An Enduring Problem: Radioactive Waste From Nuclear Energy

BY M. V. RAMANA
Program on Science and Global Security, Princeton University, Princeton, NJ, USA

Photograph of a waste container at the Waste Isolation Pilot Plant, USA, with its lid unsealed and apparent heat discoloration taken by the U.S. Department of Energy on May 15, 2015. Source: http://www.wipp.energy.gov/wipprecovery/photo_video.html

Decades after the idea was first proposed, it appears that underground repositories to manage radioactive spent fuel from commercial reactors are finally going to be constructed. In November 2015, the ruling center-right party in Finland became the first government to grant a construction license for such a repository [1]. The U.S. Department of Energy is pursuing a consent-based process to set up a similar repository. Do these developments mean that a long-sought solution to the problem of nuclear waste is imminent?

As this article will argue, there are many fundamental reasons why dealing with radioactive waste is a special and enduring challenge. Even if a repository is constructed in one or two countries, those examples are by no means generalizable. The continuing problem of radioactive waste disposal, in turn, is another reason to be wary of a large-scale expansion of nuclear power.

Digital Object Identifier: 10.1109/JPROC.2017.2661518

I. GEOLOGICAL DISPOSAL: THE PROMISE AND THE REALITY

Some of the radioactive elements produced during the operation of nuclear reactors have extremely long half-lives, and have to be isolated from human contact for hundreds of thousands of years (see Fig. 1). This requirement for stewardship is unprecedented in human history. Since the 1950s, nuclear establishments have advocated dealing with these radioactive wastes by constructing an underground repository in a suitable geological medium and placing the waste there, within special containers. Much attention from the technical community has been focused on finding a suitable location because the choice of geological media (e.g., granite, volcanic tuff, or clay) will influence the behavior of radionuclides when they escape from the container [2]. The question is one of "when," not "if"; because of corrosion, radionuclides will migrate into the biosphere over the long periods of time it would take for them to decay. As Allison Macfarlane, former Chair of the U.S. Nuclear Regulatory Commission put it, no "site will…contain nuclear waste indefinitely. The goal is to select a site and engineered features, such as the waste canister, which maximize the amount of time the waste is isolated" [3, p. 84].

Nevertheless, confidence in the idea of a repository remains high. The U.S. National Academy of Sciences'

Committee on Disposition of High-Level Radioactive Waste Through Geological Isolation opined in 2001 that "geological disposal remains the only scientifically and technically credible long-term solution available to meet the need for safety without reliance on active management" [4, p. 3].

At the same time, no country has so far constructed any such repository for storing waste from nuclear power plants. Almost all countries that have tried to site repositories have had one or more failures [5].

II. PUBLIC ATTITUDES

The main barrier to siting such repositories has been public resistance. In the words of a group of researchers who have been at the forefront of research on societal attitudes toward risks of all kinds, the "public most often responds to the idea of having a high-level nuclear waste facility located near their communities or in their state with fear, distrust, and fierce opposition. Only a few communities—usually those historically associated with other nuclear facilities such as power plants or weapons manufacturing—have shown any willingness to host a nearby repository. Elsewhere, people find radioactive materials to be the least acceptable of hazardous wastes" [6, p. 65].

Communities living close to an already operating nuclear facility are special because they are faced with a choice between the risk that derives from spent fuel or high-level waste stored at ground level, which could result in potentially catastrophic accidents [7]–[9], and the risk from the same wastes being stored in an underground repository. Thus, it is not surprising that some communities do view a repository as the lesser of two evils.

But even with such communities, acceptance of a repository is rare. In many cases, the process of getting consent from local communities to the construction of nuclear power plants in the first place often involved a commitment to removing the spent fuel/radioactive waste from the site once the reactor stopped generating electricity.

Dealing with opposition to waste disposal facilities with assertions that they are safe is unsatisfactory. It immediately raises the question: "if the proposed solution for nuclear waste is safe, why not implement it at XXX?," where XXX could be Mall in Washington, DC or the Presidential Office in Taipei or some other site seen as nationally important. Most people clearly realize that nuclear waste is not something that those in power want to be stored in their vicinity. The selection of a waste disposal site in the vicinity of their homes is an implicit assertion that their land and their environment is not valuable and can be despoiled for millennia.

