S. HRG. 112–216

# AN EXAMINATION OF THE SAFETY AND ECONOMICS OF LIGHT WATER SMALL MODULAR REACTORS

## HEARING

BEFORE A

SUBCOMMITTEE OF THE

COMMITTEE ON APPROPRIATIONS
UNITED STATES SENATE

ONE HUNDRED TWELFTH CONGRESS

FIRST SESSION

**SPECIAL HEARING**

JULY 14, 2011—WASHINGTON DC

Printed for the use of the Committee on Appropriations

Available via the World Wide Web: http://www.gpo.gov/fdsys/browse/committee.action?chamber=senate&committee=appropriations

U.S. GOVERNMENT PRINTING OFFICE

72–251 PDF WASHINGTON : 2012

For sale by the Superintendent of Documents, U.S. Government Printing Office
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# AN EXAMINATION OF THE SAFETY AND ECONOMICS OF LIGHT WATER SMALL MODULAR REACTORS

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**THURSDAY, JULY 14, 2011**

U.S. SENATE,
SUBCOMMITTEE ON ENERGY AND WATER DEVELOPMENT,
COMMITTEE ON APPROPRIATIONS,
*Washington, DC.*

The subcommittee met at 10:02 a.m., in room SD–192, Dirksen Senate Office Building, Hon. Dianne Feinstein (chairman) presiding.

Present: Senators Feinstein, Alexander, and Graham.

OPENING STATEMENT OF SENATOR DIANNE FEINSTEIN

Senator FEINSTEIN. This hearing of the Subcommittee on Energy and Water Development will come to order and I want to welcome everyone. This is an oversight hearing on the safety and economic issues for the proposed light water small modular reactor (LW SMR).

The program proposed by the administration is a major investment of taxpayer funds to help two private companies develop their designs and submit them to the Nuclear Regulatory Commission (NRC) for certification.

In today's hearing, we will look at the safety features and potential economics of LW SMRs. We may not arrive at definitive answers today to the questions that are raised. That will likely require the NRC to take action on the actual application.

However, it's important that we try to understand the potential benefits and deficits and acknowledge uncertainties to determine whether such a large investment by the Federal Government is justified.

My friend, the distinguished ranking member of this subcommittee, often talks with me about subsidies for wind energy. I look at this program and think that it appears to be one heck of a proposed subsidy.

The administration has proposed a 5-year, $452 million program to develop the designs for two LW SMRs. These designs would then be presented to the NRC for certification.

It's important to note that the program will have a cost share of at least 50 percent from industry, but this immediately raises, I think, a significant point.

I'm told that the total cost to take two designs through the proposed process will cost at least $1.5 billion. On a 50–50 cost-share basis, that would make the Federal contribution $750 million, not $452 million.

So one thing we must determine is how the administration plans to make up this difference. Will it require a higher industry cost share, say 70 percent? Will the administration choose only one design rather than two? Or will we blindly move forward hoping $300 million in additional funding will be approved by the Congress?

As with any hearing in the nuclear industry, we have to recall the recent earthquake, tsunami, and subsequent nuclear disaster in Japan. Just this morning the Japanese Prime Minister—in The Washington Post, at least—has said that he wants the country get out of nuclear power entirely.

These events have rightly caused an examination of nuclear safety internationally and here in the United States.

For me, one of the fundamental issues raised by events in Fukushima is whether multiple reactors should be collocated. The threat of high-level radiation exposure at one plant clearly compromised the ability of workers to adequately respond to events at nearby plants in the Daiichi site.

The premise of the SMR program is that utilities could start with a small number of units and then install more as funding allowed and demand necessitated. Now, how does that premise stack up against possible problems?

The Fukushima crisis also demonstrated the potential danger of storing spent fuel in pools on site, and yet the proposed SMR designs do not appear to make any improvements in this method of spent-fuel storage.

Bluntly, I'm struggling to reconcile the lessons of Fukushima with the principal design premise of SMRs, and so I look forward to witnesses addressing these issues today.

This hearing is not about spent fuel, but it's hard to have a hearing on new nuclear power without considering the issue of what we do with the waste. This country has not—and I stress not—done a good job dealing with defense or commercial nuclear waste. That's simply a fact.

Today, we have no national policy to address our commercial spent nuclear fuel, and we store it at every nuclear plant in the country in pools and dry casks for decades without end.

Yet, today we're considering investing $452 million in LW SMRs that will result in more spent fuel stored at sites with no permanent storage for waste.

By law, the Federal Government must take this waste and store it permanently but, today, the Federal Government is being sued and is making payments for lost cases because it cannot fulfill that obligation.

This is not inexpensive. The Government Accountability Office estimates that we face $12.3 billion in liability through 2020 if we fail to take the spent fuel from utilities. That's $12.3 billion of liability.

Now, that's a very deep concern and should concern every one of us in this Congress. Presumably, building new plants licensed under the SMR program would only increase this liability.

While we discuss the specific safety and economic issues of LW SMRs, I continue to view these issues with the absence of a spent-fuel policy.

I visited our two reactors in California and, candidly, I don't know how the NRC can say it's fine to keep re-racking spent fuels, adding more rods, keeping them there in California for 24 years, transferring to dry casks, most of which are designed for transportation to permanent storage, and we have no permanent storage. We have no repository. We have no regional storage. We have no permanent storage, and yet we're looking at a new start.

So I'm struggling to understand how these reactors will also be economical. The central premise I've been given is that for SMRs to be economical, they must offset the loss of economies of scale with economies of manufacturing.

If true, we need to determine how many reactors must be constructed to achieve cost effectiveness and competitiveness and how many must be sold to maintain a factory production level necessary to justify the capital investment.

The Nuclear Energy Agency, an arm of the Organization for Economic Cooperation and Development, recently released a report that said that electric power from SMRs would cost 10 to 40 percent more than large reactors.

I've been told that anywhere between 20 and 1,000 reactors would be needed to be produced in order to be economical. How many are needed to be cost effective? Clearly, a larger number makes the endeavor questionable.

I understand the University of Chicago is completing a study for the Department of Energy (DOE) on the economics of these reactors and perhaps that will provide some clarity. But, in the meantime, my hope is that representatives from the companies that are here today will elaborate on this particular issue.

Whether the companies would be selling these units in the United States or overseas, I would like to have a better understanding of what is necessary in terms of production levels to be economical and thus be a justified expenditure of Federal resources.

On our first panel today, we will hear from Pete Lyons, the Assistant Secretary for Nuclear Energy at the DOE. Dr. Lyons also, at one time, was a commissioner at the NRC.

We will also hear from Dr. Bill Magwood, a current commissioner on the NRC. Interestingly, he used to hold the position Dr. Lyons holds today.

On our second panel, we will hear from Dr. Ed Lyman from the Union of Concerned Scientists and Dr. Ernie Moniz of Massachusetts Institute of Technology. Both of these have spent time considering the merits of SMRs.

The second panel will also feature Mr. Jim Ferland from Westinghouse, Mr. Christofer Mowry from Babcock & Wilcox and Mr. Paul Lorenzini from NuScale. These gentlemen represent three companies interested in pursuing the cost-shared program, but I understand there may be other companies interested as well.

So I look forward to everyone's testimony, and even more so to the question-and-answer period and I thank everyone for coming.

Now, I'd like to turn to our distinguished Ranking Member, Senator Alexander.

OPENING STATEMENT OF SENATOR LAMAR ALEXANDER

Senator ALEXANDER. Thanks, Madam Chairman, and thank you for the way you're approaching this hearing in your typical style, which is straightforward and with a fair presentation and an attempt to get the answers. I appreciate that very, very, very much.

As the chairman said, we're talking about a 5-year, $452 million program that will end up with two SMRs operating by 2020. And, as she said, we're talking about LW SMRs.

We know how to build and operate LW SMRs. The NRC knows what they are. All 104 of our big, commercial reactors are LW SMRs, and these are smaller versions of those.

I believe we need to move ahead with this program of research and development as quickly as possible if we want to get to the 2020 timeline.

The goal should be are these designed to be safe? Can exporting our technology that is safe around the world make the world safer, keeping nuclear materials out of the hands of people who shouldn't have them? And, third, is this a useful way to promote clean electricity in a country that uses nearly 25 percent of all electricity in the world?

Talking about safety first, it's a subject we take very seriously. I believe we have the best regime of making reactors safe in the world. We certainly have the best record. No deaths ever, either at our Navy reactors or at our commercial reactors. No one was even hurt at Three Mile Island, our big nuclear accident. No one was hurt at that. No other form of energy has that record.

So the NRC's review of the design and licensing will help us know whether they themselves are safe and the places they will be located are safe, and I'm very interested in that result.

There are several questions that I'll be interested in hearing more about. I'm told the passive design of the systems, which means they'll work automatically without using any device that could fail in the event of an accident, will make them perhaps safer.

The problems at Fukushima with nuclear power all had to do with no water, no electricity to pump the water to cool the reactors.

We're not the only country in the world that is interested in small nuclear reactors. There are at least five or six other countries that are moving ahead with them—Russia, China, France, South Korea, Argentina, and Japan.

If we don't, arguably, the world will be deprived of our safety regime and our technology, and we'll be deprived of an industry that will make it easier and cheaper for us to create private-sector jobs by new ways to have low-cost, reliable, clean electricity.

