50 Years of Power
500,000 Years of Radioactive Waste

by
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Continued Storage of Spent Nuclear Fuel
and
Draft Waste Confidence Generic Environmental Impact Statement
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"Having the capacity to outlast human civilization as we know it and the potential to devastate public health and the environment, nuclear waste has vexed scientists, Congress, and regulatory agencies for the last half-century."

U.S. Court of Appeals for the District of Columbia, *Nuclear Energy Institute v. U.S. Environmental Protection Agency*, July 9, 2004

Introduction

The problem of what to do with the extraordinarily dangerous and long-lived wastes produced by nuclear fission has perplexed society since the first reactor wastes were produced on December 2, 1942, the day an atomic "pile," composed of graphite and uranium slugs, went critical in a converted squash court at the University of Chicago. More than seventy years later, despite repeated protestations of confidence by regulators that a solution would soon be found, we still have no method for disposing of the high-level wastes (HLW) produced by nuclear power plants, each enormously larger than that first device for releasing the power of the atom. And more nuclear waste is produced every day.

Perhaps no issue raises more serious questions of inter-generational ethics than whether we should continue to create such extraordinarily hazardous wastes without a solution to their safe disposal. The plutonium-239 in HLW, for example, is one of the most toxic substances on earth; a few millionths of an ounce if inhaled will cause cancer with virtual 100% statistical certainty. Yet we must find a way to successfully isolate from the environment *hundreds of metric tons* of plutonium for its hazardous life—about *half a million years*.

Our society reaps the benefits of these atomic power plants: roughly fifty years of electricity. But thousands of generations to come may pay the price if even a small fraction of the radioactive waste contaminates water, soil, or air over the time period for which it is dangerous. We get fifty years of power; they get 500,000 years of radioactive waste.

Yet those who may bear the burden of our mistakes neither will have benefited from the power nor had any say in the decisions that may so severely impact their environment. Those who will be adversely affected have not yet been born. They cannot submit comments on draft environmental impact statements or proposed rulemakings; they cannot vote for elected officials who set policy and appoint or confirm key decision-makers; they cannot file suit in an effort to defend their interests. The choices we make today can harm in grievous ways many, many generations to come who will have had no voice in those hugely impactful decisions.

It is certainly an extraordinary situation that the well-being of so many generations to come are to some significant degree held in the hands of a few individuals before whom they cannot appear to plead their case and yet on whom their lives may depend. Indeed, even members of today's public, concerned about the implications for those not yet born, have long been barred from raising the issue of waste disposal in the licensing proceedings for nuclear power plants, one of the most important questions that should lie at the heart of decisions whether to grant licenses that would produce more waste for which there is no disposal solution. The U.S. Nuclear Regulatory Commission (NRC) has by rule—a kind of nuclear gag rule, some observers have called it—prohibited perhaps the most critical issue about whether the license should issue from being raised. NRC has done so by its "waste confidence rule," in which it expressed confidence that a solution will soon be found and therefore barred consideration of what would happen if their confidence were misplaced.

The problem is that the NRC's expressed confidence that there would soon be a permanent disposal site has repeatedly been empirically disproven. In 1977, a couple years after its establishment, NRC issued a finding that it was confident that the wastes produced by reactors "can and will *in due course* be disposed of safely.''[1] (emphasis added) With no such facility having opened or even under construction underway by 1984, NRC issued a waste confidence rule that said there would be a functioning HLW disposal facility open and operating by 2007-2009. When it was clear that wouldn't happen, it revised its confidence statement in 1990 with a new expected date of the first quarter of the 21st century. When that also turned out not to be in the cards, NRC stopped giving dates by which it was confident there would be such a site and instead found that the Commission was confident there would be a HLW geological repository open "when necessary." The Court of Appeals for the District of Columbia struck down that rule, concluding that it was not clear such a disposal site would in fact ever open, and directed NRC to prepare an Environmental Impact Statement analyzing the environmental impacts of high level radioactive waste if no geological repository became available.[2]

In its proposed new Waste Confidence Rule and associated draft Generic Environmental Impact Statement (GEIS),[3] NRC no longer says it has confidence that a HLW disposal facility will open, but rather that it is "feasible" that a HLW facility can commence operation within sixty years after the end of the licensed life of a reactor, defined as the original 40-year license term and including two 20-year renewals. NRC proceeds then to purportedly analyze the potential impacts of continued above-ground storage of HLW at reactor sites or potentially at centralized surface storage facilities, for three time periods: up to 140 years from the time a reactor commenced operation, up to 240 years from start of operation; and "indefinitely."

NRC's analysis relies almost exclusively on a self-described "assumption" that institutional controls will remain in place and effective for these time periods, in order to assure that the waste is guarded 24 hours a day, seven days a week, year after year, century after century, and that someone will undertake the technically challenging task of repackage the HLW every century into eternity. It is exceedingly difficult to view this assumption as anything but arbitrary and capricious in the extreme. The NRC itself has only been in existence for forty years. Our government was not in existence 240 years ago; indeed, the United States of America did not even exist as a nation then. And with the longevity of the waste being 500,000 years or more, it is important to recall that recorded history only goes back a few thousand years. We are talking about time periods that far exceed any reasonable assumption of the longevity of institutions, let alone institutional controls.

NRC arbitrarily dismisses—in a footnote—the prospect that institutional controls may not be durable and effective over these extraordinary time periods, asserting that loss of institutional controls is "so unlikely that it is a remote and speculative occurrence."[4] In this paper we review that issue and conclude the opposite, that continued and effective institutional controls over the time periods involved are so unlikely as to be a remote and speculative occurrence. In any case, the potential for such failure is real, and the environmental consequences must be examined carefully. This the NRC GEIS does not do.

Among the "best evidence," the most viable datasets available, for judging the NRC claim that institutions can be relied upon to effectively manage radioactive waste over these kind of extraordinary time frames is the history of efforts by institutions to date to deal with radioactive waste. That history is examined in this study.

