RESET OF AMERICA'S NUCLEAR WASTE MANAGEMENT

Strategy and Policy

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Strategy and Policy

Stanford University
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Acknowledgements

During the course of the five, public Reset meetings, we benefitted from the more than 75 invited presentations. We also appreciated the vigorous discussion among experts, scholars, fellows and students who participated. The Steering committee thanks all of the participants for sharing their time and views. Most importantly, we thank all of the participants for their civility and patience as we tried to understand and articulate the fundamental issues that confront the U.S. nuclear waste management program.

This project could not have happened without the support of the Freeman-Spogli Institute for International Studies, the Precourt Institute for Energy at Stanford University, and the MacArthur Foundation for the support of the meetings at George Washington University. The grants from these institutions provided the travel support for all speakers and members of the Steering Committee.

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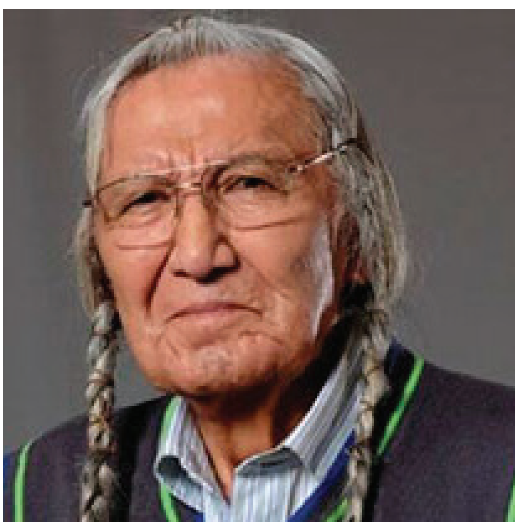
Stanford staff and students provided support for each of the meetings. We are especially grateful to Aparna Surendra, Elizabeth Gardner, Kathryn Anne Holleb, Zlator Gogolevse, Chelsea Papa, Katlyn Turner, Sulgiye Park and Paulette Wolak. Without their unfailing support and attention to detail, the meetings would not have been successful.

Finally, since the time of the meetings, two important participants have passed away: Russell Jim and Milt Levenson.

> **Russell Jim**, an Elder of the Yakama Nation, had a long history of dealing with the issues created by nuclear waste. Russell was a forceful advocate for rigorous environmental standards and the necessity of thorough cleanup at the Hanford site in Washington in order to protect the Columbia River and surrounding lands.
>
> **Milt Levenson** began his career with the Manhattan Project, working at Oak Ridge, Tennessee. He was the Associate Laboratory Director at Argonne National Laboratory,

Director of the Nuclear Power Division at Electric Power Research Institute and an executive consultant at Bechtel Power Corporation. He was the president of the American Nuclear Society (1983-1984).

Safe to say that Russell and Milt reflected two very different perspectives on nuclear waste issues, but at the Reset meetings the dignity of both set the tone of the discussions. Their knowledge and sense of purpose are a guide for us all. We were honored to know them both.



RUSSELL JIM (1935-2018)

MILT LEVENSON (1923-2018)

RESET OF AMERICA'S
NUCLEAR WASTE MANAGEMENT
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Executive Summary and Recommendations

Status of the U.S. Program

The U.S. nuclear waste management program has labored for decades at a cost of billions of dollars each year, and yet there is still no active disposal program either for spent nuclear fuel from commercial reactors or for the high-level radioactive legacy waste and spent nuclear fuel from defense programs. The program has suffered from a number of factors, including major changes to the original law; a series of amendments to the Nuclear Waste Policy Act of 1982; a slowly developed but changing regulatory framework; erratic funding; significant changes in policy with changing administrations; conflicting Congressional and Executive policies; and finally, and most significantly, inadequate public engagement in decisions about strategies for the storage and disposal of the nuclear waste.

Such disruptions are not unexpected in any extremely large technical megaproject subject to strong debates over value trade-offs extending far into the future. Only the radioactive waste-management program in Finland has been relatively immune to such challenges. The programs in Sweden, France, Switzerland, Germany, Japan, Canada, and the United Kingdom have all faced similar challenges. In some cases, the programs "reset" themselves relatively rapidly; in others, they did so over decades. Currently, Finland is in the process of constructing its repository after receiving a license; Sweden and France have selected sites and are moving through their licensing processes; and Canada and Switzerland are well into a comprehensive siting process. Germany has recently initiated a "reset" of its program with an entirely new, comprehensive siting process.

Meanwhile, the U.S. program is an ever-tightening Gordian Knot—the strands of which are technical, scientific, logistical, regulatory, legal, financial, social and political—all subject to a web of agreements with states and communities, regulations, court rulings and the Congressional budgetary process. There is no single group, institution or governmental organization that is incentivized to find a solution, nor is any single institution entirely responsible for the failure of the U.S. Program.

Reset Initative

The Reset initiative, *Reset of America's Nuclear Waste Management Strategies and Policies*, is based on the simple premise that given the scale and importance of the challenges at the back-end of the nuclear fuel cycle, there is great value in taking a penetrating look at some of the most critical problems and their possible solutions. Reset is an effort to untangle the technical, administrative and public concerns in such a way that important issues can be identified, understood and addressed.

Any new strategy must be informed by a thorough understanding of the history of the U.S. nuclear waste program, as well as the scientific, technical, social and policy challenges required to "reset" the U.S. program. Today, technical and policy issues have been overwhelmed by a partisan political process. A Democratic administration has tried to shut down the Yucca Mountain project as "unworkable", while some Republicans in Congress view Yucca Mountain as the "law of the land."

As a first step, and in order to inform any new strategy, the "Reset" meetings have provided a forum for discussing the critical issues that must be addressed in order for the U.S. program to move forward. The meetings were organized by an international Steering Committee, listed in Appendix A. The members of the Steering Committee represent diverse and international perspectives and have considerable experience with issues involving the back-end of the nuclear fuel cycle. *The members of the Steering Committee do not represent the views of their organizations.* They, however, bring considerable technical skills and experience to the discussion.

The "Reset" process involved convening five meetings, which consisted of 75 presentations by internationally recognized experts, government officials, legislators, nongovernmental organizations and members of the public (Appendix B). The series of five meetings were held at Stanford University and George Washington University (Appendix C: Prospectus and Agenda for Each Meeting). The meetings were open to the public, interested experts and scholars.

This report is a summary of the major issues that were raised during the discussions as understood by the Steering Committee during their subsequent deliberations. As one might expect, there are a range of views, and we have tried to capture the essential elements of these different perspectives. At the same time, the Steering Committee has tried to emphasize specific ways forward for the U.S. program. *This is not a consensus report.* Individual members of the Steering Committee may have preferred a different emphasis on certain options, but we have tried to capture the "center of gravity" of our different perspectives. We think that these recommendations will be useful as the U.S. fashions a new strategy and policy for the management and disposal of the Nation's nuclear waste.

A New National Radioactive Waste Management Organization with a New Funding Strategy

The lynchpin to the recommendations of the Reset Steering Committee is the recognition of the need for a new, independent, single-purpose national radioactive waste management organization and reform of the funding process.

These are not new ideas. Many reviews, most recently *The Blue Ribbon Commission on America's Nuclear Future* in 2012, have made similar recommendations. Nearly seven years after the *BRC* report, the need for such an organization has only become more evident. We review the history of organizational responsibilities for nuclear waste management in the United States and discuss possible alternatives to a government-chartered organization (a FEDCORP)—as recommended by the *Blue Ribbon Commission*. The Steering Committee is unanimous in its recommendation that the United States needs a new, independent, single-purpose nuclear waste management organization. *Further, a majority of the Steering Committee supports an alternative type of organization—a nuclear utility-owned, not-for-profit, implementing corporation, NUCO. The Steering Committee believes that it is essential that the administration of the Nuclear Waste Fund be transferred from Congress to the new organization.*

The Steering Committee recognizes that any decision about how to organize implementation and funding, whether it preserves or alters the *status quo*, carries with it both benefits and costs. But, on balance, the Steering Committee maintains that its recommendation best addresses a critical national issue, which has been left in limbo for far too long.

The new organization, regardless of its type and structure, must have a clearly stated charge; a structure that embraces public engagement and engenders trust; a focused research agenda; an implementation plan that matches the knowledge needs for geologic disposal; and, most importantly, sufficient and consistent funding over decades.

Funding for the new organization must also be removed from the annual Congressional appropriations process to ensure adequate year-to-year funding in order to maintain an efficient site selection, characterization, licensing, and construction process.

RECOMMENDATIONS:

- ***Create a new, independent, single-purpose nuclear waste management organization.*** This is not a new idea, and there are many models for such an organization. The Blue Ribbon Commission favored a FEDCORP structure. However, the Reset Steering Committee points to some unique advantages of a not-for-profit, utility-owned waste management organization (NUCO), particularly based on the clear success of this approach as evidenced by other national programs, such as in Finland, Sweden, Switzerland and Canada.

  A NUCO would align technical decisions for final geologic disposal from the moment that the used fuel is extracted from a commercial reactor until it is disposed of in a geologic repository. Financial incentives would also be aligned to support the final goal of geologic disposal.

Regardless of the type of organization, careful attention must be paid to the scope of its mandate, particularly in defining the types of waste that are the responsibility of the new organization.

Scientific integrity and public engagement will be essential to the success of any new organization.

- ***The NUCO should initially manage the storage, packaging, transportation and disposal of commercially generated waste only.*** The responsibility for defense waste would continue to reside with the federal government or a FEDCORP if one were to be created.

  The value of such an approach lies mainly with the desire to ensure the success of the NUCO. It would be a major accomplishment if a NUCO were able to successfully manage the disposal of commercially-generated spent nuclear fuel in the United States. Such an accomplishment would account for the disposal of nearly 95% of the radioactivity of the nuclear waste that requires geologic disposal.

- Funding reform is essential to ensure the timely and appropriate use of the Nuclear Waste Fund. ***The Nuclear Waste Fund should be transferred from congressional control of annual budget allocations to full access by a new, waste management organization.***

  The Reset Steering Committee recommends that the Nuclear Waste Fund be transferred from the federal government to the new waste management organization over a 25-year period. One of the advantages of a not-for-profit utility-owned organization is that it would be responsible for collecting fees for nuclear waste management and allocating funds as needed in a timely and appropriate manner.

Integration of the Back-end of the U.S. Nuclear Fuel Cycle

When policy makers contemplated nuclear waste disposal in the U.S. Nuclear Waste Policy Act of 1982, they envisioned a straightforward process: storing spent fuel in pools at reactors for no more than a few years and then transporting the spent fuel to a geologic repository starting in 1998. More than 35 years later, an *ad hoc* system for managing spent fuel has replaced this strategy, with no geologic repository in sight. The current situation exists without clear and consistent incentives on how best to manage spent fuel at reactor sites, without agreement on the necessity of centralized storage, and without consent from a host community or state for the site of a final geologic repository. As a result, there are no standardized waste management strategies at reactors, no standard waste packages, and no plan for transportation of the spent fuel from reactor sites to either interim storage or a geologic repository. Hence, it is nearly impossible to assure the compatibility of waste package design with storage or repository requirements. Spent fuel is stored using a variety of different technologies that directly impact how and when final disposal can happen. Instead of a planned, coherent system, we have the confusion of an unplanned, less than optimal system, with each player only focuses on their own small piece of the larger system. This is not a situation that builds public confidence.

More importantly, the United States has taken its "eyes off the prize"—***the prize being disposal of highly radioactive nuclear waste in a deep-mined geologic repository.***

RECOMMENDATIONS

- Congress must revise existing laws so that it:
  - **Transfers the corpus of the Nuclear Waste Fund to the new organization.**[1]
  - **Orders the Department of Justice to consider the impact of its payments on the integration of the back-end of the fuel cycle.** Payments should not limit the possibility of conditioning and packaging the spent nuclear fuel for geologic disposal, *e.g.*, packaging the fuel into smaller, potentially repository-appropriate canisters for earlier transport and disposal.
  - **Requires the nuclear utilities and the new organization to work together to establish an integrated system for spent fuel and high-level waste management** that has the capability to repackage spent nuclear fuel from the current, relatively large casks and canisters into canisters that are designed for geologic disposal.
- **The Standard Contract should be revised under the new organization to include planned removal of spent fuel first from shutdown plants.**[2]
- **The new organization should be required to work with all interested parties: industry, local, state, and tribal governments, public interest groups, academia, the regulator, to ensure that all relevant views on storage, transportation, and disposal are not only heard, but become part of the overall strategy for dealing with the waste.**
- **Finally, Congress must reaffirm that a geologic repository (or repositories) is the final goal for the fate of high-activity radioactive waste, such as spent nuclear fuel and the high-level waste from reprocessing.**

Each of these recommendations is meant to harmonize the back-end of the fuel cycle such that every decision is focused on the final goal—geologic disposal.

Public Engagement and Consent-Based Siting

Over the last half-century, implementers of national waste-management programs in more than a dozen countries have launched at least 24 efforts to site a deep-mined, geologic repository. *In only five of these efforts was a site actually chosen.* Nearly one-half of the initiatives ended prematurely because the projects failed to gain and sustain social acceptability. Those abandoned attempts typically adopted a strategy of *"decide-announce-defend,"* in which the implementer, with little or no consultation, identified potential candidate locations, informed the recipient communities, and dismissed objections and criticism as they emerged.

In contrast, Finland has selected a site near Olkiluoto, France near Bure, and Sweden near Östhammar. In the United States, a site near Carlsbad was selected for the Waste Isolation Pilot Plant in which defense-generated transuranic-contaminated waste is being disposed.

[1] Transfer of the Nuclear Waste Fund need not occur all at once but can be completed over decades. The need to re-establish the Nuclear Waste Fund can then be evaluated by the new nuclear waste management organization and done under their authority as discussed previously.

[2] The Standard Contract, 10 CFR 961, sets forth the responsibilities of the nuclear utilities and DOE in preparing and accepting commercial SNF for disposal. See the discussion in Chapter 2.

The site for the proposed Yucca Mountain repository was formally selected in 2002. Today, the fate of that site is in political limbo. In each of those instances, except the last, the development of a repository appears to be on a strong and stable track. It is no wonder that countries resetting their siting processes, such as Canada, Japan, and the United Kingdom, have decided to adopt an alternative strategy, requiring that the siting community *volunteer or consent* to the development of the facility.

Hence, the process by which a candidate geologic site is investigated, determined to be "suitable" or "unsuitable," licensed, constructed, operated and eventually permanently sealed needs to be one that involves not only the nuclear waste management organization and the regulator, *but also those affected by and interested in this process*. These can include members of local and regional communities, local, state, and tribal governments, industry, public interest groups, and the wider scientific and engineering community. All of these parties have some level of interest in, and in some cases, authority over the development of a deep-mined geologic repository. The goal, therefore, must not be a *"decide-announce-defend"* approach by the nuclear waste management organization and the regulator, but rather one in which all interested parties have the ability to participate in the process. The controversial nature of radioactive waste management demands consideration—and incorporation—of a broad range of views if a final disposal facility is to be successfully developed and used.

The details of who consents, what is consented to, and how consent is given varies from country to country. But based on the information gathered during the Reset meetings, as well as the experiences and knowledge of the members of the Steering Committee, two significant challenges have to be addressed if the United States waste management program is to move forward using a consent-based process for siting a repository for high-level waste and spent nuclear fuel.

- The implementer and the regulator have to establish strong bonds of trust with the local, tribal, and state governments involved and have to sustain that trust for the many decades during which development moves from scientific and engineering studies in support of siting through operations to final closure.
- An effective mechanism has to be put in place that allows local, tribal, and state governments to exercise decisive decision-making power throughout the repository-development program. In the chapter on public engagement and consent based-siting, the Steering Committee has outlined a process that increases the power of local, tribal and state governments in the decision-making process.

RECOMMENDATIONS:

- **The Steering Committee recommends the adoption of a consent-based siting process that (1) establishes strong bonds of trust between localities, tribes, and states on the one hand and the implementer and that (2) fairly reallocates power among the parties.**

  The Steering Committee proposes ways by which those two objectives might be secured.

  - ***Collaborate to design the siting process.*** Consent-based siting necessarily involves multiple players, such as the implementer, industry, the affected local, state, and potentially tribal government, and public interest groups, who agree to initiate a process and become active participants willing to sustain siting activities over an extended period. The extent to which the siting principles and repository-development process reflect the expectations and values of interested and affected parties improves the chances of a positive outcome.

- ***Entrust the siting process to an independent, competent and trustworthy organization***, such as a NUCO. An organization that has established itself within a stable political environment will be needed to lead the process and be the trusted guardian of the siting. Such an organization will embrace and reflect in its operations the values central to earning and sustaining public trust and confidence.
- ***Articulate a structured and transparent process for selecting candidate sites and winnowing them down to a technically suitable and socially acceptable final choice.*** From the early engagement regarding society's expectations for a siting process, it will become evident what might provide clarity and confidence at the outset.
- ***Assemble information required to support participation.*** Early engagement by the implementer can lead to an understanding of public expectations about the information required to launch the siting process.
- ***Partner with local, tribal, and state governments.*** Once engaged, these entities will wish to co-design the journey and establish appropriate control over the process.
- ***Provide an appropriate, ethically-based platform for inviting communities to explore the repository project and consider their potential interest in hosting the repository.*** The implementer will need to provide early steps focused on the learning process and exploring the repository project.
- ***Build the conditions for sustained interest and momentum.*** A community must be a continuing strong proponent of learning about the project and participating in the siting process.
- ***Respect the need for flexibility and adaptability.*** It will not be possible at the outset to foresee all of the programs, resource needs and process details that will be essential at each point in the long multi-year period of site evaluations and repository development.
- ***Adopt a process for approval of a repository site that gives substantial authority to the local municipality, tribe or state to stop the process of site selection and repository construction.*** The decision by local and tribal governments to object should come after an appropriate period of engagement and the completion of important scientific and engineering studies. A possible point of decision could be anytime before the formal submission of the license application to the regulatory authority. A state's objection after a license has been granted could only be overturned by a supermajority of both houses of Congress.

- **Finally, in order to insure a fair process, more than one site should be characterized, just as the 1982 Nuclear Waste Policy Act originally required.**

Regulations, Risk and Safety for the Geologic Disposal of Radioactive Waste

While most of the radionuclides in spent fuel and high-level waste will decay away during the first 1000 years after removal of the fuel from the reactor, some radionuclides will persist for tens of thousands to over one million years. The purpose for any deep-mined geologic disposal system is to delay the release of radionuclides to the biosphere until they are below regulatory limits or have decayed to non-radioactive elements. This is accomplished by a series of multiple barriers, both engineered and geologic. The engineered barriers include the waste form, metal canister and back-fill that surrounds the canister. The geologic barriers rely on the low solubility of radionuclides in the groundwater, high sorption onto mineral surfaces, the slow movement of groundwater through the repository, and dilution during transport in order to delay and reduce the amount of radioactivity released from the engineered barriers. Depending on the geology of a particular site, different strategies for a geologic repository have emerged, as evidenced in the different international programs (see for example, Yardley et. al., 2016).

Natural geologic systems are by nature complex. Although a substantial fraction of the radioactivity decays during the first several hundred years, a limited number of long-lived fission products, such as ^{99}Tc and ^{129}I, and actinides, such as ^{239}Pu, ^{238}U, remain for long periods. Thus, it is necessary to evaluate the performance of a geologic repository over hundreds of thousands of years. Detailed predictions of the release and fate of radionuclides in a naturally complex system over such a long time is neither possible nor necessary. The state of the art practice is to collect enough information about the long-term evolution of the entire disposal system, such that there is sufficient confidence that the disposal system will keep humans "safe" both in the near and very long term. "Safe" does not mean zero health risk for hundreds of thousands of years, but a health risk that is low enough to be acceptable to today's population and future generations. There are no absolute guarantees of safety in any activity. The decision of what constitutes "safe-enough" has been delegated to regulatory authorities in each nation.

To best achieve an understanding of whether a site is "safe" or not, the Reset Steering Committee supports the "safety case" approach in the evaluation of the performance of a geologic repository. The safety case provides a transparent and much more complete rationale as to why the selected site is safe. The safety case approach begins with the determination of appropriate site selection criteria and iteratively continues to be developed throughout the entire process leading to a successful license application. The safety case establishes a strong and consistent relationship between the criteria for the initial selection of a site and the knowledge of the site as it is characterized and understood. A safety case describes the reasoning behind the determination that a disposal site is "safe" for a range of possible future scenarios. The safety case is based on multiple lines of qualitative and quantitative evidence and clearly addresses uncertainties, safety margins and subjective decisions that are an essential part of projecting very long-term behavior of the disposal system. The safety case goes well beyond quantitative projections of the behavior of a geologic site but rather addresses the strength of the rationale for the selection of a site. The determination of the "safety" of a specific site over such long periods is a uniquely challenging effort for scientists and engineers. When the technical uncertainties are large, there should be a greater consideration of the ethical and social issues (Jasonoff 2004). The safety case encompasses all of these considerations.

RECOMMENDATIONS:

- **The Steering Committee recommends that the implementer be required to develop a safety case during the initial stages of site investigation that is based on site selection criteria, and to regularly update the safety case as additional information is revealed and as it receives comments from various stakeholders and other interested parties.** While formal compliance calculations are still an essential part of the licensing process, *the primary vehicle for communication with the broadest range of stakeholders and other interested parties should be the safety case*. In addition, the license application should be based on the safety case, as it has been developed during the characterization and design of the geologic repository.

- **The Steering Committee recommends that a new approach to geologic disposal repository regulation be adopted that recognizes that uncertainty in predicting geologic processes grows over time.** There are several good examples of how growing uncertainty should be treated over very long timeframes (beyond, for example, 10,000 years). Fundamentally, these alternative approaches include a stronger reliance on quantitative analyses for shorter periods of time (such as perhaps up to several thousand years), with reliance on more qualitative factors over longer periods of time. However, quantitative calculations for long time periods are still valuable as a starting point for more qualitative analyses. A new regulatory framework will need to be established in order to establish the safety case approach as the basis for the license application.

- Finally, an essential step in building trust and ensuring that the safety case remains adequate is thorough formal peer review. **The Reset Committee recommends an independent, continuing, internationally-based peer review of the safety case.** Sweden, Switzerland, and France conducted independent reviews through the Nuclear Energy Agency's international expert group (NEA 2012).

> *In addition to the international peer review of technical issues, local communities, tribes and states should receive funding so that they can hire their own experts, who will conduct and publish their own reviews.*

In addition to the international peer review of technical issues, local communities, tribes and states should receive funding so that they can hire their own experts, who will conduct and publish their own reviews. The important role of the Environmental Evaluation Group for the state of New Mexico in the opening of the geologic repository at the Waste Isolation Pilot Plant is a good example of the success of such an approach.

SUMMARY AND REFLECTION

The recommendations by the Steering Committee are not, in sum, a modest proposal. We are recommending that a new, independent, single-purpose organization take responsibility for spent fuel from the moment that it is removed from a commercial reactor until final geologic disposal. We are placing the responsibility for the creation, funding and oversight of the new organization on the utilities that use nuclear power. We would remove Congress from controlling the funding process through annual appropriations, and over time, we recommend that the Nuclear Waste Fund be transferred to the new organization. We would increase public engagement and redistribute the power in the decision-making process to the affected and participating parties. Finally, we recommend fundamental changes in the regulatory framework and the process by which "safety" is determined.

These recommendations are tied tightly one to the other. The centerpiece, a new organization, must be properly funded. The new organization has to be in charge of every step of the process from the creation of the used fuel to its final disposal. This is the only way that decisions at each step along the way can be aligned toward the final goal of geologic disposal. The new organization must engage the public, and the public and local political entities must have the right to exercise their own preferences and make decisions about the future of the project within an appropriate time frame. The issue of safety is paramount—but the determination of safety must go well beyond a technical evaluation and extend to the values of impacted communities, tribes and states.

We expect that experts and the old hands in this effort will scoff at our recommendations. We simply note that after tens of billions of dollars spent and decades of effort, the U.S. program has made little progress. In such a situation, we believe that new ideas and approaches are in order. This is the time to take careful stock of the U.S. and international experience and design a new strategy that seeks to avoid that in thirty years we are still trapped in the present situation. The Nation must take the time to chart a new way forward for the safe disposal of nuclear waste.

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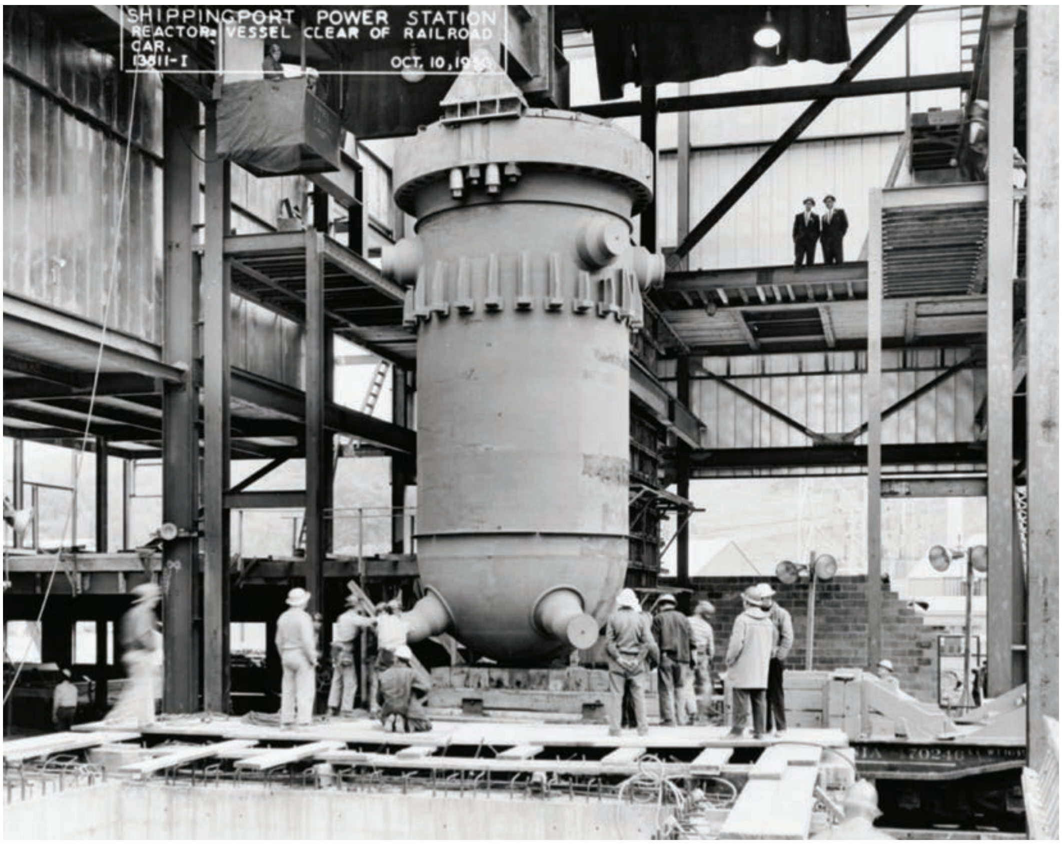

The Shippingport Atomic Power Station, located on the Ohio River in Pennsylvania, was the U.S.'s first full-scale nuclear power plant used exclusively for the production of electricity. It came on line in 1957 and operated until 1982. In subsequent years, the number of nuclear reactors grew to peak of 104 that provided some 20 percent of the U.S.'s electricity. Presently, there are 60 sites with 98 nuclear reactors operating in 30 states. Typically, a nuclear reactor will produce some 20 tons of spent fuel per year. Today, the U.S. has over 80,000 tons of spent fuel stored at 75 sites where there are operating reactors or at sites where the reactors have been decommissioned.

SOURCE: *https://flic.kr/p/qacBsH*

Introduction: Status of the U.S. Program & the Reset Process

The U.S. nuclear waste management program has labored for more than four decades at a cost of greater than $13 billion dollars, yet the program for disposing of spent nuclear fuel from commercial reactors or the high-level radioactive waste and spent nuclear fuel from defense programs continues to slip further into the future.[1] During that time, the program has suffered from major changes to the original law, a slowly developed but changing regulatory framework, erratic funding, significant changes in policy with changing administrations, conflicting Congressional and Executive policies and, finally, inadequate public engagement in decisions about fundamental strategies for the storage and disposal of the nuclear waste.

Such disruptions are not unexpected in any extremely large technical megaproject that is subject to strong debates over value trade-offs extending far into the future. Only the radioactive waste-management program in Finland has been relatively immune to these challenges. The programs in Sweden, France, Switzerland, Germany, Japan, Canada, and the United

Meeting #1 of Reset of U.S. Nuclear Waste Management Strategy and Policy (February 17, 2015).
SOURCE: CISAC

[1] To simplify the exposition, this report uses the term "high-activity radioactive waste" to mean both high-level radioactive waste and spent nuclear fuel.

Kingdom have all faced similar challenges. In some cases, the programs "reset" themselves relatively rapidly; in others, this process took decades. Currently, Finland is in the process of constructing its repository, having received a license to do so; Sweden and France have selected sites and are either moving through or embarking on efforts to obtain a license to construct a repository; and Canada and Switzerland are well into a comprehensive siting process. Germany has recently initiated a reset of its program with an entirely new, comprehensive siting process, which places on hold the presumptively selected Gorleben site.

