

**Repository Planning For Spent Nuclear Fuel And High-Level Radioactive Waste:  
Insights From U.S. And International Programs – 15638**

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**ABSTRACT**

For decades, the United States and other nations with nuclear programs have been planning for permanent disposition of spent nuclear fuel and high-level waste, to address the increasingly difficult problem of storing these materials for the long term. These plans are complicated by issues ranging from technological factors to regulatory approaches and public concerns about health and environmental protection. In its 2012 report, the Blue Ribbon Commission (BRC) on America's Nuclear Future identified a number of recommendations for creating a safe, long-term solution to the nation's problem of managing and disposing of its spent fuel and high-level radioactive waste. These include a recommendation that the U.S. Environmental Protection Agency (EPA) revise its standards for a high-level waste repository. The EPA is currently reviewing and synthesizing literature relevant to such standards, including: (1) existing national and international standards and guidelines for repositories; and (2) benefits and barriers to such standards, including limitations related to current technologies, as well as siting, licensing, and construction processes. This paper highlights findings of this literature review and synthesis. More than 90 countries, from Albania to Vietnam and Yemen, were identified as potential sources of relevant information based on existing nuclear programs or consideration of such programs to address future energy needs. Pursuant to the BRC recommendations, the U.S. Department of Energy (DOE) has compiled extensive information resources relevant to spent fuel and radioactive waste repositories in the Centralized Used Fuel Resource and Information Exchange (CURIE) database developed by Oak Ridge National Laboratory. Further valuable sources of information include annual proceedings of recent Waste Management Symposia, which provide insights into recent trends and progress across various national and international programs. Recent literature from a number of countries, including the United States and Canada, and the United Kingdom, Finland, Sweden, France, Germany, and other countries in Western Europe, as well as other regions including Australia, indicates that consent-based siting has emerged as a dominant theme. In addition to effective siting processes, key program needs identified in the literature include regulatory standards and performance context, as well as reliable technologies and engineered systems, such as for deep drilling and assured safe containment of these radioactive materials extending into the very long term.

**INTRODUCTION**

Nuclear waste disposal has long been an issue for nations with nuclear programs, including the United States. Any organization responsible for disposing of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) is subject to applicable requirements. In the United States, the U.S. Environmental Protection Agency (EPA) and U.S. Nuclear Regulatory Commission (NRC) have joint responsibility for assuring health and safety associated with the disposition of these materials. In addition to assuring environmental and public health and safety associated with any

SNF or HLW repository, the EPA is also responsible for assuring protection from other environmental impacts. Parallel agencies hold these same responsibilities in other countries.

In 2010, the current Administration formed a Blue Ribbon Commission (BRC) on America's Nuclear Future. This Commission was charged with recommending an alternative strategy for managing the back end of the nuclear fuel cycle. The BRC issued its final report to the Secretary of Energy in January 2012 [1]. The BRC report includes background context for U.S. policy regarding SNF and HLW disposal, with a review of the 1982 Nuclear Waste Policy Act (NWPA) including the provision that gave the NRC responsibility for licensing the construction and operation of waste facilities, subject to public health and environmental standards established by the EPA.

Subsequently, in the 1992 Energy Policy Act, the U.S. Congress directed EPA to develop safety standards specific to the Yucca Mountain site. (In 2009, the U.S. government announced it was no longer pursuing geologic disposal at the proposed Yucca Mountain repository.) The BRC also considered the experience of the Waste Isolation Pilot Plant in New Mexico, for which Congress required EPA to certify that the facility met applicable standards for waste disposal, including requirements of the Resource Conservation and Recovery Act (RCRA, as amended, notably by the Federal Facilities Compliance Act).

The BRC report includes eight broad recommendations for legislative and administrative action to develop a new strategy for managing nuclear waste in the United States, as follows:

1. A new consent-based approach to siting future nuclear waste management facilities.
2. A new organization dedicated solely to implementing the waste management program and empowered with the authority and resources to succeed.
3. Access to the funds nuclear utility ratepayers are providing for the purpose of nuclear waste management.
4. Prompt efforts to develop one or more geologic disposal facilities.
5. Prompt efforts to develop one or more consolidated storage facilities.
6. Prompt efforts to prepare for the eventual large-scale transport of SNF and HLW to consolidated storage and disposal facilities when such facilities become available.
7. Support for continued U.S. innovation in nuclear energy technology and for workforce development.
8. Active U.S. leadership in international efforts to address safety, non-proliferation, and security concerns.

