The Role of Independent Scientific and Engineering Analyses in the Regulatory Process

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Since it was established in 1987 by the U.S. Nuclear Regulatory Commission (NRC), the Center for Nuclear Waste Regulatory Analyses (CNWRA) has assisted NRC in fulfilling its responsibilities under the Nuclear Waste Policy Act related to a potential repository at Yucca Mountain, Nevada, and interim storage facilities for spent nuclear fuel and high-level radioactive waste. CNWRA attributes have assured its success in assisting NRC. These attributes include clearly defined roles and responsibilities, which encompass independent scientific and engineering analyses. Examples illustrate how these analyses have enhanced the regulatory process.

KEYWORDS: radioactive waste, spent nuclear fuel, regulation, analyses, independence

1. Introduction

Scientific and engineering analyses conducted independently by or for a regulator support the regulatory process. Through such analyses, the regulator can probe an applicant's safety analysis to formulate and articulate the technical bases for a regulatory decision. Independent analyses can also assess the clarity of proposed regulatory requirements and test their validity. Examples of independent scientific and engineering analyses related to a potential high-level radioactive waste repository, conducted on behalf of the U.S. Nuclear Regulatory Commission (NRC), illustrate support to the regulatory process.

2. Organizational Attributes

In 1987, the Center for Nuclear Waste Regulatory Analyses (CNWRA) was established to support NRC responsibilities under the Nuclear Waste Policy Act related to a potential repository at Yucca Mountain, Nevada, and interim storage facilities for spent nuclear fuel and high-level radioactive waste. NRC assured that CNWRA had attributes essential to that support. These attributes are that CNWRA (i) be independent, free from the potential for conflict of interest; (ii) be competent, capable of consistently high-quality support; (iii) have longevity, to assure continuity of support and a "corporate memory;" (iv) complement NRC staff, to avoid gaps or overlaps in technical expertise; and (v) have clear roles and responsibilities. These attributes are important to the success of NRC and the CNWRA. Independent scientific and engineering analyses have proven particularly important.

3. Roles of Independent Scientific and Engineering Analyses

Appropriate supporting roles and responsibilities to a regulator include providing research and technical assistance, developing technical bases for regulations and guidelines, reviewing applicant safety analyses, providing hearing support, enhancing public outreach and communications, and providing technical advice. CNWRA has assisted NRC in all these areas. In each area, independent scientific and engineering analyses have been important to the NRC regulatory process. Several examples—from field and laboratory investigations of physical processes, scoping calculations of risk to evaluate relative importance to safety, new approaches to presenting complex information to stakeholders, and hearing support—illustrate these roles.

3.1 Development and Implementation of Regulations and Guidance

Both international organizations and national authorities, such as NRC, develop and implement regulatory frameworks consistent with applicable laws. Typically, the regulatory framework includes environmental standards, implementing regulations, and associated guidelines.

In the U.S., NRC developed a regulation applicable to the potential repository at Yucca Mountain, Nevada, [1] and a formal guidance—the Yucca Mountain Review Plan [2]—on how NRC staff is to review and evaluate a license application for the repository. The NRC and CNWRA staff conducted scoping studies to build confidence that the regulations could be effectively implemented and the review guidance would result in a technically sound and comprehensive safety evaluation report.

The regulation [1] for the potential repository establishes (i) an all-pathways mean-annual-dose criterion, (ii) a human intrusion criterion, and (iii) a groundwater protection criterion. Staff judgments about regulatory implementation rely on a total-system performance assessment methodology. The NRC and CNWRA staff collaborated on the Total-system Performance Assessment (TPA) computer code to support the regulation development process. [3] This independently developed TPA code allowed the staff both to evaluate the adequacy of the performance assessment methodology in a risk-informed, performance-based regulatory context and to define the information and analyses to specify in the regulation. Staff built confidence in the adequacy of the method to treat (i) undisturbed conditions (normal evolution of the repository) and disruptions from natural phenomena, (ii) large spatial scales and the accompanying need to simplify or abstract complex models, (iii) the long time-period of interest, (iv) parameter uncertainty, and (v) alternative process models. Figure 1 illustrates an independent calculation using the TPA code.

