Sub-Seabed Repository for Nuclear Waste - a Strategic Alternative – 13102

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ABSTRACT

It was recognized at the outset of nuclear power generation in the 1950's that the waste products would require isolation away from humans for periods in excess of 10,000 years. After years studying alternatives, the DOE recommended pursuing the development of a SNF/HLW disposal facility within Yucca Mountain in the desert of Nevada. That recommendation became law with passage of the NWPAA, effectively stopping development of other approaches to the waste problem. In the face of political resistance from the state of Nevada, the 2010 decision to withdraw the license application for the geologic repository at Yucca Mountain has delayed further the most mature option for safe, long-term disposal of SNF and HLW. It is time to revisit an alternative option, sub-seabed disposal within the US Exclusive Economic Zone (EEZ), which would permanently sequester waste out of the biosphere, and out of the reach of saboteurs or terrorists.

A proposal is made for a full scale pilot project to demonstrate burying radioactive waste in stable, deep ocean sediments. While much of the scientific work on pelagic clays has been done to develop a sub-seabed waste sequestration capability, this proposal introduces technology from non-traditional sources such as riser-less ocean drilling and the Navy's Sound Surveillance System. The political decisions affecting the issue will come down to site selection and a thorough understanding of comparative risks. The sub-seabed sequestration of nuclear waste has the potential to provide a robust solution to a critical problem for this clean and reliable energy source.

INTRODUCTION

As an electricity generating source, nuclear power is very attractive as it can generate large amounts of base load electricity without emitting air or water pollution. Between the continuing pressure to reduce greenhouse gas emissions and potential for added demand from plug-in electrically powered vehicles, the market demand for clean electric power is estimated to grow 22% between 2011 and 2035, with 4% of that being nuclear power [1]. Uranium fuel sources are available domestically and from sources in Australia, Canada, Africa, and South America [2]. This clean source of power, with reliable sources of fuel from friendly countries has a worrisome problem – the safe reduction, and disposal of the waste products generated by the nuclear power plants. A larger proportion of the national base load might be generated by nuclear energy except for the risk and cost of waste management.

It was recognized at the outset of nuclear power generation in the 1950's that the waste products would require isolation away from humans for periods in excess of 10,000 years because of the long half-lives of some radionuclides. Many ideas were studied with consensus moving toward options of sequestering waste in deep geological storage away from human habitation, and out of the reach of saboteurs or terrorists. In a 1981 Record of Decision by the DOE Program of Research and Development for Management and Disposal of Commercially Generated

Radioactive Wastes, the Department decided that their most promising approach would be to develop a strategy for mined geological repositories. To keep options open, DOE planned to continue study of two other options: sub-seabed waste disposal, the emplacement of radioactive waste into the deep ocean sediments; and very deep hole disposal, burying waste vertically miles into the earth instead of horizontally, as is done for the mined geological repository. The governing considerations for this decision were radiological effects during the operational period, non-radiological effects, compliance with existing national and international law, independence from future development of the nuclear industry, and the potential for corrective or mitigating actions [3]. The mined geological alternative appeared to be the low risk approach, one which could be moved forward most expeditiously. The following year in 1982, the Congress passed the NWPA establishing policy for radioactive waste disposal under the DOE. Research was done on all options culminating in DOE's recommendation in 1986 to sequester the waste in a mined geological repository under Yucca Mountain in the desert of Nevada. The DOE believed the cost and risk were lowest for the land based option using a location on federal land, adjacent to the Nevada Test Site, where hundreds of nuclear weapons tests had been conducted, and which was surrounded on three sides by Nellis Air Force Base with established rapid response security forces, and an existing restricted air space [4]. The DOE recommendation was decided with passage of the NWPAA. With that decision, funding was cut-off for the backup options, effectively leaving the nation with only one approach for disposal of high level nuclear waste. The Geologic Repository for the Disposal of SNF and HLW at Yucca Mountain in Nye County, Nevada was planned to be online receiving waste in January 1998, twelve years later, per the NWPA. There have been many obstacles and delays since that ill-fated decision, including a misunderstanding of the level of resistance DOE would face from the State of Nevada. What appeared to be the most desirable alternative with the least technical risk, had in fact substantial political risk. In June 2008, DOE applied to the NRC for a license to receive nuclear materials at the Yucca Mountain repository. The DOE motioned for withdrawal of its licensing application to NRC in March 2010 on the basis that Yucca Mountain was not a workable option, though NRC did not accept the withdrawal on the grounds that the NWPA required it to evaluate the proposal. DOE did not request funding for the Yucca Mountain repository in its FY11, FY12, or FY13 budget requests and so progress has halted on the development of a disposal solution for SNF and HLW [5].