Brief Primer—Wastes of Extraordinary Toxicity and Longevity

When uranium splits apart ("fission"), it produces hundreds of different radionuclides that continue to decay and give off ionizing radiation. Most are fission products, fragments of what was originally uranium atoms that were broken apart by neutron bombardment. Some are activation products, elements that have changed because of absorbing neutrons; among these are the transuranic elements, such as plutonium.

These radioactive wastes are exquisitely dangerous, even in minute quantities, particularly if inhaled or ingested. As of some years ago, U.S. nuclear reactor spent fuel contained approximately 12,000,000,000 curies (Ci) of long-lived radionuclides.[5] [A curie is the amount of radioactive material that produces 37 billion radioactive disintegrations per second.] By contrast, regulators measure permissible concentrations in air and water in pico-curies (pCi), millionths of a millionth of a curie (i.e, 10^{-12} curies). See, e.g., 10 CFR 20 Appendix B and EPA Safe Drinking Water Act limits[6].

For example, EPA's Safe Drinking Water Act Maximum Contaminant Limit (MCL) for strontium-90 is 8 pCi per liter.[7] Strontium-90 concentrates in bone and can produce bone cancer and leukemia if ingested. There are at present more than three billion curies (3×10^9 Ci or 10^{21} pCi) of strontium-90 in U.S. spent reactor fuel. That amount of strontium-90 alone, not counting the other radionuclides, could contaminate more than 3.75×10^{20} liters of water (375 billion billion liters) at the Safe Drinking Water Act limit. That is 660,000 times the annual water consumption of the U.S.[8] It is thus clear that leakage of even a tiny fraction of the radioactive inventory in U.S. spent reactor fuel could have a devastating effect on the environment.

Some of these radionuclides present in HLW are also extraordinarily long-lived. Plutonium-239, for example, has a half-life of about 24,000 years, meaning that half of it will still be around 24,000 years from now, a quarter of it will still exist 48,000 years from now, and so on.

The general rule of thumb is that it takes, depending on how much one has to start with, ten to twenty half-lives for radioactive material to decay to something resembling non-radioactive status (that is, if it doesn't decay into other radionuclides, which starts the clock all over again.) After ten half-lives, the remaining amount of the original radionuclide is reduced roughly a thousand-fold. Ten half-lives reduces the remaining amount by a factor of 2^{10} (two to the tenth power) = 1024. In twenty half-lives, the remaining inventory is about a millionth of what one had at the beginning, i.e., by a factor of 2^{20} (two to the twentieth power) = 1,048,576.

The plutonium-239 (Pu-239) inventory in U.S. spent fuel for the current fleet of reactors if they operate for their current licensed period will be well in excess of 1,000 metric tons.[9] Thus, 24,000 years from now, there would still be over 500 tons. 240,000 years from now, there would still be a ton of Pu-239 in that waste. Not until about half a million years into the future, would that plutonium have decayed down to a kilogram.

Pu-239 is among the most toxic materials on earth. A tenth of a milligram (one ten thousandths of a gram, one ten millionths of a kilogram, a few millionths of an ounce) if inhaled will cause cancer with virtual 100% statistical certainty.[10] Thus, even half a million years from now, that remaining kilogram of plutonium would still be of non-neglible potency. But it would take nearly five hundred millennia to get down to a kilogram of Pu-239. And there are other significant radionuclides in high level waste, such as iodine-129 and technetium-99, that are even longer-lived than plutonium-239.

It is because of the very long hazardous life of HLW that the National Academy of Sciences (NAS) recommended, and the Court of Appeals for the District of Columbia directed, that adequate performance of HLW disposal plans be demonstrated out hundreds of thousands of years.[11] EPA had adopted regulations to only require that analyses demonstrate compliance for the first 10,000 years. NAS pointed out that the wastes were hazardous for vastly longer than that; that Yucca Mountain analyses suggested peak exposures to the public from Yucca leakage occurring at several hundred thousand years; and that one should analyze for at least one million years, the time scale for long-term geologic processes at Yucca Mountain. The Court of Appeals agreed, saying the law required the rules to be consistent with the NAS recommendations. But to have confidence that institutional controls will remain in place even for the first ten thousand years –or even the shorter periods of 140 years and 240 years--seems extraordinarily difficult to defend.

A review of the historical evidence involving how well regulators' confidence on nuclear matters was matched by subsequent events may be instructive in this regard.

Irrational Exuberance and Regulatory Fictions

From the dawn of the nuclear era, regulators have manifested an at times almost religious zeal and confidence, which subsequent events have often not borne out. A few examples:

- In 1954, Lewis Strauss, Chairman of the Atomic Energy Commission (AEC), the predecessor of the NRC, famously predicted, "Our children will enjoy in their homes electrical energy too cheap to meter."[12]

- The AEC and NRC had long declared Class IX accidents—those involving major core damage—as "non-credible" and not needing to be designed against or analyzed in environmental impact statements. Then came the Three Mile Island (TMI) accident, and NRC was forced to acknowledge its overconfidence and reverse the policy.

- The NRC's Reactor Safety Study WASH-1400 had concluded that there was a vanishingly small probability of a major nuclear accident. The American Physical Society, the U.S. Congress, and a Congressionally-ordered review all raised serious questions about the study's conclusions, and the NRC eventually had to withdraw its reliance on the study's claims—two months before the TMI accident empirically demonstrated the risks of regulatory overconfidence.

- The "design basis" required for containment structures was, and remains, for the containment to be able to withstand only the pressure from a major pipe break, not an accident involving fuel melting, so few if any of our containments are designed to withstand pressures from a major accident.

- Backup batteries are only required to be able to run for a few hours, based on the assumption that loss of offsite power and diesel generators would not credibly occur for longer than that. However, "station blackout" at the U.S.-designed reactors at Fukushima lasted for weeks, to devastating effect.

- The design basis earthquake—the largest earthquake for which a particular nuclear plant must be designed—is often considerably smaller than what nearby faults are actually capable of, again, precisely what destroyed Fukushima.

