NUCLEAR WASTE MANAGEMENT

By Abhishek Chintapalli

As air-pollution, rising energy costs and environmental concerns increasingly attract scrutiny in the public eye, clean energy sources are gaining traction in the market. Nuclear power, in particular, has been a reliable and inexpensive source, as 20% of the United States' energy isproduced in nuclear power plants (1). The nuclear power industry in the US, however, faces many challenges to expansion, the biggest being the unresolved issue of how to properly store the tons of hazardous waste that are produced every year. This issue has become even more salient with the recent tragedy in Japan, when hurricane Fukushima caused one of the worst nuclear fallout disasters in modern history. This article aims to shed light on the current technologies available to handle hazardous commercial nuclear waste, to present the obstacles involved in long-term storage options, and to describe how research is helping make the storage of nuclear waste more safe and reliable.

The idea of underground geological burial of nuclear waste is currently the most accessible—though not the most common—way of disposing commercial nuclear waste. Not only does the technology required for implementation seem to be already within reach, it is also cost-effective. However, given the endless debate over cost, location, and public opinion, not a single permanent repository has been approved for construction in the United States to this day (2). In Scandinavia, however, Swedish scientists have already built several underground research laboratories to test the suitability of geologic formations and packing technologies for nuclear waste storage. In fact, several have even been successfully converted into permanent depositories for hazardous waste (3).

In order for a particular location to be suitable for storing nuclear waste, many stringent conditions have to be met. One of the highest priorities for current research is to ensure that no waste can leak into the environment for hundreds of thousands of years, which is the time required for the waste to no longer be hazardous (4). In particular, the most pressing concern is that the waste does not leak into the water supply, which could, in turn, enter the environment through the water cycle. To prevent this, Czech researchers working with a German consultancy called DBE Technology have built what they call a "hydraulic cage" in a former limestone mine in a small Czech town that holds radioactive waste. The hydraulic cage strives to alleviate outside pressure on the storage facility by attaching a gravel layer to all sides of the chamber. This gravel layer, according to the abstract by the Czech Radioactive Waste Repository Authority, "prevents the development of advective flow through the waste/concrete body within the back-filled chambers by eliminating the pressure gradient as driving force for such a flow." More simply, the cage eliminates water pressure by providing an alternative path for moisture to travel around the containment facility (5).

In addition, there is a particularly simple form of underground waste burial called deep borehole disposal. The name is almost self-explanatory in that the idea involves packing the nuclear waste into holes drilled several kilometers deep. Of course, the holes themselves are reinforced by concrete, gravel, clay and other materials to seal the boundary between the waste canisters and the environment.

According to Fergus Gibb, a geochemist at the University of Sheffeld in England, the canisters can also be designed so that the large amounts of heat from the nuclear waste could melt the surrounding rock, which later solidifies as the waste cools to form a compact and safe repository for long-term waste storage (6).

Finally, perhaps one of the most important contributions in making underground waste burial practical has been the chemistry involved in converting such waste into more manageable forms. For instance, researchers at the Australian Nuclear Science and