DISCUSSION

When the first deadline to open the Nation's first SNF repository passed in 1998, many commercial nuclear operators sued the DOE for costs incurred when it did not accept their waste, as agreed upon in the Standard Contracts. Between settlements and US Federal Court judgments, DOE owes the nuclear plant operators close to $1 billion, with $290 million having been paid from the Judgment Fund as of October 2007. These funds were not permitted to be taken from the fees collected for waste storage and were required to be sourced from the Treasury. DOE estimates the government's liability (opportunity cost) to be $7 billion if the repository opens in 2017, and as much as $11 billion if it is delayed to 2020 [6].

As of January 2012, about 65,000 metric tons of SNF and approximately 22,000 separate canisters of defense-related radioactive waste fuel [7] were being stored at more than 125 sites in 39 states [8]. When the NWPA was amended in 1987 to select the Yucca Mountain facility as the repository, it specified waste disposal of up to 70,000 metric tons. Projections by DOE estimated that up to 130,000 metric tons of waste will be required by 2017 from existing nuclear power plants [6], and between 150,000 and 200,000 metric tons by 2050 [7]. Though Yucca Mountain's environmental impact statement indicates that up to 120,000 metric tons of waste could be safely disposed of in the repository, it appears this site will be at capacity shortly after opening and that another site may be required.

An alternative waste disposal site is required, one that meets all the criteria for safe and secure disposal, and one which is achievable in the foreseeable future. Such an alternative site exists today within the deep water, geologically stable, sub-seabed of the US EEZ.

History of the Sub-seabed Disposal Concept

The concept of burying radioactive waste in deep ocean sediments, also referred to as sub-seabed disposal, is frequently attributed to Dr. Charles D. Hollister, a marine geologist with Woods Hole Oceanographic Institution, though many others have contributed to the concept and the research on which it is based [9, 10, 11]. Because the half-lives of some radionuclides are tens of thousands of years or more, any disposal system will need to render them safely isolated from humans for that duration. Hollister and others reasoned that by burying the waste in the depositional pelagic clays of the deep seabed which have been stable for millions of years, the materials would be effectively sequestered from interaction with the biosphere. The deep seabed is the abyssal plain located at nominally 4,000 to 5,000 meters of ocean depth. The clays are the result of eons of windblown particles from land, insoluble biogenic debris, and general precipitants [9]. The clays tend to be relatively impermeable to migration of either heat or radioactive elements from mechanisms of diffusion, convection, advection, or some combination of these mechanisms [9]. The deep water isolates the waste from mankind and the geologically stable clays isolate the waste from the oceanic biosphere.

