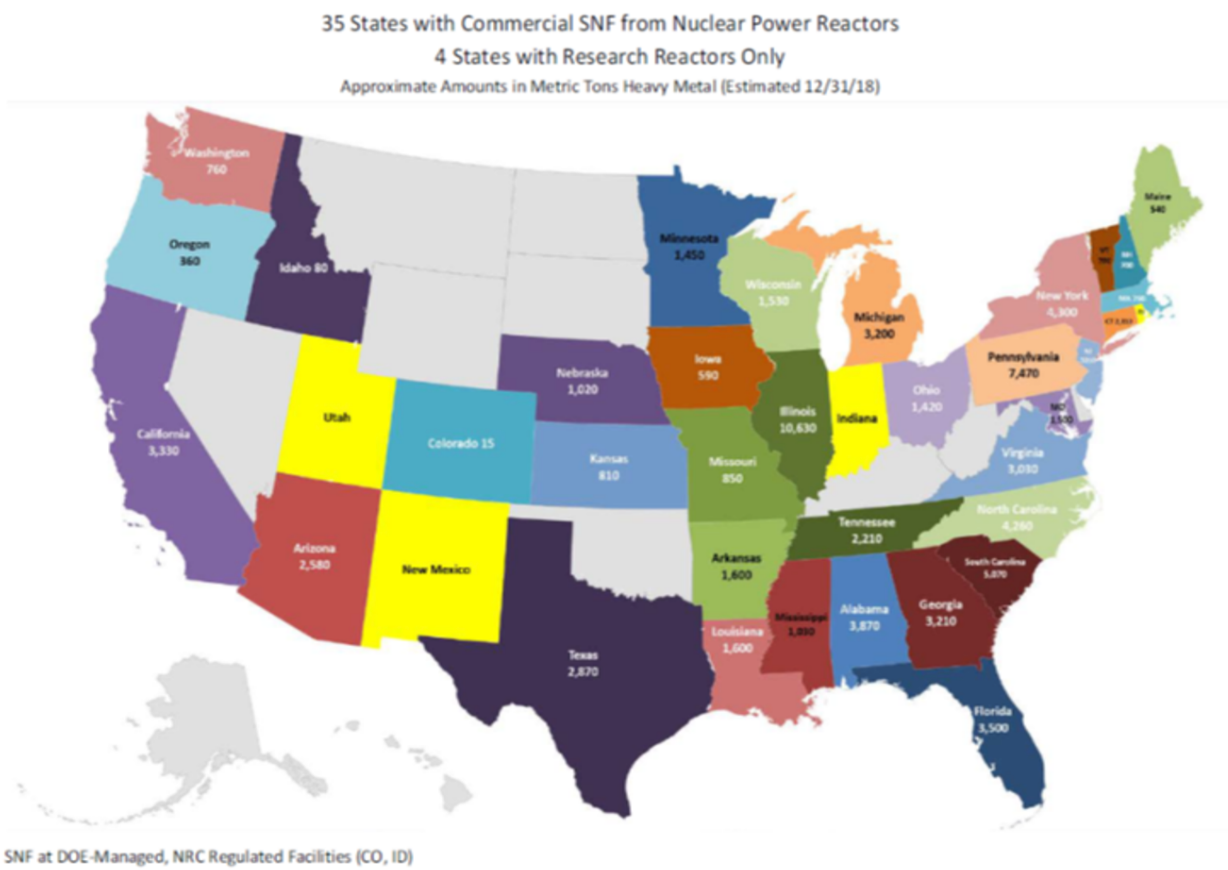
BACKGROUND INFORMATION FOR THE EESI CONGRESSIONAL BRIEFING:

TOWARDS AN EVIDENCE-BASED NUCLEAR ENERGY POLICY

Gaps in Research, Regulation, Policy, and Practice in the U.S. Nuclear Industry, and What Policymakers Can Do to Bridge Them

March 30, 2021



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INTRODUCTION

This backgrounder has been prepared as a supplement to the March 30, 2021 Congressional briefing entitled "Toward an Evidence-Based Nuclear Energy Policy: What Congress Needs to Know About Nuclear Decommissioning, Radioactive Waste, and Nuclear Energy as a Climate Strategy."

The briefing was organized by the NGO Hudson River Sloop Clearwater and planned and sponsored by a national coalition of non-profit nuclear watchdog organizations and citizens groups known as the Decommissioning Working Group (DWG). Participants in the DWG include experts in nuclear energy issues and risk management, advocates for safer nuclear energy policy and regulatory reform, as well as concerned citizens of reactor communities and others affected by the impacts of the nuclear power industry.

This backgrounder summarizes ongoing work of DWG participants and briefing presenters to identify gaps in research, regulation, policy, and practice which pose risks to public health and safety from civilian nuclear plant operations, decommissioning and radioactive waste disposition, and to recommend practical ways of bridging the gaps in order to mitigate those risks.

This document is for informational purposes only. It reflects information and a range of views from various public interest groups and advocates following nuclear decommissioning and radioactive waste issues closely. It is intended to give decision makers and the general public an accessible, non-technical introduction to certain key dimensions of these issues.

In 2021 Congress will face highly consequential decisions on nuclear energy policy, including whether to make fundamental changes to the Nuclear Waste Policy Act to enable mass shipment of spent nuclear fuel (SNF) across the country, and whether to elevate nuclear energy and fund development of "advanced reactors" as a way to fight climate change, as has been proposed for example in the 2020 report of the House Select Committee on the Climate Crisis, the Biden energy plan, the CLEAN Future Act, ARPA-C and other pending federal policies and agendas.

But currently, these propositions before Congress exist in an information vacuum, with large gaps in critical data on the safety, risks, and costs of current and proposed nuclear practices and technologies, and without any meaningful way to compare them to alternatives.

The U.S. Nuclear Regulatory Commission has often declined to gather, assess or share such information, sometimes simply accepting the representations of licensees regarding safety and risk. Its regulations and enforcement decisions are primarily based on what saves nuclear licensees money, rather than on adequate data on safety and environmental risks, or full cost accounting that includes costs to ratepayers and taxpayers.

Nonetheless, recent NRC decisions are rapidly ushering in a new regulatory regime for nuclear power that includes allowing some existing plants to keep operating for a total of 80 years (double their design basis) or even longer. For other aging and/or economically uncompetitive plants, which are increasingly shutting down, the NRC is enabling a new fast-track decommissioning model which promises to remediate sites rapidly, but which also raises a raft of unanswered questions and risks regarding safety, economic impacts, financial assurance, cleanup standards, and how to safeguard plants' spent fuel inventories and other high-level radioactive waste.

These issues are serious, and coming to a head. Climate action is urgent. So is adopting federal policies to safeguard public health and safety and the environment from nuclear industry impacts as some aging plants keep running longer, while others shut down and enter decommissioning, and as the nuclear industry pushes novel, unproven concepts and practices such fast decommissioning, consolidated interim storage, extreme license extension, advanced reactors and more.

Before the federal government can fairly evaluate whether these practices are warranted, and in particular before it can make informed decisions about whether to encourage reliance on nuclear power as a climate strategy, at a minimum it needs much better information than it currently has. To move forward in an evidence-based way as pressure to adopt new nuclear energy policies grows, Congress first needs a clear assessment of what is and isn't known about nuclear safety, costs, and risks, to what extent current nuclear policy and NRC regulation is or is not evidence-based, what germane information is missing, and what can be done to bridge the gaps.

This is an achievable goal. This paper surveys some of the gaps and makes recommendations on how they might be bridged to inform better federal policy decisions and better industry practices.

GAPS IN ASSESSING AND MANAGING DECOMMISSIONING RISKS

Decommissioning is the process of dismantling closed plants and securing or removing radioactive waste while lowering the site's residual radioactivity to safer levels. Radioactive waste disposition, including the storage and safeguarding of highly radioactive spent fuel, is different from decommissioning per se, although the decommissioning process does entail removing spent fuel from fuel pools and placing it into dry storage canisters.

Since the number of reactors in the U.S. civilian nuclear fleet peaked at 129, 35 reactors have shut down permanently. Some are considered to have completed decommissioning, at others the process is still underway, while more plants are about to begin it. 20 reactors at 15 commercial nuclear power plants are either undergoing decommissioning now or will be decommissioned soon. Many more will follow in the years ahead.

Regardless of what happens with license extension of operating reactors or development of advanced reactors, most of the existing U.S. reactor fleet will inevitably close over the next two decades, as competition from cheaper gas-fired plants and renewable sources of energy render nuclear plants uncompetitive, and as aging plants near the end of their functional operating lives.

In its 1996 rule on decommissioning (which is in the process of being updated), NRC argued "the degree of regulatory oversight required for a nuclear power reactor during its decommissioning stage is considerably less than that required for the facility during its operating stage." But reactor communities that go through it discover the risks they run during and after decommissioning are serious, albeit different than those of the operations phase.

Although the risk of a reactor meltdown ends when operations cease, other risks remain after shutdown. As nuclear plants are dismantled, the irradiated components, which in turn can irradiate adjacent material and make new radioactive waste, are cut apart, handled, and shipped, posing new risks that weren't present in the operations phase. Some of these radioactive wastes will remain dangerous for over a million years and pose an ongoing threat of release to the environment.

Spent fuel pools, where the largest amount of radioactivity is concentrated, are aging and deteriorating. Some are leaking radioactivity into groundwater and adjacent water bodies. As spent fuel gets transferred out of the pools to dry casks, the risk of fuel rods in the pools overheating or interacting and "going critical" (causing an uncontrolled fission reaction) decreases. But the risk of fuel handling accidents, such as dropping spent fuel assemblies, or failures of dry storage systems, increases.

Traditionally, decommissioning takes 20–50 years to complete, and onsite "spent" fuel storage and site monitoring can continue long after that. But several companies are positioning themselves to dominate the growing decommissioning market -- including Holtec, NorthStar/Orano, and EnergySolutions -- by greatly accelerating the timeline, promising they can complete the process in as little as five years. For more information on these companies, their approach and their track record, see "Nuclear Decommissioning Specialists: Quick and Dirty, or Lean and Clean?"

Fast-tracking decommissioning may seem like an attractive proposition for reactor communities. However, there are several catches. In fast decommissioning, the licensee's incentive is to decommission a nuclear plant as quickly and inexpensively as possible, in order to maximize the money left over in the ratepayer-financed decommissioning trust fund (DTF), which it claims as profit. This profit-driven, accelerated approach cuts corners, depends on getting a raft of regulatory waivers and exemptions, and raises many thorny public safety issues. For example, it exposes plant workers, and potentially the public, to higher doses of radiation since reactor sites have much less time for radioactivity to decay to before decommissioning begins.

