SAND2011-1164C

TECHNICAL LESSONS TO LEARN IN DISPOSAL OF SPENT NUCLEAR FUEL AND HIGH-LEVEL WASTE

Rob P. Rechard
Nuclear Fuel Cycle System Engineering Sandia National Laboratories, Albuquerque, NM 87185-1370, rprecha@sandia.gov
Thomas A. Cotton
Complex Systems Group, 4429 Butterworth Place, NW, Washington DC 20016
Mark Nutt
Nuclear Engineering Division, Argonne National Laboratory, Argonne, IL 60439
Joe T. Carter
Savannah River Nuclear Solutions, Savannah River Site, Aiken, SC 29808
Frank V. Perry
Earth and Environmental Sciences Division, Los Alamos National Laboratory, P.O. Box 1663, Los Alamos, NM 87545
Ruth F. Weiner
Risk and Reliability Analysis, Sandia National Laboratories, Albuquerque, NM 87185-0719
James A. Blink
Global Security Principal Directorate, Lawrence Livermore National Laboratory, Livermore, CA 94550

This paper provides insights on implementing the technical aspects of nuclear waste disposal in the United States, based on past experience, which may be applicable to a nuclear waste management program in the early stages of development. US experience suggests that the regulatory framework should be established prior to initiating future repository development. Concerning specifics of the regulatory framework, both a cumulative release and individual dose standard were successfully implemented using reasonable expectation as the standard of proof. Furthermore, the current retrievablity requirements in the United States were successfully implemented. Also, a country with small amounts of HLW, LLW, and hazardous waste may want to consider a more integrated regulatory framework to avoid the challenges of future waste streams from advanced fuel cycles.

I. INTRODUCTION

The paper reviews technical lesson learned from the nuclear waste management program in the United States (US) to provide insights that could be useful in the development and implementation of future nuclear waste programs, especially those in the early stages of development in other countries.[1]

The strategy adopted for identifying potential lessons to learn was to start at a high level and move into details in later years. The first topical area chosen was technical aspects of the current legal and regulatory framework pertaining to radioactive waste management and its implementation at the Yucca Mountain Project (YMP) and the Waste Isolation Pilot Plant (WIPP).

Two approaches were used to obtain information to develop this paper: First, Sandia National Laboratories (SNL) hosted a workshop in Albuquerque on 18 and 19 May 2010 in order to (1) understand events related to the legal and regulatory framework through several technical perspectives, (2) identify potential lessons to be learned, and (3) discuss the impact of changes on the technical implementation. A broad set of subject matter experts in the waste management field participated in this workshop. Several of the ideas and issues expressed at the workshop were used as input in developing this paper.

Second, SNL took advantage of a national survey it conducts annually on national security issues such as energy and added several questions related to nuclear waste disposal with the goal of identifying what might enhance acceptability and credibility of waste management facility development. The questions delved into the public perception of the risks and benefits of nuclear energy, the perception of current waste management practices, and design attributes of a storage/disposal facility (e.g., number, depth, and type).

Several general topical concepts have been examined. The first topic is summarized herein: (1) disposal issues related to technical requirements in regulations, waste classification, retrievability, and hazardous waste. Four other topics are discussed in companion papers: (2) site screening, evaluation, and associated research and development facilities (Ref. 1); (3) stages of developing the storage/disposal system such as stepwise repository development (Ref. 2); (4) concepts of a waste management system that better integrates storage, transportation, and disposal (Ref. 3); and (5) enhancing acceptability and credibility of repository development (Ref. 4).

[1] The usefulness and applicability of the lessons learned to the situation in the US with its mature waste disposal program will depend upon how much change in the current US policy that is suggested by the *Blue Ribbon Commission on America's Nuclear Future* and eventually adopted by the Congress.

II. WASTE DISPOSAL LAWS AND REGULATIONS

II.A Participants and Roles for YMP and WIPP

The United States legal framework is similar to other international programs in many aspects, but differences are evident. In the US, the cabinet level Department of Energy (DOE) sites, builds, and operates repositories for SNF, HLW, and transuranic (TRU) waste (among many other activities such as nuclear weapon stewardship and nuclear power research). In several countries (e.g., France, Sweden, Finland, Switzerland, and Japan), public utilities have set up a private entity to site, build, and operate the repository and are not required to use a government agency as in the United States. This private entity in other countries may also be more closely integrated with the storage and transportation operations than in the US.