Site Selection

The selection of a site for waste sequestration requires a number of criteria, many in common with those for a deep geologic repository. The site must be out of the habitable biosphere – human and other living creatures. The site must be able to contain the waste for the foreseeable future without inadvertently allowing it to re-enter the biosphere. To that end, the site must be geologically stable without seismic or tectonic margin activity, avoiding areas with the potential of petroleum resources, such as alluvial fans (depositional sediments found in river deltas); and avoiding areas subject to landslides and turbidity currents, such as at the base of the continental slope. It must be out of reach of persons who would use the waste to menace others. The site must allow deliberate placement and recovery of the waste in the near term. It must be expansible to accommodate growth in volume of SNF and HLW. For purposes of this discussion, the site must be located within the control of the US or its possessions' EEZ of 200 nautical miles from the coast or islands, figure 1. It should be established within the framework of international agreements. Overall, the site should allow a cost effective sequestration method. The site should not be in anyone's backyard.

Sites meeting all the selection criteria exist within a number of the island possessions of the US located in the Pacific Ocean. These islands are isolated, have no indigenous populations, and are under the control of the US federal government. Within the 200 nm EEZ around these islands are deposits of geologically stable pelagic clays in deep ocean water that are hundreds of meters thick.

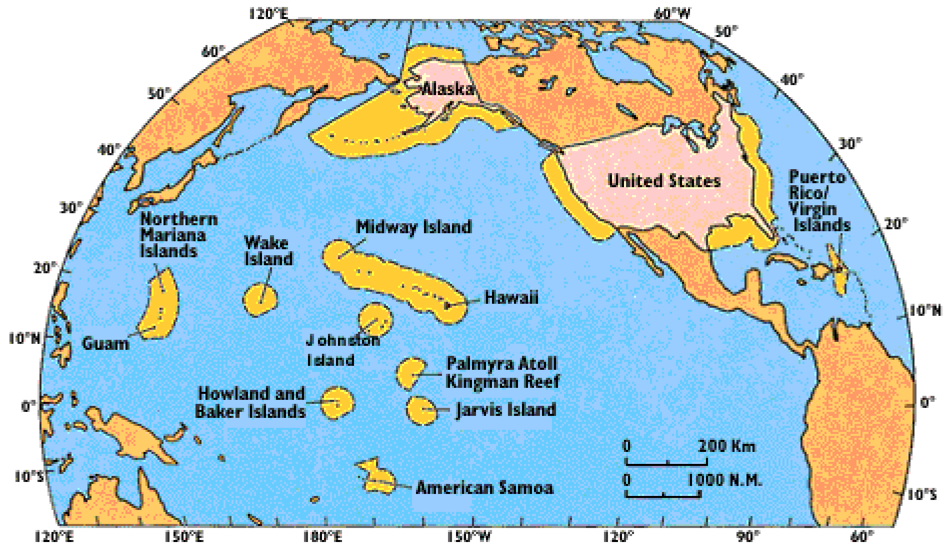

Fig. 1. US EEZ Boundaries (in yellow) [12].

APPROACH TO SUB-SEABED WASTE DISPOSAL IN 2012

The proposed approach to sub-seabed radioactive waste disposal is similar to that proposed by Hollister [11], though there are some differences based upon the maturation of technology since 1986 that are required to fully implement a sub-seabed waste disposal system. While this approach has not yet been integrated and demonstrated as a system, all of the steps have been separately demonstrated, are in use today, or are fully extensible form today's technology. The process must receive and sequester both HLW from defense weapons programs and SNF from commercial and naval reactors. Once the site is prepared, the waste must be packaged and transported, emplaced, and then protected.

Site Preparation

A dynamically positioned drillship similar to that used by the scientific Ocean Drilling Program (ODP) jets a large bore re-entry cone and surface conductor casing into the seabed, figures 2, 3, and 4. The sequestration hole is then bored out and tubing set to line the hole and prevent sidewall collapse, similar to figure 5. A packer (plug) is set in the bottom of the hole sealing it at the bottom. What remains on the seabed is a re-entry cone with an acoustic beacon over a tubing-lined cylindrical hole that is hundreds of meters deep. The volume of the hole is based upon the depth of the pelagic clay and optimal diameter of tubing. The ship then relocates and repeats the process, creating a field of sequestration holes in a grid pattern. The separation between holes in the disposal area will be a multiple of the radius of the heat-affected zone around the hole for a predicted steady state condition. The location of the re-entry cone is charted. The ability to drill into the clays of the abyssal plain and re-enter the boreholes have been demonstrated repeatedly by the ODP using deep water dynamically positioned drillships.