As more nuclear plants close and embark on decommissioning, the risks remain poorly understood, largely unquantified, and inadequately studied or addressed by regulation. When experts point them out, they are consistently dismissed as "not credible" by licensees and the NRC, but that's not the same thing as confronting and managing these significant risks.

There are many gaps in knowledge and regulatory oversight that currently make decommissioning riskier than it needs to be. Here's a representative (but by no means complete) short list of such gaps:

Uncertainty about adequacy of decommissioning trust funds -- The US Nuclear Regulatory Commission (NRC) and the Government Accountability Office analyses generally have argued that DTFs are sufficient for decommissioning needs, or will be when the time comes to spend them. But independent analysis consistently shows large shortfalls. The independent investment consulting firm Callan Institute conducts an annual nuclear decommissioning funding study. Its 2019 (pre-pandemic) assessment found that private and public utility nuclear DTFs totaled $68 billion, but that projected decommissioning costs totaled $96 billion, leaving a shortfall of $28 billion, or 30%.

Lack of transparency or accountability in how DTFs are spent -- Licensees performing decommissioning work take over the DTFs as their own asset, with the intention of pocketing any leftover money, yet they have hardly any accountability for how they spend it. Even though DTFs are public monies, paid for by ratepayers through surcharges on their electric bills, licensees aren't required to seek state approval for expenditures, or even reveal how they have spent the money. There is no NRC requirement for decommissioning licensees to be transparent in how they spend the DTFs, to adhere to standard accounting practices and principles or to hire an auditor for decommissioning projects. This creates ripe conditions for waste, fraud, and abuse. In the case of the Zion nuclear plant in Illinois, the decommissioning contractor EnergySolutions did file a so-called "audit report." But it fit on just two pages, one of which was a cover letter, with a handful of vague line items purporting to certify the legitimacy of roughly $300 million in expenditures from the DTF.

Unmanaged risks of DTF depletion -- Decommissioning companies routinely seek, and the NRC routinely grants them, exemptions to be able to use the DTF to reimburse themselves for spent fuel management, including onsite storage of spent fuel. Spent fuel management is not normally an allowable use of the trust funds, which are funded by a surtax on ratepayers' electric bills solely to finance dismantling the plant and remediating the site. Spent fuel management can run into the hundreds of millions of dollars. This raises the risk that decommissioning companies could deplete the trust funds, leaving decommissioning work half done or badly done. Decommissioning companies also routinely sue the U.S. Department of Energy (DOE) to recover spent fuel management costs. The Nuclear Waste Policy Act previously provided that DOE would begin contracting to take commercial reactor spent fuel to a geologic repository by 1998, but since Yucca Mountain was scrapped, DOE violated that provision and will have to reimburse licensees' spent fuel costs until a geologic repository opens. When licensees recover this money from DOE, they are effectively getting paid twice for the same spent fuel management activities: once via the exemption they obtain to tap the DTF, and again by suing DOE. In some cases licensees may agree to put it the DOE money into the DTF, but they aren't required to. In other cases, they've made it clear they intend to pocket the windfall.

Lack of accountability in licensee subsidiary structure -- Decommissioning licensees are invariably structured as limited liability corporation subsidiaries of their parent companies. They generally bring no capitalization of their own to the project. That means that if there is insufficient money in the DTF to complete decommissioning, the LLC can declare bankruptcy without harming the parent company, walk away, and leave ratepayers and taxpayers stuck with the cleanup costs and ongoing impacts and risks.

Lack of independent site characterization or adequate cleanup standards– Nuclear licensees conduct their own characterization of the reactor sites they operate. Since they lack financial or other incentives or the regulatory requirement to conduct comprehensive, objective assessments of site contamination, their assessments may well be perfunctory. Absent independent site characterization, there is no way to ascertain the extent of radiological and other contamination of the site, and therefore no reliable way to frame sufficient standards for site remediation and release. For example, depending on the source, radiological contamination at reactor sites may affect not only surface soils, but also subsurface soils and groundwater. There is known radioactive contamination leaking from the New York's Indian Point nuclear plant into the groundwater and the Hudson River, including the lethal isotope strontium-90. In its Post Shutdown Activities Report (PSDAR) for Indian Point, the decommissioning company Holtec said it would do nothing about that contamination (other than monitor it), and would remove above-ground structures only to a nominal depth of 3 feet. But contamination at Indian Point, and at other reactor sites, almost certainly goes much deeper.

Inadequate emergency planning and radiation monitoring – As nuclear plants cease operating and enter decommissioning, NRC emergency planning requirements are greatly reduced. Radiation monitoring even around operating plants is rarely adequate to catch radiological releases, and offsite radiation monitoring generally ceases after shutdown. This creates a situation where if radiation releases occurred in the decommissioning phase, it would be less likely to become known, and there would be little capability to respond to it to protect public health and safety. The attitude of the NRC and the industry seems to be that nothing significant could go wrong, so the precautions of emergency planning and monitoring aren't important. Yet decommissioning requires dismantling and shipping radioactive plant components and transferring intensively radioactive spent fuel from fuel pools to dry storage, which entails significant risk of radiological release.

Lack of evidence basis for accelerated spent fuel transfer – Spent fuel pools at nuclear power plants are some of the highest concentrations of lethal radioactivity on the planet. Transferring spent fuel from leaking, overcrowded fuel pools to dry storage is desirable, but decommissioning companies are foreshortening the process in risky ways without data demonstrating it's safe. For example, Holtec's PSDAR indicated that it plans to complete transfer of Indian Point's spent fuel from the fuel pools to dry storage in three years or less. Five years is the industry standard to allow ordinary, low-burnup spent fuel to cool (thermally and in terms of radiation) sufficiently to be moved. About 60% of Indian Point's spent fuel inventory is high-burnup (HBU) fuel, which is much more radioactive than ordinary spent fuel, and requires at least seven years or more before moving (some experts say much longer). Compressing the process to three years or less may cut costs, but also puts workers and residents in jeopardy.

Outdated guidance – The NRC Office of Inspector General (OIG)'s *Audit of NRC's Transition Process for Decommissioning Power Reactors* (2019) called the Nuclear Reactor Regulation (NRR) and the Office of Nuclear Material Safety and Safeguards' (NMSS) office guidance documents out-of-date. These documents have remained largely unchanged since their inception, while decommissioning processes have evolved toward the fast decommissioning model .

GAPS IN ASSESSING AND MANAGING SPENT FUEL RISKS

Just one dry spent fuel storage canister holds roughly the same amount of lethal Cesium-137 as was released in the Chernobyl disaster, and there are thousands of such loaded canisters in the U.S. today. Yet most U.S. nuclear utilities use thin-wall nuclear waste storage canisters that are vulnerable to both short-term and long-term failures that could leak radioactivity. The nuclear industry has no adequate or approved plan in place to prevent or stop these canisters from leaking. The canisters are generally inferior to those used in other countries. They are not designed or licensed for long-term disposal or transport of spent fuel. They were chosen primarily as a relatively inexpensive means of temporary surface storage for licensees, rather than an adequate means of safeguarding the waste.

Consequently, there are many gaps in the research, data, and regulatory requirements that would be needed to adequately assess and manage these canisters and storage, and to determine whether or not they can store spent fuel in a way that protects public health and safety. In fact, DOE recently published a Gap Analysis to Guide DOE R&D in Supporting Extended Storage and Transportation of Spent Nuclear Fuel identifying technical gaps which hadn't yet been adequately addressed, but which would need to be before determining whether spent fuel systems were safe for extended storage or transport. For example, gaps identified as high priority included assessing the thermal and stress profiles of canisters, stress corrosion cracking of welded canisters, how residual water inside canisters dries out, the effect of hydrides on corroding canister cladding, how to monitor stress corrosion cracking inside welded canisters that can't be opened, consequences of canister failure (e.g. if the radioactivity in highly irradiated spent fuel escapes through cracks), and the need for data to support design concepts that would enable inspecting canisters for leaks, and transferring or repackaging spent fuel from leaking canisters.

Put another way, although DOE is aware of these highly significant gaps, they have yet to be filled. That means that there are spent fuel dry storage systems now in use in the U.S. whose safety isn't proven, and the regulatory apparatus tolerates and even encourages this. As more spent fuel gets transferred to dry storage, their use is growing, while at the same time already loaded canisters are aging, so the risks are multiplying.

Meanwhile, independent analysis of these issues has found many reasons to believe that these canisters and storage systems are in fact unsafe for storage or transport, and may be subject to failure in less than two decades after loading. Yet they are being used for independent spent fuel storage installations (ISFSIs) at reactor sites, where spent fuel canisters will typically be stored for many decades, and proposed for transport to consolidated interim storage facilities (CISFs) in New Mexico and Texas, where they would be stored indefinitely.

As a result, spent fuel storage in the U.S. is fraught with serious but poorly understood, inadequately studied and poorly managed risks to public health and safety. Here's a representative (but by no means complete) short list of the many gaps in knowledge and regulatory oversight that would need to be bridged to make spent fuel management safer:

Uncorrected design flaws and QA problems -- Canister designs currently in use have significant design flaws and chronic quality assurance problems. For example, in its decommissioning and spent fuel management work, Holtec uses dry storage spent fuel canisters of its own manufacture. Since 2001 Holtec committed multiple violations of NRC quality assurance procedures, which are meant to insure its canisters met safety standards. The violations included Holtec changing designs in ways that did not follow NRC procedures, revising quality assurance procedures on its own without NRC approval, and taking ineffective corrective actions. Dr. Ross Landsman, NRC dry cask inspector for the Midwest regional office, wrote a damning memo to his superiors expressing full support for a whistleblower's quality assurance allegations against Holtec's storage/transport casks, but was overruled. Holtec uses its spent fuel system at the San Onofre Nuclear Generating Station (SONGS) near San Diego and at nuclear plants it acquires for decommissioning. It unilaterally changed the design of its canisters in safety-significant ways without seeking NRC permission. The NRC fined Holtec for the unauthorized change, but let it stand. A design flaw in redesigned canisters surfaced at SONGS during loading, when loose bolts from the shim support that holds the waste were discovered inside. Due to poor engineering, the canisters are unavoidably damaged by protrusions as they are downloaded into carbon steel-lined concrete casks and storage holes, embedding carbon particles into the canisters, and creating scratches, scraped and gouges. This hastens corrosion and cracking which can cause early canister failure. At San Onofre, loaded canisters are stored just steps away from a popular surfing beach, and subject to moisture intrusion from fog and on-shore winds along the Pacific Coast, not to mention flooding and earthquake risks. Moisture intrusion also hastens corrosion of the canisters and eventual cracking and failure. Although the Electric Power Research Institute (EPRI) claimed ambient moisture even in the coastal environments of SONGS and the Diablo Canyon plant would be too low to dissolve salt particles, corrosive salts were nonetheless found on the canisters. At San Onofre, seagull droppings, which are highly corrosive to stainless steel, are damaging the spent fuel storage system lids, which Holtec is trying to combat with metal sprays on air vents. Similar problems threaten SNF storage systems widely used throughout the U.S. and cast serious doubt on claims they can adequately safeguard spent fuel. Since the NRC is not even evaluating many key triggers for cracking in thin-walled canisters, including manufacturing defects, gouging and scratching, carbon particles, chlorides (formed by moist salt air, potash, etc.), pitting, bird droppings, mishandling, etc., these claims remain unsubstantiated, and lack credibility.