3.2 Evaluation of the Relative Importance of Factors Affecting Repository Performance

Characteristics of all geologic repositories include (i) large spatial scale; (ii) long performance timeframe; (iii) interaction among natural and engineered systems; (iv) complex thermal-hydrological-mechanical-chemical processes; (v) a large variety of radiotoxic materials and physical-chemical behaviors; (vi) large uncertainties; and (vii) events of very low probability, but potentially high consequence.

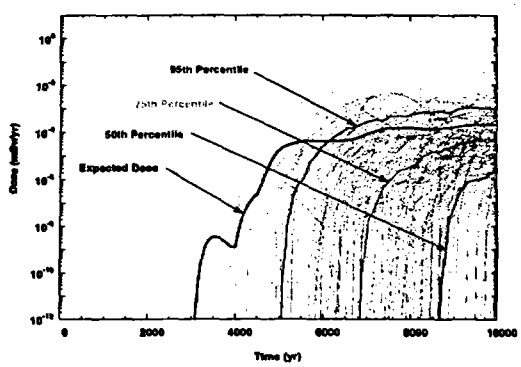


Fig.1 Individual dose estimated for undisturbed conditions with NRC-CNWRA TPA code. Each Monte Carlo realization is shown with various percentiles, and the mean. The spread represents the effect of parameter uncertainties.

To effectively and efficiently focus efforts, both developers and regulators of geologic repositories must understand the relative importance of the factors affecting performance. In the U.S. program, this focus is fostered by the risk-informed framework of the regulation and facilitated by application of both process-level (i.e., subsystem-level) and total-system analyses.

Fundamental to the consideration of locating a geological repository at Yucca Mountain is the notion that waste packages would remain relatively dry for long periods in the hydrologically unsaturated rocks. [4,5] Questions about the potential for salts in groundwater and atmospheric dusts to accumulate on waste packages and create conditions that could foster localized corrosion led CNWRA to conduct independent investigations of the processes involved and the likelihood of such conditions developing. Laboratory studies examined the effect of salts in groundwater and atmospheric dusts on the deliquescence point of solutions that could contact the waste package

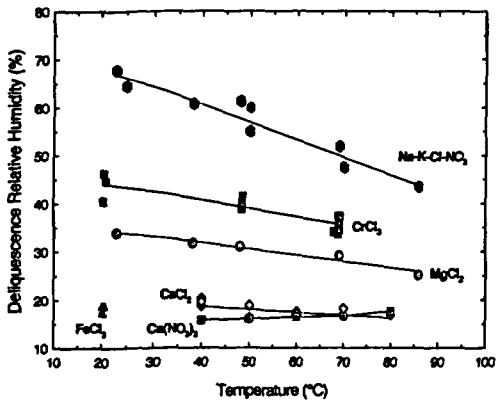


Fig.2 Relative humidity in the presence of salts as a function of temperature. Relative humidity can affect potential onset of localized corrosion.

[Figure 2]. Results included the in-depth understanding staff needed to support evaluations of DOE studies, assessed the factors (e.g., temperature dependence) affecting the magnitude of the potential effect, and identified the presence of chemical species that could mitigate localized corrosion. These results allowed assessment of the likelihood of localized corrosion in the presence of deleterious and effect-mitigating chemical species.

Relative importance can be evaluated from major repository subsystems down to individual radionuclides. For example, independent analyses examined the relative importance of waste packages and drip shields (designed to prevent infiltrating water from contacting the waste package at high temperatures). Using the best available information about the natural system and proposed repository design [6,7], a 350-realization run of TPA was used to estimate the basecase dose for undisturbed conditions [Figure 3]. This calculation was repeated, first assuming all drip shields failed at 0 year (time of closure) and then assuming both the drip shields and waste packages failed at 0 year. The results illustrate how these components affect the onset of radionuclide release (i.e., when contaminants begin to reach the accessible environment) and the magnitude of release (i.e., the peak dose to a receptor in the accessible environment). Similar importance analyses have enabled the staff to better understand repository performance and focus regulatory oversight on the most important factors affecting performance [Figure 4].

