

**Testimony of
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Fukushima and Directions for U.S. Nuclear Power

Chairman Feinstein, Senator Alexander, and Members of the Committee, thank you for the opportunity to present and discuss views on the development of nuclear power in the U.S. in the wake of the Fukushima events. I must start by emphasizing that this testimony represents my personal views, not those of the President's Council of Advisors on Science and Technology, the Blue Ribbon Commission on America's Nuclear Future, or my home institution M.I.T.

Fukushima has reopened the global discussion about the future of nuclear power. Several factors had led many countries to consider expanding their nuclear capacity, reversing phaseouts, or initiating new nuclear programs. These factors include a very good safety and reliability record for the last decades, increasing concern about the risks of climate change, and a concomitant recognition that enormous amounts of additional electric generating capacity will be needed without increasing greenhouse gas and other polluting emissions. Exactly how the new debate will end is unclear and will remain so for some time, as the events and responses in Japan are investigated and fully understood, and as safety systems, operating procedures, regulatory oversight, emergency response plans, design basis threats, and spent fuel management are reexamined by the Nuclear Regulatory Commission for currently operating U.S. reactors.

Nevertheless, *some outcomes are a good bet:*

- *The cost of doing business at nuclear reactors will go up*, reflecting factors as diverse as new requirements for on-site spent fuel management to measures needed to address possible elevated design basis threats.
- *The expected relicensing of forty year old nuclear plants for another twenty years of operation will face additional scrutiny*, taking more time than expected. Indeed some of the license extensions already granted for more than 60 of the 104 plants operating in the U.S. could be revisited. These plants, like those at Fukushima, rely to a large extent on active safety systems in case of accidents or natural disasters, rather than the passive safety systems built into the new designs.
- *Options for the entire spent fuel management system* – on-site storage, consolidated long-term storage, geological disposal – will be reevaluated. This will be based both on what we learn from the Fukushima investigations about the spent fuel behavior under accident conditions to a broader imperative to rationalize our overall SNF management system.

The consequences of such outcomes could be very significant for nuclear power and for the entire energy system. We shall selectively address some of the associated issues.

Cost

Currently operating nuclear plants would face an expensive proposition to retrofit if design threats are elevated substantially. On the positive side, nuclear power plants have low operating and fuel costs compared with coal and natural gas plants, and the owners might be able to absorb reasonable costs. However, the business decisions would be on a plant-by-plant basis depending on the design basis threat assigned to the plant's specific circumstances (e.g., seismic). In many cases, perhaps most, the design basis threats are likely to be deemed sufficiently conservative and remain unchanged. The regulatory decisions about safety requirements can be assisted by application of new capabilities, such as advanced large-scale modeling and simulation. The first of DOE's innovation hubs, located at Oak Ridge (with MIT as a major partner) is dedicated to developing related computational tools over the next several years.

Other types of retrofits could be more easily absorbed into normal operations. For example, there has long been a discussion of transitioning to silicon-carbide fuel cladding in order to gain higher safety margins and other operational benefits as well. The cladding can be formed into the same size and shape as zircaloy cladding used in currently operating reactors but has much less reactivity with steam (this was the source of the hydrogen in the Fukushima loss-of-coolant situation). But, long after this was proposed and investigated, we are still several years from evaluation in commercial reactors, and widespread adoption will take many more years. This timetable reflects a history of underfunded R&D programs that have been poorly aligned with strategic priorities. Last year's DOE R&D roadmap is a step in the right direction.

New nuclear power plants are already challenged by high capital costs, and increased capital and operating costs could tip the balance for many projects, depending on many financing and cost recovery factors. The costs are illustrated in the table showing levelized electricity costs for new plant construction. This is taken from a 2010 MIT report on the Future of the Nuclear Fuel Cycle. Today's natural gas prices are in the \$4-5/MBtu range, making natural gas plants much more economical with respect to both capital requirements and levelized electricity cost. However, we have been through many significant excursions in natural gas prices over the last decade, resulting in caution about committing to only one fuel source. The generation portfolio decisions are likely to be different in different parts of the country according to the integrated resource planning methodology of public utility commissions, the availability of infrastructure, the ability to incorporate costs into a rate base, generation portfolio standards, and state/regional carbon dioxide emissions requirements.