Lack of transparency and regulatory requirements concerning spent fuel mishandling and transfer risks -- At San Onofre, Holtec had a serious near-miss accident in 2018, when it nearly dropped a heavy container loaded with spent fuel dangling from a crane as it was transferred into dry cask storage, which could have resulted in a severe radiological release. The incident was kept quiet, and only came to light thanks to a whistleblower. When the SONGS Citizen Engagement Panel raised concerns about it, Holtec shot back with a vitriolic, dismissive response, and withdrew from participation in the CEP. A similar near-miss incident occurred at Michigan's Palisades nuclear plant in 2005, which long went unreported, where the spent fuel container dangled from a crane for two days. Citizen's groups had to FOIA relevant documents to assess what happened. Plenty of mishaps and non-compliances in moving spent fuel have occurred at other reactor sites (e.g. Clinton, Fort Calhoun, Kewanee, Pilgrim, Prairie). "Although there is no specific requirement to do so," the NRC wrote concerning these incidents, "licensees can prevent [such] issues…by verifying that calculations for load-handling systems and structures designated to support spent fuel casks are consistent with the plant-specific design and licensing bases; and that procedures, training and oversight of spent fuel movement are adequate." It's remarkable that there is no regulatory requirement that licensees do this.

Uncertain, inadequate canister lifespan – The NRC approved thin-wall dry storage canisters short-term storage of spent fuel, and they are being widely used in ISFSIs and proposed for CISFs, which will store spent fuel for decades or centuries. EPRI claims it would take at least 80 years for thin-walled canisters to develop through-cracks and leak radioactivity. Yet a comparable component, a refueling water storage tank (RWST) at the Koeberg nuclear plant in South Africa, failed after just 17 years from chloride induced stress corrosion cracking triggered by corrosive salt in the marine environment. The Koeberg tank had cracks as deep as 0.61." The steel walls of thin-wall canisters used in the U.S. are 0.5" to 0.65" thick. There are over 3200 of these canisters loaded with spent fuel in the U.S. Most are about a decade old, some are as old as 27 years. More such casks are being loaded all the time. Yet they could be subject to failure in less than two decades. The NRC acknowledged in 2014 that that once cracks start they can grow through the thin wall and cause component failure in as little as 16 years. High heat loads can also accelerate component failure. The NRC now approves more than doubling previously permitted heat loads for each storage canister, in order to accommodate faster transfer from fuel pools in fast decommissioning. It also stopped requiring verification of heat loads. When it approved the Holtec UMAX system of thin-walled, convection-cooled canisters, it did away with the requirement that licensees verify that the cooling is working. Today, as long as the utilities assert that heat load in each canister is under 30 kW, the NRC doesn't require proof. Monitoring canisters is obviously necessary for safe extended storage or transportation of spent fuel. But given the intense heat and radiation of loaded canisters and the difficulty of transmitting sensor signals, monitoring isn't easy to do, and the NRC has refused to require it. There is therefore no reliable way to know when the canisters might become damaged and fail.

Damaged canisters can't be repaired – The 2019 DOE gap analysis acknowledged there is currently no way to find cracks in the canisters. Even if there were a way to identify cracks, DOE also admitted there is currently no way to stop them from progressing, or to repair them. It offered no real solutions, and the industry and the NRC has adopted the stance the reparability is irrelevant since the canisters can't fail. Speaking about Holtec's canisters at a 2014 SONGS Community Engagement Panel meeting, Holtec CEO Kris Singh said, "It is not practical to repair a canister if it were damaged…if that canister were to develop a leak, let's be realistic; you have to find it…and then find the means to repair it; we think it's not a path forward…In the face of millions of curies of radioactivity coming out of canister; we think it's not a path forward."

Lack of evidence-based regulatory requirements for High Burnup Fuel – High burnup fuel (HBU) makes up a substantial portion of U.S. spent fuel inventory. The NRC approved it for use in civilian reactors to lengthen the time between reactor refueling and cut owner's operating costs. It generally contains a higher percentage of uranium-235, allowing reactor operators to effectively double the time between refueling. Since it stays inside reactors about twice as long as conventional fuel, when it comes out of the reactor as spent fuel, HBU is about twice as radioactive, has much higher decay heat, and is more unstable. According to the NRC "there is limited data to show that the cladding of spent fuel with burnups greater than 45,000 MWd/MTU [megawatt-days per metric ton of uranium] will remain undamaged during the licensing period." But there is a body of research showing HBU degrades the zirconium metal cladding around the fuel rods, causing it to thin, become embrittled and fail. The same research shows that high burnup fuel temperatures make spent fuel more vulnerable to damage from handling and transport. Cladding can fail when HBU spent fuel assemblies are removed from cooling pools, vacuum dried, and placed in dry storage canisters. Failure limits for HBU in dry storage, or for newer zirconium cladding alloys (which degrade faster with HBU than older alloys) remain unknown, but the unknowns don't suggest HBU dry storage is safe – on the contrary. There is currently no way to monitor to HBU in dry storage canisters to ensure it has not become damaged, and no way for damaged HBU in canisters to be repacked in damaged fuel cans. At a minimum, HBU loaded into canisters is supposed to be surrounded by conventional low-burnup fuel to serve as a buffer. But Holtec and other canisters are loaded the opposite way: HBU surrounds the low-burnup fuel which enables packing more of it into the canister. The NRC acknowledged that this is a mistake. Yet despite unknown failure limits and evidence it's unsafe, the NRC continues to allow HBU to be loaded into dry storage canisters. Since the NRC concedes that "data is not currently available" to support the claim transportation of spent HBU fuel is safe, DOE researchers suggest HBU could be "trapped" at reactor sites for long periods -- presumably overloaded into canisters which aren't safe to store it.

Ignoring explosion and criticality risks – Spent fuel exposed to air in fuel pools or dry storage can result in hydrogen gas buildup and explosions. As spent fuel is removed from fuel pools, any remaining water is irradiated and converts to hydrogen. Uranium reacts with water to produce uranium dioxide and hydrogen, forming uranium hydride, which can further damage zirconium cladding. Hydride formation in both uranium fuel and zirconium cladding gets worse with moderate- and high-burnup fuel, which accounts for a substantial portion of U.S. spent fuel inventory. Zirconium hydride gas and zirconium powder (which is used in fireworks and old flash bulbs) ignites at 270 degrees Celsius. Oxidation of fuel cladding also compromises fuel rod integrity, which can lead to criticality risks and buildup of potentially explosive hydrogen. Spent fuel can also go critical when exposed to unborated water (i.e. water in the environment as opposed to boron-treated water in spent fuel pools). Many reactors located in coastal areas, on islands, in flood plains and adjacent to water bodies are at risk for flooding. Given the lack of monitoring inside the canisters in the U.S., there is no way to know how much water will infiltrate them. The thin-walled canisters in wide use in the U.S. today have no pressure monitors or pressure relief valves, but over time, buildup of gases can overpressurize the canister, embrittle the welds, and reach flammable concentrations. These risks have been documented by experts and researchers, but NRC dismisses them. It ignores the problem of hydride formation, assumes through-cracking in canisters won't happen, and concludes criticality and explosion of stored spent fuel won't occur. But that doesn't mean these risks are dismissible. On the contrary, dismissing them and failing to mitigate them makes them more of a threat.

Ignoring ASME standards and NWTRB recommendations -- For both short-term and long-term storage of spent nuclear fuel, the Nuclear Waste Technical Review Board recommends that SNF and its containment must be maintained, monitored, and retrievable in a manner that prevents radioactive leaks and hydrogen gas explosion. It also recommends canisters have pressure monitoring and pressure relief valves, since canisters are pressure vessels subject to gas buildup. The American Society of Mechanical Engineers (ASME) N3 standards *require* pressure vessels to have pressure monitors or and pressure relief valves. ASME further requires them to be examined for surface defects and for defects to be eliminated. Thin-walled canisters used in the U.S. don't and can't meet these basic standards, though canisters used in many other countries do (e.g. Switzerland, Germany, Belgium Czech Republic, France, Italy, and others). The NRC simply exempts the canisters from ASME standards, and ignores NWTRB expert recommendations, for example refusing to require remote sensor monitoring systems.

Lack of a backup plan in case of canister failure – Under current NRC regulations and industry practices, if a canister does fail, there is virtually no way to repair or repackage it. The NRC permits destruction of fuel pools once the fuel is removed (which saves saves licensees about $25 million per pool per year in overhead costs). But even for sites with intact fuel pools, it's not proven whether putting damaged spent fuel canisters back into a pool would be safe. This has never been done with a welded canister, for example. Many experts argue the only way to repackage damaged canisters safely is to use a dry handling facility, aka a "hot cell," where spent fuel can be repackaged while inside a radiation containment vessel. The NRC has admitted hot cells will eventually be needed at some point, though it doesn't say when. Since loaded canisters may fail in less than two decades, and surface damage and other problems that can accelerate failure are common, the timing question is urgent. But hot cells are expensive, so with one exception, U.S. nuclear reactors don't use them, and the NRC doesn't require them. The proposed alternative, to put breached canisters inside a sealed, thick metal overpack, is little more than a fig leaf, designed to save money and create the appearance of a solution while avoiding dealing seriously with canister failure risks. Overpacks can't work because sealing the canister inside will eliminate convection cooling, causing it to overheat. Rather than incur the expense of building hot cells, the industry and the NRC prefer to assume that canisters won't fail, though that's far from a safe assumption for reasons described above.