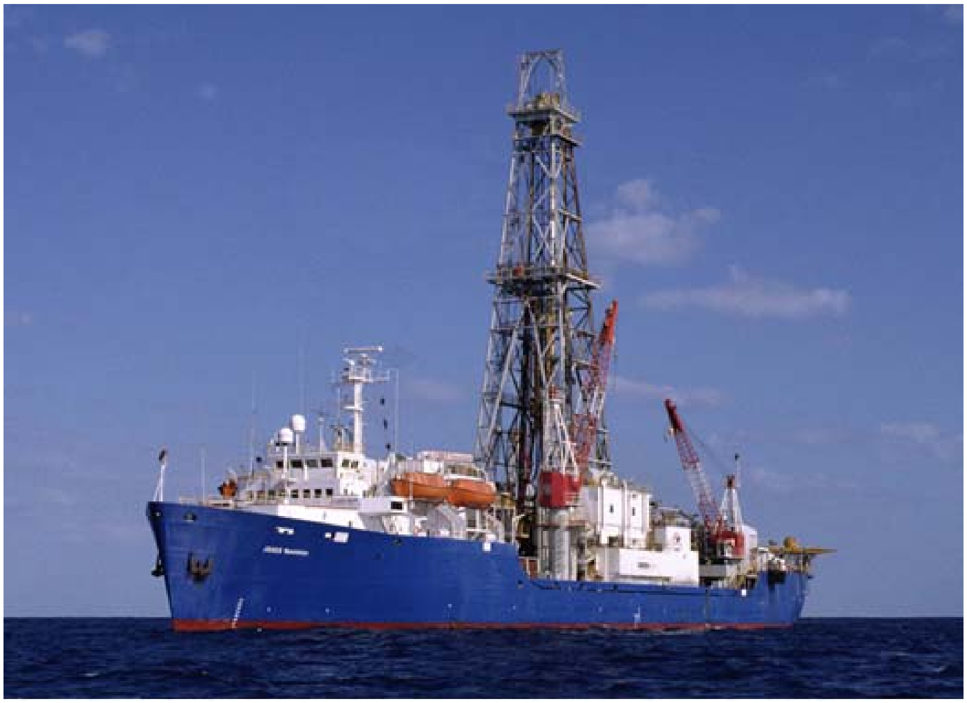

Fig. 2. Deepwater Drillship D/V JOIDES Resolution [13].

Fig. 3. Re-entry Cone Assembly Staging in Moonpool [13].

Fig. 4. Large Bore Casing in Rotary Table on Drill Floor [13].

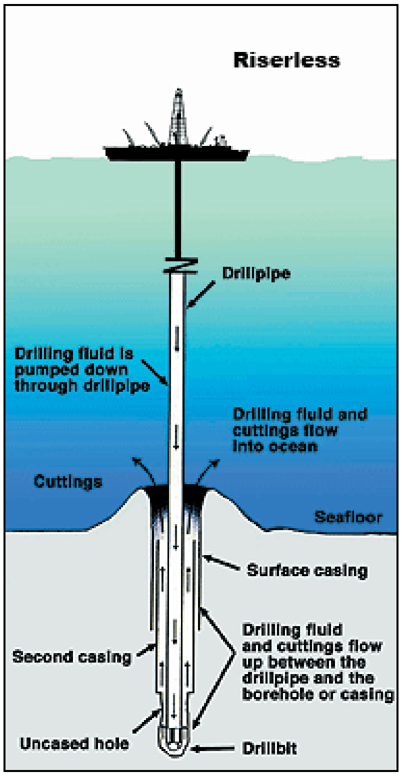

Fig. 5. Deep Sea Drilling Illustration [13].