- The design basis threat—the largest terrorist assault on a plant that it must be prepared to defend against—was for decades only three people, on foot, operating as a single team, with only equipment they can hand-carry, up to hand-held automatic weapons.[13] For years, NRC asserted it was not credible that there could ever be a truck-bomb used in the United States and therefore nuclear plants didn't need to be protected against them.[14] That finally changed when the truck bombing of the World Trade Center occurred, almost simultaneously with a standoff over a vehicular intrusion at the undamaged Three Mile Island accident.

- In response to contentions by the Governor of California in the Diablo Canyon licensing proceeding that there could be an attack by up to twelve terrorists, NRC claimed it was not credible that there would ever be a terrorist attack of any sort involving more than three terrorists.[15] 9/11, of course, involved 19 terrorists, operating as separate teams, and they didn't come in on foot.

The history of over-confident assumptions about radioactive waste disposal has followed the same pattern.

History of Disposal of AEC Wastes

From the earliest days of the AEC, and the Manhattan Project from which it arose, how to safely dispose of the wastes produced was largely an afterthought, driven by a confidence that the problem was manageable or would somehow soon be solved.

The Smyth Report, the official history of the Manhattan Project issued shortly after the conclusion of the Second World War, notes that the Hanford Reservation on the Columbia River was chosen as the site of massive reactors and reprocessing facilities in part because of its access to one of the largest sources of pure freshwater in the country. But not for long. The Columbia was used as a sewer for much of the radioactive waste created at Hanford. The large production reactors employed once-through-cooling; water was sucked in from the river to cool the irradiated nuclear fuel, and then dumped back directly into the river, carrying with it the radioactivity that had leaked out of the fuel.

High level liquid wastes from reprocessing, containing huge amounts of long-lived radioactivity mixed with reactive chemicals, were stored in single-walled tanks, with the premise they would be remove before they ate through the tank walls. However, the wastes remained in the tanks; the tanks corroded and leaked; HLW migrated into the soil beneath the site and is working its way toward the Columbia River.

Vast quantities of other wastes were dumped just directly into the ground, where they could migrate to groundwater and from there into the Columbia. The operators of the facility had a belief in an almost infinite capacity of the soil to retain large amounts of radioactivity, a belief strenuously questioned by the National Academy of Sciences' committee on waste disposal in the 1950s and 1960s:[16]

> The Committee thinks that the current practices of disposing of intermediate and low-level liquid wastes and all manner of solid wastes directly into the ground above or in the fresh-water zones, although momentarily safe, will lead in the long run to a serious fouling of man's environment. Such methods represent a concept of easy disposal that has had and will continue to have great appeal to operators, but we fear that continuation of the practices eventually will create hazards that will be extremely difficult and expensive to eliminate.

A fundamental conclusion "was that continuing disposal of low-level waste in the vadose water zone, above the water table, probably involves unacceptable long-term risks."[17] Unsafe practices existed throughout the AEC nuclear complex nationwide. The NAS said:[18]

> [N]one of the major sites at which radioactive wastes are being stored or disposed of is geologically suited for safe disposal of any manner of radioactive wastes other than very dilute, very low-level liquids.

The response of the AEC to the concerns expressed by the NAS was to threaten withdrawal of AEC funding unless NAS disbanded the waste committee, reconstituted it with new members acceptable to AEC, and gave AEC the right to review reports before release and block their public release if it didn't like the conclusions.[19] The NAS acquiesced to these demands.[20] The concerns were ignored, the problems continued and grew.

At the Rocky Flats facility in Colorado, repeated assurances that the plutonium used there was fully contained and prevented from entering the environment turned out to be poorly-founded, as numerous fires and other events led to significant quantities of plutonium being released into the air and contaminating large amounts of land in the surrounding area, essentially in perpetuity. At the AEC's Idaho Falls facility, optimism about reactors was chastened by the meltdown of the first breeder, the EBR-1, and the power excursion (a kind of small nuclear explosion) of the SL-1, killing its workers and releasing radioactivity into the environment that has contributed to the ongoing contamination of the site. Poor waste disposal problems there, and at Savannah River, Fernald, Oak Ridge, and indeed virtually the entire nuclear complex across the United States resulted in massive legacy contamination problems that still vex us today.

After the Chernobyl accident in 1986, the Department of Energy (DOE, a successor to AEC), commenced reviews of the DOE complex that identified severe contamination problems throughout it. Cleanup operations have commenced, but despite legally binding agreements between DOE and the affected states, milestones have been continuously missed, cleanup budgets trimmed, remediation technologies failed to work as hoped. For example, efforts to construct waste vitrification facilities have encountered significant problems and resultant schedule slippage.[21]

Additionally, the government appears to have lost track of significant numbers of formerly utilized sites that remain contaminated. A recent series in the *Wall Street Journal* by John Emshwiller has documented continuing problems at a variety of sites which have receded from the institutional memory of the agencies responsible for assuring they are cleaned up.[22]

Ocean Dumping of Radioactive Waste

From 1946 to approximately 1970, the U.S. disposed of radioactive wastes by dumping at sea. Wastes were placed in various kinds of packages, predominantly 55-gallon drums, placed on tugs or ships, taken out to ocean dumpsites, and tossed overboard. Sometimes they wouldn't sink; sometimes they would subsequently get caught in fishing nets and hauled back to the surface.