Ignoring risk multipliers – In addition to the inherent risks spent fuel handling and storage, and the self-inflicted risks of flawed dry storage systems, there are also external factors that can multiply these primary risks, such as earthquakes, tsunamis, terrorism, cyberattacks, loss of backup power, and more severe storms and flooding due to climate change. These risks were mostly unforeseen when U.S. civilian reactors were built, but evolved in the decades since. The NRC has downplayed or ignored them as not credible. It has consistently failed to update risk assessments for civilian reactors as their risk profiles evolve, for example dismissing the threat a new high-pressure natural gas pipeline passing near Indian Point poses to the plant and the spent fuel stored there. A whistleblower complaint, sustained by the NRC's Inspector General, showed that rather than take the threat seriously, NRC staff ignored key data and tailored its risk modeling of explosion risks to fit the desired foregone conclusion of no action being necessary. In addition to ignoring or downplaying certain primary risks as described above, failure to consider risk multipliers (both individually and in terms of how they might interact), to incorporate new data and modeling, or to update risk assessments, is aggravating spent fuel risks.

Ignoring canister failure risks in transport – Canisters used in the U.S. rely on convection (passive) cooling. For convection cooling to work, canisters must be upright. But in transport, canisters are laid down horizontally, which stops convection, causing the canister to overheat. Higher heat loads exacerbate canister failure risks, including higher pressurization and radiation leaks. The 2019 DOE gap analysis admitted we need to learn more about the horizontal orientation on temperature profiles inside dry casks, and proposed using a dry cask simulator for more study, as well as more modeling and new methodologies to predict temperatures inside real casks "without excess conservatism." There is no technology in place to fully inspect canisters for damage, and the impacts of shaking and bumping of radioactive materials on railways are not known. In 2019 the NWTRB identified 30 unresolved technical issues in transporting SNF and other high-level radioactive waste that still need to be addressed. No cask has been approved for transporting thin-walled spent fuel canisters – in fact no vendor has even requested such approval. The NWTRB recommended DOE allow for a minimum of a decade to develop new cask and canister designs for SNF and HLW storage and transportation. Yet decommissioning companies and the NRC are pushing ahead with licensing proposed consolidated interim storage facilities in New Mexico and Texas which would accept spent fuel shipped from around the country in the next few years.

The vast majority of these shipments would be thin-walled canisters. No new technology for transporting thin-walled spent fuel canisters is on the horizon now. It's much more likely that when CISFs are ready to open in 2023, the NRC will adjust its methodologies to avoid "excess conservatism" and approve current cask technology for transport, despite the risks.

Ignoring accident risks in transport -- In addition to the risk of canisters leaking and failing in transport, there is also significant risk of transportation accidents. Transporting spent nuclear fuel by rail long distances, through major cities, via out-of-date or weakening infrastructure would subject large numbers of people to accident risks. Roads, rails, bridges, and other infrastructure are not designed for the 100-ton weight of loaded spent fuel canisters plus transport casks plus vehicles. Trucks carrying them are massive and travel at very low speeds on secondary roads, with communities and neighborhoods all along the way running risks of accidents and exposure to leaking canisters. In 2002, DOE proposed barge routes for shipping spent fuel from reactors for reactors without direct rail access. That plan has been echoed recently by decommissioning companies, including in Holtec's PSDAR for New York's Indian Point, and in plans for shipping radioactive components and eventually high-level radioactive waste from Michigan's Palisades plant. Holtec is seeking to acquire Indian Point and Palisades for decommissioning. Barge shipment raises the prospect of potentially catastrophic maritime accidents involving spent fuel. Planned DOE barge routes from Indian Point would go down the Hudson River past Manhattan. From Palisades, Holtec's planned barge route crosses Lake Michigan, the source of drinking water for 40 million people, then goes down the Mississippi River. From the Oyster Creek plant in New Jersey, which Holtec is now decommissioning, the DOE barge route crosses Barnegut Bay, where past barge shipments to Oyster Creek ran aground in bad weather, and in which other barges have sunk.

GAPS IN ASSESSING AND MANAGING CONSOLIDATED INTERIM STORAGE RISKS

The permitting process is well underway for two proposed consolidated interim storage facilities 40 miles apart, located in southeastern New Mexico and western Texas. Together they plan to store some 216,000 metric tonnes of spent fuel in shallowly buried casks. The prospective licensees are Holtec International in New Mexico, and in Texas, Interim Storage Partners, LLC, a subsidiary of Orano. Both Orano and Holtec are also in the business of decommissioning U.S. nuclear plants.

Environmental review for the proposed CISFs will be completed this summer. Despite the lack of approved transport casks and the many other unsolved safety dilemmas with transportation, these facilities expect to start taking shipments no later than July, 2023.

But there are important and unresolved gaps in knowledge, policy and regulatory oversight that make consolidated interim storage risky, unfair, and even illegal. Here's a representative (but by no means complete) short list:

Lack of risk assessment for SNF transport to CISF-- DOE transport routes for Yucca Mountain proposed to ship spent fuel from around the country through 75% of Congressional districts, in addition to barge routes. Proposed CISF transport routes will likely be similar to those proposed for Yucca. If the facilities are licensed, it would trigger thousands of shipments of spent fuel across the country over a period of decades. With so many issues with transportation safety left unresolved, there is no risk assessment that remotely adequately profiles the risks and potential consequences of such a massive transportation scheme.

Unresolved conflict of interest for decommissioning companies -- Both Holtec and Interim Storage Partners expect to be well paid by the federal government to store spent fuel at their CISFs. They therefore have a strong financial incentive to expedite spent fuel transfer at nuclear plants they are decommissioning to dry storage and to transport, despite the heightened safety risks. That poses a fundamental conflict interest between decommissioning the plants safely vs. maximizing revenues from disposition of their spent fuel.

Incompatibility with federal law -- The business model of these CISFs also violates current federal law, and the NRC is currently being sued in federal court over permitting them. The facility is predicated on the idea that DOE will take title to spent nuclear fuel as it leaves the reactor site, thus relieving the decommissioning companies of their liability for it. But this is specifically prohibited by the Nuclear Waste Policy Act, unless and until a geologic repository is up and running. The lawsuit against the NRC argues that advancing the NRC licensing procedure despite this, in anticipation of the law changing, is itself illegal.

Incompatibility with consent-based siting and environmental justice principles -- The proposed CISFs violate basic principles of environmental justice and consent-based siting, since the indigenous communities and communities of color located nearby do not consent. They are already overburdened by impacts from the nuclear industry, including uranium mining and milling and nuclear weapons testing over the past 75 years. They have yet to be compensated for these impacts under the Radiation Exposure Compensation Act (RECA). The governors of New Mexico and Texas, the All Pueblo Council of Governors, and many other state and municipal officials oppose these CISF projects. Hotlec's CISF threatens significant Native American cultural sites in New Mexico. Forcing lower-income, more impacted, predominantly indigenous and LatinX communities to accept spent fuel from from wealthier reactor communities also implicates those communities in violating basic principles of justice and consent.

Ignoring and misrepresenting siting risks – The International Atomic Energy Agency (IAEA) has warned against co-locating high-level radioactive waste storage or disposal facilities in areas also hosting fossil fuel extraction, as too high risk. For example, certain fracking activities can induce significant artificial earthquakes, which can damage CISFs. Holtec's proposed CISF in is cited in the oil- and gas-rich Permian Basin. Up to 2,500 oil, gas and mineral wells or sites are operated in the area by 54 businesses within a 10-mile radius of the site. The New Mexico State Land Office owns the mineral estate beneath the surface. New Mexico State Land Commissioner Stephanie Garcia Richard opposes the project, citing "serious safety concerns." "We are talking about storing over 120,000 metric tons of nuclear waste in an extremely active oil field without a clear picture of the potential hazards of that combination," she said. She questioned any contention that hydraulic fracturing can occur safely beneath a nuclear storage site, or that the waste can be safely transported through New Mexico joint venture with numerous local organizations, owns the surface rights. According to Garcia Richard, Holtec "falsely" represented it secured agreements with nearby oil and gas operators to restrict extraction operations near the proposed site. She also accused Holtec of making misleading statements on the matter in submissions to the NRC. "I understand that we need to find a storage solution," she said, "but not in the middle of an active oil field, not from a company that is misrepresenting facts and unwilling to answer questions, not on our state trust lands."

Lack of emergency planning -- As former NRC Chair Gregory Jaczko points out, CISFs are "interim" in name only, and should be viewed as *de facto* permanent storage sites. Yet the permitting and planning processes are treating them as temporary installations. CISF host communities are ill-equipped and ill-prepared to manage their risks over the long term. "Transporting material of this nature requires both well-maintained infrastructure and highly specialized emergency response equipment and personnel that can respond to an incident at the facility or on transit routes," wrote New Mexico Governor Michelle Lujan Grisham in a letter to the NRC and DOE. "The state of New Mexico cannot be expected to support these activities."

Hostility to any contentions opposing CISF – In a 2018 NRC Atomic Safety Licensing Board proceeding on licensing Holtec's CIS, it dismissed all 50 contentions of the intervenors opposing the project, including Sierra Club, Beyond Nuclear, Fasken Oil, AFES, and others. Not a single contention of opponents of the project was allowed, but that doesn't mean they didn't have merit. The ASLB did acknowledge that the CISF violates the Nuclear Waste Policy Act, but it dismissed Beyond Nuclear's legal challenge anyway, on the ground that Holtec could be depended on not to implement the unlawful provision if the license were granted. The issue is now before the U.S. Court of Appeals for the District of Columbia Circuit.

Unknown impacts on the nuclear fuel cycle – Part of the business case for gathering spent fuel in one place is to facilitate reusing it. DOE has funding for "integrated fuel cycle management," seeking to reclose the fuel cycle to create more uses for spent fuel. A planned Urenco high-assay low-enriched uranium (HA-LEU) facility capable of re-enriching spent fuel has been sited near the New Mexico and Texas CISFs. Small modular reactors of the kind Holtec is seeking to build may run on re-enriched spent fuel. But re-enrichment entails new risks. One of HA-LEU's byproducts is depleted uranium, which becomes chemically unstable over time and for which there is no disposal or management plan. Some proponents of the project, including the Mayor of Hobbs, NM where Holtec's CISF is sited, have suggested that storing spent fuel there would make it a center of spent fuel reprocessing. Reprocessing is an especially dirty and dangerous process. Reprocessed fuel can be used in the weapons industry, and is considered a nuclear proliferation risk.