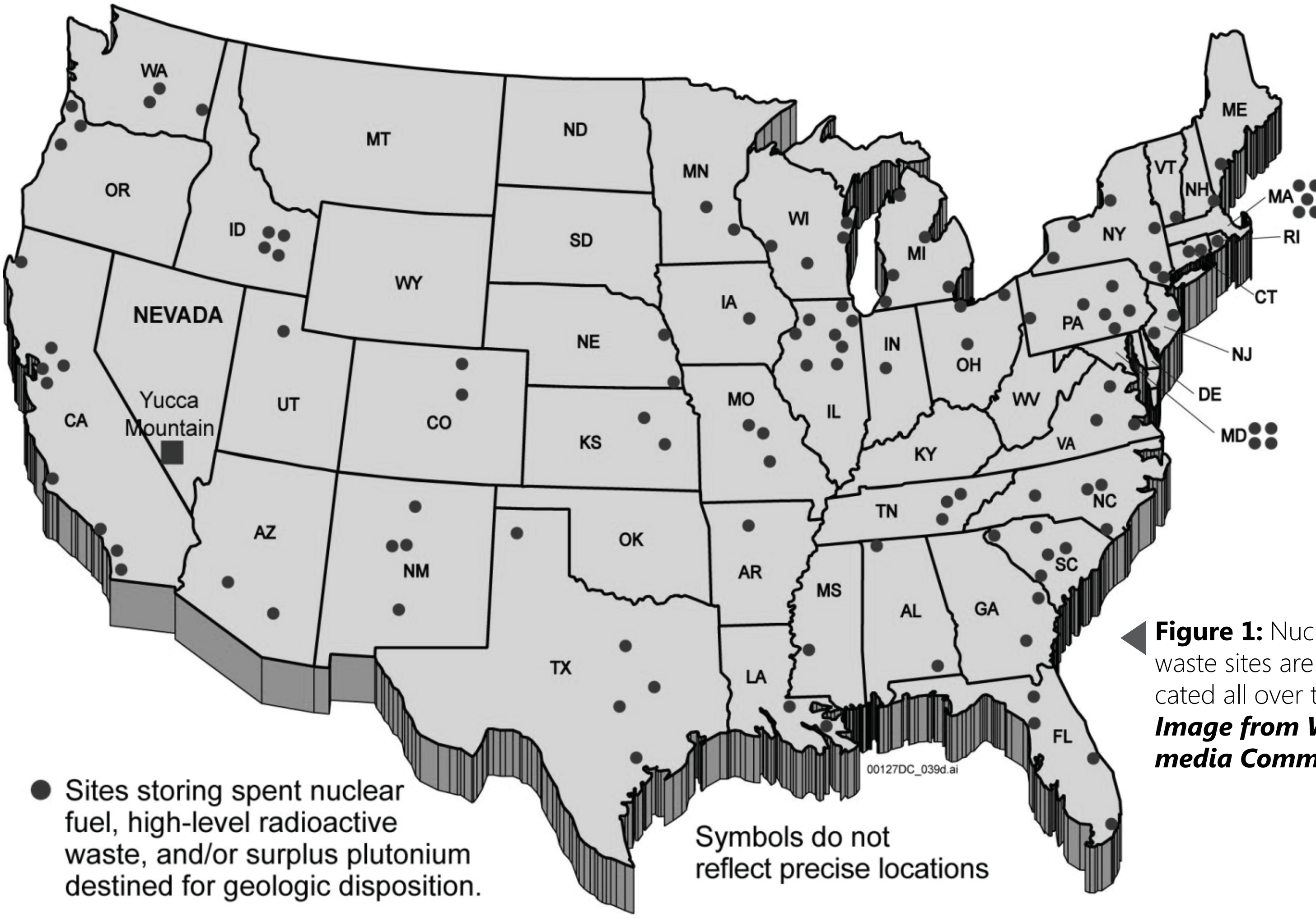

Figure 1: Nuclear waste sites are located all over the US. ***Image from Wikimedia Commons.***

Technology Organization have found a new method of safely storing radioactive waste by converting liquid nuclear waste into a powder form, which through further processing could be compressed into hard, dense, black synthetic rock. Though this method does not render the nuclear waste harmless—the rocks themselves are still radioactive—it does significantly reduce the risk of the leakage of nuclear waste into the environment and waterways by converting the waste into a solid form (7).

Despite the tremendous advances in underground storage technology, all spent commercial nuclear waste in the US, as of today, is stored at on-site local storage facilities (see Figure 1, 2). The waste is initially placed at the bottom of pools of water that are at least 20 feet deep. The pools themselves are fitted with stainless steel and aluminum racks that hold the fuel assemblies and prevent leaking. As pool capacity has gradually decreased over the years—since the US government has not yet fulfilled their promise to build a centralized storage facility—many plants have had to resort to dry cask storage. Dry-cask storage is an above ground storage method in which the nuclear waste is placed in bolted steel containers and subsequently surrounded by an inert gas. The casks are further reinforced by concrete or steel to shield workers from the radiation (2).