Another difference is that regulatory responsibility is divided among several entities in the US, which can make integrating storage, transportation, and disposal functions for waste challenging as discussed further in a companion paper (Ref. 3). For HLW and SNF under the *Nuclear Waste Policy Act of 1982* (NWPA), the Environmental Protection Agency (EPA) sets the pre- and post-closure radiation protection standards for repositories and the Nuclear Regulatory Commission (NRC) implements those standards. Also, NRC implements requirements for storage of waste and licenses transportation casks for radioactive waste. For the disposal of defense TRU waste at WIPP, EPA both sets and implements the standards. For hazardous waste constituents in TRU waste, EPA granted the State of New Mexico the authority to regulate, and so WIPP has both a federal and state regulator.

II.B HLW/SNF Post-Closure Performance Requirements

II.B.1 EPA Standard, 40 CFR 191

Immediately following congressional passage of NWPA in December 1982, EPA promulgated the draft 40 CFR 191 Standard for SNF, HLW, and TRU waste disposal. EPA promulgated the final version of 40 CFR 191 in 1985, 3 years later.

As originally promulgated, the EPA Standard, 40 CFR 191, consisted of two subparts: Subpart A described criteria for management and storage during operations. Subpart B described repository Containment Requirements (§191.13) related to the post-closure performance assessment; design Assurance Requirements (§191.14), which are discussed further in relation to retrievablity; Individual Protection Requirements (§191.15); and Groundwater Protection Requirements (§191.16). The Containment Requirements selected the cumulative release of radionuclides as the primary compliance indicator. The measure of this indicator was the cumulative release 10,000 years after disposal of long-lived radionuclides that reached the surface or crossed a vertical boundary a maximum of 5 km in any direction from the perimeter of the emplaced waste. The cumulative release was normalized by (a) EPA derived limits for specific radionuclides and (b) the mass placed in the repository expressed as a waste unit factor.

The 40 CFR 191 introduced a new regulatory concept by requiring the performance measure to be expressed as a complementary cumulative distribution function (CCDF) to display uncertainty. Hence, the performance measure in 40 CFR 191 was not simply a limit on the expected value of a cumulative release, nor the variance, but rather a limit on the distribution of cumulative releases (primarily the extreme tail).

By specifying cumulative release, normalized by the size of the repository, as the primary indicator, EPA accomplished several goals. First, by normalizing the release limit by the size of the repository, the Containment Requirements did not penalize use of one or two large repositories, which inherently creates a large source-term.

Second, the use of cumulative release (i.e., the time integral) did not penalize the location of the repository away from large volumes of water (which promotes dilution and thus could lower estimates of individual dose). Third, the use of cumulative release was less sensitive to the release rate of radionuclides from the engineered barrier and dispersion coefficients in the geologic barrier, thus, the fidelity of the source-term model could be less (e.g., package failure could be conservatively assumed to be instantaneous) and, hence, the regulation did not promote use of expensive engineered barriers. Finally, estimates of cumulative release are less sensitive to parameters with overly broad uncertainty ranges than are estimates of the time and magnitude of peak dose.

However, in response to comments received on the proposed regulation, EPA also required an evaluation of individual annual dose rate (i.e., potential *rate* of exposure by an individual) as a secondary indicator of risk in the Individual Protection Requirements (§191.15) of 40 CFR 191. These requirements would foreshadow those eventually required for the YMP.

II.A.2 NRC Implementing Regulation, 10 CFR 60

In 1981, NRC issued repository regulations (10 CFR 60) that set forth the requirements applicable to DOE for submitting an application for a license and specified the procedures which NRC would follow in considering the application. NRC licensing proceeding were to be formal and involve a judicial process with administrative judges, judicial hearings, attorneys, rules of evidence, and cross-examination of witnesses.