The confidence underlying AEC approval of this practice was based on two somewhat contradictory assumptions employed at different times. The first was that "dilution is the solution to pollution." The ocean is large, so it was assumed by AEC that it had essentially infinite capacity to received radioactive wastes safely. This was based on the premise that there were thresholds below which radiation was not dangerous and thus thresholds of carrying capacity of the oceans for radioactive waste.[23]

However, the National Academy of Sciences committees reviewing ocean dumping repeatedly raised questions about this assumption. They noted that genetic effects from radiation had no threshold below which the damage didn't occur, and they questioned whether there was a scientific basis for setting a capacity of the oceans to receive safely radioactive wastes.[24]

As time went on, the lack of thresholds for radiation-induced cancer also became accepted, not just by NAS but as official policy of NRC, DOE, EPA, and other agencies. The Linear No Threshold presumption—all radiation exposure increases cancer risk, and the risk increases roughly linearly with dose—is the fundamental premise of all radiation safety regulation now. So the "waste confidence" determination by AEC allowing ocean dumping was premised on an assumption of thresholds that turned out to be incorrect. (If there is no threshold below which radiation is safe, but all doses carry some risk and risk is linear with dose, diluting contamination so as to spread it results in lower amounts per fish but very much larger numbers of fish exposed, so the number of people potentially exposed by eating fish increases even if the individual doses go down. The operative figure is the number of person-rems of exposure, a function of the number of people exposed times the amount of exposure per person. Dilution does no good in reducing person-rems, it just affects a wider portion of the environment.)

Additionally, the assumption that ocean dumping would in fact result in dilution also turned out to be largely incorrect. The radioactivity released from the degrading canisters was subsequently found to adsorb instead onto and concentrate in bottom sediments. Bottom-dwelling organisms root through those sediments, ingesting the radionuclides and concentrating them in their bodies. They are then consumed by other marine organisms, and then by higher organisms, with radionuclides concentrating as they go up the food chain through a process called bioaccumulation. So, rather than dilution, it turned out there were radioactivity concentration phenomena at work.[25]

Alternately, it was asserted that the radioactivity would remain in the barrels for the hazardous life of the radionuclides, and that even if some got out, it would remain in the water near the barrels where, it was presumed, there was no marine life due to supposed lack of oxygen or upwelling. Every one of those assumptions turned out to be incorrect.

A study done by attaching monitoring devices on barrels being dumped found roughly a third of them imploded before even hitting the bottom because of the differential pressure. Investigations by EPA personnel in the Alvin submersible of the Farallons Islands dumpsite and one off the East Coast, and earlier similar submersible inspections of the Santa Cruz Basin dumpsite off Santa Barbara, found that in just a few years the barrels had degraded substantially. There was significant corrosion and deformation, and radioactivity was found in the sediments nearby at levels far in excess of fallout background, having leaked from the drums.[26]

Additionally, rather than being "ocean deserts," these dumpsites were teaming with marine life. There was plenty of oxygen to sustain them; much upwelling bring material further up into the water column and recirculating back down; and the barrels themselves, generating heat from the radioactive decay, appeared to be if anything attracting fish and other sea organisms to them. These fish provided also a mechanism for the contamination to move back up higher into the ocean column, as they swam up and were consumed by other fish, providing a migration mechanism for the contaminants in the fish themselves. Furthermore, fish sampling resulted in evidence of radionuclide uptake in the fish from the leaking wastes, including in edible portions of edible fish.[27]

These scientific findings, contradicting the optimistic premises of the regulators who had permitted ocean dumping for so long, led in the 1980s to the London Dumping Convention passing a resolution against continuation of the practice and subsequently a prohibition on it. The "waste confidence" assumptions underlying ocean dumping had been eviscerated, leading to stopping the practice; but not before tens of thousands of barrels of radioactive waste were disposed of in this questionable way.

The troubled experience with ocean dumping of radioactive waste also sheds light on NRC's current reliance on the assumed continuity of institutional controls for long-term or indefinite storage of HLW at surface terrestrial locations such as reactor sites. In 1980, Michael Rose of the Committee to Bridge the Gap researched records and identified fifty old ocean disposal sites off the East and West Coasts and in the Gulf of Mexico.[28] Government officials had lost track of a significant fraction of these, not knowing any longer of their existence, to the extent they had to ask the public interest group for help in identifying their own lost dumpsites.[29]

Additionally, the NAS recommended, and the State of California and the U.S. Congress required by laws passed, continued monitoring of the dumpsites. However, not only had the government failed to even know any longer where many of the ocean disposal sites were located, with a couple of exceptions, the requirement to monitoring them was not carried out.

The empirical historical evidence is not particularly helpful, therefore, to a claim that one can rely on institutional controls for radioactive waste over the long periods in question, when in the very much shorter periods to date (i.e., just a few decades), government has forgotten even where some of the disposal sites are and has failed, despite legal requirements, to continue to monitor them.

Land-Based Disposal of "Low-Level" Radioactive Waste (LLRW)[30]

As the erroneous optimism about ocean dumping became more apparent and it was phased out, emphasis was placed instead on shallow land burial. However, the same pattern of over-confidence, followed by failure of the dumpsites, evidenced itself.

Shallow land burial of LLRW generally involves placing boxes and drums of radioactive wastes in unlined trenches and then covering them with dirt. 10 CFR Part 61 It was predicted that radionuclides would not migrate for ten thousand years. Over and over again, the sites were found to fail instead in decades.

Such a claim had been the underpinning of the original licensing of the Sheffield, Illinois dumpsite and a request to expand. While that request was pending, a tritium plume was found to have migrated from the trenches, traveled offsite and contaminated nearby Trout Lake. When this finding made approval unlikely, the dump operator abandoned the site. Rain filled open trenches, exacerbating the migration. The leaking site was closed.[31]

Similarly, the Maxey Flats, Kentucky dumpsite was predicated on no migration for on the order of ten millennia. Instead, after a decade or two, EPA found plutonium had migrated. It had been asserted that this couldn't happen, that the radionuclides would adsorb onto soil particles and be largely immobilized. It turned out that there were organic complexing agents in the soil that dramatically altered the soil partition coefficient (K_d), which greatly increases migration rates. This failure of the optimistic assumptions to actually hold led to the shutdown of the site and its designation as a Superfund site.[32]

After these failures of its assumptions regarding sites in humid locations, NRC and the Agreement States under its regulation argued that there would be no migration in more arid locations. In so doing, they and other regulators relied in large part on the presumed experience at the Beatty, Nevada disposal site, in a very dry location not far from Yucca Mountain. Based largely on a theory called "chloride mass balance," it was asserted that no migration from the Beatty disposal trenches would occur for ten thousand years. However, within just a few decades of the site commencing operations, USGS found radioactive material had migrated offsite and down to groundwater. The finding was instrumental in abandoning a proposed similar project at Ward Valley, California, where the same optimistic claims had been made. The Beatty site is now also shut down.