It's important to note there are now 60 countries that are considering introducing nuclear power to their power grids. South Korea is helping the United Arab Emirates build reactors. I would argue that the world needs our technology and our safety standards as much as we do.

My final point is this: The Energy Information Administration estimates that electric consumption in the United States will rise by more than 20 percent by 2035. Where will that electricity come from?

We know where it comes from now—nearly one-half coal, 20 percent nuclear power, 20 percent natural gas, and a very small amount from renewables.

Most of us believe we need clean electricity, and we know where that comes from—67 percent nuclear power, .10 of 1 percent from solar, a little less than 8 percent from wind. So any new way to safety and inexpensively create new options for nuclear power, I would argue, is something we should treat seriously.

The Tennessee Valley Authority has recently said it would close a number of coal plants, 18 of its coal plants. What will it replace them with? It will still have coal—35 percent—but it'll be going up to 40 percent nuclear power. That's really its only option, other than natural gas, and we've seen the natural gas prices go up and down over the years.

So because of our safety record, because of the opportunity that it presents for an American business, because of the lower cost and the possible improved safety standards, even though the reactors we now have are safe, I think this is a promising opportunity and I welcome the chairman's decision to hold this hearing to consider whether to go ahead.

I would make these points, if I may, in commenting on what Chairman Feinstein said. In terms of used nuclear fuel, I agree with her. We badly need a place to put, in the end, used nuclear fuel. But all the used nuclear fuel we have today from all of our plants would fill one football field 20 feet deep. So it's not that much mass, but we need a place to eventually put it.

The NRC and Dr. Chu have said it is safe where it is for 100 years, and the President has appointed distinguished people to figure out how to deal with that. I think we can do it.

In terms of subsidies, my view on subsidies is we should use subsidies to jump start technologies, like offshore wind, but we shouldn't be spending $26 billion over the next 10 years to support subsidies for mature technology, which is existing wind, and the 104 commercial nuclear reactors today operate without Government subsidy.

So I would expect to hear from the industry folks whether they would expect subsidies once we get past this research and development stage.

Those are my comments, Madam Chairman. I agree with you. The questions and answers will be the most important part of this, and I thank you for the balanced cast of witnesses that we have and your inquiry into important questions.

Senator FEINSTEIN. Thank you very much, Senator. I very much appreciate your comments and really look forward to working with you, as we always have.

Senator ALEXANDER. Thank you.

Senator FEINSTEIN. Mr. Secretary, can we begin with you, Secretary Lyons?

**STATEMENT OF PETER B. LYONS, ASSISTANT SECRETARY FOR NUCLEAR ENERGY, DEPARTMENT OF ENERGY**

Dr. LYONS. Thank you, Chairman Feinstein, Ranking Member Alexander and Senator Graham. Thank you very much for the opportunity to appear before you today to discuss SMRs and the administration's request to begin a cost-shared program to accelerate the certification and licensing of LW SMRs.

The Department believes that SMRs have the potential to provide our Nation with clean, cost-effective energy, improved safety and an opportunity to compete in the global clean-energy marketplace.

In my written testimony, I address the role of nuclear power to provide the Nation with clean, safe energy and the strong support from the administration to increase utilization of nuclear power.

I also noted that the capital investment in large plants makes it very, very difficult for utilities to move ahead with them. SMRs offer a chance to change that paradigm by providing power in increments that may better fit utilities' fiscal constraints.

In my oral comments today I'll just focus on a few of the issues that are sometimes raised with SMRs.

In general, enhanced safety is easier to achieve in smaller reactors as many design challenges are simplified when reactor size is reduced.

Current SMR designs offer notable safety advantages, including passive safety features that minimize the need for prompt operator actions in any upset conditions. In addition, these SMRs utilize so-called integral designs resulting in a much lower susceptibility to a loss of coolant accident.

You'll hear from some prospective vendors in the second panel about a host of innovative approaches that they are including to significantly enhance SMR safety and security.

For example, features like underground siting offer increased resistance against seismic events while also providing for more robust security. SMRs are also designed for long periods of unattended operation under accident conditions.

Some have suggested that SMRs can only succeed if safety and security requirements of the NRC are weakened. Such statements, I think, confuse weakened safety or security with the reality that the character and risk presented by SMRs may enable identical or enhanced safety and security to be addressed with alternative prescriptions, and, in any case, licensing of any SMR would be considered through the normal, rigorous, open, transparent processes of the NRC.

Concerns have also been raised about the potential proximity of multiple SMR modules and the potential that any concern with one module might affect the safety of other modules.

These modules are being designed such that their safety systems are completely independent, but, again, the NRC will address any potential common failure mode as the licensing process progresses.

And, finally, I'd like to just very briefly address the intertwined issues of global competitiveness and global security. Innovative technologies certainly contribute to our Nation's global competitiveness providing good jobs for American workers.

As Secretary of Energy Steven Chu noted in his Wall Street Journal editorial about SMRs: "If we can develop this technology in the United States and build these reactors with American workers, we will have a key competitive edge."

As part of a robust, nuclear industry supply base in the United States, SMRs may also contribute to our national security interests by helping to increase the global reach of U.S. nuclear technology.

The nations that export and build the majority of nuclear power plants will strongly influence safety standards for the world. A strong U.S. presence in the global marketplace will allow U.S. safety standards to be adopted more broadly around the world while also improving the ability of the United States to influence decisions about waste management and nonproliferation.

PREPARED STATEMENT

In conclusion, while there are significant uncertainties in the future competitiveness of SMRs, the DOE's proposed LW SMR licensing tech support program would address those uncertainties to enable a demonstration of their market potential.

The United States is by no means the only country exploring these technologies. Some countries are already licensing or building SMRs. In my view, SMRs represent our best and perhaps our only option for regaining a larger share of the nuclear technology global market.

Thank you and I'll look forward to your questions.

[The statement follows:]

PREPARED STATEMENT OF PETER B. LYONS

Chairman Feinstein, Ranking Member Alexander, and members of the subcommittee, thank you for the opportunity to appear before you today to discuss small modular reactors (SMRs) and the administration's request to begin a cost-share program to accelerate the certification, licensing, and deployment of light water (LW) SMRs. The Department believes SMRs have the potential to provide our Nation with clean, cost-effective energy, improved safety, and an opportunity to compete in the global clean-energy marketplace.

Today in the United States, nuclear power provides about 20 percent of all electricity consumed. It accounts for 70 percent of our carbon-free electricity. And it has demonstrated an outstanding safety record. Many attributes of our nuclear power operations contribute to this record, starting with independent regulation from the Nuclear Regulatory Commission (NRC). In addition, industry groups such as the Institute for Nuclear Power Operations (INPO) help maintain robust operational excellence in the industry. The NRC provides the necessary regulatory enforcement and INPO relies on peer evaluation, peer pressure, information sharing among operators, and financial incentives. Our combination of efforts has established the international "gold standard" for nuclear operations.

President Obama has repeatedly emphasized the importance of clean energy to our Nation's future. During his State of the Union Address earlier this year, he outlined a goal of obtaining 80 percent of our electricity from clean-energy sources by 2035. It's an ambitious goal. And as he noted, we're going to need all clean-energy sources—including nuclear energy—to achieve that goal. As the President has said, "To meet our growing energy needs and prevent the worst consequences of climate change, we'll need to increase our supply of nuclear power. It's that simple."

The reactors being considered by utilities today are in the gigawatt (GWe) class—meaning they provide at least 1,000 megawatts of electrical power. These are large plants and the size of the investment to build them is correspondingly large. A new, GWe class nuclear powerplant requires an investment on the order of $6 billion to $10 billion, which poses a challenge even to large nuclear utilities whose market capitalizations are around $19 billion. A major rating agency has characterized this kind of investment as a "bet the farm" endeavor for most utilities. Certain polices can help mitigate some of this risk, but construction of such plants remains a significant financial risk for a utility.

THE CASE FOR SMRs

SMRs may provide an alternative to these larger plants that overcomes some of these challenges. Because we expect that they would be built in factories in a mass production format, SMRs could achieve cost savings through replication, rather than relying upon the economies of scale for larger reactors built individually at each construction site. Of particular note is the prospect for driving down costs over time through the process of learning-by-doing in a factory setting with an experienced workforce. The Department anticipates that SMR powerplants will be able to be purchased in smaller sizes that better fit the financial needs of the utilities, and generation capability could be expanded to meet demand.

For this business model to work the economics of factory fabrication will need to prove successful and that is still uncertain. Based upon the experience of cost savings in the U.S. Navy submarine program or in the aerospace industry, there is reason for optimism that these learning effects can be substantial, but it is unproven for this application.

Operational efficiencies may also be possible for SMRs, but the NRC will determine if any such possibilities are acceptable without compromising safety or security. For the SMR business model to be viable, an improved economic case must materialize. The proposed DOE light water reactor (LWR) SMR Licensing Technical Support program will focus on engineering support related to design certification and licensing for two LWR-based SMR designs through cost-shared arrangements with industry partners, which is expected to help to reduce some uncertainties and increase the potential for reducing costs over time.

To understand these issues, the Office of Nuclear Energy has supported a study on the economics of nuclear energy with a particular emphasis on SMRs. This report is currently undergoing review, but one of the anticipated findings is that a mature SMR industry will likely be competitive with natural gas generation. The smaller upfront capital investment should reduce the financial risk of the projects, but more work is still needed to reduce the uncertainties around the construction costs for SMRs over time.

