFR Part 191)[19,20] and *Critieria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations* (40 CFR Part 194).[21]

The WIPP is the first licensed facility in the United States for the deep geologic disposal of radioactive waste. As a result, there is extensive interest in both the WIPP and the analyses that led to its certification by the EPA for the disposal of TRU waste. The WIPP program has produced large amounts of documentation both as part of the CCA itself and in large numbers of technical reports and supporting analysis documents. Although this information is publicly available, in practice its great quantity and availability at only specific locations (e.g., EPA Docket locations, the WIPP Records Centers in Albuquerque and Carlsbad) make obtaining a detailed understanding of the 1996 WIPP PA an arduous undertaking.

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As a result, the Guest Editors are pleased that Professor Apostolakis has invited us to prepare a special issue of *Reliability Engineering & System Safety* on the 1996 WIPP PA. In preparing this issue, our goal was to develop descriptions of the WIPP and the 1996 WIPP PA that would allow a complete understanding of the technical details of this analysis. Thus, for example, when a model is a system of partial differential equations, a complete description of this system, associated boundary and initial value conditions, and numerical solution procedures is given. However, details of the implementing computer program and associated input/output file manipulations are omitted. As a result, the descriptions given are considerably more detailed than several recent presentations intended to give high-level overviews of various aspects of the PA[22-24] but, at the same time, less detailed than full analysis reports intended to provide complete archival descriptions of individual parts of the PA and the logistics of their implementation.[25-32]

The issue begins with a sequence of background papers on the WIPP and the 1996 WIPP PA. In particular, these papers provide summaries pertaining to the WIPP on ( ) historical development (Rechard), ( ) geologic and hydrologic setting (Swift and Corbet), ( ) development of conceptual models for chemical conditions and hydrology (Larson), (v) design and construction of shaft seal systems (Hansen and Knowles), (v) radioactive and non-radioactive waste intended for disposal (Sanchez, et al.), (v) regulatory requirements (Howard, et al.), and (v) scenario development (Galson, et al.). These papers provide an overview of the basic information underlying the 1996 WIPP PA and references to sources of additional information.

An interesting and challenging aspect of the EPA's regulations for the WIPP (40 CFR 191, 40 CFR 194) is that they require a separation of stochastic (i.e., aleatory) and subjective (i.e., epistemic) uncertainty.[33,34] In essence, these regulations require that the results of a PA supporting a CCA for the WIPP be presented as a distribution of complementary cumulative distribution functions (CCDFs), with the individual CCDFs arising from stochastic uncertainty and the distribution of CCDFs arising from subjective uncertainty. Maintaining this separation required a clear conceptual model to guide the design and numerical implementation of the 1996 WIPP PA. Individual articles provide descriptions of ( ) the conceptual structure of the 1996 WIPP PA (Helton, et al.), ( ) the characterization of stochastic uncertainty (Helton, Davis and Johnson), and ( ) the characterization of subjective uncertainty (Helton, Martell and Tierney).

The 1996 WIPP PA is underlain by extensive modeling of the physical processes that can occur in the vicinity of the emplaced waste and possibly result in the movement of some of this waste to the accessible environment. Individual articles provide descriptions of the models for ( ) two-phase flow in the vicinity of the repository (Vaughn, et al.), ( ) releases due to cuttings, cavings and spallings movement to the surface at the time of a drilling intrusion (Berglund, et al.), ( ) releases due to brine movement to the surface at the time of a drilling intrusion (Stoelzel, et al.), (v) long-term transport of radionuclides away from the repository due to flowing groundwater (Stockman, et al.), and (v) long-term transport of radionuclides in the Culebra Dolomite due to flowing groundwater (Ramsey, et al.).

With the exception of the presentation on two-phase flow, the preceding articles ( ) describe the models in use, ( ) present CCDFs for the particular release mode or modes under consideration, and ( ) present uncertainty and sensitivity analysis results, with the CCDFs deriving from the effects of stochastic uncertainty and the uncertainty and sensitivity analysis results deriving from the effects of subjective uncertainty. Uncertainty and sensitivity analysis results for two-phase flow are presented in two separate articles, with one article describing results for undisturbed conditions (Helton, et al.) and the other article describing results for disturbed conditions (Helton, et al.). Here, disturbed and undisturbed refer to whether or not the repository has been penetrated by a drilling intrusion associated with exploration for natural resources.

The 1996 WIPP PA underwent extensive outside review.[35,36] The only important part of the PA that this review identified as being inadequate was the model for spallings. In response, additional model development was carried out,[37] and the conclusion was reached that the model used in the PA overestimated the size of the spallings release (Knowles, et al.). Thus, as the spallings-release estimates did not violate the EPA's release limits for the WIPP, the spallings model did not lead to erroneous implications about the WIPP's compliance with applicable regulations.

Implementation of the 1996 WIPP PA was a large effort. Given that the PA would undergo rigorous scrutiny in a regulatory, and possibly contentious, environment, the analysis had to be developed and then carried out with great care. Thus, appropriate QA procedures were an integral part of the 1996 WIPP PA (Froehlich, Ogden and Byle).

Further, the large scale of the analysis resulted in significant computational requirements in the performance and subsequent archival storage of the large number of calculations underlying the analysis (Froehlich, Williamson and Ogden). The two preceding articles on QA and computational logistics describe important, and often underreported, components of large analyses.

The issue ends with a summary article (Helton, et al.) that presents the overall CCDF used in comparison with the EPA release standards. Further, this article describes various insights that emerged from the 1996 WIPP PA and provides suggestions on the performance of similar analyses.

This issue provides an unusually complete description of a large, and potentially influential, analysis. The Guest Editors are grateful to Professor Apostolakis for the opportunity to present this description in *Reliability Engineering & System Safety* and hope that this issue will be helpful to individuals who wish to understand the 1996 WIPP PA and the CCA that it supports and also to individuals who must plan and carry out similar analyses.

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