TYPES OF NUCLEAR WASTE

In the United States, the high-activity radioactive wastes are of two main types: i.) spent nuclear fuel generated by defense programs or commercial nuclear power reactors and ii.) the highly radioactive material, containing mainly fission product elements, that results from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations and other highly radioactive material that the Nuclear Regulatory Commission, consistent with existing law, determines by rule requires permanent isolation. Some 95% of the total radioactivity in high-activity radioactive waste in the United States is in the spent nuclear fuel from commercial nuclear power reactors.

Meanwhile, the US program is caught in an ever-tightening Gordian Knot—the strands of which are technical, scientific, logistical, regulatory, legal, financial, social and political—all subject to a web of agreements with states and communities, regulations, court rulings and the congressional budgetary process. There is no single group, institution or governmental organization that is incentivized to find a solution nor is any single institution entirely responsible for the failure of the U.S. Program.

Why does the United States find itself in its current situation?

Managing High-Activity Radioactive Waste Continues to be a Low Priority

Seventy-six years ago, Enrico Fermi and colleagues demonstrated sustained nuclear fission using the Chicago Pile–1 reactor in a squash court under the stands of Stagg Field at the University of Chicago. This historic moment was the culmination of rapid advances in physics after Otto Hahn and Fritz Strassman demonstrated that the uranium atom could be split by a neutron, causing the release of huge amounts of energy and creating highly radioactive fission products. That discovery was massively scaled-up by the Manhattan Project during World War II. At what is now the Hanford Site in eastern Washington, uranium fuel rods were "burned" in nuclear reactors and then chemically processed to recover fissionable plutonium that would be used in the bomb exploded over Nagasaki. Large volumes of high-activity radioactive waste were subsequently generated. Because stainless steel was needed for the war effort, the high-level radioactive waste from the processing activities was stored in large carbon-steel tanks, which are prone to corrosion and leakage. The Cold War stimulated a massive plutonium-production program that the Atomic Energy Commission carried out not only at the Hanford Site but also at the Savannah River Site in South Carolina. In addition, at the Idaho National Laboratory, smaller volumes of high-level radioactive waste were generated from reprocessing the fuel from nuclear submarines. The waste management "strategy" at each location was to store the waste in tanks, pending the development of permanent disposal technologies. For the most part, that strategy remains in place today. Consequently, at each of these sites, the clean-up from these waste-producing activities will stretch into future decades at a cost of roughly six billion dollars per year.

The first commercial nuclear power plant at Shippingport, on the Ohio River in Pennsylvania, came online in 1957. Eventually over 100 nuclear power plants would provide electricity in the United States. These reactors have generated some 80,000 metric tons of spent nuclear fuel, most of which are still stored at some 75 reactor sites across the country.

From the early days of the Manhattan Project and the Atomic Energy Commission, there has been little focus on the fate of high-activity radioactive waste. This benign neglect continued in part because of competing budgetary priorities but also because both policymakers and the technical community underestimated how difficult it would be to manage and dispose of these radioactive materials. The situation remains much the same today. There is still no accepted strategy for dealing with high-activity radioactive waste generated by nuclear defense programs and commercial reactors.

A Technical—If Temporary—"Fix" Was Available

During the first decade after high-activity waste was generated in the defense program, a commonly held view was that its management was a straightforward and easily solved technical problem. If a tank needed to be replaced, it was a simple matter of pumping the contents of one into a replacement. This feat could be carried out "in perpetuity."

By the mid-1950s, the prospect of commercially generated nuclear electricity began to be realized. Although perpetual tank storage might have been an option in the plutonium-production program, it did not seem viable once utilities began to generate spent nuclear fuel. The Atomic Energy Commission decided to ask the National Academy of Sciences (NAS) to provide advice on a more sustainable approach. At that time, a wide variety of possible solutions were considered from disposal in the deep ocean to deep space.

In 1957, an Academy Committee issued a report that even today frames how high-activity waste is to be managed (NAS 1957). The Committee maintained that the material could be disposed of in mined-out, stable, and deep geologic formations. Therein lay the idea of constructing a permanent waste-disposal repository. Although the committee believed that many sites in the United States would be suitable, it was particularly attracted to the idea of disposing the waste in salt. To overstate the case, "solving" the radioactive waste management "problem" meant digging a hole and emplacing the waste therein.

The Academy's endorsement of a long-term technical solution rationalized the AEC's decision to support only a low level of research and development funding. Compared to its reactor and weapons design programs, much smaller efforts for the waste problem were cobbled together at the agency's national laboratories.

Implementing a Technical "Fix" Was Not as Easy as Expected

A fire in 1969 at the Rocky Flats Plant, a weapons facility in Colorado that produced bomb components, led AEC Chairman Glenn Seaborg to send the contaminated material to Idaho along with a promise to Idaho's governor to remove that waste within a decade.

Those commitments forced the AEC to fund a more aggressive waste-management program. By 1970, the agency proposed to construct a repository in a salt formation outside of Lyons, Kansas. The leader of the Kansas Geologic Survey convinced state officials and one congressman that the nominated site was technically suspect. Moreover, vocal opposition arose to the very idea of developing a nuclear waste repository. Ultimately, the Lyons project was abandoned.

Further complicating matters, in 1974 India tested a "peaceful" nuclear device using plutonium separated from US-provided fuel irradiated in a Canadian-designed research and test reactor. This led President Ford and then President Carter to propose indefinitely deferring the reprocessing of spent nuclear fuel from civilian reactors in order to set an example for other countries that had or were contemplating a nuclear power program. Spent nuclear fuel that might have been shipped off site to a reprocessing facility would now certainly build up at the reactor sites across the country. Although President Reagan lifted the indefinite ban on reprocessing in 1981, commercial spent fuel is still not reprocessed in the United States.

By the end of the 1970s, environmental protection as well as opposition to further development of commercial nuclear power emerged as salient political issues. Environmental advocates found their views bolstered by, among other things, the passage of the National Environment Policy Act (NEPA). NEPA forced the question of radioactive waste management to be deliberated in forums outside the technical community. Reflecting this change, President Carter established an Interagency Review Group on Nuclear Waste Management (IRG) to propose wide-ranging policies that would fundamentally alter the dynamics underlying the management of radioactive waste.

Released in 1979, the Interagency Review Group recommendations came at a time when key members of Congress were exploring initiatives and approaches that might be included in new legislation. In 1982, the IRG recommendations and Congressional ideas, which in many cases overlapped, were incorporated into the Nuclear Waste Policy Act (NWPA).

Key Bargains in the Nuclear Waste Policy Act (1982) Unravel

At its core, the NWPA contains four interlinked "bargains": (1) sites for a repository would be chosen based on technically driven evaluations of at least three candidate sites; (2) to promote geographic equity, two repositories would be developed; although not explicitly stated in the law, it was generally accepted that the first one would be in the western U.S. and the second in the east; (3) in return for a fee levied on the generation of nuclear-powered electricity, the federal government would begin accepting high-level radioactive waste and spent nuclear fuel for disposal by January 31, 1998, and (4) states would be given a meaningful role in approval of the selected site.

The NWPA laid out a plan to achieve a repository: the Department of Energy (DOE) would recommend to the President three sites for extensive investigation and characterization. Subsequently, DOE would recommend one of those sites as the location for the first repository for high-activity waste. Congress would either sustain an objection from the state where the proposed site was located or override it. DOE would submit an application to construct a repository at the site and would submit it for approval by the Nuclear Regulatory Commission (NRC). The repository's projected performance would have to comply with standards set by the Environmental Protection Agency (EPA).

Almost immediately after the passage of the NWPA, each of the bargains started to unravel. The cost of exploring multiple sites was higher than anticipated. Moreover, public and political opposition to siting both a facility in the west but especially to a repository in the east intensified. Consequently in 1986, the Secretary of Energy determined that the second repository was "no longer needed."

FIGURE 1.1. The underground Exploratory Studies Facility built at Yucca Mountain by the Department of Energy to determine whether the location was suitable as a deep geological repository.

SOURCE: *https://flic.kr/p/qacBkD*

Attempting to address these problems, Congress passed the Nuclear Waste Policy Amendments Act (NWPAA) in 1987. This law designated the Yucca Mountain site in Nevada as the sole location for the Department of Energy (DOE) to characterize to determine whether it might be suitable for a repository. The law also officially terminated the second repository program by requiring that DOE report on the need for a second repository by 2010.

The faith placed in the "technical fix" soon appeared to be based more on wishful thinking than on actual evidence. Nevada's continued opposition to developing a repository at Yucca Mountain, erratic policy directions at DOE, intermittent budgetary support from Congress, and the intrinsic difficulty of characterizing a complex site all contributed to repeated failures to meet targeted milestones.

By the late 1990s, it became clear that the January 1998 date to begin accepting spent nuclear fuel could not be met. Reactor owners sued DOE for damages for the agency's partial breach of contract. To date, the courts have awarded those parties several billion dollars in damages. Depending on when waste acceptance finally occurs, the anticipated final total will be in the tens of billions of dollars and will be paid out of the Judgment Fund using general revenues.

In a vibrant pluralistic democracy, policy opponents retain many avenues for making their views felt. As it turned out, one of Nevada's senators, Harry Reid, rose to a position of political power. As the Majority Leader in the Senate, he convinced incoming President Barack Obama that the Yucca Mountain project had become "unworkable." In 2010, the Obama administration tried to withdraw DOE's license application to construct the repository at Yucca Mountain, which was then pending before the NRC. When that tact did not succeed, Reid and the Obama Administration eliminated the project's funding at both DOE and NRC.

Yet support for the Yucca Mountain Project remains strong. A comprehensive bill to provide funding to restart the suspended NRC hearings has passed in the House. For those supporters, the more than $13 billion already spent represents a significant sunk cost that members of Congress were unwilling to walk away from. Moreover, who among them would want to place their state back into play? The Trump Administration's request for $160 million in new funding, however, has been rejected so far.

It is unclear how long the current stalemate will continue. One can envision at least two possible futures. In the first, comprehensive waste-management legislation is passed within the next year or so. That legislation would, at a minimum, provide funding to DOE and NRC to resume the suspended hearings on Yucca Mountain. In the second scenario, the United States adopts an approach similar to the one just chosen in Germany. A new site-selection process is launched. Yucca Mountain remains in contention but is not automatically the preferred choice. Depending on which scenario emerges, the following pages of this report will be more or less relevant.

"Yesterday's solutions have become today's problems."

These words, spoken by a DOE official who asked to remain anonymous, capture the essence of the fundamental dilemma. Over the course of decades, decisions meant to provide solutions often created even greater problems. When one surveys the fate of nuclear waste at the back-end of the nuclear fuel cycle in the United States, "today's problems" include:

- Spent nuclear fuel from commercial nuclear power plants continues to accumulate at some 75 sites in 35 states. The United States produces approximately 2,000 metric tonnes of spent fuel per year. The total inventory is over 80,000 metric tonnes, more than the legislated capacity for the geologic repository proposed at Yucca Mountain. Even if a repository is built at Yucca Mountain, a change in law will be required in order to authorize DOE to permanently dispose of all of the waste anticipated to be generated by the continued operation of existing nuclear power plants to their end of life. In 2008, the life cycle costs for the repository at Yucca Mountain were revised upward from $58 billion to $96 billion for the 150 years of research, construction and operation of the geologic repository (Sproat 2008). To date, the cost of developing the repository at Yucca Mountain is approximately $13.5 billion.
- The Nuclear Waste Policy Act of 1982 established the Nuclear Waste Fund (NWF) mainly from receipts from the collection of fees by nuclear utilities. The fee (one-tenth of a cent per kilowatt-hour) was to be used to fund the permanent disposal of spent nuclear fuel from commercial nuclear power plants. The fund presently has accumulated over $40 billion, including interest (Bearden 2015). In the absence of an active program to establish a geologic repository, the collection of the fee was suspended in May 2014, by a federal court, but interest continues to add significantly to the fund's balance.
- U.S. taxpayers pay over $500 million dollars a year to the utilities as a result of a judgments against the federal government for its failure to take ownership of the spent nuclear fuel in 1998, as required by the Nuclear Waste Policy Act of 1982. Estimated future liabilities for these judgments may reach $23.7 billion (Cotton 2016), but the total could be higher if there is a continuing delay in opening a geologic repository.
- Funds from the Nuclear Waste Fund were appropriated annually by Congress, but the amount of funding is subject to statutory (Budget Control Act of 2011) and procedural (Congressional budget resolutions) limits. Thus, appropriations for the nuclear waste disposal program remain under the spending cap applicable to all domestic programs, even though the NWF is self-financed and well-funded. In summary, the rate payers using electricity generated by nuclear power plants have provided substantial funds to support the disposal of nuclear waste, but few of these funds are available to DOE for this purpose.

This landscape of major challenges is decorated by cascading controversy and legal action caused by the continued delay in implementing the U.S. Nuclear Waste Policy Act of 1982, its subsequent amendment in 1987, and numerous unmet agreements between the Department of Energy and states that presently have large amounts of nuclear waste.

No Repository in Sight

Central to all of these issues is the need to locate, build, license and operate a geologic repository for the disposal of high-level nuclear waste. However, after nearly thirty years of effort, there is now no clear path forward for the selection, characterization and development of a geologic repository for spent nuclear fuel and high-level nuclear waste. When one surveys and reflects on the types of problems that have plagued the Department of Energy, it may well be that Yucca Mountain is not the major issue but rather is a symptom of the intrinsic challenges of the U.S. program for the disposal of radioactive waste. Even if the Yucca Mountain project should move forward, it has become clear to most parties that important changes will need to be made in the U.S. strategy and policy for the management of the back-end of the nuclear fuel cycle.

Yucca Mountain is not the major issue but rather is a symptom of the intrinsic challenges of the U.S. program for the disposal of radioactive waste.

The problematic issues are many: program management has been plagued by political interference, such as abandoning the original idea of characterizing multiple sites; the funds, though collected, have not been appropriated when needed; the affected state has not consented to the process; the waste at reactor sites is not managed with an eye to final disposal in a geologic repository; and the current site evaluation methodology is opaque and controversial.

The Reset Initiative

The Reset initiative, *Reset of America's Nuclear Waste Management Strategies and Policies*, is based on the simple premise that given the scale and importance of the challenges at the back-end of the nuclear fuel cycle, there is great value in taking a deep look at some of the most critical problems and their possible solutions. Reset is an effort to untangle the technical, administrative and public concerns in such a way that important issues can be identified and addressed.

Any new strategy must be informed by a thorough understanding of the history of the U.S. nuclear waste program, as well as the scientific, technical, social and policy challenges required to reset the U.S. program. Today, technical and policy issues have been overwhelmed by a partisan political process. A Democratic administration has tried to shut down the Yucca Mountain project as "unworkable," while Republicans in Congress view Yucca Mountain as the "law of the land."

The members of the Steering Committee do not represent their organizations.

As a first step, and in order to inform any new strategy, the Reset Project has provided a forum for the discussion of the critical issues that must be addressed in order for the U.S. program to move forward. Meetings were organized by an international Steering Committee, listed in Appendix A. The members of the Steering Committee represent diverse and international perspectives and have considerable experience with the back-end of the nuclear fuel cycle. The members of the Steering Committee do not represent their organizations. They bring their technical experience and professional views to the discussion.

The Reset process involved convening five meetings, which consisted of 75 presentations (Appendix B) by internationally recognized experts, government officials, legislators, non-governmental organizations and members of the public. The meetings were held at Stanford University and George Washington University (Appendix C: Prospectus and Agenda for each meeting.) The meetings were open to the public.

Some of the critical issues discussed during the Reset meetings had been previously identified by the *Blue Ribbon Commission on America's Nuclear Future* in its 2012 final report. However, in contrast to the broader agenda of the BRC, the Reset meetings were focused only on the back-end of the nuclear fuel cycle. In cases where the Reset topics overlapped with the BRC, we tried to push further into the details of the issue, such as the need for a new organization and the consent-based siting process. We also identified additional issues as being important, such as the need for integration of the back-end of the nuclear fuel cycle, particularly in the analysis of risk and the regulatory framework.

CRITICAL ISSUES

At the first meeting in February 2015, the Steering Committee identified critical issues, each of which was the subject of a subsequent meeting:

- ***A new waste management organization:*** Although recommended by the Blue Ribbon Commission, there has been only limited discussion of the structure, characteristics and funding of such a new organization. The committee identified four very different issues that needed to be addressed: i.) the structure or anatomy of the organization; ii.) the behavior or physiology of the organization; iii.) the lifetime of such an organization; iv.) funding. Although the Blue Ribbon Commission considered the structure of a new organization and how it might be funded, there was little attention to how such an organization would operate, particularly over an extended period of time. However, it is exactly the behavior of the organization that goes immediately to the issue of trust. Any large technical program that deals with nuclear topics requires trust. The issue of trust is seldom discussed, but it is critical to success. Issues include:

  > *Any large technical program that deals with nuclear topics requires trust.*

  - *What are the values of the organization?*
  - *How does the organization interact and communicate within its political and technical sphere while maintaining credible, constructive interactions with the affected public and state governments?*
  - *How does the organization set priorities?*
  - *How does the organization learn and change, particularly as it moves from the research stage to implementation and construction of the repository?*
  - *How does one design an organization that will function for a very long time, perhaps more than one hundred years, through a constantly changing political environment?*
  - *How should such an organization be funded?*

  This issue was the subject of the meeting at Stanford in September 2015.

- ***Definition of a consent-based process for siting geologic repositories:*** Although the Blue Ribbon Commission and the DOE under the Obama administration often referred to the need for a consent-based process, there was little discussion of what this meant and how such a process might be designed. The Trump administration appears to have abandoned this concept. A consent-based process requires the blending of social and technical criteria in the selection, characterization, and development of one or more geologic repositories, but there has been no effort to design a technically-based, legal process that is compatible with the needs of a community, tribes, the states, and the federal government. Simple questions remain unanswered:

    - *What constitutes consent? If consent is a "legally binding agreement", how does it differ from the present array of legally binding agreements that the DOE has already entered into with states and communities?*
    - *What technical criteria will be used in the consent-based process?*
    - *How does a community or state give informed consent?*
    - *To what extent can a local community or state affect the repository design and strategy?*
    - *When and how can a local community, tribe or state government withdraw consent? Should the U.S. government have the power to override withdrawal of consent, and, if so, at what stage in the development of the repository and by what mechanism?*
    - *Once consent is achieved, how can important aspects, such as the type of waste to be disposed, be modified? Who has the power to modify the agreement?*
    - *Can a consent-based siting process succeed in the federal system of the United States?*

    This issue was the subject of a meeting at Stanford in March 2016.

- ***Integration of the entire commercial nuclear waste generating system:*** The value of a "total system analysis," from the point of waste generation to its final disposal, is generally recognized. However, such an evaluation has not been completed in terms of the analysis of risk, the development of incentives, or the development of a consistent regulatory framework. In fact, there are many disconnects in the back-end of the U.S. nuclear fuel cycle. For example, the nuclear utilities can make locally rational decisions for optimizing the storage of their spent nuclear fuel that may complicate its final disposal. Issues include:

    - *Can incentives for all parties be aligned such that they drive the back-end of the nuclear fuel cycle to a final solution—permanent geologic disposal?*
    - *Does the Standard Contract between the utilities and the federal government require modification?*
    - *Are regulations consistently applied across all activities at the back-end of the fuel cycle, such as for storage, transportation and geologic disposal?*

Can incentives for all parties be aligned such that they drive the back-end of the nuclear fuel cycle to a final solution—permanent geologic disposal?

This was the subject of a meeting at George Washington University in May 2016.

- ***Regulations, risk and safety:*** The present regulatory framework for a geologic repository in the U.S., unlike other nations, requires the quantitative calculation of risk out to hundreds of thousands of years. This approach is technically complex, difficult to review and provides a poor basis for public engagement. However, a revision of the regulations and standards may open the way to a more straightforward siting process for nuclear facilities and generate greater public acceptance.
  - o *Is a quantitative, probabilistic approach necessary or realistic in its goals?*
  - o *What is the relation between calculated risk and safety?*
  - o *Does reliance on a quantitative approach instill pubic confidence or skepticism?*
  - o *Are there alternative approaches to determining safety?*
  - o *How are these issues addressed in other countries?*
  - o *Although the ultimate goal of the back-end of the nuclear fuel cycle is geologic disposal, this results in an emphasis on long-term impacts, but what about risk and safety during the early period of construction and emplacement of the waste in a repository?*

  This was the subject of a meeting at Stanford in October 2016.

- ***What are the risks with present U.S. policy:*** The Steering Committee determined that in order to develop a compelling case for a new U.S. policy, it is necessary to understand the risks of continued delay of the U.S. waste program. Many of these risks are of great interest to the affected public:
  - o *What are the risks of continued storage of spent nuclear fuel at reactor sites?*
  - o *What are the risks associated with the transportation of spent nuclear fuel, first to an interim storage site and then to a geologic repository?*
  - o *Does consolidated storage prior to geologic disposal reduce the overall risk?*

  The Steering Committee has not yet completed such a risk assessment, as this will require substantial funding and time. The basic approach, however, would be to assemble a risk assessment team with representatives from all affected parties with diverse perspectives and concerns, so that the final results are generally understood and, perhaps, accepted.

Each of these critical issues has a generally under-appreciated level of complexity. The discussion of each issue requires input across the broadest range of disciplines – science, engineering, social science, political science and the law. The discussions also importantly benefit from the participation of concerned members of the public, state governments, national laboratories, and universities, as well as members of the executive and legislative branches of government. The purpose of the Reset meetings has been to provide such a forum for discussion from a wide range of perspectives.

This report is a summary of the major issues that were raised during the discussion as understood by the Steering Committee during their subsequent deliberations. As one might expect, there are a range of views, and we have tried to capture the essential elements of these different perspectives. At the same time, the Steering Committee has tried to emphasize specific ways forward for the U.S. program. This is not a consensus report. Individual members of the Steering Committee may have preferred a different emphasis on certain options. Still, we hope that the recommendations will prove useful as the U.S. fashions a new strategy and policy for the management and disposal of the Nation's nuclear waste.

Reset Meeting #5 on Regulations, Risk, and Safety (October 16, 2016). SOURCE: CISAC

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Director Yukiya Amano touring the Onkalo spent nuclear fuel repository on Olkiluoto—a sparsely inhabited island off Finland's western coast. The Finnish implementer—a utility-owned corporation, Posiva Oy—has adopted the Swedish KBS-3 disposal concept (see page 74), essentially, spent fuel in a copper canister with a bentonite backfill in crystalline rock. The Finish program began in the early 1980s, and if construction proceeds according to schedule, the repository will begin accepting spent nuclear fuel by the mid-2020's. SOURCE: *https://flic.kr/p/d4RYob*

A New National Radioactive Waste Management Organization with a New Funding Strategy

The lynchpin to the recommendations of the Reset Steering Committee is the recognition of the need for a new, independent, single-purpose national radioactive waste management organization and reform of the funding process.

These are not new ideas. Many reviews, most recently *The Blue Ribbon Commission on America's Nuclear Future*, have made similar recommendations. Nearly seven years after the BRC report, the need for such an organization has only increased. In this chapter we review the history of organizational responsibilities for nuclear waste management in the United States and discuss possible alternatives to a government-chartered organization, a FEDCORP, recommended by the Blue Ribbon Commission. Based on its analysis, a majority of the Steering Committee supports an alternative model– a non-profit, nuclear utility-owned implementing corporation, NUCO. The Steering Committee maintains that a new organization will be needed even if the license application for Yucca Mountain, filed and presumably defended by DOE, is approved.

The lynchpin to the recommendations of the Reset Steering Committee is the recognition of the need for a new, independent, single-purpose national radioactive waste management organization and reform of the funding process.

Regardless, of the type of organization, there is a compelling case to be made that a new organization and funding reform are absolutely essential to the future success of the management and disposal of nuclear waste in the United States.

The new organization, regardless of its type and structure, must have a clearly stated charge, a structure that embraces public engagement and engenders trust, a focused research agenda that matches the knowledge needs for geologic disposal over long periods of time and, most importantly, sufficient and consistent funding over decades. Funding for the new organization must also be removed from the annual Congressional appropriations process so as to ensure adequate year-to-year funding to maintain an efficient site selection, charac-

Regardless, of the type of organization, there is a compelling case to be made that a new organization and funding reform are absolutely essential to the future success of the management and disposal of nuclear waste in the United States.

terization, licensing, and construction process. Federal oversight would be through the determination of standards by the Environmental Protection Agency, the determination of regulatory compliance by the Nuclear Regulatory Commission and active surveillance of the NUCO by federal agencies, such as the Nuclear Waste Technical Review Board.

History of U.S. Organizations Responsible for Nuclear Waste

As part of the Manhattan Project, high-level radioactive waste was first created at the Hanford Reservation in eastern Washington State in 1944. For the next 25 years, the federal government was the sole generator of nuclear waste as it produced the plutonium used in nuclear weapons. In 1946, the Atomic Energy Act (AEA 1946) assigned responsibility for radioactive waste management to the federal government. The federal agency in charge from 1947 onward, the Atomic Energy Commission, retained the implementing approach that had served the Manhattan Project well. Rather than using federal personnel, the AEC contracted with private corporations and universities to carry out its research, development and materials production activities.

Such an approach seemed defensible, even optimal, because a private corporation or university could better recruit scientists, engineers, and managers. Private corporations and universities also ran the national laboratories that were a legacy of the Manhattan Project. Further, contracting with a private corporation or university allowed the AEC to retain control over classified information and materials while facilitating technology transfer to industry (Orlans 1967). However, for reasons well documented elsewhere (OTA Appendix A 1985), competing congressional priorities relegated to the back-burner the AEC's efforts to direct its contracting corps to establish a program for long-term management of its radioactive waste. Nonetheless, as a for-profit nuclear power industry began to mature in the mid-1960s, the AEC felt pressure from Congress and the public to clarify how not only defense, but also commercial, high-activity radioactive waste would be managed.

In 1971, the Atomic Energy Commission promulgated a rule governing the operation of soon-to-be-constructed private reprocessing plants and regulating the waste that would be generated within them (10 CFR 60: Appendix F). The rule placed on the federal government the responsibility to develop a deep-mined, geologic repository to isolate the waste from the biosphere for millennia.

Under legislation in place today, the Nuclear Waste Policy Act (as amended) (NWPA 1982; NWPAA 1987), DOE is responsible for siting, designing, and operating a deep-mined, geologic repository and transporting defense and commercial high-activity radioactive waste from 121 sites where the material is stored to a geological repository. For a limited time in the mid-1980s, DOE was authorized to construct and operate a centralized storage facility. To do so in the future, however, new legislation would have to be enacted. The NWPA calls for the waste generators to pay the costs incurred either through a fee based on the electricity produced by the nuclear utilities for the disposal of commercial waste or through appropriations from the federal government's general fund for the disposal of defense waste. Although DOE's activities are mostly sanctioned under the amended 1982 law, it retains residual authorities under the 1954 Atomic Energy Act (AEA 1954). Funding for commercially generated spent nuclear fuel and DOE-owned high-activity radioactive waste is controlled by Congress.

Most of the underlying presumptions and conditions that led the federal government to become the implementer of the U.S. waste-management program have changed. For example, the technical expertise needed to design, site, and license a deep-mined, geologic repository is no longer to be found in a single government agency. Measured by Curie-content, the inventory of commercial spent nuclear fuel now dwarfs the inventory of DOE-managed high-activity radioactive waste. Gone too is the original cohort of contractors, such as DuPont, General Electric, and AT&T, whose management fees were minimal. These corporations have been replaced by companies whose management fees can be substantial.

Had DOE and its predecessor agencies successfully negotiated these changes in their technical and political environments, the question of whether a government agency is the appropriate implementer for the nation's radioactive waste-management program likely would never have arisen. But, for many reasons, some of which are beyond its control, after 35 years, DOE has not delivered an operating geologic repository despite decades of effort and an expenditure of more than $13 billion. The current structure has shown itself to be too susceptible to changing political influence over the sustained period of effort necessary to site, construct and operate a repository. Funding fluctuations, changes in policy direction, and continuous changes in the technical strategy of the program have led to a situation where the DOE consistently fails to meet its goals and schedules.

The Steering Committee believes that the responsibility for developing a repository should be transferred to a new, independent, single-purpose organization outside of DOE. Furthermore, the Steering Committee believes that it is essential for control of the administration of the Nuclear Waste Fund be transferred from Congress to the new organization.

The Steering Committee believes that the responsibility for developing a repository should be transferred to a new, independent, single-purpose organization outside of DOE.[1] Furthermore, the Steering Committee believes that it is essential for control of the administration of the Nuclear Waste Fund be transferred from Congress to the new organization.

The Steering Committee recognizes that any decision about how to organize implementation and funding, whether it preserves or alters the *status quo*, carries with it both benefits and costs. But, on balance, the Steering Committee maintains that its recommendation best ad-

[1] The timing for this shift depends on when and if the NRC's suspended hearing on the Yucca Mountain license application is resumed as well as the outcome of that adjudication.

dresses a critical national issue, which has been left in limbo for far too long. In the following pages, the Steering Committee provides the basis for its recommendation.

What Type of Organization?

Over the course of nearly four decades, students of organizational behavior and practitioners have been considering the question of an appropriate institutional form for the radioactive waste-management implementer. In particular, they have explored whether the responsibility for the long-term management of high-level radioactive waste and spent nuclear fuel was appropriately placed in the hands of the federal government. No consensus has emerged from that prolonged debate in large part because the choice is typically cast as depending on difficult trade-offs being made between efficiency and effectiveness on the one hand and credibility and responsiveness on the other.