COSTS OF ELECTRIC GENERATION ALTERNATIVES (2007\$)

	Overnight cost (\$/kW)	Fuel cost (\$/MBtu)	Levelized cost of electricity (cents/kW)		
			Base case	\$25/ton-CO2 price	Same cost of capital
Nuclear	4000	0.67	8.4	8.4	6.6
Coal	2300	2.60	6.2	8.3	
Gas	850	4/7/10	4.2/6.5/8.7	5.1/7.4/9.6	

Modest carbon dioxide emissions charges would make nuclear competitive with coal. A major factor is the cost of capital, which hits nuclear power plant construction particularly hard because of the high capital costs and the longer construction times that are typically required. *Reducing the financing risk premium for nuclear power is a major objective of government support for “first mover” nuclear power plants, principally through the loan guarantee program first put in place in the Energy Policy Act of 2005. The events of Fukushima clearly do not help in this regard.*

An entirely different approach to new nuclear power plant construction lies with small modular reactors (SMRs). This could be a powerful way to address the cost issue. SMRs come in a variety of proposed forms, some based on the same underlying light water reactor (LWR) technology that is used in almost all nuclear plants today, while others are based on gas or metal cooled designs. They range in size from ten to three hundred megawatts. None have been through a licensing procedure at the Nuclear Regulatory Commission, and this is a time consuming process for any new nuclear technology – especially those that are farther away from the NRC’s established experience and procedures.

A major advantage of SMRs is that their small size compared with LWRs (whose size is typically 1000 Megawatts and now going up to 1600 Megawatts) means that the total capital cost is more in the billion dollar range rather than a significant multiple of that. Capacity can be built up with smaller bites, and this may lead to more favorable financing terms – a major consideration for high capital cost projects that take years to license and build. Still, the SMR must come in with a cost that is also competitive with LWRs on a unit basis; that is, the cost per installed Megawatt must be comparable or less. The LWRs have been driven to larger and larger size in order to realize economies of scale. The SMRs may be able to overcome this trend by having factory construction of the SMR or at least of its major components, presumably with economies of manufacturing, the ability to train and retain a skilled workforce at manufacturing locations, quality assurance, continuous improvement, and only fairly simple construction on-site. The catch-22 is that the economies of manufacture will presumably be realizable only if there is a sufficiently reliable stream of orders to keep the manufacturing lines busy, and this in turn is unlikely unless the large number of designs is winnowed down fairly early in the game. Reaching the n-th plant for a small number of reactor types is likely to require a complex interplay between government support and proponents of the many contending SMR designs.

A 2020 SMR option will be available only if we start now, and even then it will be tight. Prior to Fukushima, the Obama administration submitted to the Congress a proposed 2012 budget that would greatly enhance the level of activity in bringing SMRs to market. LWR-based technology options would be advanced towards licensing, and other SMR technologies would be supported for the remaining R&D needed to have them follow in the licensing queue. The program is modest but sensible. Obviously the Federal budget deficit makes it difficult to start any new programs, but a hiatus in creating new clean energy options – be it nuclear SMRs or renewables or advanced batteries – will have us looking back in ten years lamenting the lack of a technology portfolio needed to meet our energy and environmental needs economically or to compete in the global market.

Relicensing

Relicensing decisions at the NRC will almost certainly experience some delay. A measured approach is appropriate since the NRC is constantly monitoring plant operations and safety margins; the 40 year licensing period does not represent any particular milestone with regard to the reactor systems themselves.

If the anticipated life extensions are not realized to any appreciable degree, we will be faced with replacing tens of thousands of Megawatts of non-emitting generation. For the U.S., this is not an immediate problem since the end of the original forty-year reactor operating periods will not be reached for most plants for a while, and we have both substantially underutilized natural gas generation and lots of natural gas. Natural gas does have emissions, but far less than coal, and will serve as a bridge to a very low emissions future. However, the challenge of developing and demonstrating “no-emissions” options for 2020 and beyond is immediate, given the significant timeline from R&D to regulatory approval to market.

Next generation nuclear plants with advanced passive safety systems are among those options. This includes, but is not limited to, SMRs. The fact remains that nuclear power is the “emission-free” baseload generation technology that is, in principle, scalable without problems of variability and intermittency. Clearly, a rigorous design certification and licensing process will be needed to assure public confidence.

Spent fuel management

The Fukushima problems with spent fuel pools co-located with the reactors will undoubtedly lead to a reevaluation of spent nuclear fuel (SNF) management strategy. There is no need to act precipitously, but the fact is that our overall waste disposal system is fundamentally broken and needs reexamination in any case (as is being done by the Blue Ribbon Commission).