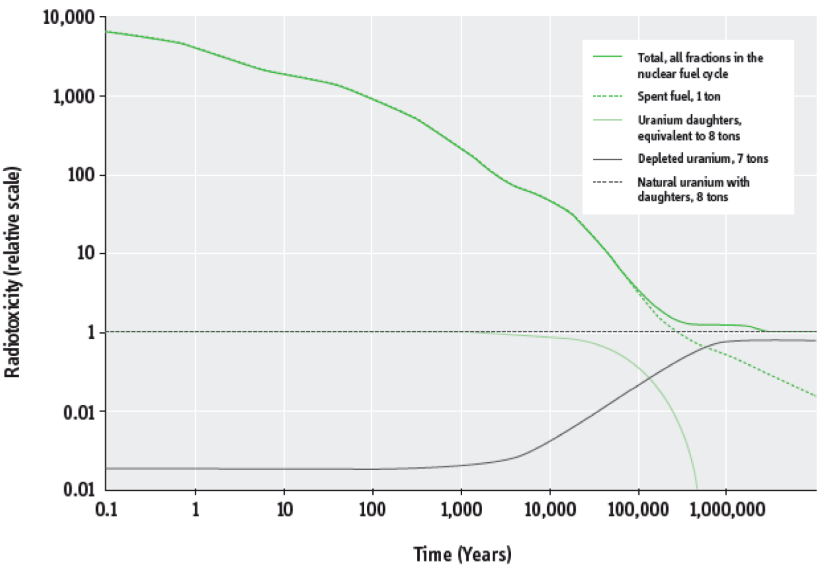

Fig. 1. ***Relative ingestion radiotoxicity of uranium ore, of the spent LWR fuel that could be derived from it, the toxicity of the uranium decay products that are separated in the uranium mill, and of the depleted uranium that is stored at the enrichment plant. Source: A. Hedin, "Spent Nuclear Fuel—How Dangerous Is It?," Swedish Nuclear Fuel and Waste Management Co, SKB Technical Report 97–13, 1997.***

III. RELATIONSHIP WITH NUCLEAR POWER

Public attitudes to nuclear waste are, naturally, related to their attitudes to nuclear power in general. Concerns about the disposal of nuclear waste are an important element in public opposition to nuclear power, the other concerns being about reactor safety and low levels of trust in the nuclear establishment [10, p. 426]. Even while the low-carbon nature of nuclear power is a desirable characteristic, many in the public are wary of the fact that using nuclear power to mitigate climate change implies having to tolerate the production of long-lived radioactive waste. In a study conducted in the United Kingdom, both climate change and radioactive waste "were equally associated with unknown consequences, risks to future generations and low levels of personal control" but the latter "was associated with a greater level of dread…and an unfair distribution of risks" and "survey respondents were more concerned about radioactive waste" [11, p. 152]. Many polls also find low levels of support for most fossil fuels. In contrast, there is widespread public support for increased reliance on renewable sources of energy, especially as these technologies have become significantly cheaper and rates of installation of solar and wind energy have grown dramatically.

IV. WHY TECHNICAL SOLUTIONS WILL NOT SUFFICE

Technically, the solution preferred by nuclear establishments in almost all countries is a geological repository. The World Nuclear Association, for example, states: "Safe methods for the final disposal of high-level radioactive waste are technically proven" [12]. But, there are two problems with this assertion.

First, in the absence of any operational geological repositories for waste from commercial reactors, there is no empirical proof. Even theoretical safety cases for repositories contain significant uncertainties. As the U.S. National Academy of Sciences' Committee put it: "progress in achieving geological disposal has been marked by surprises, new insights, and the recognition that for even the best-characterized sites, there always will be uncertainties about the long-term performance of the repository system" and goes on to recognize that "not all…of today's uncertainties in predicting the future behavior of a repository system can be reduced or eliminated by further research and development" [4, p. 3]. There "are a variety of factors that make it difficult to predict repository behavior over geologic time, including climate, saturated zone behavior, volcanism, unsaturated zone behavior…the environmental and chemical conditions of the repository environment as it evolves over time, especially the chemistry of the water that will exist in the repository" [13, p. 394]. A further complication is that "the act of emplacement of the waste affects some of the fundamental properties of the surrounding rock. The construction of tunnels creates a disturbed zone of increased fracture, and pore waters move in response to the thermal pulse generated by the decay of radionuclides" [14, p. 254].