In 1983, prior to final promulgation of 40 CFR 191 but cognizant of its likely contents, NRC added technical requirements to 10 CFR 60, which set deterministic criteria on subsystems of the waste disposal system in addition to the expected EPA criteria for overall performance of the repository (subsequently issued in 1985). The rule also included a requirement to maintain the ability to retrieve waste packages for safety reasons up to 50 yr after disposal operations begin, as discussed further in a later section.

The 10 CFR 60 also invoked "reasonable assurance" as the standard of proof for compliance with the limits, similar to reactor licensing, rather than "reasonable expectation" as subsequently specified by EPA, as discussed further in a later section.

II.B.2 EPA Standard, 40 CFR 197

Congress, in the *Energy Policy Act of 1992,* required EPA to issue a site-specific standard for Yucca Mountain, based upon and consistent with recommendations and findings of a study to be performed by the National Academy of Sciences (NAS). The NAS completed their study in 1995 and made three primary recommendations: (1) use of a standard that sets a limit on the risk to individuals of adverse health effects from repository releases; (2) conduct the compliance assessment for the time when the greatest risk occurs, within the limits imposed by the long term stability of the geologic environment (which was stated to be on the order of one million years at the Yucca Mountain site); and (3) evaluate only the potential consequences (not probability) of a few selected situations of inadvertent human intrusion. Another recommendation was to avoid specifying criteria for subsystems of the disposal system, since these criteria could potentially result in suboptimal behavior of the overall disposal system.

In 2001, EPA promulgated the site-specific standard (40 CFR 197), leaving the generic 40 CFR 191 applicable to other geologic repositories such as WIPP. In 40 CFR 197, EPA selected individual dose as the primary risk indicator and the expected value of the maximum committed expected dose equivalent to a reasonably maximally exposed individual at a point of compliance 18 km from the repository over a regulatory period of 10,000 years as its primary measure for undisturbed and disturbed performance of the disposal system. Similar to the Individual Protection dose requirements in 40 CFR 191, EPA set a limit of 0.15 mSv/yr for the peak dose over time.

The use of individual dose has two advantages over the cumulative release measure. First, dose is directly evaluated from concentrations calculated from the exposure consequence model using a dose conversion factor. Thus, development of the regulatory limit for dose is more transparent than development of a generic regulatory limit for cumulative release or population dose. Second, the measure is comparable to individual dose measures in other international radioactive waste programs.[2]

II.B.3 NRC Implementing Regulation, 10 CFR 63

By 2001, the 10 CFR 63 regulation promulgated by NRC regulations adopted EPA characterization of "reasonable expectation" as the standard of proof for compliance. Furthermore, NRC removed subsystem performance objectives as recommended by the NAS as well as the design and siting criteria that existed in 10 CFR 60. However, NRC still required maintaining the ability to retrieve waste packages for safety reasons up to 50 yr after disposal operations begin as previously required in 10 CFR 60.

II.B.3 Observations from WIPP and YMP

US experience with WIPP and the YMP suggests that the regulatory framework should be established prior to initiating a future repository development program, with top-level repository regulations established first followed by siting guidelines and site evaluation criteria, to provide clear guidance to those siting and developing the repository. Changes in the performance indicator and its measure did not contribute to clarity within the US. For example, changes in the performance indicator subtly increased the importance of the waste package and changes in the compliance boundary necessitated changes in the characterization program.

Interactions with the regulator were relatively straightforward for WIPP because EPA defined a certification process using a standard rulemaking process under the *Administrative Procedures Act of 1946* that allowed continued interaction with the regulator, review panels, and the public throughout the certification process and thus contributed to transparency.

Interactions with NRC during the Yucca Mountain Project were much more formal, lengthy, and costly. Furthermore, once the license was submitted communication was controlled by two different but small groups within DOE. Communication that was related to contentions submitted to the Atomic Safety Licensing Board of NRC (the board of 3 administrative judges charged with overseeing the formal hearing) by outside parties (e.g., State of Nevada) was controlled by the legal team. Communication that was related to requests for

[2] For example, the International Commission on Radioactive Protection (ICRP) has recommended a maximum health risk of 10^{-5}/yr or maximum public dose limit of 1 mSv/yr (about average from natural sources at sea level) and average of 0.3 mSv/yr (Ref. 5, ¶C66). Many radioactive waste programs have specified design targets about a factor of 10 lower for some variable period after disposal.

additional information (RAIs) from NRC staff (which were reviewing the license application) was controlled by DOE management. The RAI typically required a response within 30 days. The response process involved triage of RAIs to technical staff, writing a response, several review steps by peers and technical leaders in closely related topical areas, and final review by DOE designated manager.