The MIT Future of Nuclear Power report in 2003 and the MIT Future of the Nuclear Fuel Cycle summary report in 2010 called for *consolidated spent fuel storage* (these reports can be accessed at web.mit.edu/mitei). There are many reasons for this quite independent of the Fukushima experience. The 2010 report made a recommendation (pg xi):

“Planning for long term managed storage of spent nuclear fuel – for about a century – should be an integral part of nuclear fuel cycle design. While managed storage is believed to be safe for these periods, an R&D program should be devoted to confirm and extend the safe storage and transport period.

The possibility of storage for a century, which is longer than the anticipated operating lifetimes of nuclear reactors, suggests that the U.S. should move toward centralized SNF storage sites – starting with decommissioned reactor sites and in support of a long-term SNF management strategy.”

The consolidated storage recommendation has many drivers:

- The SNF would be stored in dry casks. There is no need for the SNF to be located at the reactor site, as the operational requirements are quite different; for example, the reactor needs access to large amounts of cooling water, while the SNF storage system does not.
- Issues such as the Federal liability for not moving SNF from reactor sites would be resolved.
- A degree of opposition to expanding nuclear power would be addressed by moving the fuel to a consolidated secure location, most likely under Federal control (this does not rule out privately developed sites under NRC license).
- While the risks of cascading failures are extremely small, the Fukushima incident showed that the probability is not zero. The spent fuel, which contains considerable radioactivity and needs cooling, would be mostly removed from the reactor site in case of major accident or natural disaster (the SNF recently removed from the reactor core would still need some cooling time in a pool).
- “Densification” of spent fuel in pools beyond the original design density should not be necessary.

The Congress should allow use of the waste fund for development of consolidated storage.

Eventually, the SNF, or the high level waste (HLW) that would result from a future decision to reprocess, would need to go to a geological repository. Indeed, the intermediate step of consolidated dry-cask storage could be eliminated if a repository were in place to accept the SNF. However, there is still a debate about whether SNF is a waste or a valuable energy resource to be harvested by reprocessing. The uncertainty has multiple origins. One is that the trajectory of nuclear power deployment is not clear. If nuclear power does not grow, it is unlikely that reprocessing will be attractive. However, even if nuclear power does grow, it is not obvious that reprocessing is the preferred path; for example, a new generation of recycling reactors might be started with enriched uranium rather than plutonium recovered from reprocessing. This uncertainty argues for maintaining options by committing to century-scale consolidated storage for commercial SNF, as recommended above, while pursuing geological repository development in parallel. The arduous and time-consuming process needed to establish and utilize one or more geological repositories for the growing amount of power reactor SNF calls for renewed commitment even as consolidated storage is established. These are core results of the MIT analysis of fuel cycle options.

Going beyond those studies, I suggest that the decision to co-mingle defense and civilian nuclear wastes should be revisited. The conditions today are much different from when the co-mingling decision was put forward in 1985. In particular, the timeline for establishing a commercial spent fuel repository is evidently much longer than anticipated at that time.

- The defense wastes are small compared with civilian wastes and are essentially bounded (there is a small amount of additional SNF each year from the naval nuclear propulsion program).
- Much of the waste is very old and therefore relatively cool.
- There is no argument about a possible energy value; all agree that it is waste to be disposed of, so there is no need to preserve options through longer term storage.
- There are agreements with the affected states to remove the fuel, and these are important for continuing nuclear defense missions at these sites.
- A separate defense repository, while still subject to NRC licensing, would have simpler finances going forward, although a reconciliation would be needed with the civilian program that recognized the defense financial contributions to the development of Yucca Mountain.
- Responsibility would reside with the DOE as a government function to dispose of waste generated in an inherently governmental enterprise – the development of nuclear weapons.
- At the same time, a future commercial SNF/HLW repository would not have the complication of dealing with national defense HLW and SNF.

The recommendation is that consolidated SNF dry-cask storage be established as soon as possible at one or a few sites for commercial power reactor fuel and that a geological repository be established as soon as possible for defense HLW/SNF. A commercial repository would be pursued in parallel, but most likely in a longer time frame given the current realities. The defense waste repository would provide invaluable knowledge and experience for the civilian waste repository.

In summary, while it is too early to understand the causes and full implications of the Fukushima events, it is not too early to start thinking about the cost, relicensing, and SNF management issues that will inevitably arise and influence the future of nuclear power. These deliberations should be carried out in a measured way.

Thank you again for the opportunity to present these views. I look forward to a discussion.