LACK OF EVIDENCE BASIS FOR EXTREME LICENSE EXTENSION

As more nuclear plants become uncompetitive with other forms of generation and shut down, nuclear owners have sought subsidies to keep operating plants running longer. Given the unfavorable economics of nuclear energy, new nuclear construction has proven infeasible, so extending the operating lives of existing plants is one of the few remaining avenues for extending the life of the nuclear industry. Even with billions in direct federal subsidies (e.g. $10.9 billion in 2016) and indirect subsidies (such as indemnifying non-military nuclear plants at taxpayer expense under the Price-Anderson Act) the nuclear industry still requires large state subsidies to keep aging, uncompetitive plants running.

The industry argues that keeping existing nuclear plants running longer is a way of fighting climate change. Accordingly, it has sought and received large state subsidies under "clean energy" standards on the basis of "zero emissions credits." The Decommissioning Working Group participants and many other citizens' and environmental groups dispute the claim that nuclear energy is zero-emissions, and strongly reject the claim it is clean energy. But those issues aside, expert analysts, including Amory Lovins who is presenting at the March 30, 2021 Congressional briefing, have demonstrated clearly that continuing to rely on and subsidize nuclear energy will actually make climate change worse.

The NRC has long had a license extension process where licensees could apply for extensions up to 20 years, so that some reactors which were originally licensed for 40 years might get re-licensed to run for a total of 50 or 60 years. Recently, it doubled the potential relicensing to period 40 years, so plants may apply to get relicensed to run for a total of 80 years, or even longer. Within the last 18 months, the NRC granted 80-year authorization to four nuclear reactor – two at Florida's Turkey Point and two at Pennsylvania's Peach Bottom. They were already running on extended licenses, and are now licensed to keep running until the 2050s. Six more reactors have already applied for license extensions to keep operating for a total of 80 years, and more will follow.

But the evidence basis for such extreme license extension is missing. In fact, there is no more evidence for 40-year license extension being safe than there is for 20-year license extension being safe. According to the NRC, of 94 civilian reactors remaining in the US fleet, only 11 are operating under their original 40-year licenses. Three withdrew their application for license extension, and eight that actually received license extensions shut down anyway. That's some indication that just because a plant receives a license extension from the NRC doesn't mean it's safe to keep operating for 20 more years -- let alone 40 more years.

The NRC has virtually never rejected an application for license extension, and doesn't see why it should. It says that as long as licensees follows NRC regulation, there is no reason why nuclear plants should have to stop running after 40, 60, or even 80 years. Nor does it abide by any upward limit on the operating lives of existing nuclear plants. "The Atomic Energy Act does not put a limit on the number of license renewals the NRC can issue," said an NRC spokesperson.

Yet licensing nuclear plants built in the 1970s using mid-20th century technology and materials for 80 years or even longer is obviously an inherently risky proposition, and it remains an unproven one.

The NRC's practice of extreme license extension is currently being challenged before the Atomic Safety Licensing Board and in litigation on the grounds that it has not been scientifically qualified. In particular, the NRC has declined to harvest and study components of decommissioned nuclear plants. But as plants enter decommissioning, they present a unique opportunity to build an evidence base for license extension that can't be reproduced by lab testing new materials. By salvaging and testing actual dismantled plant components, both metal and non-metal, to assess their durability, corrosion, embrittlement, etc. – so-called "nuclear autopsy" -- researchers and regulators can study and compile data on many real-world degradation pathways affecting operating nuclear plants, and use the information to inform relicensing decisions scientifically.

The NRC, Oak Ridge National Labs, and Pacific Northwest National Labs were working on plans for such a program before they were scrubbed during the Trump administration. They have not been revived. Meanwhile, without the benefit of scientific evidence nuclear autopsies could provide, the NRC continues to make relicensing decisions, looking favorably on granting extreme license extensions which are the nuclear industry's chief way of staying in business.

GAPS IN ASSESSING COSTS AND RISKS OF ADVANCED REACTORS

The U.S. federal government has recently signaled elevated interest in stepping up research and development of small modular reactors (SMRs) as a source of carbon-free energy to fight climate change, including in the 2020 report of the House Select Committee on the Climate Crisis, the Biden energy plan, the CLEAN Future Act, ARPA-C and other pending federal policies and agendas.

But although the climate change argument for them is new, it's important to note that SMRs aren't new. The design concepts date back to the 1950s, the companies pursuing them are mostly subsidiaries of established old-line nuclear companies, and DOE has been funding their development for decades, with little to show for it. In 2001, DOE's Office of Nuclear Energy projected that there were nearly 10 SMR designs that "have the potential to be economical and could be made available for deployment before the end of the decade, provided that certain technical and licensing issues are addressed." Two decades later, deployment and commercialization of SMRs are nowhere in sight.

Utah Associated Municipal Power Systems (UAMPS) has an SMR pilot underway at Idaho National Labs to build and test the NuScale's Nuclear Power Module, with some DOE funding. But its 2029-2030 projected earliest projected deployment date is unrealistic. In 2015 UAMPS projected the pilot would cost $2.9 billion to build, but that estimate has since more than doubled to $6.1 billion, even before construction has started. DOE pulled out of an agreement to lease the first two reactors, municipalities that subscribed to take the power have withdrawn, and the subscriptions for 230 MW that UAMPS reported in 2019 have now dwindled to less than 100MW.

Future federal funding for the UAMPS project now depends entirely on annual appropriations from Congress over the next decade. Under a proposed cost-sharing agreement with UAMPS, which has not yet been appropriated or awarded to DOE, DOE would provide $1.355 billion to UAMPS over nine or ten years, depending on the availability of Congressional appropriations. That represents about a quarter of the project's projected cost. It's also a significant portion of DOE's total annual nuclear energy budget, which was $1.5 billion in FY2020. For now, current DOE funding for the UAMPS/NuScale project comes from DOE's Advanced Small Modular Reactor Research & Development Program with final appropriations in FY2019 and FY2020 of $100 million each year. Today DOE has spent $314 million on development of the NuScale SMR design and has reportedly agreed to spend up to $350 million more in matching funds. It also spent over $100 million on Babcock & Wilcox's mPower design, which was abandoned in 2017 because there were no customers.

Before deciding if continued SMR funding is warranted, Congress will need to be able to assess whether SMRs are safe and economical.

Regarding SMR economics, independent analysts say that cost overruns for building NuScale, a light water reactor SMR design, are endemic, and that large cost escalations can also be expected for building other SMR design concepts including the sodium-cooled Natriam reactor Bill Gates' TerraPower proposes to build. Governments have already spent about $100 billion on sodium-cooled reactors since 1950, so far with little success.

Building SMRs at the required scale would be even more challenging. Conventional SMRs have power outputs in the range of 1,000-1,600 MW. Most planned SMRs envision outputs of 1.5-300 MW. To substantially replace conventional reactor fleets would therefore require building many thousands to tens of thousands of new SMRs, which on its face seems cost prohibitive.

Assuming SMRS can be built, there could be many difficulties to operating them efficiently. For example in pressurized water reactor SMRs, steam generators, which convert high-pressure hot water from the reactor to steam which drives turbines, have often failed prematurely and needed replacing. Stream generator problems recently forced permanent shutdown of conventional reactors at San Onofre and Florida's Crystal River plant. In several SMR light water designs (including NuScale) the steam generators are located inside the reactor vessel. Replacing them would extremely difficult if not impossible, so steam generator problems could result in permanent reactor shutdown.

According to BASE, Germany's Office for Nuclear Waste Safety and Management, which conducted a Safety Analysis and Risk Assessment of SMR Concepts, economic selling points claiming SMRs will be cheaper than conventional reactors or more cost-effective than renewables -- such as modular design allowing low output units to be integrated into the larger energy system, and shorter construction time -- are not borne out by experience. "On the contrary," BASE found, "planning, development and construction times usually exceed the original time horizons many times over. Experience with historical SMRs indicates that the operating times of non-light water reactors are short, and that decommissioning proves to be very lengthy....The potential uses of SMRs are economically far inferior to other energy technologies, [i.e.] renewables combined with storage technologies. In particular, complete coverage of decentralized regions by microgrids is technically feasible today and is more cost-effective than by SMRs."

Regarding SMR safety, BASE noted that "various safety risks associated with the envisaged plants are largely neglected in the planning, especially questions regarding transport, dismantling and interim and final storage."

Proponents claim SMRs have the advantage of being able to operate with reduced regulatory requirements and less redundancy in safety systems. For example Holtec claims its SMRs, which it plans to build at its facility in Camden, New Jersey, are "walk away safe" and require no operator action if cooling is lost.

Holtec's SMR design is not yet approved by the NRC, and it has not yet applied to build an SMR. But that doesn't mean the possibility is only theoretical or remote. Until recently, Holtec told journalists its SMRs were intended for foreign markets such as Ukraine, and that it saw no market for them in the U.S. But that changed after it acquired the closed Oyster Creek nuclear plant in New Jersey for decommissioning. In January 2021 Holtec announced its intention to install an SMR at Oyster Creek.

"Some developers even demand that current requirements be waived, for example in the area of internal accident management or with reduced planning zones, or even a complete waiver of external emergency protection planning," the BASE assessment points out. But it concludes that "since the safety of a reactor plant depends on all of these factors, based on the current state of knowledge it is not possible to state, that a higher safety level is achieved by SMR concepts."

Some SMR designs would run on unconventional fuels, including higher enriched uranium, plutonium, and reprocessed spent fuel. "This is fundamentally detrimental to proliferation resistance," according to BASE, because making these fuels can also yield materials used in nuclear weapons. If SMRs are scaled to many thousands of installations around the world as proponents intend, proliferation risks scale up accordingly. Higher burnup and non-conventional fuels also compound spent-fuel disposition and storage problems.

The nuclear fuel company Urenco, which is also in the SMR business, plans a dedicated high-assay/low-enriched uranium plant at its uranium re-enrichment plant in Eunice, New Mexico, near the proposed consolidated interim storage facilities in New Mexico and Texas. This raises the prospect Urenco may intend to re-enrich spent fuel stored at CISFs as fuel for SMRs. In 2017 Sam Cobb, mayor of Hobbs, New Mexico where Holtec's CISF site is located, said, "We believe if we have an interim storage site, we will be the center for future nuclear fuel reprocessing," he said. But reprocessing is the dirtiest part of the nuclear fuel cycle, generating some of the worst high-level waste. It would in effect re-close the nuclear fuel cycle, breaching the essential separation between civilian reactors and the weapons industry.

