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EPRI Review of Geologic Disposal for Used Fuel and High Level Radioactive Waste

Volume IV—Lessons Learned

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ABSTRACT

The effective termination of the Yucca Mountain program by the U.S. Administration in 2009 has further delayed the construction and operation of a permanent disposal facility for used fuel and high level radioactive waste (HLW) in the United States. In concert with this decision, the President directed the Energy Secretary to establish the Blue Ribbon Commission on America's Nuclear Future to review and provide recommendations on options for managing used fuel and HLW. EPRI is uniquely positioned to provide an independent scientific and technical perspective on used fuel and HLW management as well as related impacts of alternate nuclear fuel cycles.

While there are, in fact, numerous options for managing the wastes associated with the nuclear fuel cycle, all waste management and fuel cycle alternatives eventually require permanent disposal for some form and amount of long-lived radioactive material. The disposal of used fuel and HLW is often mischaracterized as an intractable problem. To the contrary, there exists today an international consensus on the appropriateness and capability of deep geologic disposal to provide long-term isolation of used fuel and HLW from the biosphere. This consensus has emerged from more than five decades of scientific study and peer-review, technical and regulatory developments, and site selection and characterization. This report, *Lessons Learned*, is the final volume of a four-volume series, entitled *EPRI Review of Geologic Disposal for Used Fuel and High Level Radioactive Waste*, which surveys and evaluates past, present, and planned disposal options gleaned from a half-century of geologic disposal efforts in the United States and abroad. EPRI's review of technical and nontechnical elements deemed critical for successful implementation of a repository program has identified a number of lessons learned in the following areas: 1) laws, regulations, and institutional and financial arrangements; 2) site screening, selection, and characterization; 3) repository design concepts; 4) independent peer review and advisory bodies; and 5) stakeholder and public involvement.

Keywords
Used Fuel
Spent Nuclear Fuel (SNF)
High Level Radioactive Waste (HLW)
Deep Geologic Disposal
HLW Repository

EXECUTIVE SUMMARY

Numerous options are available for managing wastes associated with the nuclear fuel cycle, but all waste management and fuel cycle alternatives eventually require permanent disposal for some form and amount of long-lived radioactive material. While recycling of used nuclear fuel can lead to reductions in the amount of high level radioactive waste (HLW) requiring disposal, reprocessing and other activities associated with recycling of nuclear fuel create additional waste streams that include significant quantities of long-lived radionuclides requiring geologic disposal.

The disposal of used fuel and HLW is often mischaracterized as an intractable problem. To the contrary, there exists today an international consensus on the appropriateness and capability of deep geologic disposal to provide long-term isolation of used fuel and HLW from the biosphere. This consensus has emerged from more than five decades of scientific study and peer-review, technical and regulatory developments, and site selection and characterization. Many important lessons can be gleaned from a half-century of experience that includes notable successes and failures.

A universally accepted principle has evolved during the past half-century of geologic disposal efforts that safety and performance are functions of multiple barriers—both natural and engineered—working in concert to provide a robust disposal system. Safety assessments from numerous international repository programs have shown that a wide diversity of geological formations and repository concepts (tailored to site-specific conditions) can ensure safe, long-term waste isolation. The goal of a repository program is to demonstrate that a repository system consisting of *both* a suitable candidate site and an appropriate repository design—based on multiple, integrated engineered barriers—will adequately protect the public and the environment. This is accomplished by demonstrating that the repository *system* meets established regulations and standards. At present, there are numerous repository concepts having the necessary engineering flexibility to adapt the engineered barrier system so as to complement a variety of site-specific conditions.

The discovery of new information and progressive refinement of conceptual models for HLW isolation is an inherent and inevitable aspect of the site characterization process; therefore, so-called "surprises" arising during characterization are a common feature of all repository programs. An adaptive management plan anticipates the need to address this new information and understanding. Modification and evolution of a repository design thus represents an anticipated, deliberate, and prudent engineering practice to ensure public safety. While there remains the possibility that a site would be abandoned if adequate long-term performance and safety could not be demonstrated, the use of an adaptive management approach can enhance program sustainability and credibility throughout the site selection and characterization process.

Repository design concepts and program implementation—integrated with storage, transportation, reprocessing, and disposal activities—can provide flexibility in national policies and decisions for nuclear waste management. International experience has shown that such an integrated approach appears as a common element in efficient, effective geological disposal programs. This international experience also indicates that organizations in the best position to achieve this full integration are derived from nuclear power utilities themselves.

Another lesson from U.S. and international experience is that consistent, stable funding is essential to efficient, effective repository programs, with funding derived from fees on waste generators. Stability is generally realized if the funds are managed directly by the disposal program implementer. This approach avoids the uncertainty and fluctuations that typically accompany funding reliant on legislative appropriations. Consistent, stable funding of a repository program also allows for the continuity required to execute characterization, design, licensing, construction, and operational phases over an extended timeframe.

The technical qualification of a repository system is ultimately determined by its ability to satisfy regulatory requirements; accordingly, regulatory development and licensing play crucial roles in the repository development process. Licensing of a geologic repository for used fuel and HLW in the United States at a site other than Yucca Mountain, Nevada, reverts to regulation under the older, generic standards and regulations of 40 CFR 191 and 10 CFR 60. This regulatory set, first developed in the early 1980s, is now out-of-step with international best practices and needs revision or replacement. The site-specific regulations for Yucca Mountain, 40 CFR 197 and 10 CFR 63, are more up to date and include an important emphasis on total system performance. A logical evolution would be the promulgation of revised or new regulations applying a risk- or dose-based all-pathways approach, without either subsystem performance requirements or separate groundwater protection standards.

One of the key issues to be addressed in the revision of geologic disposal regulations is the timeframe for demonstrating performance and regulatory compliance. Significant technical and licensing uncertainties arise when carrying safety analyses out to extremely long timeframes. As a result, there is a general convergence of approaches to compliance periods within the international community, one of which recognizes the need for increasingly qualitative treatment of safety analyses as compliance periods are extended into the far distant future. However, the need to treat analyses as increasingly qualitative may be challenging in a licensing process, such as that used by the U.S. Nuclear Regulatory Commission (NRC). Clear legislative or regulatory guidance regarding how to handle geologic timeframes and associated uncertainties in an adjudicatory licensing environment would be beneficial.

In the U.S. context, the extension of the regulatory compliance period for the U.S. Environmental Protection Agency (EPA) standards under 40 CFR 197 to 1 million years resulted from a narrow legal ruling specific to the Yucca Mountain program. By contrast, a 10,000-year compliance period for deep geologic disposal has withstood legal challenge and remains in place for the generic U.S. standards under 40 CFR 191. Moreover, this 10,000-year compliance period has been successfully applied for certification of the Waste Isolation Pilot Plant (WIPP), an operating deep geologic repository located in a bedded salt formation near Carlsbad, New Mexico. It is clear that in light of the positive WIPP example as well as international experience, a 10,000-year compliance period could be retained as the licensing basis for generic regulations governing HLW repository performance for sites other than Yucca Mountain.

For a fully integrated and consistent waste management program that avoids gaps and provides optimum protection of the public and environment, all wastes regardless of classification should have a designated path toward an appropriate disposal system in the United States. There is general consensus on the appropriate path to disposal for low level radioactive waste (LLW) in near-surface burial facilities and for HLW and used nuclear fuel in deep geological settings. However, gaps remain; for example, the so-called "Greater Than Class C" wastes in the United States have no clear disposal pathway identified at present. In the future, such problems could be exacerbated by reprocessing and other activities associated with the deployment of advanced fuel cycle technologies, as these activities are expected to generate substantial quantities of wastes that would be orphaned under the current U.S. radioactive waste management regime.

Several countries have identified one or more potential rock formations combined with appropriate engineered systems that are expected to be publicly acceptable and adequately safe for geologic disposal. Many repository concepts, linked to specific rock types, have been refined to an advanced state of scientific and engineering understanding. This should facilitate relatively rapid implementation and significant cost savings if such existing concepts could be applied to U.S. sites with similar host rock characteristics. The United States has a diverse and geographically distributed collection of potentially suitable rock formations, including *all* rock types under consideration by disposal programs in other nations.

The 1982 Nuclear Waste Policy Act called for siting of a second repository in the United States and imposed a legal disposal limit on the first—to be lifted once the second became operational. Thus, it is important to distinguish between the technical disposal capacity of a repository system and any legislative or regulatory limits established for other reasons. The ultimate need for more than a single repository may depend on a number of technical and nontechnical factors, including waste inventory (which may be affected by future decisions on advanced fuel cycles), political judgments as to regional balance and perceived fairness, and attributes of an initially selected repository site. Since the underlying technical capacity of a host site may be substantially greater than imposed limits, as was the case for Yucca Mountain, U.S. HLW disposal requirements could, in principle, be addressed by a single repository.

The WIPP facility, which provides geologic disposal for defense-origin transuranic (TRU) waste, presents useful precedents with respect to siting of a U.S. geologic repository. However, there are technical, siting, regulatory, and policy factors that could present significant challenges to a potentially expanded WIPP mission as a host for used fuel and HLW disposal. Moreover, lessons from the successful *certification* of WIPP under EPA authority may not directly translate to a more complex NRC *licensing* process and compliance under dual NRC and EPA regulations.

Public acceptance is essential to the success of HLW disposal programs. Accordingly, geologic disposal programs must recognize and embrace the value of public involvement. Worldwide, major delays and barriers have arisen in geologic disposal programs due to the lack or loss of adequate support from the public and other key stakeholders, including those levels of government involved in the critical path for repository siting, licensing, construction, and operation. Reaching and sustaining support from intermediate or regional groups and levels of government (such as states, provinces, cantons, prefectures, and Native Peoples) has proven particularly critical both in the United States and internationally.

Technical concerns by the public and other stakeholders are a vital consideration. Such concerns are best addressed by a national repository program that is subject to an open and transparent licensing process, including oversight by a technically competent and independent regulator and periodic scrutiny by national and international peer-review panels of experts. Another important aspect of stakeholder involvement that warrants consideration is the asymmetry of perceived risks associated with disposal program activities relative to the perceived benefits. The public, various levels of affected governments, and other stakeholders typically do not perceive the same levels of benefits-to-risks in selection of a specific site.

All options regarding the management of nuclear materials eventually require disposal of some types and amounts of long-lived radioactive waste in stable, deep geological formations, the universally accepted method for such disposal. Direct comparisons of progress toward disposal between the United States and other nations are complicated by differences in political systems, acceptance and reliance on nuclear power, regulatory precedents, social attributes, and other factors. However, more than 50 years of geologic-disposal-related efforts worldwide—from scientific study through construction and operation—do provide useful precedents, examples, and possible paths forward for a post-Yucca-Mountain HLW disposal program in the United States. National programs achieving steady progress toward safe, final disposal are characterized by having 1) an implementing organization with a secure, steady funding level; 2) an independent, technically competent regulatory authority; and 3) an inclusive, transparent, stepwise, and adaptive process for siting, design, and licensing of a geological repository.

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1 INTRODUCTION

From 1989 until 2008, the Electric Power Research Institute (EPRI) conducted independent assessments of a proposed deep geologic repository for the disposal of used fuel and high-level radioactive waste (HLW) at Yucca Mountain, Nevada. Over this two-decade time period, EPRI's expert team has followed the development of the US repository program closely and provided an independent, third party perspective on this national undertaking with respect to technical issues, including site suitability and regulatory compliance.

EPRI pioneered application of the total system performance assessment (TSPA) approach for evaluating performance of geologic repository systems on a probabilistic basis. Along the way, EPRI developed and updated computational tools for TSPA-based evaluations. Over the two decades of research in this area, EPRI has released and maintained a substantial body of work in the public domain to inform its member organizations, the public, government, independent technical review bodies, and other stakeholders.

In June 2008, the US Department of Energy (DOE) submitted a license application to the US Nuclear Regulatory Commission (NRC) for the construction of a geologic repository at Yucca Mountain, Nevada. The license application was accepted for formal NRC review in September 2008. Once docketed, the US disposal program entered a new and fundamentally different phase – one involving formal regulatory review and administrative law proceedings via the Atomic Safety Licensing Board. Following this programmatic transition, EPRI ended its Yucca Mountain-specific research program and refocused its used fuel and HLW management research program on more generic topics related to the evaluation of nuclear fuel cycle options. In parallel, EPRI has also expanded its research program on the performance of used fuel storage systems to address extended aging periods, i.e., beyond the current 60-year licensing timeframe for dry storage and reactor operations.