Waste Packaging and Transportation

The preparation of waste for storage and shipping relies extensively on the work done by DOE and its contractors. Of particular interest is the vitrification process employed for incorporating the waste into a glass matrix. The radioactive waste is vitrified by mixing it with glass powders, heating it to a molten state, and pouring it into metal containers, likely made of titanium or stainless steel for durability, where it solidifies for safer handling. This process lends itself to the cylindrical configuration required for the waste to be placed and stacked into a sequestration hole. Vitrification technology is already in use at the DOE national laboratories and in Europe for entraining HLW in an impermeable glass matrix. Whether vitrified or not, all waste planned for sequestration will need to be packaged into cylinders which can be lowered into the pre-drilled holes and stacked on top of each other.

DOE waste sites are connected to the national railroad system, which could safely transport waste containers to a port of embarkation, and shipped to the sequestration site. Much work has been done to ensure safe transport of nuclear waste within the US, and this process would rely upon that work.

Upon arrival at the port, a self-loading transport and emplacement ship would bring the waste aboard into purpose-designed holds and sail to the sequestration location. This element of the process has not been demonstrated previously, but is well within the state of the art, as partially demonstrated by SKB with their transport vessel M/S Sigyn [14]. The ship must be able to store and transport the waste and once onsite, dynamically position itself on location, and lower the waste cylinders into the prepared holes. That requirement could optimally be met by either purpose-built vessels or converted deep water drilling rigs.

Emplacement and Recovery

The waste cylinders are lowered into the hole and stacked to approximately 30 meters below the level of the seabed. A packer (plug) is fitted in the hole above the waste cylinders and filled with concrete back to the level of the seabed. All that is visible is the re-entry cone protruding from the seabed. The location of the re-entry cone, hole and contents are charted. Should there ever be a reason to recover the waste canisters within the first 100 years, the hole would be re-entered, the concrete plug drilled out, the packer recovered, and the waste cylinders retrieved back to a ship. Their condition could be inspected remotely before they were recovered to the ship. Re-entering a hole, drilling out a concrete plug, and recovering equipment from a well are state of the art in the offshore oil industry. The safe recovery ability will be a function of the durability of the metal cylinders used to enclose the waste.

Protection

By the nature of its remote location and depth in thousands of meters of water and tens of meters of seabed, humans and sea life are protected from the waste repository. Anyone attempting to reach the waste will require large, seaborne sophisticated equipment to locate, drill out the plug, and recover the contents of a sequestration hole. Additionally, such an action will take time. To protect against such an attempt, a number of security features are available using existing capabilities.

An acoustic array can be installed around the perimeter of the disposal area and cabled back to a shore station on the proximate island. This technology is based upon the Navy's Sound Surveillance Systems (SOSUS) installed during the Cold War to passively monitor the movement of Soviet submarines [15]. The cable is multifunctional, providing power and data links to multiple site instruments. The hydrophone array provides early acoustic warning of any attempts to access the disposal area by intruders. Acoustic array shore stations are typically automated and alert an operator if there are changes from a preset acoustic baseline. Satellite detection capability could also monitor the site for intruders. Should an attempt to access the site be detected, national authorities would be alerted to intervene. Their authority would be enforcement of activity within the US EEZ.

Approach Summarized

To summarize the process, SNF and HLW would be consolidated into cylindrical storage containers suitable for transporting and disposal. Those containers would be transported to the port of debarkation and loaded aboard a ship. The ship would sail to the repository, stack the waste canisters into prepared holes, and plug the holes with concrete. The waste is now sequestered safely within the seabed. This process is repeated as many times as required, only limited by the site's surface area and the consideration to space the wells far enough apart to prevent overlap of the heat affected zone around the well. The radioactive waste has multiple levels of containment from the deep ocean environment: vitrification glass, metal cylindrical shells, well tubing, and pelagic clay sediments. It is isolated under kilometers of ocean. Should there ever be a need to recover the cylinders within the first 100 years, a drillship could return to the site, re-enter the hole, drill out the concrete, and recover the waste cylinders.