Pre-licensing interactions between DOE and NRC on the Yucca Mountain project, such as the interactions on key technical issues, criticality topical report, and an NRC review of a dry spent fuel transfer system, showed the value of such interactions as an indicator of progress during repository development even though they did not constrain NRC in its formal licensing review. In other countries, it would be helpful for repository regulations to be crafted to ensure that regulatory-licensee interactions can take place. This interaction would be an important part of a staged development process.

II.C Reasonable Expectation as the Standard of Proof

The standard of proof for the demonstration of compliance with the quantitative post-closure performance standard is an integral part of the standard. In its standards for geologic repositories, EPA has employed "reasonable expectation" as the standard of proof, used it successfully in certifying compliance of WIPP with its 10,000 year performance requirement, and included it in the Yucca Mountain standard (40 CFR 197) to apply to both the 10,000 year and one million year standards. In promulgating its final rule for Yucca Mountain, 10 CFR 63, NRC explicitly adopted EPA's concept of reasonable expectation as the standard of proof for post-closure performance, while retaining the familiar NRC concept of reasonable assurance for pre-closure regulation.

Early on, the WIPP Project interpreted EPA's "reasonable expectation" standard as requiring that the performance assessment for the repository use an approach that quantified uncertainties realistically and over their full range, rather than one that involved conservative point estimates or a bounding assessment. By 1996, EPA explicitly stated this intent in the implementing regulations 40 CFR 194.34. For the WIPP certification, EPA was also the implementing agency, and issued separate regulations (40 CFR194) clarifying the implementation requirements. EPA's final certification of compliance in 1998, and its 5-year recertification (after opening in 1999) in 2005 and 2010, demonstrates that a 10,000 year performance standard, subject to a reasonable expectation standard of proof as understood by EPA, can be successfully applied to a geologic repository.

The reasonable expectation approach placed a requirement to be neither too optimistic about the information that was available nor too pessimistic about the uncertainty in the data when assigning parameter values. Maintaining a focus on realistic models and parameters proved challenging. Participants often had the mistaken notion that "conservative" models and parameters values were "more defensible" and thus results using these models and parameters were "more convincing." However, conservatism was often not "more defensible" or "more convincing" at WIPP, for several reasons (Ref. 6):

1. Parameters values that are conservative for all scenarios cannot be assigned in a complex system. A value that is "conservative" for one scenario might be non-conservative for another.
2. Maintaining a consistent level of "conservatism" for such a complex system is difficult. For example, in the 1989 PA [performance assessment], individuals had different notions of 'conservatism'.
3. Casual readers might not fully understand the concepts in a conceptual model, in which case an appeal to conservatism is futile.
4. An appeal to conservatism can engender a suspicion that the model and parameters have not been developed using current scientific knowledge. Technically astute reviewers understand the concepts of a conceptual model but often want convincing evidence that the analyst can quantify how much uncertainty this component contributes to the overall uncertainty in the results.

The focus on the use of reasonable models and the full range of parameters is consistent with and supportive of a growing international recognition of the importance of showing an understanding of the performance of a repository system in addition to simply demonstrating compliance with quantitative disposal standards.

II.D Retrievability of Emplaced Waste

The question of whether and for what purpose nuclear waste should be retrievable after it has been emplaced in a repository has been debated for decades. As discussed below, retrievability of SNF during repository operations is required under NWPA, and EPA and NRC have provided additional relevant regulatory requirements. These regulatory requirements have not been a significant complicating factor in the certification and operation of WIPP, nor did is raise difficulties for the Yucca Mountain License Application for the construction authorization submitted by DOE in June 2008 and docketed by NRC that September.