The effective termination of the Yucca Mountain program by the US Administration in 2009 has further delayed the construction and operation of a permanent disposal facility for used fuel and HLW. In concert with this decision, the President directed the Energy Secretary to establish the Blue Ribbon Commission on America's Nuclear Future (BRC) "…to conduct a comprehensive review of policies for managing the back end of the nuclear fuel cycle and to provide recommendations for developing a safe, long-term solution to managing the Nation's used nuclear fuel and nuclear waste." The BRC has been given 24 months from January 2010 to complete its review and deliver a final report to the Energy Secretary, which is to include: (1) "Consideration of a wide range of technological and policy alternatives, and should analyze the scientific, environmental, budgetary, financial, and management issues, among others, surrounding each alternative it considers;" (2) " …a set of recommendations regarding policy and management, and any advisable changes in law;" and (3) "Recommendations on the fees currently being charged to nuclear energy ratepayers and the recommended disposition of the available balances consistent with the recommendations of the Commission regarding the management of used nuclear fuel."[1]

EPRI is uniquely positioned to provide a scientific and technical perspective for the ongoing national (and international) conversation on the future of nuclear power in general, and nuclear fuel cycles and their impacts on the management of used nuclear fuel and HLW in specific. This perspective is informed by a combination of experience, expertise, and collaboration in the relevant areas of geologic disposal, used fuel storage and transportation, and advanced nuclear fuel cycle assessment and by EPRI's role as a center for international collaborative research supporting electric power generation. To this end, EPRI has prepared a number of technical reports on storage, disposal, and advanced fuel cycle issues relevant to the management of used fuel and HLW.

There are numerous options for managing the wastes associated with the nuclear fuel cycle; however, all nuclear fuel cycles eventually require permanent disposal for some form and amount of long-lived, highly radioactive material. This report is the final volume of a four-volume series entitled "EPRI Review of Geologic Disposal for Used Fuel and High-Level Radioactive Waste" that surveys and evaluates past, present, and planned disposal options gleaned from five-decades of geologic disposal science and regulation in the US and abroad. This effort is not intended to provide a comprehensive review of the US program or of those in other countries. Instead, EPRI has prioritized its efforts to focus on a handful of key areas and topics to avoid unnecessary duplication of other efforts and to direct attention and resources on those areas where EPRI could make the greatest contribution to the ongoing technical debate on the management of the back-end of the fuel cycle. The target audience includes but is not limited to the EPRI members, the public, the technical community, and decision makers and their staff. A key audience for this work is the Blue Ribbon Commission.[2] To this end, EPRI has presented its views to the Commission on a number of topics, and will continue to do so as requested.

EPRI report 1021056, Volume I of this series (EPRI, 2010b), reviews and summarizes the implementation of the 1982 Nuclear Waste Policy Act in the technically based identification, screening and comparison of diverse geological sites prior to the 1987 amendments that re-focused US attention solely on Yucca Mountain. EPRI report 1021384, Volume II of this series (EPRI, 2010c), reviews and compares the generic and Yucca Mountain specific standards and regulations promulgated by the US Environmental Protection Agency (EPA) and the NRC. EPRI report 1021614, Volume III in the series (EPRI, 2010d), summarizes the developments and status of leading international repository programs in countries with major repository programs.

This report, *Volume IV—Lessons Learned*, draws on the observations of the first three reports in the series and on other pertinent experience and information sources to provide a concise set of lessons learned from US and international repository programs with respect to technical issues as

[1] Blue Ribbon Commission on America's Nuclear Future, Advisory Committee Charter. <http://brc.gov/pdfFiles/BRC_Charter.pdf> U.S. Department of Energy, Washington, D.C., March 2010; accessed 14 May 2010.

[2] The "Blue Ribbon Commission on America's Nuclear Future" was formally established in a 29 January 2010 Presidential memorandum to Energy Secretary Chu.

well as technically driven policy issues associated with geologic disposal for the long-term isolation of used fuel and HLW. There are both technical and non-technical policy areas that need to be addressed and resolved in any national program for managing used fuel. Implementation and continuity of national policy define the context of disposal (as well as storage and possibly reprocessing) activities for which technical studies must be conducted.

The critical elements of repository program implementation include:

- Laws, regulations, and institutional and financial arrangements;
- Site screening, selection, and characterization;
- Repository design concepts;
- Independent peer review and advisory bodies; and
- Stakeholder and public involvement.

Failure to adequately address and implement *all* of these elements will lead to costly delays, expanding opposition and conflict, and possible derailment of the entire process. This report examines lessons learned with respect to these critical elements both from US and international experiences on radioactive waste disposal. International experiences and approaches, as documented in Volume III of this series (EPRI, 2010d) and other reviews (for example, NWTRB, 2009; WNA, 2009; NEA, 2010), offer an independent source of knowledge and perspective that can inform and possibly expedite future US decisions and plans for a new disposal program and a broader integrated approach to nuclear waste management.

A review of countries seriously pursuing a HLW disposal pathway reveals that the countries involved are at significantly different stages in terms of planning for the disposal of HLW and used nuclear fuel (EPRI, 2010d). Some countries, for example, Belgium, Spain, and Japan, have not yet decided that geologic disposal is the best option; in these countries, a compelling case for implementing a long-term solution in the near term in order to avoid passing the problem onto future generations has not been made convincingly. In contrast, other nations, such as Sweden, Finland, and France, are on a more defined path for repository development. In this respect, the termination of the Yucca Mountain program can be viewed as a major US policy shift from the defined path to the undecided camp. In the absence of a clear disposal solution for used fuel, the undecided countries such as Belgium and Spain generally favor long-term storage as a path forward.

The relevance of international experience to the US situation is limited by the individual and sometimes unique circumstances and conditions faced within each country in the pursuit of a national HLW management strategy and implementation of a repository program. Important factors to consider include: size of country, total population, population density, cultural norms, form of government, regulatory infrastructure, quantity and nature of nuclear waste inventory, and past precedents and decisions on which management options to pursue. Given the complexity of and diversity in national contexts, drawing overly specific conclusions from the international experience is difficult if not ill-advised.

2
THE NEED FOR A GEOLOGIC REPOSITORY FOR USED FUEL AND HIGH-LEVEL RADIOACTIVE WASTE

There are numerous options for managing the wastes associated with the nuclear fuel cycle, each with different motivations, advantages, constraints, and optimization goals. Many nations consider used nuclear fuel as a resource due to the residual fissile and fissionable isotopes that can be recovered and recycled as mixed U-Pu oxide fuel (MOX) in current light water reactors (LWRs) and as fuel for fast reactors (FRs). The waste management challenges and options vary by nuclear fuel cycle, but all eventually require permanent isolation or disposal of some form and amount of long-lived radioactive waste to provide adequate protection of human health and the environment.

There is a general international consensus that has developed and been sustained since the 1957 US National Academy of Sciences report (NAS, 1957) that deep geologic disposal is the preferred option for permanent disposal of used fuel or the HLW from reprocessing used fuel.[3] A number of alternatives such as sub-seabed disposal, emplacement in ice sheets and space-launch have been thoroughly investigated and rejected for substantive reasons such as conflicts with international conventions in the case of sub-seabed disposal and the potential for atmospheric dispersal of radioactivity following a launch failure (NAS, 2001). All countries seriously pursuing permanent disposition pathways for used fuel and HLW management have selected deep geologic repositories as the technology of choice. While beyond the scope of this review, it is important to recognize that geological disposal is also needed in the US to disposition the used naval nuclear fuel and HLW from ongoing defense activities and as a legacy of the US nuclear weapons program.

2.1 Disposal as a Fundamental Element of all Fuel Cycles

Figure 2-1 illustrates the major components of representative once-through and advanced nuclear fuel cycles, and highlights the universal need for an appropriate disposal pathway for either used fuel, HLW, or both.[4] Adoption of more advanced fuel cycles, i.e., beyond the once-through approach currently in use in the US and most other nations with nuclear power programs, is often incorrectly cited as a solution to the nuclear waste management problem obviating the need for a

[3] For simplicity, the term HLW may be used in this report to refer to both used fuel and waste from the reprocessing of used fuel.

[4] The figure makes an important distinction between open and closed fuel cycles. A closed fuel cycle generally implies the incorporation of reactors utilizing fast neutron spectra (fast reactors) or other technology to fully access the energy contained in the fissile and fertile material in nuclear fuel. Accordingly, the recycling of Pu as MOX in LWRs exclusively does not qualify as a closed fuel cycle, as direct disposal of irradiated MOX fuel would still be required eventually.

permanent deep geologic disposal facility. However, all fuel cycles generate some radioactive by-products that require permanent disposal. The recycling of used fuel generates a number of waste streams, including HLW, intermediate-level radioactive waste (ILW), and LLW, with each requiring eventual disposal (NEA, 2006; DOE, 2008d; EPRI, 2009a; 2010a). The LLW generated from many activities in the fuel cycle as well as from reprocessing, contain short-lived radionuclides and low concentrations of longer-lived radionuclides, such that they may be safely disposed in the near surface in trenches or vaults. There is considerable experience with the design and safe operation of LLW disposal facilities, both commercially and in the DOE Weapons Complex. While reprocessing of used fuel can lead to a smaller amount of HLW for disposal, there are significant amounts of long-lived ILW produced that, based on IAEA classification and international practice, require isolation in deep geologic disposal systems (IAEA, 2009). In several countries that have reprocessed irradiated fuel, co-disposal of reprocessed HLW and ILW are planned, and some also intend to seek geologic disposal of LLW (EPRI, 2010d).

The US has successfully sited and constructed and is currently operating a deep geologic repository for defense related transuranic (TRU) wastes at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico. TRU wastes have higher activity concentrations than are appropriate for near-surface disposal, but do not approach the concentrations of long-lived radionuclides found in HLW and used nuclear fuel.

Independent safety assessment studies have been performed by the US National Academy of Sciences to investigate impacts of partitioning and transmutation (P&T) activities on performance of geological disposal (NAS, 1996). These analyses indicated that for current geologic repository systems, i.e., designed with multiple engineered and natural barriers for a diverse range of host rock types, favorable P&T impacts are heavily dependent on (1) the repository concept and host rock environment being considered, (2) the type of radionuclides removed and effectiveness of the transmutation, and (3) the release scenario envisioned. The need for a deep geological repository, however, is not eliminated.

Thus, the inevitable generation of long-lived radioactive materials not suitable for recycling in any fuel cycle, the international consensus on the appropriateness of deep geologic disposal for long-lived low and intermediate level radioactive wastes (LILW-LL) generated from reprocessing of irradiated fuel (IAEA, 2009),[5] and the challenges associated with implementing transmutation schemes in a timely and economic manner make disposal a necessary component of all foreseeable nuclear fuel cycle options.[6]

[5] This waste classification is derived from IAEA guidelines and is not consistent with the US waste classification system (IAEA, 2008).

[6] Although technically achievable, the feasibility of transmutation for alleviating waste management burdens remains speculative due to substantial technical hurdles yet to be surmounted, long timeframes required, and economic challenges (NAS, 1996).

2.2 Disposal as a Fundamental Element of an Integrated Nuclear Waste Management Strategy

The optimum approach to waste management is now generally recognized to be one in which all elements and stages of the back-end of the nuclear fuel cycle are addressed in an integrated fashion, including generation of waste and waste streams, conditioning and treatment of waste, development of waste forms, storage and thermal management, and final disposal (e.g., IAEA, 2009; NEI, 2010; NRC, 2010a). Therefore, it is important that the national authorities responsible for final geological disposal have a leading role in coordinating and decision-making across such waste management stepwise activities. Yet in practice, authority over waste management activities is typically fragmented and distributed among multiple governmental agencies. This leads to gaps in planning at a systems level and provides considerable opportunity for disconnects, inconsistency, and inefficiency with little or no overall benefit. For example, the disjointed US system, with the former DOE Office of Civilian Radioactive Waste (OCRWM) heavily focused on the transportation and disposal elements and separate EPA and NRC regulations for each part of the system,[7] led to a repository design for Yucca Mountain that minimized the repository post-closure dose with corresponding increases in costs and potential radiation exposures and other health risks in other parts of the system (EPRI, 2008).

Currently, the availability of wet and dry storage options provides proven modes for the safe and secure management of used fuel in the coming decades. Accordingly, in the short term, the timing for construction of a deep geologic repository or other permanent disposal facility appears to be more a matter of policy concern than technical imperative. This, however, does not preclude the need for a repository program, given the long lead times required for siting, characterization, licensing, and construction operations and other drivers. Furthermore, numerous other countries with nuclear power are opting for prompt implementation of geological disposal as a demonstration of environmental stewardship of the overall nuclear fuel cycle and to bolster confidence in the sustainability of nuclear power (EPRI, 2010d). For the intermediate term, dry storage is expected to perform beyond the current licensing period of 60 years (EPRI, 2009c),[8] although storage requiring indefinite institutional control is clearly not a long-term solution. For longer time frames (beyond expectations of institutional control), geologic disposal for some form and quantity of used nuclear fuel and/or HLW and ILW remains an absolute necessity for all foreseeable fuel cycle options.