Mason Willrich and Richard Lester prepared the first detailed analysis of alternative institutional arrangements for implementing the U.S. radioactive waste-management program (Willrich and Lester 1977). They concluded, "the existing organization for radioactive waste management is likely to be unworkable if left unchanged." They recommended "a national Radioactive Waste Authority be established as a federally chartered public corporation." The authority would be governed by a Board of Directors, composed of members drawn from academia, the nuclear industry, the research community, and the general public. It would be self-financing. It would, in the view of Willrich and Lester, provide *comprehensive, integrated, efficient* management of both defense and commercial radioactive waste.

When Congress crafted the 1982 NWPA, it was not unaware of the concerns about the federal government's performance that non-governmental organizations and policy analysts alike were raising. The congressional General Accounting Office was especially critical of DOE and its predecessor agencies. (See, for example, GAO 1971, 1974.) In response, Congress included in the 1982 law specific instructions to revisit the question of institutional form. [2]

> The Secretary of Energy shall undertake a study with respect to alternative approaches to managing the construction and operation of all civilian radioactive waste management facilities, including the feasibility of establishing a private corporation for such purposes.

In June, 1983, the Secretary of Energy established a diverse, 13-person Advisory Panel on Alternative Means of Financing and Managing Radioactive Waste Management Facilities (AMFM Panel). He charged the panel with developing "a thorough and objective analysis of the advantages and disadvantages of each alternative approach."[3]

The AMFM Panel compared the *status quo*, the Office of Civilian Radioactive Waste Management, the sub-cabinet unit then reporting directly to the Secretary, with three to five (depending on how one counts) alternatives (AMFM Panel 1984). Each institutional form reflected specific (and different) policy assumptions.

[2]NWPA, Section 303.
[3]Amended Charter for the AMFM Panel. Reproduced in AMFM 1984. pp. A3-A4.

- Independent Government Agency
    - o Independent Federal Commission, modeled after the Atomic Energy Commission
    - o Independent Federal Administration, modeled after the Environmental Protection Agency
- A mixed public/private Corporation for Waste Management, modeled after AMTRAK
- Private Corporation
    - o Federally chartered American Nuclear Corporation, mostly owned and operated by nuclear utilities and purveyors of nuclear energy equipment and services
    - o A company, ownership and structure to-be-determined, that would bid for the national franchise to develop and operate repositories for high level waste and spent nuclear fuel.

Notably absent from the alternatives considered was the option of a fully private not-for-profit corporation that would be operated by a Board of Directors composed of members of the U.S. nuclear utilities and would be fully self-financing.

The AMFM Panel evaluated each institutional form against 14 "organizational tests," such as mission orientation, credibility, stability, responsiveness, technical excellence, political immunity and political accountability. The "scores" represented "expert judgments." No attempt was made to reference or use academic research or studies by business consultants. The panel concluded that none of the alternatives was optimal; although each possessed clear advantages, each were burdened by substantial disadvantages.

Instead, the AMFM Panel advanced an additional possibility, advocating the creation of a FEDCORP. FEDCORP would be a single-purpose organization focusing solely on implementing the U.S. radioactive waste-management program. It would be a government-chartered corporation with no equity apportionment, making it a wholly owned instrument of the federal government. FEDCORP would have a Board of Directors appointed by the President and confirmed by the Senate. The Board of Directors would function like analogous bodies in the private sector. A strong chief executive officer would report to the Board.

In the view of the AMFM Panel, FEDCORP scored highly on all 14 organizational tests. Creating it, however, would be especially valuable with respect to credibility, stability, internal flexibility, political immunity and cost-effectiveness. The one downside noted was the significant transition costs that would be involved. But, as the panel observed, this shortcoming was common to all changes in the *status quo*.

Within two months after he received the panel's report, Secretary Donald Hodel appointed a four-person review committee composed of senior DOE political appointees. The committee took exception to virtually every judgment on the organizational tests rendered by the AMFM panel (Boggs *et al.* 1985). In particular, the committee maintained:

- Credibility was improving with the passage of the Nuclear Waste Policy Act.
- Although the political cadre changed with changes in the Administration, civil servants provide sufficient stability.

- Internal flexibility could be improved if the Office of Civilian Radioactive Waste Management had decided to seek exemptions from the requirements of the Civil Service Act.
- Political immunity would be bought at the cost of having a less accountable organization.
- Cost-effectiveness will improve as OCRWM moves up the learning curve of operating under the Nuclear Waste Policy Act.

Moreover, the committee pointed to strong opposition from states and the nuclear utilities to any reorganization. Thus, the committee's bottom-line recommendation to the secretary: if institutional redesign is at all called for, it only should be undertaken once a construction license for a repository had been approved.

Fifteen years later DOE prepared a congressionally mandated report aimed at revisiting the question of institutional form. The management consultant firm of Booz-Allen & Hamilton compared three institutional possibilities:

- Transforming Office of Civilian Radioactive Waste Management into a performance-based organization within DOE
- Establishing an autonomous internal authority within DOE with its own personnel and procurement systems
- Creating an independent authority, governed by a corporate-style board of directors.

DOE's bottom-line position shifted somewhat from the one it held earlier. Rather than await the granting of the construction license: "No decision on whether to implement any of these alternatives or other approaches should be made until the Site Recommendation [dealing with the proposed repository at Yucca Mountain] process is completed" (DOE 2001:3). Yet when that effort concluded the following year, 2002, DOE never returned to the question of institutional form.

The Blue Ribbon Commission's Recommendation

This situation changed markedly after the Obama Administration took office in 2009. Within a year, it determined that the Yucca Mountain project was "unworkable" and that DOE's license application to construct the facility, then before NRC, should be withdrawn. The President instructed the Secretary of Energy to charter a *Blue Ribbon Commission on America's Nuclear Future* (BRC). Among its duties was the analysis of management issues.

Two years after its creation, the BRC issued its final *Report to the Secretary of Energy* (BRC 2012). One key recommendation was that Congress should create a new single-purpose implementing agency, outside of DOE, charged with the responsibility of implementing the nation's radioactive waste management program.

> "[T]he record of the last several decades indicates that the current approach is not well suited to conducting the steady and focused long-term effort, and to building and sustaining the degree of trust and stability necessary to establish one or more disposal facilities and implement other essential elements of an integrated waste management strategy."

Although the BRC acknowledged that "previous studies have concluded that a number of different organizational forms could get the job done," it favored a FEDCORP structure as compared with a new single-purpose federal agency.

DOE reviewed the analyses and recommendations contained in the BRC report for the next year. During that time, among other things, it commissioned a study by the RAND Corporation (Davis *et al.* 2012). RAND evaluated three institutional forms:

- PRIVCORP—a federally chartered private, for-profit, corporation.
- GOVCORP—a federally chartered government instrumentality, typically formed with a commercial purpose.[4]
- IGA—an independent government agency.

Like the AMFM study, the RAND study did not evaluate the advantages and disadvantages of a nuclear utility-owned, not-for-profit corporation.

Nonetheless, the RAND study concluded that a PRIVCORP would lack critical attributes, such as political credibility, capacity to develop public trust and confidence, and accountability. In particular, the analysis maintained that the Swedish model, a not-for-profit corporation formed by nuclear power plant owners, is "unlikely to be a viable option in the United States." RAND declined to choose between a GOVCORP and an IGA, arguing that either institutional form could be structured to meet critical performance goals. Ultimately, the study observed, policymakers will have to strike a "balance between the competing values of accountability and flexibility called for in the design of the new management and disposition organization."

In January 2013, DOE released its "Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste" (DOE 2013). It concurred with the Blue Ribbon Commission's recommendation that a new implementing organization was needed to "provide the stability, focus, and credibility to build public trust and confidence." DOE further asserted that the management of high-level waste and spent nuclear fuel was "inherently a governmental responsibility." However, consistent with the RAND analysis, DOE declined to endorse either the FEDCORP or IGA institutional form.

In June 2013, a bipartisan group of four Senators introduced the Nuclear Waste Administration Act. The Act called for, among other things, the creation of an independent government agency to execute the nation's nuclear waste-management program. A hearing was held in July 2013, but no vote was taken. Two years later, the same group of Senators re-introduced the legislation.[5] However, no hearings were held then or later. Thus, the question of whether a new implementing organization will be established remains unanswered.

Waste Management Organizations in Other Countries

Across the globe, five national radioactive waste-management programs stand out: Canada, Finland, France, Sweden, and Switzerland. With the exception of Finland, the programs in

[4] This form corresponds closely to what other analysts have termed FEDCORP. For consistency sake, this report shall continue to use the term "FEDCORP."

[5] Nuclear Waste Administration Act, S.1240, 113th Congress, 2013; and S.854, 114th Congress, 2015.

each of the other countries experienced significant disruptions and had to be reconstituted. But in each case, the necessary changes needed to put the efforts back on track were adopted in a relatively short time, typically three to five years.

- In Canada, 23 communities expressed interest in learning more about hosting a repository. By 2018, the implementer had winnowed them down to five potential sites and is now conducting more detailed assessments in five of them. Importantly, none of the communities chose to withdraw from the site-selection process.
- In the beginning of 2016, the Finnish government approved a license application to construct a repository.
- In 2018, the Swedish regulator advised Government that SKB's application to construct a repository in the Municipality of Östhammar met the requirements of the Nuclear Activities Act. The Land and Environment Court, however, advised Government that SKB had failed to demonstrate that it had fully complied with the requirements of the Environmental Code. As of mid-2018, it is unclear how Government will respond to this divergent advice.
- The French implementer is preparing a preliminary license application, which is scheduled to be considered by Parliament in 2019.
- The Swiss implementer has begun extensive, site investigations in three regions (NWTRB 2016).

The radioactive waste-management programs in Canada, Finland, Sweden, and Switzerland have two features in common. First, their aim is to dispose of all types of commercially generated radioactive waste.[6] Thus, those firms manage all elements of the back-end of the nuclear fuel cycle, including, in most nations: interim storage of low- and intermediate-level radioactive waste, geologic disposal of high level waste and spent nuclear fuel, as well as waste packaging and transportation. *Consequently, those companies have a strong technical incentive to align decisions at every stage with the final goal of geologic disposal.* Second, responsibility in all four countries has been placed in the hands of *a single not-for-profit organization owned by the nuclear utilities*.[7] The programs in Canada, Finland, Sweden and Switzerland are *also mostly self-funded with the funds administered by the program*.

The importance of aligning the incentives of the various actors is illustrated by the example of extended storage of commercial spent nuclear fuel in the United States. As the prospects for operating a deep-mined, geologic repository recede, nuclear utilities will have to store increasing amounts of spent nuclear fuel in dry casks. They have strong economic incentives to use larger and hotter containers. Without a significant repackaging campaign, the size and thermal output of the disposal packages could complicate the design of a geologic repository. (See discussion in the following chapter on the integration of the back-end of the nuclear fuel cycle in the United States).

The situation in France differs in some respects. The French implementer, ANDRA, a government-owned Public Service Agency, must not only provide for the long-term manage-

[6]The Canadian implementer focuses only on the disposal of spent nuclear fuel.
[7]The Swiss Federal Government provides three percent of the implementer's financing to cover the cost of disposing of radioactive waste from medicine, industry, and research. The Federal Government holds one of nine seats on the Board of Directors.

ment of commercially generated reprocessed radioactive waste, but it must also dispose of waste produced by that country's defense nuclear program. It must engage the three major waste-generating organizations, Électricité de France, Orano (formerly Areva), and the Commissariat à l'Energie Atomique et aux énergies alternatives, that play important roles, especially with respect to the interim storage, packaging, and transportation of radioactive materials. However, all four organizations are wholly or partly controlled by the French government, thereby minimizing, although not eliminating, barriers to integrating the entire waste management system.

An Alternative for the United States: A Utility-Owned Nuclear Waste Management Organization

In the view of the Steering Committee, the track record of nuclear utility-owned implementers abroad, coupled with the intrinsic harmonization of technical and business incentives, makes at least a *prima facie* case for considering the creation of a not-for-profit, nuclear utility-owned implementing corporation (NUCO).[8] Such an approach is consistent with the "polluter pays" principle to which other energy producing systems are subject.

Below, the Steering Committee examines the conditions under which a NUCO might be effective in the United States. The first question that must be considered is the scope of responsibilities for the non-profit, nuclear utility-owned implementing corporation (NUCO).

Commercially-generated spent nuclear fuel and high-level defense waste. The NWPA does not require commercial spent nuclear fuel to be "co-mingled" with defense high-level waste in the same repository. The decision of whether to "co-mingle" these wastes is left to the President. Since 1985, the decision had been to combine these two types of waste into a single repository, but a determination in March 2015 by President Barack Obama that a separate repository was "required" for defense waste, has also raised the possibility that defense high-level waste and commercial spent fuel might be managed by different institutions (DOE 2015). Under the Steering Committee's proposal NUCO would initially manage the packaging, storage transportation, and disposal of commercial waste only.[9]

The responsibility for defense waste would continue to reside with the federal government or a FEDCORP if one were to be created. The value of such an approach lies mainly with the desire to ensure the success of the NUCO. It would be a major accomplishment if a NUCO were able to successfully manage the disposal of commercially generated high-activity radioactive waste in the United States. Such an accomplishment would account for the disposal of some 95% of the radioactivity of the nuclear waste that requires geologic disposal.

The rationale for such an approach includes:

- The utility-owned NUCO should not be burdened by the legacy waste of the U.S. defense program. Nuclear waste from defense programs is a uniquely federal responsibility.

[8] Indeed, this option was recently suggested by an analysis the Heritage Foundation (Tubb, Loris, and Spencer, 2017), who proposed that industry should be responsible for managing the waste of the commercial nuclear industry in compliance with federal rules and regulations.

[9] The Steering Committee recognizes that a FEDCORP could take over responsibilities for managing commercial-origin radioactive waste. Such an arrangement would be an improvement over the *status quo*. The Steering Committee has concluded, however, that creating NUCO with those responsibilities is the preferred option.

- The NUCO should not inherit the obligations and agreements that the DOE has entered into with communities and states for the disposal of defense waste.
- One of the advantages of the NUCO strategy is that it provides for the necessary integration at the back-end of the nuclear fuel cycle - from the production of the spent fuel in a utility reactor to its disposal by a NUCO in a geologic repository.
- Defense wastes are not part of the back-end of the nuclear fuel cycle created by nuclear power plants.

Such an approach would create two nuclear waste management programs in the United States: one private and one federal. Given the history of the past thirty years, it would certainly be prudent to advance nuclear waste management in the United States across these two fronts. Over time one could monitor the success of each approach. If the NUCO successfully develops a geologic repository, one can imagine that on a fee basis some or all of the defense waste could be disposed of in the repository. The contract would also contain the criteria for waste-acceptance along with a waste acceptance schedule. Table 1 lays out NUCO's initial responsibilities, as well as additional responsibilities it might assume at a later date.

As Table 1 demonstrates, the Steering Committee's proposal for a NUCO would fundamentally restructure the U.S. nuclear waste-management program.[10] Whether it will be adopted depends on how well it can satisfy the interests of key affected parties, including owners of nuclear reactors, state and local authorities, the NRC, non-governmental organizations, and the public-at-large represented by the federal government. It is to that question that the Steering Committee now turns.

Congress would authorize the creation of NUCO as a not-for-profit organization. NUCO would be owned exclusively by the nuclear utilities. NUCO would be governed by a Board of Directors elected by the owners. Its senior management team would include a Chief Executive Officer, Chief Nuclear Officer, and a Chief Financial Officer. Because NUCO might have to site one or more deep-mined, geologic repositories, a Chief Scientist and a Chief Engineer would report to a Chief Site Investigations Officer. Also, at the highest level, perhaps as a Vice-President, there should be a corporate officer directly responsible for public engagement.

Responsibilities now held by the federal government would transfer to NUCO over a period of 12 months beginning with the enactment of authorizing legislation. The Nuclear Waste Fund would slowly be transitioned from federal control to control by the new organization. The formula for levying fees deposited in the Nuclear Waste Fund for commercial high-activity radioactive waste would be retained. However, those fees would be provided to the new organization. Annual appropriations for general tax revenues to manage defense-origin radioactive waste would continue as long as the Federal Government retains those responsibilities. The Federal Government would still be obligated to pay the full cost of managing defense-originated radioactive waste, either directly or through payments to NUCO. Upon its creation, NUCO would receive 2.5 percent of the *corpus* of Nuclear Waste Fund. The remainder (including the accumulated interest earned) would steadily transfer to NUCO over a period of 25 years. If additional revenue is required to fulfill its mission to dispose of

[10] Management of defense transuranic waste should remain with the federal government since WIPP is currently in operation.

TABLE 1: NUCO's initial responsibilities with respect to nuclear waste as well as additional responsibilities it might assume at a later date.

WASTE TYPE AND ACTIVITY	CURRENT	PROPOSED
Commercial Greater-Than-Class-C (GTCC) and Defense GTCC-like Waste		
Storage	Private Sector	Private Sector or NUCO
Transportation	Federal Government	NUCO
Packaging	Federal Government	NUCO
Disposal	Federal Government	NUCO
Defense Transuranic*		
Storage	Federal Government	Federal Government
Transportation	Federal Government	Federal Government
Packaging	Federal Government	Federal Government
Disposal (WIPP)	Federal Government	Federal Government
Defense HLW		
Storage	Federal Government	Federal Government
Transportation	Federal Government	Federal Government initially and perhaps NUCO ultimately
Packaging	Federal Government	Federal Government initially and perhaps NUCO ultimately
Disposal	Federal Government	Federal Government initially and perhaps NUCO ultimately
Defense SNF		
Storage	Federal Government	Federal Government
Transportation	Federal Government	Federal Government initially and perhaps NUCO ultimately
Packaging	Federal Government	Federal Government initially and perhaps NUCO ultimately
Disposal	Federal Government	Federal Government initially and perhaps NUCO ultimately
Commercial SNF		
Storage	Private Sector	NUCO
Transportation	Federal Government	NUCO
Packaging	Federal Government	NUCO
Disposal	Federal Government	NUCO

commercial, high level waste and spent nuclear fuel, it would be provided by the new organization's owners. Provisions to cover increased costs for the disposal of defense radioactive waste would be included in any contract between the federal government and NUCO. The Standard Contract (DOE 1983) between nuclear utilities and the federal government would remain in force. The owners of nuclear reactors would maintain their ability to obtain damages from the Department of Justice Judgment Fund. Damage awards shall cease after 25 years or until all of the commercial high-activity radioactive waste has been removed from reactor sites, whichever comes first.

The new organization's responsibilities would include the development of facilities to manage commercial Greater than Class-C waste, high-level radioactive waste, and spent nuclear fuel, and any waste types transferred from the federal government. The new organization should establish a transportation system for moving all those waste forms from sites where they are stored to centralized facilities. The new organization would be responsible for the construction of a waste handling facility that would include a capacity to repackage and conduct research and development on the characteristics of the waste and its pre- and post-disposal containers. The new organization would have the authority to construct a consolidated storage facility. Depending on the fate of the proposed repository at Yucca Mountain, the new organization would select at least one new site to characterize as a potential repository. Ultimately, at least two repositories would be developed in separate states. The location of all these facilities shall be chosen by the new organization, but all nuclear facilities would have to be licensed by NRC.

Key Issues for Any Nuclear Waste Management Organization

During the Reset meetings there was considerable discussion of the key attributes or values that a nuclear waste management organization should have. Here we summarize some of the important points that apply to both the NUCO and FEDCORP:

- The new organization must be created with careful attention to the roles of other organizations. Nuclear waste management requires a *strong* and *engaged regulator*, a web of university, national laboratory and other researchers, diligent review by independent scientific organizations, and support for community, tribal and state organizations that are charged with the continuous review of the project. The latter point is particularly important. Affected communities, tribes and states must be provided with support so that they can engage their own independent experts.
- Public engagement cannot be left as an afterthought to the project. Early public engagement and an explicit strategy for continued public engagement have to be part of the values and mission of the new organization. This goes well beyond public education, but rather requires careful attention to the concerns of local communities, as well as the interested public and state agencies. (See further discussion in the chapter on public engagement.)
- The new organization must be insulated from a changing national political environment, but never insulated from scientific review or engagement with the local communities or state agencies. Congress and the Executive should not be involved in site selection.

- The new organization must be designed with the expectation that it will last for a very long time. The selection, construction and final emplacement of waste in a geologic repository will take over one hundred years. During that time, societal values, political and funding constraints, and scientific knowledge will change considerably. A new organization must be able to adjust to these external changes and new knowledge.
- Considering the challenge of geologic disposal over unprecedented time frames, the new organization must be able to direct a robust science program, manage a major engineering and construction project, handle large quantities of highly radioactive material—and do this all while under intense public scrutiny and engagement.
    - The scientific programs must balance fundamental scientific studies that provide the basis for the safety assessment and applied science and engineering that implements the design strategy and construction of the repository. Up until now, the science program in support of the siting and evaluation of a geologic repository has been fragmented among contracting organizations, and the programs come and go on an annual basis depending of appropriations or the problem of the day. The program has been large but without a proportional scientific impact. In fact, the program could probably be smaller and more successful if the implementing organization had the opportunity to fund experts and laboratories around the world based on their expertise and could provide extended funding so that the necessary intellectual capital would be created and maintained throughout the project.
    - Should the direction of the nation's radioactive waste-management program shift to explore new sites for a repository, the early stages of site characterization and evaluation are mainly scientific. However, the next stage—construction and emplacement of the waste—requires considerable engineering expertise, very different from that provided by the scientific community. This means that the new organization must be able to transition from laboratory scale and modeling activities to field studies and, finally, to the actual construction of the repository.
- Finally, maintaining public trust and scientific integrity have to be part of the DNA of the new organization—valued throughout all parts of the organization and through all stages of repository development. Public trust requires early and continuing engagement with the public and state authorities. Scientific integrity requires transparency in data collection and interpretation, publication in peer-reviewed journals and tolerance for the tough questions that go with any rigorous scientific process.

RECOMMENDATIONS:

- Create a new, independent, not-for-profit, single-purpose nuclear waste management organization. This is not a new idea, and there are many models for such an organization. The Blue Ribbon Commission favored a FEDCORP structure. However, the Reset Steering Committee points to some unique advantages of a not-for-profit, utility-owned waste management organization (NUCO), particularly based on the clear success of this approach as evidenced by other national programs, such as in Finland, Sweden, Switzerland and Canada.

A NUCO would align technical decisions for final geologic disposal from the moment that the used fuel is extracted from a commercial reactor until it is disposed of in a geologic repository. Financial incentives would also be aligned to support the final goal of geologic disposal.

Regardless of the type of organization, careful attention must be paid to the scope of its mandate, particularly in defining the types of waste that are the responsibility of the new organization.

Scientific integrity and public engagement will be essential to the success of any new organization.

- The NUCO should initially manage the storage, packaging, transportation and disposal of commercially generated waste only. The responsibility for defense waste would continue to reside with the federal government or a FEDCORP if one were to be created.

  The value of such an approach lies mainly with the desire to ensure the success of the NUCO. It would be a major accomplishment if a NUCO were able to successfully manage the disposal of commercially-generated spent nuclear fuel in the United States. Such an accomplishment would account for the disposal of some 95% of the radioactivity of the nuclear waste that requires geologic disposal.

- Funding reform is essential to ensure the timely and appropriate use of the Nuclear Waste Fund. The NWF should be transferred from congressional control of annual budget allocations to full access by a new, waste management organization.

  The Reset Steering Committee recommends that the Nuclear Waste Fund be transferred from the federal government to the new waste management organization over a 25-year period. One of the advantages of a not-for-profit utility-owned organization is that it would be responsible for collecting fees for nuclear waste management and allocating funds as needed in a timely and appropriate manner.

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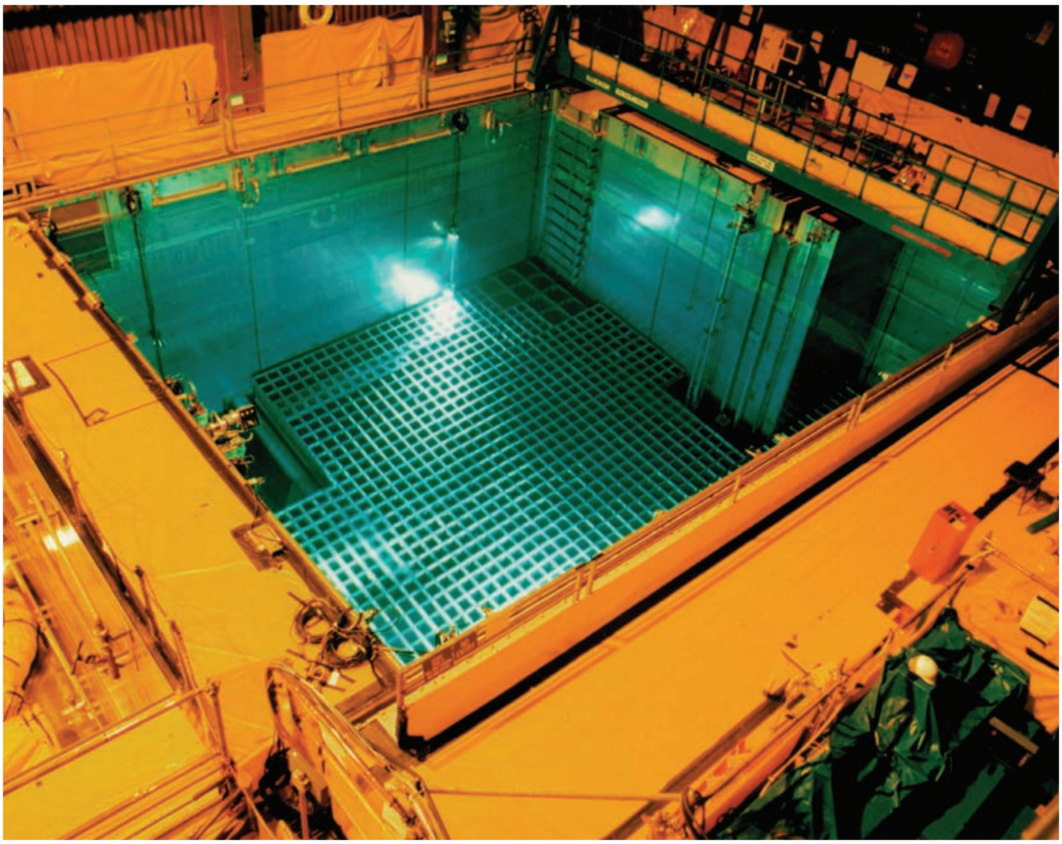

Spent fuel pool located at the San Onofre Nuclear Generating Station (SONGS) located 60 miles north of San Diego. The nuclear power plant, consisting of three nuclear reactors, was shut down in 2013. In the absence of a geologic repository for the disposal fuel, some 1,700 tons of spent fuel at SONGS will be transferred to dry cask storage. The transfer to dry cask storage is expected to be completed in 2019. The 80 steel-lined concrete monoliths will remain on site, unless another interim storage site can be identified. SOURCE: *https://flic.kr/p/qrBH8p*

Integration of the Back-end of the U.S. Nuclear Fuel Cycle

When policy makers contemplated nuclear waste disposal in the early 1970s, they envisioned storing spent fuel in pools at reactors for roughly five years and then transporting the fuel to a reprocessing plant. The high-level radioactive waste from reprocessing would be solidified and then transported to a deep-mined, geologic repository, again roughly within five years. The NWPA of 1982 set 1998 as the date when a repository would start to receive nuclear waste from the commercial reactors of the utilities.

Regardless of Yucca Mountain's fate as a geologic repository, the integration of the back-end of the fuel cycle is essential to the future of nuclear power in the United States.

More than 35 years later, an *ad hoc* system for managing spent fuel has replaced this strategy; there has been no reprocessing of commercially generated nuclear fuels, and there is no geologic repository in sight. The current situation exists without clear and consistent incentives on how best to manage spent nuclear fuel at reactor sites, without agreement on the necessity of centralized storage, and without consent from a host community or state for the site of a final geologic repository. As a result, there is no standardized waste management strategy at reactors, no standard waste packages, and no plan for transportation of the spent nuclear fuel from reactor sites to either a centralized interim storage facility or a geologic repository. Spent nuclear fuel is stored using a variety of different technologies that impact how and when final disposal can happen. Instead of a planned, coherent system, we have the confusion of an unplanned, less than optimal system with each player focused only on their own small piece of the larger system. This is not a situation that builds public confidence. Regardless of Yucca Mountain's fate as a geologic repository, the integration of the back-end of the fuel cycle is essential to the future of nuclear power in the United States. Integration deals with all aspects of the back-end of the nuclear fuel cycle, including the integration of knowledge, methods, practices, as well as the application of a regulatory framework that covers all aspects of the back-end of the nuclear fuel cycle. We are not the first to note this need, others (*e.g.*, Rechard *et* *al*., 2015; Bonano *et al*., 2018) have examined options for improving the level of integration of the back-end of the nuclear fuel cycle in the United States.