Though both on-site and permanent depositories are a necessity, many argue in favor of technology that can reduce and recycle nuclear waste to help alleviate the burden of storage and provide more fuel and materials to use in industry and medicine. Currently, all nuclear power plants in the United States use their uranium fuel once before it is sent for storage (2). This method, called an open fuel cycle, is convenient, as reprocessing fuel is often a costly and time consuming process. Moreover, a closed fuel cycle, where spent fuel is reprocessed, was originally banned because it almost always resulted in the production of pure plutonium, which can be used for the manufacturing of nuclear weapons. For primarily this reason, President Jimmy Carter banned research into closed fuel cycles in 1977 (8).

Today, the standard method with which almost all commercial plants around the world process used nuclear fuel is called Plutonium and Uranium Recovery by Extraction (PUREX). Due to the dangers involved with plutonium extraction in this method, the materials used in spent nuclear fuel reprocessing are heavily monitored. PUREX essentially works by separating the two liquid streams of uranium and plutonium from the extracted waste. Chemically, this involves dissolving the waste in concentrated nitric acid, separating plutonium and uranium from the fission products, separating uranium from the plutonium by reduction with excess U^{4+}, and converting of both these products into a powdered form through calcination. The purified uranium and plutonium are then sent back into the fuel cycle—i.e. to be used in nuclear plants—while the remaining liquid, now only about 3% of its original volume, is sent for storage (see Figure 2, 9).

In addition to PUREX, many other techniques have been developed that both circumvent the need to produce plutonium and convert the waste back into useful forms. For instance, in 2009, scientists at Oak Ridge National Laboratory demonstrated a new technique called UREX (URanium EXtraction) that does not require independent separation of plutonium and uranium and consequently does not require that plutonium be extracted in pure form (10). UREX is essentially a modification of the PUREX method in which plutonium is prevented from being extracted by adding acetohydroxamic acid, a plutonium reductant, before the first metal extraction. However, both these methods, along with many others, are still very well in their early stages and several more years will be needed for them to commercialize and become cost effective.

Indeed, the obstacles to storing nuclear waste economically and securely present a huge challenge to the nuclear power industry. Though there has been a wealth of important research in improving fuel conversion and reprocessing technology, the issue of how to store over 60,000 tons of hazardous waste will remain a pressing concern for a long time to come (2). Thus, long-term storage technology is an absolute necessity to any solution to the problem of handling nuclear waste, and thankfully, as we have seen, the technology is well within our grasp. As technology in this sector further improves, nuclear power will continue to play an important, and perhaps even vital, role in finding a path towards energy sustainability and independence.

