The Evolution of Chemical Waste Treatment in the Nuclear Industry Simple Solutions for Complex Problems - 16694

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ABSTRACT

The U.S. nuclear waste treatment industry was born in the 1980s and early 1990s with the end of the Cold War, the peak of commercial nuclear power, and after implementation of federal regulations that drove new disposal requirements for radioactive waste generators. New regulations resulted in soaring costs for radioactive waste disposal, and thus an industry was born that focused on recycling, volume reduction, and waste form improvement. New treatment facilities and technologies were started that primarily dealt with low-level radioactive wastes; however, there was little to no treatment capacity for wastes commingled with hazardous chemicals. Large volumes of "mixed wastes," of which many became known as "orphan wastes," were being stored on U.S. Department of Energy (DOE) sites with no path for disposal and thus posed a risk to workers, the public, and the environment.

Perma-fix Environmental Services, Inc. (Perma-Fix), which started in the hazardous waste industry in 1990 and had developed facilities and technologies to treat hazardous wastes, evolved in the late 90's to meet this mixed waste market opportunity. By adapting our technologies and collaborating with waste generators to understand their needs, we successfully developed treatment and disposition solutions for some of the most challenging mixed wastes in the U.S.

By establishing a pathway for treatment and disposal of orphan wastes, Perma-Fix played an important role in the safe treatment and disposition of orphan wastes, which facilitated closure of DOE sites such as Rocky Flats, Mound, and Fernald. We found that understanding chemistry and having experience in managing the hazardous constituents of mixed wastes allowed us to apply solutions that were not overly complex and expensive. Further, by adapting proven hazardous waste treatment solutions to wastes commingled with contaminants such as polychlorinated biphenyls (PCBs), mercury, and organics we were able to safely manage even more problematic mixed wastes.

During the 1980's, commercial low-level radioactive waste treatment and disposal solutions were being developed. At the same time, the federal government began dealing with increasing stakeholder demands for permanent solutions of more complex radioactive wastes such as high-level waste (HLW) and transuranic (TRU) wastes. HLW and TRU waste disposal became a contentious political issue between the federal government, regulatory agencies, and the public. As a result, DOE was mandated to develop treatment and disposal methodologies to address these wastes.[1] DOE's Waste Isolation Pilot Plant (WIPP) facility solved most issues with disposition of TRU wastes; however, for HLW (for example tank wastes at Hanford, Savannah River, and Idaho) the complexity of the wastes and the fact that government entities were developing political solutions for waste treatment resulted in a variety of complex and expensive solutions. Decades later we still do not have a permanent solution for HLW. Whether some simple commercial approaches are possible, what regulatory changes should occur, and what the implications may be if we do not change our current path, will be discussed.

After two decades, we see the low-level nuclear waste industry maturing and replicating the path of the hazardous waste industry. When new hazardous waste federal regulations were enacted in the 1970s and 1980s, the hazardous waste industry began to boom with new company startups and construction of numerous treatment and disposal facilities. Initially, this was a good business to be in, managing dangerous wastes in an environmentally safe and responsible manner, and it was profitable. However, overcapacity and fierce competition drove down pricing, and companies failed. This ultimately led to a major consolidation within the hazardous waste industry. Similarly and more recently in the nuclear industry, overcapacity and competition has driven down profitability, companies have failed, and there is a major consolidation occurring within sectors of the industry. For consolidation to be successful and healthy for either industry, a leader must emerge to set the direction for the others and establish a sustainable path that is acceptable for waste generators, stakeholders, and investors. This was the case for the hazardous waste industry. This paper will examine the parallels between the hazardous and nuclear waste industries as they have matured and evolved, and what discuss the long term implications of consolidation within the nuclear industry.

INTRODUCTION

Nuclear materials and the use of nuclear power have had a major positive impact on the security and economic power of the U.S. Nuclear power is unique as it is the only form of energy that will meet both the world's growing baseload energy requirements and global climate change goals. And yet, the growth in nuclear has been hampered by the lack of a coherent national policy to address the back end of the nuclear fuel

[1] Nuclear Waste Policy Act of 1982

cycle. Managing wastes in a politically and publicly acceptable manner is vital for nuclear energy to flourish in the U.S. and around the world.