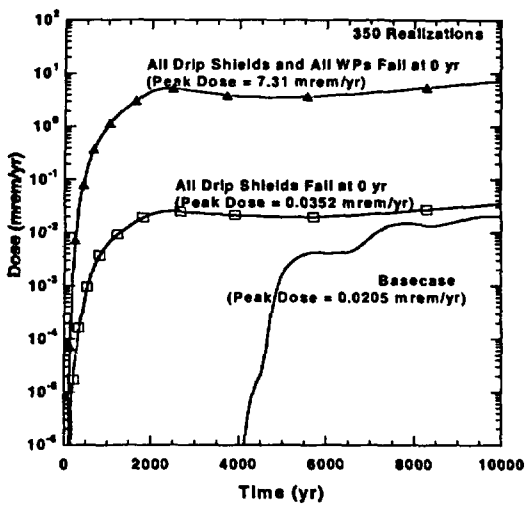
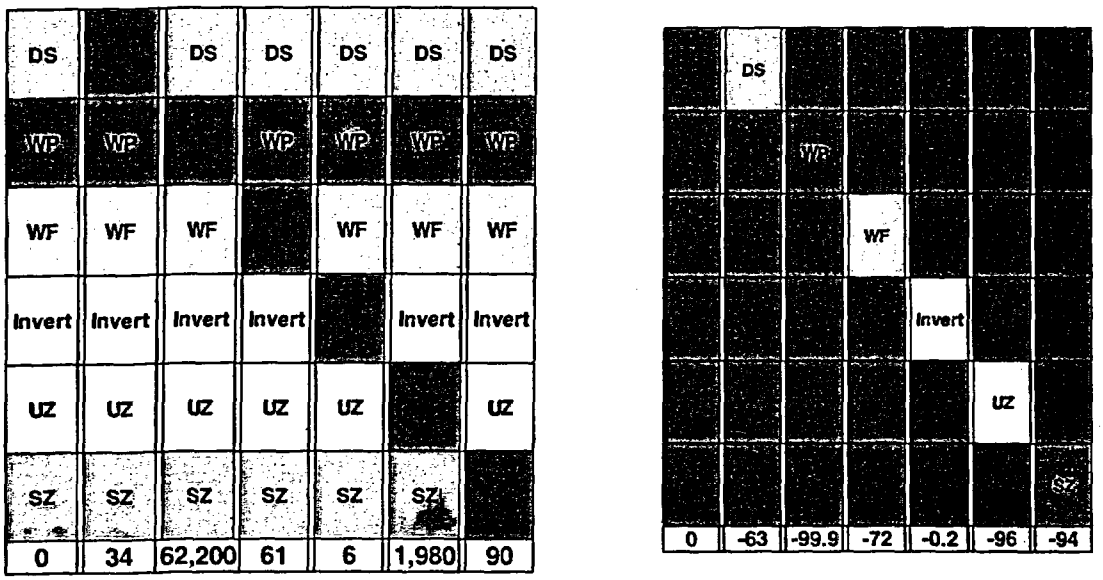


Fig.3 A representation of system sensitivity to subsystem performance. The graphs indicate that drip shields have a relatively moderate influence while waste packages have a significant influence on system performance. (1 mrem = 0.01 mSv).

Relative contribution of radionuclides can be similarly evaluated. Table 1 illustrates the results of an evaluation of radionuclides that contribute most to estimated dose at the receptor location for the groundwater release pathway (i.e., undisturbed performance). More than 90 percent of the estimated dose results from only three radionuclides. Importantly, the independent study also provided insight into why these radionuclides dominate dose estimates, and what repository system components contribute to total-system results. Because Tc-99 and I-129 are long-lived and unretarded, factors affecting their release will have the greatest influence on their contribution to dose. Similarly, retardation is important in the movement of Np-237 from the geological repository to the accessible environment. Knowing this, the regulator can focus on the assumptions and technical bases in the license application to ensure that dose estimates adequately consider these factors.