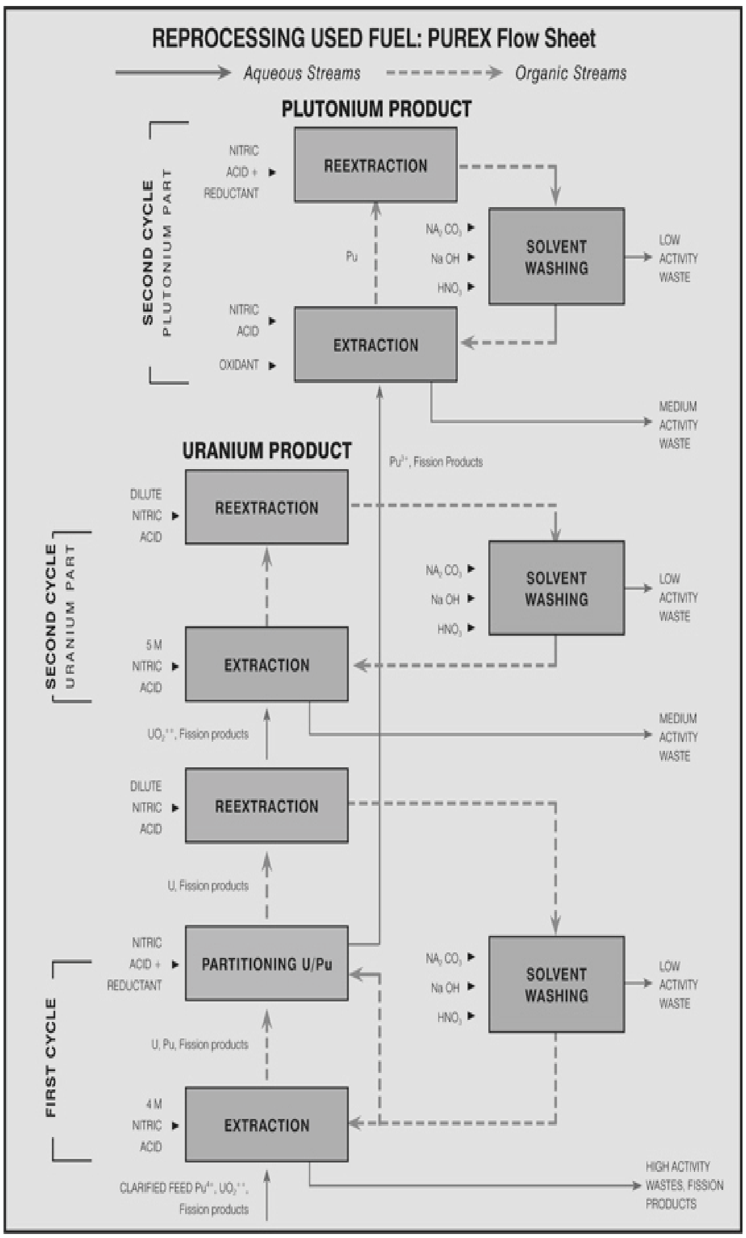

Figure 1: The protocol for processing nuclear waste such as uranium. ***Image from the World Nuclear Association.***

Abhi Chintapalli '14 is a Mathematics concentrator in Leverett House.

References
1. U.S. Department, U.S. Energy Information Administration. (2012). Monthly energy review. <http://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf>.
2. LaTourrette, Tom, 1963-, et al. Managing Spent Nuclear Fuel : Strategy Alternatives and Policy Implications. Santa Monica, CA: RAND, 2010.
3. Svemar, C., S. Pettersson, and T. Hedman. "Äspö Hard Rock Laboratory." WM´03 Conference. (2003).
4. United States. United States Nuclear Regulatory Commision. Backgrounder on Radioactive Waste. 2007. <http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/radwaste.pdf>.
5.Miroslav Kučerka, B. Haverkamp, E. Biurrun, N. Müller-hoeppe, paper presented at the European Nuclear Society TopSeal Conference, Olkiluoto, Finland, 17-20 September 2006.
6. F.G.F. Gibb. 1999. High-temperature, very deep, geological disposal: A safer alternative for high-level radioactive waste. Waste Management, 19, 207-211.
7. World Nuclear Association, Synroc, Nuclear Issues Briefing Paper 21.
8. Carter, Luther J., Nuclear Imperatives and Public Trust: Dealing with Radioactive Waste, Washington, D.C.
Resources for the Future, 1987.
9. Charles Madic, Overview of the Hydrometallurgical and Pyrometallurgical Processes Studied Worldwide for the Partitioning of High Active Nuclear Wastes, NEA/OECD 6th Information Exchange Meeting on Actinide and Fission Product Partitioning and Transmutation, Madrid, Spain (11-13 December 2000)
10. Guillermo D. Del Cul, et al.. "Advanced Head-End Processing of Spent Fuel: A Progress Report" (PDF). 2005 ANS annual meeting. Oak Ridge National Laboratory, U.S. DOE.