> *Most importantly, the United States has taken its "eyes off the prize," that is, disposal of highly radioactive nuclear waste in a deep-mined geologic repository.*

Most importantly, the United States has taken its "eyes off the prize," that is, disposal of highly radioactive nuclear waste in a deep-mined geologic repository. Spent nuclear fuel stored above ground—either in pools or dry casks—is not a solution to the very long-term hazard posed by these nuclear materials. One has to assume, as all countries with nuclear power programs have, that eventually spent nuclear fuel containers stored near the surface will degrade, which could result in the radioactive contamination of the environment and exposure to human beings. The need for a deep geologic repository is predicated both on the assumption that societal institutions cannot be relied upon to ensure safety in perpetuity and on the ethical responsibility of present generations to safely manage the nuclear waste that they have created, as they have benefitted from the nuclear energy.

What is Integration?

In the United States, the back-end of the fuel cycle comprises many steps that begin when spent nuclear fuel is removed from the reactor core and placed in a spent fuel pool. The pool storage allows the fuel to cool and provides shielding from its intense radiation field. Spent nuclear fuel may then be transferred to large concrete casks for dry storage at the reactor site, later transported to a centralized, away-from-reactor interim storage facility (if available), and finally shipped to a deep geologic repository for final disposal. The properties of spent nuclear fuel evolve over time, and this affects how it should be handled and managed as it passes from one stage to the next of initial storage, transportation, interim-storage and, finally, disposal (Ewing 2016).

Integration *of the back-end of the fuel cycle should include clear plans for storage (on-site and centralized), transportation, and the final disposal of high-activity radioactive waste.*[1] *This requires many decisions, such as the selection of waste containers, a determination of transportation means and routes, and the design and development of a geologic repository. Each of these activities is tightly interdependent. Their proper function requires thoughtful, but challenging, decisions to ensure that they remain integrated. For the U.S. program, disconnects among these activities have become increasingly evident with the continuing delay in the development of a deep-mined geologic repository for high-activity radioactive waste.*

For instance, a well-thought out strategy for the back-end of the nuclear fuel cycle would have selected a repository site relatively early in the process of storage and transportation planning—with an understanding of the geologic environment into which the nuclear waste would be emplaced. Early knowledge of the selected site and/or the disposal concept allows

[1] Although reprocessing of spent nuclear fuel is not precluded, no private-sector entity has recently expressed interest in constructing such a facility.

the implementer to tailor the canisters of spent nuclear fuel used initially for storage and transportation so that the fuel would not have to be repackaged before being emplaced in a repository; thereby, decreasing costs and worker exposure. Spent fuel pools would be sized appropriately (they are currently often holding 4 times their originally designed volume of spent fuel) and equipment would be in place at reactors to transfer fuel from the pools to dry storage after an appropriate cooling period. Transportation systems would be thought through and set in place so that when spent nuclear fuel needs to be transported, potentially over long distances, the necessary equipment and infrastructure would already exist.

Feasible, safe, and efficient integration should strive to minimize fuel handling to ensure that health risks and costs are reduced. A good strategy would involve a single managing organization responsible for the spent fuel from discharge to disposal, and this would be done within a regulatory framework that is consistent across each stage of the fuel cycle. Because long periods, years to tens of years, are involved at each stage, funding should be available when needed to transfer the fuel to the next stage of the process.

A good strategy would involve a single managing organization responsible for the spent fuel from discharge to disposal, and this would be done within a regulatory framework that is consistent across each stage of the fuel cycle

Current Practice for the Management of Spent Nuclear Fuel

Storage of Commercial Spent Nuclear Fuel. By April 2016, civilian nuclear reactors had generated approximately 80,000 metric tonnes of heavy metal (MTHM)[2] of commercial spent nuclear fuel in the U.S., of which roughly 55,000 MTHM was in pool storage and 25,000 MTHM was in dry storage (Figure 3.1). The 99 currently operating reactors in the U.S. discharge about 2,000 metric tonnes of spent fuel each year, and because most reactor pools are operating at full capacity, dry storage capacity must increase at an equivalent rate. This requires adding about 160 new storage canisters each year to the approximately 2,080 already in service at active and decommissioned reactor sites. Assuming no new reactors are built and all currently operating reactors receive full renewals of their NRC licenses, and also assuming that no permanent disposal facility becomes available, by the time the last of the current reactor fleet is retired in the mid-21st century, the United States will have approximately 134,000 metric tons of spent nuclear fuel in dry storage if no permanent repository becomes available. Essentially all of this fuel will be in approximately 11,000 dry storage canisters at more than 75 different locations.

Although there are some 30 designs of dry storage cask and canister systems in use in the U.S today, sites are now loading dual-purpose canisters that are designed by vendors

[2] Under current law, the statutory limit for Yucca Mountain is 70,000 MTHM.

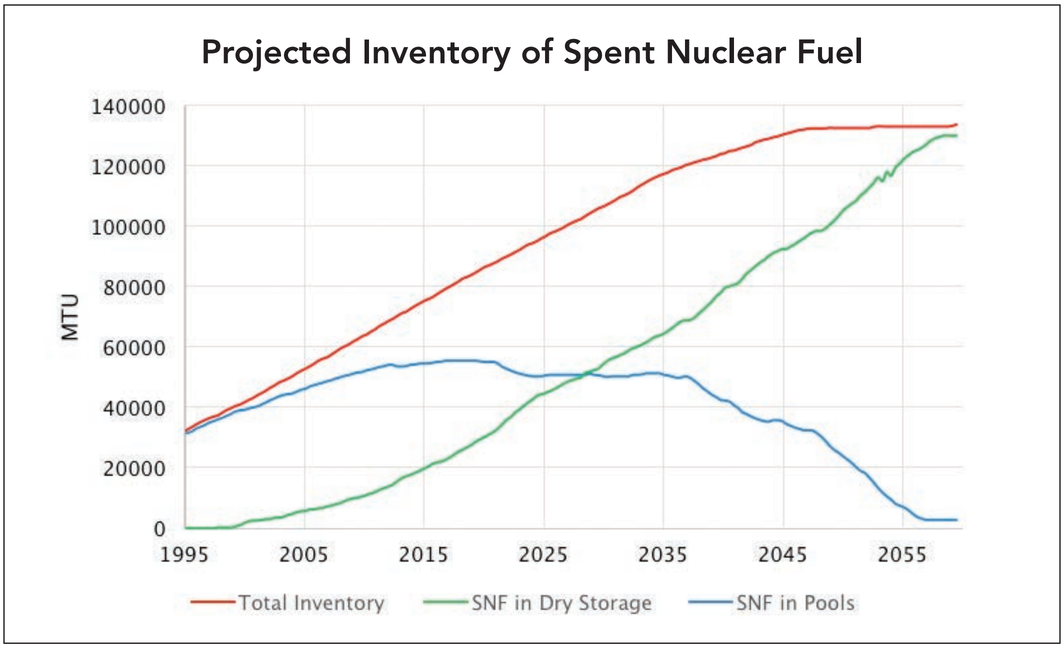

FIGURE 3.1. The existing and projected inventory of commercial spent nuclear fuel in the U.S. Projections assume full license renewals of operating reactors, no new reactor construction, and no permanent disposal of spent nuclear fuel.

SOURCE: updated from Figure 6 of Rechard *et al.* 2015 or Figure 3 of Bonano *et al.*, 2018

and licensed by NRC for both storage and transportation.[3] The majority of commercially available canister designs in the U.S. place welded stainless-steel canisters inside concrete or concrete and steel overpacks[4] in both vertical and horizontal configurations (Figure 3.2), with options for vertical emplacement both above and just below the ground surface. The canisters themselves are large: up to two meters in diameter and five meters in height, and the largest currently in use can accommodate up to 37 intact fuel assemblies from pressurized water reactors, which account for about two thirds of the U.S. reactor fleet.[5] A loaded canister weighs approximately 70 metric tons, and transportation shielding may increase the weight to 150 metric tons. Cost and operational efficiencies at reactor sites often compel licensees to order and deploy larger and larger canisters.

In the United States, the heat limit for the transport mode of these relatively large storage and transportation systems is often half of that of the storage mode. This means that some of the spent fuel in dry storage will need to remain at reactor sites up to tens of years until they are cool enough to be transported. This will have a direct effect on how long some spent fuel storage sites must exist before they can be cleared of all of their spent fuel.[6]

[3]An example of the inconsistent regulations is that the DPC's heat limit for transport is often one-half of that for storage.
[4]The majority of dry storage systems in use outside the US are the bolted lid metal casks as do a few utilities in the U.S.
[5]One bolted lid metal cask design in use at one reactor site can hold 40 pressurized water reactor assemblies.
[6]This situation is exacerbated as utilities move to higher and higher burn-up.

FIGURE 3.2. An example of a vertical (left) dry storage configuration of spent nuclear fuel from the decommissioned Trojan Nuclear Power Plant in Oregon. The horizontal (right) configuration, under construction, shown is from the Calvert Cliffs Nuclear Power Plant in Maryland.

SOURCE: https://flic.kr/p/dcNYfE, https://flic.kr/p/bmV9E5

Centralized interim storage. Interim storage of spent fuel at a centralized location has been proposed as an approach to alleviating storage concerns at reactor sites. Developing such a facility may also provide a path to resolution of legal issues discussed below associated with federal responsibility for spent nuclear fuel management (DOE 2013). Moving spent fuel to such a facility may avoid the creation of orphaned sites where spent nuclear fuel is the only remnant of past nuclear reactors. Centralized storage facilities could also be used to provide flexibility in repackaging options for ultimate disposal as well as being able to avoid the need to construct repackaging facilities at more than one site. However, no consolidated dry storage facility exists in the United States, and, as discussed below, legislative amendments to the NWPA will be required before substantive federal storage facilities can be licensed and operated.[7]

Transportation. Transportation of high-activity radioactive waste is integral to the nuclear fuel cycle. However, transportation routes, the order in which spent fuel is transported, and the existence of appropriate transportation equipment and infrastructure must be developed before there can be large-scale transportation of spent nuclear fuel to either a centralized storage facility or a geologic repository. Approximately 22 percent of the loaded canisters do not have the transportation overpacks required for transport and an additional 15 percent of canisters may not have appropriate casks for transport (Jones Jr 2016). Transportation will be done by barge, heavy haul truck, or rail. Many power plants are not yet transport-ready, in other words, their rail spurs have not been maintained, their barge slips are not ready for use, and railroad tracks are not appropriately sized to transport spent nuclear fuel off site (Maheras *et al.* 2016). Under the NWPA, the DOE is charged with developing a transportation plan for spent fuel to a repository but has completed only preliminary work on this task. Thus, final decisions regarding the plan for transporting spent fuel—by road, rail, or ship have not yet been made.

[7] Two private initiatives have been launched to develop a centralized storage facility, one in Texas and the other in New Mexico. Regulatory review of the license application submitted by Texas project has been suspended (Exchange Monitor 2017) but may be revived.

FIGURE 3.3. A spent fuel cask being transported at the Surry nuclear plant in Virginia. A typical dry storage cask is approximately 18 feet tall and can weigh up to 350,000 pounds when fully loaded.
SOURCE: *https://flic.kr/p/bmVajm*

Repository. Under the NWPA, a U.S. repository was to have begun accepting spent nuclear fuel by January 31, 1998. This has not happened, and plans for developing a repository in the United States remain mired in political controversy. Whether the Yucca Mountain site should be developed continues to be open to political and technical debate. In the absence of a specific site and a knowledge of its geologic characteristics, decisions on the packaging, storage and transportation of spent nuclear fuel are constrained by the absence of the clear strategy for handling the highly-radioactive waste at the back-end of the nuclear fuel cycle.

Lack of Integration of the Back-end of the Nuclear Fuel Cycle

The current U.S. program is not integrated at a number of different levels. As an example, there is no government regulation of a number of spent nuclear fuel practices at reactor sites. For instance, the Nuclear Regulatory Commission does not maintain an inventory of spent nuclear fuel at reactor sites—not amounts, burnups, time since discharge, or other factors associated with the fuel (Jones Jr 2016). Some reactors do not now have the capability to off-load the full core of a reactor into the pool in case of emergency. Whether the utility offloads recently discharged spent nuclear fuel into one location in the pool or distributes it around the pool is not known. Some plants do not have the capability to transfer spent nuclear fuel to dry casks. For example, the Indian Point facility in New York had to add this capability at significant cost long after reactor operation began. From the beginning of reactor operation, then, there has been limited thought into spent fuel management practices starting with discharge into the pool. Managing the pool efficiently, having the capabilities to load spent nuclear fuel into dry storage canisters/casks and predetermining locations to store them at reactor sites was not done early in the operation of these facilities.[8] These capabilities have all had to be added as the U.S. program continues to experience significant delays.

Early in the development of dry storage technology, many approved cask designs were not approved for transportation. At least some fuel that remains in those casks might require repackaging in order to be moved off-site. Currently, dual-purpose casks are approved with different permitting conditions for storage and transportation, thus some are loaded to the maximum allowed heat load and will require decades of cooling before they can be transported. For economic reasons, the nuclear reactor owners are increasing the level of fuel burn-up, that is, the length of time the fuel is allowed to remain in the reactor before it is permanently removed. Vendors have responded to those decisions by designing casks that can manage the increased heat and different radionuclide content of high burn-up spent fuel. None of the casks currently in use were designed for disposal in a repository: the thermal limits, criticality limits, and canister materials have not been optimized for safe disposal. In addition, the lifetime requirements of a cask have not been determined. In other words, with continued delays in the repository program, the integrity of the casks could be compromised. The required period for safe, interim storage, prior to transportation, is not known.

One of the most significant gaps in integration of the back-end of the nuclear fuel cycle in the U.S. is caused by the lack of knowledge surrounding the final geologic repository. Uncertainty about the fate of the Yucca Mountain site and the potential need for additional repositories has impacted the entire back end of the fuel cycle. Because the geologic environment and the design of a new repository is not yet known, both storage at reactors and transportation will likely be affected. Both the size and thermal load of the dual-purpose canisters may exceed conditions that might otherwise be considered optimal for waste packages destined for geologic disposal. With respect to the size and mass of the canisters, engineering solutions for hoist, ramp, and transport operations appear to be feasible, but need to be part of an integrated plan. With respect to thermal load management in repositories, different types of geology impose different temperature constraints on the underground environment. For example, many repository designs have assumed that the maximum temperature in clay backfill must remain below 100 °C, while salt may accommodate higher temperatures. The heat from larger canisters that contain many assemblies may be accommodated by cooling the canister above ground for decades to centuries.[9]

Most of the existing dual-purpose canisters may also pose complications for repository licensing analyses of long-term post-closure criticality control in the repository environment. Criticality control only becomes a concern in scenarios in which the canister and its disposal overpack fail and sufficient water is available to flood the waste package before

[8] The first dry storage systems were not loaded until 1986.
[9] The choice of thermal management strategies is important even if Yucca Mountain is developed as a repository site (NWTRB 2002).

radioactive decay has reduced the inventory of fissile material. Aluminum-based neutron absorbers used in some dual-purpose canisters will degrade in water, causing an increase in the nuclear reactivity of the spent fuel. Options for assuring criticality control in dual purpose canisters, following geologic disposal, include the use of long-lived corrosion-resistant disposal overpacks and, potentially, opening already-sealed dual-purpose canisters to add additional criticality control materials. Post-closure licensing may require case-by-case criticality analysis of individual dual-purpose canisters, taking into account details of package loading and the potential for neutron sorption by naturally occurring chlorides in groundwater. Estimates of the consequences of criticality events in the overall safety assessment for mined repositories will also be required.

FIGURE 3.4. Larger red circles show the locations of shutdown reactors (Independent Spent Fuel Storage Installation Only and License Terminated). Smaller yellow circles show the locations of nuclear power reactors to be decommissioned or currently in the process (SAFSTOR or DECON). SOURCE: *https://www.nrc.gov/info-finder/decommissioning/power-reactor/*

Impacts from the Lack of Integration

The lack of integration of the back-end of the nuclear fuel cycle has significant impacts on safety, cost, technological solutions, and long-term environmental effects. This lack of integration has occurred because the incentives at each stage of the back-end of the nuclear fuel cycle are not aligned toward the final goal—geological disposal of high-activity radioactive waste.

Technological Impacts

Inventory of commercial spent nuclear fuel. As shown in Figure 3.1, the quantity of spent nuclear fuel in dry storage will unavoidably increase in coming years. Because a number of reactors have already shut down and more reactors are planning to shut down over the next few years (Figure 3.4), the fraction of spent fuel that is stored at decommissioned reactor sites where a pool is no longer available for repackaging canisters will also increase (Figure 3.5). Spent fuel is currently stored at 15 sites without an operating reactor, and eight of these sites have already decommissioned their fuel-handling facilities; the rest have plans to do so in the coming decade.

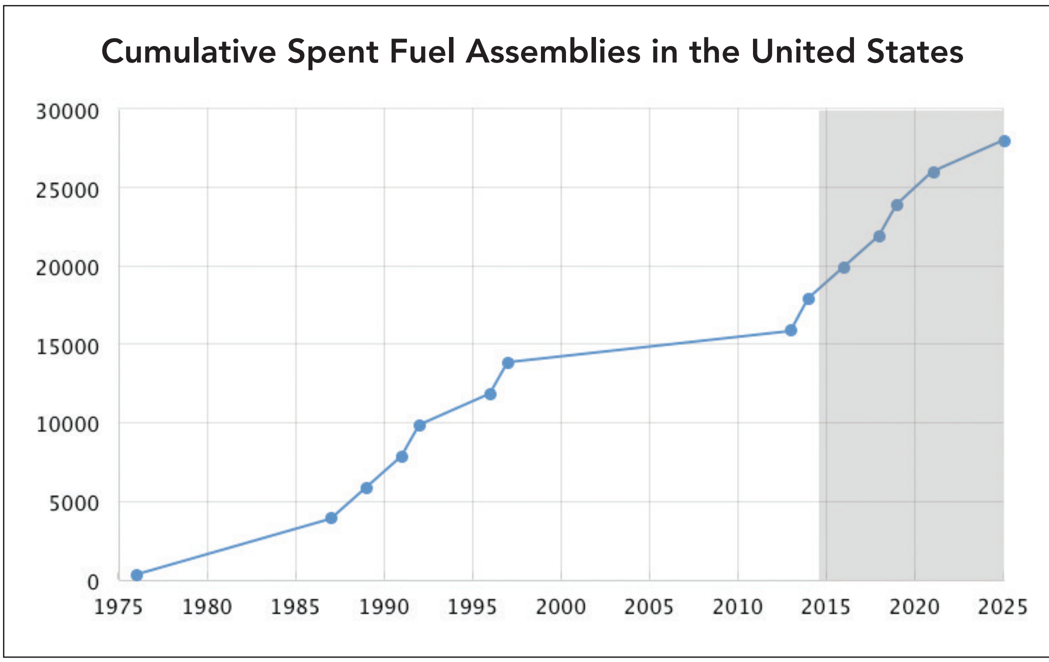

FIGURE 3.5. Existing and projected (in gray) cumulative spent fuel assemblies at shutdown nuclear power plants in the United States. DATA FROM: https://curie.ornl.gov/map

Assuring safety and security of extended storage. At least some, and perhaps most, spent nuclear fuel will remain in dry storage at the current reactor sites for decades longer than initially intended. Options for detecting and mitigating potential problems during storage will change as fuel-handling capabilities are decommissioned at former reactor sites. Any decision to open storage canisters at decommissioned sites for any reason (such as repackaging fuel to replace damaged or degraded canisters or in response to future decisions about transportation or disposal options) will require a significant capital investment to build fuel-handling capabilities at the site. Alternatively, and perhaps more likely in most circumstances, spent nuclear fuel that requires repackaging will be shipped off-site with appropriate overpacks to assure safety. Physical security requirements and commitments at storage sites will also change through time with the changing mission of former reactor sites. Over longer periods, the dose rate at the surface of the canisters associated with the decaying radioactivity of the fuel decreases the extent to which its own radiation provides protection against diversion or theft, conceivably resulting in a counter-intuitive need for increased security measures at the storage facility decades after the rest of the nuclear power plant has been decommissioned.

Economic and Financing Impacts

The financing of the back end of the fuel cycle in the United States is broken. The Nuclear Waste Policy Act originally set up a mechanism to finance the construction and operation of a geologic repository. The Nuclear Waste Fund received charges to ratepayers $0.001/kWh for electricity generated by nuclear power. The fund collected over $34.3 billion (CBO 2015) but appropriations from the fund are controlled by Congress, which has used it to offset the national debt, rather than for its original purpose to develop a repository. This state of affairs first arose in the 1980s when Congress sought to reduce the national debt. The Gramm-Rudman-Hollings Act of 1985 reclassified the Nuclear Waste Fund, so that the money collected into the fund was put in the "mandatory" portion of the budget, treated like tax revenue, and spent on mandatory measures. Congress placed the money paid out of the fund into the discretionary portion of the budget. Follow-on legislation, such as the 1987 amendments to the Gramm-Rudman-Hollings Act and the 1990 Budget Enforcement Act, required discretionary spending (*i.e.*, using Nuclear Waste Fund) to be offset by cuts in other programs at the Department of Energy. In effect, this situation made it impossible to provide necessary funding when it was needed most by the nuclear waste program (BRC 2012). Finally, due to a 2013 federal court decision, ratepayers are no longer paying into the Nuclear Waste Fund because of the federal government's failure to make sufficient progress on removing spent fuel from reactor sites.

Moreover, taxpayers bear the additional burden of the federal government's inability to construct and operate a repository for final disposal of spent nuclear fuel. The Standard Contract mandated by the NWPA (Section 302) and defined by 10 CFR 961 governs interactions between the nuclear utilities and the DOE with respect to the management of spent nuclear fuel. The Standard Contract requires that the DOE begin to take title to spent nuclear fuel for disposal "not later than January 31, 1998." The DOE's failure to fulfill the terms of the Standard Contract has been the subject of complex and ongoing litigation between the utilities with nuclear power plants and the U.S. Department of Justice and has resulted in the payment of substantial damages to utilities to compensate them for the unanticipated costs of on-site storage of spent fuel. The Judgment Fund, paid for by taxpayers, has already paid out $5.3 billion, and payments are projected to balloon to $23.7 billion, even if the federal government begins to accept spent fuel in 10 years (Cotton 2016). Based on a ruling by the U.S. Court of Appeals for the District of Columbia Circuit, this taxpayer liability cannot be resolved by the government simply taking title to the spent fuel, but still leaving it at the reactor sites. The DOE must physically move the spent fuel off site to fulfill its contract with utilities (USCA-DC 2013).

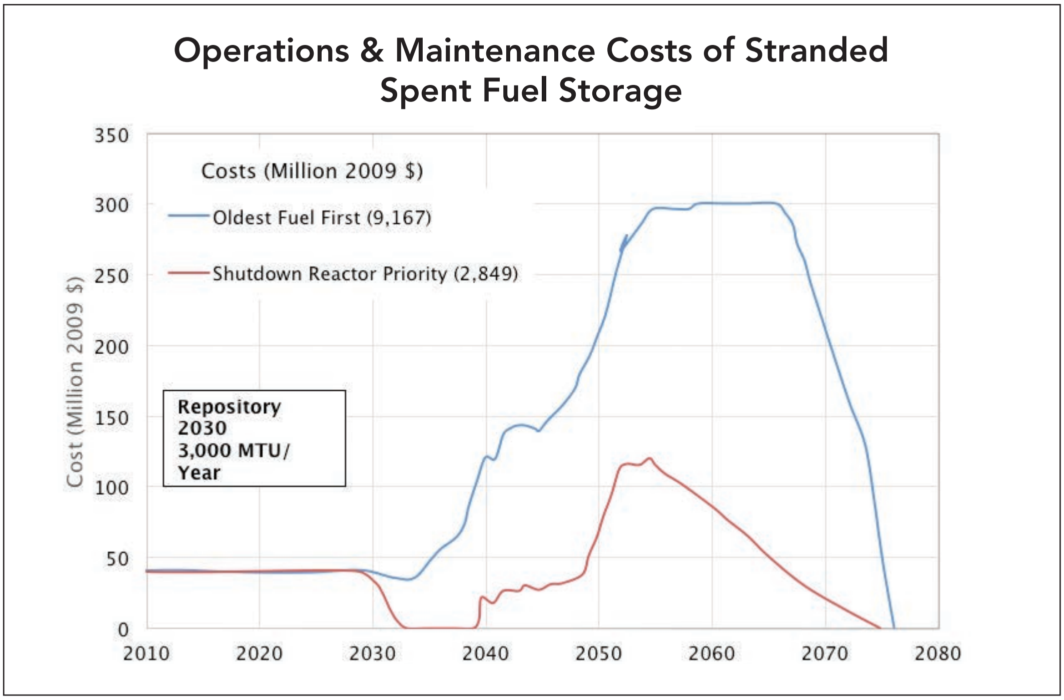

FIGURE 3.6. The dark red curve shows the cost savings for moving spent fuel at shutdown reactor sites first *versus* the blue curve, which is based on moving oldest fuel first (modified from BRC 2012, Fig. 16).

These economic impacts are likely to increase in the future if the planned removal of spent fuel from reactor sites follows the provisions of the current Standard Contract, which specifies that the oldest fuel should be moved first. Still, the utilities have some discretion as to which fuel should be moved and could decide to move the hottest transportable fuel first. This strategy could produce an inefficient system that results in shut-down reactor sites having to stay open longer. *The Blue Ribbon Commission on America's Nuclear Future* (2012) showed that moving fuel from shutdown reactors first, instead of the oldest fuel first, would result in significant cost savings (Figure 3.6). A better strategy would be to reduce the number of active transport routes, as well as optimize moving fuel from shutdown sites first, so they can be fully decommissioned and save hundreds of millions of dollars (Cotton 2016).

Social and Political Impacts

The United States now has more than 70 commercial nuclear power plant sites that store spent fuel of which 60 are at still operating reactor sites. As of early 2017, 18 reactors are shutdown, and 9 reactors have been designated for shutdown by 2025. Thus, in 2018, 15 sites (by 2025 this will increase to 20 sites) host "orphaned" spent fuel.

Active public groups near some shut-down power plants have reacted strongly to the continued storage of spent fuel as these sites. At the Vermont Yankee plant, public interest groups along with state government officials have opposed leaving the spent fuel on site for the decades as planned by the owner, 3 Yankees. The local municipal governments and many members of the public near the San Onofre Nuclear Generating Station (SONGS) in southern California also oppose leaving the spent fuel on site indefinitely (Victor 2016). In fact, the SONGS plant owner, Southern California Edison, has created a Community Engagement Panel to provide public input into the decommissioning process.

Public interest advocacy groups, such as the Union of Concerned Scientists and Public Citizen, have concerns about the continued management of spent fuel at reactor sites. Their main concern is focused on the safety and security of spent fuel pools, which currently contain about two-thirds of the nation's spent nuclear fuel. They would prefer that these pools be thinned out and most of the spent nuclear fuel be placed in dry storage. In the event of damage to the pool from a terrorist attack or natural disaster, this reduction in the amount of fuel in the storage pools would reduce the possibility of fire and release radioactivity.[10] Many of these groups favor what they call hardened onsite storage of spent nuclear fuel, storing it in dry casks surrounded by berms to protect against terrorist attack.

Environmental Impacts

If the status quo in the United States continues indefinitely and a geologic repository for disposal of spent fuel is not developed, then the environmental impact may be high in the absence of institutional control. The Final Environmental Impact Statement for a repository at Yucca Mountain explored the potential for "no action" and found that within 70 years of the loss of institutional controls that would have ensured casks and spent fuel pools remained intact, water would begin to infiltrate into the waste packages, eventually degrading them and leading to the release of radionuclides into the air, surface and ground water, as well as soils (DOE 2002). The EIS assumed that waste packages begin to release radionuclides 1,000 years after institutional controls are lost. As a result, the Environmental Impact Statement estimated significant radiation doses to the public, up to 31 rem/yr for a person living 5 km from the site (DOE 2002).

Nuclear Industry Impacts

The owners of nuclear power plants are suffering significant impacts themselves. Because the DOE did not meet its contractual obligation to begin moving fuel off reactor sites in January, 1998, most utilities are receiving payments from the Judgment Fund to manage spent fuel at their sites. To save taxpayers money, the funds released by the Justice Department to utilities are kept at a minimum and, therefore, constrain decisions about spent fuel management on site. Further compounding this situation is the economic strain that a number of nuclear power producers are experiencing. These two factors result in decision-making that minimizes industry spending on at-reactor storage and does not allow for adequate planning for the next stages in the future of spent fuel.

[10] This concern resulted in extraordinary efforts to add water to the pool at reactor #4 during the Fukushima accident in Japan in 2011.

Perhaps most deeply affected by this situation are plants that are already shut down. Maine Yankee, for instance, has fully decommissioned its site—all except for the spent nuclear fuel, which sits on a concrete pad. The owner of the Maine Yankee site, 3 Yankees, must pay for security and monitoring at the site, using payments from the Judgment Fund. Further, 3 Yankees must keep up their licenses with the NRC. In the case of the Maine Yankee, Yankee Rowe, and the Haddam Neck reactors, some of their cask storage licenses expire in 2020, requiring them to enter into an expensive effort to relicense the casks (Howes 2015). In fact, the 3 Yankees Company continues to exist simply to monitor and maintain the casks at their three sites.