The "waste confidence" in shallow land burial of radioactive waste turned out to be no better based than the confidence initially held regarding ocean disposal.

High Level Waste Disposal Siting Efforts

A pattern of over-confidence very similar to that described above about ocean disposal and shallow land burial occurred in efforts to establish geologic repositories for HLW, resulting in the failure of those endeavors.

The AEC early on decided that disposal of HLW in salt formations would isolate it indefinitely and a location near Lyons, Kansas chosen. At first glance, salt would seem an ideal location for such waste. Because it is so soluble, it presence would seem to indicate the lack of water for long periods of time. It is fairly plastic, so the salt would tend to mold itself around the waste packages.

But salt formations have other, less-desirable qualities. For example, the waste produces a great deal of heat by radioactive decay, at least for many centuries. That heat tends to draw moisture from the salt toward the canisters, so that they end up sitting in pools of hot brine, which can corrode the containers and leach out the radioactive materials.

And then there was the institutional control problem. The performance of a waste facility inside a salt formation is dependent upon there being no oil, natural gas, or other drilling into the formation that punctures its integrity. Such drilling can produce pathways for rainwater and surface water to enter the repository, pick up contamination, and carry it back to the general environment. One would need to be able to guarantee, for very long periods of time, that such drilling activity would be barred and such prohibition effectively enforced. This is difficult in the extreme.

It turned out, however, that this problem was not merely a hypothetical one for the future, but had already occurred. State geological authorities had tried to explain to the AEC that the formation was already riddled with numerous such wells, and that governmental records were so poor that even if one could seal permanently many of the known wells, there were many others for which there were no records. But the political commitment to the project left the AEC resistant to considering seriously such scientific impediments. Eventually, the evidence that the site was punctured with a great many wells became overwhelming and could no longer be ignored. Additionally, it turned out that there was nearby a salt leaching operation, a kind of hydraulic fracturing that injected high pressure water into the formation at one location to force out salt, dissolved in that water, elsewhere. A large volume of water had disappeared, somewhere in the salt formation, not far from where the repository was to be located. These problems resulted in a last-minute abandonment of the entire project and significant embarrassment for the AEC.[33]

This failure contributed to a substantial rethinking of the policy for attempting to select sites for permanent repositories, and resulted in the passage of the High Level Waste Act. It directed that nine candidate sites were to be winnowed down to three, and then those studied thoroughly so as to select the one that was technically superior. A similar process was to be undertaken for selecting the location of a second repository, to be located in the eastern half of the country.

But then politics intervened. To appeal to voters in a presidential election, the east coast sites were dropped from consideration. Then the western sites were reduced to Texas, Washington State, and Nevada, and rather than follow the law and analyze all three to pick the one that had the most favorable geological features, Texas and Washington State used their political clout in Congress to be removed from consideration, leaving just Nevada. Rather than scientific criteria, a simple mathematical formula was essentially used—which state had the smallest Congressional delegation. Nevada won, or lost, depending on one's perspective. But science and the environment were the real losers, because our institutions once again proved incapable of making decisions about high level radioactive waste in a fashion that was driven by safety.

The law still required that Yucca Mountain be analyzed and if demonstrated to be unsuitable, dropped and a new site selected. DOE based much of its asserted confidence in the appropriateness of the site on its arid location. It was assumed the mountain had almost no water in it, and that there was almost no percolation of rainwater into the mountain and extremely slow migration of whatever moisture might exist deep inside.

But then the scientific evidence began, once again, to bite the heels of those optimistic assumptions. It was soon found that, rather than being dry as a bone, there was a great deal of water inside Yucca Mountain. In one experiment, DOE carved a chamber out of the rock deep inside the mountain, installed sensitive moisture sensing devices, and sealed off the chamber. When it was reopened to retrieve the data it was discovered that they had lost most of the measurements because there was so much water that it had shorted out the monitoring devices.[34]

There in fact turned out to be so much water that it would be drawn toward the hot waste packages, which would then boil the water into steam for the first hundreds of years; then when the spent fuel cooled down some, the water would recondense and rain onto the waste packages, corroding them and releasing their radioactive contents. Extraordinary schemes were then proposed to deal with this new problem, including remotely going back into the repository a hundred years after the last packages were put in and construct drip shields made out of the very expensive and rare metal titanium.

Despite this discouraging surprise, DOE still hung on to the second optimistic assumption: that rain wouldn't percolate into the mountain and whatever water might be inside the mountain wouldn't migrate except at very slow rates. But then there was another disconcerting discovery: chlorine-36, a radionuclide associated with nuclear weapons tests, was found deep inside the mountain.[35] If the theories about slow migration rates were correct, this shouldn't have been possible. Nuclear weapons have been exploded only since 1945. Any chlorine-36 from weapons tests thus took less than a few decades to migrate inside Yucca Mountain, not millennia.

DOE models showed that doses to the public would far exceed current regulatory limits and would peak a couple hundred thousand years into the future. But with all this scientific evidence that the site wasn't suitable—it wasn't dry, as originally assumed; water migrated quickly, not slowly within the mountain; and peak doses to the public could far exceed current permissible limits—politics trumped science and the project proceeded. If one couldn't meet the standards, set standards one could arguably meet. Lower the bar.

So EPA issued regulations that the project only had to show it could meet normal standards for the first 10,000 years. Even though the waste was hazardous for hundreds of thousands of years, and even though DOE's models showed doses peaking far after the 10,000 year point, EPA's rule cut off consideration of impacts long before they would reach their maximum.