The NuScale pilot has received conditional certification from the Nuclear Regulatory Commission. But serious safety issues must be addressed and resolved before any utility applies for a permit to build an SMR, and before the NRC grants one. No national or international safety standards have been established for SMRs to date. Before such standards could be framed, and before it could be determined whether a particular SMR design concept warrants development, many fundamental questions would need to be answered, requiring extensive investigation that has not been done. Here's a representative (but by no means complete) short list:

- **What evidence exists to prove or disprove the claim that SMRs are safer** than conventional nuclear power plants?
- **What is the evidence basis for determining the appropriate integral safety level** that should be required of SMR concepts, including those for which there is little or no operating experience?

- Since SMRs can be deployed in many different kinds of settings and sites (not just large power stations), **what site-specific regulatory requirements should apply?**
- **What should the containment criteria be for various SMR concepts?** Some SMR designs don't see the need for reactor containment, relying instead on the properties of the reactor fuel. How should adequate containment of various SMR designs be defined, assured, and verified?
- **What should the reactor control criteria be for various SMR concepts?** Some SMR designs use reflectors or other control devices not usual in convention light-water reactors to keep reactors subcritical and shut reactions down in emergencies. How should adequate reactor control of various SMR designs be defined, assured, and verified?
- **What should the cooling criteria be for various SMR concepts?** Some SMR concepts are not water-cooled (sodium-cooled designs, for example); some propose "passive residual heat removal" instead of water cooling. How should adequate cooling of various SMR designs be defined, assured, and verified?
- **What safety-related criteria should be used?** Internal hazards such as pump failure, power supply loss in the equipment, pipeline leaks, or internal fires, as well as external hazards like earthquakes, external flooding or extreme weather conditions, terrorism or airplane crashes must be considered. How can the safety of various SMR designs, adherence to defense in depth principles, and protection of public health and safety be assured and verified?
- **What emergency planning criteria should be used for various SMR concepts?** SMR developers sometimes assert that SMRs are "walk-away safe" and that emergency planning zones aren't needed. But the question of emergency planning is critical and needs extensive investigation, for both single- and multiple-unit installations. According to BASE, the "need for planning zones that extend significantly beyond the plant site must be assumed for off-site emergency protection in SMRs."
- **What are the risks of using unconventional fuels in SMRs and how can they be safeguarded?** Various non-water cooled SMR concepts would run on unconventional fuels, including higher enriched uranium, plutonium, and reprocessed spent fuel. "This is fundamentally detrimental to proliferation resistance," according to BASE, because these fuels can be used in nuclear weapons. If SMRs are scaled to many thousands of installations around the world as proponents intend, proliferation risks scale up accordingly. Higher burnup and non-conventional fuels also compound spent-fuel disposition and storage problems.

GAPS IN COST ACCOUNTING OF PROPOSED NUCLEAR ENERGY POLICY CHANGES

In the same way that federal funding for SMRs is moving forward without an adequate accounting of the risks and costs, Congress is being asked to make other significant changes to U.S. nuclear energy policy without reliable cost analysis.

For example, pending legislation before Congress includes S.1234, H.R.3053, S.2699 and S.2917. Among other things, these bills would:

- Remove important safety requirements from the Nuclear Waste Policy Act (NWPA).
- Allow title and liability for spent nuclear fuel at existing nuclear waste sites to be transferred to the federal government, which will not solve spent fuel disposition problems**.** Federal nuclear waste sites such as Hanford and Savannah River have leaked radiation into the environment including water sources for decades.
- Make funding for spent nuclear fuel storage and management discretionary, to be voted up or down in annual appropriations. Current federal funding for SNF storage from the Treasury Department's Judgment Fund is mandatory. Without it, there's a danger that although the federal government will have responsibility for safeguarding spent fuel from civilian reactors, year to year it may not have adequate funding to execute it.

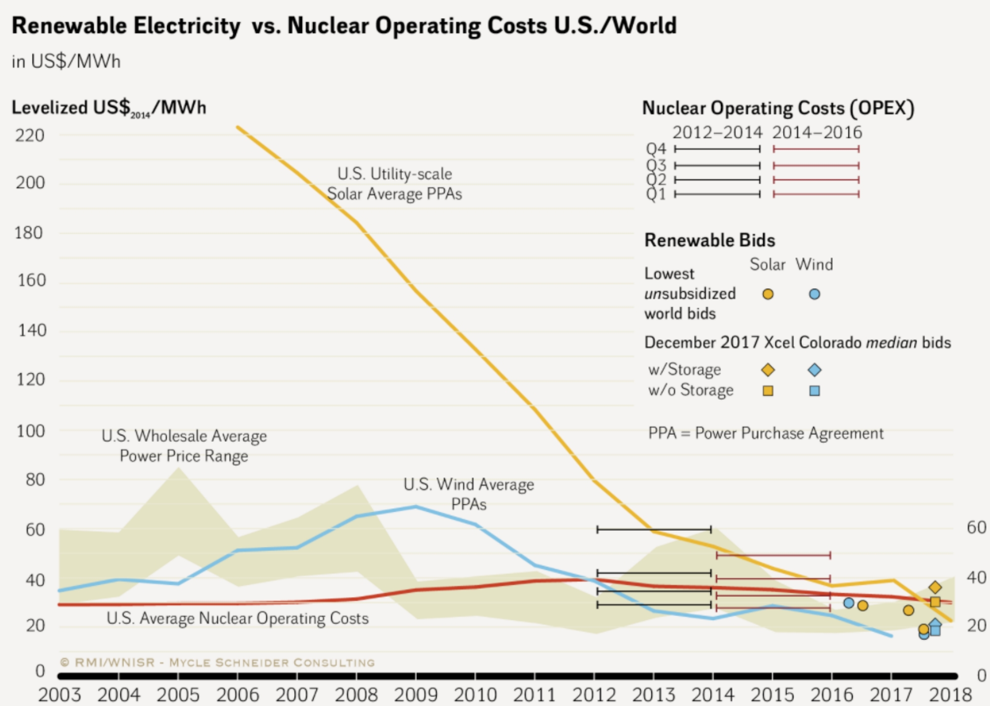
The costs of these policy changes if enacted have not been adequately studied and remain unknown. Far-reaching nuclear policy questions that will likely come before Congress as soon as this year (2021), but whose costs and risks have not been studied, include:

- Whether to continue to permit and effectively subsidize fast decommissioning, without financial assurance from decommissioning companies, any reliable independent assessment of the costs, any accountability for decommissioning trust fund expenditures;
- Whether to enable consolidated interim storage by radically altering the Nuclear Waste Policy Act the authorize DOE to take title to spent fuel and relieve licensees of liability for it, without quantifying the costs and risks of transport and extended "interim" storage vs. alternatives like hardened onsite storage of spent fuel at reactor sites;
- Whether to appropriate funding for CISFs, and adopt other legislation to authorize and prioritize shipment of spent fuel through 75% of Congressional districts and via water routes to CISFs, without assessing the real costs and risks;
- Whether to authorize increased reliance on nuclear energy, including through extreme license extension and possibly through funding "advanced" reactors, as a way of fighting climate change, without independent analysis of the costs and risks, especially compared to alternatives.

Ostensibly, current pressure for such fundamental changes to U.S. nuclear energy policy occasioned by climate change and the search for zero-carbon energy. More fundamentally, it's occasioned by the demands of a nuclear industry which has become uncompetitive economically with other forms of power generation, including renewables, and wants to be relieved of its costs and liabilities.

Although average U.S. nuclear operating costs have declined since 2012—especially as the most distressed units close down, new wind power and new utility-scale solar power have declined even faster. Most operating reactors and the 2018 average U.S. nuclear operating costs are uncompetitive by $10/MWh or more with those renewable sources and with energy efficiency, which is often even cheaper. Operating costs for existing nuclear plants may have limited room to fall further but, says Amory Lovins, "renewables have far more; they're a rapidly moving target that nuclear operating costs are unlikely ever to hit."

Figure 51 | Cost Evolution of New Renewables vs. Operating Nuclear



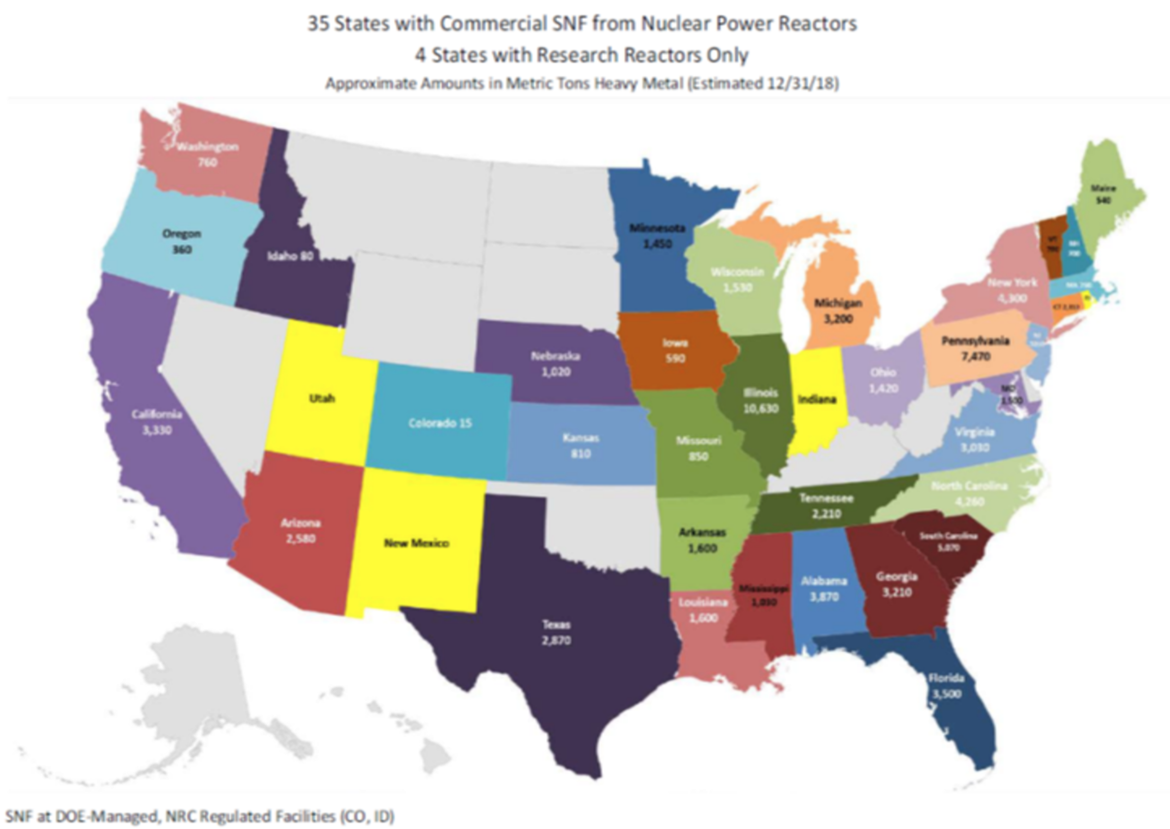
Sources: various compiled by Amory Lovins, Rocky Mountain Institute, 2019[1026]

Notes
Wind and Solar PPAs: US generation-weighted-average Power Purchase Agreements prices, by year of signing.
Nuclear operating cost: fuel, operation and maintenance, and Net Capital Additions average and quartiles. See Table 20 and Table 21.