Regulatory Impacts

The passage of the Continued Storage Rule by the NRC in 2014 represented a significant change in policy for the back-end of the nuclear fuel cycle (NRC 2014). The rule replaced the amended Waste Confidence Decision, which represented the NRC position that the federal government would be able to open a geologic repository for spent fuel. The Continued Storage Rule provides a generic evaluation of the potential environmental impacts of the storage of spent fuel at reactor sites beyond the licensed lifetimes of the reactors. In particular, the Continued Storage Rule found that all environmental impacts, including those 60 years and 160 years after license expiration, as well as indefinitely into the future, were small (NRC 2014), based on the assumption that institutional controls, such as the site monitoring and the physical security measures, would remain in place indefinitely.

FIGURE 3.6. A RH72-B cask containing a load of high-activity waste contaminated with transuranics en route to the Waste Isolation Pilot Plant near Carlsbad, New Mexico. SOURCE: *https://flic.kr/p/omVazd*

As a result of this rule, there is no regulatory requirement or incentive to address current cask loading procedures. Moreover, there is no regulatory push to move spent nuclear fuel from reactor sites—either from the spent fuel pools or the dry casks where it now sits - because the rule has found that there will not be any significant environmental impacts, ever (NRC 2014).

Further, when plants are decommissioned, they are regulated under rules for operating power plants because no separate regulations for shutdown reactors exist. The NRC is currently in the process of developing decommissioning regulations, but their final publication is likely to be some years away. Thus, in order to decrease security measures or change emergency planning (since the reactor is no longer operating) at a shutdown plant, plant owners must apply for an exemption to the operating reactor rules. Asking for an exemption has the appearance of trying to avoid regulations (though clearly that is not the case here), but the process of seeking an exemption can contribute to a negative public image of the licensee.

Incentives Not Aligned Toward the Goal of Geological Disposal

In the United States, the entire nuclear fuel cycle has become quite fragile. Incentives to craft an integrated strategy for the back-end of the nuclear fuel cycle are simply lacking, and the mechanisms that do exist, such as the Standard Contract, do not align incentives to the final goal—geologic disposal. Congress itself is in gridlock, with only a minority of members truly engaged in solving the issue of final disposal of nuclear waste. A majority seems to be content to continue to use the Nuclear Waste Fund for purposes other than that intended by Congress itself. Political awareness of the massive price tag associated with the Judgment Fund may eventually prompt action in Congress. That the ratepayer funded Nuclear Waste Fund is being used to finance the country's debt while the taxpayer forfeits billions because of lack of progress on nuclear waste disposal should be unacceptable.

That the ratepayer funded Nuclear Waste Fund is being used to finance the country's debt while the taxpayer forfeits billions because of lack of progress on nuclear waste disposal should be unacceptable.

The nuclear industry has few incentives to champion this issue. What might have held them back in the past —not being able to build new reactors before resolving the waste problem—has been removed by the NRC's Continued Storage Rule. The Department of Justice, which administers the Judgment Fund, is forcing the lowest-cost solution on the utility industry in an effort to save taxpayers money, and it has no incentive to change its strategy. Finally, many public interest advocacy groups oppose both a repository and transportation of spent nuclear fuel, so they have no incentive to encourage movement on an integrated back-end of the nuclear fuel cycle, with the exception of moving spent nuclear fuel out of pools into dry casks that are housed in hardened onsite storage sites.

The only constituency with a clear incentive to urge that there be progress on an integration of the back-end of the nuclear fuel cycle, which includes development of a repository, are the communities near decommissioned sites. Currently ten states have decommissioned sites. The number of these communities will grow to include six more states by 2020. With time, this constituency may apply political pressure for an integrated solution.

Recommendations—Aligning Incentives

> *Every country that uses nuclear power and generates nuclear waste must assume responsibility for its safe disposal. Internationally, the consensus is for safe, long-term disposal of nuclear waste in a deep-mined geologic repository.*

Every country that uses nuclear power and generates nuclear waste must assume responsibility for its safe disposal. Internationally, the consensus is for safe, long-term disposal of nuclear waste in a deep-mined geologic repository.

There will have to be a change in federal policy, and this requires Congressional action across the entire legislative and regulatory framework that now guides and constrains the U.S. nuclear waste-management program. Piecemeal changes to present laws will not be enough to provide an integrated system of nuclear waste management for the United States. There are technological, political, and policy "fixes" that are required in order to integrate the back-end of the nuclear fuel cycle. Overall, it is essential to recognize and set forth in policy a well-thought out strategy for the management of the back-end of the nuclear fuel cycle—from the removal of spent fuel from reactor sites to its final disposal in a geologic repository. Such an approach will provide a more efficient, more secure, more proliferation-resistant and cheaper strategy for finally solving the nuclear waste problem. Decisions about this strategy must have a solid technical basis, as well as include engagement with those affected by these decisions, including the nuclear industry, relevant government agencies, transportation companies, officials and regulators, and, importantly, public interest groups, including the affected public, local governments, tribes and states.

There are two essential legislative changes required:

- There must be a new funding mechanism for the new waste management organization. The organization responsible for the successful disposal of nuclear waste must be able to use the funds in a timely and appropriate matter and plan expenditures for a program that will last many decades.
- A new legislative framework and organization will only be successful if there are incentives to bring the goals of the utilities with nuclear power plants and the federal government into alignment.

RECOMMENDATIONS

- Congress must revise existing laws so that it:
    - o Transfers responsibility for storage, transportation, and disposal of commercially generated spent fuel, and perhaps high-level radioactive waste, to a new, independent, single-purpose organization.
    - o Transfers the *corpus* of the Nuclear Waste Fund to the new organization.[11]
    - o Orders the Department of Justice to consider the impact of their payments on the integration of the back-end of the fuel cycle and, instead, enable the packaging of smaller, potentially repository-appropriate canisters for earlier transport.
    - o Requires the nuclear utilities and the new organization to work together to establish an integrated system for spent fuel and high-level waste management that has the capability to repackage spent nuclear fuel from the current, relatively large casks and canisters into canisters that are designed for geologic disposal.
- The Standard Contract must be revised under the new organization to include planned removal of spent fuel first from shutdown plants.
- The new organization will have to work with all interested parties: industry, local, state, and tribal governments, public interest groups, academia, the regulator, to ensure that all relevant views on storage, transportation, and disposal are not only heard, but become part of the overall strategy for dealing with the waste.
- Finally, Congress must reaffirm that a geologic repository (or repositories) is the final goal for the fate of high-activity radioactive waste, such as spent nuclear fuel and the high-level waste from reprocessing.

Each of these recommendations is meant to harmonize the back-end of the fuel cycle such that every decision is focused on the final goal—geologic disposal.

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[11] Transfer of the Nuclear Waste Fund need not occur all at once but can be completed over decades. The need to re-establish the Nuclear Waste Fund can then be evaluated by the new nuclear waste management organization and done under their authority as discussed previously.

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The Waste Isolation Pilot Plant (WIIP), located near Carlsbad, in southeastern New Mexico, opened in 1999 and is the world's only operating geologic repository. The WIPP repository horizon is located in a thick bed of salt at a depth of more than 300 meters. The waste consists of materials contaminated by transuranium elements, mainly plutonium, which were generated by defense programs. In 2014, a release of radioactivity from a breached drum of waste caused WIPP to be shut down for more than two years. Estimates of the cost of the accident reach as high as two billion dollars due to the need to decontaminate the underground workings, replace the ventilation system, and the delay in the continued disposal of transuranic waste. WIPP has now returned to operation.

SOURCE: *https://flic.kr/p/omQPAk*

Public Engagement and Consent-Based Siting

Over the last half-century, implementers of national waste-management programs in more than a dozen countries have launched at least 24 efforts to site a deep-mined, geologic repository. In only five of these efforts was a site chosen. Nearly one-half of the initiatives prematurely ended because the projects failed to gain and sustain social acceptability (NWTRB 2015). The failed attempts typically have adopted a strategy of *decide-announce-defend*, in which the implementer, with little or no consultation, identified potential candidate locations, informed the recipient communities, and dismissed any criticism that emerged.

However, Finland has selected a site near Olkiluoto, France near Bure, and Sweden near Östhammar. In the United States, a site near Carlsbad was selected for the Waste Isolation Pilot Plant in which defense-generated transuranic-contaminated waste is being disposed. In each of those instances, the development of a repository appears to be on a strong and stable track. It is no wonder then countries resetting their siting processes, such Canada, Japan, and the United Kingdom, have decided to adopt an alternative strategy, requiring that the siting community volunteer on consent to the development of the nuclear waste repository.

In contrast, the site for the proposed Yucca Mountain repository was chosen in 2002 through a process that permitted the objections of the State of Nevada to be overridden. But subsequently the fate of that site has become mired in political limbo. It remains unclear whether it will be possible to carry out a repository-development process—licensing, construction, and operation—that will have to span decades. In a vigorous pluralistic democracy, one "no" can defeat many "yeses." *Although such an outcome is not eliminated by using a consent-based siting process, pursuing such an approach can increase the odds that a site is successfully selected for a geologic repository and current generations meet their ethical responsibility to establish a means to manage the risks that they have created.*

In those nations that have adopted such a process, the details of who consents, what is consented to and for how long, and how that consent is given and can be withdrawn varies. But based on the information gathered during the Reset meetings, as well as the experiences and knowledge of the members of the Steering Committee, two significant challenges have to be addressed if the United States choses to launch a new site-selection effort. ***In the opinion of the Steering Committee, such a decision has to learn the key lesson of the past: finding a new site for a repository is almost certain to fail if it does not, in some fashion, provide a means for local, tribal, and state governments to register their agreement with the choice of a site.*** For a consent-based siting process to succeed two conditions must be met.

An effective mechanism has to be put in place that allows local, tribal, and state governments to exercise decisive decision-making power throughout the repository-development program.

- The implementer and the regulator have to establish strong bonds of trust with the local, tribal, and state governments involved and have to sustain that trust for many decades as development moves from scientific and engineering studies in support of siting through operations to closure.[1]
- An effective mechanism has to be put in place that allows local, tribal, and state governments to exercise decisive decision-making power throughout the repository-development program.

Notwithstanding the creation of an authentic and transparent consent-based siting process, the possibility remains that it will not produce a technically suitable and socially acceptable site. The experiences in Japan and the United Kingdom provide examples for this cautionary note.

Consent is a Process of Continuous Engagement

The *Blue Ribbon Commission on America's Nuclear Future* (BRC) deserves credit for recognizing that any new siting effort must use a consent-based process (BRC 2012). By making such a forceful recommendation, the BRC firmly placed this question on the public agenda. Any discussion of the future of waste-management policy in the United States should seriously consider the BRC's views. The BRC's recommendation for consent-based siting is consistent with the growing realization that public engagement and values should have an important impact on diverse and highly technical issues, from the use of genetically modified organisms to preventing the poaching of ivory (Biggs et al. 2017; Dinneny, 2018). Public engagement not only improves communication and the possibility of acceptance, but also can lead to a better final result (Lavery, 2018).

The strategy subsequently released by DOE embraced consent-based siting as proposed by the BRC (DOE 2013). The DOE underscored the important prerequisites of public trust and confidence. It advocated the development of a process through engagement with communities, tribes, and state governments, as well as other interested and affected parties. But, like the BRC, the DOE strategy did not advance any specific framework for implementing a consent-based process.

[1] Strong bonds of trust are evidenced in the interactions between the implementer and the community and are also revealed in public opinion surveys.

Building on the BRC's advice, the Bipartisan Policy Center (BPC) issued a report that recommended a process that featured "voluntary participation, transparency, trust, and inclusion" (BPC 2016). But like the BRC, the BPC did not go into any detail about how to achieve those aims. The DOE spent seven months listening to the views of interested and affected parties on how to design a consent-based siting process. Meetings were held across the country, in which interested and affected parties had an opportunity to present their views. DOE published a valuable summary of what it had heard (DOE 2016) and followed up with a draft process (DOE 2017). The present administration has not pursued this initiative.

Notwithstanding these contributions, the Steering Committee believes that past efforts to design a consent-based *process* have provide little guidance in addressing the two challenges of *trust* and *power*. DOE (2017), for example, mentions "trust" only with respect to the federal government's "trust relationship" with Native American tribes. "Power" is barely touched upon. What follows, then, is an attempt to fill in some of the remaining gaps.

The BRC, BPC, and DOE narrowly focus on a decision taken at a single point in time: siting. This emphasis fails to take fully into account two fundamental characteristics of the repository-development and operation process: (1) the timescales involved prior to repository closure are on the order of tens of decades and (2) technical and social changes—some of which might be substantial and uncertain—are likely to arise over that period. For these reasons, the Steering Committee has broadened its perspective to recognize explicitly that the two challenges of timescales and socio-technical changes must continuously be attended to. In particular, consent-based siting is more than simply obtaining agreement from relevant local governments—whether contractual or not. Rather consent-based siting is an ongoing effort of public engagement that demands transparency, accountability, and respect for all parties over many decades.

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Establishing and Sustaining Strong Bonds of Trust

Fundamental to the successful launch of consent-based siting will be a decision-making process that is clearly articulated and communicated. The core principles underlying the consent-based process, the level of detail required to launch the process, what details may be best left to emerge as the process unfolds, and who is involved in shaping the process are all important first order considerations, each of which can powerfully influence the level of public trust and confidence in the process.

Collaborate to design the siting process. Consent-based siting necessarily involves multiple players, who agree to initiate a process and become active participants willing to sustain siting activities over an extended period. The extent to which the siting principles and repository-development process steps reflect the expectations and values of interested and affected parties improves the chances of a positive outcome.

Providing early opportunities for broad public input into the design of the siting process will help identify the key values and principles that people expect to see in the decision–making process. These values include benefitting from open dialogue on the past experiences (what worked well and what did not) to ensure the new siting process fully leverages the lessons learned. Taking the time to invite a variety of perspectives, including those with direct experience in past siting projects, will help to reveal important requirements in order for a siting process to be socially acceptable. As DOE (2016) observes, interested and affected parties possess a vast store of experience that can be shared, as well as an interest and willingness to contribute.

Early canvassing of input can provide insight into the values and behaviors important to build and maintain trust and confidence in the players mandated to lead the siting process. Such input can also identify key principles that people see as important for the process. For example, who needs to be involved and the kinds of information and programs are required for those who engage in the siting process? Taking the time to design a siting process that will be broadly accepted as a fair and appropriate basis for taking decisions may support more durable decisions leading to tangible progress of the program.

Entrust the siting process to a strong and trustworthy organization. As noted in Chapter 2, an organization that has established itself within a stable political environment will be needed to lead the process and be the trusted guardian of the siting. Such an organization will embrace and reflect in its operations the values that will be central to earning and sustaining public trust and confidence. SEAB (1994)'s earlier effort provides examples of what is required. The early engagement on expectations for a fair and appropriate siting process will reveal the expectations for the organization. Key to the success of consent-based siting will be the organization's ability to demonstrate competence, transparency, accountability, and adaptability.

Key to the success of consent-based siting will be the organization's ability to demonstrate competence, transparency, accountability, and adaptability.

In addition to the implementer, the regulator also needs to work towards earning and sustaining public trust and confidence. Clarity and agreement on regulatory requirements (discussed in Chapter 5) for the implementer, regulator and communities engaged in siting is important. Consequently, the regulator must be candid and credible, especially when or if those requirements have to be changed. The regulator also needs to be involved in briefing the public, as well as building confidence on safety and regulation at the start of the siting process.

Articulate a clear decision-making path These might include such fundamentals as:

- How will sites be selected, including key technical safety considerations, as well as consent? These rules should establish firmly at the outset that safety will not be compromised to secure a willing host.[2]

[2] Countries have adopted a variety of approaches for developing site-suitability criteria. In many of those nations, the process used has been long and controversial. See NWTRB (2015).

- What are the screening or exclusionary site-selection criteria?
- How might local, tribal, and state governments that enter the process withdraw from it?
- How and when will consent be sought after a site has been selected?
- Is there a clear road map in terms of milestones starting in the study phase from early assessments through to site characterization, regulatory approvals, and decisions regarding repository operation?
- When can consent be withdrawn and under what circumstances?
- How will interested and affected communities be involved and what power will they be able to exercise when the initial set of decisions have to be modified?

The proposed process below explicitly addresses many of these questions.

Assemble information required to support participation. Early engagement by the implementer can lead to an understanding of public expectations about the information required to launch the siting process. Examples of information requirements discussed at meetings with the public include:

- Why is this project needed?
- What is the focus of the siting exercise?
- What kind of repository and related infrastructure will be sited?
- What is the waste inventory and its characteristics that is intended to be disposed of in the repository?
- What information and financial resources will be available to those engaging in the siting process in the initial stages?
- What is the nature of economic benefits or other benefits to local, tribal, and state governments?

A confident launch of a new consent-based siting process will require that this early phase of siting, design and planning be well defined in advance prior to any formal call for proposals to enter into the voluntary process. The responsibility for doing so initially falls on the implementer, although ultimately each question must be answered through authentic and sustained engagement with interested and affected parties.

Provide an appropriate, ethically-based platform for inviting communities to explore the repository project and consider potential interest in hosting. The implementer will need to provide early steps focused on the learning process and exploring the repository project.

- How is the right to withdraw exercised and when?
- What does initial entry into the siting process imply?
- Why is safety non-negotiable? What does that look like in the siting process?
- Why is broad engagement and dialogue at many levels of government required?

Again, the responsibility for creating a platform initially falls on the implementer, although ultimately each of the questions noted above must be answered through engagement with interested and affected parties.

Sustain the process by behaving in a manner that fosters public trust and confidence. Consent is not a one-time achievement, but a process that requires a cultural shift in how to design policies and make decisions. Trust and confidence must be earned and maintained over the large number of years of a siting process, that unavoidably will experience uncertain changing conditions. A process of continuous engagement aimed at sustaining trust can provide the basis for possible changes in strategy as the repository siting, construction and operation proceed.

Be open to partnering with local, tribal, and state governments. Once engaged, these entities will wish to co-design the journey and have some measure of control, including the approach to dialogue in their local areas, establishing platforms for learning, facilitating dialogues, and influencing the pace at which siting studies progress in the area. It may be helpful at the start to underscore the role for active involvement of communities/tribe/state during the multi–year siting and repository-development process, including the scope for shared decision making. It is helpful to also anticipate local interest in discussing what the project will look like at each stage of the regulatory approvals, construction, and operation phases. What involvement will local, tribal, and state governments have at all stages of project execution, such as monitoring, providing first responder services, maintaining community dialogues, and empowering community advisory committees?

Properly implemented, partnering has the advantage of avoiding many of the problems that have plagued DOE's implementation of the cleanup agreements that it has entered into with state governments. Too often these have ended up in extended litigation that truly benefits neither party.

Build the conditions for sustained interest and momentum. A community must be a continuing strong proponent of learning about the project and participating in the siting process. The implementer will need to build diverse engagement opportunities locally and regionally to broaden the base of interest and support such that the siting process can withstand multiple elections. For example, the implementer should establish and support a group that is broadly representative of the community to foster ongoing interactions and sustain momentum and facilitate community input on siting studies. The implementer will have to employ some locally-based staff to support ongoing dialogue and interest. The implementer will also need to provide resources to the local community or tribe to support independent technical reviews of the implementer's proposals.

Respect the need for flexibility and adaptability. It will not be possible at the outset to foresee all of the programs, resource needs and process details that will be essential at each point in the long multi-year period of site evaluations and repository development. It may be beneficial to recognize this and to explicitly provide room to refine and adapt siting resources, schedules, and plans as the process advances. The BRC proposed adoption of an adaptive management framework for the repository plans. Explicitly embracing the merits of adaptive management and bringing this into the design of the siting process will facilitate the creation of trustworthy relationships. Of course, recognizing the need and importance for adaptability without providing the local community or tribe with the power to secure it is just rhetoric.

Many siting processes begin with learning programs, enabling potentially interested communities to fully explore the project and their own interest in being selected as a site. Over time, the level of inquiry and scope of key issues and interests become more sophisticated, with a commensurate evolution required in information, resources, funding programs and access to third party expertise. By retaining flexibility to adapt public engagement programs and funding programs for capacity building with communities, the implementer can respond in a way that is culturally appropriate and meaningful to the range of players involved. The parties involved in the siting process will be able to identify the topics and issues that need exploring. Continuing to welcome input from those involved and undertaking to be responsive to emerging demands will strengthen the foundation for future partnerships and collaboration, thus slowly building the trust and confidence necessary for making decisions under uncertainty.

Allocating Power between Central and Peripheral Governments

How can local, tribal, and state interests be accommodated in the siting and development of a deep-mined, geologic repository for high-activity radioactive waste? Those involved in the waste-management policymaking have debated this question for nearly 40 years without reaching a clear and settled conclusion. For some, the activity self-evidently falls within the purview of the Federal Government, and thus it rightly ought to have the final say. For others, managing radioactive waste is so fraught with risks—both calculated and perceptual—that those subordinate units of government rightly ought to have a decisive voice.

In 1979, President Jimmy Carter adopted a recommendation from an Interagency Review Group and held that states should be consulted during the siting process and should have the authority to concur at each stage (IRG 1979). This formulation threaded the needle between outright federal preemption and a state's absolute veto. In passing the NWPA, Congress morphed the formulation from "consultation and concurrence" to "consultation and cooperation." In the 1987 Nuclear Waste Policy Amendments Act (NWPAA), Congress limited the investigations required to determine the suitability of a potential site to Yucca Mountain in Nevada. Not affected by the change in the legislation, authority was given to states (now just the State of Nevada) to disapprove the President's choice of site; but that authority could be overridden if each house of Congress passed, by a simple majority, a resolution of repository-siting approval. Following the law, President George W. Bush in February 2002 selected Yucca Mountain as the location for the country's first deep-mined, geologic repository for high-activity radioactive waste. In April, the Governor of the state of Nevada disapproved the selection, but in July, Congress voted to sustain the President's choice.

This argument over how the power over siting and developing a deep-mined, geologic repository should be distributed between the central and the peripheral units of government has been recapitulated in a number of other pluralistic democracies. In Finland and Sweden, municipalities hold near absolute power to reject a proposed repository site up to a pre-specified point in the siting process. In Canada, France, Japan, and the United Kingdom, communities must volunteer before locations within their jurisdiction can be considered for a repository or an underground research laboratory.[3] In contrast, Switzerland and Germany do not grant localities the formal power to veto a proposed site. However, in each country, the siting process requires extensive public engagement and dialogue.

The challenge then is to craft a sustainable repository-development process that protects the interests of both the central and peripheral governments. The terms "partnering" and "partnership" cover a wide variety of institutional forms that are designed to facilitate engagement by the implementer with interested and affected parties including localities, regional and state governments, and tribal nations (NEA 2010). At one extreme, these terms suggest informal dialogues that take place between the implementer and various interested and affected parties. The interactions arising during the siting of Long-lived Intermediate-Level Waste (ILW-LL) repository in South Korea are an example of this type of partnering.

At the other extreme, the terms can refer to formal arrangements that allow a specially constituted association, composed of governmental bodies and civil society organizations, to engage with the implementer. For example, the formation of the STOLA (renamed STORA) and MONA partnerships in Belgium led to the siting of a repository for short-lived, low and intermediate waste in Dessel.[4] The partnerships have a General Assembly composed of local politicians, social and cultural organizations, environmental organizations, and economic organizations, such as local businesses, farmers, and union members. An Executive Committee undertakes the day-to-day management of the partnership. The implementer, ONDRAF/NIRAS, provides funding to operate the partnerships. The partnerships make recommendations to the Mol and Dessel Municipal Councils, which either approve or reject the advice. ONDRAF/NIRAS granted the Councils the power to veto the siting of a repository in the Mol-Dessel district. Once the Councils gave their approval, they retained significant decision-making power over the design and monitoring of the repository as well as over the content of a socio-economic benefits package. These powers have been delegated to the STORA and MONA partnerships.

The Way Forward

The combined experiences of the waste-management programs in Belgium, Canada, Sweden, and the United Kingdom suggest a path forward for the United States. Below the Steering Committee sets forth the outlines for how to allocate power between communities, tribes, and states on the one hand and the Federal Government on the other.

[3] Twenty-three communities in Canada have expressed an interest in learning more about hosting a repository, but none have committed to do so. Communities in the Haute-Marne region in France have supported the construction of an underground laboratory, knowing that if the geology was found to be suitable, a repository could be constructed nearby. Thus far no community has, in fact, volunteered in Japan and the United Kingdom.

[4] The "Managing Radioactive Waste Safety" initiative in the United Kingdom also relied heavily on formal partnership relations. However, when that approach did not succeed in finding a "willing and informed" host community, the government adopted another strategy that does not seem to rely on partnerships.

To begin with, a broad discussion among interested and affected parties needs to take place about what standards and criteria should be used to select and license a repository site.[5] Communities and tribal nations would be encouraged to express an interest in learning more about hosting a repository. If no locality or tribe volunteers, the implementer could identify potentially suitable sites based on a literature review and would have the authority to carry out surface-based geological investigations in those locations.[6] Regardless of whether a community or tribal nation steps forward, the implementer would provide financial and other resources to create formal partnerships in the areas under study. The partnerships would be composed of representatives from interested and affected parties. It would interact with the implementer to discuss outstanding technical, design, and monitoring issues. After some minimum time has passed, perhaps two to three years, the partnership would make a recommendation to the local or tribal government whether investigations should continue. At that point, the local or tribal government could exercise an absolute veto halting the implementer's work. Even if further studies are allowed, the partnership would periodically review the implementer's work and make recommendations about whether it should proceed.

The communities and tribal nations' power to exercise an absolute veto over the implementer's siting decision expires once the implementer announces that it has gathered sufficient information to submit an application to construct a deep-mined, geologic repository.

The regulatory authorities would then review the application using an adjudicatory process. Participants would include the implementer, regulatory staff, members of the partnership, host state, and other affected parties. If a license is granted, the state then could disapprove construction within some specified period. This objection could be overridden by supermajorities in both houses of Congress and approval by the President but only if it was determined that no other site was suitable.[8] Once construction begins, the local or tribal government would maintain strong oversight, including the authority to specify needed studies, participate in monitoring, and, under predetermined conditions, stop work.

[5] The BRC maintained that the Yucca Mountain-specific standards adopted in 2002 by the Environmental Protection Agency (EPA) and the Nuclear Regulatory Commission (NRC) are inappropriate and that the earlier generic standards need to be updated (BRC 2012). EPA's Yucca Mountain-specific standard is found at 10 CFR 197, and NRC's conforming regulation is found at 10 CFR 63. The earlier generic standards are, respectively, 10 CFR 191 and 10 CFR 60. The Steering Committee's views on regulatory structure are laid out in the final chapter of this document.

[6] As elaborated below, under the Steering Committee's proposal, a community or tribe ultimately will possess unconditional power to halt site investigations and a state will have a strong (but not unconditional) veto power. Thus, it is unlikely that the implementer would venture into a jurisdiction where it is passionately unwelcome. Nonetheless, the national interest in developing a deep-mined, geologic repository requires that technically promising locations not be eliminated at the start.

[7] The partnership could also include representatives of local and tribal governments.

[8] To make explicit what may have been implicit, the Steering Committee recommends that more than one site be characterized as the 1982 Nuclear Waste Policy Act required. The implementer would determine which of them, if any, meet the site-suitability criteria.

Trust and Power

This proposed repository-development process attempts to address the two major challenges: sustaining trust and allocating power. With respect to the first challenge, the proposed process provides for a substantial period of engagement, two to three years, between the implementer and the partnership *before* a local or tribal government can make an initial determination whether it wishes to continue. During that time, the implementer will have to demonstrate its trustworthiness by the series of decisions and actions it takes. In particular, a community or tribe that did not volunteer can test whether the implementer has come to merit trust and confidence.

With respect to the second challenge, the proposed process protects the interests of each level of government. The community or tribe retains the right to withdraw up until the time that a license application is submitted. During that period, it will be able to evaluate the trustworthiness of the implementer. Of course, the community or tribe through the partnership will continue to exercise substantial power during the construction and operational phases of the repository-development process.

A state government would retain a strong, but not absolute, veto, which it could exercise once the partnership and the regulatory authorities have spoken. Under the current law, passage of an override resolution requires just the approval of simple majorities in both houses. That rule makes it too easy for a reverse "Not-In-My-Backyard" sentiment to prevail. *By requiring supermajorities in both houses of Congress, the proposed process makes it much more difficult to reverse a state's objections, especially if other suitable sites can be developed. In this way, the proposed process protects the national interest but does so in a way that respects a state's views.*[9]

RECOMMENDATIONS

- The Steering Committee recommends the adoption of a consent-based siting process that (1) establishes strong bonds of trust between local communities, tribes, and states on the one hand and the implementer and that (2) fairly allocates power among the parties.

  The Steering Committee proposes ways by which those two objectives might be secured.

  - ***Collaborate to design the siting process.*** Consent-based siting necessarily involves multiple players, who agree to initiate a process and become active participants willing to sustain siting activities over an extended period. The extent to which the siting principles and repository-development process reflect the expectations and values of interested and affected parties improves the chances of a positive outcome.

  - ***Entrust the siting process to a strong and trustworthy organization.*** An organization that has established itself within a stable political environment will be

[9] Moreover, like the host community or tribe, the state will continue to exercise substantial influence during the construction and operational phases of the repository-development process.

needed to lead the process and be the trusted guardian of the siting. Such an organization will embrace and reflect in its operations the values that will be central to earning and sustaining public trust and confidence.