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[7] For example, under the current NRC regulatory framework as of August 2010, wet storage of used fuel in on-site reactor fuel pools is regulated under 10 CFR 50; dry storage of used fuel is regulated under 10 CFR 72; transportation of used fuel is regulated under 10 CFR 71; and disposal would be regulated under 10 CFR 63 for Yucca Mountain or 10 CFR 60 for any other HLW repository. In many cases, the bases for compliance are not consistent among the related regulations; this situation has proven problematic in used fuel management when transitions from one regulatory space to another occur, such as for the transfer of used fuel from pools (10 CFR 50) to dry storage (10 CFR 72).

[8] As of 2009, an EPRI-led collaborative effort among government (NRC, DOE, and national laboratories) and the nuclear industry (utilities, vendors) was initiated to provide the technical bases demonstrating safe, long-term used fuel storage (including dry storage exceeding the current 60-year licensing basis) and future transportability.

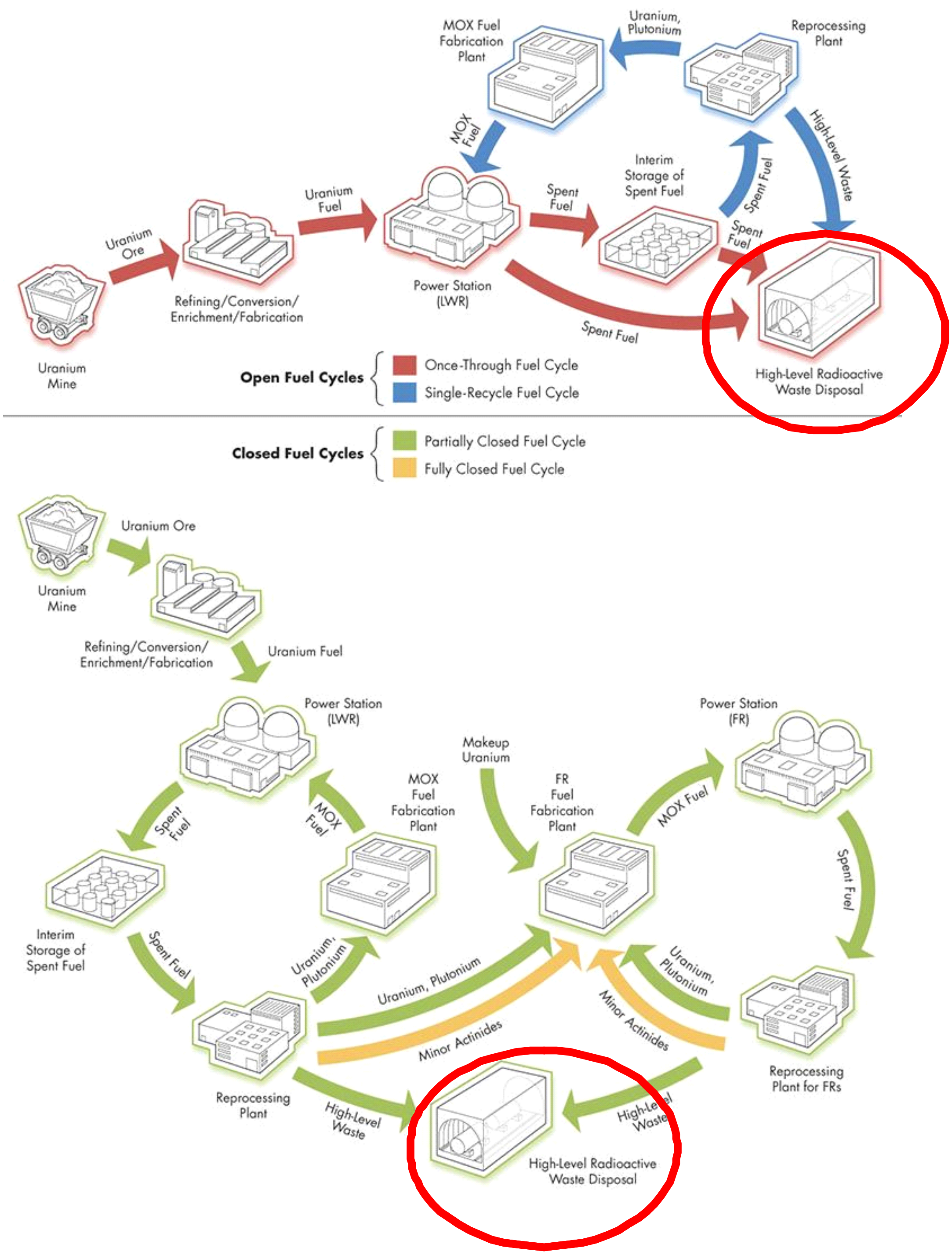

Figure 2-1
Illustration of Open and Closed Fuel Cycles with HLW Disposal Element Highlighted as an Integral Component for Both

3
LAWS, REGULATIONS, AND INSTITUTIONAL ARRANGEMENTS

3.1 National Laws

The origins of any HLW disposal program lie in the enabling governmental laws that define the roles and responsibilities of implementer, regulator, and impacted levels of governments and communities, as well as the funding source. The Nuclear Waste Policy Act of 1982 (NWPA) formalized and organized the US repository program for the first time after several decades of efforts and set into motion a step-wise approach for siting of a first repository, specified the need for a second US repository, and called for study of centralized interim storage as an integral part of the HLW management system. The NWPA clearly defined the roles and responsibilities of the implementer, the regulators, utilities, and concerned stakeholders and established a funding mechanism: the Nuclear Waste Fund. This precedent-setting approach became a template for subsequent national laws for geological disposal programs established in other countries. Now, that international experience, including a number of disposal program restarts,[9] holds useful lessons for the US in a post-NWPA era.

Subsequent modifications to the NWPA via the Nuclear Waste Policy Amendments Act of 1987 (NWPAA) significantly changed the nature and tone of the US repository program by abridging the multi-site nominative approach to site selection for the initial repository site and abandoning the pursuit of a second repository. Federal efforts to site a monitored retrievable storage (MRS) facility were also abandoned in 1987.[10] The NWPAA legally designated the Yucca Mountain site in Nevada as the sole candidate site for further characterization out of a field of three finalists. Political intervention in the site selection process, manifested in modifications to and deviations from the NWPA, has been widely viewed as a major contributor to the failure of the US repository program.

There are examples in other countries that suggest that strong political leadership can and will go a long way in setting a sustainable repository program into motion. Notable and instructive examples include (EPRI, 2010d):

[9] The US is not unique in facing the prospect of having to restart its geologic disposal program. A number of other countries have abandoned well-established programs and launched new efforts (e.g., Canada, France, and the UK), or have been driven to revise their siting approaches (e.g., Switzerland) (EPRI, 2010d).

[10] In the period since 1987, a consortium of private electric utilities identified a MRS site on the Goshute Indian reservation in Utah and eventually obtained an NRC license to construct the site in 1995. However, the progress on the Private Fuel Storage (PFS) facility stalled following intervention by the State of Utah and Congress, which eventually led to the denial of critical federal agency approvals to provide access to the site.

- Progress made since 1991 towards a geologic repository in France as a result of the 1991 Law that marked a new, transparent approach and set in motion a carefully supervised 15-year period of research and development with well-established deadlines towards the identification of a suitable site. France continues to move towards the licensing phase for the construction of a geologic repository.
- Passage of the revised Nuclear Energy Act in Switzerland in 2005, which removed the right of cantons to veto a repository, although a national referendum is required. Previously, two canton vetoes halted progress towards a geologic repository for LLW and ILW.

A common feature of effective national waste management programs is the adoption of a flexible, step-wise decision and implementation process that allows for adaptation and optimization while still achieving progress toward final disposal of nuclear wastes. Adaptive, phased deployment of disposal systems has been recommended by the US National Academy of Sciences (NAS, 2003). More recently, this approach, termed "adaptive phased management," has been adopted as a central pillar of the reinvigorated Canadian disposal program (NWMO, 2005).

Arguments for timely disposal of used fuel or HLW are often based on the need for inter-generational equity and honoring of the so-called "polluter pays" principle. These concepts are central to basic internationally agreed principles for waste management (IAEA, 2006). However, they are also often in conflict with arguments for intra-generational equity with respect to questions of if, when, and how to dispose of nuclear wastes (Okrent, 1999). In response to this tension, newer disposal concepts are emerging that can provide greater flexibility in maintaining management options for current and future generations, while enabling the present generation that benefited from the nuclear power produced to pay for final waste disposal, even if deferred (EPRI, 2010d, Appendix B). However, as disposal comprises only one key element of many in an integrated waste management system, the benefits of deferral must be weighed against the potential impacts on recycling, transportation, and storage options, as well as further development of nuclear power. Furthermore, the lack of a coherent, active disposal program leads to inefficiencies in the deployment of storage, transportation, and advanced fuel cycle options.

3.2 Independent Regulatory Oversight and Safety Standards and Regulations

National laws pertaining to nuclear waste disposal generally empower independent regulatory authorities to develop and implement safety standards for pre- and post-closure performance and conduct regulatory reviews of license applications for construction and operation of disposal facilities and licensing procedures. Maintaining a credible, technically competent, independent regulatory authority is an essential element of effective national disposal programs, and can provide non-technical stakeholders with confidence that adequate protection of public health and the environment will be assured regardless of the disposal implementation program or decision. A technically competent, independent regulator committed to assuring public health and radiological safety is also widely recognized as essential for gaining and maintaining public acceptance during the long, step-wise process in a national waste disposal program. There are diverse international regulatory approaches, and for a given nation, there can be significant internal variation in the approach to regulation of different classes of radioactive wastes (EPRI, 2010d).

3.2.1 Performance Assessment

Standards and regulations in the US and internationally have evolved toward a total system performance based approach and away from approaches in which separate performance requirements are established for individual system components. EPRI strongly endorses the "total systems" approach to regulations for geologic repositories, which allows for a holistic view in which the natural and engineered barriers are considered together as an integrated system. This robust approach provides more flexibility, offers stronger overall assurance of repository performance, and allows for greater focus on risk-significant issues (EPRI, 2010c).

A total system performance assessment TSPA approach based on dose or risk based metrics is now generally considered to be equally protective, but more consistent and transparent than the standing generic regulatory set of 40 CFR 191 and 10 CFR 60, which include cumulative release limits, as well as redundant and potentially conflicting subsystem performance requirements and separate groundwater protection standards (EPRI, 2010c). A dose or risk based approach is also more in step with international practice and guidance (e.g. ICRP, 2000). As has been shown in many total system assessments, it is the combined performance of the system of processes and barriers, including the engineered barrier system (EBS) and natural barriers (geological, hydrological, and geochemical), that provides a robust assurance of long-term, safe isolation of radioactive wastes disposed in geological repositories, e.g. Canada, Sweden, Finland, Switzerland and Japan (EPRI, 2010d). However, within this paradigm, there exists a high degree of flexibility for the repository program's implementing organization to tailor repository design concepts to the host site characteristics in order to achieve the desired level of performance and safety. There is varying emphasis among national programs on the performance of different components of the repository system, largely related to the type of host formation and geological stability. For example, in Sweden, Finland and Japan, there is greater emphasis on the performance of the EBS, whereas in France, Belgium and Switzerland, the low-permeability clay formation dominates performance.

The International Atomic Energy Agency (IAEA), the Nuclear Energy Agency (NEA), the NRC, the EPA, and all international repository and regulatory programs explicitly endorse performance or safety assessments of repository systems as an integral part of step-wise licensing. Outside of the US, the "Safety Case" concept is widely applied; the US National Academy of Sciences (NAS, 2003) has asserted that the current US regulations and the international Safety Case are essentially equivalent. Two key aspects of the Safety Case include the extensive use of supporting arguments (such as industrial and natural analogue data) and alternative safety indicators (e.g., comparison of repository releases to the flux of natural radionuclides from a site). The latter topic is especially useful as application of dose-models based on present-day human habits and activities becomes increasingly uncertain at time scales beyond several hundreds of years. An illustrative example of how the Safety Case concept and approach have been implemented in the UK for both nuclear and non-nuclear activities appears in EPRI (2010d, Appendix D).

Use of excessively conservative (i.e., unrealistically pessimistic) assumptions in performance assessments skew both the resulting dose estimates and the relative importance of individual components of the repository system. While some level of conservatism for TSPA is justified and necessary for regulatory compliance purposes, the use of a "best estimate" approach to the extent practical can provide a more realistic, defensible assessment methodology for siting and detailed repository design decisions. The effect of compounding conservatisms in TSPAs of the Yucca Mountain project, and their effect on repository design decisions, have been documented and extensively discussed in prior EPRI reports (e.g., EPRI, 2007; 2008, 2009b).