II.D.1 Retrievablity Requirements for WIPP

The Assurance Requirements in EPA's generic high-level waste disposal regulations for WIPP (40 CFR 191.14(f)) state that "disposal systems shall be selected so that removal of most of the waste is not precluded for a reasonable period of time after disposal." In promulgating the rule, EPA noted that positive and negative comments about this provision were divided fairly evenly, and that many of the critics were concerned that it "would encourage designing a geologic repository to make retrieving waste relatively easy—which might compromise the isolation capabilities of the repository or which might encourage recovery of the waste to make use of some intrinsic value it might retain (the potential energy content of spent nuclear fuel, for example)." In other words, some objected to retrievability precisely on the grounds that it might encourage recovery of spent fuel for economic reasons. In response, EPA noted that the intent of the provision "was not to make recovery of waste easy or cheap, but merely possible in case some future discovery or insight made it clear that the wastes needed to be relocated," and re-iterated that "any current concept for a mined geologic repository meets this requirement without any additional procedures or design features." There would be no need to keep repository shafts open, but only for it to be technologically feasible "to mine the sealed repository and recover the waste—albeit at substantial cost and occupational risk." In summary, "this provision should not have any effect upon plans for mined geologic repositories. Rather, it is intended to call into question any other disposal concept that might not be so reversible -- because the agency believes that future generations should have options to correct any mistakes that this generation might unintentionally make."

EPA specified that the Assurance Requirements at 191.14 did not apply to repositories licensed by NRC, and left it up to NRC to specify its own requirements.

II.D.2 Retrievability Requirements for HLW and SNF

Section 122 of NWPA requires repositories to be "designed and constructed to permit the retrieval of any spent nuclear fuel placed in such repository, during an appropriate period of operation of the facility, for any reason pertaining to the public health and safety, or the environment, or for the purpose of permitting the recovery of the economically valuable contents of such spent fuel." Inclusion of the provision specifically mentioning retrievability of SNF for economic purposes reflected a compromise between those who thought SNF should be treated as an energy resource and those who saw it as a waste. NWPA stated that the appropriate period of economic retrievability for spent fuel would be defined by DOE. DOE never formally defined such a period for economic retrievability of SNF.

NRC specified retrievability of SNF and HLW for safety reasons. Both NRC's generic and Yucca Mountain-specific repository regulations include essentially identical requirements (in 10 CFR 60.111(b) and 10 CFR 63.111(e)):

> (1) The geologic repository operations area must be designed to preserve the option of waste retrieval throughout the period during which wastes are being emplaced and, thereafter, until the completion of a performance confirmation program and Commission review of the information obtained from such a program. To satisfy this objective, the geologic repository operations area must be designed so that any or all of the emplaced waste could be retrieved on a reasonable schedule starting at any time up to 50 years after the waste emplacement operations are initiated, unless a different time period is approved or specified by the Commission. This different time period may be established on a case-by-case basis consistent with the emplacement schedule and the planned performance confirmation program.
>
> (2) This requirement may not preclude decisions by the Commission to allow backfilling part or all of, or permanent closure of, the geologic repository operations area prior to the end of the period of design for retrievability.
>
> (3) For the purposes of paragraph (e) of this section, a reasonable schedule is one that would permit retrieval in about the same time as that required to construct the geologic repository operations area and emplace waste.

In explaining the 50-year retrievability period, NRC stated that "After 50 years of waste emplacement operations and performance confirmation …it is likely that significant technical uncertainties will be resolved, thereby providing greater assurance that the performance objectives will be met," and noted that DOE could design a repository for a longer retrieval period if desired. However, in responding to a suggestion "that stewardship of the waste be maintained (indefinitely) so that waste could be made available for future energy needs," NRC noted that its retrieval provision is not intended to facilitate recovery of the material in the repository as a potential resource. Instead, "Waste retrieval is intended to be an unusual event only to be undertaken to protect public health and safety."

II.D.3 Ready Retrievability

A distinction exists between the "retrievability" required for safety reasons by the regulations, which does not preclude backfilling of disposal rooms and allows a long time for the process at possibly high cost and difficulty, and "ready retrievability" to allow relatively rapid and inexpensive recovery of materials for economic reuse, which requires maintaining open access to the disposal rooms (Ref. 7). As noted above, NRC and EPA regulations focus on safety while NWPA allows DOE to specify a period of retrievability for SNF for economic purposes. The designation of Yucca Mountain as the only site to be characterized rendered the distinction between ready retrievability and retrievability for safety reasons moot, since Yucca Mountain faced no difficulty in meeting a 50-yr retrieval period because of the relative ease of maintaining open drifts in unsaturated tuff for an extended period compared to plastic salt and saturated basalt.

