Nuclear Waste Management – A Need to Ensure that the Waste Decays While the Knowledge Does Not

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ABSTRACT
The unique time scales associated with nuclear waste management require active work to preserve the knowledge associated with programs that can often span long time frames. For example, repository programs are designed and developed for the safe containment of radionuclides with half-lives on the order of 24,000 years (for Pu-239). Performance assessment studies are required to show, by predictive modeling, that these repositories can safely contain the waste for tens of thousands of years, with one million years a reality in the debate. Development of successful repository programs can span several decades. Once operational, a repository is expected to function until closure for a period of 30 to 40 years. Yet, the decision-makers at all levels in such a repository program exert influence and authority over much shorter periods of time (e.g., four years for executive appointments). A discontinuous decision-making process and the associated potential for loss of critical program knowledge are challenges that nuclear waste management programs face in various countries. Due to the disparity of the time frames for the project and associated decision-making, a proactive program to preserve original and developing knowledge for technical and programmatic decisions is vital to the success of any nuclear waste management program. While the mechanisms for knowledge preservation may be program specific, the need for programs to acknowledge and implement a methodology for maintaining program intelligence is collectively shared.

INTRODUCTION
Geologic repositories for the disposal of nuclear waste present distinctive challenges because they are long-term projects that must be actively managed for many decades and must safely contain nuclear waste for many millennia after repository closure. A characteristic feature of this nuclear waste disposal system is the extensive time scale spanned by its various components, including radioactive half-lives of the waste (e.g., Pu-239 has a half-life greater than 24,000 years) and regulatory compliance periods that span tens of thousands of years (e.g., repository performance is required to be analyzed for 10,000 years or longer). Arguably, nuclear waste management is the only scientific arena where the time frame for planning, execution, operation, and impact covers multigenerational periods. Nuclear waste management projects must allow sufficient time for the consideration of various interests (e.g., technical, societal, political, and legal issues) by stakeholders in this multigenerational context. Given the timeframes involved, concerted efforts are necessary to preserve the knowledge associated with the technical and programmatic decisions made during the project life, which involves generations of project personnel and other stakeholders. Complicating this knowledge preservation and project continuity is the fact that the decision-makers at all levels in a repository program exert influence and authority during much shorter periods of time (e.g., four years for executive appointments).

This paper discussed the nuclear waste disposal time-scale framework and the resulting need for a system for preserving and transferring knowledge that is robust enough to handle temporal disruptions of varying impacts within a nuclear waste management program. While the mechanisms for knowledge preservation may be program specific, the need for programs to acknowledge and implement a methodology for maintaining program intelligence is collectively shared.

NUCLEAR WASTE DISPOSAL TIME-SCALE FRAMEWORK

The global scientific community is in general agreement that geologic repositories are capable of safely isolating nuclear wastes for the protection of human health and the environment. In the U.S., as early as 1957, the National Academy of Sciences (NAS) recommended the disposal of long-lived nuclear waste in repositories in deep geologic formations [1]. The U.S. Department of Energy (DOE) performed two decades of study to confirm the NAS recommendation for nuclear waste disposal as the preferred U.S. approach for spent nuclear fuel (SNF), high-level waste (HLW), and transuranic (TRU) waste. These are high-activity wastes or wastes contaminated with long-lived radionuclides, with half-lives on the order of tens of thousands of years. The current U.S. repository program, comprised of the Waste Isolation Pilot Plant (WIPP) and Yucca Mountain sites, is illustrative of the time required to address nuclear waste disposal. These U.S. repository programs are used as examples in framing the issues discussed in this paper.

Fig. 1 summarizes the key elements of a nuclear waste repository program in terms of time scales.