NAS had recommended against employing such a regulatory fiction, and because the law required consistency with NAS's recommendations, the Court of Appeals for the D.C. Circuit overturned the EPA rules. In the face of the discoveries that the fundamental technical assumptions for safety of the site were in question, and having to now demonstrate compliance with radiation standards for the full period of the toxicity of the wastes rather than the regulatory fiction of 10,000 years, DOE chose to not proceed with the Yucca Mountain project. A Blue

Ribbon Commission was established to try to identify a path forward, and its recommendations largely reflect how difficult a task it is to find a solution to the waste problem. The BRC focused on establishing interim storage sites while the nation tried to figure out a permanent solution. We thus returned to square one, little closer to solving the HLW problem than we were on December 2, 1942, when the first atomic reactor waste was created.

NRC Waste Confidence Rule Redux, and Reliance on Institutional Controls

Despite the above history of repeated misplaced confidence that there was a solution at hand to the radioactive waste disposal problem, NRC continued to bar consideration of the waste issue in proceedings on whether to grant licenses to produce more of it. NRC did so based on its Waste Confidence Rule, repeatedly revised as it became clear that prior dates by which it had confidently predicted the opening a repository would not be met. In the end, the Court of Appeals for the District of Columbia struck down the NRC's most recent statement of confidence that such a repository would be available "when needed," and directed the agency to perform an environmental review of the impacts that would arise should no such facility get constructed, a prospect that the Court said should not be ignored.

The NRC, in its proposed new Waste Confidence Rule, puts forward several draft findings. One is that a geological repository is "feasible" within 60 years of the end of the licensed period, with any renewals, of existing reactors. That, of course, is a far cry from being confident that that will happen. It is feasible that one will win the lottery, but not likely, not something one should count on.

The evidence put forward by NRC to support this finding is not very robust. After recounting some of the history, in this country and abroad, where plans for opening repositories have repeatedly failed and been put off, NRC then identifies new hoped-for opening dates and says because such dates have been put forward, they are thus feasible. It is a circular argument without foundation. Indeed, the actual data identified—continued failure of all nations with nuclear power plants to open even a single high level waste disposal site—suggest quite clearly the difficulty in having confidence that such a facility will in fact open here in the next decades.

NRC then proceeds to indicate its confidence that irradiated nuclear fuel not just can but will be safely stored on the surface, at reactor sites or elsewhere, for three different periods: (1) 140 years from the time the reactor started operations, (2) 240 years from startup, and (3) indefinitely. NRC presumes that after a certain point, spent fuel is moved to dry casks and that there is continuity of institutional controls for these time scales for guarding, maintaining, and at regular intervals, repackaging the fuel in new casks. These are rather extraordinary assumptions.

For hundreds of years the fuel gives off enough heat that they must be constantly cooled. The dry casks involve passive cooling, but this requires the cooling vents to be kept free of snow, leaves, dirt and other debris, so regular maintenance is needed. The fuel inside, if attacked by terrorists, could release large amounts of radioactivity, and so NRC requires constant guarding of the material by plant security forces. Over the centuries, as the radiation levels diminish from decay of the intermediate-lived radionuclides such as cesium-137 and strontium-90, it will at some point become much easier and thus more attractive as weapons-usable material for theft, i.e., to obtain the plutonium inside that could be used for atomic bombs.[36] Thus, need for security to protect the spent fuel will not diminish over time and arguably increases.

Additionally, NRC presumes the spent fuel can be safely stored in dry casks for a century, but will then need to be repackaged. This will involve complex remote handling and construction of repackaging devices. NRC assumes some institution will in fact take care of this task every hundred years, a difficult and expensive undertaking, given the hazard involved.

These presumptions are predicated on the assumption that the utilities that own the reactor sites where the material will be stored will continue to exist and will have the resources and commitment to undertake these tasks over these very long periods. This is hard to countenance, given that no utility has been in existence that long, maintenance of funds for such a non-income-producing activity seems unlikely, and institutional memory at such utilities to carry out these functions difficult to maintain.

NRC also assumes that the regulatory institutions will also continue to function over these time periods, and, presumably, that if the utilities cease to exist, government will take over the responsibility for the maintenance, guarding, and repackaging. But the NRC itself has only existed for less than forty years, a century less than even the first time period under consideration, 140 years. The U.S. government has existed for less than the 240 years of the second time period. And all of recorded history is two orders of magnitude shorter than the hazardous life of the plutonium-239 in the waste. Assuming institutions will be around to guard, maintain, and repackage these wastes over these time periods is exceedingly hard to defend.

But NRC does not try to technically defend this proposition—it just assumes it. And it relegates to a footnote (fn. 2) its discussion of this extraordinarily consequential assumption. After conceding numerous situations where long-term reliance on institutional controls is not allowed, including disposal of HLW in a geologic repository and disposal of LLRW in near-surface sites,[37] NRC proceeds to assert that indefinite surface storage of HLW is somehow different and the prospect of institutional controls being ineffective or non-existent at some point is so unlikely as to be completely speculative and thus should not be considered.

NRC says the casks will be visible and the consequences of not guarding, maintaining, and repackaging them indefinitely so severe, that future institutions *will* without question supply the resources, essentially forever, to so protect them. This proposition appears to turn the actual situation on its head.

NRC is refusing to analyze in its draft GEIS the consequences of institutions failing. Its sole basis for doing so is its assertion that institutional controls will not fail. And its argument as to why institutional controls will not fail is because the consequences of failing are so severe. This is completely circular.

Additionally, the fact that the HLW casks will be on the surface and visible increases rather than eliminates the prospect of them being broken into. Like the pyramids of Egypt, they are likely to be seen as tombs or vaults containing items of great value, worth stealing.

NRC also assumes that long into the future, unspecified institutions will somehow remember what is inside the HLW casks and how dangerous that material is, and therefore spend precious resources to indefinitely protect material from which they received no benefit. But such institutional memory is rather quickly lost. We still do not understand well, for example, for what purpose the *moai*, the monumental statues of Easter Island, were constructed. And what language would one write the documentation about the risks and the necessary technology needed for repackaging the casks so it can be understood far into the future? Most Americans cannot readily read even the early English of Chaucer, let alone the languages of ancient peoples. And how would those instruction manuals for repackaging the waste be preserved for future generations? And on what media? Floppy disks went the way of the dinosaurs after just a few years; operating systems become obsolete in very brief intervals; paper disintegrates, burns, or just gets lost.