Admittedly, full cost accounting for nuclear energy isn't easy to achieve. It would have to include pricing in risks and costs that are inadequately assessed and hard to quantify, including the risks and costs of extreme license extension, decommissioning risks, and extended spent fuel storage and transport, including the risks and costs of potential spent fuel accidents. It would have to account for risks and costs of advanced reactors, unconventional fuels, and possible re-enrichment or even reprocessing of spent fuel to power them, despite many of these details being unknown. And it would have to compare them objectively to alternatives such as wind and solar.

But the difficulty of adequately assessing the costs doesn't make doing it any less necessary for informed policy decisions. In particular, policymakers need a comprehensive understanding of the lifecycle costs that U.S. government will incur in order to store and dispose of the world's single largest inventory of highly radioactive spent nuclear fuel.

U.S. nuclear power plants are now the nation's largest de facto radioactive waste management operations. Today, 113 sites in 35 U.S. states store some of the largest amounts of long-lived, artificial radioactivity on the planet.



The amount of spent nuclear fuel at these sites dwarfs high-level wastes generated by the U.S. nuclear weapons program. Since 1960, U.S. nuclear power reactors generated roughly 20% of the total global inventory of spent nuclear fuel – by far the single largest national inventory in the world.

According to former DOE senior policy adviser Robert Alvarez, since a geologic repository such as Yucca Mountain hasn't opened, and prospects for opening one remain uncertain, surface storage of reactor spent fuel surface is likely to continue into the next century. Failure to establish a federal geological repository site for spent nuclear fuel has shifted storage costs to the U.S. taxpayer, as nuclear owners routinely sue the U.S. Treasury to recover spent fuel management funds in the absence of a repository, and routinely win. But awards from those suits (e.g. $56.9 million awarded to Energy Northwest in 2010) are the tip of the iceberg. The full costs of extended surface storage have yet to be assessed.

As Alvarez points out, a 2016 DOE study did consider costs and benefits of consolidated interim storage of spent fuel vs. storing it onsite at reactor sites, but only in a very general way within limited parameters. It assumed no changes in existing storage packaging (which given the vulnerabilities of current dry storage systems may not be a safe assumption). It provided only an order of magnitude estimate, and found that "any delay in opening a repository increases total system costs, regardless of whether the system has an ISF [interim storage facility] or not."

Many factors could affect the costs of spent fuel storage. For example, with the continued operation of several more reactors in doubt, the backlog of stranded wastes could double over the next decade – comprising more than a third of current nuclear power-generated spent nuclear fuel. DOE is expecting a "wave" with as many as 60 reactor shutdowns that could clog transport and impact the schedule for a centralized storage operation. Among the other uncertainties DOE identified that would affect SNF storage and transport costs are the following:

- Transportation infrastructures at or near reactor sites are variable and changing.
- Each spent nuclear fuel canister system has unique challenges. For instance, reactor sites have dry casks that are licensed for at-site storage only, not for transport.
- The requirements for a geological repository are unknown. Site-based constraints on decay heat from spent nuclear fuel impact the timing of shipping.
- The pickup and transportation order of spent fuel has yet to be determined. It has been assumed that the oldest would have priority, leaving sites with fresher and thermally hotter fuel that may be "trapped" at sites to cool down further.
- Packaging of transport containers could have a major impact. As many as 11,800 storage canisters may have to be reopened.

Any adequate study of the costs of predisposal storage (i.e. storing it until it can be shipped to a geologic repository) should provide strategic "road maps" that address these and other specific challenges and technical issues which must be overcome. For now, they are treated as unknown quantities and inscrutable dilemmas to be deferred to a later date.

For example, according to a US Government Accountability Office study on Yucca Mountain, existing large dry casks "have no easy path to disposal unless (1) disposal is further delayed (up to 150 years or more for some mined repository concepts); (2) the contents are repackaged into smaller, cooler packages; or (3) the high temperatures are used as de facto site-selection and design criteria for a repository."

It should be noted that Yucca Mountain is not viable and not a panacea. Opening it would change spent fuel storage cost calculations but wouldn't solve spent fuel dilemmas. It was designed to hold less than half of the spent fuel projected to be generated in the U.S. None of the current storage canisters currently in use in the U.S. could be stored there, as they do not meet NWPA or NRC requirements. According to former NRC chair and geologist Alison Macfarlane, Yucca fails two of four International Atomic Energy Agency siting criteria for safe isolation of high-level radioactive waste. It also violates the principle of consent-based siting, since a majority of Nevadans oppose it, and would pose unquantified risks to communities along the transportation routes as well as to the host community.

Unless and until an adequate study is done, lifecycle costs of spent fuel storage will remain unknown and inscrutable. Meanwhile, Congress is being urged to fundamentally alter U.S. nuclear policy so the federal government assumes those costs from licensees, without any way to quantify them. Proposed amendments to the NWPA would have DOE take title and shoulder all subsequent liabilities for spent fuel before a geologic repository is opened. According to Alvarez, this is like signing and putting a down payment on a "balloon mortgage" whose future costs are unknown.

GAPS IN NRC ACCOUNTABILITY AND OVERSIGHT

Frank von Hippel, former assistant director for national security in the White House Office of Science and Technology, recently wrote, "Over the past two decades, the US Nuclear Regulatory Commission (NRC) has been captured by the nuclear power companies it is supposed to regulate. The process of capture and resulting erosion of regulation has been driven in part by the increasingly poor economics of nuclear energy as companies struggle to avoid large costs due to additional safety measures. However, the path has been laid to a potential disaster."

The NRC has adopted a "risk-informed" regulatory approach which assesses any proposed safety regulation or proposed regulatory relief according to the likelihood of something going wrong vs. the cost of preventing it. The NRC website states, "we examine both the probability of an event and its possible consequences to understand its importance (risk). In other words, we ask our questions of what can go wrong, how likely it is, and what its consequences might be…The NRC uses a risk-informed regulatory approach to identify and support additional requirements or regulatory actions, when needed. Risk information can also be used to reduce unnecessary requirements in purely deterministic approaches."

But according to von Hippel, the NRC primarily uses "risk-informed regulation" to justify avoiding imposing costly upgrades on nuclear licensees, by defining the costs and risks very narrowly. The costs considered are mainly the compliance costs that would be incurred by nuclear owners. "One problem with risk-informed regulation is that probability calculations for major accidents are very uncertain and subject to arbitrary assumptions," von Hippel argues. "An example is the commission's decision to assume that there is zero probability that terrorists could cause a large release [of radioactivity]."

This denial of the possibility of mishaps or failures resulting in radiological releases is part of a systemic pattern at the NRC. Whenever experts and advocates have assembled evidence and formally raised concerns about such risks, the NRC has almost universally dismissed or rejected them, and assumed there was no probability worth considering that anything serious can go wrong. From 1975 to 2012, an estimated 1000 petitions for the NRC to take enforcement actions were filed under section 2.206. The NRC summarily dismissed about two thirds of them without reviewing them. Of the 387 the NRC's Petition Review Board (PRB) agreed to consider, only *two* were granted substantive relief -- one of which was brought by the nuclear industry. By contrast, each year the NRC grants over 800 exemption requests from the nuclear industry for regulatory relief (i.e., to be exempted from existing NRC regulations). These industry requests are rarely if ever questioned, and have been granted on the basis of a phone call in as little as an hour.

One independent expert who has had more success than most challenging the NRC on behalf of the public is Paul Blanch, a nuclear consultant with over four decades of experience whose credibility with the NRC is well established. Over the past five years alone, he brought six 2.206

petitions to the NRC. Four were dismissed. One was initially accepted by the PRB, only to be denied by a formal Director's decision. Another was rejected by the PRB but investigated by the NRC's Office of the Inspector General, which found NRC staff had "misrepresented" its information, but no corrective action was taken.

On March 9, 2021, Blanch gave a presentation before the NRC on the pattern of consistently dismissing 2.206 petitions and citizen concerns as "not credible." For example, Blanch described a 2.206 petition he helped file, working with the NGO Public Watchdogs. It asked the NRC to revoke Southern California Edison's permit to bury spent fuel at the shuttered San Onofre nuclear plant. SoCal Edison is currently permitted to bury spent Holtec's UMAX spent fuel canisters 108 feet from beach, where they would be vulnerable to flooding risks. The burial site is located in an inundation zone on tsunami maps. UMAX canisters are convection cooled, with 4-inch holes at the bottom. There is no drainage, and no provision for getting water out of canisters. A king tide or storm or other severe weather event could cause sufficient coastal flooding to inundate the buried canisters. Flood risks in the San Diego area and elsewhere along California's coast are rising dramatically due to climate change. Contact with salt water would not only accelerate degradation of the canisters, it could also trigger a "geyser" effect where sudden heat and pressure causes a sudden release of radioactive steam. "If the site is flooded, the integrity of the 5/8" thick stainless-steel canisters may be compromised by pressure and thermal shock," said Blanch. "We expect the phenomenon to occur whenever water floods the silos."

The petition assembled evidence for this, including expert statements and statements from SoCal Edison and Holtec themselves. Holtec's own Final Safety Analysis Report admits the UMAX canister must be kept pressurized with helium gas to stay within design limits. But it never analyzed how moist salt air or salt water might cause helium to escape from the canisters. If that happened, there would be no possible way to repressurize them.

Nonetheless, the NRC called the petition "not credible" and declined to even consider it. In this, it followed the representations of Holtec and SoCal Edison that the UMAX canisters are safe, and that its analysis showed failure or leakage is "not credible." When Public Watchdog asked Holtec for the details and documentation of its analysis, Holtec said it was proprietary and refused. The NRC's own Management Directive MD 8.11 requires it to provide supporting documentation for its decisions, but it's routinely ignored by NRC staff.