(a) (b)

Fig.4 *Estimated sensitivity of system performance to switching off (Figure 4a) or switching on (Figure 4b) component functions. The numbers at the bottom indicate percentage increase (positive) or decrease (negative) in calculated individual dose. A large absolute value indicates a greater potential role for a component in overall system performance.*

Table 1 Radionuclides contributing most to individual dose for basecase in 10,000 years.

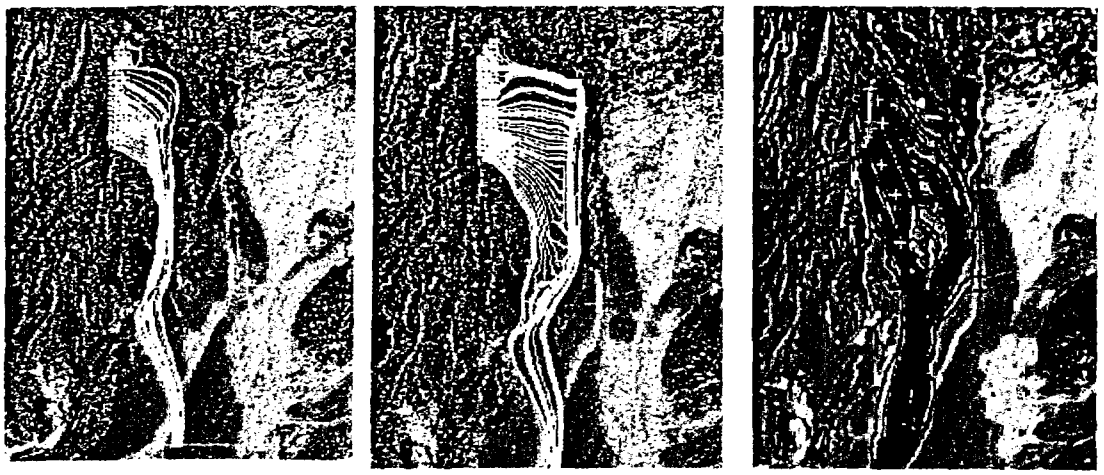
Radionuclide	Dose Contribution (%)	Remarks
Tc-99	48	No retardation; long-lived
I-129	24	No retardation; long-lived
Np-237	19	Moderately retarded; long-lived

3.3 Evaluation of Alternative Models

DOE information indicates that strata in the unsaturated zone overlying the potential repository will cause water to flow laterally, thus shedding water from the repository footprint. [8,9] The presence and characteristics of faults and fractures in the overlying nonwelded volcanic tuffs could affect the lateral diversion of flow and, hence, the amount of water that (i) percolates downward to the repository, (ii) intersects the emplacement tunnels, and (iii) is available to corrode drip shields and waste packages and subsequently dissolve the waste form and transport radionuclides to the groundwater table beneath the repository. [10,11]

To better understand the site characteristics and how these were used by DOE in assumptions and calculations concerning lateral diversion of flow, CNWRA investigated the effects of faults and fractures at an analog field site. [12] These field investigations indicate that the presence, extent, and hydrological properties of faults and fractures in non-welded tuffs are likely to limit the lateral diversion of flow. These results provide a basis for NRC and CNWRA comments on DOE methods and assumptions [8,9] and pre-licensing interactions with DOE. These activities, in turn, aim to assure the license application satisfies the regulatory requirements and the guidelines.

Independent analyses also examined alternative groundwater flow models. Using available information, [13] CNWRA developed two alternatives to the DOE basecase model. [11] Case 1 [Figure 5a] used a model calibrated only with field data, such as water table depth and measured hydraulic parameters. Significant differences between the calculated and observed water table remained after calibration. In contrast, an alternate calibration [Case 2, Figure 5b] using not only the data from Case



(a) (b) (c)

Fig.5 Exploration of alternate models for recharge over the repository footprint and comparison with DOE estimates. Figure 5a shows particle tracks using a model calibrated with field data only, Figure 5b shows the particle tracks with a model calibrated with field data and qualitative information, and Figure 5c shows the plume presented by DOE. The location and dimensions of the plume play a role in determining compliance with quantitative standards.