A focus on overall system safety and performance is not compatible with requirements for the isolated performance of individual barriers or processes. The US EPA's historical preference for a separate groundwater protection standard introduces a redundant, potentially conflicting, and unnecessary regulatory element into a dose or risk standard based on an all pathways approach. Likewise, the NRC's 10 CFR 60 criteria imposes subsystem performance objectives on both engineered barrier and natural barriers of a repository, which can arbitrarily penalize certain sites and restrict some repository concepts that might otherwise have proven useful for enhancing or ensuring the safe, long-term isolation of used fuel and HLW. Revised or new regulations for geologic disposal of HLW can be promulgated without subsystem performance requirements and separate groundwater standards, while maintaining levels of public and environmental protection and providing a simpler, more consistent regulatory basis.

3.2.2 Timeframe for Regulatory Compliance

Time scales for regulatory compliance are a key issue. There is general international consensus that the time scale of compliance must be appropriate to the hazard of the waste under consideration for disposal; however, the regulatory timescale cannot be so long that the safety analyses fall prey to increasing uncertainty with time and become of questionable utility.

Timeframe requirements over which safety assessments are performed vary from country to country, with differing levels of quantification required for different timeframes; there is no single international consensus or approach. This variability results from the interplay of many factors that necessarily vary by country, including regulatory precedents and specific domestic societal and technical community concerns. Many countries have yet to decide on a specific timeframe, while several countries limit evaluation of repository performance to periods on the order of 10,000 years (e.g., France and Finland). Some of the clearest guidance can be found from the Finnish regulatory authority, STUK, which has set out a phased set of regulatory safety criteria that apply at different post-closure time periods for a repository (EPRI, 2010d). Such criteria reflect the diminishing radiological hazard of the waste and the increasing uncertainties in future conditions arising from processes such as glaciation.

Consistent with the generic standards in 40 CFR 191, the original EPA standards for Yucca Mountain in 40 CFR 197 were applicable to a period of 10,000 years following closure of the facility. Following multiple legal challenges to the standard, the US Court of Appeals ruled in favor of EPA on all counts except for one: the court found that EPA's 10,000-year compliance period could not stand because it was not consistent with the findings of the National Academy of Sciences report (NAS, 1995) as mandated by Section 801 of the 1992 Energy Policy Act, that called for a timeframe consistent with geologic stability, on the order of 1 million years. It is noteworthy that the Court's finding was not driven by the protectiveness (or the lack thereof) of a 10,000-year standard, but rather specifically by the legal requirements in the NWPA for EPA to follow the 1995 recommendations from the US National Academy of Sciences.

In response to the Court ruling, EPA revisited 40 CFR 197 to satisfy the legal requirement of a compliance period extending to the period of geologic stability, defined in the final rule to end one million years after disposal. EPRI (2005) published an analysis of the technical challenges associated with carrying out a performance assessment for such long time periods and the findings of this analysis are discussed in greater depth in Volume II of this series (EPRI 2010c). To meet the unprecedented challenge of demonstrating regulatory compliance out to such a long timeframe, EPRI (2005) recommended that the revision to 40 CFR 197 should:

- Keep the draft regulations for Yucca Mountain unchanged for the first 10,000 years after repository closure;
- Accommodate stylized analyses for the post-10,000 year period to allow projection of repository performance in a manner that protects public health but does not introduce elements that require arbitrary scientific assumptions;
- Fix climate behavior at a steady state, such as the current interglacial climate, throughout the analysis to avoid the technical difficulties in evaluating a transient and hypothetical set of future climate trajectories;
- Assume human actions consistent with the postulated climate, which implies the use of the reasonably maximally exposed individual (RMEI) approach with the current interglacial climate projected out to peak dose;
- Exclude from the post-10,000-year analysis additional Features, Events, and Processes (FEPs) not already considered in the pre-10,000-year period; the FEPs included under the 2001 draft regulation reflected a very conservative cutoff criterion and any additional FEPs would be overly conservative and unnecessary; and
- Apply a separate, higher dose standard after 10,000 years; a value of 1 mSv/y (100 mrem/y) was suggested as being technically defensible.

The final revised rule under 40 CFR 197 promulgated by EPA in 2008 was consistent with the 2005 EPRI recommendations, including the maintenance of a public dose limit of 0.15 mSy/y (15 mrem/y) for the first 10,000 years and addition of a higher post-10,000 year mean dose standard of 1 mSv/y (100 mrem/y) out to 1 million years.[11]

3.2.3 Evolution of Regulatory Approach

Today, 40 CFR 197 and conforming 10 CFR 63 represent the most evolved US regulations governing geologic disposal. However, as these regulations apply only to a repository developed at Yucca Mountain, Nevada, the licensing of a geologic repository for used fuel and HLW in the

[11] Also consistent with the EPRI (2005) recommendations was the NRC specification in 10 CFR 63 of net infiltration values at specific times in the future in order to address the issue of uncertain future climate states.

US at a site other than Yucca Mountain, Nevada, reverts to regulation under the generic standards and regulations of 40 CFR 191 and 10 CFR 60 as they currently exist. This older regulatory set is out-of-step with international norms and is widely viewed as obsolete and in need of revision or replacement. Such a process would benefit from, and should be informed by, the substantial experience and knowledge acquired in the US and internationally during the period following the initial promulgation of generic standards and regulations in the 1980's through the final regulatory rulemaking for Yucca Mountain in 2008.

The extension of the regulatory compliance period for 40 CFR 197 resulted from a narrow legal ruling specific to Yucca Mountain. In contrast, a compliance period of 10,000 years has withstood legal challenge and remains in place for 40 CFR 191, which has been successfully applied to WIPP certification and recertification under exclusive EPA regulatory oversight. Given the international experience and US precedence, a 10,000-year compliance period could be retained for a US repository other than Yucca Mountain.

3.3 Implementing Organizations

National laws establishing a program for nuclear waste management and ultimate disposal universally identify an implementing organization - the implementer - charged with finding suitable sites for disposal, and then researching, designing and developing a suitable disposal concept that will meet established regulatory safety standards. Where governments are responsible for oversight of both implementing and regulatory organizations, there must be a clear separation between the two organizations (IAEA, 2006). A second common approach internationally is to have waste producers collectively establish the implementing organization as an independent company, either public or private, that remains answerable to government.

Leading international used fuel and HLW disposal program implementers, such as those in Sweden, Finland, Switzerland, and France, have been established either through a public-private partnership or a fully privatized arrangement, rather than placing the implementer into a national government agency. Commitment to an independent nuclear waste implementer, guided and restricted by both national laws and regulatory oversight, buffers the deliberate process of siting, licensing, constructing, and operating a repository from political disruptions and associated financial uncertainties.

In the US, Section 303 of the 1992 NWPA directed the Secretary of Energy to evaluate alternative approaches to managing the then nascent geologic disposal program. The resulting report from the Advisory Panel on Alternative Means of Financing and Managing Radioactive Waste Facilities characterized the lack of "stability and continuity" as a primary factor in early problems encountered by the newly formed Office of Civilian Radioactive Waste Management (OCRWM) within DOE. The Panel called attention to its general preference for a dedicated federally chartered corporation to run the US geologic repository program based on organizational principles (APAM, 1984). Many of the findings of this Panel remain valid. In light of the pending failure of the Yucca Mountain program and the positive examples culled from international experience regarding feasible alternative models for implementing organizations (EPRI, 2010d), a serious reconsideration of the nature of the implementer for a post-Yucca Mountain repository program should be a high priority to provide a robust solution to the "stability and continuity" problem.

Given the recognized importance of integrating all waste management activities and options (i.e., waste generation, handling, waste storage, reprocessing, transportation, and final waste disposal), the implementing organization responsible for carrying out these functions represents one of the most critical elements of a geologic disposal program. Globally, the commercial nuclear utilities typically are the best-positioned organizations for ensuring vertical integration of commercial waste handling, storage, transportation, and regulatory licensing of nuclear facilities.

3.4 Funding

Reliable and adequate funding derived from generators of nuclear waste is a universally recognized attribute for successful planning and management for implementing and regulatory entities. A nuclear waste fund, paid by generators of nuclear waste and directly managed by the implementer, avoids uncertainties about annual legislative appropriations, establishes a 'waste stewardship' approach to promote public confidence and acceptance not only of nuclear waste disposal, but of continuity of nuclear power as a vital part of a nation's energy supply. A dedicated nuclear waste fund assures a consistent, predictable and adequate basis for long-term planning and maintenance of national waste disposal programs. In the US, the DOE budget for the Yucca Mountain program was far from consistent and predictable. Project delays and uncertainties have been attributed, in part, to large swings and shortfalls in annual appropriations (CRS, 2001; GAO, 2002; Holt, 2009a).

National nuclear waste funds are typically collected and controlled outside of a nation's general revenue and taxpayer funds, in order to assure that the collected funds from nuclear power rate-payers are allocated to their intended use (WNA, 2009; NEA, 2010; EPRI, 2010d). Related but ancillary management functions involving potential reprocessing schemes or advanced waste forms are typically funded by governmental agencies. The underlying principle of reserving nuclear waste funds is to ensure sufficient funds are available to cover final disposal costs if and when disposal occurs, and not to burden future generations with waste disposal costs on nuclear power from which they did not directly benefit.

In terms of disposal program size and annual funding, the US Yucca Mountain program operated on an average annual budget around $400 million during its peak years (Holt, 2009b) and with a peak staffing level of government employees and contractors exceeding 2700 prior to its termination in 2009. In contrast, the Swedish implementer SKB projected *cumulative* costs through 2009 of 3 billion SEK for siting, site investigation, and design for its used fuel repository, which corresponds to approximately 420 million USD; SKB also provided *annual* budget projections in the 250 – 300 million SEK range (35 – 42 million USD) for the same activities in 2008 and 2009 as the program neared site selection in advance of licensing (SKB, 2008).[12] SKB reported a workforce of 377 direct employees and 600 consultants in 2009 for *all* of its radioactive waste programs and activities, including those associated with operation of its short-lived LLW disposal facility and the CLAB facility for centralized wet-storage of used fuel from all Swedish reactors (SKB, 2009).

There are also other examples from smaller national repository programs with privatized implementing organizations, such as those in Finland and Switzerland, which suggest significant

[12] Projected annual and cumulative used fuel repository development costs through 2009 obtained from Table 2-6 in SKB *Plan 2008* Report (SKB, 2008). Costs were reported in "current money terms." For the illustration purposes, conversion to US Dollars for this report assumes an SEK to USD exchange rate of 0.14 for 2008.

pre-construction progress can be achieved in a geologic disposal program on annual budgets that are significantly smaller than required for the US model. Efficiencies are realized in various ways, but are typically characterized by engaging in international partnerships to share development and testing costs, promoting open and continuing interaction between the implementer and a technical competent, independent regulatory authority, and focusing on obtaining a sufficient understanding on those issues affecting long-term safe isolation. The Finnish program, for example, has realized significant repository development cost savings by adopting the Swedish developed KBS-3 disposal concept and siting its repository in a similar host geology (EPRI, 2010d).

In terms of total estimated project costs for geologic disposal programs worldwide, the US Yucca Mountain program generally dwarfed all national programs (Table 3-1). However, direct comparison of programs is difficult due to the large number of contributing factors, underlying assumptions, and the large and varying degree of uncertainty associated with programs in different countries at very different stages of development. For example, the Swedish estimate also includes decommissioning funds for the nation's nuclear power plants and centralized storage of used fuel, and the Japanese estimate is for a repository for disposal of HLW from reprocessing, not direct disposal of used fuel (Alexander and McKinley, 2007). As Table 3-1 shows, total estimated costs for the US program far exceeded all others except France, and in the case of France, the estimates correspond to an extremely diverse set of fuel cycle scenarios. In general, the total cost estimates (which include construction, operation, and closure costs) appear to track with metrics reflecting the size of the commercial nuclear program such as net nuclear electricity generation (Table 3-1). It is important to recognize that these figures date from the early 2000's timeframe and that the Yucca Mountain program includes costs for disposal of defense HLW (on the order of 20%). The cost estimate for the Yucca Mountain program grew to over $96 billion by 2008 for disposal activities through 2033, reflecting both inflation as well as a number of important repository design and system changes (DOE, 2008c).

Table 3-1
Estimated Costs of HLW - Used Nuclear Fuel Management Programs from Early 2000's for Selected Countries, Expressed in 2003 Euros

Country	Estimated Program Cost[a] (millions Euro)	Net Nuclear Power Generation, 1980 – 2007[c] ($TWhr_e$)
Belgium	290 – 580	1,052
Czech Republic	1,472	447
Finland	1,287	526
France	15,000 – 58,000[b]	8,642
Japan	22,250	6,126
Spain	10,000	1,267
Sweden	6,466	1,689
Switzerland	7,238	609
United States	48,239	16,406

[a]Costs based on estimates dating to the year 2000 with currency conversion rates from 2003 applied (1 Euro = 1.22 USD), except for France. Data are from Alexander and McKinley (2007).