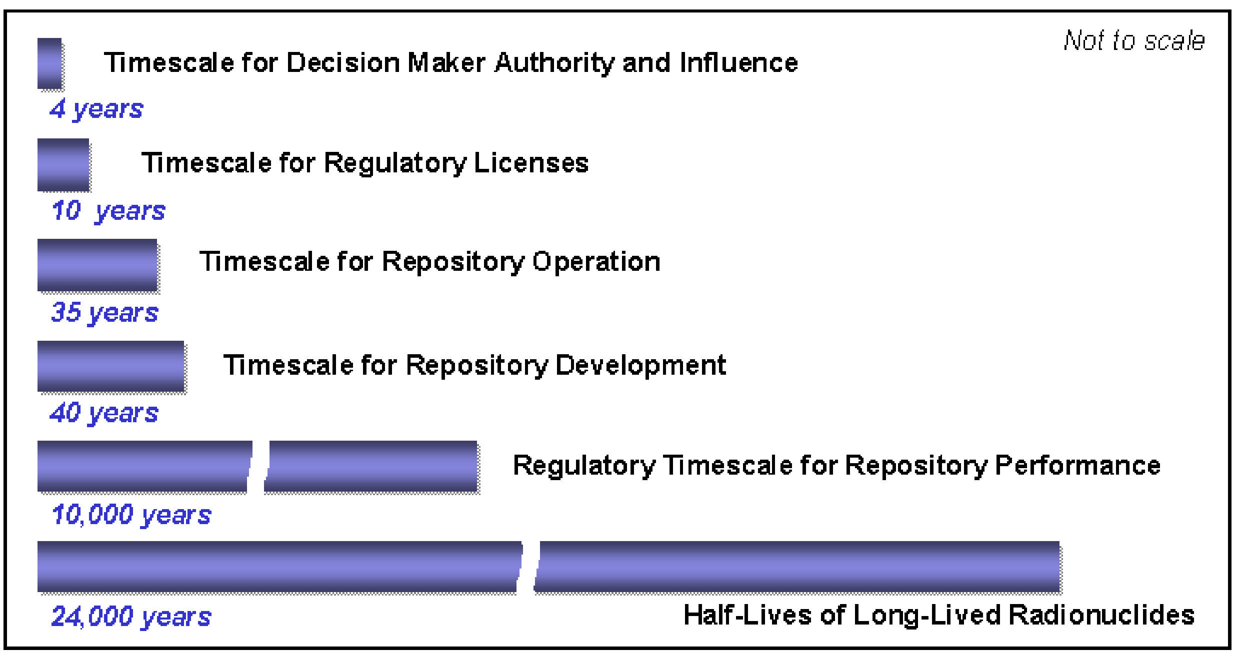

Fig. 1. Key elements of nuclear waste disposal time scale

These key elements are as follows:

- **Time Scale of Long Half-Lives**. At the "high-end" of the nuclear waste disposal time scale framework are the half-lives of long-lived radionuclides such as Pu-239, which has a half-life greater than 24,000 years. Disposal must be carefully planned so that the waste poses no undue threat to public health or the environment, but the mere fact that the waste could be active for such a long time period requires an unusual amount of predictive ability on the part of technical experts and adds to the uncertainty and apprehension that affects stakeholders in nuclear waste disposal projects.

- **Time Scale of Repository Performance**. WIPP is a DOE nuclear waste repository located in Southeastern New Mexico that has been operational since 1999 for defense-related TRU wastes [2]. To date, this is the only U.S. repository that has been licensed for operation. The WIPP Land Withdrawal Act [2] required the U.S. Environmental Protection Agency (EPA) to promulgate final standards applicable to WIPP and all other SNF, HLW, and TRU waste disposal facilities except for those (e.g., Yucca Mountain) developed under the Nuclear Waste Policy Act of 1982. These standards protect public health and the environment from harmful exposure to the radioactive waste that would be stored and disposed of in the underground geologic repository. EPA's standards address all environmental pathways: air, ground water, and soil. In 1993, EPA issued final amendments to its radioactive waste disposal standards [3, 4]. The regulations required disposal systems to be designed to limit the amount of radiation to which an individual can be exposed for 10,000 years; to be designed so that, for 10,000 years after waste disposal, contamination in off-site underground sources of drinking water will not exceed the maximum contaminant level for radionuclides established by the EPA under the Safe Drinking Water Act; and to be designed to limit releases of radionuclides to specified levels for 10,000 years after the facility accepts its final waste for disposal [5, 6]. In 1998, EPA issued its final certification decision that the WIPP repository will comply with EPA's radioactive waste disposal regulations and is safe to contain TRU waste for 10,000 years [7]. The EPA decision [6, 8] was based on the evaluation of a DOE application that considered normal operating conditions and human intrusion scenarios to show that potential releases from the repository were within regulatory limits.