1, but also qualitative information, reduced the residual errors. The width of the contaminant plume was slightly greater in Case 2. For comparison, Figure 5c shows the plume presented by DOE. This investigation increased staff understanding of the effects of model uncertainty, supported direct evaluation of alternative models, and built confidence that the DOE basecase was in reasonable agreement with alternative hydrogeologic interpretations of the available data.

3.4 Evaluation of Adequacy of Analyses and Hearing Support

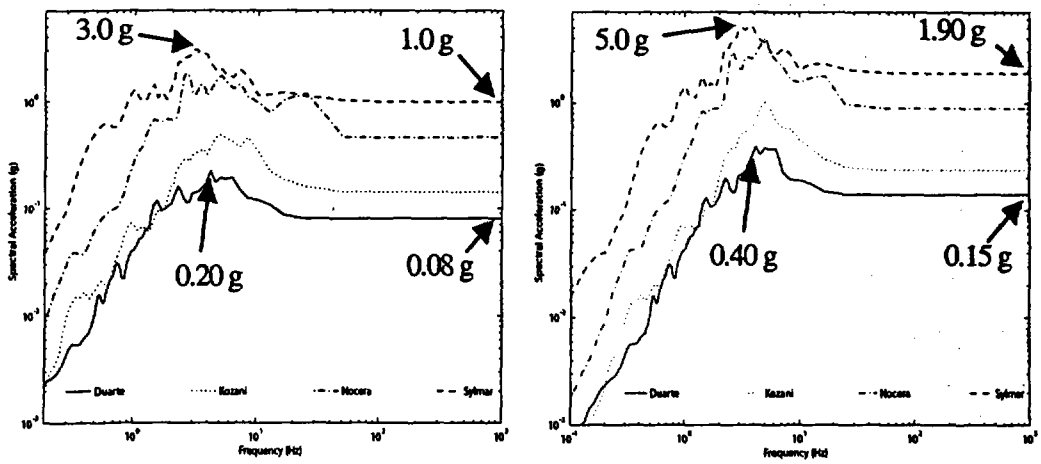
Independent scientific and engineering analyses support the regulator in evaluating the adequacy of analyses both before and during the hearing process. Two examples illustrate this.

For the potential repository at Yucca Mountain, CNWRA integrated available geologic and geotechnical data to construct a three-dimensional EarthVision™ model of the surface facility area. This model forms the basis for earthquake ground response calculations. In the CNWRA model, geotechnical data were explicitly correlated with known stratigraphic units in comparison to the DOE approach, which relies on stochastic sampling of the geotechnical data that does not consider geologic layering of the subsurface strata. The CNWRA analysis shows that ground response varies significantly across the site and that stratigraphic effects at locations with thick subsurface layers of alluvium and unwelded tuff can amplify ground motions by a factor of two times the input motions [Figure 6].

Another example involves the aircraft crash probability for an interim storage facility. When the applicant analysis of the probability of aircraft crash was contested during the hearing for an interim storage facility, staff independently analyzed the aircraft crash hazard to support NRC. This investigation included independent checks on supporting data, calculation of the probability of crash onto the proposed facility, and estimation of potential consequences.

3.5 Support to Public Outreach and Communications

Finally, independent analyses bolster public outreach and communication with stakeholders. Various techniques are used to increase the effectiveness of communications. Independent scientific



(a) (b)

Fig.6 Ground Response Analysis (spectral acceleration versus frequency) for the potential repository at Yucca Mountain. Figure 6a shows the input motions and 6b shows the estimated motions at the ground surface for the four input spectra shown in 6a.

and engineering analyses often underlie the physical models, computer visualizations, and animations that illustrate repository performance. More broadly, the fact that independent analyses have been conducted conveys to the stakeholders that CNWRA and NRC are fully competent to challenge the assumptions and conclusions of the applicant and independently arrive at a conclusion about the safety of the potential repository.

4. Conclusion

NRC assured that CNWRA had attributes essential to successfully supporting NRC. These attributes include independence, competence, longevity, complementary skills, and clearly defined roles and responsibilities. Since its inception in 1987, these attributes have been important to the success of CNWRA. Independent scientific and engineering analyses have proven to be particularly important, as illustrated in the examples presented.

5. Acknowledgment and Disclaimer

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