SAFETY FEATURES OF SMRs

The Department anticipates that enhanced safety can be more readily achieved in small reactors. Current SMR designs offer notable potential safety advantages. LW SMR designs proposed to date incorporate passive safety features that utilize gravity-driven or natural convection systems—rather than engineered, pump-driven systems—to supply backup cooling in unusual circumstances. These passive systems should also minimize the need for prompt operator actions in any upset condition. Some concepts use natural circulation for normal operations, requiring no primary system pumps. In addition, many SMR designs utilize integral designs, meaning all major primary components are located in a single, high-strength, pressure vessel. That feature is expected to result in a much lower susceptibility to certain potential events, such as a loss of coolant accident, because there is no large external primary piping. In addition, LWR SMRs would have a much lower level of decay heat than large plants and therefore require less cooling after reactor shutdown.

Vendors are proposing an additional host of innovative approaches to significantly enhance SMR safety and security. For example, features like underground siting can offer increased resistance against seismic events while also providing more robust security. These systems are also designed for long periods of unattended operation under accident conditions and no emergency diesel generators are required for several of the designs. Several of the concepts rely only on stored energy in an accident, so that there is no dependence on external power sources. And these are only a sampling of the enhanced safety features that could potentially be part of these systems.

The NRC—through their rigorous, open, and transparent process—will determine the precise requirements for future SMR deployment and issue any future licenses. In that process, the NRC will evaluate whether the smaller size and anticipated improved safety and security envelope enables adequate safety and security with somewhat different operational mandates than those applied to the large plants.

SAFETY OF MULTIPLE MODULES

Some have raised questions about safety of multiple modules at a site and whether a serious problem in one module might affect the safety other modules. The NRC will address any common mode failures and many more questions as the licensing process progresses. The onus will be on the SMR vendors to convince NRC that no common mode failure, including those due to natural events such as a tsunami or earthquake, could lead to a common failure of multiple modules or that a failure of one module could prevent the safe shutdown of other modules. The NRC will demand, as they do for any design, that the safety case proposed by SMR vendors be subjected to intense study and evaluation, both within the NRC staff review and through their standard, extensive, public opportunities for participation in the licensing process.

### FUEL

The SMR concepts of near-term interest are based upon the well-understood LWR technology. This is important because our current regulatory knowledge base and experience are built on LWR technology. The choice to stay within the proven performance envelope of the existing commercial, low-enriched uranium, nuclear fuel cycle has two important benefits. First, it means that the most promising near-term SMRs can build upon the well-established LWR fuel industry, avoiding the need to establish a parallel fuel manufacturing capability. Second, this fuel cycle minimizes the technical risk of the most demanding technology component of any new nuclear reactor system, a new fuel design, and reduces the time to license within the NRC regulatory system.

### WASTE MANAGEMENT

For the LW SMR designs that would be considered in the Department's proposed program, the amount of electricity produced per kilogram of waste will be about the same as for current LWRs since these units utilize very similar, and very well-understood, technologies. But in contrast to the current fleet of plants where used fuel pools were not initially designed to hold a lifetime of used fuel, most current LWR SMR concepts propose storing the used fuel underground where it may be more easily protected from external hazards or sabotage. Provisions have also been incorporated in the current SMR concepts to provide long-term cooling so that the used fuel remains safe under potential upset conditions.

In the longer term, after the operational lifetime of an SMR, a used-fuel management program will be essential, just as it is for the current fleet. This question of used fuel disposition is currently the subject of examination by the Blue Ribbon Commission. The Department is eagerly awaiting their recommendations to inform the administration as it develops a strategy on used fuel management. Used fuel from newly deployed SMRs should not need another storage location during the plants' operational lifetime.

### SITING

Traditional siting of large nuclear power stations has primarily been limited to locations that have abundant water for cooling, sufficient demand to justify the size of the plant, transportation capabilities suitable to handle the very large components, and other defining attributes that limit the places where large plants are feasible. While these factors will continue to be considered in the siting of SMR plants, the draft designs of most LWR SMRs may be able to overcome these limitations with reduced cooling water requirements, the ability to tailor the generation capacity to meet the needs of the local market, and more flexible transportation options based on transport of much smaller components to any site. Hence, new SMR designs could potentially open up new markets to nuclear, a step that could be useful for meeting our clean-energy goals.

Some have taken these design features to imply that SMRs could be sited without due consideration of safety and security. Nothing could be further from the truth. The NRC remains the regulatory authority that must license any commercial reactor including an SMR and their review will be no less thorough for SMRs than it has been for the existing plants.

### ADVANCED R&D

DOE also proposes to support the development of advanced small reactor concepts that depart from the well-known LWR technology base. These advanced SMRs are in the very early development stage, but have the potential to greatly increase the amount of electricity produced per kilogram of waste. Such systems could increase uranium utilization through the use of long-lived cores, for example, which may also have nonproliferation benefits. Moving beyond LWR technology would allow for systems that are better suited to serve markets that are not practical for the current reactors, such as the use of nuclear energy for process heat or transportable deployments. The fuel cycles for these advanced reactors could also open the possibilities of long-lived cores or could enable transmutation of elements in used fuel.

The R&D performed today will establish the knowledge base that will be needed to inform further development of these designs by industry.

GLOBAL COMPETITIVENESS

Innovative technologies can effectively contribute to our Nation's global competitiveness, which can mean good jobs for American workers. As Secretary of Energy Steven Chu noted in his editorial in the Wall Street Journal supporting SMRs, "If we can develop this technology in the United States and build these reactors with American workers, we will have a key competitive edge." As part of a robust nuclear industry supply base in the United States, SMRs may also contribute to our national security interests by helping to increase the global reach of U.S. nuclear technology.

Today, about 60 new reactors are under construction around the world. The TVA Watts Bar 2 unit is completing construction, four Westinghouse AP–1000s are in pre-construction in the United States, and four are under construction in China. By any measure, the U.S. share of the global market in terms of new reactor builds is currently small. About 26 reactors are under construction in China alone, almost one-half of the world's total. China plans substantial expansion of its nuclear power capabilities, with estimates reaching about 130–180 GWe by 2030. They intend to quickly become self-sufficient in reactor construction, and are clearly poised to take over the global lead in nuclear energy capacity in the coming decades.

This situation is in sharp contrast to the early days of nuclear power. In the 1960s and 1970s, the United States was the world leader in nuclear technologies; we invented most of the technologies and successfully implemented many of them in commercial systems. In the 1980s, virtually all U.S. nuclear plant equipment was manufactured domestically. Today, that figure is more like 25 percent. The United States still has a seat at the table internationally, but domestic deployment of this technology could lead to increased domestic manufacturing, which in turn would likely create increased export opportunities for the United States.

The Nations that export and build the majority of nuclear powerplants are expected to strongly influence safety standards for the world. If industry chooses to deploy SMR technology, it can provide an opportunity to gain a share of the global market, and more importantly, leadership in this new area of nuclear technology. A strong U.S. presence in the global marketplace will allow U.S. safety standards to be adopted more broadly around the world while also improving the U.S. position in decisions about waste management and nonproliferation.

CONCLUSION

While there are significant uncertainties in the future competitiveness of SMRs, the Department of Energy's proposed LW SMR Licensing Technical Support program will seek to address those uncertainties and provide a concrete demonstration of their market potential. But the United States is by no means the only country exploring these technologies. The recent report from the Nuclear Energy Agency of the Organization for Economic Co-operation and Development listed seven countries with strong SMR programs, some of which are already licensed or under construction.

In addition to meeting part of our own clean-energy needs, I've also tried to emphasize that SMRs could help strengthen U.S. competitiveness in the global nuclear technology market. This would not only be supportive of good jobs in America, but also directly supportive of international nuclear safety and our nonproliferation goals.

Senator FEINSTEIN. Thank you very much, Mr. Secretary.

Commissioner Magwood, welcome.

**STATEMENT OF WILLIAM D. MAGWOOD, IV, COMMISSIONER, NUCLEAR REGULATORY COMMISSION**

Mr. MAGWOOD. Thank you, chairman. Thank you, chairman and Ranking Member Alexander and Senator Graham for the opportunity to speak today.

Senator FEINSTEIN. Could you see your mike is on?

Mr. MAGWOOD. Yes, it is. I'll try——

Senator FEINSTEIN. Well, bring it a little closer please. Great.

Mr. MAGWOOD. I've provided a written statement for the record and so I'll summarize my remarks very briefly.

I also want to stress I appear today as an individual member of the NRC and will provide my personal views and perspectives and will not speak for the agency or the NRC as a whole at this particular hearing.

The various concepts known as SMRs have garnered a great deal of interest both inside the Government and in the public, and I understand this interest for all the reasons that Dr. Lyons has outlined. I won't try to repeat all those points.

These are all laudable and important interests. However, I'm sure the subcommittee will hear, over the course of the morning, that all these possibilities are really just still that, possibilities. We're really only at the very early first steps of this venture and there's much work to be done.

I wanted to highlight in my remarks today that SMRs are really not a new idea. We've been talking about this subject for quite some time. For example, the potential advantages of small reactors prompted the Government to provide considerable financial support for the development of midsize passively safe reactors in the early 1990s.

Unfortunately, these efforts proved unable to overcome the economic realities of building and operating nuclear plants, realities that tend to penalize small reactors and reward larger designs.