  Pursuant to the Energy Policy Act, the EPA issued site-specific standards for the proposed Yucca Mountain repository sited in Nevada [9]. The U.S. Nuclear Regulatory Commission (NRC) is responsible for implementing the standards developed by EPA. These standards required DOE to limit radiation releases from the repository for 10,000 years [10]. As a departure from this previously accepted performance assessment period, a court ruling vacated the EPA standards in so far as they contained the 10,000-year compliance period, suggesting that the timeframe should be longer to cover estimated peak doses consistent with technical advice from the NAS [11]. EPA is currently revising the Yucca Mountain standards to extend the compliance period to cover the time of peak dose, which includes the addition of new protections to 1 million years [12].

- **Time Scale for Repository Development**. For the development of a repository program that comprehensively addresses the isolation of long-lived radionuclides and assesses performance for the time scales discussed above, the average time period from conception to reaching operational status, including site selection and characterization, licensing, and construction, spans a few decades. Four decades were required for WIPP to become operational. The historical timeline for the WIPP repository in achieving operational status is shown in Fig. 2. The 40-year time period included the completion of technical research, the demonstration of compliance with governing regulations, the negotiation of organizational agreements pertaining to states' rights, and the resolution of various lawsuits challenging regulatory authority [13].

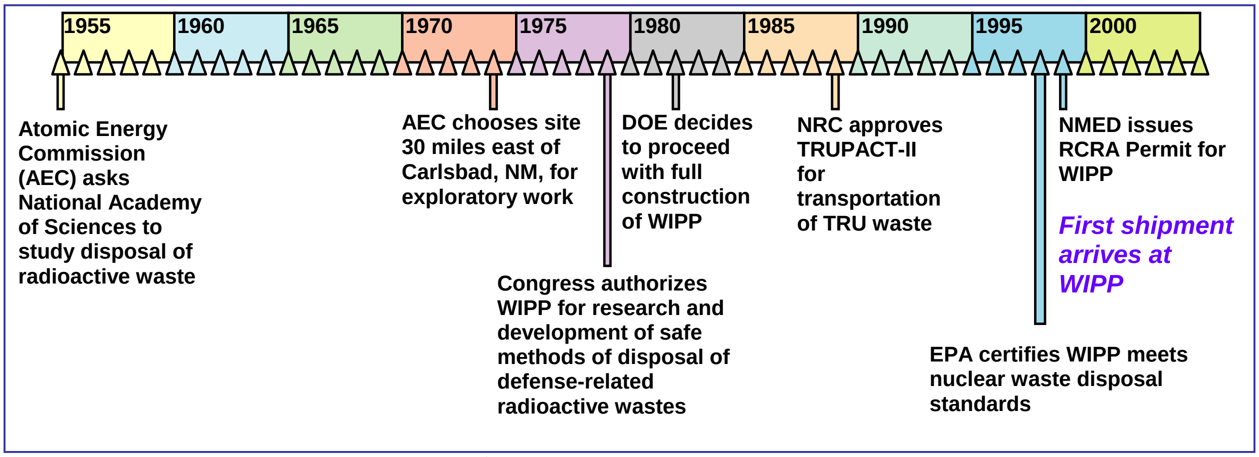

Fig. 2. Time scale for WIPP repository program development

For 15 years, the U.S. HLW management program has focused almost exclusively on the proposed repository site at Yucca Mountain in Nevada. The Yucca Mountain site was officially designated by the U.S. Congress in 2002 as the site for a HLW and SNF repository [14], in accordance with the Nuclear Waste Policy Act of 1982 [15]. EPA is currently revising the public health and environmental radiation protection standards for Yucca Mountain [12]. Based on the EPA's proposed standards, the NRC must issue licensing regulations for Yucca Mountain. The DOE must submit a license application to the NRC showing how the proposed repository meets all licensing requirements. The NRC must review and approve DOE's license application. This decision process includes a multi-year review and public hearings. Only if NRC determines that the facility will meet EPA's standards and other licensing requirements will the license be approved and construction of the facility begin [16]. It is not unreasonable to expect that the repository development time scale for Yucca Mountain to reach operational status will be at least as long as that for the development of WIPP.