With an emphasis on the importance of regulations, the BRC notes EPA's responsibility for issuing generally applicable standards for protecting the environment from offsite releases from

radioactive material in repositories. These standards would apply both to the operational period, during emplacement of the SNF and/or HLW, and to the long-term performance of the repository following closure.

The EPA standards for sites other than Yucca Mountain are established in 40 Code of Federal Regulations (CFR) Part 191 [2]. (First issued in 1985, these standards were subsequently remanded then reissued in 1993 to apply only to geologic disposal facilities other than Yucca Mountain.) Per these standards, containment at the disposal facility is required to protect humans by limiting cumulative releases of key isotopes over 10,000 years following facility closure.

Further, a quantitative performance assessment is required to demonstrate compliance, to achieve a reasonable expectation of less than 10% chance of low releases and less than 0.1% chance of higher releases, and an annual dose to a member of the general public not to exceed 15 millirems (150 microsieverts) for 10,000 years from an undisturbed repository system. The dose standard for Yucca Mountain, which is presented in 40 CFR Part 197 [3], has the same annual dose limit for the first 10,000 years, and then an annual limit of 100 millirem extending one million years.

In its recommendations for future standards for nuclear waste disposal facilities, the BRC encourages the Agency to use the same language it has established for the standard of proof. That is, the EPA is encouraged to reflect a reasonable expectation that the standards will be met as a practical basis for future nuclear waste disposal regulations [1].

The Commission further recommends that the development of such standards: (1) be generic (rather than site-specific, to avoid potential misperceptions regarding site pre-selection or tailoring); (2) stay within reasonable limits of what current science can achieve, to improve credibility (e.g., with regard to predicting exposures/doses 1 million years in the future); (3) include rules for demonstrating compliance, established at the same time the standards are developed; (4) incorporate an adaptive, staged approach; (5) be finalized before the site-selection process; and (6) be coordinated closely among agencies, notably calling for EPA and NRC to work together in defining an appropriate process for developing a generic disposal facility safety standard, to include the opportunity for public input. The BRC also extends its recommendations beyond geologic disposal, encouraging research, development, and demonstration efforts related to borehole disposal. Specifically, the BRC recommends that EPA and NRC begin work on a regulatory framework for borehole disposal in parallel with their development of a site-independent safety standard for mined geologic repositories [1].

The BRC encourages EPA and other agencies to tap the extensive literature and regulatory experience toward developing the appropriate form and stringency of regulatory standards for nuclear waste disposal facilities. Pursuant to this recommendation, the EPA conducted a review of the available literature on standards and regulatory issues related to repositories for the permanent disposal of commercial SNF and HLW. This review is designed to consider: (1) existing national and international standards and guidelines for repositories; and (2) benefits and barriers to such standards, including limitations related to current technologies, as well as siting, licensing, and construction processes.

## APPROACH

A two-phased approach was applied to search the literature for this project. An initial, broad screening step was conducted to identify key sources, and a more targeted search of those sources then followed. Main elements of the approach are illustrated in Figure 1.

A key outcome of the initial screening phase was the determination of the Centralized Used Fuel Resource and Information Exchange (CURIE) website [4] as a key resource. In implementing the BRC recommendations, the DOE has compiled extensive information resources relevant to spent fuel and radioactive waste repositories in this valuable database developed by Oak Ridge National Laboratory.

An additional key resource determined from the initial screening phase is the Waste Management Symposia – with proceedings of recent meetings being particularly valuable in providing insights into recent trends and progress across a considerable number of U.S. and international programs. Proceedings of the International Conference on Environmental Remediation and Radioactive Waste Management (ICEM) are also a useful resource.