II.D.4 International Discussion on Retrievability

In 2001, the Nuclear Energy Agency (NEA) of Organisation of Economic Co-operation and Development (OECD) summarized arguments for and against retrievability (Ref. 8):

> Broad factors that might lead or contribute to a decision to retrieve waste and weigh in favour of building provisions for retrievability are as follows:
>
> - technical safety concerns that are only recognised after waste emplacement and/or changes in acceptable safety standards,
> - a desire to recover resources from the repository, e.g. components of the waste itself, or the recognition or development of some new resource or amenity value at the site,
> - a desire to use alternative waste treatment or disposal techniques that may be developed in the future,
> - to respond to changes in social acceptance and perception of risk, or changed policy requirements.
>
> Reasons for not including retrievability provisions in repository design may be connected to factors such as the additional complexity, the cost-worthiness of a retrieval option, and long term security concerns. They include:
>
> - uncertainty about negative effects, including conventional safety and radiological exposure of workers engaged in extended operations and/or associated monitoring, or marginal gains;
> - the possibility of failure to seal a repository properly due to the adoption of extended or more complex operational plans to favour retrievability;
> - the favouring of irresponsible attempts to retrieve or interfere with the waste during times of political and/or social turmoil; and
> - a possible need for enhanced nuclear safeguards.

NEA pointed out that the concept of retrievability of waste from a repository after emplacement is gaining increasing attention internationally in the context of stepwise decision making, where the transition from readily retrievable economically to merely retrievable is a decision point.

In Finland, the public was clear in that they wanted their repository to be designed for retrievability. Hence, expanded use of retrievable repository design concepts may be necessary. Furthermore, members of the public consider the possibility of waste retrieval in their preferences for disposal concepts as discussed in a companion paper (Ref. 4).

Retrievability requirements could impact future disposal concepts, as discussed further in a special session in this conference. To facilitate a repository program in the early stages of development it may be necessary to define the roles of recovery for economic reuse and retrievability for safety reasons. Also, it would be beneficial to clarify whether it means that a repository is to be constructed to facilitate retrieval of the disposed waste, or only that nothing should be done in construction to obstruct retrieval.

II.E. Waste Classification

II.E.1 High-Level Waste Classification

The US regulatory framework generally uses a source based waste classification system. HLW is defined in NWPA as

> the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and other highly radioactive material that the Commission, consistent with existing law, determines by rule requires permanent isolation.

Traditionally, NRC and DOE have used the first aqueous extraction as the point of generation of HLW as described in 10 CFR 50, Appendix F. However, a federal court ruling prompted a re-evaluation. The federal court noted that HLW waste definition in NWPA is any "highly radioactive material resulting from reprocessing;" and is not limited to material derived from the liquid waste of extraction. The court ruling resulted in a provision in the *Defense Authorization Act of 2005* (in §3116) to provide some flexibility. The Waste Incidental to Reprocessing (WIR) process in §3116 allows flexibility in excising what can be considered "highly radioactive." However, this determination must be done with consultation of NRC and the state, the process currently applies only to the States of Idaho and South Carolina, and the process was designed specifically for the disposition of HLW in tanks.