[b]Costs for French disposal program are from a 2003 Cour des Comptes report, the French equivalent of the US Government Accountability Office, expressed in 2003 Euros. Reported in Schneider and Marignac (2008).

[c]Cumulative net nuclear electricity generation data are from USEIA (2009).

3.5 Waste Classification

Waste classification can have a large impact on options involving interim storage and reprocessing, and will affect planning and coordination among all aspects of the coordinated waste management system. There are numerous international classification systems of radioactive wastes based on physical characteristics of the waste itself, principally radioactivity and half-life, such as that from the IAEA (IAEA, 2009). In general, nuclear wastes arising from the nuclear fuel cycle are internationally classified as low-level waste (LLW), intermediate-level wastes (ILW) and high-level wastes (HLW), the last of which includes irradiated reactor fuel slated for direct disposal as a waste; LLW and ILW are typically further sub-divided into 'short-lived' and 'long-lived' categories, depending on the abundances of radionuclides with half-lives shorter or longer than about 30 years. These systems differ dramatically from the US classification system, which distinguishes LLW, HLW, and other wastes based primarily on waste origin. LLW in the US is secondarily sub-divided into classes A, B, and C based on the nature of the waste itself, i.e., radiotoxicity and half-life.

Use of reprocessing and P&T technologies generate significant quantities of ILW. There is no such waste category in the US. In the US waste classification system, ILW would likely fall outside of the defined US LLW waste classes A, B, and C deemed suitable for near-surface disposal due to isotopic composition and activity levels and would therefore be relegated to Greater than Class C (GTCC) status low-level waste. Currently, there is no commercially available disposal path for GTCC. This situation needs to be rectified if a coherent and fully integrated radioactive waste program and the associated benefits are to be realized in the US.[13,14] The implications of the US waste classification system on management of wastes from alternative fuel cycles and reprocessing also need to be better understood. Adoption of a more modern and relevant waste classification approach would lead to a more rational and risk-driven radioactive waste management system in the US. [15]

Disposal options and routes for nuclear wastes from non-power origins should also be considered in an integrated and coordinated national radioactive waste management program, which includes US defense wastes, medical sources, industrial wastes, agricultural wastes, wastes arising from academic research, accelerator wastes, wastes from decommissioning of nuclear power plants, and waste from decommissioning of reprocessing plants, which all can contribute significant amounts of LLW, GTCC waste and HLW.

Although the IAEA has provided a framework for classifying different types of radioactive waste, individual countries for the most part prefer to maintain their own waste classification system tailored to national needs. Accordingly, there is variation among international waste classifications systems, such as distinctions made between heat-producing and non heat-producing (Germany) or categories identified in terms of waste management route (Belgium, France). On the other hand, as evidenced by the contents of national reports pursuant to the terms of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, many countries are able to use the IAEA (2009) classification system as a point of reference for comparisons with each. All countries pursuing disposal programs for HLW and used fuel have adopted deep geologic disposal in a mined repository as the reference technology. In addition, some countries, including Switzerland and Germany, have chosen geologic disposal for *all* categories of radioactive waste.

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[13] In principle, Yucca Mountain would also have qualified as a repository for GTCC wastes, and in the 2008 Yucca Mountain Final Supplemental Environmental Impact Statement, GTCC disposal is explicitly considered (DOE, 2008a).

[14] Currently, DOE is developing a Generic Environmental Impact Statement (GEIS) to identify a strategy for disposal of GTCC waste (72 Federal Register No. 140, 40135 - 40139, July 23, 2007).

[15] One proposal is to extend the concept of Waste Incidental to Reprocessing (WIR) to commercial reprocessing regulation. This concept and its associated procedures allow for reclassifying certain wastes from reprocessing activities as LLW appropriate for near-surface disposal based on waste properties and not sources. Such a risk-based classification has precedence in DOE determinations on WIR under its own authority made in consultation with NRC (NRC, 2010b).

4
SITE SCREENING AND SELECTION

4.1 Geologic Diversity

Despite widely varying territorial area, geology and long-term tectonic stability, implementers of geologic repository programs in all countries reviewed are confident of identifying one or more locations suitable for geologic disposal. The original NWPA emphasized geological diversity in site screening and selection, and throughout the 1980's, the concept of geological diversity was favored and actively promoted by the US repository program in its search for suitable host sites.

The United States as a continental nation has a diverse set of rock formations, including *all* of those under consideration by programs in other nations (Table 4-1): 'crystalline rock' (igneous and metamorphic rock), salt formations, and impermeable argillaceous (clay-containing) sedimentary formations. The availability and geographic distribution of these diverse rock types across the US are illustrated in Figures 4-1 to 4-3. Figure 4-1 shows the distribution of major argillaceous deposits across the continental US, and Figure 4-2 depicts major salt formations, including bedded and dome deposits. Figure 4-3 maps sediment thickness as a proxy for depth to basement rock across the US and, by extension, the availability of accessible crystalline rock formations. The shallower basement rock in Figure 4-3, indicated in the white end of the color legend, corresponds to those states identified as potential candidates for a second repository under the DOE crystalline rock program (DOE, 2008). It is also worth noting that the US national program has extensively characterized volcanic tuff as a host formation for a candidate repository at Yucca Mountain, and performance assessments by DOE, NRC, and EPRI have shown this geology to be a technically viable formation for geologic disposal as well (e.g., EPRI, 2009b).[16]

A number of repository concepts have been developed outside the US for the wide range of diverse rock types, which could allow for a more rapid implementation of a repository for whatever type of host rock and specific site might be eventually nominated or volunteered. The international experience indicates that even countries with extremely limited geologic diversity and land area are able to (or anticipate being able to) successfully site a geologic repository in an appropriate host location. The assortment of repository design concepts now available for a number of geological, hydrological, and geochemical settings should aid in the rapid identification of possible candidate locations and associated repository concepts within the US for a new, post-Yucca Mountain repository program.

[16] As of September 2010, NRC review of the Yucca Mountain license application submitted by DOE in June 2008 continues (DOE, 2008b).

Table 4-1
Candidate Geologies Available in the Continental US for a Geologic Repository and Corresponding Countries in Which That Geology is a Primary Candidate (Adapted from IAEA, 2003)

Geology	Countries
Crystalline rock (e.g., granite, gneiss)	Sweden, Finland, Japan, Canada
Argillaceous rock (e.g., clay)	France, Switzerland, Belgium
Salt	USA (WIPP), Germany
Volcanic tuff	USA (Yucca Mountain)

In its 2008 report on the need for a second repository mandated by the NWPA, DOE calls attention to the nine sites examined under the first repository screening effort including Yucca Mountain; 25 States identified having potentially promising granitic host formations for a second repository; and the existence of potentially suitable shale deposits across the contiguous US such that "... all states in the contiguous United States have a potential area that could be considered for the second repository" (DOE, 2009). Thus, the US does not face a shortage of geographically distributed, technically suitable candidate locations if a new site selection campaign is instituted.

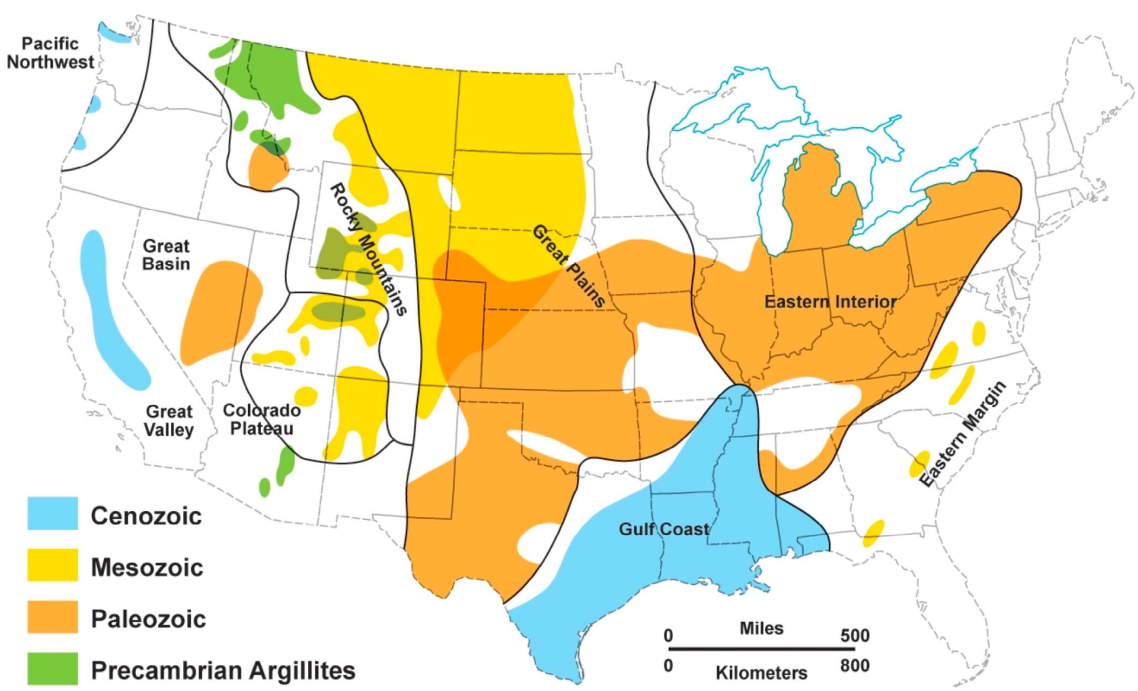

Figure 4-1
Map Showing Distribution of Argillaceous Rock Formations Across the US. [Adapted from Gonzales and Johnson, 1984]

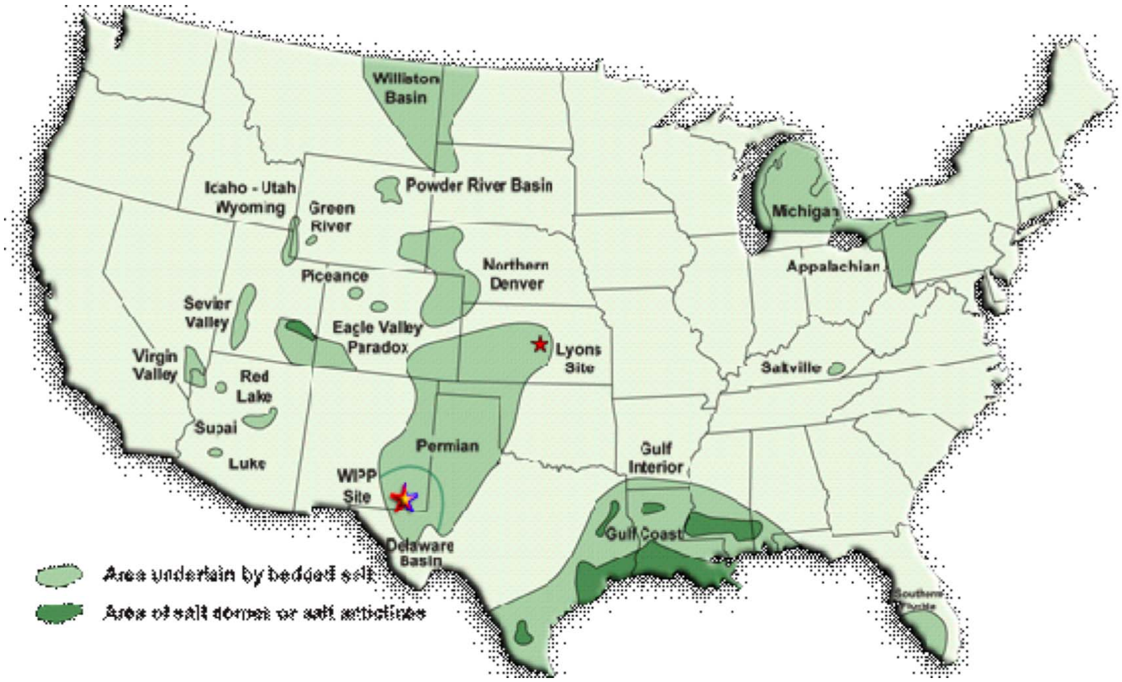

Figure 4-2
Map Showing Distribution of Salt Formations Across the US. [Adapted from Johnson and Gonzales, 1978]