Here we focus on how to do deal with the waste generated from the use of nuclear materials whether from medical research or nuclear power to ensure that waste management innovations can drive growth. Public pressure drove enactment of federal regulations that resulted in soaring costs for low-level radioactive waste (LLW) disposal, and thus an industry was started that focused on recycling, volume reduction, and waste form improvement. Therefore, solutions to nuclear waste challenges do exist. We have the technologies today to recycle, treat, and dispose of all categories of nuclear waste. All we need is to adopt the right standards, policies, and procedures, and, through education and stakeholder collaboration, gain public and political acceptance for these solutions.

Nuclear wastes may contain hazardous chemicals in addition to radionuclides, and these special wastes are known as "mixed wastes". Until the early 2000s, this capability to treat mixed wastes did not exist. Utilizing Dr. Centofanti's experience from starting up hazardous waste treatment companies, he founded Perma-Fix and developed a suite of technologies and processes that could address the broad range of mixed wastes that had no available pathway for safe and affordable disposal. The ability to treat unique chemicals in wastes generated from nuclear power production, weapons production, medical research, and isotope production has had an important positive impact on the nuclear industry. Without this capability, former weapons facilities would not have closed and nuclear power plants would have to store large volumes of mixed wastes, all of which provide added political and public disincentive for growing the nuclear industry.

DISCUSSION

By adapting existing technologies and collaborating with waste generators to understand their treatment needs, regulatory requirements, and disposal site limitations, Perma-Fix has successfully treated and dispositioned some of the most challenging mixed wastes in the U.S. Problematic wastes containing PCBs, mercury, and organics now can be safely disposed. The once long list of orphan mixed wastes in storage around the country is now virtually gone. Creating these capabilities facilitated the closure of DOE sites such as Rocky Flats, Mound, and Fernald, thus turning land back to host communities for other use. Perma-Fix's foundation is to utilize the processes that occur in nature to ensure that wastes are treated in a manner that has long term stability in our environment.

Simple Treatment Solutions

Federal regulations drive treatment requirements for hazardous chemicals so that the technologies applied must ensure compliance with those treatment standards. Specifically, the U.S. Environmental Protection Agency (EPA), Resource Conservation and Recovery Act (RCRA), and Toxic Substances Control Act (TSCA) regulations dictate treatment standards that must be met in order for a waste to be safely land disposed. Dr. Centofanti found that understanding chemistry, mimicking natural processes, and having experience in managing the hazardous constituents of wastes facilitated solutions that are not overly complex and expensive to meet these standards.

Perma-Fix deployed relatively simple and affordable technologies that took advantage of "wet chemistry" and in-drum treatment, which led to its early success treating large populations of characteristic mixed waste streams. Mixed wastes contaminated with heavy metals, acids, bases, and reactives, that often had been stored for decades, were successfully treated and disposed thus minimizing risk to the public and environment.

Although the use of wet chemistry or "Pozzolanic Chemistry" processes are straight forward, there can be confusion between what is required to "treat" waste to meet regulatory disposal standards, and what is required to ensure the physical form is the most appropriate for disposal. Treatment occurs first by reacting chemicals with a waste resulting in an end product that is chemically inert and can be safely disposed for millions of years without concern that the chemicals will leach into the environment. After treatment, a waste may also require stabilization or solidification to improve its physical form (e.g., adding "grout" or cement). Interestingly, these steps mimic nature's own processes.

Over the years, Perma-Fix has added more complex treatment processes to address mixed wastes contaminated with PCBs, organics, mercury, etc., including combustion, vacuum thermal desorption, and amalgamation. Dr. Centofanti's philosophy is to apply the lowest cost technology solution to treat wastes, and to collaborate with waste generators to ensure that these solutions meet their needs. This simplified approach differs from pursuit of "silver bullet" solutions such as vitrification, steam reforming, plasma arc, and other technologies that would be applied to large varieties of wastes indiscriminately. These technologies may be necessary for a small portion of more exotic waste, but have significant challenges in terms of reliability, cost, and stakeholder acceptance. Numerous companies have gone out of business pursuing these complex solutions.