Thus, instead of the AP–600 and the 500 megawatt Simplified Boiling Water Reactor of the early 1990s, the market pushed vendors to increase the size of their designs.

Today, vendors offer the Generation III+ technologies based on those small systems, including the 1100 megawatt AP–1000 and the 1600 megawatt ESBWR reactor from General Electric.

So the big question is why is today different from yesterday? Well, as Secretary Lyons pointed out, the greatest difference is the fact the technology has evolved quite significantly over the years.

Having learned the lessons from the development of Generation III+ technologies and from the failures of previous small reactors, today's vendors clearly believe they have solved the riddle of small reactor economics.

Today's SMR technologies apply novel design approaches, such as integral pressure vessels that contain reactor systems and are comprised of far fewer parts. These new SMRs are also much smaller than the systems of the 1990s. This choice was made to assure they could be factory built and shipped by rail for deployment.

Importantly from a regulatory standpoint, today's SMRs also have features that could lead to very important safety benefits. For example, design concepts I've seen thus far further the advanced use of passive safety systems by applying gravity, natural circulation and large inventories of cooling water to reduce reliance on human intervention.

And those large inventories are also used to make the spent-fuel pools safer, which I think is a very important aspect of designs.

There's still a great deal of work to be done, and this is really much the same place I think we were in the 2000 timeframe when the DOE launched the Nuclear Power 2010 program (NP2010) to spur the development of the certification of Generation III+ designs, such as the AP–1000.

At that time, the level of design completeness was insufficient to enable vendors to provide utilities with reliable cost estimates. After this cost-shared work was completed, vendors and utilities were able to negotiate contracts on realistic bases.

A decade later, utilities are awaiting final regulatory approval to begin constructing new plants based on technologies advanced by NP2010.

At the same time, one often hears the industry is concerned that the NRC might make decisions that will render these new systems to be uncompetitive. In my opinion, these concerns are not well grounded in an understanding of how the NRC develops regulatory requirements.

Using security as a general example, the size of guard forces and the nature of security barriers protecting U.S. nuclear powerplants is not determined in accordance with a set formula that might somehow be applied to SMRs. The security strategies of each individual plant are designed by licensees to defend their facilities against threats postulated by NRC.

These strategies are tested on a periodic basis using force-on-force exercises, and when issues arise as a result of these exercises, licensees are obligated to make necessary adjustments. I believe this exact same process will work very well with SMRs.

Whatever else they are SMRs are power reactors. While the size of SMRs may eventually prove to have financial or implementation benefits the fact that they are small has far less significance from a regulatory standpoint than I think many expect.

That said, SMR vendors have proposed design components that, if fully realized, incorporate technologies and approaches that can have significant safety benefits and, therefore, must be considered as risk-informed regulatory decisions are made.

### PREPARED STATEMENT

At the end of the day, as the many issues SMRs present are discussed and resolved, I do not expect the decisions made by NRC will be the critical factor in the success or failure of these technologies.

More likely, the success or failure of this newest attempt to build small reactors will depend on the ability of today's vendors to avoid the pitfalls of the past.

Thank you very much. I look forward to answering your questions.

[The statement follows:]

### Prepared Statement of William D. Magwood, IV

Chairman Feinstein, Ranking Member Alexander, and members of the subcommittee, I thank you for the opportunity to speak to the subcommittee this morning. I appear today as an individual member of the Nuclear Regulatory Commission (NRC) and will provide my personal views and perspectives. I am not here today to represent the NRC as a whole or to speak for the agency.

The various technology concepts that have become known collectively as small modular reactors (SMRs) have generated a great deal of attention and interest in recent years. The prospects for SMRs have garnered considerable press coverage, significant interest in industry circles, and support from Members of Congress and the administration.

I understand this interest. For utilities, SMRs present the possibility of a new financial model for nuclear powerplant deployment—one which allows generating assets to be built and installed on a more certain and predictable basis. Utilities are also attracted by the idea that reactors could be deployed in a modular fashion, avoiding the large, upfront costs inherent to today's nuclear plants.

For vendors, SMRs are technologies that could be manufactured in U.S. facilities at lower and more predicable cost than is typical of conventional nuclear reactors. They envision large numbers of SMRs being built to meet a range of energy requirements, including the possible replacement of outdated, small coal-fired powerplants across the country.

For many Government officials, SMRs provide a means to support the revitalization of the Nation's heavy manufacturing base, providing thousands of well-paid, skilled jobs, and reducing U.S. reliance on overseas suppliers for vital energy technologies.

These are all laudable and important interests. However, as I'm sure the subcommittee will hear over the course of this morning, all of these possibilities are still just that—possibilities. We are only at the first early steps of this venture and there is much work still to do.

That is not to say that SMRs are a new idea. The conceptual benefits of small reactors have been the subject of discussion and analysis for decades, and all the potential benefits I've mentioned have been considered in the past. The potential advantages of smaller reactors prompted the Government to provide considerable financial support for the development of the mid-size, passive-safety reactors in the 1990s and to encourage the pursuit of the pebble-bed modular reactor in the early years of this century. Both efforts proved unable to overcome the economic realities of building and operating nuclear powerplants—realities that tend to penalize small reactors and reward larger designs. Thus, instead of the AP–600 and 500 megawatt Simplified Boiling Water Reactor of the early 1990s, the market pushed vendors to increase the size of their designs; today, vendors offer Generation III+ technologies based on those smaller systems—the 1,100 megawatt AP–1000 and the 1,600 megawatt Economic Simplified Boiling Water Reactor.

Around the turn of the century, both DOE and industry became interested in the Pebble Bed Modular Reactor, or PBMR. This was a small, high-temperature, gas-cooled reactor with a generating capacity of about 165 megawatts. This technology captured considerable media attention after United States companies became involved in an effort to build a commercial pilot in South Africa. However, as the high costs of the project became apparent, commercial participants began to peel away and eventually the South African project was abandoned.

All small reactor technologies of the past failed to find a way to overcome the fact that the infrastructure required to safely operate a nuclear power reactor of any size is considerable. Tons of steel and concrete are needed to construct containment buildings. Control rod drives, steam generators, and other key systems are hugely expensive to design and build. A larger plant with greater electric generating capacity simply has an inherently superior opportunity to recover these large upfront costs over a reasonable period.

So why is today different from yesterday? The greatest difference is the fact that the technology has evolved significantly over the years. Having learned lessons from the development of Generation III+ technologies and from the failure of previous small reactors, today's SMR vendors clearly believe they have solved the riddle of small reactor economics. They are presenting novel design approaches that could lead to significant improvements in nuclear safety. For example, design concepts that I have seen thus far further advance the use of passive safety systems, applying gravity, natural circulation, and very large inventories of cooling water to reduce reliance on human intervention during an emergency. SMR designs also apply novel technologies such as integral pressure vessels that contain all major system components and use fewer and smaller pipes and pumps, thereby reducing the potential for a serious loss-of-coolant accident.

Very importantly, these new SMRs are much smaller than the systems designed in the 1990s; this choice was made to assure that they could be factory-built and shipped largely intact by rail for deployment. The ability to "manufacture" a reactor rather than "constructing" it onsite could prove to be a major advantage in terms of cost, schedule reliability, and even quality control.

But will innovations like these allow this new breed of SMRs to be successful? Maybe.

Many years of work remain for SMR vendors to refine their designs and allow for the development of realistic and reliable cost estimates. This is much the same state of affairs that existed in the 2002 timeframe when DOE launched the Nuclear Power 2010 program (NP2010) to spur the development and certification of Generation III+ designs such as the AP–1000. At that time, the level of design completeness was insufficient to enable vendors to provide utilities with reliable cost and schedule estimates. After the cost-shared effort to complete more design and engineering work, vendors and utilities were able to negotiate contracts on a realistic basis. A decade later, utilities are awaiting final regulatory approval to begin constructing new plants based on technologies advanced by the Nuclear Power 2010 initiative. I understand that DOE has proposed a similar approach that is generally modeled after the success of NP2010 in order to further the development and licensing of SMRs.

At the same time, one often hears that the industry is concerned that the NRC might make decisions that will render these new systems uncompetitive. Industry representatives have voiced concern over regulatory issues such as the number of operators needed to run these reactors, the size of the security forces needed to protect them, and the requirements for emergency planning. According to these concerns, if NRC holds SMRs to the same requirements as currently operating plants, the operating costs will be too high and utilities will turn away from the potential benefits of small reactors.

In my opinion, these concerns are not well-grounded in an understanding of how the NRC develops regulatory requirements. Using security as a general example, I note that it is certainly true that NRC requires licensees to maintain significant security capabilities to protect existing nuclear powerplants from a range of potential threats. U.S. nuclear plants are protected by highly trained security professionals, many of whom have military or law enforcement backgrounds. With these people on the job, U.S. nuclear plants are the most secure, best-protected, privately owned commercial facilities on the planet. Given the threats that exist in the world today, it is essential that U.S. nuclear plants be secured in this manner.

But the size of guard forces and the nature of security barriers protecting U.S. nuclear powerplants are not determined by NRC in accordance with a set formula that might somehow be applied to SMRs. The security strategies of each individual plant are designed to defend these facilities against postulated threats. These strategies are tested on a periodic basis using Force-on-Force exercises and when issues arise as a result of these exercises, licensees are obligated to make the necessary adjustments. If, for example, the layout of a particular plant creates a blind spot that could be exploited by a potential adversary, then the security strategy must be modified to eliminate this vulnerability.