The SONGS 2.206 petition is just one example of numerous such petitions for regulatory enforcement that the NRC has treated the same way, dismissing safety concerns as "not credible," and declining to provide documentation for its decision. The pattern is ongoing. As recently as February 23, 2021, Holtec requested a license amendment from the NRC to exempt if from any offsite emergency planning requirements against possible radiological release from spent fuel canisters stored at Oyster Creek. Holtec's request simply asserted that "leakage of fission products from a canister is not considered to be a credible event…After removal of the spent fuel from the spent fuel pool, there are no credible fuel-related accidents for which actions are required to prevent occurrence or to mitigate the consequences. There is no credible accident resulting in radioactive releases requiring offsite protective measures."

But if that's so, then why are there NRC inspection and repair provisions for canisters at all? "Credible" and "not credible" have evolved into catch-all terms of art without a clear definition. They are not defined by law or by regulatory statute, only by the usage of NRC staff according to its own internal interests. Well in advance of the March 9 NRC presentation, Blanch submitted questions to NRC staff, asking them to define what it meant by "not credible." In the meeting, NRC staff repeatedly declined to answer the question, saying only that the purpose of the session was to hear any additional information related to the petition (which it had summarily dismissed). In this instance and in general, when asked by the public to account for its decisions, the NRC staff response is that it isn't permitted to discuss the details with the public. But there is no law passed by Congress and no regulation promulgated by NRC that prohibits staff from discussing its decisions with the public, in fact MD 8.11 requires it to provide documentation explaining them.

These are just a few examples of how the NRC insulates itself against hearing public input, let alone acting on it. It offers the public extremely limited access, little recourse, and no appeal. The industry can and routinely does appeal NRC decisions it doesn't like. But the public may only ask questions about NRC process, typically in Q&A sessions at the end of hearings. It can't question the substance of NRC decisions and expect an answer, and it can't appeal them, other than by suing the NRC.

This insular attitude extends to state government petitions and even to some extent to members of Congress. For example, Massachusetts, New York and Michigan asked the NRC for hearings so the states could air their objections to the NRC approving license transfer of the Pilgrim, Indian Point, and Palisades nuclear plants to Holtec. The states expressed serious concerns over Holtec's lack of financial assurance and other qualifications to hold the licenses. Members of the states' Congressional delegations and their governors also weighed in to express their concerns and demand hearings. But the NRC ignored this input and approved the license transfers without granting hearings. The Attorneys General of Massachusetts, New York and Michigan each responded by suing the NRC, supported by amicus briefs signed by other state AGs. Massachusetts settled its suit in return for some concessions from Holtec. The other two suits are still pending, and the hearings have still not been granted.

Seeking recourse through litigation is no substitute for the NRC being responsive and accountable to the public. Cutting itself off from accountability to the public is the hallmark of a captured regulatory agency. The NRC's stated mission is "to provide reasonable assurance of adequate protection of public health and safety and to promote the common defense and security and to protect the environment." The stakes of that mission are existential for Americans. But the NRC can't fulfill it as long as its stonewalling public input and public concerns and catering to the industry it's supposed to regulate on the public's behalf.

BRIDGING THE GAPS

From a public interest perspective, the multiple systemic problems that U.S. nuclear energy policy needs to address are serious, even daunting. Major policy changes are being advanced without sufficient scientific data, without basic information about the threats they would pose to public health and safety or how much they will cost, and without basic accountability to the public. Critical information gaps and unsolved dilemmas abound in decommissioning, spent fuel dry storage systems, consolidated interim storage and eventual geologic storage, license extension for operating plants, and proposed SMR development.

Some of these dilemmas can't currently be solved. In particular, there is currently no adequate solution for spent fuel disposition, only riskier vs less risky options within a given timeframe. The U.S. Nuclear Waste Technical Review Board (NWTRB) has stated that the technology does not currently exist to make any geological repository work in the short term or long term. There is no approved system in place to prevent or remediate containment failure at reactor sites, proposed consolidate interim storage facilities or during transport. The NRC approves independent spent fuel storage installations (ISFSIs) at reactor sites on the unfounded "risk-informed" assumption nothing will go wrong.

But that doesn't mean that the risks are zero, or should be ignored, or that the relative risks and costs of the options we do have can't be assessed. In fact, to make informed policy decisions, we are obligated to understand those risks and costs, and take them into account.

While the gaps described in this paper can't all be closed, there is no lack of ways forward that can help bridge them, and ameliorate if not solve systemic problems. Here's a representative (but by no means complete) list of ten recommendations to policymakers that would help make nuclear energy policy more evidence-based and more effective at protecting public health and safety:

1. **Mandate science-based standards for spent fuel dry storage,** starting with the requirement all nuclear spent fuel waste be stored in containers that meet ASME N3 Nuclear Pressure Vessel Certification for storage and transport. These ASME standards require ability to inspect, repair, maintain and monitor the containers and fuel to prevent radioactive leaks or explosions, and the ability to remove a failing container from service. A draft list of additional recommended minimal standards for spent fuel storage systems is posted here. Mandated spent fuel standards should also adhere to Nuclear Waste Technical Review Board recommendations, including that SNF and its containment must be maintained, monitored, and retrievable in a manner that prevents radioactive leaks and hydrogen gas explosions.

2. **Adopt a "best available technology" (BAT) standard for spent fuel storage systems**, like the one the U.S. Environmental Protection Agency uses to implement the BAT

provisions of the Clean Water Act and Clean Air Act. This should include a scientific study of the characteristics of more robust dry storage systems, including bolted, thick-walled canister systems (12 – 18" thick) used in Germany, Switzerland, Japan and elsewhere, and how they could be implemented in the U.S. Thick-walled canisters at Fukushima withstood the tsunami, and radiological release at Fukushima would have been much worse had they ruptured. Currently, U.S. systems typically use thin-walled, welded canisters ½ -⅝" thick. There is no requirement for the NRC to apply a BAT or similar standard to decommissioning or nuclear waste handling and storage, or for a nuclear waste facility operator to use the best available technology to enhance safety and security at storage sites.

3. **Mandate dry handling facilities or "hot cells"** be installed at ISFSIs and CISFs, where spent fuel canisters are stored and leaking or damaged spent fuel or failing canisters may need to be repackaged. The mandate should have a date certain to resolve the current situation in which the NRC admits hot cells will be required for repackaging, but won't say when. Since evidence shows that spent canisters currently used in the U.S. can fail in less than two decades, hot cells should be required to be operational at these facilities before that happens.

4. **Commission a comprehensive cost/benefit/risk analysis** comparing the risks and costs of transporting civilian reactor spent fuel to CISFs to safeguarding it at the reactor sites. Such a study could be conducted by the Government Accountability Office or the Congressional Research Service. A list of Principles for Safeguarding Nuclear Waste at Reactor Sites, adopted by over 200 national, regional and local organizations in all 50 states, includes minimizing vulnerable dense pool storage of irradiated nuclear fuel, and establishing hardened on-site storage (HOSS) where irradiated fuel is stored as safely and securely as possible as close to the site of generation as possible. To be comprehensive, such a cost/benefit risk analysis would have to study both boiled water reactors and pressurized water reactors, establish lifecycle costs of spent fuel surface storage, thoroughly assess transportation costs and risks, and take into account external hazards and risk multipliers such as earthquakes, tsunamis, terrorism, cyberattacks, loss of backup power, and more severe storms and flooding due to climate change.

5. **Halt funding for CISFs and enabling legislation such as amending the Nuclear Waste Policy Act until transport risks and lifecycle costs are fully assessed** and appropriately compared to alternatives. Accordingly, suspend the permitting process for CISFs, which would violate the current provisions of the NWPA. Reaffirm that all nuclear waste storage, whether CISFs or ISFSIs, must uphold consent-based siting, environmental justice principles, and federal law.

6. **Mandate science- and evidence-based policies to guide nuclear plant decommissioning**, including requiring independent site characterization to frame adequate decommissioning plans and remediation standards, requiring on-site and off-site radiation monitoring and emergency planning for decommissioned plants and

ISFSIs, requiring an independent evidence basis for the safety of accelerated transfer of spent fuel from fuel pools (including HBU), and updating obsolete guidance on decommissioning and nuclear materials safety. In particular, the NRC's "risk-informed" penchant for setting aside its own regulations and routinely granting regulatory relief to decommissioning companies should not be codified in NRC decommissioning rulemaking process now underway.

7. **Require decommissioning companies demonstrate that they meet minimum requirements for competency, financial assurance, trustworthiness, and transparency** as a condition of license transfer. In cases where states have concerns about a prospective licensee, affirm their right to demand hearings, and the jurisdiction of state public utility commissions to adjudicate license transfer approval themselves. Demand accountability in how decommissioning trust funds are spent, including adhering to standard accounting practices and reporting to state and local governments as well as the NRC. In particular, prohibit the practice of "double-dipping" where licensees reimburse themselves for spent fuel management twice over, once from the DTF, and once from suing DOE, pocketing the windfall rather than reimbursing the DTF. Require bonding or other forms of financial assurance so that compartmentalized LLCs conducting decommissioning will not deplete the DTF and walk away from the project, leaving states and reactor communities to bear the costs and risks. Establish and fund Decommissioning Oversight Boards composed of relevant state agencies, independent experts, and public interest advocates.

8. **Mandate and fund harvesting and testing of dismantled nuclear components and materials in decommissioning**, in order to compile an evidence basis to close knowledge gaps on materials safety and inform license extension. Halt the granting of extreme license extension unless and until it is scientifically qualified.

9. **Frame basic safety standards for SMRs *before* funding any further development or deployment of SMR concepts.** This would require independent scientific investigation of SMR safety claims, and safety criteria for containment, reactor control, cooling, emergency planning and other features of various SMR concepts and sites. It would also require thorough analysis of the proliferation and safety risks of running SMRS on unconventional fuels, including re-enriched and reprocessed fuel.

10. **Call for reforms and exert closer Congressional oversight of the NRC.** Oversight should include Congressional hearings inquiring into the NRC's pattern of dismissing and denying virtually all public petitions for regulatory enforcement while granting virtually all industry requests for regulatory relief, license extension, etc. Congress should require NRC reforms that hold the Commission accountable for regulatory enforcement according to science, law, and regulation, following its own rules regarding transparency and furnishing documentation of the evidence basis for its decisions, and providing the public with meaningful ways to weigh in.

While the U.S. nuclear energy is replete with unsolved dilemmas, these recommended steps at least are clear and achievable. They would help establish more effective oversight and would make current dangers from the industry less acute. They should be viewed as prerequisites for any major changes to U.S. nuclear energy policy, including increasing reliance on existing nuclear plants or pursuing advanced reactors as a climate strategy. At a minimum, to even consider nuclear power as a future energy source, we will first need a science-based, transparent approach, stronger evidence and more complete information to inform our decisions, and much more effective oversight.

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