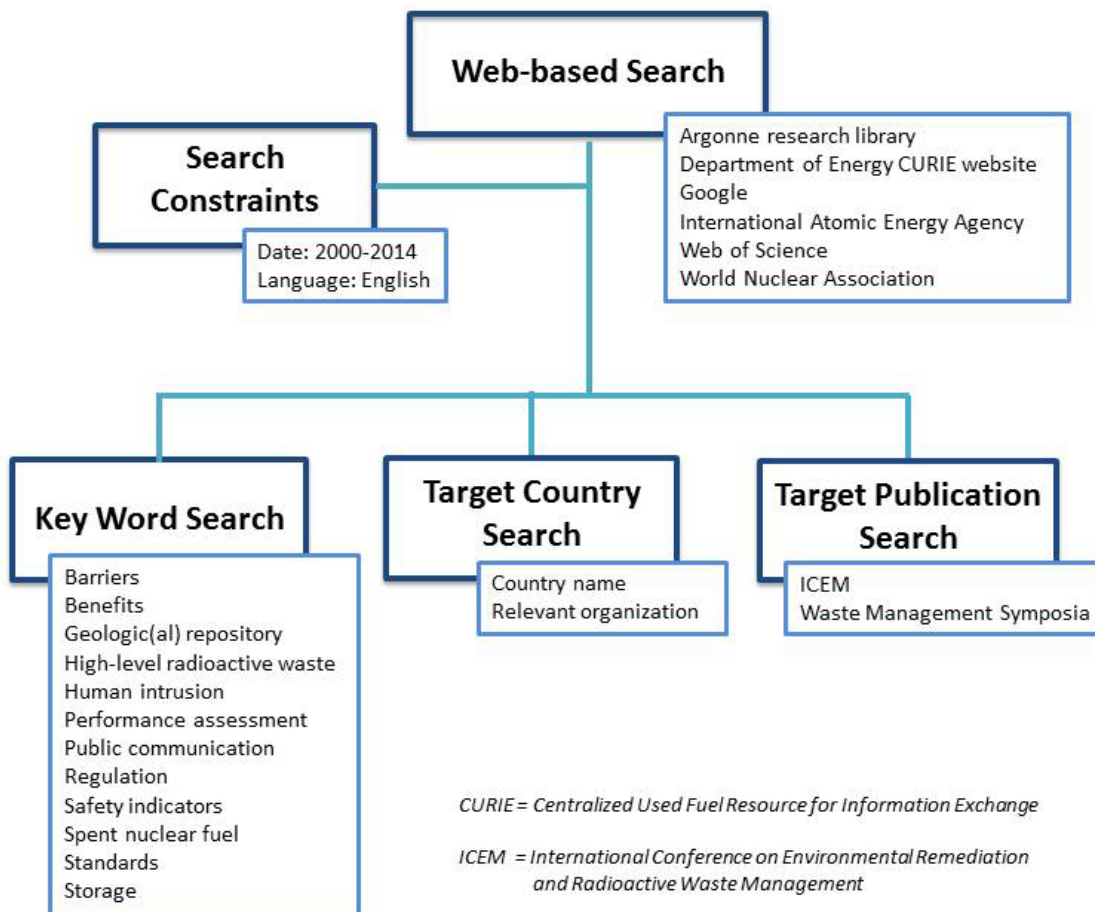


Fig. 1. Key Elements of the Literature Search

## RESULTS AND DISCUSSION

The literature search identified more than 90 countries, from Albania to Vietnam and Yemen, as potential sources of information related to nuclear power. From the more targeted search, a number of countries were found to be in the early stages of considering nuclear power generation as a potential component of their future energy portfolio. A dozen countries are in the more advanced stage of developing or implementing plans for a nuclear waste repository. Figure 2 presents an initial categorization of the countries reviewed to assess their status with regard to developing commercial nuclear power and their plans for a nuclear waste repository.