- ***Articulate a clear decision-making path.*** From the early engagement regarding society's expectations for a siting process, it will become evident what is required to provide clarity and confidence at the outset.
- ***Assemble information required to support participation.*** Early engagement by the implementer can lead to an understanding of public expectations about the information required to launch the siting process.
- ***Partner with local, tribal, and state governments.*** Once engaged, these entities will wish to co-design the journey and establish appropriate control over the process.
- ***Provide an appropriate, ethically-based platform for inviting communities to explore the repository project and consider their potential interest in hosting the repository.*** The implementer will need to provide early steps focused on the learning process and exploring the repository project.
- ***Build the conditions for sustained interest and momentum.*** A community must be a continuing strong proponent of learning about the project and participating in the siting process.
- ***Respect the need for flexibility and adaptability.*** It will not be possible at the outset to foresee all of the programs, resource needs and process details that will be essential at each point in the long multi-year period of site evaluations and repository development.
- ***Adopt a process for approval of a repository site that gives substantial authority to the local municipality, tribe or state to stop the process of site selection and repository construction.*** The decision by local and tribal governments to object should come after an appropriate period of engagement and the completion of important scientific and engineering studies. A possible point of decision could be anytime before the formal submission of the license application to the regulatory authority. A state's objection after a license has been granted could only be overturned by a supermajority of both houses of Congress.

- **Finally, in order to insure a fair process, more than one site should be characterized, just as the 1982 Nuclear Waste Policy Act originally required.**

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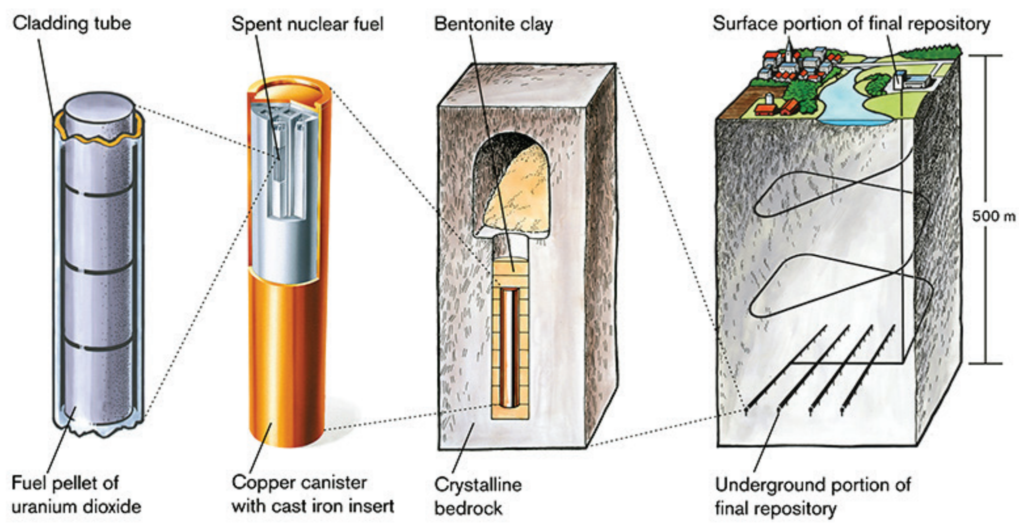

A key tenet of geological disposal of nuclear waste is the concept of multiple barriers—engineered and geologic. In Sweden, the KBS-3 concept is based on placing the spent nuclear fuel in iron inserts that are then placed within copper canisters that are five centimeters thick, and then the whole waste package is surrounded by bentonite clay and emplaced at approximately 500 m depth in groundwater-saturated granitic rock. Each element of this strategy has a role to play in delaying the release of radionuclides. Engineered barriers are designed to contain the fuel within the canister. When and if the canisters are breached, the second safety function of the barriers is to retard the release of radionuclides. One of the compelling arguments for safety is the use of natural materials, copper and bentonite, that are known for their very long-term stability. Also, the repository is designed to avoid high temperatures that might accelerate the corrosion and failure of materials. SOURCE: *Permission from SKB. Allan Hedin and Olle Olsson (2016)* Elements, *vol. 12, page 247.*

Regulations, Risk and Safety

There is an international consensus that a deep-mined, geologic repository, at an appropriate site and properly designed, can contain radioactive waste for the long periods required to meet regulatory requirements and ensure public safety. The "containment "strategy has three legs:

- containment until radioactive decay has eliminated most of the inventory of radionuclides;
- reduced mobility of radionuclides to ensure that they only arrive to the biosphere after a long time;
- sorption on mineral surfaces and dilution during transport that reduce the exposure to humans.

The safety assessment of a geologic repository evaluates the changing inventory of radioactive nuclides, their release from engineered barriers, such as the waste package, and the movement of radionuclides through surrounding geology to the near surface, and finally, the biosphere. The spatial and temporal scales of the assessment extend from atomic-scale phenomena to distances of tens of kilometers and out to hundreds of thousands of years.

TIME

One of the unique challenges of the geological disposal of nuclear waste is that safety assessments extend to times far into the future. This is because a number of the principal radionuclides have very long half-lives (*e.g.*, ^{238}U = 4.5 billion years; ^{129}I = 16 million years; ^{99}Tc = 400,000 years; ^{239}Pu = 24 thousand years). Fortunately, most of the radioactivity emanates from short-lived fission product elements (*e.g.*, ^{90}Sr and ^{137}Cs = 30 year half-lives). As a rule of thumb, over 99% of the radioactivity is gone after ten half-lives; hence after 300 years nearly all of the ^{90}Sr and ^{137}Cs have decayed away. In some cases radionuclides decay to longer-lived radionuclides (*e.g.*, ^{241}Am to ^{237}Np, which has a half-life of 2.1 million years). Thus, the composition and types of radioactivity change over time. Safety depends

TIME (CONTINUED)

on an evaluation of the ability of a geologic repository to contain highly-radioactive elements over short time periods and the reduced mobility of longer-lived radionuclides that will still be present after hundreds of thousands of years.

Regardless of the time frame, this is an unprecedented effort to protect future "human" generations out to times comparable to the evolution of the human species. EPA's standards are based on advice from the National Academy of Sciences (1995) that suggested that, "compliance with the standard be measured at the time of peak risk, whenever it occurs" (National Academy of Sciences 1995). Of course, this means, ironically, that the better the performance of the repository, the longer the time to peak risk and the longer the period of compliance.

Importantly, the period for regulatory compliance makes a difference in the results of the safety assessment. As an example, the compliance period for the New Mexico's Waste Isolation Pilot Plant, which is the disposal site for defense-generated transuranic waste, is 10,000 years. The compliance period for the proposed repository at Yucca Mountain for spent nuclear fuel and high-level waste is one million years. Why the differences in time frame? The DOE, which manages both sites, has not provided an explanation. Moreover, the original U.S. strategy for disposing of plutonium from dismantled nuclear weapons was to have placed this material (either immobilized in a ceramic waste form or as a used mixed-oxide fuel) at Yucca Mountain. But recently, the DOE has proposed to dilute-and-dispose of this same material at the WIPP site. The same plutonium will have vastly different regulatory frameworks—depending on the disposal site. Small wonder that the public remains confused about the standards for safety.

...this is an unprecedented effort to protect future "human" generations out to times comparable to the evolution of the human species.

In the course of developing a geologic repository, an implementing organization must make a persuasive case that the site that has been selected is technically suitable.[1] The implementer typically presents an argument that the location in question satisfies a pre-established set of site selection criteria for the repository's projected ability to isolate and contain the radionuclides. The strength of that argument generally is judged, in at least a *pro forma* manner, by a designated political institution, such as Congress or the country's parliament.[2]

[1] In addition, the choice of a site must also be socially acceptable. This requirement is discussed in detail in the chapter on public engagement and consent-based siting.
[2] Sweden is a notable exception to the last two statements. The implementer, SKB, never established formal site-suitability criteria. Further, its choice of a location in the Municipality of Östhammar was never formally ratified by any arm of the Swedish Government.

At a later date, after the site has been more intensively explored and characterized, the implementer submits to its regulatory authority a license application to construct the facility. That body determines whether the implementer has demonstrated *compliance* with pre-established rules or regulations. In making that compliance determination, the regulator most often uses qualitative statements, such as "reasonable assurance" or "reasonable expectation" to describe its confidence in its safety analysis.

At its October 2016 meeting, the Steering Committee heard presentations by implementers and regulators from France, Sweden, and the United States. In addition, it listened to scientists describing the strengths and weaknesses of several quantitative modeling methodologies used to project the behavior of natural and engineered systems in a geologic repository into the far future.[3] From those discussions came one clear conclusion: nations differ substantially in how they craft site-selection criteria and how they design the rules by which a license application is evaluated, but almost all are using or intend to use a *safety case* to evaluate their sites. Thus, there is an opportunity to reflect on and devise a regulatory framework that responds to the technical and social requirements for safety.

In the pages that follow, the Steering Committee first reviews how site-selection criteria have been fashioned. Most important is the question of how those criteria are used to compare and rank potential sites and to determine which particular site should be chosen as the location of a geologic repository. The Steering Committee then considers options for designing licensing rules. Of particular interest is how evidence is marshalled to support a claim that the repository can meet societal safety goals over the very long term.

UNCERTAINTY

There are many types of uncertainty that must be considered in the safety assessment of a geologic repository. Most commonly, analysts focus on the uncertainty in parameter values that are inputs to the models and the conceptual uncertainty in the models themselves. Does the model describe the physical or chemical process accurately? Are we even aware of all the relevant processes? Since the repository is expected to operate over geologic periods, we may not have even yet observed some of the relevant processes and therefore they will not be included in the analysis. Equally important over very long periods, but more difficult to quantify, is the uncertainty in the boundary conditions over time, such as the possibility of earthquakes, glaciation or erosion. Hence, the model uncertainty increases over time. Furthermore, natural geologic systems are complex and difficult to characterize completely. Any assessment of a disposal facility system will need to consider both constraints. Therefore, assessments of the disposal system will by their nature be more qualitative for longer times.

In addition, natural geologic systems are complex: the geologic properties relevant to the long-term safety of the geologic disposal facility can vary from location to location

[3] These methodologies are critically important in making the case for site suitability and for judging whether a license application complies with regulatory requirements.

UNCERTAINTY (CONTINUED)

underground, and over very long timeframes, can gradually change. While the engineered portions of the disposal system, such as the containers in which the spent fuel or high-level waste will be placed, are designed to last a long time, they, too, will eventually degrade in a manner that may not be known. The development of conceptual and numerical models of individual parts of the geologic disposal system must take into account such variations and uncertainties. Detailed site investigations should provide a better qualitative and quantitative understanding of these variations and uncertainties that will then be used in the development of the conceptual and numerical models.

SITE-SELECTION CRITERIA

When implementers began work in the mid-1960s, they focused on developing a repository within a particular host rock. Salt was the preferred formation in Germany and the United States. Crystalline rock was favored in Scandinavia and Switzerland. The implementer adopted *exclusion criteria*, such as proximity of natural resources or volcanic and earthquake prone regions, to initially disqualify certain locations. *Host-rock-specific criteria* also were used to winnow broad areas down to candidate sites. These criteria included the degree of fracturing, rate of groundwater flow, water chemistry (Eh and pH), homogeneity, and sorptive capacity of the surrounding rock.

A fundamental paradigm shift arose in the mid-1970s that changed the focus from the host rock to the repository system as a whole, therefore including other natural barriers, such as the hydrogeologic environment and engineered barriers, such as the waste form and backfill. Implementers in countries with diverse geologies realized that a different type of site-selection criteria might be required in order to compare and rank potential locations where dissimilar disposal concepts might be developed. *Generic criteria* were crafted that would arguably portend a site's suitability.[4]

A prototypical example of generic criteria was proposed by the International Atomic Energy Agency (IAEA 1977). It proposed the following hydrogeologic characteristics that could affect how well a repository might isolate and contain high-activity radioactive waste.

- Age, size and homogeneity of the rock unit
- Parameters that constrain the rate and amount of groundwater flow
- Geochemical conditions that will reduce the concentration of radionuclides in the groundwater or increased their sorption onto mineral surfaces
- The possibility of confounding geologic events, such as earthquakes, volcanism, glaciation or erosion
- The possibility of human intrusion, such as drilling or excavation, in the search and development of mineral or energy resources.

[4] See NWTRB 2015: 29-32 for a detailed discussion of these three types of site-selection criteria.

Experience in the United States

The United States is a large country and one with diverse geologic possibilities for a nuclear waste repository. Conceivably a repository might be developed, not only in salt and crystalline rock, but also in clay formations. With the passage in 1982 of the Nuclear Waste Policy Act (NWPA), Congress authorized the Environmental Protection Agency (EPA) to set standards for developing a repository and the Nuclear Regulatory Commission (NRC) to implement those standards through regulation. Both the standard and the regulation would apply to any repository of high-activity radioactive waste.[5]

Congress also made clear its intention that sites associated with different disposal concepts *had to be compared* before one could be selected (NWPA Section 112[a]). NRC's rule has a section devoted to the considerations that had to be incorporated into generic site-selection criteria (10 CFR 60.122). The NRC required DOE to adopt those considerations into its own regulation.

Between 1983 and 1985, DOE worked to develop the site-selection criteria. In the Steering Committee's view, DOE made a serious effort to engage interested and affected parties, even to the point of not truncating the public-comment process for the sake of meeting project schedules. The DOE produced several draft rules and, in some important respects, took suggestions from those parties to heart.

The final rule, 10 CFR 960, contains three major parts:

- Implementation guidelines detailing a process for selecting a site for repository development
- Technical criteria
    - o Pre-closure guidelines delineating the site characteristics that affect the construction and operation of a repository, including cost, transportation, and socioeconomics.
    - o Post-closure guidelines governing the site characteristics that affect the long-term performance of a repository.
- Guidelines setting forth very general principles for comparing sites.

For each technical criterion, the regulation specifies qualifying conditions, favorable conditions, potentially adverse conditions, and disqualifying (exclusion) conditions.

DOE officials soon discovered that the methodology outlined in the regulation for comparing and ranking sites was of limited value. In 1985, DOE attempted to use the rule to winnow down potential sites for the legislatively mandated second repository. That effort exacerbated political concerns and was terminated by Secretary John Herrington.

[4] In 1985, the EPA issued a standard (40 CFR 191) that set the allowable release to the public at the dose equivalent of 10 mrems/year. It further required that any repository meet that release limit for at least 10,000 years. That standard was overturned by the Court of Appeals for 1st Circuit. Only in 1992 did Congress permit EPA to reinstate that standard for repositories other than one built at Yucca Mountain.

The Steering Committee looked more closely at DOE's second attempt to apply its site-selection criteria in the following year. As required under the 1982 NWPA, DOE carried out Environmental Assessments for each of what it considered the five most promising locations. It then had to decide how to synthesize the collected information on all the various characteristics. The objective was to identify three sites worthy of further investigation.

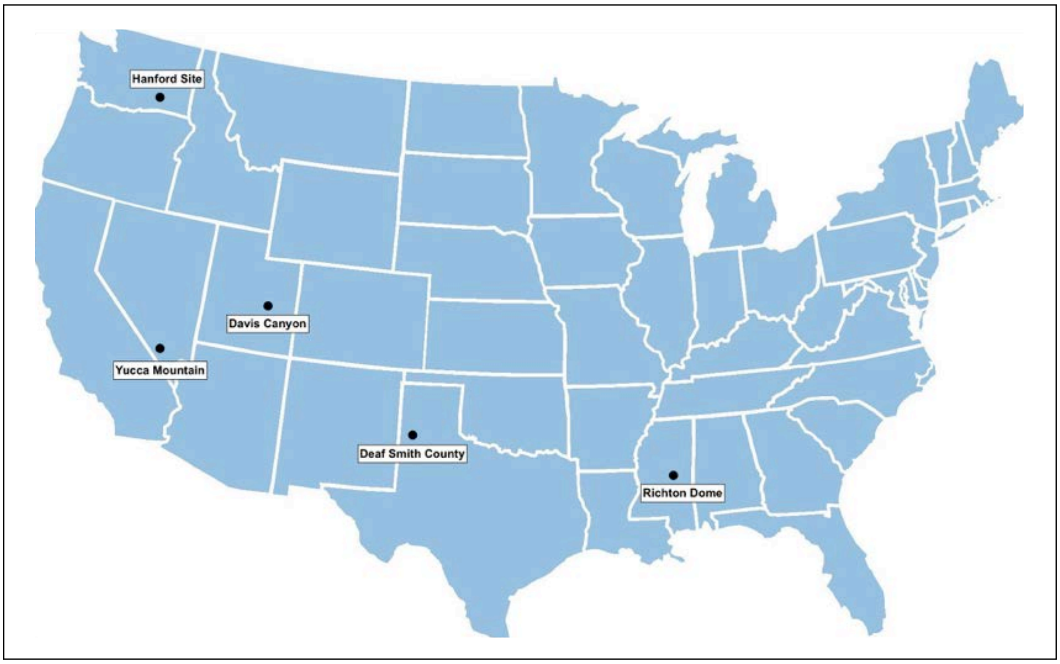

FIGURE 5.1. The early, initial sites considered for a geologic repository by DOE.
DATA FROM: *SWIFT 2018*

DOE proposed three site-ranking methodologies, all of which became the object of immediate and strong criticism from interested and affected parties.[6] Most devastating and influential was the critique leveled by National Academy of Sciences' Board of Radioactive Waste Management (Parker 1985).

After a set of tense exchanges with the Academy panel, DOE eventually settled on a methodology termed "Multiattribute Utility Analysis (MUA)." Based on its evaluation of both the pre- and post-closure guidelines, DOE officials ranked the sites in the following order: Yucca Mountain, Richton Dome, Deaf Smith County, Davis Canyon, and an undefined site on the Hanford Reservation (DOE 1986a).

However, when Secretary Herrington recommended to President Ronald Reagan the three sites that merited further characterization, the order he proposed was Yucca Mountain, Deaf Smith, and Hanford. The Secretary explained why he departed from the MUA results

[6] None of these were clearly envisioned in the regulation.

by noting that the methodology was a "decision-aiding" not a "decision-making" process. In particular, he maintained that the MUA over-weighted the importance of cost and neglected completely the value of selecting sites in differing hydrogeologic environments (DOE 1986b).

One IAEA report put it well: "Members of the general public and representatives of local communities recognize that they have a clear stake in the outcomes of [siting] decisions and almost always seek to have their views taken into account by the policy elites" (IAEA 2007:40).

The "five-to-three" example, like the earlier one involving the second repository, confirms the accuracy of that observation. Whatever credit DOE earned for conducting an intensive public engagement process dissipated almost instantaneously. A congressional investigation produced documents that seemed to call into question DOE's objectivity (Memorandum to Jim Weaver 1986). The three states that had become clear targets called "foul" and rushed to explain why the sites within their borders were technically unsuitable.

DOE's experience in trying to apply its site-selection criteria also makes clear the dilemma that an implementer might very well be exposed to when it seeks to compare and rank potential sites in vastly different hydrogeologic environments. On the one hand, it needs to prove to interested and affected parties that it is trustworthy by applying a "rule" that it is unbiased and uninvested in the outcome. On the other hand, it has a bureaucratic and legal interest in retaining its discretion in applying a "rule" to capture considerations that can escape even the most complex and sophisticated methodology. Trying to find an algorithm to avoid this dilemma strikes the Steering Committee as a futile exercise. However, there is an alternative.

The Safety Case Approach

The Nuclear Energy Agency (2004) defines a safety case as,

> "The synthesis of evidence, analyses and arguments that quantify and substantiate a claim that the repository will be safe after closure and beyond the time when active control of the facility can be relied on."

In many respects, the safety case is akin to a legal brief, advancing a compelling argument for safety. Through a safety case, an implementer reveals its understanding of the repository site and how it expects the radionuclides to behave in the repository over long periods of time. The safety case for a complex, geological repository system should consider the disposal site, its environment, and its evolution over time. To do so, it should address the waste inventories and waste form characteristics. It will need to explain how the disposal concept (repository architecture and engineered barrier system) contributes to the long-term performance of the system.

...the safety case is akin to a legal brief, advancing a compelling argument for safety.

The safety case undoubtedly includes quantitative analyses of the performance of the site, but these are only a part of the argument for safety. Qualitative arguments for safety, such as the site remaining consistent with the site selection criteria, multiple lines of evidence, traditional notions of defense-in-depth, references to other similar geologic systems, and natural analogues should also be part of the safety case. The safety case includes a detailed examination of scenarios, including those that involve repository failure (IAEA 2012).

> *The safety case undoubtedly includes quantitative analyses of the performance of the site, but these are only a part of the argument for safety.*

The safety case must use plain language and jargon-free explanations of the most current understanding of repository behavior over time and the associated uncertainties. The plain language included in the safety case not only serves to make the information accessible to all and to build confidence and trust in the waste management organization and regulator, but it serves another important purpose. The safety case frames the strategy and reasoning of the safety assessment.

In sum, like the author of a legal brief, the implementer provides, through the safety case, an analysis of the system that is consistent with not only the expectations of the site selection criteria but also the combined behaviors of the major safety elements of the analysis. The safety case reveals the reasoning behind why the disposal facility is expected to be "safe" for whatever reasonable scenarios can be envisioned in the future.

"Confidence in safety" can be the most important result of creating of a solid and robust safety case. Such confidence is increased when the independent lines of evidence contained in the "brief" all point to the same conclusion. Confidence in safety is increased when affirmative answers can be given to questions such as these:

- Has the implementer displayed a deep understanding of the evolution of the repository system?
- Have alternative conceptual models of key phenomena been considered and have their implications for repository performance been evaluated?
- Have the uncertainties in the technical and qualitative analyses been clearly identified?
- Have "what if" scenarios of interest, not only to the implementer, but also to interested and affected parties, been considered?

Indeed, these questions can form the basis for a *dialogue* between implementer and regulator and between implementer and society. In the Swedish context, such dialogue has been termed "stretching." The implementer opens itself to queries from a variety of sources. If the response is deemed to be unsatisfactory, the queries are repeated until the responses are convincing.

For such a dialogue to be effective, the implementer must show an open, fair, and honest attitude toward those possessing less technical training; it must display a clearly visible attitude of care and concern for all interested and affected parties. The implementer and regulator should hold many public meetings to answer questions and provide explanations in person. Alternatives, questions, and issues posed by interested and affected parties must all be given fair and due consideration by the implementer and the regulator. In addition, funding should be made available for the affected community to hire their own technical experts to evaluate the claims contained in the implementer's safety case.

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In the course of engaging in this dialogue, disagreements are almost inevitable. It is possible, even desirable, to "institutionalize" mechanisms for ventilating and perhaps resolving these differences. A few examples of how to obtain and incorporate a diversity of technical views are:

- Recruit an independent group of technically competent scientists or engineers to review the work on the relevant scientific or technical aspects of the disposal system.
- Use of a formal "expert elicitation" process (Kotra et. al 1996). A range of experts can be asked to estimate the relevant system or process characteristics, and in some cases, the probability of a particular range of characteristics.
- Interact with the Nuclear Waste Technical Review Board (NWTRB), an independent federal agency established by the Nuclear Waste Policy Amendments Act in 1987. The NWTRB conducts regular public meetings on a range of specific scientific, technical, and logistical issues and reports to Congress and the President with its findings.

By advancing a transparent safety case and promoting an authentic dialogue with interested and affected parties, the implementer can minimize, although probably not eliminate, the consequences of being caught in the dilemma noted above. Universal agreement on the selection of a site will probably remain out of reach. But the process may increase the trust necessary to sustain the repository development process. Certainly, DOE's experience clearly demonstrates that repeating past approaches is unlikely to be successful.

Yucca Mountain – a Brief History

In 1987, in large part because of the controversies engendered by the process to select sites for both the first and second repositories and because of the escalating cost of characterizing multiple sites, Congress passed the Nuclear Waste Policy Amendments Act (NWPAA). This legislation, among other things, prohibited DOE from characterizing any site other than Yucca Mountain and placed the second repository on the back-burner. In effect, then, the NWPAA mandated Yucca Mountain as the site for the first repository for high-activity waste. Yet, DOE was still obliged to make a determination of suitability before Congress could make the selection official. Deciding how to do so would preoccupy DOE for more than a decade.

That saga begins in 1992, when Congress passed the Energy Policy Act. This legislation, among its other provisions, required EPA to promulgate Yucca Mountain-specific standards for developing a repository. Congress instructed the agency to base those standards on the advice of a committee chosen by the National Academy of Sciences. NRC would then conform its regulation to EPA's standard.

The panel's report concluded that the regulatory regime laid out in EPA's still-contested environmental standard, 40 CFR 191, was out of date and difficult to implement.[7] For Yucca Mountain, the report recommended that probabilistic performance assessment (PRA) methodology be used in its place. The panel also recommended that the period over which compliance had to be shown should be increased to the time of peak dose as determined by the performance assessment. For Yucca Mountain, that time extends to one million years (NRC 1995).

EPA and NRC eventually promulgated new regulations, 40 CFR 197 and 10 CFR 63 respectively, which were generally consistent with the Academy's advice.[8] Those actions resolved DOE's predicament about how to evaluate Yucca Mountain's suitability when, in effect, Congress had already declared the site suitable. If NRC were to review a license application, DOE reasoned, it would use probabilisitic risk assessment (PRA) to do so. It made sense then to harmonize suitability with licensability. To do so DOE also promulgated a new regulation, 10 CFR 963, which enshrined PRA as the methodology of choice. In 2002, Congress used that analysis to officially select Yucca Mountain as the site for the first repository for high-activity radioactive waste.

LICENSING

It is difficult to overstate the significance of the shift that took place when EPA and NRC adopted Yucca Mountain-specific standards and regulations. Formerly, the basis for granting a license to construct a repository was set forth in general terms.

> "The geologic setting shall be selected and the engineered barrier system and the shafts, boreholes and their seals shall be designed to assure that releases of radioactive materials to the accessible environment following permanent closure conform to such generally applicable environmental standards for radioactivity as may have been established by the Environmental Protection Agency with respect to both anticipated processes and events and unanticipated processes and events (10 CFR 60.112)."

In addition, the implementer had to demonstrate that the projected performance of specific barriers met precisely defined requirements (60.113). How compliance with the general and specific conditions was to be shown was left to the implementer's discretion.

[7] By extension, NRC's licensing regulation, 10 CFR 60, was equally flawed.
[8] Both agencies, however, retained the 10,000-year compliance period. That decision was challenged in the Appeals Court for the District of Columbia Circuit and was overturned. For the moment at least, the Yucca Mountain compliance period is 1,000,000 years. The dose limit is 15 mrem for the first 10,000 years and 100 mrem subsequently. The State of Nevada has challenged those limits in court, but the suit has been suspended for nearly a decade.

A Total System Performance Assessment (TSPA), a variant of PRA, occupies the center of NRC's Yucca Mountain-specific licensing regulations. TSPA "is a probabilistic analysis that identifies the features, events, and processes that might affect the performance of the repository; examines their effects on performance; and estimates expected annual dose to the potential receptor" (DOE 2002: Section 4.2). To show compliance with the regulations, DOE depends almost exclusively on the results of TSPA.

TSPA is a complex computer simulation of repository behavior over hundreds of thousands of years based on many tens of quantitative models of the overall repository system. These "subsystem" models include models that project climate conditions, hydrologic models of the zones above and below the water table, models of the thermal, mechanical, and chemical changes that the waste and the local geology would experience over time, models of the waste form itself and how it would degrade over time, and models of radionuclide nuclide transport, once released from the waste. The interconnections among the subsystem models are illustrated in Figure 5.2.