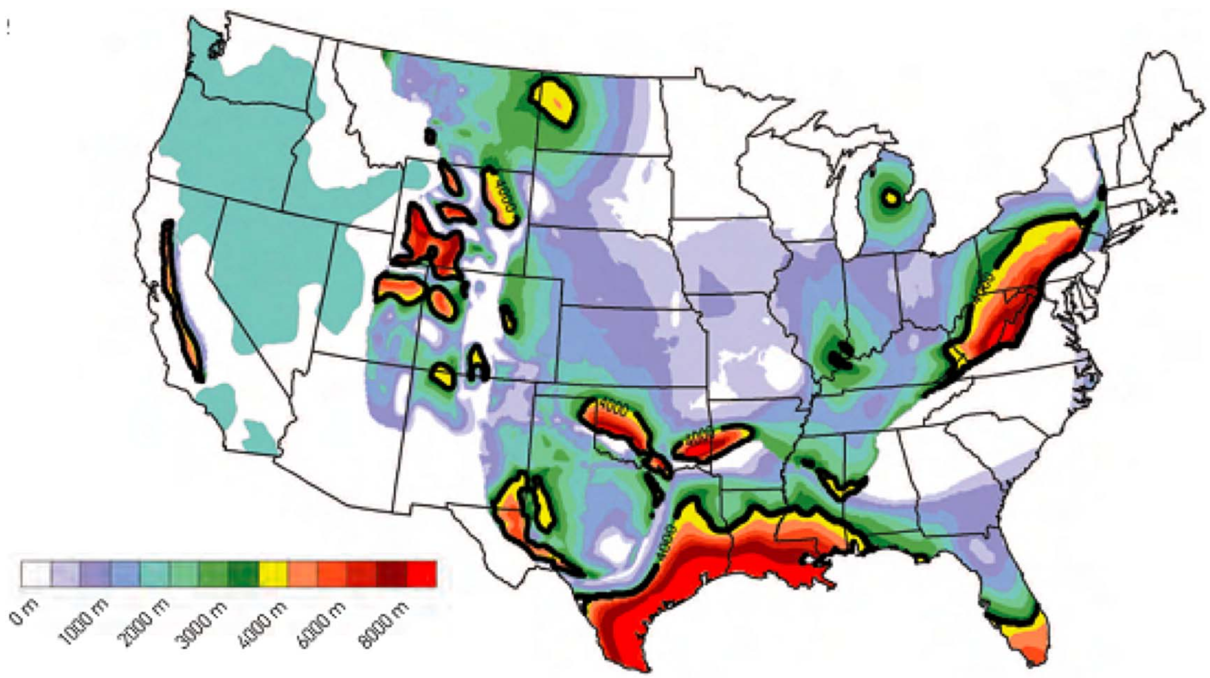

Figure 4-3
Map Showing Distribution of Sediment Thickness Across the US as a Proxy for Depth to Crystalline Rock. [Graphic used with permission from The Future of Geothermal Energy MIT, 2006]

4.2 Site Selection Process and Siting Guidelines

The geological diversity and geographical extent of the US, while clearly an asset for providing options for site selection, also presents substantial challenges for comparing and ranking many different factors among the candidate host locations. A rigorous, well documented, traceable process for site selection that includes meaningful public involvement provides a sound basis for defending that decision. Comparative assessments of different sites and/or different design options require statistical treatment to permit the summation and comparison of extremely different features and processes for a final ranking.

The challenges posed by diversity of candidate sites and conceptual designs compel use of some rational, systematic, and defensible approach for conducting the requisite comparisons and rankings. Under the NWPA-driven site screening and selection program, the US DOE's use of the multi-attribute utility analysis (MUA) represented a pioneering effort in this area and was generally supported by the National Academy of Sciences and other credible peer-review groups (EPRI, 2010b). While the actual MUA as conducted by DOE for site ranking was criticized by the NAS and others in terms of its implementation (EPRI, 2010b), the approach remains a valid and potentially useful model for future US site selection efforts.[17]

Complementary DOE siting guidelines, chiefly those in 10 CFR 960, present a comprehensive examination of diverse physical-chemical characteristics of candidate host environments, with an initial attempt to define what conditions would be qualifying or disqualifying. However, in the intervening years since 10 CFR 960 was developed, experience in the US and abroad has increased understanding of the relative importance of certain site characteristics, reliability of screening and characterization data, and impacts from potentially disruptive events. As a result, certain factors that might have been considered "disqualifying" in the nascent 1980's US repository program may now either rank as merely "unfavorable" or be considered irrelevant or of little value for site ranking. Such experience could be used to inform a prudent review and revision of siting guidelines for future applications. While there are site attributes that can be generally favorable to long-term isolation, the diverse range of international site environments and repository concepts tailored to such diverse site environments (EPRI, 2010d) argues against setting overly specific siting criteria that might otherwise needlessly restrict selection of candidate sites.

As embodied in DOE's siting guidelines in 10 CFR 960, a pragmatic site screening and selection process should recognize that less favorable values of one environmental parameter (e.g., faster groundwater flow rate) can be compensated by a highly favorable value for other environmental parameters (e.g., limited solubility; high sorption capacity of radionuclides by minerals along the flow paths), or other engineering parameters (e.g., slow container degradation rate, use of backfill). This reflects the value and relevance of considering the performance of the repository system as a whole, rather than focusing on assessing performance based on individual sub-systems.

[17] It is worth noting that in spite of the abridgement of the NWPA site selection process via a political process, i.e., the 1987 amendments, Yucca Mountain was determined by the MUA process to be the top ranked candidate site.

Site selection for geologic HLW repositories presents substantial challenges in terms of technical characterization and societal acceptance. The two basic approaches for siting can be identified as a "nominative" process guided by technical criteria and focus on a certain type of host rock and repository concept, or a "volunteer" process in which local community interest is the required first step before proceeding to characterization and qualification of a site.

Successful nominative siting of various radioactive waste disposal facilities has been conducted in some countries (e.g., Switzerland; EPRI, 2010d, Appendix A), whereas a volunteer approach has been successful in other countries (e.g., Sweden, Finland), and the factors leading to these successes have been identified (EPRI, 2010c).[18] It is notable that sites adjacent to communities with current nuclear facilities are often among the first to volunteer for consideration, and if the site meets siting criteria, such sites (along with their respective host communities) have been chosen in several countries, such as Finland, Sweden, and Canada.

A voluntary approach to siting of a HLW repository has been attempted in several countries, with varying degrees of success. Sites for geologic disposal of used fuel in Finland and Sweden were selected on technical factors from volunteer communities. On the other hand, an approach pursued for the last 10 years in Japan seeking volunteer sites for provisional characterization has not succeeded. There has been some success with voluntary siting of LLW and/or ILW disposal facilities in a number of countries, including Belgium, France, Canada, Sweden, and Finland.

A recurring theme in outcomes of voluntary siting approaches has been the degree to which all levels of governments, ranging from local community government, through intermediate/regional governments (e.g., States, Cantons, Prefectures, Native Peoples), to the national government, can reach and sustain agreement on the benefits, functional controls and oversight, and participation in an open, transparent and safety-focused siting process.

Countries such as Sweden and Finland that site underground research laboratories (URLs) or select candidate HLW repository locations in areas that already host some form of nuclear facility generally report more favorable public acceptance, presumably due in part to the greater public familiarity with, and understanding of, nuclear issues observed in the vicinity of existing nuclear power plants. The construction of at least one URL to allow in situ investigations, as well as the testing of engineering designs, has been favored by most countries as a means of developing expertise and engineering know-how concerning geologic disposal (EPRI, 2010d).

The fundamental objective of a site selection process is to identify a "safe" site.[19] Inevitably, the challenge becomes to bound the site selection process in terms of how good is "good enough." Geological, hydrological, and geochemical complexity also present significant challenges in site ranking and selection efforts. A complex site may be desirable in its overall performance, but demonstrating such performance may prove more difficult than less complex alternatives.

[18] Success in this context refers to a demonstration of the feasibility of a disposal concept that takes into account the identification of a potential radioactive waste disposal site (LLW, ILW or HLW), subject to further characterization to confirm suitability.

[19] A safe site is one that has the ability, when combined with an appropriate engineered barrier system, to meet applicable regulatory requirements.

Repository sites worldwide have been selected in diverse geological formations, each possessing different, site-specific positive and negative attributes with respect to assuring waste isolation. There is no one “best” rock formation for siting a repository. Moreover, a so-called “best” site is not required for geologic disposal as the ultimate goal is to provide an adequate level of protection to human and environmental health, not zero risk. It is necessary and sufficient to select sites that possess adequate characteristics that assure long-term performance and safety. And as emphasized in Chapter 5 below, the development of repository concepts outside of the US appropriate for multiple rock types and site conditions underscores the availability of multiple isolation strategies and ample engineering flexibility to adapt repository designs to address and complement site-specific conditions.

4.3 Experiences from Siting of a US HLW Disposal Facility

Historically, the US was viewed as a leader in developing, implementing and maintaining a technically based, nominative process for the selection of a site or sites for the final disposal of commercial used fuel and defense HLW. As described in Volume I of this series (EPRI, 2010b), the NWPA established a national program for HLW disposal, defining roles and responsibilities for implementers, regulators and other impacted stakeholders and a step-wise site selection process that required a series of governmental decisions and approvals based on an ever-increasing knowledge base for the selected sites. The NWPA siting process, as revised by various Congressional amendments, eventually led to the characterization, selection and a construction license application for a used fuel and HLW repository located within volcanic tuffs at Yucca Mountain, Nevada. However, the failure of the US process to ultimately result in a geologic repository site warrants a critical evaluation of the process in order to identify lessons learned and recommendations for a post-Yucca Mountain program that can be implemented.

The multiple-site process was abridged with the enactment of the 1987 Congressional amendments to the NWPA, designating Yucca Mountain as the only site for further characterization. As discussed in greater depth in EPRI (2010c), the 1987 amendment of the NWPA provisions governing the safety assessment of Yucca Mountain significantly impacted the US site characterization process in other ways. For example, the extension of the regulatory compliance period from 10,000 to 1 million years compelled the consideration of extremely slow or exceptionally rare geological processes that might impact future repository isolation performance.

The post-1987 site characterization of Yucca Mountain produced a considerably expanded understanding of the site, which in some cases rendered earlier assumptions about the site invalid or inaccurate, as highlighted in Volume I of this series (EPRI, 2010b). Such discoveries, which inevitably lead to the revision of site conceptual models, are an inherent aspect of scientific research of this kind (NAS, 1990) and are a feature common to all international siting processes[20] (EPRI, 2010d). However, such discoveries or “surprises” are often misinterpreted as failures or shortcomings of the repository program rather than as inevitable steps or events along

[20] For example, issues like high stress anisotropy/ rock spalling in several granite sites and the potential for deep penetration of oxidizing groundwater to repository depths during glacial episodes have emerged in several national programs (EPRI, 2010d).

the path to knowledge and understanding of a site. A flexible, adaptive approach to site characterization and repository design anticipates and acknowledges this evolutionary learning process and the likely need for iterative development of conceptual modes and repository designs. This approach, referred to as adaptive phased management (APM), can therefore serve to dampen the programmatic impacts resulting from negative swings in stakeholder perception and support (NAS, 2003).

In 2008, the DOE submitted a construction license application to the NRC that contained a multi-volume safety assessment report (DOE, 2008b). These safety analyses indicate that the reference repository concept containing 70,000 MTHM of used commercial fuel and defense high level waste (DHLW) would comply with the EPA 40 CFR 197 standard. Separate safety analyses by EPRI (2009b) show that in several areas the DOE analyses are conservative, and that the reasonably expected long-term release of radioactivity from a repository at Yucca Mountain would likely be several orders of magnitude lower than values reported in the DOE analyses (DOE, 2008b). EPRI has concluded based on its own extensive independent technical analyses through 2009 and review of published DOE results that the proposed repository at Yucca Mountain as described in the June 2008 license application, would comply with applicable regulations and standards with respect to performance.

The need for more than one geologic repository for HLW will depend on several factors, including waste inventory (which may depend on future decisions on advanced fuel cycles), political judgments as to regional balance and perceived fairness, and technical attributes of an initially selected repository site. Technical disposal capacity should be distinguished from a legislative or regulatory limit, such as that imposed by the 1982 NWPA. The fundamental technical capacity of a host site may be substantially greater than regulatory imposed limits (as was the case for Yucca Mountain) and could therefore eliminate any technical justification or need for more than one repository.[21] In a 2007 study, results from EPRI analysis of the technical disposal capacity at Yucca Mountain, based on the available site characterization data, was 4 to 9 times the legislative limit of 70,000 MTHM, depending on various lateral and vertical options in waste emplacement (EPRI, 2007). Likewise, DOE recognized the higher (than 70,000 MTHM) technical capacity for Yucca Mountain in its Second Repository Report (DOE, 2008e).