II.E.2 Low Level Waste Classification

Disposal requirements for LLW are based on a classification scheme developed 30 years ago by NRC in 10 CFR 61. This classification scheme focuses on those radionuclides that were expected to cause the greatest short-term and long-term concerns for human health and the environment in 1981. NRC defined four classes of LLW in 10 CFR 61.55 based on the concentrations of specific short-lived and long-lived radionuclides. These four classes are A (not hazardous to a human intruder after 100 yr), B (not hazardous to a human intruder after 100 yr and requiring 300-yr waste stability for disposal), C (not dangerous to a human intruder after 500 yr and requiring 300-yr waste stability and greater placement depth or 500 yr intruder barrier for disposal), and greater-than-class C (GTCC) (dangerous to a human intruder beyond 500 yr and requiring geologic repository for disposal).[3] Although other radionuclides can cause a waste to be categorized as LLW GTCC, generally the activity is >100 nCi/g of long-lived radionuclides and is thus similar to defense TRU waste, however, defense TRU waste derives from DOE defense activities. In other countries, this LLW classification scheme may not be appropriate for LLW resulting from advanced fuel cycles and the reprocessing of uranium and plutonium from SNF, since new LLW may contain a different mix of radionuclides (in particular higher concentrations of various TRU radionuclides and some fission products) than used to develop the waste classifications in 10 CFR 61 based on the radionuclides in LLW being generated 30 yr ago.

II.E.3 Observations

Regardless of the overall economics of reprocessing and advanced fuel cycles, the waste classification system should not provide a disincentive to pursue such advances Several professional societies and National Academies studies, have suggested a revision to the classification system in the US to support future fuel cycles based on risk that other countries may wish to examine (Refs. 9,10). A risk-based approach may be appropriate if a repository program relies heavily on the results of risk assessment. However, the details of applying such a risk approach need to be developed.

II.F RCRA Requirements

HLW, LLW, or TRU waste that contain hazardous non-radioactive waste in addition to the radioactive components (i.e., mixed wastes) poses added institutional challenges in the US because of the potential for dual regulation under regulations established for two different statutes (NWPA and the *Resource Conservation and Recovery Act* (RCRA) and their amendments) and implementation by two or three different regulatory agencies (potentially, EPA, NRC, and a state agency).

As much as 60% of TRU waste destined for the WIPP is mixed waste; thus, the WIPP has dual regulation with both a federal and state regulator. While this dual regulation has been workable, it is time consuming and costly.

The YMP was not designed to accept mixed waste and sought to minimize any incidental mixed waste that might have been generated during waste handling operations. The YMP acceptance criterion precluded use of some hazardous materials (e.g., lead) as part of the disposal system. Some waste streams generated by alternative fuel cycles may involve hazardous wastes that would be regulated by EPA under RCRA, which would introduce this institutional complication for a HLW repository in the US.

Although not particularly common now, a country with small nuclear and hazardous waste volumes may want to integrate hazardous chemical and radioactive waste evaluations in a regulatory framework. A country may wish to use a performance assessment to show the contribution of the hazardous chemical and radioactive waste to overall risk. Such a framework is described by the National Council of Radiologic Protection and Measurements (Ref. 10). In 1988, a scheme for equating the hazards of radioactive waste and chemical waste was developed for DOE and applied in simple scoring approach to provide an order of magnitude ranking based on risk (Ref. 11). A country may also want to consider use of an integrated health-based regulation. Finally, regulations could focus on the most hazardous component of the waste.

IV. SUMMARY

Experience at YMP and WIPP in the US suggests that the regulatory framework should be established prior to initiating a repository development. Concerning specifics of the regulatory framework, both a cumulative release and individual dose standard were successfully implemented using reasonable expectation as the standard of proof. Furthermore, the current retrievablity requirements were successfully implemented in the US; Although the US was not initially successful in developing an integrated health-based regulation for LLW and HLW in the 1970s (or hazardous waste later), a country with small amounts of HLW, LLW, and hazardous waste may want to considered a more integrated regulatory framework to avoid the challenges of future waste streams from advanced fuel cycles.

As discussed further in companion papers, (1) integrating storage, transportation, and waste packaging, and emplacement at the repository involve significant challenges because of the large scale of operations required to manage and dispose of existing and projected US inventories of SNF and HLW (Ref. 3); (2) simplicity of site selection and controlling costs of multiple site characterization through the deliberated use of risk assessment will be important attributes, (3) diversity of geologic media is not particularly necessary as a criterion

[3] In the 1970s, the US considered co-mingling waste categories at repositories; but the *Low Level Waste Policy Act of 1980* (LLWPA) assigned the responsibility of LLW disposal to the states. Then in 1986, Congress amended LLWPA to assign responsibility of GTCC LLW to the federal government. In 1989, NRC stated GTCC was to be disposed in a geologic repository, unless NRC allowed another method.

in site selection because of experience gained here and abroad (Ref. 1); (4) flexibility to adapt to changing circumstances was an important attribute at both YMP and WIPP and stepwise repository may help provide this program flexibility (Ref. 2); and (5) social science research provides important lessons concerning how the public understands and responds to SNF and HLW siting initiatives and a repository program should be cognizant of those policy and technical attributes that enhance initial acceptance (Ref. 4).