In my opinion, it would be perfectly reasonable to apply the same basic approach to SMRs. Future operators of SMRs should be required to deal with the same potential security threats as today's plants. The size and configuration of the security forces required for a given SMR should depend on what is needed to assure the protection of the facility. As issues are found, SMR operators should have the same responsibility as current licensees to close any security concerns.

From the early discussions I've had with SMR vendors, I understand that they are designing facilities that are to be largely subsurface facilities with security requirements anticipated in the choices made with regard to their configuration. I would expect to see the regulatory process credit the security benefits of design, configuration, and plant lay-out—just as it does in the case of today's plants. I therefore believe the current regulatory approach provides a reasonable framework for industry to pursue the development and deployment of small reactors.

Hopefully, this simple example illustrates what I believe is a vital point. Whatever else they are, SMRs are power reactors. While the size of SMRs may eventually prove to have financial or implementation benefits, the fact that they are "small" has far less significance from a regulatory standpoint than I think many expect. SMR concepts may have unique characteristics that prompt issues such as the size of security forces and control room operations, but the basic concepts related to the licensing of reactors should not fundamentally change as a result of the size of the reactors. That said, SMR vendors have proposed design concepts that, if fully realized, incorporate technologies and approaches that can have significant safety benefits. The application of passive safety design strategies, very large water inventories, and subsurface configurations all must be considered as risk-informed regulatory decisions are made.

The safety and security of the American people require a clear, strong, and consistent regulatory approach if the construction and operation of SMRs is to be permitted. At the same time, it is only rational to apply this regulatory approach in a graded manner that takes account of the safety and security risks presented by each design. I have been informed that the NRC staff is already working on these issues and considering how best to apply this framework to SMR designs.

While I have attempted to draw a clear line today to identify fundamental issues, there remain numerous complex regulatory decisions to be made. I still have many questions that will need to be answered. For example, what are the safety and security implications of installing single SMRs in remote locations? In the case of multimodule facilities, what measures might be necessary to assure the safety of adjacent modules should a problem occur with one reactor?

It is important to highlight the fact that industry has not yet submitted SMR applications for regulatory review. Once this is done, I'm certain that for each SMR design, there will be a public, transparent discussion about these and no doubt many other issues. In anticipation of applications that could be forthcoming in 2012 and 2013, the NRC staff recently issued a general schedule anticipating that SMR-relevant analysis, stakeholder interaction, and publication of guidance documents regarding issues such as emergency planning requirements and control room staffing will continue into next year.

At the end of the day, as these issues are discussed and resolved, I do not expect that the outcomes of decisions made by NRC are likely to be the critical factor in the success or failure of SMRs. More likely, the success or failure of this newest attempt to build small reactors will depend on the ability of today's SMR vendors to avoid the pitfalls of the past.

Thank you for your attention.

## FEDERAL SUBSIDY FOR NUCLEAR POWER

Senator FEINSTEIN. Thank you very much.

I have a question. In 2005, the Congress enacted legislation creating a 2-cent-per-kilowatt-hour subsidy for the first eight newly built nuclear reactors in our country. So there's an existing tax subsidy for nuclear power, and it's the same subsidy that wind power gets in value, as I understand it.

The new plant being built in Georgia will claim this subsidy, but seven more plants will take it into the future. If those plants are SMRs, then they will get a subsidy. Is that correct, Secretary Lyons?

Dr. LYONS. Senator Feinstein, I believe that is correct. I would need to reread exactly the wording as to whether there was an expiration date on the production tax credit, but the 1.8-cents-per-kilowatt-hour that you described, yes, that is correct. It is limited per plant.

## SAFETY AND LOGISTICS OF CLUSTERING REACTORS

Senator FEINSTEIN. It is my understanding that these plants on their own are not cost effective and that the eventual plan is to cluster them, so that you cluster 6, 7, maybe 10, maybe 15 of them together, again, without permanent waste disposal, with waste remaining on the site. As you look at that, do you find that to be in the best interests of this country?

Dr. LYONS. As I noted in my written and oral comments, Senator, the plants are designed to be completely independent, from a safety standpoint, between modules. That has to be verified by the NRC. The vendors will need to convince the NRC that that is the case.

In addition, the underground siting, which can be well hardened, the large quantities of water, as Commissioner Magwood mentioned, and the substantially enhanced safety features of these smaller units, yes, I think we can end up with a very effective safety case. But it remains to be verified or not verified by the NRC.

Senator FEINSTEIN. Are you saying then that lining up 5 or 10 or more SMRs is safer than one 1,100, 1,200 megawatt plant?

Dr. LYONS. I'm saying that the NRC will evaluate however many modules are at a site from a safety perspective just as they would evaluate the safety of a single unit. And to the extent that the vendor can demonstrate to the NRC's acceptance that that is achieved, then, yes, they can proceed.

NEED FOR FEDERAL APPROPRIATION

Senator FEINSTEIN. Okay. Your Department is proposing this $452 million program to pay one-half the cost of licensing, yet the firms before us today seeking this help are extremely financially capable. B&W, for instance, had revenues exceeding $2.6 billion in 2010.

In other parts of our economy, we don't invest Federal dollars to pay for private industry to obtain a safety license. We don't help Ford comply with the crash test, nor do we pay Boeing to obtain FAA certification.

I don't understand why it's necessary for the taxpayers to pay one-half of the cost of licensing. I just said it is likely that they will get a subsidy. Now, in addition to that, we're going to pay one-half the cost of licensing?

Dr. LYONS. The NP2010 program was a 50–50 cost share and I think highly successful. As part of the competitive solicitation that we will put out for these plants, we will give preference to situations where a vendor comes in with greater than a 50–50 cost share. So I don't know what the cost share will actually end up being until we have gone through the procurement process.

But I am quite confident that, looking at the number of countries that are moving ahead rapidly with SMRs, that if we want to see this country competing at the table for those opportunities that we do need to provide Government encouragement to take some of the first-mover costs of exploring whether this model—and there is uncertainty in this model—but whether this model of relying on manufacture in factory settings, can result in sufficient economies-of-scale to gain a competitive system.

Senator FEINSTEIN. Would you agree that taking two SMR designs through design certification will cost at least $1.5 billion? That means the Federal cost share at 50–50 would need to be $750 million, not $452 million. Do you agree with that? If not, why not?

Dr. LYONS. Until we have gone through the procurement process, I don't know what those numbers will be.

If you look at NP2010, for the two designs, you would end up with numbers right in the range that you are describing. Those were for different systems. They're much larger systems, and exactly how the overall costs for the gigawatt class can be compared to the smaller units, I don't know until we go through the procurement process.

And, in any case, I indicated that we will give preference to companies that can depart from the 50–50 cost share.

SPENT-FUEL MANAGEMENT

Senator FEINSTEIN. My final question: Why should the Government fund a new reactor design instead of investing in additional R&D to help find solutions to the waste issue?

Dr. LYONS. Our research portfolio, I believe, has a balanced approach based on the resources that your subcommittee and others are providing to us. We certainly have strong programs looking at a range of different approaches to management of used fuel.

We also are awaiting—and we won't be waiting much longer—for the interim report of the Blue Ribbon Commission (BRC), which I'm hoping will provide useful guidance to the administration, and to the Congress to help to move toward what you indicated the country so needs, which is a comprehensive policy on used-fuel management.

CONCERNS RAISED IN LIGHT OF JAPANESE NATURAL DISASTER

Senator FEINSTEIN. I would like to make a comment and then I'd like to turn it over to the ranking member. I have a hard time with a new start before we have any permanent method of fuel storage. It just seems that it is not the right thing to do for safety reasons.

I was profoundly impacted by Fukushima and the Daiichi issues that have come up, and I think we haven't seen the end of reaction yet. You know, this was at the time the grouping of large reactors together. Now, with no permanent fuel safety, we're proposing, well, maybe we won't do large ones. Let's do small ones and let's group them together. But the bottom line is we still have no permanent spent-fuel site.

To me, that is putting the cart before the horse. I think we have to assure people that the waste can be taken care of. We have a permanent site. We have regional sites. The Government is monitoring it. It is safe. We can't say that to people, and we've got $13 billion in liability for not doing it.

Dr. LYONS. You just said that was a comment. Do you want me to respond or——

Senator FEINSTEIN. Sure. Spice it up a little.

Dr. LYONS. No, I will agree with many of your comments, but we are waiting for the BRC. Many of the suggestions you have made are incorporated within at least the subcommittee recommendations of the BRC. It remains to be seen what the full committee report will be, and it remains to be seen how the administration and the Congress will respond to that report.

But I think a very key point with the SMRs is that the spent-fuel pools for the SMRs are in hardened underground enclosures with very, very large quantities of water. These are extremely robust systems designed to hold fuel for many decades.

When the fuel eventually emerges from underground, it certainly could go in dry casks, but we're also looking at a time probably at least 2050, 2060, something like that. I would sincerely hope that the actions of the BRC, the actions of the administration and the Congress will have us well on the path to used-fuel solutions well before then.

Senator FEINSTEIN. I hope so, too. Thank you, Mr. Secretary, Senator.

Senator ALEXANDER. I'll defer to Senator Graham since he didn't have an opening statement.