- **Time Scale for Repository Operational Life**. Once operational, the life of a repository spans several decades. For example, the WIPP repository is expected to be operational for 35 years before closure activities commence. During the operational phase, waste shipments are received from various locations and generating processes. As the waste profile changes during this time, the repository operations may require adjustment to ensure continued compliance with applicable regulations and repository performance criteria and to efficiently accommodate any revised rate of waste receipt through modified mining and operational activities. The operational phase is then followed by closure and post-closure activities, including provisions for future generations such as permanent markers indicating the presence of the repository.

- **Time Scale for Regulatory License Renewals**. Typically, regulatory licenses are granted for five to ten years and require periodic renewals. For example, the WIPP repository certification and the certifications for the transportation casks used to ship waste to WIPP are valid for five-year periods. EPA is currently conducting a recertification evaluation to determine whether the WIPP continues to comply with EPA's radioactive waste disposal standards [6, 8]. The original repository certification was valid for the time period 1999 – 2004. The certificates of compliance for the WIPP transportation casks have been renewed multiple times by NRC [17, 18, 19, 20]. The U.S. Resource Conservation and Recovery Act (RCRA) hazardous waste facility permit for the WIPP repository was issued in 1999 by the New Mexico Environment Department, who is authorized by EPA to regulate mixed wastes under RCRA in the State of New Mexico, and requires renewal every 10 years.

- **Time Scale for Decision Maker Authority and Influence**. The management and disposal of nuclear waste is governed by multiple organizations within the executive and legislative branches of the U.S. federal government. The leadership of each of these organizations is part of the U.S. President’s administration. Those serving in policymaking and key administrative positions in these organizations do so by Presidential appointment (and, in general, confirmation by Congress). These organizations include primarily EPA, NRC, and DOE. EPA, which was established in 1970, leads the nation's environmental science, research, education, and assessment efforts and is led by an administrator, who is appointed by the President. NRC was established by the Energy Reorganization Act of 1974 to regulate civilian use of nuclear materials. The NRC is headed by a five-member commission, one member of which the President designates to serve as chairman and official spokesperson. DOE, which in part is responsible for ensuring environmental cleanup of the national nuclear weapons complex, is led by the Presidentially-appointed U.S. Secretary of Energy. With the U.S. Presidential administration limited to two consecutive four-year terms, the typical stint of a decision-making executive in a federal organization is approximately four years. Organizational structures operating within similarly influenced time scales also exist at field and state levels.

As shown above, the time scales involved in the nuclear waste disposal program range from approximately 24,000 years (half-life for Pu-239) to a few years (term of a typical decision-maker). These disparate time scales lead to an operating system where decision-making and continuity in that decision making are necessary, but challenging and complex. Maintenance of project history with routine communication and formal transfer of project knowledge is essential in pursuing continuity in decision making. The communication and knowledge transfer issue is best addressed and is practical to implement within the portions of the time scale framework that definitively fall within a single generation of workers. Within the nuclear waste disposal time-scale framework, this includes the time scales for regulatory license renewals and for decision maker authority and influence.

Knowledge Preservation within the Arena of Regulatory License Renewals

An obvious challenge to scientists and engineers evaluating repository performance is in defining the logic by which long-term predictions of geologic and weather conditions, groundwater behavior, and human activity covering a timeframe of tens of thousands of years can be made and evaluated for repository performance. The inherent uncertainty in prediction complicates the implementation of a repository program. The methodology for addressing these uncertainties within a given regulatory framework requires some form of continuity, which in turn requires that knowledge transfer be part of the process.

For a licensed and operational repository, the impact of uncertainties given the predictive nature of the science is mitigated in part by regulations that require the regular re-evaluation of performance assessment throughout the operational life of the repository. In the case of WIPP, applicable EPA regulations require the DOE to report changes in activities or in conditions that have the potential for any releases, however small. This necessitates the periodic evaluation of elements of the performance assessment. In addition, DOE must apply for re-certification of the repository by EPA every five years. These established regulatory processes force the continuous evaluation of performance assessment by the project scientists and regulators. In addition to lessening the ambiguity of the predictive science, this obligation also serves to remind and reinforce project scientists and regulators of the project technical basis. With the requirement to review the entire program for performance assessment impacts and to explain any differences from previous results, the technical basis for the repository design is continually at the forefront of the program activities. Regular opportunities are provided to indoctrinate new project associates and to encourage interface between project experts perhaps nearing retirement and those just joining the project. In this case, the regulatory requirements provide a tool or forcing function that promotes knowledge transfer.