ACKNOWLEDGMENTS

Sandia National Laboratories (SNL) is a multi-program laboratory operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Company, for the U.S. Department of Energy (DOE) National Nuclear Security Administration under contract DE-AC04-94AL85000. The statements expressed in this article are those of the authors and do not necessarily reflect the views or policies of DOE, SNL, Argonne National Laboratory (ANL), Savannah River Nuclear Solutions (SRNS), Los Alamos National Laboratory (LANL), or Lawrence Livermore National Laboratory (LLNL), and shall not be used for advertising or product endorsement purposes. Neither the United States government, SNL, ANL, SRNS, LANL, nor LLNL, and any of their employees makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

REFERENCES

1. RECHARD, R.P., F.V. PERRY, T.A. COTTON. 2011."Site Selection, Characterization and Research and Development for Spent Nuclear Fuel and High-Level Waste Disposal," *International High-Level Waste Radioactive Waste Management Conference, Albuquerque, NM April 10-14, 2011*. LaGrange, IL: American Nuclear Society.
2. WILLIAMS, J.R., T.A. COTTON, R.P. RECHARD. 2011. "Role of Flexible Design in Staged Development of Repositories for Spent Nuclear Fuel and High-Level Waste," *International High-Level Waste Radioactive Waste Management Conference, Albuquerque, NM April 10-14, 2011.* LaGrange, IL: American Nuclear Society.
3. RECHARD, R.P., J.A. BLINK, W.G. HALSEY, T.A. COTTON. 2011. Integrated Waste Management System for Spent Nuclear Fuel and High-Level Waste," *International High-Level Waste Radioactive Waste Management Conference, Albuquerque, NM April 10-14, 2011*. LaGrange, IL: American Nuclear Society.
4. JENKINS-SMITH, H.C., C.L. SILVA, K.G. HERRON, R.P. RECHARD. 2011. "Enhancing Acceptability and Credibility of Repository Development for Spent Nuclear Fuel," *International High-Level Waste Radioactive Waste Management Conference, Albuquerque, NM April 10-14, 2011*. LaGrange, IL: American Nuclear Society.
5. ICRP (International Commission on Radiological Protection). 1991. "ICRP Publication 60: 1990 Recommendations of the International Commission on Radiological Protection," *Annals of the ICRP,* **21**(1-3).
6. RECHARD, R.P., M.S. TIERNEY. 2005. Assignment of Probability Distributions for Parameters in the 1996 Performance Assessment for the Waste Isolation Pilot Plant, Part 2: Application of Process, *Reliability Engineering and System Safety,* **88**(*1*):33-80.
7. OTA 1985. Managing the Nation's Commercial High-Level Radioactive Waste, U.S. Congress Office of Technology Assessment, OTA-O-171, March, 1985, http://www.fas.org/ota/reports/8514.pdf.
8. OECD-NEA (Nuclear Energy Agency). 2001a. Radioactive Waste Management Committee, Considering Reversibility and Retrievability in Geologic Disposal of Radioactive Waste, NEA/RWM/RETREV(2001)2, September 17, 2001.
9. NAS (National Academy of Sciences/National Research Council). 2006. *Improving the Regulation and Management of Low-Activity Radioactive Wastes*, the National Academies Press.
10. NCRP (National Council on Radiological Protection and Measurements). 2005. *Risk-Based Classification of Radioactive and Hazardous Chemical Wastes*. Report No. 139.
11. RECHARD, R.P., M.S.Y. CHU, S.L. BROWN. 1988. *SRS: Site Ranking System for Hazardous Chemical and Radioactive Waste,* SAND86-2994. Albuquerque, NM: Sandia National Laboratories.