Senator GRAHAM. Well, I want to thank the chairman and the ranking member for having this hearing. This is a great debate, long overdue.

Mr. Lyons, I've had the pleasure of meeting with you several times. Do you agree with the general statement that the world is passing us by as Americans when it comes to nuclear technology development?

Dr. LYONS. I'm afraid, Senator Graham, that you would reach that conclusion from any number of indicators.

Senator GRAHAM. As a matter of fact, in the last 30 years, we haven't built a reactor and we're trying to build the first one in 30 years. Is that correct?

Dr. LYONS. It's more than 30 years since the last one was licensed.

Senator GRAHAM. I stand corrected.

So to my really good friend from California who is very smart and has asked a lot of good questions.

Senator FEINSTEIN. Uh-oh, something's coming.

Senator GRAHAM. Something's coming. That's right.

NUCLEAR WASTE REPROCESSING

The point of not having a storage plan is that we don't have a plan at all for nuclear power. If you shut down Yucca Mountain after you've spent $12 billion and say you can't have central storage, you've got nobody to blame but yourself. The French have been reprocessing for decades. So have other countries, and we have no reprocessing plan.

Now, here's where I want to applaud the administration. The small nuclear reactor—modular reactor is the future. Either we're going to embrace it or get left behind and all the jobs that are going to be created from the nuclear power industry are going to come overseas or they're going to come here in America. We've got a chance to lead, finally.

I embrace the administration's effort to try to lead. Why should you subsidize this? Because if I'm in business, I would be very reluctant to spend a bunch of money in a country where nobody's been able to build a reactor for 30 years, we've been building airplanes all the time.

So, if I'm in the private sector, I'd be willing to pony up some money, but this is a very iffy deal because the Congress seems to be very schizophrenic. We complain about the lack of a storage plan, but we won't allow storage at Yucca Mountain and we can't reprocess. So the only alternative available to you is on-site storage. That's the problem we've created. We've got nobody to blame but ourselves.

Now, the administration has put together a blue ribbon panel. Are you familiar with that, Dr. Lyons?

Dr. LYONS. Yes, Sir.

Senator GRAHAM. All right. Here's what I'm proposing to the ranking member: Secretary Chu is, I think, one of the best Secretaries of Energy I've dealt with since I've been here since 1995. He's convinced me rather than spending billions of dollars on trying to duplicate the French PUREX system, let's spend a decade or so looking at ways to come up with a reprocessing system that's a generation or two advanced.

That makes sense to me, and I'm here to offer to the country H-Canyon at Savannah River Site as an experimental program to see how you could come up with advanced reprocessing technologies.

So to the ranking member, our choices are not new starts, current system. We've got to do both. We're going to have to lead or we're going to follow.

So I'll support the administration's efforts to come up with a new generation of reprocessing. That's going to cost money. At the same time you're spending money in developing the new reactors of the future, you have to do both. If you don't do both, you're going to get left behind on all fronts.

So, Mr. Lyons, when it comes to SMRs, the United States Navy has been doing this for a long time, haven't they?

Dr. LYONS. Yes, Sir.

Senator GRAHAM. I think an aircraft carrier is about 5,000 people?

Dr. LYONS. At least, yes.

Senator GRAHAM. Yes, or more. So the concept works. Now, whether or not we can get it for a city of 100,000, that's what you're trying to do. So on the nuclear waste storage front, I think it was a mistake to shut down Yucca Mountain, but I don't see that changing any time soon.

So what I would like to do is urge this subcommittee to be forward thinking, embrace the administration's suggestion to develop a waste-disposal system beyond what the French have today and encourage this subcommittee to embrace the competition to build a SMR in America.

NUCLEAR TECHNOLOGY COMPETITION

Mr. Lyons, do you believe more competition, generally speaking, is better than less?

Dr. LYONS. Yes, Sir.

Senator GRAHAM. So rather than having two sites that could develop this technology, I would urge you to think outside the box and there are a bunch of companies out there who are dying to get into this business. There are a bunch of sites, like Savannah River Site, Tennessee Valley Authority (TVA) and other places, Oak Ridge that would love to be able to show the country we can do this safely. So would you consider more competition rather than less if the Congress gives you the go-ahead?

Dr. LYONS. Certainly, we will be following the direction of the Congress, Sir.

Senator GRAHAM. Okay. Now, my time is about up. Do you agree that we have to do two things at once? We have to come up with a way to reprocess beyond the French. And, at the same time, we have to invest in new starts, because, if we don't, America is going to lose a golden opportunity to create jobs and lead the world when it comes to clean energy.

Dr. LYONS. Senator, I'll agree if you'll let me rephrase it ever so slightly.

Senator GRAHAM. You certainly can.

Dr. LYONS. I very much agree we need to continue with new starts on power reactors. I would hope that instead of mandating that we move ahead with reprocessing that we could mandate that we move toward a comprehensive fuel management program for the country which may well include reprocessing, and that, to me, should be the subject of the research programs of the BRC output. There are——

Senator GRAHAM. But we have to do both at the same time. But we have to deal with the waste-stream situation as well as new starts. You can't pick one over the other?

Dr. LYONS. That is the intent of the research program in my office and that is what we will continue to do assuming it is funded by——

H-CANYON

Senator GRAHAM. Final question. Do you see H-Canyon as a national asset when it comes to being able to figure out what kind of waste disposal systems to adopt in the future?

Dr. LYONS. H-Canyon is very much a national asset, and, as you know, Senator, we're in the process of evaluating ways in which H-Canyon can contribute to research in used-fuel management.

Senator GRAHAM. Well, I applaud your efforts.

And, Mr. Magwood, I'm sure you've enjoyed these conversations. Do you believe as an individual member of the board that the country should lead when it comes to SMR because it is indeed the future of nuclear power?

Mr. MAGWOOD. Well, certainly, from an NRC standpoint, I don't think we're in a position to encourage one way or the other whether we lead in those technologies or not.

What I can say is that we're going to be prepared to deal with whatever applications come before us, and I can assure you that the staff is very eager to take on the new challenge that these technologies present.

Senator ALEXANDER. Thank you, Senator Graham.

Senator Feinstein had to take a call. I hope she would hear the answers to some of these questions, but we can go back over them in a little time.

ON-SITE SPENT-FUEL STORAGE

Mr. Magwood, has the NRC made a decision about whether it's safe to store spent fuel on site?

Mr. MAGWOOD. Yes, the NRC has issued a waste-confidence determination—in fact, we did it just late last year—indicating that spent fuel can be stored safely on site for up to 60 years past the licensed life of a reactor.

Senator ALEXANDER. Up to 60 years. And that's a determination by the NRC.

Mr. MAGWOOD. Yes.

Senator ALEXANDER. The chairman of the NRC has testified that spent-fuel rods can be safely stored on site for——

Senator FEINSTEIN. 100 hundred years.

Senator ALEXANDER [continuing]. 100 hundred years. And Dr. Chu has said the same.

Mr. Magwood or Mr. Lyons, do either of you have—my understanding of the President's BRC to study used nuclear fuel is that while we safely store this material on site, which—I mean, it's the job of the NRC to decide whether we can or not, and they have repeatedly said we can. And the amount of mass we're talking about is about one football field worth of material 20 feet deep.

Do you think it's likely that within the next 10 to 20 years that we'll come up with new and better ways to recycle used nuclear fuel in a way that doesn't isolate plutonium and that reduces the mass even further? Either of you want to comment on that?

Dr. LYONS. Well, certainly, Senator, the research programs within our fuel cycle R&D program are focused on exploring more advanced approaches than PUREX toward used-fuel management.

At the same time, we're definitely not ruling out variations on the—cycle that we have now. And, again, the BRC will provide advice very soon now—July 29 being the deadline—on their views for how to move ahead with an effective used-fuel management program for the Nation.

Senator ALEXANDER. So where we really are is that the people who are in charge of looking at the safety of nuclear power and have so far presided over a system where there's never been a death in a commercial reactor and where no one was hurt at Three Mile Island and they have been so effective in looking at safety that we haven't been able to build any for 30 years, they've said that we can store it safely on site for 60 years.

And the President has said—he's appointed a distinguished commission to say let's look carefully at the very best ways to recycle used nuclear fuel as a way of reducing any proliferation risk and reducing the mass.

I want to go to a couple of points that the chairman raised, which I think are appropriate points, first. Madam Chairman, I agree with you that a good use of our research and development money would be to take the recommendations of the President's BRC on used nuclear fuel and do an extensive—In fact, I've described it as a mini Manhattan Project to find out the very best way to do it. And I think that's an appropriate use.

I've come to the conclusion that R&D is a proper use of Federal money and that jump starting new technologies may be and that long-term subsidies probably are not, which leads me to the subsidy point that we've gone back and forth about a little bit.

I support, for example, jump starting electric cars. The President has supported that. There's a bill in the Congress to do that, but not over the long term.

I support jump starting better batteries. I would like to see us have several of these hubs, as we've discussed, which I call mini Manhattan Projects, in recycled nuclear fuel, in batteries, in making solar cost $1 a watt to give us a jump start, but then leave it to the private sector.

And so that's the line I would draw is to say that R&D for batteries, for solar, for the first small modular nuclear reactors is appropriate. Long-term subsidies are not.

I would support subsidies for offshore wind, which we don't know how to do yet, but I don't support them anymore for the mature technology.