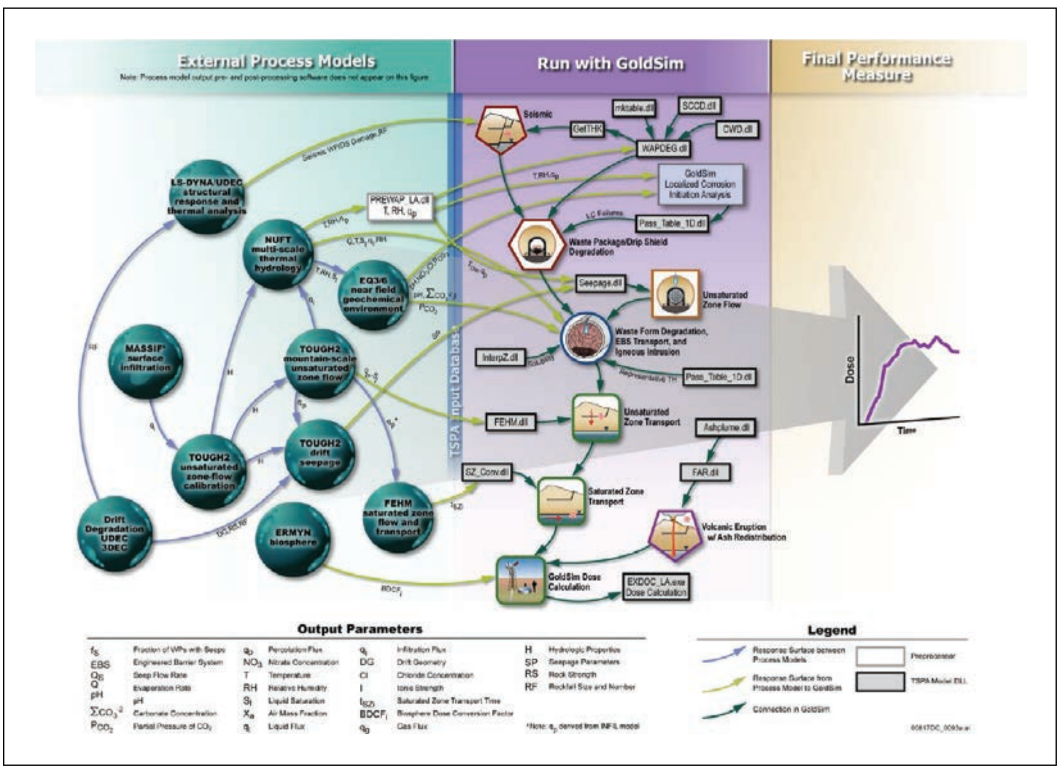
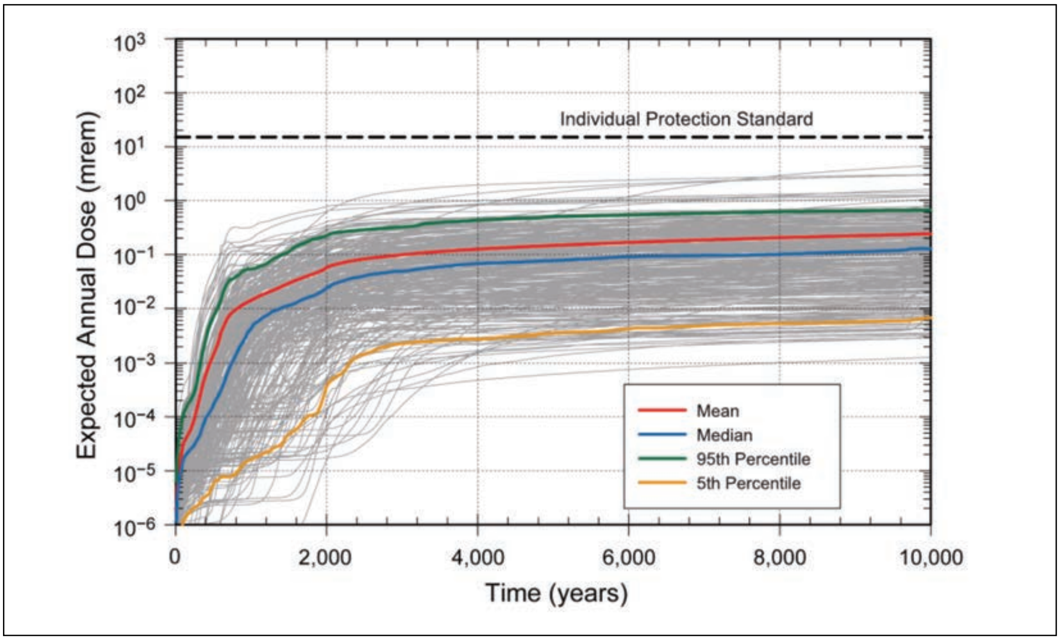


FIGURE 5.2. Schematic of the model linkages used for the total system performance assessment of the proposed geologic repository at Yucca Mountain. SOURCE: *SWIFT 2018*

TSPA relies on Monte Carlo techniques to generate a set of “realizations.” These realizations are displayed in the “horsetail” diagram shown below (Figure 5.3.) Compliance with the dose limits would be demonstrated if the mean of the realizations fell below the relevant dose limit at the relevant time.



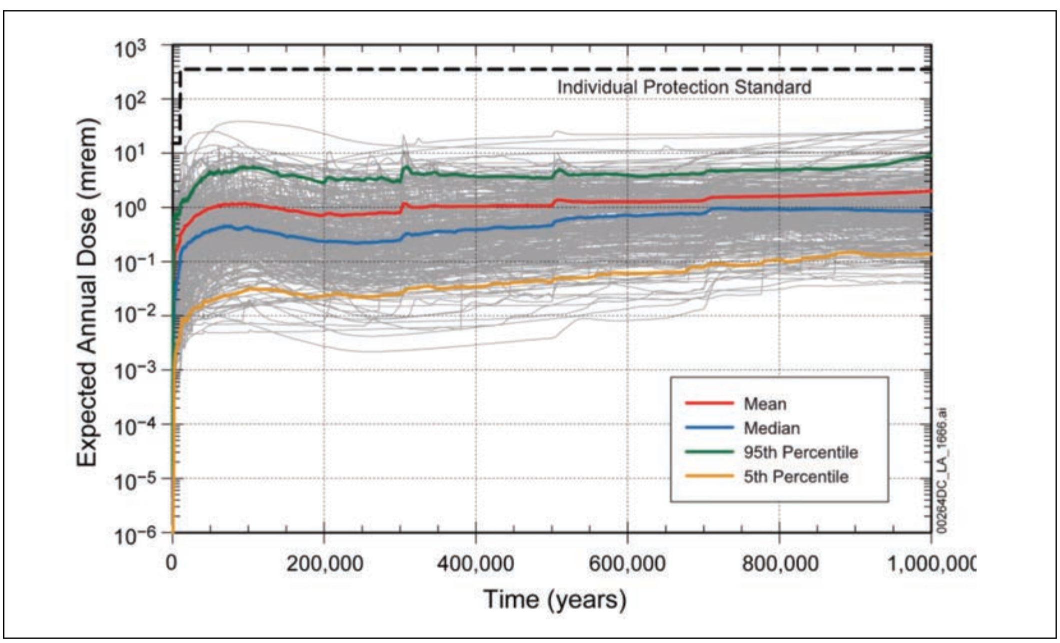


FIGURE 5.3. Example of a horsetail diagram used to evaluate the long-term performance of Yucca Mountain after 10,000 years (top) and 1,000,000 years (below). SOURCE: *Modified from DOE/RW-0573 Rev. 1 Figure 2.4-10, SWIFT 2018*

TSPA, although documented by thousands of pages of highly technical detail, is difficult to understand and opaque to virtually all interested and affected parties. Only a handful of experts can comprehend all the different subsystem models and how they are integrated. TSPA therefore fails to offer a clear and convincing answer to the question: *How confident can we be that the repository site will perform as required?*[9]

Evidence—*pro and con*—to support the technical bases for all models and parameter values is not transparent. The development of the final models in the TSPA, along with the regulatory review, occurs among a small set of technical and regulatory experts. In addition, the emphasis on a calculation of dose as a measure of risk means that all of the uncertainty in the physical and chemical models is conflated with the uncertainty in understanding the exposure and effects of low doses of ionizing radiation. The probabilistic calculations provide numerical results of the "dose risk,"[10] but the uncertainty of the physical and chemical process models is then hard to evaluate. Even though probabilistic models are mandatory for addressing the conceptual and parameter uncertainties, their results offer only one of many indicators of safety. Consistent deterministic scenarios, like those used in France and Sweden, provide additional indicators allowing a clearer explanation of how the repository is expected to evolve and its potential impact on the biosphere. For example, simple bounding case analyses can show in a transparent, understandable manner whether the results of the more complex analyses are credible, even if quantification of many processes remains highly uncertain.

The overall state of uncertainty in risk analyses must be made transparent for both external technical and non-technical stakeholders. One of the most striking panel discussions during the Reset meetings (October 2016) occurred among experts in hydrology and geochemistry and skilled practitioners of probabilistic risk assessment methodologies. This conversation exposed a huge gap between the limitations of the use of models to describe geologic systems and the application of those models in a PRA (see for example, Konikow and Bredehoeft 1992; Bredehoeft and Konikow 1993; Nordstrom, 2012; Ewing *et al.* 1999; Oreskes *et al.*, 1994). When the public sees such a divergence among the judgments of technical experts, their confidence is understandably diminished.

The need for openness and clarity in the development of conceptual and numerical models of the long-term evolution of the disposal system and the choice of numerical model parameter values is an essential part of the successful evaluation of repository performance. The Steering Committee recognizes that a TSPA-like analysis can provide valuable insights into the long-term behavior of a complex natural and engineered system, such as a deep-mined, geologic repository. But it is not the sole means of doing so, and it should not be the only basis for determining whether a particular design meets expectations for protecting health, safety, and the environment.

[9] It might well be argued that the adjudicatory hearing, which must be held before a license can be approved, provides the venue for contesting these issues. The Steering Committee agrees but believes that additional measures need to be taken to understand the value and limitations of relying on TSPA.

[10] "Dose risk" expresses the actual intention of the EPA and NRC regulations for Yucca Mountain and the Waste Isolation Pilot Plant—a probability-weighted assessment of the projected annual dose rate. An alternative approach when considering probabilistic approaches is to calculate "health risk" in which the projections of annual dose rate are supplanted by the projections of the probability of, for example, a latent cancer fatality.

The Steering Committee holds that the safety-case approach, which includes, but is not limited to quantitative calculations, is a better way to establish confidence that the repository system will meet the demands that the public expects.

The Steering Committee holds that the safety-case approach, which includes, but is not limited to quantitative calculations, is a better way to establish confidence that the repository system will meet the demands that the public expects.

This conclusion follows naturally from the discussion above. When there is a divergence of views over technical issues, the broader arguments for safety become even more important to understand (Jasonoff 2007). A process built around a dialogue over an augmented safety case, even prior to submission of a license application, provides an opportunity for interested and affected parties to challenge key hypotheses (alternative scenarios and conceptual models, parameter values) in the overall risk analyses.[11] Moreover, the safety case encourages a reassessment of a site's suitability in light of new information derived from intensive characterization that occurs after a location has been selected.

This reexamination must be able to clearly address not only technical issues, but also political and stakeholder questions and concerns. It must also account for other qualitative factors, such as economic impacts at the federal, state, and local levels, intergenerational risk tradeoffs, psychological risks, impacts to biota, and others. The safety case allows for multiple exchanges among interested parties in the definition of risk.

Finally, using a safety case approach helps to ensure that the regulatory determination of compliance is consistent with common sense expectations for the role that important parameters (e.g., tectonic stability, limited movement of water through the repository horizon, and redox conditions) play in determining the long-term safety of a site (Ewing and Macfarlane, 2002). In short, the quantitative analysis of safety must, in the final analysis, support the qualitative understanding of repository performance and public expectations.

STANDARDS

Yucca Mountain Standard: The safety assessment of the Yucca Mountain site is based on a probabilistic analysis of the annual dose that a person might expect to receive at a distance of 20 kilometers from the site. During the first 10,000 years the dose limit is 0.15 milliSieverts (= 15 millirem). Beyond 10,000 years out to one million years the dose limit is one milliSievert (100 millirem). For comparison, typical exposure to natural radiation sources is on the order of 300 millirem per year.

Waste Isolation Pilot Plant Standard: The safety assessment of WIPP combines a probabilistic analysis with a probabilistic standard. The cumulative release should have a

[11] This means that local communities and states should be provided support so that they have their own, trusted experts who participate in the safety evaluation.

STANDARDS (CONTINUED)

likelihood of one chance in ten of exceeding specified quantities (Table 1 in Appendix A; 40 CFR191.13) and a likelihood of one chance in a thousand of exceeding the specified quantities by a factor of 10 over a period of 10,000 years. The calculated cumulative release based on Table 1 in 40 CFR191.12 is scaled to the total inventory disposed of at WIPP, *e.g.*, increasing the inventory increases the amount that can be released.

An important recommendation of the *Blue Ribbon Commission for America's Nuclear Future* (2012) is that the U.S. have a generic standard and supporting regulatory framework. A generally applicable standard would be very useful in the comparison of different sites that have different geologic settings and certainly would enhance public trust in the process of site comparison and selection.

SAFETY ASSESSMENTS IN OTHER COUNTRIES

Most countries with advanced nuclear waste repository programs have developed safety cases for their proposed repositories, including Finland, Sweden, France, Belgium, Switzerland, the UK, and Canada. Finland and Sweden have already completed safety cases for their license applications and provide good examples of what safety cases should include. In most cases the safety case analysis extends to one million years.

Posiva Oy, Finland's nuclear waste management organization, submitted their safety case, TURVA-2012, to support their license application to construct a repository in 2012. Their safety case included a description of the radioactive waste intended to go into the repository, a description of the geology of the site (Olkilouto), and both the natural and engineered systems that will make up the repository. The data in the safety case included quantitative analysis: models and data to support a performance assessment that evaluated not only the performance of the repository but also the ways in which it might fail and release radionuclides to the environment. The safety case also included qualitative data that supported the quantitative analysis as well as a synthesis of all the arguments that show the repository will perform safely (Vira and Snellman 2013).

Another example of a safety case was provided by Svensk Kärnbränslehantering AB (SKB, the Swedish organization responsible for used fuel storage, transportation, and disposal in that country). Svensk Kärnbränslehantering AB (SKB) 2011 describes the safety assessment in simple terms:

"The main purpose of a safety assessment of a final repository is to investigate whether the repository can be considered radiologically safe over time. In principle, this is established by comparing estimated releases of repository derived radionuclides and associated radiation doses with regulatory criteria. For a KBS-3 repository, the primary safety function is to completely contain the waste for hundreds of thousands of years.... An important purpose of this safety assessment is, therefore, also to analyse the repository's

SAFETY ASSESSMENTS IN OTHER COUNTRIES (CONTINUED)

> potential for containing the wastes under a wide range of circumstances and for a very long time.
>
> Appropriate scientific and technical support for all statements made and data selected is essential to give confidence in the calculated results. Demonstrating understanding of the disposal system and its evolution is thus a crucial component in any safety assessment."

The lead technical report supporting SKB's license application for a disposal facility is an example of a detailed safety case. It starts with a general description of what was explored and how the assessment of long-term disposal facility behavior (performance assessment) was conducted by Svensk Kärnbränslehantering AB. The safety case in its simplest form describes the disposal facility, the purpose of the safety assessment, the regulations that guide nuclear waste disposal, the organization of the site project, and some of the technical issues: site investigations and modeling, the engineered systems in the repository, and the development of the spent fuel canisters.

The remainder of the three-volume, approximately 700-page report describes these issues in more detail, but still at a higher level. The report addresses the features of the disposal system and discusses the uncertainties in future scenarios and system parameters, and how they were addressed (*e.g*, bounding (worst case) scenarios, probabilistic risk assessments, and use of "natural analogs"). Supporting this report are thousands of pages of additional, more detailed reports on all aspects of the disposal system, regulations, and how compliance was demonstrated.

RECOMMENDATIONS:

- The Steering Committee recommends that the implementer be required to develop a safety case during the initial stages of disposal site investigation, and to regularly update the safety case as additional information is included and as it receives comments from various stakeholders and other interested parties. While formal compliance calculations will still be an essential part of the licensing process, the primary vehicle for communication with the broadest set of stakeholders and other interested parties should be the safety case. In addition, the license application should be based on the safety case, as it has been developed during the selection, characterization and design of the repository.
- The Steering Committee recommends that a new approach to geologic disposal repository regulation be adopted that recognizes that uncertainty in predicting performance grows over time. Fundamentally, these alternative approaches include a stronger reliance on quantitative analyses for shorter periods of time (such as perhaps up to

several thousand years), with reliance on more qualitative factors over longer periods. However, quantitative calculations for long time periods are still useful as a starting point for qualitative analyses. A new regulatory framework will need to be established in order to establish the safety case approach as the basis for the license application.

- Finally, an essential step in building trust and ensuring that the safety case is adequate is through formal peer review. The Reset Committee recommends an independent, continuing, internationally-based peer review of the safety case. Sweden, Switzerland, and France conducted such an independent review through the Nuclear Energy Agency's international expert group (NEA 2012).

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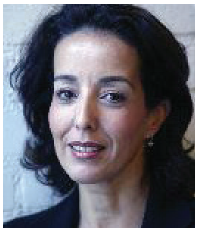
Appendix A:
RESET OF U.S. NUCLEAR WASTE MANAGEMENT STEERING COMMITTEE MEMBERS*

Professor **Sally M. Benson** is a Professor of Energy Resources Engineering at Stanford University and the director of Stanford's Precourt Institute for Energy and the Global Climate and Energy Project (GCEP), a pioneering university-industry partnership to develop innovative, low-carbon energy supplies to meet global energy needs. Prior to coming to Stanford, Professor Benson was at Lawrence Berkeley National Laboratory, a U.S. Department of Energy National Laboratory.

Professor **Rod Ewing** is in the Department of Geological Sciences at Stanford University and the Frank Stanton Professor in Nuclear Security at the Center for International Security and Cooperation. Professor Ewing's research focuses on the back-end of the nuclear fuel cycle, mainly nuclear materials and the geochemistry of radionuclides with application to permanent geologic disposal.

Dr. **Peter Davies** is the Director of Sandia's Nuclear Energy and Fuel Cycle Programs (retired in 2017) and responsible for programs and capabilities that include nuclear engineering, nuclear safety and risk analysis, nuclear material transportation and storage, and repository science and engineering. Stepped down from the Steering Committee in May, 2017.

*Steering Committee members represent their own views and expertise not the positions or policies of their organization or employer.



Ms. **Saida Laârouchi Engström** is the Senior Adviser onVattenfall´s Strategy on power production and nuclear waste management. She has a background in chemical engineering and started her career in the Swedish Nuclear Inspectorate as a safety inspector of nuclear installations in Sweden. After 11 years, she joined SKB, first as a leader for feasibility studies to select a site for a final repository for spent fuel in Sweden. Under the site investigation project, Ms. Laârouchi Engström was in charge of the environmental assessment studies and licensing. Ms. Laârouchi Engström has been instrumental in establishing a trustworthy dialogue between SKB and all the stakeholders in Swedish society including the government.

Professor **Bernd Grambow**, Ecole des Mines de Nantes, holds the Chair on nuclear waste disposal and is head of the Subatech Laboratory. Professor Grambow is the former director of the national CNRS-academic/industrial research network NEEDS (nuclear: environment, energy, waste, society). His areas of scientific expertise are radiochemistry, nuclear waste disposal science, geochemical modeling, radionuclide migration in the environment, chemical thermodynamics, and dynamics of solid-liquid interfaces.

Dr. **John Kessler** was with the High-Level Waste and Spent Fuel Management Program at the Electric Power Research Institute (EPRI) from 1993 to June 2015. His experience includes the Yucca Mountain total system performance assessment using probabilistic methods, colloid-aided contaminant migration, LLW and spent fuel storage system design, waste solidification R&D, and aging management for used fuel storage systems. John led EPRI's effort to develop a probabilistic approach to understanding the overall impact of disposing of spent fuel in the candidate repository at Yucca Mountain. In June 2015 John formed his own consulting company with work in the general area of spent fuel and HLW management.

Dr. **Allison M. Macfarlane** is Professor of Science and Technology Policy at George Washington University and Director of the Institute for International Science and Technology Policy at the Elliott School of International Affairs. She served as Chairman of the U.S. Nuclear Regulatory Commission from July, 2012 until December, 2014. She was the agency's 15th Chairman, its 3rd woman chair, and the only person with a background in geology to serve on the Commission. Dr. Macfarlane holds a PhD in geology from the Massachusetts Institute of Technology and a BSc degree in geology from the University of Rochester. From 2010 to 2012 she served on the Blue Ribbon Commission on America's Nuclear Future. In 2018, she held the Fulbright Distinguished Chair in Applied Public Policy at Flinders University and Carnegie Mellon University Adelaide, Australia.

Dr. **Daniel Metlay** recently retired as a member of the Senior Professional Staff of the U.S. Nuclear Waste Technical Review Board after a 24-year career. Prior to his work at the NWTRB, Dr. Metlay taught in the political science at Indiana University, Bloomington and the Massachusetts Institute of Technology. He worked as a Research Scientist at Brookhaven National Laboratory, investigating operational and organizational issues at nuclear power plants. Dr. Metlay served as a Task Force Director on the Secretary of Energy Advisory Board and has testified before Congress and state legislatures.

Dr. **Mark Peters** is the Director of Idaho National Laboratory. Prior to becoming Director at INL, Dr. Peters was Argonne's Associate Laboratory Director of the Energy and Global Security Directorate, which is responsible for Argonne's programs in energy research—including energy storage, renewable energy, energy efficiency and nuclear energy—and national security. Dr. Peters also serves as a senior advisor to the Department of Energy on nuclear energy technologies and research and development programs and nuclear waste policy. Stepped down from the Steering Committee in January, 2017.

Christophe Poinssot is, as of August 2018, the Nuclear Counselor at the French Embassy in Beijing representing the French government in China for the whole civilian nuclear domain and supporting the industrial and scientific French nuclear partnerships within China. Previously, he was Head of the Research Department on Mining and Fuel Recycling Processes at the Nuclear Energy Division, French Atomic and Alternatives Energy Commission (CEA) where his department was tasked with developing spent nuclear fuel recycling processes and operating the Atalante facility. Since 2011, Poinssot has been a Professor of Nuclear Chemistry at the National Institute of Nuclear Science and Technology (INSTN). In 2017, he was awarded Officer from the French order "Palmes Académiques" and received the Van Geen Prize and Chair from SCK-CEN.

Dr. **Chris Whipple** is now retired but was formerly a Principal at ENVIRON. He has over 40 years of environmental engineering experience in the management of human health and environmental risk. Dr. Whipple has served on and chaired numerous national committees studying and advising on radioactive waste management, including committees of the National Academy of Sciences, USEPA and the National Council on Radiation Protection and Measurement. He currently serves as co-chair of the National Academy of Sciences (NAS) Report Review Committee.

Kathryn Shaver is former Vice President of Site Selection and Engagement for the Nuclear Waste Management Organization in Canada. She oversaw the site selection process for Canada's deep geological repository for used nuclear fuel. Ms. Shaver joined the NWMO upon its establishment in 2002 as Executive Director. She supported the three-year national dialogue and study of alternative management approaches and the development of the Adaptive Phased Management program subsequently approved by the Government of Canada in 2007. Ms. Shaver has an M.A (Economics) from Queen's University in Kingston, Canada. Ms. Shaver retired from the NWMO in 2016 and is presently an independent consultant.

Appendix B:

RESET SPEAKERS AND AFFILIATION FOR EACH MEETING

Meeting 1:

Dan Metlay, *Senior Professional Staff, U.S. Nuclear Waste Technical Review Board*

Peter Davies, *Director Emeritus, Sandia National Laboratories*

Mark Peters, *Associate Laboratory Director, Argonne National Laboratory*

Saida Laârouchi Engström, *VP of Strategy and Program, Swedish Nuclear Fuel and Waste Management Co. (SKB)*

Christophe Poinssot, *Director of Radiochemistry and Processes Department, French Atomic and Alternatives Energy Commission (CEA)*

Bernd Grambow, *Professor, Ecole des Mines de Nantes; Director, SUBATECH Laboratory*

Sally Benson, *Professor, Stanford University; Director, Precourt Institute for Energy*

Chris Whipple, *Principal, Environ, retired*

Jason Reinhardt, *Ph. D. Student, Stanford University*

Peter Swift, *Senior Scientist, Sandia National Laboratories*

Meeting 2:

Jeff Bingaman, *U.S. Senator (D-NM, retired)*

Allison Macfarlane, *Professor, Science and Technology Policy, Elliot School (George Washington University)*

Todd La Porte, *Professor Emeritus, Political Science, University of California, Berkeley*

Debra Knopman, *Principal Researcher, Rand Corporation*

Admiral Jim Ellis, *President and CEO, Institute of Nuclear Power Operations (INPO), retired*

John Kessler, Manager, *Used Fuel and High-Level Waste Management Program, Electric Power Research Institute* (*EPRI*), *retired*

Russell Jim, *Yakama Tribal Elder, Director of Yakama Environmental Waste Management Program*

Roy Gephardt, *Pacific Northwest National Laboratory* (*PNNL*), *Hanford, retired*

Bob Halstead, *Director, State of Nevada Agency for Nuclear Projects*

Margaret Chu, *Director, Office of Civilian Radioactive Waste Management, retired*

Ward Sproat, *Director, Office of Civilian Radioactive Waste Management, retired*

Siegfried Hecker, *Director Emeritus, Los Alamos National Laboratory* (*LANL*); *Senior Fellow, CISAC*

Dave Clark, *Director, National Security Education Center* (*LANL*)

Hans Forsström, *Senior Advisor, Swedish Nuclear Fuel and Waste Management Co.* (*SKB*)

Kathryn Shaver, *Vice President of APM Engagement and Site Selection, Nuclear Waste Management Organization*

Gerald Ouzounian, *Director of International Division, French National Radioactive Waste Agency* (*ANDRA*)

Meeting 3:

John Kotek, *Acting Assistant Secretary for the Office of Nuclear Energy DOE; former Staff Director, Blue Ribbon Commission of America's Nuclear Future*

John Heaton, *Volunteer Energy Coordinator, Carlsbad Department of Development, NM*

Don Hancock, *Director, Nuclear Waste Safety Program for the Southwest Research Center, NM*

Cash Jaszczak, *Consultant, Nye County, NV*

Timo Äikäs, *former Vice President, Posiva* (*video connection*), *retired*

Claude Birraux, *former Member, French Parliament*

Saida Engström, *Vice President, Swedish Nuclear Fuel and Waste Management Co.* (*SKB*)

Bruce Cairns, *Head of Geological Disposal, Department of Energy and Climate Change*

Kathryn Shaver, *Vice President of APM Engagement and Site Selection, Nuclear Waste Management Organization*

Daniel Metlay, *Senior Professional Staff, U.S. Nuclear Waste Technical Review Board*

Geoffrey Fettus, *Senior Attorney, Natural Resources Defense Council*

Ingvar Persson, *Legal Adviser, Swedish National Council for Nuclear Waste*

Ken Niles, *Assistant Director for Nuclear Safety, Oregon Department of Energy*

Talia Martin, *Tribal/DOE Program Director, Shoshone Bannock Tribe, Idaho*

Tom Clements, *Director, Savannah River Site Watch*

Russell Jim, *Yakama Tribal Elder, Director of Yakama Environmental Waste Management Program*

Geoffrey Fettus, *Senior Attorney, Nuclear Program, National Resources Defense Council (NRDC)*

Meeting 4:

Tito Bonano, *Senior Manager, Advanced Nuclear Energy Programs Group, Sandia National Laboratories*

Tom Cotton, *Vice President, Complex Systems Group, LLC*

Holger Volzke, *Division Manager, Bundesanstalt für Materialforschung (BAM)*

Andrew Orrell, *Section Head, Division of Radiation, Transport, and Waste Safety, IAEA*

Tyler Ownens, *Clerk, Senate Appropriations Subcommittee on Energy and Water Development*

Rod McCullum, *Senior Director, Used Fuel and Decommissioning, Nuclear Energy Institute*

Sylvia Saltzstein, *Manager, Used Nuclear Fuel Storage and Transportation, Sandia National Laboratories*

John Wagner, *Associate Laboratory Director, Nuclear Science and Technology, I daho National Laboratory*

Allison Macfarlane, *Professor, Science and Technology Policy, Elliot School (George Washington University)*

Adam Levin, *Director, Spent Fuel and Decommissioning, Excelon Generation Company*

Eric Howes, *Director, Public and Government Affairs, Maine Yankee*

John Kessler, *Manager, Used Fuel and High-Level Waste Management Program, Electric Power Research Institute (EPRI), retired*

James Rubenstone, *Branch Chief, Material Control and Accounting (Office of Nuclear Material Safety and Safeguards), U.S. Nuclear Regulatory Commission*

Mark Lombard, *Division Director, Spent Fuel Storage and Transportation (Office of Nuclear Material Safety and Safeguards), U.S. Nuclear Regulatory Commission*

David Lochbaum, *Director, Nuclear Safety Project, Union of Concerned Scientists*

Ted Quinn, *member, SONGS Community Engagement Panel*

Bob Halstead, *Executive Director, Nevada Nuclear Projects Office*

Allison Fisher, *Outreach Director, Public Citizen's Energy Project*

Meeting 5:

Allison Macfarlane, *Professor, Science and Technology Policy, Elliot School (George Washington University)*

Chris Whipple, *Principal, Environ, retired*

Tim McCartin, *Senior Advisor, U.S. Nuclear Regulatory Commission*

Peter Swift, *Senior Scientist, Sandia National Laboratories*

Claudio Pescatore, *Principal Administrator, Radioactive Waste Management, Nuclear Energy Agency (NEA, OECD), retired*

Allan Hedin, *Safety Analyst, Swedish Nuclear Fuel and Waste Management Co. (SKB)*

Patrick Landais, *Chief Technology Officer, French National Radioactive Waste Management Agency (ANDRA)*

Mathilde Maillard, *Head, La Gestion des Dechets Radioactifs, Autorité de Sûreté Nucléaire (ASN)*

Céline Kermisch, *Professor, Philosophy and Ethics of Risk, Université Libre de Bruxelles*

David Victor, *Director, Laboratory of International Law and Regulation; Professor, School of Global Policy and Strategy (UC San Diego)*

Otwin Renn, *Scientific Director, Institute for Advanced Sustainability Studies in Podstdam, Germany; Professor and Chair, Environment Sociology and Technology Assessment, Stuttgart University (video-chat)*

John Downer, *Senior Lecturer, Risk and Resilience, University of Bristol*

Andrew Stirling, *Professor, Science and Technology Policy, University of Sussex*

Kirk Nodstrom, *Senior Scientist, U.S. Geological Survey*

Lenny Konikov, *Scientist Emeritus, U.S. Geological Survey*

Kate Maher, *Assistant Professor, Earth System Science, Stanford University*

Ali Mosleh, *Director, John Garrick Institute for the Risk Sciences, University of California, Los Angeles*

George Apostolakis, *Professor, Nuclear Science and Engineering, Massachusetts Institute of Technology*

Appendix C:
PROSPECTUS AND AGENDA FOR EACH RESET MEETING

Meeting 1:

Reset of U.S. Nuclear Waste Management Strategy and Policy

February 17-19, 2015

PROSPECTUS:

The United States' nuclear waste management program is under extreme stress, with the Department of Energy (DOE) faced with substantial challenges across the country. In Hanford, Washington, the facility intended to solidify high-level waste is plagued with significant design challenges and significant cost overruns. In South Carolina, the construction of a Mixed Oxide Fuel Fabrication facility has exceeded its budget to the extent that development may be halted and alternative strategies pursued. In New Mexico, two accidents have led to the closure, for at least two years, of the Waste Isolation Pilot Plant. Yet, amidst these many challenges, the most demanding remains the siting and development of a deep-mined geologic repository for high-level radioactive waste and spent nuclear fuel, as evidenced by the stalemate in the Yucca Mountain project.