4.4 Experiences from Siting of a US TRU Geologic Disposal Facility

The successful certification of the WIPP for disposal of the US defense TRU waste in a bedded salt formation near Carlsbad, NM, is often cited as a possible way forward for the siting of a geologic repository for disposal of commercial used fuel and defense HLW. There are many positive features and instructive precedents of the WIPP certification by the EPA that can be used to inform the development and implementation of a post-Yucca Mountain disposal program in the US, notably the value of garnering strong local and state level support among public and political communities. However, these positive features and precedents do not automatically translate to qualification and licensing of WIPP as a repository for used fuel and HLW.

[21] The non-technical nature of such limits is self-evident in the context of the 1992 NWPA itself; the 70,000 MTHM limit imposed on the first US repository site was to be lifted once a second repository began operation.

The WIPP certification process for TRU disposal under the exclusive authority of the EPA represents a less complex regulatory process than licensing of a geological repository for disposal of commercial nuclear fuel under joint EPA and NRC regulation (EPRI, 2010c). In particular, WIPP was certified for a 10,000-year period of performance, whereas under the NWPA regime, the final EPA and NRC regulations for a repository at Yucca Mountain require compliance out to 1,000,000 years. The 10,000-year period lies within the range of internationally accepted compliance timeframes for HLW repository performance; by contrast, the 1,000,000-year compliance period is among the longer timeframes being considered internationally. As the 40 CFR 197 and 10 CFR 63 regulations apply exclusively to a repository at Yucca Mountain, NV, any repository at a location other than Yucca Mountain, NV, will either revert to the generic (and generally recognized as obsolete) geologic disposal regulations under 40 CFR 191 and 10 CFR 60, or come under new or substantially revised regulations. Either way, the unique process for WIPP certification does not apply to licensing a repository facility for used fuel and HLW disposal under the current US dual-authority paradigm. Accordingly, the applicability of the WIPP precedent (as a TRU disposal facility *certified* exclusively under EPA authority) to siting and licensing of repository for used fuel and HLW may be limited.

Beyond consideration of WIPP as a useful precedent and example for development and implementation of a new US HLW repository program, any consideration of the WIPP site as a candidate host site for a HLW repository is speculative. Under a NWPA regime, licensing a repository as an extension of WIPP would require a protracted process, as with any such facility, and would likely include additional site characterization and technical design activities in concert with pursuit of political approvals. The successful outcome of the WIPP site selection process for TRU disposal was the result of carefully balanced political negotiations and understandings among the State of New Mexico, the US Federal Government, and other parties that were linked to specific quantities of a narrowly defined waste inventory. Any departure from these initial conditions could also undermine the very support of stakeholders that is frequently offered as a positive example. There are also likely technical challenges and uncertainties to be considered if WIPP were to be evaluated as a HLW repository. Some examples include:

- The effect of significantly higher thermal loading from HLW and used fuel inventories the thermal-hydrological-mechanical-chemical (T-H-M-C) evolution of salt and fluid inclusions in salt that were not relevant to the certification on nonthermal TRU waste disposal;
- The effect of T-H-M-C interactions from HLW on TRU wastes would also need to be addressed if the two were emplaced together or were found to interact with one another;
- The radiological inventories and masses of HLW and used fuel are much greater than the TRU waste currently certified for WIPP disposal;
- Additional site characterization would likely be needed to accommodate an expanded repository footprint.

These technical and regulatory issues mean that, in developing a HLW repository at WIPP, the site would need to be evaluated like any other site. There may some benefits, such as reduced costs for site characterization and the presence of a skilled work force. However, as a cautionary note, the current status of WIPP and its successful history would not, by themselves, necessarily indicate that the repository could be successfully extended to accommodate HLW.

5
REPOSITORY DESIGN CONCEPTS

5.1 Multiple Barrier Isolation Strategy

Modern geologic disposal strategies are generally based on the fundamental concept of a multiple barrier repository system in which a suite of natural and engineered barriers are relied upon to assure safe, long-term isolation of the radioactive waste. Consequently, it can be misguided to focus too narrowly on a specific barrier or process; therefore, risk-informed, system-level evaluation is especially needed to place issues on individual barriers and processes into a proper and defensible safety context. Groundwater interaction and subsequent aqueous transport of radionuclides to the biosphere are expected to be the dominant vectors leading to significant radiological consequences to humans associated with HLW disposal.

Given the expectation that site characterization for any candidate repository location will uncover new information that challenges or contradicts pre-existing assumptions and conceptual models (NAS, 1990; 2003), repository design modifications and updated site characterization are activities that can be inherently linked through systems-level assessment, which can then be applied to identify key risk-important areas for further study, and to help adapt the overall repository concept in light of new information or understanding. The nature of the barriers and the features of a repository are based on consideration of the radiological hazard of the waste (often affecting depth of the repository system, for example), regulatory requirements, available disposal sites and geological formations, and practicality and effectiveness of additional engineered barriers.

Considerations regarding reversibility and retrievability have played an increasingly more important role in siting for a number of national geologic disposal programs, such as France and more recently Canada (EPRI, 2010d). The US NRC's 10 CFR Part 60 developed in the early 1980's included a provision requiring that the emplaced waste be retrievable up until the time of a final decision on closure. This "retrievability" requirement was to assure that US NRC's decision on closure would not be pre-empted or rendered meaningless by the waste disposal concept if that concept was found to be unsafe during the licensing process. Retrievability during the multi-decade operational phase of construction and waste emplacement would also allow a future flexibility with respect a possible future decision to recover and reprocess used fuel placed into a repository. This option can be termed "recoverability" based on economic reasons to distinguish it from retrievability based on safety and licensing considerations. By the 1990's several European repository programs proposed the concept of reversibility, in which each of the several steps and decisions for implementing a deep geological repository should be considered as fully reversible. With reversibility, it is conceivable that a national authority could decide to retrieve waste from a repository after closure. A primary concern with this concept is that steps taken to ensure complete reversibility at all stages have the potential to compromise the long-term ability of the repository to function as planned. Caution needs to be exercised that repository design features meant to improve retrievability do not do so at the expense of compromising long-term performance. It should be noted that wastes could be retrieved from almost any disposal option; it is more a matter of engineering difficulty and cost to do so, and whether the repository should be intentionally designed to allow straightforward retrieval.

Repository disposal concepts for used fuel and reprocessed HLW are usually similar; there are currently about 12 variant repository concepts being considered, including deep borehole disposal (EPRI, 2010d, Appendix B). Many repository concepts have been refined to an advanced state of scientific and engineering understanding, including that proposed for the Yucca Mountain site (DOE, 2008b; EPRI, 2010d, Appendix B). A few, including the KBS-3 disposal concept developed in Sweden and Finland (EPRI, 2010d), have been either adopted or are under evaluation by many countries, but there remain certain outstanding issues, including (a) the constructability and emplacement of nuclear waste packages, most notably with respect to the handling, emplacement and quality assurance of swelling-clay (smectite) based buffers and backfills, and (b) the potential, slow but significant erosion or disruption of clay buffers and backfills during both pre-closure and post-closure periods.

5.2 Adaptable Disposal Concepts

The majority of current repository concepts for deep geological repositories (EPRI, 2010d, Appendix B) were developed over 30 years ago with a primary focus on providing a direct means for permanent disposal of used nuclear fuel and/or high-level waste (HLW). More recently, however, it has been recognized that revised repository design concepts could provide enhanced flexibility in national policies and decisions for management of nuclear wastes involving linkages among storage, reprocessing, and disposal activities. In particular, new repository design options that include an initial phase of sub-surface storage for nuclear wastes followed by later decisions on either a direct disposal or a reprocessing step then HLW disposal are under development worldwide (EPRI, 2010d, Appendix C).

6
INDEPENDENT PEER-REVIEW AND ADVISORY BODIES

Frequently, national laws establish technical- and social-review groups to provide independent oversight reports to the national government authorities. The US has perhaps the greatest experience, both positive and negative, regarding the application of independent peer-review. Independent peer-review of the US program, particularly by the US National Academy of Sciences, served as an influential driver for credibility and acceptability of site selection process and siting decisions in the years leading up to the NWPA and amendments. Subsequently, establishment of standing advisory bodies, notably the US Nuclear Waste Technical Review Board (NWTRB)[22] and the NRC's Advisory Committee on Nuclear Waste and Materials (ACNW&M)[23] provided independent technical reviews of and recommendations for the US geologic disposal program. Such peer-reviews are particularly critical in the evaluation and justification of assumptions made for safety analyses supporting site screening and selection actions.

Because geological disposal involves assessment of the long-term behavior of engineered and natural materials under the service environment of deep geological formations far beyond human experience, a diversity of engineering and geoscientific disciplines must be involved in review of long-term safety of geological disposal. Formal technical peer-review, such as through national academies of science and engineering, is most effective in aiding a national disposal program when staffed by technical experts with an understanding of their discipline within the context of geological disposal systems. Peer-reviews with a clearly defined technical-oversight role can provide independent judgments as to the adequacy, defensibility and feasible alternatives of research, development and design plans. Therefore, it is vital that the membership of peer-review teams should reflect the spectrum of technical, social and policy issues and should align with the intended scope of the review. An independent, open and transparent peer review process also promotes wider understanding and acceptance of geological disposal by engineering and scientific communities not directly engaged in nuclear waste management activities.

Some conflicts may arise from peer-review efforts focused too narrowly on scientific perspectives and technical details that do not place such concerns within a total system, multiple barrier context regarding what information and what confidence is needed for demonstrating the scientific basis for regulatory compliance. The very nature of overlapping, multiple barrier

[22] The NWTRB is an independent federal agency established by the 1987 NWPAA to provide independent technical oversight of the US DOE Yucca Mountain repository program.

[23] The ACNW&M was established by the NRC in 1988 to provide independent technical review and advice to NRC staff on radioactive waste disposal facilities. In 2008, the ACNW&M was disbanded and its functions were merged with the NRC's Advisory Committee on Reactor Safeguards (ACRS).

isolation functions often means that failure of one particular barrier or safety function does not necessarily imply that the overall performance of the repository system will be compromised. Accordingly, the independent evaluation of technical questions and concerns associated with long-term repository safety are most useful and relevant if conducted within a risk-informed, total system performance context.

A number of international advisory agencies, including the IAEA, NEA and ICRP, have developed, and continue to revise, broad guidelines regarding many technical and social aspects of radioactive waste management and disposal. However, the perspectives of international organizations, while often guided by and often aligned with national programs, can also conflict with details of national programs, especially with respect to nation-specific safety regulations and legal precedents. Accordingly, due caution should be exercised in the application of international perspectives.

7 STAKEHOLDER AND PUBLIC INVOLVEMENT

Stakeholder and public involvement is universally recognized as essential to the successful implementation of each component of the nuclear fuel cycle, especially the siting of a facility for the permanent disposal of used fuel and HLW in a geologic setting. Defining the impacted stakeholders and allocating resources to enable stakeholder participation in the overall disposal process is a key for sustained progress, but different nations have formulated different approaches to reflect their own societal, legal and cultural standards (EPRI, 2010d). In some countries local public acceptance, especially regarding the selection of storage and disposal sites, is an absolute requirement, while elsewhere national governments hold the authority to override local opposition, although at potentially great cost to the useful partnership and cooperation of local communities.

Public consultation and hearings have been part of the siting processes in most countries including the US, especially in countries where environmental impact statement (EIS) and assessment (EIA) procedures are a necessary part of the process; the ability of impacted public and local levels of government to participate in a step-wise siting process has been key to attain local public acceptance of siting decisions.

The formal involvement of the general public in decisions on disposal varies widely among nations, again in large part because of nation-specific cultural, legal and precedent reasons. Historically, most implementers pushed towards the selection of a site without having adequate public support and this led to varying degrees of protest, the more extreme examples occurring in France and Germany (EPRI, 2010d). Implementers and governments have come to the realization that public acceptance is essential to progress and the way in which this is achieved varies, although a staged selection process, moving from generic studies to site-specific investigations, is the norm. Thus, the approach to stakeholder engagement has evolved from the classical "*decide, announce, defend*" or "DAD" approach to one in which stakeholder engagement is deliberately front-loaded in the process, as well as emphasized throughout the entire site selection and evaluation process (e.g., IRPA, 2008).

There have been variable international experiences with regard to public acceptance of geologic disposal. Key concerns that have been commonly raised include:

- Siting strategy imposed without allowing the public and other stakeholders to discuss the overall approach;
- Site screening begun with pre-defined candidate regions with little or no stakeholder input;
- Stakeholder engagement focused on a limited set of parties, typically the potential host community, with little or no regional input to discuss relevant issues such as waste transportation.