Perma-Fix is taking its collaborative and simplified waste management approach to international waste generators. Countries around the world have similar waste issues as the U.S., but the U.S. is more advanced in treatment and disposal capabilities. This leadership provides further opportunity for companies in the nuclear waste industry to provide innovative solutions to international waste management challenges.

Research and Development

Continually innovating is a key to success in the waste management business. Perma-Fix invests heavily in research and development (R&D) to find treatment solutions for new and exotic waste streams that are frequently encountered. An exciting new discovery from these R&D efforts is the development of a very unique resin that has the ability to hold technetium-99 (Tc-99) and release molybdenum-99 (Mo-99) – two elements that are nearly identical and sisters on the periodic table. The advantage of holding Mo-99 and releasing Tc-99 brings about significant potential application for medical diagnostics, which Perma-Fix is working to commercialize.

As background, Tc-99 is the world's most commonly used medical radioisotope, used in 80-85% of all nuclear medicine procedures. Currently, Tc-99 is generated from the use of highly enriched uranium (HEU) in very specialized reactors. This process produces enormous quantities of radioactive waste, and obviously use of HEU raises major proliferation concerns. There are only a handful of specialized reactors around the world that can handle this process, with two of them scheduled for closure within the next few years. As a result, the industry has been plagued by major supply chain disruptions and reliability concerns.

In comparison, Perma-Fix's process uses molybdenum as a starting material. Molybdenum is a common metal, very safe and in abundant supply. Using this process, molybdenum can be irradiated in any research reactor, ensuring decentralized, low-cost production. Moreover, this process does not have proliferation nor nuclear waste issues associated with current production methods. This new discovery illustrates that pursuit of waste treatment innovations can result in breakthroughs that provide positive and far reaching impacts beyond the nuclear industry.

LESSONS LEARNED FROM THE HAZARDOUS WASTE INDUSTRY

RCRA - A Sound Regulatory Framework

RCRA was enacted in 1976 to address the increasing problems the nation faced from its growing volume of municipal and industrial waste. The goal of RCRA was to protect human health and the environment from chemical hazards of waste disposal by ensuring the management of waste in an environmentally sound manner. RCRA set standards to reduce hazardous waste generation through source reduction and recycling, and has been successful by building upon other related environmental regulations including TSCA and the Clean Water Act (CWA). These regulations form a framework that holds generators responsible for the waste they produce, places protections against and penalties for polluting the environment, and ensures that wastes are properly transported and disposed.

The key tenets of the RCRA philosophy are universal and should apply to all waste treatment and disposal. The goals of RCRA are:

1. Recycle – which refers to both energy and materials recovery;
2. ***Treatment – to meet standards that prevent materials from leaching into the environment over geologic time;***
3. Minimize organics – including solvents and chelates that can interact with metals in a landfill and exacerbate environmental problems; and
4. Good landfill design – strict construction standards that prevent water intrusion, migration of contaminants, and siting landfills in appropriate geologic/geographic locations.

The most critical of the RCRA tenets is the requirement for treatment. As previously stated, performing chemical treatment that result in an inert and stable product is essential for the protection of human health and the environment. This is best explained with a simple example. Lead is known to be toxic and causes very harmful effects when ingested, and yet we drink out of leaded crystal without any risk of lead exposure. The reason is leaded crystal is in a chemical form that is completely inert and will remain so for millions of years.

Unlike RCRA, there are no uniform standards for nuclear waste treatment for disposal. There are few or no landfill construction or treatment standards. In fact, nuclear landfills have the lowest standards of any landfills including solid waste, which are not adequately protective or rational. Current regulations allow for disposal in radioactive landfills of chelates and organics, which are known to be very problematic for a landfill and create significant migration issues.