Adding to this technical complexity is uncertainty about how human populations will behave tens or hundreds of thousands of years from now. How are we to know, for example, that in the 29th century, people might not be mining in the vicinity of the repository to obtain some mineral that has become widely used at that time? Efforts to try and communicate about the dangers of buried radioactive waste through millennia border on science fiction, and believing that the proposed design elements would deter human intrusion thousands if not tens of thousands of years into the future strains one's credulity.

The second factor that undermines claims about safety are failures of different kinds: design failure, human failure, or institutional failure. Even the limited experience with existing repositories provides ample examples of failure. In the case of the Asse repository in Germany, planners chose a poor location within the salt dome and ignored warnings from local NGOs about flooding [5, p. 48]. At the Waste Isolation Pilot Plant (WIPP) in the United States, a drum of transuranic waste exploded and released plutonium and americium, which made their way to the surface (see the opening graphic). The accident is now ranked at among the costliest in U.S. history, and resulted from the use of an organic version of "kitty litter—used to blot up liquids in sealed drums," instead of a mineral one [15]. This seemingly minor error, albeit with major consequences, was symptomatic of deeper problems. The official Department of Energy analysis of the WIPP accident concluded that organizations that were involved in managing the facility had allowed safety culture "to deteriorate within pockets of the organization" [16, p. ES-17]. If such failures have occurred just 15 years after the facility started receiving wastes, how is one to trust that other failures would not occur during the many decades it would take to construct and load large quantities of highly radioactive waste into a geological repository, let alone over the millennia that the waste will remain hazardous?

Such failures further undermine trust in organizations involved in managing nuclear waste, which already experience widespread and pervasive public distrust, as acknowledged even by a 1991 U.S. Department of Energy Task Force [4, p. 74].

V. REPROCESSING

A second technical proposal that is most often articulated to be a solution to nuclear waste is to reprocess the spent fuel. There are two problems with this purported "solution." First, it mischaracterizes the problem as a quantitative one. Reprocessing, being a chemical process, does not change the radioactive nature of the waste. A reprocessing plant simply redistributes the radioactivity present in the spent fuel across multiple waste streams. The stream that contains the bulk of the radioactivity content in the spent fuel, high-level waste, still has to be disposed of in a repository. Nevertheless, its proponents argue, reprocessing is advantageous because the volume of the waste is reduced when compared to spent fuel. Therefore, the claim goes, the geological repository needed is smaller.

But it is the rate of heat generation, not the volume of the materials being disposed, that determines the necessary area for the repository, and that rate is dependent primarily on the radioactive content. Further, when the requirements of disposing off the plutonium that has been separated and used as fuel in reactors is included, the repository area increases further. In all, there is only a marginal benefit from reprocessing on the required repository area [5, p. 15, 151].

More important, a reduction in repository size does not solve the problem of nuclear waste. The public's concern about repositories is not that they will be too big, but simply that they are being built and will remain hazardous for millennia. Thus, a smaller repository does little to address the underlying concern.

Second, reprocessing plants also release low-level waste streams into the environment after some treatment. This radioactivity makes it way into marine life and can be detected far away from the source. Radioactive discharges from the Sellafield reprocessing plant in England, for example, have been detected as far away as Norway. The public's concern also extends to such impacts.

And finally reprocessing facilities are sites of accident risk [8], [17]. The recent protests over the proposed reprocessing plant in Lianyungang in China, because of the health and safety concerns of residents, leading to the cancellation of the project, offers an illustration of public concern about reprocessing facilities. In summary, reprocessing as a solution to nuclear waste mischaracterizes the nature of the public's concern about the problem in the first place. Reprocessing as a cure for the growth of nuclear waste inventories is worse than the problem, whether viewed in technical or social terms [17].

VI. CONCLUSION

In 2003, the influential report, *The Future of Nuclear Power*, produced by researchers at the Massachusetts Institute of Technology, characterized the "management and disposal of high-level radioactive spent fuel from the nuclear fuel cycle" as "one of the most intractable problems facing the nuclear power industry throughout the world" and observed that no "country has yet successfully implemented a system for disposing of this waste" [18, p. 10]. Our exploration of some of the challenges confronting nuclear waste disposal reinforces this conclusion. Attempts to set up nuclear repositories in many different countries suggest that a solution in theory is not the same as a solution in practice. Although there may be a few exceptional circumstances, where some community, for reasons specific to it, has agreed to live near a nuclear waste repository, the nature of the challenges described above suggest that such areas will remain exceptional. One swallow does not a summer make. ■

REFERENCES

[1] J. Rosendahl, "Finland approves underground nuclear waste storage plan," *Reuters*, Nov. 2015.