In 2002, Congress approved President George W. Bush's decision to site the nation's repository at Yucca Mountain in Nevada and, in 2008, the DOE submitted a construction application to the Nuclear Regulatory Commission. The process came to a standstill in 2010, when the Obama administration declared the repository "unworkable" and established the Blue Ribbon Commission on America's Nuclear Future (BRC) to recommend next steps. The BRC has since issued its report, the DOE has responded favorably, and there have been Senate hearings on bi-partisan legislation to implement the BRC's recommendations. Yet the measure never came to vote, and the stalemate is unlikely to end soon.

The current stalemate has overwhelmed serious discussion of technical and policy issues. Any new legislation must be informed by a thorough understanding and analysis of the history of the U.S. nuclear waste management program, and by the scientific, technical, social science, and policy challenges that beset it.

Purpose of this meeting: To inform efforts to reset the U.S. nuclear waste program, Stanford University's Freeman Spogli Institute for International Studies (FSI), Precourt Institute for Energy, and Center for International Security and Co-operation (CISAC) will sponsor a series of meetings over a two-year period, beginning in Fall 2015. Each meeting will focus on a critical issue for the formulation of a new legislative roadmap, and produce a white paper framing the critical issues that are likely to underpin any policy discussion. Taken as a whole, the white papers could be a "handbook" for Congress and the Executive as they fashion new legislation and restructure the federal agencies involved in nuclear waste management.

A preliminary meeting will take place in February 2015, when a steering committee of experts in nuclear waste management will guide a discussion (Chatham House Rules) of nuclear waste management strategies in the United States and abroad, and identify the critical topics for discussion in subsequent meetings.

Although no final determination has been made about the topics for future meetings, they may include:

- ***The creation of a new waste management organization:*** *Although recommended by the BRC, there has been only limited discussion of the structure, characteristics and funding of such a new organization.*
- ***Definition of a consent-based process for siting nuclear facilities:*** *A consent-based process requires the blending of social and technical criteria, but there has been no effort to design a technically-based, legal process that is compatible with the needs of a community, states, and federal government.*
- ***Alternatives to a mined geologic repository for SNF and HLW:*** *Because of the stalemate in siting a repository, there have been a number of new proposals on possible, alternative, disposal strategies (e.g., extended on-site storage or deep bore hole disposal), but there has been very limited discussion of how alternatives should be evaluated and compared.*
- ***Standards and regulations:*** *The regulatory framework in the U.S. places heavy demands on science and engineering (e.g., predictions of repository performance out to one million years). The revision of the regulations and standards may open the way to a more straightforward siting process for nuclear facilities and generate greater public acceptance. The fundamental question is how do we determine whether the repository is safe?*

Each of these issues has a generally unappreciated level of complexity. The discussion of each requires input across the broadest range of disciplines – science, engineering, social science, political science and law. Also, it is important to insure the participation of concerned members of the public, state governments, federal agencies, national laboratories, and universities, as well as members of the Executive and Congress.

Stanford's FSI and CISAC, as distinguished, policy-oriented organizations, offer a unique opportunity to address these difficult and controversial issues on neutral ground. Although broad participation is welcome, invited presentations from knowledgeable experts, in the U.S. and abroad, are absolutely necessary. There will be ample opportunity for Stanford faculty, FSI and CISAC fellows and Stanford graduate and undergraduate students to participate in the meeting.

The program committee for each future meeting will clearly state the purpose and issues to be addressed. After the meeting, the organizers will publish a white paper on the critical issues raised and proposed strategies for addressing those issues. The topical meetings would occur over two years, beginning in the fall, 2015. Taken as a whole, the white papers could be a "handbook" for Congress and the Executive as they fashion new legislation and restructure the federal agencies involved in nuclear waste management.

AGENDA:

Tuesday, February 17

8:00 Continental breakfast at CISAC

8:30 Welcome by Professor Mike McFaul, Director, FSI

8:45 Welcome: Organization and Purpose
Professor Rod Ewing, *Senior Fellow Center for International Security and Cooperation (CISAC)*

9:00 **The management of radioactive waste as a socio-technical challenge**
Dan Metlay, *Nuclear Waste Technical Review Board*

9:45 Coffee Break

10:00 **U.S. Experience with WIPP**
Peter Davies, *Sandia National Laboratories*

10:55 **U.S. Experience with Yucca Mountain**
Mark Peters, *Argonne National Laboratory*

11:45 Lunch

1:00 **The Swedish Program in granite**
Saida Laârouchi Engström, *SKB Sweden*

1:55 **The French program in clay**
Christophe Poinssot, *French Atomic and Alternatives Energy Commission (CEA, National Institute of Nuclear Science and Technology (INSTN)*

2:45 Coffee Break

3:00 **Nuclear waste disposal—safety and public debate in France**
Bernd Grambow, *Ecole de Mines, SUBATECH Laboratory*

3:50 Coffee Break

4:00 Open Discussion

** The open sessions are conducted under the Chatham House Rule. Participants are free to use the information received, but neither the identity nor the affiliation of the speaker(s), nor that of any other participant, may be revealed.*

Wednesday, February 18

8:30 Continental breakfast at CISAC

9:00 Overview and Plan for the Day, Professor Rod Ewing, *Senior Fellow Center for International and Cooperation* (*CISAC*)

9:15 **Impact of different fuel cycle options on disposal options**
Christophe Poinssot, *French Atomic and Alternatives Energy Commission* (*CEA*, *National Institute of Nuclear Science and Technology* (*INSTN*)

10:00 **Role of national laboratories in the U.S. program**
Sally Benson, *Stanford University*

10:45 Coffee Break

11:00 **Role of review bodies, such as the NAS, EEG, NEA and NWTRB, in the U.S. waste management program**
Chris Whipple, *ENVIRON*

11:45 Lunch

1:00 **Roundtable discussion: What does "safe" mean?**
Bernd Grambow, *Ecole des Mines de Nantes, SUBATECH Laboratory*
Jason Reinhardt, *Stanford University*
Peter Swift, *Sandia National Laboratories*
Chair: Rod Ewing, *CISAC*

2:30 Coffee Break

2:45 **Roundtable discussion: Issues that need to be addressed in the U.S. nuclear waste program**
Chair: Dan Metlay, **Nuclear Waste Technical Review Board**

Meeting 2:

The Structure and Behavior of a New Nuclear Waste Organization

Sept. 30 - Oct. 1, 2015

PROSPECTUS:

The first meeting of the Reset Project was held on the Stanford campus on February 17-18, 2015 (http://fsi.stanford.edu/events/“reset”-us-nuclear-waste-management). Three Stanford organizations, the Freeman Spogli Institute for International Studies, the Precourt Institute for Energy, and the Center for International Security and Cooperation, sponsored the meeting. After two days of presentations, the project’s steering committee identified a set of issues that were judged to be critical to the future success of the U.S. nuclear waste program. *A second meeting, September 30 to October 1, 2015, will be held at Stanford. This meeting will focus on one of the identified critical issues: the structure and characteristics of a new waste management organization for the United States.*

Issues associated with the design of a new waste management organization in the United States have been debated for at least 40 years. When Congress passed the Nuclear Waste Policy Act in 1982, it instructed the Secretary of Energy to undertake a study of alternative approaches for developing civilian radioactive waste-management facilities, including a deep-mined, geologic repository. Nearly 30 years later, Congress directed the Secretary to carry out another evaluation on alternative organizational arrangements. Neither study resulted in any change from the *status quo*. In 2012, the *Blue Ribbon Commission on America’s Nuclear Future* recommended that DOE’s responsibilities for managing radioactive waste be transferred to a new single-purpose organization. To date, Congress has not acted on this recommendation.

Discussions about a new waste management organization have focused on organizational form as the principal determinative factor, typically comparing the *pros* and *cons* of a traditional government agency, an independent government corporation, or a private nuclear utility-owned company. The situation is further complicated by the unique histories of success and failure in other countries. There is no clear evidence for the effectiveness of one organizational structure over another. A critical issue is the design an organization that can accomplish its mission in a complicated environment that requires interacting with and responding to the Federal government, States, and local authorities, as well as the concerned and affected public. Finally, by focusing only on the structure of an organization, its authority and source of funding, equally important questions are overlooked: What factors influence critical organizational behaviors? How can an organization facilitate its credibility and public acceptance? How do organizations learn and evolve in a changing political and social environment?

The Reset Project’s second meeting will focus on a broader exploration of organizational issues:

(1) How does an implementing organization interact with its technical, political, and legal environments? How does it maintain credibility within each of these three realms?

(2) How does an implementing organization “learn” over time? How does it adjust to new knowledge and a changing political environment?

The meeting will include presentations by experts in organizational behavior, both scholars and practitioners. In addition, panels representing different perspectives will be held on each day of the meeting. Considerable time will be set aside for discussion and audience participation.

AGENDA:

Wednesday, September 30th

Morning Session—Structure and Behavior of Organizations (Session Chair: Rod Ewing)

8:00 Continental breakfast at CISAC

8:15 Welcome by Professor Mike McFaul, *Director, FSI*

8:30 Welcome: Organization and Purpose, Professor Rod Ewing, *Senior Fellow Center for International Security and Cooperation (CISAC)*

9:00 U.S. Senator Jeff Bingaman *D, NM, retired*

9:45 Questions for all Speakers

10:15 Coffee Break

10:30 Allison Macfarlane, *Blue Ribbon Commission (BRC) member and former Nuclear Regulatory Commission (NRC) Chair*

11:00 Todd Laporte, *Professor Emeritus UC Berkeley*

11:30 Debra Knopman, *Rand Corporation*

12:00 Questions for all Speakers

12:30 Lunch

Afternoon Session—Interacting with Affected Parties (Session Chair: Chris Whipple)

1:30 Admiral Jim Ellis, *Institute of Nuclear Power Operation (INPO)*

2:00 John Kessler, *Electric Power Research Institute (EPRI), retired*

2:30 Russell Jim, *Yakama Tribal Elder and Director of Yakama Environmental Waste Management Program*

3:00 Coffee Break

3:30 Roy Gephardt, *Pacific Northwest National Laboratory (PNNL), Hanford, retired*

4:00 Bob Halstead, *Director State of Nevada Agency for Nuclear Projects*

4:30 Questions for all Speakers

5:00 Close of First Day

5:10 Shuttle from Encina Hall to Dinner

Thursday, October 1st

Morning—The Framework of Federal Organizations (Session Chair: Mark Peters)

8:00 Continental Breakfast at CISAC

8:45 Rod Ewing: Opening Summary of Previous Day

9:10 Margaret Chu, *Director of Office of Civilian Radioactive Waste Management (OCRWM), retired*

9:40 Ward Sproat, *Director of OCRWM, retired*

10:10 Questions for all Speakers

10:20 Coffee Break

11:00 Sig Hecker, *Director Emeritus of Los Alamos National Laboratory (LANL), Senior Fellow CISAC*

11:30 Dave Clark, *Director National Security Education Center, LANL*

12:00 Questions for all Speakers

12:30 Lunch

Afternoon Session—International Experience (Session Chair: Saida Engstrom)

2:00 Hans Forsström, *Swedish Nuclear Fuel and Waste Management Co. (SKB) – Sweden*

2:30 Kathryn Shaver, *Nuclear Waste Management Organization (NWMO) – Canada*

3:00 Gerald Ouzounian, *French National Radioactive Waste Agency (ANDRA) – France*

3:30 Coffee Break

4:00 Questions for all Speakers, *Saida Engström – Moderator*

4:30 Close of Meeting

4:30 Wine and Cheese Reception with CISAC Fellows, Faculty & Staff

Meeting 3:

Consent-Based Siting

March 9-10, 2016

PROSPECTUS:

The Reset Project's third meeting, March 9-10, 2016, will focus on another key issue: consent-based siting. In 2012, the Blue Ribbon Commission on America's Nuclear Future recommended a new, consent-based approach to siting future nuclear waste-management facilities. As a near-term action, the Commission recommended that future siting efforts be informed by past experience, drawing on experience gained in siting nuclear waste facilities in the U.S. and abroad. In 2013, the Secretary of Energy released the Administration's Strategy for the Management and Disposal of Used Nuclear Fuel and High-level Radioactive Waste, which endorsed the principles underlying the BRC recommendations (adaptive, phased implementation). Recently, the Department of Energy has invited public comment on the design of a consent-based siting process.

Critical to the success of any consent-based approach in the U.S. is that the implementer sustain public trust and confidence over decades and that there be a resolution of how power is distributed between the federal government on the one-hand and state/local governments on the other.

The Reset Project's third meeting seeks to advance the understanding of how a consent-based siting process might be designed in the U.S.:

1. What insights are provided from the U.S. experience for building local, Tribe and State confidence, and for initiating and sustaining consent-based siting?
2. How can consent-based siting be informed by the experience by other nuclear projects in the U.S or internationally?
3. How is "consent" sought, demonstrated and sustained?
4. What are priority areas for preparing the policy and regulatory foundations for consent-based siting?

These topics will be addressed over a two-day meeting, through presentations and panel discussions. Invited speakers will share their experience, drawing on their first-hand experience with consent-based siting—from those with direct experience at the levels of local government, Tribe and State governments, to implementers and regulatory authorities involved. Scholars and other experts will be invited to address some important ethical and legal dimensions of consent-based siting. Considerable time will be set aside for discussion and audience participation.

AGENDA:

Wednesday, March 9 :

9:00 **Welcome**, Professor Rod Ewing, *CISAC*

9:30 **U.S. and International Experience with Consent-Based Siting** (**Group Discussion**)

United States Strategy and Experience

John Kotek, *Acting Assistant Secretary for the Office of Nuclear Energy DOE and Former Staff Director, Blue Ribbon Commission of America's Nuclear Future*

John Heaton, *Carlsbad Department of Development, NM*

Don Hancock, *Southwest Research Center, NM*

Cash Jaszczak, *Nye County, NV*

12:00 Lunch

1:00 International Experience

Timo Äikäs (Finland), *Former Vice-President, Posiva* (*video-chat*)

Claude Birraux (France), *Former Member, French Parliament*

Saida Engström (Sweden), *Vice-President, SKB*

Bruce Cairns (United Kingdom), *Head of Geological Disposal, Department of Energy and Climate Change*

Kathryn Shaver (Canada), *Vice President, APM Engagement and Site Selection, Nuclear Waste Management Organization*

3:30 ***Group Discussion: Key Points and Issues from the Discussion***

4:30 Wine and Cheese Reception with CISAC Faculty, Fellows & Staff

7:00 Small Group Dinners

Thursday, March 10

9:00 **Welcome**, Professor Rod Ewing, *CISAC*

9:15 **Prerequisites for an Effective Consent-Based Siting Process in the U.S.**
Chair: Kathryn Shaver
Review of and key factors in the U.S. and international programs:
Daniel Metlay, *Nuclear Waste Technical Review Board*
Managing Consent in Two Nations:
Geoffrey Fettus, Senior Attorney, *Natural Resources Defense Council*
Ingvar Persson, *Legal Adviser, Swedish National Council for Nuclear Waste*

Maintaining Public Trust and Confidence over Decades:
Ken Niles, *Assistant Director for Nuclear Safety, Oregon Department of Energy*
Talia Martin, *Tribal/DOE Program Director, Shoshone Bannock Tribe, Idaho*
Tom Clements, *Director Savannah River Site Watch*

11:00 **Critical Issues in Consent-Based Siting—Part I**
Moderator: Mark Peters
Panel Discussion: *Bottom-Up or Top-Down: What does the public want?*
John Heaton, *Carlsbad Department of Development, NM*
Don Hancock, *Nuclear Waste Safety Program for the Southwest Research Center, NM*
Tom Clements, *Director Savannah River Site Watch*
Talia Martin, *Tribal/DOE Program Director, Shoshone Bannock Tribe, Idaho*

12:30 Lunch

1:30 **Critical Issues in Consent-Based Siting—Part II**
Moderator: Saida Engström
Panel Discussion: *Who Consents and How?*
Russell Jim, *Yakama Tribal Elder, Director of Yakama Environmental Waste Management Program*
Geoffrey Fettus, *Senior Attorney, Nuclear Program, National Resources Defense Council (NRDC)*
Cash Jaszczak, *Consultant, Nye County, NV*
Ken Niles, *Oregon Department of Energy*
Panel Discussion: *Withdrawing Consent: When and Under What Circumstances?*
Geoffrey Fettus, *Senior Attorney, Nuclear Program, National Resources Defense Council (NRDC)*
Kathryn Shaver, *Nuclear Waste Management Organization*
John Heaton, *Carlsbad Department of Development, NM*
Saida Engström, *SKB Sweden*

4:00 **What are the next steps in establishing a consent-based process?**
Moderator: Rod Ewing

5:00 Adjourn

7:00 Dinner for Speakers and Steering Committee Members

Meeting 4:

Integration of the Back-End of the Nuclear Fuel Cycle: Storage, Transportation and Disposal

May 17-18, 2016

PROSPECTUS:

Spent nuclear fuel must be managed from the time it is removed from the reactor to its eventual reprocessing or permanent disposal in a geologic repository. The present management strategy for commercial spent fuel in the United States is not what was originally envisioned, even as recently as a decade ago.

The inventory of commercial spent nuclear fuel in in the U.S. is growing at a rate of ~2,000 metric tons per year and is projected to be ~140,000 metric tons by mid-century, which is the earliest time that current Administration policy projects the availability of a permanent geologic repository. Without options for off-site storage or disposal and with no prospects for reprocessing, utilities have expanded their capacity to store the growing spent fuel inventory at existing reactor sites, choosing without exception to rely on large dry-storage casks. These casks are characterized as "dual purpose" systems, in that the sealed canisters are designed for both extended on-site storage and, with appropriate over-packs, subsequent transportation. The dual-purpose canisters are not, however, designed for disposal, and they are significantly larger than the disposal canisters planned for all repository concepts currently proposed world-wide.

1) Current Practice and Technical, Operational, and Institutional Concerns
   The current practice of loading commercial spent fuel into dry storage systems carries with it an unavoidable commitment to one of three future alternatives:

   a) all spent fuel placed in large dual-purpose canisters will eventually need to be repackaged into purpose-built casks for disposal,

   b) the nation will need to construct one or more repositories that can directly accommodate large dual-purpose canisters for disposal, or

   c) spent fuel will remain indefinitely at interim storage facilities and be repackaged as needed, perhaps every century.

Suboptimal alternatives will lead to increased uncertainties.

All of these options are technically feasible, but none are what was originally planned, and all introduce major new uncertainties regarding the design and operation of future storage and disposal facilities. These uncertainties will impact already large and uncertain future costs: for example, as part of its 2013 assessment of the adequacy of the Nuclear Waste Fee to meet total disposal costs, the DOE estimated a range for $24 billion to $81 billion (2012 dollars) for future repository costs, not including costs associated with repackaging spent fuel.

Industry continues to load larger and heavier canisters, which pose logistical challenges.

The dual-purpose storage canisters themselves are large: up to 2 meters in diameter and 5 meters in length, and the largest currently in use accommodate up to 37 intact fuel assemblies from pressurized water reactors, which account for about two thirds of the U.S. reactor fleet. A loaded canister may weigh on the order of 70 metric tons, and transportation shielding may increase the weight to 150 metric tons. Because it is economically advantageous for nuclear power plants to load larger canisters, the canister size exceeds sizes and weights that may be optimal for transportation and subsequent disposal. Engineering solutions for hoist, ramp, and transporter operations appear to be feasible, but need to be accounted for in planning.

Although dual purpose canisters are certified by the Nuclear Regulatory Commission for both storage and subsequent transportation, the certificates of compliance set different temperature limits for storage versus transportation. This results in a situation where some canisters may need to cool before they can be transported. This delay may be on the order of decades for some canister designs, and in particular for higher-burnup fuels that generate more heat.

Larger canisters will be hotter for longer and therefore may require a longer time to cool before transportation and subsequent disposal.

With respect to disposal, different geologies impose different temperature constraints on the underground environment. For example, some repository designs have assumed that the maximum temperature in clay backfill must remain below 100°C, while salt may accommodate temperatures up to 200 to 250°C. High thermal loads may be accommodated by cooling canisters above ground for many years, ventilating the repository for many years after waste emplacement, or increasing the spacing between canisters. These choices will affect repository costs.

Consolidated Interim Storage is an option.

Constructing consolidated interim storage facilities has the potential to alleviate storage concerns at reactor sites and may provide a path to resolution of legal issues associated with federal responsibility for spent fuel management. Consolidated storage facilities could also be used to provide flexibility in repackaging options for ultimate disposal. Consolidated storage facilities will introduce additional cost and siting concerns, and technical issues associated with the mechanical effects of repeated transportation and storage will need to be addressed.

Legislative and regulatory issues must be addressed.

All options for the management and disposal of commercial spent nuclear fuel currently under consideration in the U.S. will require legislative and regulatory actions.

AGENDA:

Tuesday, May 17

9:00 **Welcome**, Professor Allison Macfarlane, *Elliot School, George Washington University*

Reset Initiative Background & Purpose, Rod Ewing, *Stanford University*

9:30 **Setting the Stage** (Moderator Peter Davies, *Sandia National Laboratories*)
Current Status of US Back End of the Nuclear Fuel Cycle, Tito Bonano, *Sandia National Laboratories*
Policy Barriers to Integration, Tom Cotton, *Complex Systems Group*
Integration in Other Countries, Germany, Holger Volzke, *Bundesanstalt für Materialforschung (BAM), Federal Institute for Materials Research and Testing*
Integration in Other Countries, IAEA, Andrew Orrell, IAEA, *Division of Radiation, Transport and Waste Safety*

Morning Session Moderated Panel Discussion

12:30 Lunch

1:30 **Key Issues** (Moderator Saida Laârouchi, *Engström, SKB*)
Congressional Perspectives on Back End Integration, Tyler Owens, *Senate Appropriations Subcommittee on Energy and Water Development*
Previous Models for Spent Fuel Integration, Rod McCullum, *Nuclear Energy Institute*
Current Studies of Storage/Transportation Technical Issues, Sylvia Saltzstein, *Sandia National Laboratories*
Storage and Canister Concepts for Integrated Spent Fuel Management, John Wagner, *Idaho National Laboratory*

4:30 **Day 1 Wrap Up**, Peter Davies, *Idaho National Laboratories*

5:00 Adjourn

Wednesday, May 18

9:00 **Introduction**, Mark Peters, *Idaho National Laboratories*

9:15 **Industry and Regulatory Perspectives** (Moderator Christophe Poinssot, *French Atomic and Alternatives Energy Commission*)

Industry Path to Back End Integration,
Adam Levin, *Excelon Generation Company*

Stranded Fuel Management and Pathways for Disposition,
Eric Howes, *Maine Yankee*

Industry Models for Back End Integration, John Kessler,
Electric Power Research Institute (*EPRI*), *retired*

NRC Perspectives on Integration Across Storage, Transportation and Disposal Regulations, James Rubenstone and Mark Lombard,
U.S. Nuclear Regulatory Commission

Morning Session Moderated Panel Discussion

12:30 Lunch

1:30 **Broader Perspectives** (Moderator Mark Peters, *Idaho National Laboratories*)

Technical Issues and Needed Actions for Integrated Spent Fuel Management,
David Lochbaum, *Union of Concerned Scientists*

SONGS Community Engagement Perspective, Ted Quinn, *SONGS Community Engagement Panel*

Role of Transportation in Integration, Bob Halstead, *Nevada Nuclear Projects Office*

Public Perspectives on Spent Fuel Storage, Transportation and Disposal,
Allison Fisher, *Public Citizen's Energy Project*

Afternoon Session Moderator Panel Discussion

5:00 **Comments from Meeting Host**, Allison Macfarlane

5:30 Adjourn

Meeting 5:

Regulations, Risk and Safety

October 26-27, 2016

PROSPECTUS:

One of the unique challenges of the safe storage and disposal of nuclear waste is the very long time frame over which the safety of different strategies is evaluated. These evaluations typically involve models that capture atomic- scale processes, such as diffusion and corrosion, to global-scale processes, such as climate change and tectonic events. At each scale, the models are often highly coupled, the outcome of one modeled process becoming the input for the next. The safety analysis becomes the basis for determining risk to the public and environment and is used to determine whether a specific, nuclear waste repository or storage facility will meet regulatory requirements. Thus, there is an inter-play among the determination of risk, regulatory compliance and safety. Finally, these analyses become part of the discussion of safety and acceptability by political institutions and the public.

In this fifth meeting of the series of RESET meetings, the speakers will explore a number of these issues from a technical, as well as social science, perspective.

Topics and questions that we expect to discuss during the meeting include:

- Comparison of different international approaches to the analysis of risk.
- Comparison of the regulatory structures of different countries.
- What is a "safety case" and how is this approach related to a quantitative probabilistic risk analysis?
- What is the relation between regulatory compliance and safety?
- What time periods can be evaluated? Why one million years? Is this necessary or credible?
- How does one maintain the credibility of the regulations and the regulator?
- Once a facility or repository is determined to be in regulatory compliance, how can subsequent, new knowledge be applied to the safety analysis?
- What is the role of public engagement? What role should communities near nuclear facilities play in the regulatory process?

AGENDA:

Wednesday, October 26

8:30 Breakfast

9:15 Introduction to the meeting by Professor Rod Ewing, *Senior Fellow Center for International Security and Cooperation (CISAC)*

9:30 **U.S. program** (Moderator Allison Macfarlane, *Elliot School at George Washington University*)

- **History and status of U.S. Repository Program**, Allison Macfarlane, *Elliot School at GWU*
- **Rationale for NAS report (1995) for the Yucca Mountain standard**, Chris Whipple, *ENVIRON*
- **Framework and regulatory requirements for U.S. geological repository**, Tim McCartin, *U.S. Nuclear Regulatory Commission*
- **Implementing a license application for a geological repository in the U.S.**, Peter Swift, *Sandia National Laboratories*

Morning Session Moderated Panel Discussion

12:00 Lunch

1:00 **International Programs** (Moderator Christophe Poinssot, *French Atomic and Alternatives Energy Commission*)

- **Regulation, safety, uncertainty, confidence**, Claudio Pescatore, *Nuclear Energy Agency (retired)*
- **Swedish regulations and SKB's compliance demonstration for an SNF repository**, Allan Hedin, *Swedish Nuclear Fuel and Waste Management Company (SKB)*
- **A tool for fully integrating scientific models in the safety analysis: The Phenomenological Analysis of Repository Situation (PARS)**, *French National Radioactive Waste Management Agency (ANDRA)*
- **French DGR regulatory infrastructure**, Mathilde Maillard, *Autorité de sûrete nucléaire (ASN)*

Afternoon Session Moderated Panel Discussion

5:00 Session ends

6:55 Dinner for speakers and Steering Committee members

Thursday, October 27

8:00 Breakfast

8:30 **Risk, Regulation, and Safety from the Perspective of the Social Sciences** (Moderator Dan Metlay, *Nuclear Waste Technical Review Board*)

Towards an ethical management of HLRW: challenging the notion of future generations, Céline Kermisch, *Université Libre de Bruxelles*

What we have learned from Community Engagement at San Onofre: long-term stewardship of a decommissioning site, David Victor, *UCSD School of Global Policy and Strategy*

Governing and communicating complex risks: the case of nuclear energy, Otwin Renn, *Stuttgart University, Institute for Advanced Sustainability Studies in Potsdam*

Three questions in search of an accident: policy makers misconstrue nuclear risk assessments, John Downer, *University of Bristol*

Changing the nuclear waste management paradigm: from risk and regulation to innovation democracy, Andrew Stirling, *University of Sussex*

Morning Session Moderated Panel Discussion

12:00 Lunch

1:00 **Modeling and Probabilistic Risk Assessments** (Moderator Bernd Grambow, *Ecole de Mines, SUBATECH Laboratory*)

Geochemical modeling and the case for safety, Kirk Nordstrom, *U.S. Geological Survey*

Reliability of long-term predictions made using groundwater models, Lenny Konikow, *U.S. Geological Survey*

Modeling actinide fate and transport, Kate Maher, *Stanford Department of Geological Sciences*

Why and how we do PRA, Ali Mosleh, *UCLA John Garrick Institute for the Risk Sciences*

Regulatory decision making, George Apostolakis, *MIT Department of Nuclear Science & Engineering*

Afternoon Session Moderated Panel Discussion

5:00 Wine and Cheese Reception with CISAC Faculty, Fellows, and Staff

6:55 Dinner for Steering Committee members

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