LEGAL ENVIRONMENT

For centuries, people have used the ocean as a dump. Many things were disposed with little thought for future consequences. Some examples include ordnance, chemical weapons, industrial chemicals, municipal garbage, medical waste, sewage, and even nuclear waste in 208-liter (55-gallon) drums. This abuse of the oceans threatened the health of fishing grounds on the continental shelf, and some of these materials washed up on beaches. This provoked an international outcry which resulted in the passage of the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, also known as the London Convention. The US signed on to the London Convention. The London Convention prohibited the "dumping" of radioactive wastes into the ocean. This has been interpreted by some as prohibiting drums full of radioactive waste being rolled off the back of ships, but not prohibiting HLW being emplaced below the seabed [16].

In 1996, an update to the Convention, known as the London Protocol, banned all dumping with a list of exceptions for dredged material; sewage sludge; fish wastes; vessels and platforms; inert organic geological material; organic material of natural origin; bulky items primarily comprised of iron, steel, and concrete; and carbon dioxide for sequestration [17]. The Protocol took the added step of clarifying that sub-seabed disposal of HLW was considered to be "dumping" [16]. The view at the time was that nuclear waste was the source country's problem, and not to be transferred to a common area. As of this writing, the 1996 London Protocol has not been ratified by the US.

The United Nations Convention on the Law of the Sea (UNCLOS) of 10 December 1982 is another treaty pending ratification by the US which includes provisions to limit ocean dumping. Between the London Protocol of 1996 and the UNCLOS, both unratified by the US at this time, the window of international law under which sub-seabed disposal can be implemented is closing.

WAY AHEAD – PILOT PROJECT PROPOSAL

The way ahead is to restart and accelerate the research for a sub-seabed waste disposal capability as an alternative or complement to Yucca Mountain or the status quo. To that end, a full scale pilot project is proposed which will develop and implement a prototype sub-seabed disposal area within the US EEZ as a way to demonstrate the process, work out process details and procedures, instrument a subsea test site, and collect data on a small HLW disposal installation – which would be fully recoverable within the timeframe of the pilot program. With a coordinated inter-agency approach, such a pilot project could be implemented in a few years and give the US a credible alternative to mined geological repositories.

An international solution will require international legislation for the London Convention and Protocol and the UNCLOS. Such support will be much easier to obtain with full scale pilot data in hand and a viable proposal to safely implement waste sequestration. The existing UNCLOS should permit such an experiment. From UNCLOS Part 1, Article 1, Part 1 (5) (b) (ii) "Dumping does not include placement of matter for a purpose other than the mere disposal thereof, provided that such placement is not contrary to the aims of this Convention." [18]. This provision implies that placement of waste in the sub-seabed for an experimental pilot project would be permissible under the UNCLOS. In the interim, the US should defer ratification of the 1996 London Protocol, as the US is complying with the spirit of the agreement already. Its ratification would remove sub-seabed disposal as an option until 2019. Eventually for sub-seabed waste disposal to work in the long term, the London Protocol will need to be amended to reclassify managed sub-seabed disposal as a recognized exception.

CONCLUSION

The proposed strategy for safely sequestering nuclear waste in the sub-seabed is an opportunity to permanently solve the US radioactive waste disposal problems. The present approach of a deep geological repository at Yucca Mountain, now on hold, has led to inadequate facilities for storage and disposal of SNF and HLW. A consequence of the government's inability to provide long-term storage or disposal facilities is a growing liability to the US Treasury from the power industry. Additionally, the inability to develop adequate facilities for sequestration of SNF and HLW for present and future needs constrains the development and construction of a clean source of electric power.

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