[2] R. C. Ewing, "Geological Disposal," in *Managing Spent Fuel from Nuclear Power Reactors: Experience and Lessons from Around the World*, H. Feiveson, Z. Mian, M. V. Ramana, and F. Von Hippel, Eds. Princeton, NJ, USA: International Panel Fissile Materials, 2011, pp. 130–138.

[3] A. Macfarlane, "Is it possible to solve the nuclear waste problem? Innovations case discussion: Siting of Eurajoki nuclear waste facility," *Innov. Technol. Governance, Globalization*, vol. 1, no. 4, pp. 83–92, 2006.

[4] "Committee on disposition of high-level radioactive waste through geological isolation, board on radioactive waste management, national research council," in *Disposition of High-Level Waste and Spent Nuclear Fuel: The Continuing Societal and Technical Challenges*. Washington, DC, USA: National Academy Press, 2001.

[5] H. Feiveson, Z. Mian, M. V. Ramana, and F. Von Hippel, *Managing Spent Fuel From Nuclear Power Reactors: Experience and Lessons From Around The World*. Princeton, NJ, USA: International Panel Fissile Materials, 2011. [Online]. Available: http://fissilematerials.org/library/rr10.pdf

[6] J. Flynn, *One Hundred Centuries of Solitude: Redirecting America's High-level Nuclear Waste Policy*. Boulder, CO, USA: Westview, 1995.

[7] "Committee on lessons learned from the Fukushima nuclear accident for improving safety and security of U.S. nuclear plants," in *Lessons Learned From The Fukushima Nuclear Accident for Improving Safety and Security of U.S. Nuclear Plants: Phase 2*. Washington, DC, USA: National Academies Press, 2016.

[8] M. V. Ramana, A. H. Nayyar, and M. Schoeppner, "Nuclear high-level waste tank explosions: Potential causes and impacts of a hypothetical accident at India's Kalpakkam reprocessing plant," *Sci. Global Security*, vol. 24, no. 3, pp. 174–203, 2016.

[9] R. Alvarez et al., "Reducing the hazards from stored spent power-reactor fuel in the United States," *Sci. Global Security*, vol. 11, no. 1, pp. 1–51, 2003.

[10] S. C. Whitfield, E. A. Rosa, A. Dan, and T. Dietz, "The future of nuclear power: Value orientations and risk perception," *Risk Anal.*, vol. 29, no. 3, pp. 425–437, 2009.

[11] K. Bickerstaff, I. Lorenzoni, N. F. Pidgeon, W. Poortinga, and P. Simmons, "Reframing nuclear power in the UK energy debate: Nuclear power, climate change mitigation and radioactive waste," *Public Understand. Sci.*, vol. 17, no. 2, pp. 145–169, 2008.

[12] World Nuclear Association, *Radioactive Waste Management*, 2016. [Online]. Available: http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/radioactive-waste-management.aspx

[13] A. Macfarlane and R. C. Ewing, *Uncertainty Underground: Yucca Mountain and The Nation's High-Level Nuclear Waste*. Cambridge, MA, USA: MIT Press, 2006.

[14] R. C. Ewing, "Long-term storage of spent nuclear fuel," *Nature Mater.*, vol. 14, no. 3, pp. 252–257, Mar. 2015.

[15] R. Vartabedian, "Nuclear accident in New Mexico ranks among the costliest in U.S. history," *LA Times*, Aug. 2016.

[16] *Accident Investigation Report, Phase 2: Radiological Release Event at The Waste Isolation Pilot Plant, February 14, 2014*, U.S. Dept. Energy Office Environ. Manage., Washington, DC, USA, Apr. 2015.

[17] M. V. Ramana and F. Von Hippel, Eds., *Plutonium Separation in Nuclear Power Programs: Status, Problems, and Prospects of Civilian Reprocessing Around The World*. Princeton, NJ, USA: International Panel Fissile Materials, 2015. [Online]. Available: http://fissilematerials.org/library/rr14.pdf

[18] J. Deutch et al., *The Future of Nuclear Power: An Interdisciplinary MIT Study*. Cambridge, MA, USA: MIT Press, 2003.