In far shorter periods, institutional reliability appears questionable. It is not without its own irony that the NRC had to cancel several of its scheduled hearings on the Waste Confidence Rule because the U.S. government shut down. Sequesters and other budget cuts, depressions, wars, and natural catastrophes all can result in institutional obligations not being met, even in relatively modest time frames. To count on institutional controls over centuries, millennia, or longer is difficult to defend. The recent history of waste disposal, recounted briefly in this paper, demonstrates that even in a period of just a few decades, institutions have lost track of waste disposal sites, failed to meet legally binding cleanup requirements or monitoring obligations, and otherwise have not been reliable. Long-term reliance on such institutions and institutional controls seems without basis.

Conclusion

The history of waste practices to date has been one of irrational exuberance, misplaced confidence that things will just work out. But the historical evidence suggests the opposite. And despite that long history of failure, the NRC repeatedly asserts, "this time will be different."

The latest iteration of the Waste Confidence Rule relies on a remarkable regulatory fiction: that just leaving large amounts of extraordinarily hazardous and long-lived material sitting on storage pads at numerous locations around the country will not result in unacceptable environmental impacts because institutions will continuously guard, regularly maintain, and periodically repackage the waste for hundreds of years, or even hundreds of thousands of years. This seems, to use a favorite phrase of the NRC, "non-credible."

In a 1972 article in *Science Magazine,* Alvin Weinberg, then Director of the AEC's Oak Ridge National Laboratory, famously wrote: "We nuclear people have made a Faustian bargain with society." On the one hand reactors offer an extraordinary source of energy. "But the price that we demand of society for this magical energy source is both a vigilance and a longevity of our social institutions that we are quite unaccustomed to." He went on to suggest that what might be needed was a kind of nuclear priesthood to manage these risks over the long time periods involved. He concluded by asking the fundamental question: "Is mankind prepared to exert the eternal vigilance needed to ensure proper and safe operation of its nuclear energy system?"[38]

The National Environmental Policy Act is based on a critical principle: that one should honestly and thoroughly evaluate potential environmental impacts of major federal actions *before* deciding to undertake them. Here, NRC proposes to make licensing decisions that would result in creation of large amounts of additional high level radioactive waste for which no disposal solution exists. Yet NRC has declined to evaluate the environmental consequences of such production, solely on the assumption that institutions will exercise "eternal vigilance" of the waste.

"Eternal vigilance" seems quite outside of any reasonable expectation for human institutions and the hazardous lives of high level radioactive wastes. Perhaps the more important question is whether it is morally appropriate to produce more of such wastes, dangerous for hundreds of millennia, if one cannot reasonably expect such eternal vigilance. At the end of the day, that is what is at issue in NRC's proposed Waste Confidence Rule and associated environmental review.

Note about citations and references contained in this document: all citations and references are hereby incorporated by reference. If the NRC wishes copies of any cited reference, please contact contact.cbg@gmail.com.

[1] 42 FR 34391, 34393; July 5, 1977, *pet. for rev. dismissed sub nom.,NRDC* v. *NRC,* 582 F.2d 166 (2d Cir.1978)), as cited in 78 FR 56776,78, Proposed Waste Confidence Rule.
[2] This history is summarized in the NRC notice of the Proposed Waste Confidence Rule, 78 FR 56776.
[3] 78 FR 56621 and 56776.
[4] GEIS, footnote 2, pp. 1-14 – 1-15.
[5] Robert Alvarez, *Spent Nuclear Fuels in the U.S.: Reducing the Deadly Risks of Storage,* Institute for Policy Studies, Washington, D.C., 2011, p. 9, Table 1, citing DOE/EIS-0250, Appendix A.
[6] U.S. Environmental Protection Agency, Office of Groundwater and Drinking Water, *Radionuclides in Drinking Water: A Small Entity Compliance Guide,* February 2002, p. 13
[7] U.S. Environmental Protection Agency, Office of Groundwater and Drinking Water, *Radionuclides in Drinking Water: A Small Entity Compliance Guide,* February 2002, p. 13
[8] Estimated Use of Water in the United States in 2005. U.S. Geological Survey. 2009, *http://pubs.usgs.gov/fs/2009/3098/pdf/2009-3098.pdf,* last viewed December 14, 2013. The USGS estimate includes all water uses, including agriculture and power generation.

[9] A standard-size nuclear power reactor produces about a ton of plutonium every four years. We have approximately 100 nuclear power reactors in the U.S. currently operating, with more than 70% having already received 20-year extensions of their original licenses. Plutonium-239 inventory in spent fuel as of more than a decade ago was already 600 metric tons. DOE's Final EIS for Yucca My. in 2002 Appendix A.

[10] See, e.g., Steve Fetter and Frank von Hippel, "The Hazard from Plutonium Dispersal by Nuclear-warhead Accidents," in *Science and Global Security* , Vol. 2, No. 1 (1990), pp. 21–41. http://drum.lib.umd.edu/bitstream/1903/4300/1/1990-SAGS-Pu.pdf . Last accessed December 14, 2013. IPPNW and IEER, *Plutonium: Deadly Gold of the Nuclear Age,* International Physicians Press, 1992, p. 14 and the references cited therein.