Thus, can the lessons learned from implementing RCRA standards in the hazardous waste industry, which forced the evolution of hazardous waste generation and management, provide improved waste management technologies and processes to the nuclear industry? The answer is yes, they can. Not doing so has consequences as evidenced by the operational suspension at DOE's WIPP. This facility disposes of TRU wastes in a salt formation, but due to an agreement between DOE and the State of New Mexico does not require that hazardous constituents be treated to RCRA standards. An unexpected reaction with a nitrate salt waste led to the closure of that facility in 2014, at the cost of hundreds of millions of dollars, with hopes to reopen at the end of 2016.

Applying Lessons to Low-Level Waste Management

What needs to be done to improve management of radioactive wastes? Implementing standards similar to those for hazardous waste would greatly improve the performance of low-level waste (LLW) disposal facilities and provide confidence to the public. Two primary areas of focus should be:

1. Implementing standards similar to those for hazardous wastes. Specifically for LLW, utilize treatment to ensure that radionuclides and other constituents do not cause performance or migration issues, and
2. Require stricter landfill construction and management standards.

The nuclear industry has treated and disposed of LLW for over 25 years. The technology exists and the solutions are available to ensure that radionuclides are immobilized. However, there are no federal requirements for treatment of the radioactive component of wastes. The lack of treatment requirements greatly increases the risk of migration of mobile radionuclides into groundwater or air and does not protect humans from exposure to high energy nuclides. The radionuclides of most concern are those that easily mobilize into the environment (e.g., technetium, cesium, strontium). Because of the lack of federal requirements, state agencies are trying to address this issue. The State of Texas required much stricter design criteria for the new LLW landfill at the Waste Control Specialists, LLC (WCS) Andrews Texas Site. Unlike conventional shallow land disposal at other sites, this landfill has superior natural barriers of clay, and significant separation from groundwater; however, Texas added the requirement for concrete vaults. This added barrier ensures that mobile radionuclides are contained, which is more protective of the environment and has the advantage of allowing wastes containing higher concentrations of radioactivity to be disposed.

Allowing organic solvents and chelates to be disposed in a LLW facility without treatment may be a cheaper short term solution, but long-term can cause significant environmental issues from chemical reactions within the landfill. Applying wet chemistry techniques that include sulfides, silicates, sulfates, geo-polymers, pozzolans, and aluminosilicates to chemically treat and make LLW inert ensures that wastes meet disposal performance standards, and coincidentally are the same reactions that would naturally occur over geologic time.

Applying Lessons to High-Level Waste

The real challenge with HLW disposal is public and political acceptance. Because this issue is politically charged, we have seen solutions created and mothballed over the last 20 years that have cost tax payers billions of dollars and resulted in no answer for the disposal of HLW. HLW primarily includes spent fuel from nuclear reactors, contaminated equipment, and dewatered salts generated from power and weapons research and production. These divergent groups of materials are categorized the same, but present very different waste management challenges.

If RCRA principles of recycling and treatment are applied to HLW management, a more coherent and environmentally responsible policy for its ultimate disposition could be found. First, by recycling and recovering materials from HLW we can recover energy and re-use materials that were developed at great cost and still have important value in the fuel cycle. The concept of deep geologic disposal of all HLW without the benefit of recycling violates all basic tenets of sound environmental practices.

An example of recycling is the creation of mixed oxide (MOX) fuels from surplus weapon-grade plutonium (Pu). By removing impurities and mixing Pu with uranium oxide, MOX fuel pellets are created that can be used in commercial nuclear reactor fuel assemblies. This may not be the least expensive option to disposition Pu compared to landfill disposal, but it is more environmentally conscious and could prevent future proliferation or criticality concerns from the disposal of this material.

From the perspective of treatment, processes that are currently used for LLW management can provide improved long-term geologic disposal performance for HLW as well. As previously discussed, the use of processes that mimic chemical reactions that would occur in nature (e.g., use of wet chemistry) should be considered. An example of how nature dealt with a criticality issue is that approximately 1.7 billion years ago in Oklo, Gabon Africa, a uranium deposit went critical. Water intrusion into this uranium formation reacted with its geologic makeup (i.e., sandstone, granite) to create a natural treatment barrier that for the past billion years has prevented radionuclide migration, and thus we see natural processes are ideally suited for HLW.