The long time scale of a repository program implies that organizational performance needs to be maintained over decades, possibly centuries. Stability on this order is not the norm in governmental organization, whose inherent limitations do not support long-term projects. Making coherent regulatory decisions at any one point in time is extremely challenging considering the uncertainties associated with long-term repository program development. The knowledge available at project initiation is obviously less complete than in subsequent project phases. The NAS made this observation in recommending the "adaptive staging" approach to repository program development, which encourages the acquisition of additional knowledge and allows regulations to develop and to take account of new knowledge gained during the multi-decade repository development program [21]. It is unrealistic to expect that a regulator can set forth regulations that would govern activities for more than a century with no need for modification. In the case of WIPP, the EPA has used knowledge from the project duration to date to refine the regulations governing the repository performance. In 2004, the EPA revised its regulations to incorporate efficiencies into the regulatory process based on experience gathered, while ensuring the adequacy and robustness of the regulatory process. This update to the regulations is formally documented by the EPA as part of a process that includes public comment and review [22]. Once again, the regulatory process offers an opportunity for knowledge transfer and incorporation of "lessons learned" from the breadth of experience gathered during the operational life of a repository.

Knowledge Preservation within the Arena of Decision-Maker Authority and Influence
Continuity among personnel and positions within the project management organization and regulatory organizations is limited to a much shorter time scale than that associated with a nuclear waste disposal program. The leadership that initiates the implementation of a nuclear waste disposal program or any other such long-term program is unlikely to see its completion [23]. Similarly, the direction initiated by an organization may not be continued by the successors in the organization. This reality must be recognized as having the potential to disrupt the continuity of project activities and the identification of essential knowledge and associated its associated preservation.

Knowledge preservation is critical in creating a system that can accommodate and absorb the impacts of changes in personalities. While characteristics including priorities specific to individuals and personalities cannot be changed, if the logic and basis for decision making is explained and preserved for future use, changes in individuals at local levels will not irreversibly disrupt the continuity of the program knowledge even if the individuals impose their own values on decision making. The knowledge preservation system should be robust enough to handle disruptions of varying impacts.

Other than the crucial impact from changing individual decision-makers during the life of a program, technical, social, economic, and political conditions at global and local levels may have a significant impact on decision making. In this context, knowledge preservation in nuclear waste management is not simply a historical record of "what" was done at any point in time. In most cases, the "how" and "why" pertaining to the decision making process are important data points and reflect the overall environment in which a decision was made. Nuclear waste management may be unique in this respect as the end result is often a result of competing and sometimes conflicting stakeholder viewpoints that reflect much more than simple technical analysis and resolution. "Lessons learned" from various stages of a nuclear waste management program, including successes and failures from various viewpoints, are an important part of knowledge preservation.

Lastly, a nuclear waste program can benefit from a conduct of operations that builds in a formal process for facilitating knowledge preservation. This could include strong training programs that impose (to the extent possible) uniformity on the process that is transferred over time, an open process that encourages and facilitates the examination of lessons learned, and formal transition of the logic behind key decisions even if made by different individuals (i.e., if the "how" and "why" of decision making are clearly documented and preserved along with the "what," a new set of decision makers is better equipped to maintain continuity of a program).

SUMMARY

The time-scale framework for nuclear waste disposal projects is unparalleled. The technical basis for the program must continue to be evaluated and preserved during the multigenerational time frame as the composition of the administrators, technical experts, and public change. It is unlikely that those who initiate the planning of projects in the nuclear waste arena will be the same ones seeing these to completion. What is essential in a nuclear waste project from a technical perspective is knowledge preservation and maintenance of project history. Given the timeframes involved, this requires formalized efforts to transfer information across experts and generations. If continuity of technical knowledge is not maintained and lessons learned are not preserved, project progress may be negatively impacted. While programs will identify specific methods for conserving knowledge within the given program structure, beneficial efforts may include debriefing of retirees to address the aging workforce issues, training programs to transition technical knowledge, and maintaining a qualified core workforce. Equally important is the preservation of knowledge of factors that provide the basis for decision-making. These include the social, political, economic, and cultural realities that were in force at any given point in time.

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