Mr. Lyons, for the 104 commercial reactors that are operating today, what is the Government subsidy in terms of operating cost to those 104 reactors?

Dr. LYONS. There is none.

Senator ALEXANDER. There is none. There's none at all. And we have $26 billion of subsidies going to wind power over the next 10 years. It's already committed to.

As far as the production tax credit for nuclear power, it probably won't be available to the small reactors because that production tax credit is limited to the first 6,000 megawatts. No one's getting it yet because there have been no new plants and there probably won't be small reactors in time to take advantage of it.

Mr. Magwood, I wonder if you or Mr. Lyons would have any comment on this quote by Dr. Moniz who will testify later this morning. In referring to the SMR, he said the program proposed by the administration 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 10 years lamenting the lack of a technology portfolio needed to meet our energy and environmental needs economically or to compete in the global market. Let's get on with it.

Do either of you have a comment on that?

Dr. LYONS. I am very happy to endorse Professor Moniz's comments and I have also learned over the years that one had better be very careful before one argues with Professor Moniz on an issue.

Senator ALEXANDER. Mr. Magwood.

Mr. MAGWOOD. I've trained myself not to answer questions like that since moving into the NRC. I'll let Dr. Lyons take that.

Senator ALEXANDER. I understand that, and, Madam Chairman, I thank you for the time.

Senator FEINSTEIN. Oh, thank you very much.

### COST TO FEDERAL GOVERNMENT

I have another question and I don't know whether the commissioner can explain this or Dr. Lyons can explain it, but why does it cost $1.5 billion to take this small reactor design through the NRC design process? Could even be more even with a 50–50 cost-share basis.

Mr. MAGWOOD. Well, I can start that and Dr. Lyons can certainly add to it.

I think that when—I'm not familiar with the specific number you're quoting, so I don't know what entirely is contained in that $1.5 billion, but when I reflect on NP2010, which was going on while I was at DOE, the money that was spent was not simply for licensing costs at the NRC.

A lot of the money was also spent for design and engineering work. And it was work that was necessary to make not just to answer questions from the NRC. It was work that was done to establish sufficient design detail to make negotiations with utilities viable, because before that point there wasn't enough information for utilities to make a decision.

So I think that the money that gets spent on these programs isn't just for the licensing. It's also to develop the engineering work in the background to be able to have those commercial discussions.

Dr. LYONS. The only thing I'd add to that is certainly some of the NRC questions can be very detailed and should be very detailed and do require significant engineering design for the companies to provide effective answers to the NRC, and that also—that certainly ties in with the commissioner's response.

Senator FEINSTEIN. Yes. I understand that, but these are very profitable companies. We've already established they're going to be subsidized. Now, something that I learned today is that the engineering phase is essentially going to get paid for by the Federal Government, and I have a problem with that.

You know, I'm watching everything get cut back. We're in one fierce argument over the debt limit. There isn't going to be money. We've had two continuing resolutions during the year that have cut back money, and the one thing that is going ahead without any problem so far is the nuclear stuff. Everything else is getting cut back.

It seems to me that we're in a brave new world and these are big companies. They make profits. This is going to be very profitable. It's estimated it's going to raise everybody's utility rates. To me, it's just not the best thing since sliced bread.

Dr. LYONS. Senator, if I may.

Senator FEINSTEIN. Go ahead, please.

Dr. LYONS. Whether these units will be profitable remains to be seen. There are significant first-mover costs that they are going to have to take on in order to prove whether this model can be effective.

So, certainly, I'm sure the companies that you'll talk to in a second panel are hoping to be profitable, but I think they would agree that there is substantial uncertainty in the models at this point as to exactly what will be the outcome of this.

The other point I would make is you've highlighted the large companies several times, and you've also suggested concern over the 50–50 or whether it should be more cost share.

I've been in several discussions with different folks on whether the number should be changed from 50–50. To me, it is far better to say as we are doing—that we will give preference to someone going above 50–50, but we won't put that in the demand.

If you do demand a very large industry share, you will, I think, be guaranteeing that only the large companies can compete, and some of the companies who will be sitting here in a few minutes I don't think would fit into the category of large companies. Some would. Some wouldn't.

I don't know if that response helps.

Senator FEINSTEIN. Well, it does help. It gives me something else to think about as to whether this is appropriate for the Government to do in a day when we just don't have money.

I mean, we face terrible things happening right now on August 3 and yet here's a whole, huge, new-start program that I'm trying to grasp what the public costs are. Does this add to our liability of having no permanent waste? We'll get sued; I'm sure, somewhere and have to pay for the fact that we're keeping this hot stuff in pools and in casks on site.

You know, I'm trying to, I guess, grasp the whole picture of what it means. Does it increase rates 10 to 30 percent as I'm told? Do they have to be clustered together to be cost efficient?

I think all of this goes into the decision as to whether the Government should subsidize which we're already doing, and then provide these additional funds as well, so that the Government is bearing, really, a substantial part of the cost, well more than 50 percent with the subsidy.

Anyway, those are just my humble thoughts. Do you have any comments you want to make?

NUCLEAR PLANT OPERATION SUBSIDY

Senator ALEXANDER. The only one, Madam Chairman, I think it's important that we establish as a matter of fact I asked Dr.—Mr. Lyons, is there any Government subsidy to the operation of the 104 commercial nuclear plants we have today and his answer was, "No."

Senator FEINSTEIN. That's because the subsidy was passed in 2005.

Senator ALEXANDER. That's correct. There's a production tax credit——

Senator FEINSTEIN. Two cents per kilowatt——

Senator ALEXANDER. Two cents per kilowatt hour for new nuclear plants of which there haven't been any.

Senator FEINSTEIN. Correct.

Senator ALEXANDER. Now, it's unlikely—and we can ask the others here when they come—that the new SMRs would benefit from that because under the terms of the law they'd have to be under construction by 2014 and in operation by January 1, 2021, and there'd be a limit of $175 million for that and the estimate is there might be two by then.

So there's no subsidy today for the operation of a nuclear powerplant. There is for new ones up to 6,000 megawatts. It's limited and it's unlikely, I believe, that these small reactors would benefit.

At the same time, if you'll excuse me for mentioning it again, the production tax credit for wind, a mature technology, continues through this year and next year at the rate of a couple of billion or $3 billion a year.

So we could take some of that money and use it for this promising new technology. I'd like to make a difference between jump starting new technologies and subsidizing mature technologies.

Senator FEINSTEIN. I very much appreciate that. I think that's a lot of food for thought. I think, before we get into it, we really need to think it out what it actually means, and, hopefully, the next panel will be able to add some additional clarity.

Secretary Lyons, Mr. Magwood, thank you very much for coming. Did you have a comment you wanted to make?

LESSONS LEARNED FROM FUKUSHIMA

Mr. MAGWOOD. I just want to make one comment, something you said earlier in your opening remarks—which I think covered a lot of important issues. There was one item I wanted to highlight.

You mentioned the example of the Fukushima event, and, as you know, the NRC is working very hard to deal with the lessons learned at Fukushima.

And for me personally, and I think you had the same reaction, watching the four reactors lined up and realizing that the loss of one of those reactors could lead to a very unfortunate set of cascading events certainly gives one pause when you think about the idea of having multiple reactors in one place.

One thing I'd like to say about that is that, first, I myself have a lot of questions about how these multi-module reactors will work and what the safety parameters will be and how we'll make sure that if there's a problem in one module that we'll be able to protect the rest of them and make sure that there's not a cascading event. So that's something we're looking forward to interacting with the vendors about when they make their applications.

But as we work to learn the lessons of Fukushima, whatever conclusions we reach, those conclusions and those lessons learned will be applied to every technology that ever comes before the NRC. It'll apply to the existing reactors. It'll apply to Generation III+ reactors like the AP–1000. And if they're ever approved, it'll apply to the SMRs as well. So we will apply those lessons learned well into the future. We'll not stop with what we're doing today.

Senator FEINSTEIN. Well, I very much appreciate that, and you certainly have my full support to do that. I mean, it's clear that the NRC has a big, big task in front of it.

So I thank you for being here and for representing your personal views. And I thank you, Secretary Lyons.

And we'll move on to the next panel.

Welcome, gentlemen. I wish I could say ladies and gentlemen, but this is a field that we clearly need to level in terms of female gender.

In any event, what I'd like to do is just begin with Dr. Lyman and go right down the line, and we have a very distinguished wrap-up person in Dr. Moniz.

So, Dr. Lyman, why don't you begin?

**STATEMENT OF DR. EDWIN LYMAN, SENIOR SCIENTIST, GLOBAL SECURITY UNION OF CONCERNED SCIENTISTS**

Dr. LYMAN. Good morning. On behalf of the Union of Concerned Scientists (USC) I would like to thank you, Chairman Feinstein, Ranking Member Alexander, for the opportunity to provide our views on the safety and economics of LW SMR.

UCS is neither pro- nor anti-nuclear power, but we have served as a nuclear power safety and security watchdog for more than 40 years.

The Fukushima Daiichi crisis has revealed significant vulnerabilities in nuclear safety and has shaken public confidence in nuclear power around the world.

If we want to reduce the risk of another Fukushima in the future, new nuclear plants will have to be significantly safer than the current generation. And to this end we do believe that it is appropriate for some level of support for the DOE to work with the nuclear industry to develop safer nuclear plant designs.