Millions of gallons of HLW at DOE sites, mostly dewatered salts contained in tanks, have different disposition methods being applied to them dependent on the site in which they are located. A subset of these HLW streams may present an opportunity to apply lower cost treatment options by using wet chemistry techniques (e.g., silicates and pozzolans), rendering the waste suitable for land disposal without the need for more expensive treatment methodologies and deep geologic disposal. Therefore, the lessons learned from application of hazardous waste management practices (i.e., RCRA framework) may be used to improve management of radioactive wastes.

THE NUCLEAR WASTE MANAGEMENT INDUSTRY GOING FORWARD

Who Will Lead the Way?

The nuclear waste treatment and disposal industry is in a state of flux, and experiencing a parallel fate to that of the hazardous waste industry. When RCRA, TSCA, and the CWA were enacted in the late 1970s and early 1980s, large numbers of hazardous waste treatment, transportation, and disposal companies were started to service waste generators and help them comply with these new regulations. It was a strong and profitable business until overcapacity, competition, and a divergence from company core competencies drove down profitability and resulted in facility closures and companies failing in the 1990s. The large disposal companies that tried to enter into the service side of the business were responsible for many of these problems. There is a natural conflict between the business goals of a disposal company that deals in large volumes and fills air space to that of service companies that deal with a large number of generators (large and small) requiring more customer focused services. Service companies often perform services that reduce waste volumes, which is obviously not in the best interest of the disposal companies. Ultimately in the hazardous waste industry, companies that were created from the services/treatment side survived and began to thrive. Through growth and acquisition, these companies have added disposal to their service lines; however, they have maintained their focus on customer service (e.g., Clean Harbors). This evolution has led the industry back to a place of profitability, and provides an important lesson for the nuclear industry.

The nuclear industry has also seen overcapacity and a divergence from core competencies lead to lower profitability, facility closures, and companies failing. The accident at Fukushima, Japan further complicates matters because it has stalled the nuclear renaissance in this country. The slow down on resurgence of nuclear power, competition for shrinking federal budget dollars, and the commercial utility strategy for taking reactors to cold and dark versus decommissioning have had negative long term impacts on nuclear companies. Large companies with a core competency of disposal, such as Energy*Solutions,* have struggled to lead this industry, which is no surprise. As a result, there is a major consolidation occurring in the commercial disposal sector with Energy*Solutions* returning to its core strength of providing disposal.

Similar to the hazardous waste industry experience, for consolidation to be successful and healthy for the nuclear industry requires a leader to emerge that sets the direction for the others and establishes a sustainable path that is acceptable for waste generators, stakeholders, and investors. That company has to have a business model that supports leadership over the long term, and whether or not current mergers, acquisitions, and consolidation results in that leader is yet to be seen. Ultimately, we all need nuclear energy and the industry that supports it to be successful for the sake of our environment; and thus we must find an answer to this problem in the near term.

CONCLUSION

In conclusion, by adapting existing technologies and collaborating with waste generators to understand their treatment needs, regulatory requirements, and disposal site limitations, Perma-Fix has successfully treated and dispositioned some of the most challenging mixed wastes in the U.S. This was accomplished using the basic tenets of RCRA, and utilizing wet chemistry processes that mimic those found in the natural environment.

We need to expand the use of these concepts of recycle within the nuclear industry. We should not only require processing of the hazardous components, but also the radionuclides present, in order to enhance radioactive disposal cell performance and protect the environment.

For nuclear energy to gain public acceptance, we must develop disposal paths for radioactive wastes that are more protective. We recommend the principles of RCRA be applied to all types of radioactive wastes, and we must have consent-based siting, disposal, reprocessing, and MOX fuel production collocated, which gives the local community dramatic incentive to participate.