The last siting concern is particularly challenging and has played out to the detriment of siting efforts in several countries, for example initial rejection of the Wellenburg site in Switzerland for ILW and LLW disposal (EPRI 2010d). There are numerous reasons for opposition to siting arising at the regional level and include: asymmetric perceptions of risks vs. benefits, transportation concerns, and differences in local and regional views on industrial development. Whatever the causes or specific entities involved, an underlying principle appears constant: unless the public and all levels of affected government possessing authorities and responsibilities vital to the progress of a disposal program are adequately engaged, the program risks significant delay or failure given the controversial and long-lived nature of such an endeavor. Accordingly, the resolution of such disconnects associated with siting decisions centers on providing for a robust, sustainable policies that provide for an approach with meaningful engagement with stakeholders from start to finish.

There has been notable progress in siting efforts internationally in which public participation has played a prominent role. Such examples include efforts in Sweden, Finland and France (EPRI, 2010d) in which the both implementer and regulatory authorities were involved in promoting dialogue among all impacted stakeholders to identify and address technical and nontechnical siting concerns.

Technical information alone, however, may not sufficient to gain the support of the public and all impacted stakeholders. One example of this is found in Canada (EPRI, 2010d), where a 20-year program concerning the development and investigation of a geologic disposal concept was abandoned in 1995 not on technical grounds but on the basis that the program was judged not to have involved sufficient public involvement and acceptance. Thus, nontechnical aspects such as social, political, and ethical concerns were determined by the Government of Canada to be of co-equal importance with technical factors. This required policy makers to reconsider the national program for managing Canada’s used fuel waste, leading to the establishment of the Nuclear Waste Management Organization (NWMO) in 2002 under the Nuclear Fuel Waste Act (NFWA). To address public participation and acceptance, NWMO has adopted an adaptive phased management approach described earlier in Chapter 3 in which program plans are broken down into discrete, manageable steps or “phases”, with each phase characterized by an explicit decision in consultation with all stakeholders (EPRI, 2010d). This approach provides geologic disposal programs an inherently flexible system and allows for “go/no-go” decisions at each stage of the program to take advantage of new knowledge or changing societal priorities. In this way, the public and other stakeholders are provided more meaningful and sustained opportunities for engagement with and input into the repository siting process than are offered in most other approaches.

8
SUMMARY

There are numerous observations and lessons learned reported in the previous Chapters of this report gleaned from over fifty years of international efforts to site, license, and construct a deep geologic repository for disposal of used nuclear fuel and HLW. Key points from are summarized here.

8.1 The Need for a Geologic Repository for Used Fuel and High-Level Radioactive Waste

- Many options exist for managing the wastes associated with the nuclear fuel cycle, but all options eventually require permanent disposal for some form and amount of long-lived radioactive material.
- A general international scientific consensus has developed over the past fifty-years on deep geologic disposal as the preferred option for permanent disposal of used nuclear fuel and HLW from reprocessing used fuel.
- While wet or dry storage of used nuclear fuel is an acceptable interim waste management approach and can aid in thermal management strategies for subsequent transportation and disposal, storage does not eliminate the eventual need for a deep geologic repository.
- Recycling of used nuclear fuel can lead to reductions in the quantity and volume of HLW, but reprocessing and other required activities inevitably create additional waste streams that include significant volumes of long-lived, intermediate level waste requiring geologic disposal as well. Moreover, unless recycling of plutonium as MOX in LWRs is eventually expanded to closed fuel cycles (i.e., ones incorporating fast reactor technologies), significant quantities of irradiated MOX fuel, having higher thermal loads and inventories of actinides than irradiated UOX fuel from once-through cycles, will eventually also require disposal.
- Partitioning and transmutation technologies can theoretically aid in reducing waste volume and inventories of certain radionuclides from used fuel, but their implementation would not eliminate the need for a geological repository.
- Based on numerous international examples, the most efficient and effective geological disposal programs are found in countries where the entire waste management process is fully integrated, from waste generation through interim storage, transportation, siting and finally licensing of geologic disposal. International experience indicates that the organization(s) best placed to achieve this full integration are derived from nuclear power utilities themselves.

8.2 Laws, Regulations, and Institutional Arrangements

- Consistent and stable funding must be established to ensure an effective and efficient repository program. Funding derived from fees on waste generators is a common approach adopted worldwide. Stable funding can be realized if the funds are directly managed by the implementer, avoiding uncertainties and fluctuations that can accompany appropriations from legislative processes. Such an approach also fosters a waste stewardship mindset in the implementing agency, and can also bolster public confidence and acceptance.
- Licensing of a geologic repository for used fuel and HLW in the US at a site other than Yucca Mountain, Nevada, reverts to regulation under the generic standards and regulations of 40 CFR 191 and 10 CFR 60 as they currently exist unless revised via rulemaking or superseded by new standards and regulations; this regulatory set is widely viewed as obsolete and in need of revision or replacement.
- The regulations for Yucca Mountain, 40 CFR 197 and 10 CFR 63, represent a contemporary approach with their emphasis on total system performance, rather than on relatively arbitrary subsystem performance criteria and cumulative release limits. However, this regulatory framework retains separate standards for the groundwater pathway that is inconsistent with an individual health risk standard based on an all-pathways approach.
- A logical evolution of US HLW disposal standards and regulations would be an exclusive reliance on an individual health- or risk-based standard which implicitly includes an all-pathways approach, thereby obviating the need for subsystem performance requirements or separate groundwater protection standards.
- The timeframe for evaluating repository performance and regulatory compliance is one of the principal issues to be addressed in any revision of current US HLW disposal regulations. There is general international agreement that the time scale of compliance must be appropriate to the hazard of the waste under consideration for disposal, but that significant technical and licensing issues arise when carrying safety analyses to extremely long times in the future. As a result, there is growing international consensus that safety analyses for the far distant future should be regarded as more qualitative than those for shorter times.
- The treatment of repository performance and compliance analyses in an increasingly qualitative manner may be challenging in an adjudicatory licensing setting. Legislative or regulatory guidance regarding how to handle geologic timeframes and associated uncertainties in an adjudicatory licensing environment would be beneficial.
- The extension of the regulatory compliance period for the EPA Yucca Mountain standards under 40 CFR 197 resulted from a narrow legal ruling specific to the Yucca Mountain program. In contrast, a compliance period of 10,000 years has withstood legal challenge and remains in place for 40 CFR 191. In light of international experience and successful application in the US of 40 CFR 191 to WIPP certification, a 10,000-year compliance period could be retained for a repository program other than Yucca Mountain.
- Lessons drawn from the success of the WIPP program should be tempered with an understanding of the differences between the WIPP certification process and the adjudicatory processes that will be followed in licensing a HLW repository subject to NRC regulations.

- The US waste classification system differs both qualitatively and quantitatively from waste classification systems used internationally. These differences need to be kept in mind when considering the effects of alternative fuel cycles on the needs for a geological repository. Fuel cycles based on reprocessing spent nuclear fuel may give rise to significant non-HLW radioactive waste streams requiring disposal.
- For an integrated and consistent waste management program, all radioactive wastes streams regardless of classification should have a designated path toward an appropriate disposal system. There is general international consensus on the appropriate path to disposal for LLW disposal in near-surface burial facilities and HLW and used nuclear fuel in deep geological settings. However, notable gaps remain; for example, the so-called "Greater Than Class C" (GTCC) wastes in the US have no clear disposal pathway identified at present. In the future, such problems may be exacerbated by reprocessing and other activities associated with the deployment of advanced fuel cycle technologies, as these activities are expected to generate substantial quantities of GTCC-like wastes that would be orphaned under the current US radioactive waste management regime.

8.3 Site Screening and Selection

- Based on an international survey, many countries representing a wide range of size, geological diversity, population, among other factors, have been capable of identifying one or more potential rock formations that, in combination with appropriate engineered systems, are expected to prove adequately safe for geologic disposal.
- The US, as a continental nation, has a diverse and geographically distributed collection of potentially suitable rock formations, including all of those rock types under consideration by disposal programs in other nations such as: crystalline rock, salt formations, and clay-containing sedimentary formations. Therefore, the US should be able to take advantage of this diversity, coupled with international experience in siting and repository design in various geologies, for a new repository program.
- Well crafted siting guidelines can provide an open and transparent basis by which site characterization and site selection will be conducted and evaluated by all impacted stakeholders. However, overly restrictive siting criteria may result in premature disqualification of otherwise suitable candidate sites.
- The discovery of new information and greater understanding during site characterization is an inherent part of the process, and is a common feature of all repository programs. Programs that openly anticipate the occurrence of such discoveries, and are designed from the start to adapt to them in a transparent manner, are better positioned to mitigate threats to program credibility and continuity posed by such events and associated stakeholder reactions.
- Identification of potential sites for characterization has been made in a *nominative manner* (e.g., based on specific technical and non-technical criteria) in some countries, and using a *voluntary approach* in other countries. The choice of different siting approaches reflects different national perspectives, forms of governments, historical precedents and other factors, and notable progress has been made using both approaches. Accordingly, there is no single "best" approach to siting appropriate for all contexts.

- Multi-attribute utility analysis and other decision-support techniques can provide an inclusive and traceable framework for weighing and comparing diverse siting factors.
- There is no such thing as a “best” site, nor is a “best” site is necessary. The goal of a repository program is to demonstrate that a candidate site mated with an appropriate repository design will adequately protect the public and the environment; this is accomplished by demonstrating that the repository system meets established regulations and standards.
- The need for more than one geologic repository for HLW will depend on several factors, including waste inventory (which may be affected by future decisions on advanced fuel cycles), political judgments as to regional balance and perceived fairness, and attributes of an initially selected repository site. Technical disposal capacity should be distinguished from a legislative or regulatory limit, such as that imposed by the 1982 NWPA for the first repository until a second became operational. The fundamental technical capacity of a host site may be substantially greater than imposed limits (as was the case for Yucca Mountain) and could therefore negate technical arguments or justifications for multiple repositories.
- The WIPP site for TRU waste disposal presents useful precedents with respect to siting of a geological disposal facility, especially with respect to successful public and political engagement. However, technical, regulatory and policy hurdles remain that would need to be overcome in order for the WIPP site to qualify for HLW disposal.

8.4 Repository Design Concepts

- It is a universally adopted principle that geologic disposal relies on a multiple barrier approach to long-term waste isolation, including engineered barriers as well as the geologic system. Accordingly, both natural and engineered barriers must be considered together as a system in order to effectively evaluate repository performance.
- There are numerous repository concepts that have been developed for the leading types of host rock (i.e., crystalline, salt, clay, and volcanic tuff), providing a wide range of options and flexibility to tailor a repository design to site-specific conditions.
- Repository disposal concepts for used fuel and reprocessed HLW are usually similar. Co-disposal of used fuel, HLW and ILW within the same geological formation, but involving different sets of engineered barriers are being considered in some countries.
- The motivation for reversibility and retrievability can vary dramatically among different national geologic disposal programs, ranging from fundamental safety considerations to public acceptance of siting and maintaining future fuel cycle options such as reprocessing of used fuel for recycling.
- Many repository concepts, linked to specific rock types, have been refined to an advanced state of scientific and engineering understanding. This would conceivably allow relatively rapid implementation and significant cost-savings if such concepts were to be implemented in the US for host sites with similar geological and geochemical characteristics.

- Recent repository design concepts involving linkages among storage, reprocessing, and disposal activities could provide enhanced flexibility in national policies and decisions for management of nuclear wastes.

8.5 Independent Peer-Review and Advisory Bodies

- Independent and open oversight and review of geologic disposal program are critical for a credible geologic disposal program.
- It is also important that the independence of such bodies be complemented with appropriate charters such that the peer-review of geologic disposal and the perspective of the review team are placed in the context of the specific national repository requirements and goals. Of special relevance is the desirability of maintaining a total system perspective as opposed to over-emphasis on individual subsystems.
- The peer-review process should be commensurate with the needs of the geologic disposal program, with "fit-for-purpose" context of the review, i.e., review team members should have a broad diversity of technical and engineering backgrounds, all of which are relevant to the program being reviewed.

8.6 Stakeholder and Public Involvement

- Even though the technical quality of a geologic disposal program may be high, engagement of, and acceptance by, stakeholders is critical to the success of geologic disposal programs.
- Geologic disposal programs must recognize and, therefore, embrace the value of stakeholder involvement. However, the level and type of involvement of such stakeholders are beyond the intent of this series of technical reports by EPRI.
- Given the cultural and legal/political differences that exist between countries, there is clearly no single approach to how to engage stakeholders in geologic disposal programs.
- Sustained acceptance of a US geologic disposal program is necessary at all levels of affected government, from the national through intermediate (State, county, and municipal) levels and down to the local community level. Intermediate and regional governments and groups often do not perceive or accept the same levels of benefits-to-risks in selection of a specific site, as do the local and national governments and groups.
- Historically, many repository programs have started with minimal or no involvement of the general public, adopted a defensive posture early, and subsequently faltered as a result of stakeholder opposition. Learning from such negative experiences, most national approaches now involve public debate and involvement at an early stage of program development and continuing throughout the process.

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