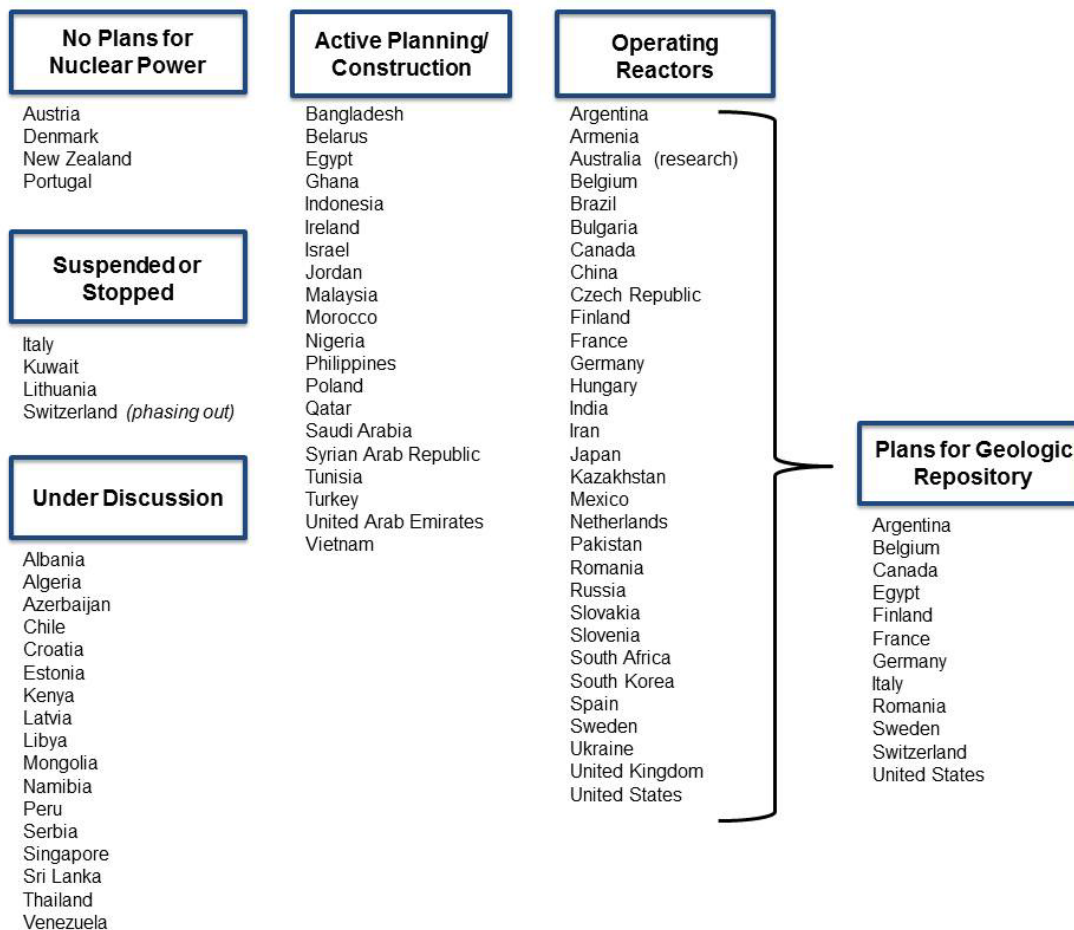


Fig. 2. Countries Reviewed for Consideration of Nuclear Power and Waste Disposal Plans

Examples of ongoing efforts are provided as follows. Canada is among the handful of countries with advanced plans for nuclear waste disposal in a deep geologic repository. In applying its adaptive phased management (APM) approach, Canada developed a nine-step process that is serving as a road map for site selection. Both technical and social factors are considered, with step-wise consideration of geoscientific suitability in tandem with extensive efforts dedicated to soliciting and coordinating with volunteer communities [5, 6].

France has also made substantial progress in its planning for a geologic repository. Multiple reports outline the planning and siting methodology, industrial and economic issues, safety and

security issues, and reversibility issues being addressed prior to licensing, which is anticipated in the near term. Issues include technical factors such as adapting current safety practices to underground facilities, as well as social factors including dialogue with the community [7, 8].

The European Commission recently supported a project for Implementing Public Participation Approaches in Radioactive Waste Disposal (IPPA) in three countries where existing approaches were legally mandated rather than locally negotiated. These countries are the Czech Republic, Poland, and Slovenia, and as part of the IPPA initiative, public input was solicited on these two approach options, including regarding issues such as trust in the institution and the legal framework [9, 10].

Like other countries with operating reactors, Argentina (which recently increased its nuclear energy production) is storing its waste where it is generated. Argentina aims to achieve an operational disposal facility by 2050, and the siting features being considered include geologic formation (sedimentary, volcanoclastic, and granites), seismicity, neotectonism, volcanism, hydrogeology, and climate change [11].