[11] National Academy of Sciences/National Research Council, *Technical Bases for Yucca Mountain Standards*, 1995; U.S. Court of Appeals for the District of Columbia, *Nuclear Energy Institute v. U.S. Environmental Protection Agency*, July 9, 2004

[12] "Abundant Power from Atom Seen; It Will be Too Cheap for Our Children to Meter, Strauss Tells Science Writers," *New York Times*, September 17, 1954,

[13] Hirsch, Murphy, and Ramberg, "Protecting Reactors from Terrorists," *Bulletin of the Atomic Scientists,* March 1986; and Hirsch, "NRC: What Me Worry?", *Bulletin of the Atomic Scientists,* January/February 2002

[14] Committee to Bridge the Gap, *Petition for Rulemaking,* PROPOSED AMENDMENTS TO 10 C.F.R. PART 73)(Upgrading the Design Basis Threat/ Regulations for Protection Against Terrorist Attacks on Nuclear Reactors), July 23, 2004.

[15] Hirsch, Murphy, and Ramberg, *Nuclear Terrorism: A Growing Threat,* A report to the NRC Advisory Committee on Reactor Safeguards, May 7, 1985; Stevenson Program on Nuclear Policy, UC Santa Cruz, SPNP-85-F-1 Rev. 1

[16] Committee on Geologic Aspects of Radioactive Waste Disposal, National Academy of Sciences-National Research Council, *Report to the Division of Reactor Development and Technology, United States Atomic Energy Commission,* May 1977, p.66

[17] *ibid.* p. 2

[18] as quoted in Phillip Boffey's book on the National Academy of Sciences, *The Brain Bank of America: An Inquiry into the Politics of Science,* New York: McGraw-Hill, 1975, p.96

[19] Boffey, chapter "Radioactive Waste Disposal: The Atomic Energy Commission Brings the Academy to Heel"

[20] *ibid.*

[21] Ralph Vartabedian, "Doubts grow about plan to dispose of Hanford's radioactive waste: Experts raise concerns about the complex technology intended to turn 56 million gallons of radioactive sludge at the former Hanford nuclear facility into glass and prepare it for safe burial." *Los Angeles Times*, November 29, 2013

[22] See, e.g., Emshwiller and Singer-Vine, "Waste-Lands: A Forgotten Legacy of Nuclear Buildup," *Wall Street Journal,* October 30, 2013

[23] See Jacob Darwin Hamblin, *Poison in the Well: Radioactive Waste in the Oceans at the Dawn of the Nuclear Age,* Rutgers University Press, 2008

[24] *ibid.*

[25] W. Jackson Davis, John Van Dyke, Daniel Hirsch, Mary Anne Magnier, Sherry P. Broeder, *Evaluation of Oceanic Radioactive Dumping Programs,* study presented by the nations of Naura and Kiribati to the London Dumping Convention, LDC7/INF.2, 1982

[26] *ibid.*
[27] *ibid.*
[28] EPA indicated that it is possible that some of the sites were planned for ocean dumping but not so utilized, but was unable to identify which sites those might be.
[29] Daniel Hirsch, Testimony, *Ocean Dumping of Radioactive Waste Off the Pacific Coast*, a Hearing Before a Subcommittee of the Government Operations, U.S. House of Representatives, October 7, 1980.
[30] The term "low-level radioactive waste" is something of a misnomer, as the category is generally not based either on the level or type of radioactivity in the waste. LLRW is defined by what it is not—it is not spent fuel or HLW wastes from reprocessing spent fuel, nor is it uranium mill tailings, or TRU wastes (wastes with transuranics above a certain concentration.)
10 CFR§61.2
[31] U.S. Congress, *Low-Level Radioactive Waste Disposal,* Hearings Before a Subcommittee of the committee on Government Operations, House of Representatives, Ninety-Fourth Congress, Second Session February 23, March 12, and April 6, 1976: Washington, DC, U.S. Government Printing Office
[32] Shrader-Frechette, K., *Burying Uncertainty: Risk and the Case Against Geological Disposal of Nuclear Waste,* University of California Press, Los Angeles and Berkeley: 1993; Cleveland, J.M., and Rees, T.F., 1981, "Characterization of Plutonium in Maxey Flats Radioactive Trench Leachates," *Science Magazine,* v. 212, p. 1506-1509; Weiss, A.J., and Czyscinski, K.S., 1981, *Trench Water-Soil Chemistry and Interactions at the Maxey Flats Site,* in U.S. Nuclear Regulatory Commission, 1981, Research Program at Maxey Flats and Consideration of Other Shallow Land Burial Sites, NUREG/CR-1832: Washington, DC; and Fowler, E.B., and Polzer, W.L., *A Review of Research Conducted by Los Alamos National Laboratory for the NRC with Emphasis on the Maxey Flats, KY, Shallow Land Burial Site,* NUREG/CR-5170.
[33] See discussion in Boffey, *supra.* Also, William and Rosemary Alley, *Too Hot to Touch: The Problem of High-Level Nuclear Waste,* Cambridge University Press, 2013.
[34] *Las Vegas Sun,* "Water Damage Sparks Yucca Worries," April 6, 2001; and *Congressional Record,* "High Level Waste Storage at Yucca Mountain," May 10, 2001, p. 7915-6
[35] Macfarlane, Allison and Ewing, Rodney, eds., *Uncertainty Underground: Yucca Mountain and the Nation's High-Level Nuclear Waste,* MIT Press, 2006,
[36] It has long been accepted that that reactor-grade plutonium can be used to make nuclear explosives. It has somewhat larger percentages of the higher-numbered plutonium isotopes than plutonium produced specially for weapons states, but can produce a large nuclear yield. The primary difference is in the reliability of predicting what that yield will be; i.e., it could be 1 kiloton or 10, whereas with weapons-grade plutonium one has high confidence that the yield would be, say, 5.3 kilotons. But even that issue can be overcome by designs that employ faster insertion of reactivity. Cite sources.
[37] 10 CFR 20 Subpart E, rules for cleanup of contaminated sites and license termination, also bars reliance on institutional controls, unless one can show that failure of the controls would not result in doses exceeding specified limits. So even for cleanups, the impact of failure of institutional controls must be evaluated and cannot be relied upon unless that impact is within limits.
[38] Weinberg, Alvin, "Social Institutions and Nuclear Energy," *Science,* Vol. 177, No. 4043 (Jul. 7, 1972), pp. 27-34