Even in countries without commercial nuclear power, a phased approach is being considered for managing higher-activity radioactive wastes resulting from other peaceful nuclear applications (such as research or medical uses). An example is Australia, which operates the Open Pool Australian Lightwater (OPAL) research reactor and operated two research reactors before that. In the statement of reasons for granting the OPAL operating license, the then Chief Executive Officer (CEO) of the Australian Radiation Protection and Nuclear Safety Agency stated

*“Overall, I believe that the path that Australia is following in dealing with its spent fuel and other intermediate-level radioactive waste is consistent with international best practice in relation to radiation protection and nuclear safety. This is so in that the option of longer term storage pending the development in a phased and adaptive approach of geological disposal facilities is the approach being reached by several significant countries in regard to the management of spent fuel arising from nuclear power facilities. Australia will need to start to explore options for disposal, but these can and should take time and be thoroughly considered in the light of world developments.”* [12]

This continues to be the case as outlined in recent regulatory guidance, which states that a post-closure safety assessment for disposal facilities

*“shall effectively take into consideration the uncertainties arising from changes in human behavior and environmental and facility conditions over the very long timescales that have been agreed as appropriate (e.g. [as imposed by the proponent, but not less than] 10 000 years for ILW disposal).”* [13]

Other countries such as Turkey have developed legal and regulatory structures for their evolving programs for future commercial nuclear power, and other countries such as Vietnam have also begun developing their frameworks.

The evaluation of existing standards for waste disposal facilities can be organized into several key themes, as reflected in the BRC report [1]. The first theme is time, recognizing the substantial uncertainties inherent in projecting disposal system performance into a very distant

future. As noted by the BRC, EPA initially proposed a compliance period of 10,000 years for the proposed Yucca Mountain geologic repository and later increased that to 1,000,000 years in accordance with recommendations from the National Research Council [14]. Meanwhile, some countries have developed time frames of a few thousand to 100,000 years, while others have avoided identifying any prescriptive duration. Some follow a phased approach; for example, Finland and Sweden have established regulations that are more stringent for the first thousand years after closure. (In comparison, Brazil is planning a repository for low and intermediate level waste from nuclear energy and radioisotopes from other uses – including medicine, agriculture, and industry. For that type of repository, a post-closure period of 360 years is being considered for maintaining institutional controls, as plans for the regulatory structure and methods for project management, site selection, and licensing are developed [15].) In Belgium, planning for the post-closure period includes this qualitative expectation: “Repository planning will assume that post-closure surveillance and monitoring will continue for as long as reasonably possible” [16].

A second theme for waste disposal standards is the method used to demonstrate compliance. The EPA had embedded in its geologic disposal standards for Yucca Mountain a requirement for a quantitative performance assessment extending to a million years from the closure of the disposal facility. Given the enormous uncertainties associated with projecting doses or risks across that period, the collective mindset has been shifting in the past ten years toward compliance methods that incorporate both quantitative and qualitative information. For example, in Finland, a quantitative assessment is required where possible, with complementary (qualitative) considerations presented when such assessments are infeasible or too uncertain [17]. The BRC encourages EPA to incorporate flexibility by distinguishing between compliance over the first 10,000 years and beyond, and also to consider performance assessment as but one method in a set that can be used to develop the overall safety case instead of being prescriptively included within the standard itself [1]. Similarly, in Australia, the regulator recommends that the performance of a disposal facility be quantitatively assessed against realistic scenarios in a safety case, with presentation of uncertainties and provision for periodic safety reviews [13].

A third theme is the nature of effects considered. In addition to assessing potential health and safety impacts for humans, the EPA includes consideration of environmental impacts. The U.S. standards for high-level waste (and transuranic waste) disposal include a separate standard for protecting groundwater. The same consideration of “beyond-human” effects applies elsewhere. In Canada, Finland, Sweden, Switzerland, and the United Kingdom, the waste disposal regulations have incorporated qualitative requirements for protecting flora and fauna and diversity. Several countries require such non-human impacts to be included in future risk analyses and performance assessments. In Australia, detailed environmental assessments are required for relevant wildlife where exposures are likely to be higher than a screening dose rate of 5-10 micrograys per hour ( $\mu\text{Gy/h}$ ) [13].

## **FINDINGS**

More than 90 countries are operating, developing, or have at least considered commercial nuclear power plants, with just over 10% in the planning or implementation phase for ultimate disposition of the SNF and HLW generated by such operations. Recent literature from the

United States and Canada, the United Kingdom, Finland, Sweden, France, Germany, and other countries in Western Europe, as well as Australia, indicates that consent-based siting has emerged as a dominant theme. Key program needs identified in the literature include regulatory standards and performance context, as well as reliable technologies and engineered systems, such as for deep drilling and assured safe containment extending into the very long term.

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