But we do think that that money should be directed to spend taxpayer money only on supportive technologies that have clear potential to significantly increase levels of safety and security compared to currently operating reactors.

Also, in light of Fukushima, we do believe it is appropriate for the Department to devote resources to addressing safety and security issues with the current fleet that have been revealed by the Fukushima crisis.

Proponents of SMRs claim that their designs have inherent safety features compared to larger reactors and some even argue their reactors would have been able to withstand an event as severe as Fukushima.

We find these claims to be unpersuasive. For any plan, whether it's large or small, the key factor is the most severe event that it's designed to withstand, the so-called maximum design-basis event. But unless nuclear safety standards for new reactors are strengthened, one cannot expect that either small or large reactors will be able to survive the beyond-design-basis event like Fukushima.

Although some LW SMR concepts may have desirable safety characteristics, unless they are carefully designed, licensed, deployed, and inspected they could pose comparable or even greater risks than large reactors.

Some SMR vendors argue their reactors will be safer because they can be built underground. While underground siting could clearly enhance protection against certain events, it could also have disadvantages.

For instance, at Fukushima, emergency diesel generators and electrical switched gear were actually installed below grade to reduce their vulnerability to seismic events, but this increased their vulnerability to flooding. In the event of a serious accident, emergency crews could have difficulty accessing underground reactors if intervention was necessary.

Some SMR vendors emphasize their designs are passively safe, but no credible reactor design is completely passive and can shut itself down in every circumstance without need for intervention.

Small reactors may have an advantage because the lower the power of a reactor, the easier it may be to cool through passive means, but accidents involving multiple small units may cause complications that could outweigh the advantages of having lower heat removal requirements for each unit.

Moreover, passively safe reactors do require some equipment, such as valves that are designed to operate automatically, but are not 100 percent reliable.

All passive systems will have to be equipped or should be equipped with highly reliable active backup systems in order to compensate for these uncertainties, but more backups mean generally higher costs and this poses a particular problem for SMRs, which begin with a large economic disadvantage compared to large reactors.

Given there is no apparent capital cost benefit for SMRs, we are concerned that the industry is trying to cut the potential operating maintenance costs by asking the NRC for regulatory relief for a number of requirements.

These do include reduced operator staffing for each unit and potentially reducing the number of operators that you need to monitor the safety of each individual unit. They also are interested in reducing emergency planning zone sizes and also adjusting security requirements that may end up with a reduced number of security officers.

We think one of the early lessons of Fukushima is that you need to prevent serious accidents with significant margins of safety, so now is not the time to start reducing regulatory requirements for small reactors.

Emergency planning zone should be maintained. Security certainly should be maintained, especially in light of potential increased threats following the potential for retaliation of the death of Osama bin Laden, and we believe that the multiple reactor issues will require additional enhancements to regulations for collocated units to make sure that you do not have interactions that can affect the safety of each site because of an accident its neighbors.

So all these suggest that we need to increase nuclear safety standards, not reduce them, and to the extent that that may further impact the economics of SMRs, it could be an issue for their economic viability.

Just one last point, with regard to export, we believe that SMRs should only be exported to areas where there's an established infrastructure to cope with emergencies and you can provide sufficient numbers of trained operator and security staff.

PREPARED STATEMENT

We do agree that U.S. safety standards are worth exporting, but that's exactly why we need to maintain and strengthen them rather than weaken them.

And I refer to my written remarks for more details. Thank you.

[The statement follows:]

PREPARED STATEMENT OF DR. EDWIN LYMAN

Good morning. On behalf of the Union of Concerned Scientists (UCS), I would like to thank Chairman Feinstein, Ranking Member Alexander, and the other distinguished members of the subcommittee for the opportunity to provide our views on the safety and economics of light water small modular nuclear reactors.

UCS is neither pro- nor anti-nuclear power, but has served as a nuclear power safety and security watchdog for more than 40 years. UCS is also deeply concerned about global climate change and has not ruled out an expansion of nuclear power as an option to help reduce greenhouse gas emissions—provided that it is affordable relative to other low-carbon options and that it meets very high standards of safety and security. However, the Fukushima Daiichi crisis has revealed significant vulnerabilities in nuclear safety and has shaken public confidence in nuclear power. If we want to reduce the risk of another Fukushima in the future, new nuclear plants will have to be substantially safer than the current generation. To this end, we believe that the nuclear industry and the Energy Department should work together to focus on developing safer nuclear plant designs, and that the Congress should direct the Energy Department to spend taxpayer money only on support of technologies that have the potential to provide significantly greater levels of safety and security than currently operating reactors. The nuclear industry will have to work hard to regain the public trust.

Proponents of small modular reactors (SMRs) claim that their designs have inherent safety features compared to large reactors, and some even argue that their reactors would have been able to withstand an event as severe as Fukushima. We find these claims to be unpersuasive. For any plant—large or small—the key factor is the most severe event that the plant is designed to withstand—the so-called maximum "design-basis" event. Unless nuclear safety requirements for new reactors are significantly strengthened, one cannot expect that either small or large reactors will be able to survive a beyond-design-basis event like Fukushima. Although some light-water SMR concepts may have desirable safety characteristics, unless they are carefully designed, licensed, deployed and inspected, SMRs could pose comparable or even greater safety, security and proliferation risks than large reactors.

Some SMR vendors argue that their reactors will be safer because they can be built underground. While underground siting could enhance protection against certain events, such as aircraft attacks and earthquakes, it could also have disadvantages as well. For instance, emergency diesel generators and electrical switchgear at Fukushima Daiichi were installed below grade to reduce their vulnerability to seismic events, but this increased their susceptibility to flooding. And in the event of a serious accident, emergency crews could have greater difficulty accessing underground reactors.

Some SMR vendors emphasize that their designs are "passively safe". However, no credible reactor design is completely passive and can shut itself down and cool itself in every circumstance without need for intervention. Some reactor designs—large or small—have certain passive safety features that allow the reactor to depend less on operator action for a limited period of time following design-basis accidents. Small reactors may have an advantage because the lower the power of a reactor, the easier it is to cool through passive means such as natural convection cooling with water or even with air. However, accidents affecting multiple small units may cause complications that could outweigh the advantages of having lower heat removal requirements per unit. Moreover, passively safe reactors generally require some equipment, such as valves, that are designed to operate automatically, but are not 100 percent reliable.

Operators will always be needed to monitor systems to ensure they are functioning as designed, and to intervene if they fail to do so. Both passive systems and operator actions would require functioning instrumentation and control systems, which were unreliable during the severe accidents at Three Mile Island and Fukushima. Passive systems may not work as intended in the event of beyond-design-basis accidents, and as result passive designs should also be equipped with highly reliable active backup systems and associated instrumentation and control systems.

But more backup systems generally mean higher costs. This poses a particular problem for SMRs, which begin with a large economic disadvantage compared to large reactors.

According to the standard formula for economies-of-scale, the overnight capital cost per kilowatt of a 125 megawatt reactor would be roughly 2.5 times greater than that of a 1,250 megawatt unit, all other factors being equal. Advocates argue that SMRs offer advantages that can offset this economic penalty, such as a better match of supply and demand, reduced upfront financing costs, reduced construction times, and an accelerated benefit from learning from the construction of multiple units. However, a 2007 paper by Westinghouse scientists and their collaborators that quantified the cost savings associated with some of these factors found that they could not overcome the size penalty: the paper found that at best, the capital cost of four 335 megawatt reactors was slightly greater than that of one 1,340 megawatt reactor.[1]

Given that there is no apparent capital cost benefit for SMRs, it is not surprising that the SMR industry is seeking to reduce operating and maintenance (O&M) costs by pressuring the Nuclear Regulatory Commission (NRC) to weaken certain regulatory requirements for SMRs. Deputy Assistant Energy Secretary John Kelly told the NRC in March that the NRC's regulatory requirements for SMRs will "directly influence the operating cost, which will be a large determinant into the economic feasibility of these plants."

For example, the industry argues that regulatory requirements for SMRs in areas such as emergency planning, control room staffing, and security staffing can be weakened because SMRs contain smaller quantities of radioactive substances than large reactors and therefore pose lower risks to the public. The NRC is currently considering the technical merits of these arguments.

However, small reactors will not necessarily be safer than large reactors on a per-megawatt basis. Simply put, the risk to the public posed by one 1,200-megawatt reactor will be comparable to that posed by six 200-megawatt reactors (assuming that all units are independent), unless the likelihood of a serious accident is significantly lower for each small reactor. But such an outcome will not be assured under the current regulatory regime. The NRC has a long-standing policy that new nuclear reactors—large or small—are not required to be safer than operating reactors. One consequence of this policy is that new reactor designs that have inherent safety features not present in current reactors may not actually end up being safer in the final analysis if designers compensate by narrowing safety margins in other areas, such as by reducing containment strength or the diversity and redundancy of safety systems. Any safety advantages will be eroded further if the NRC allows SMR owners to reduce emergency planning zones and the numbers of required operators and security officers.

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[1] M.D. Carelli et al., "Economic Comparison of Different Size Nuclear Reactors", 2007 LAS/ANS Symposium, Cancun, Mexico, 1–5 July 2007. Available at http://www.las-ans.org.br/Papers%202007/pdfs/Paper062.pdf.

One of the early lessons from Fukushima is that prevention of serious nuclear accidents requires significant margins of safety to protect against extreme events. Earlier this week, UCS and the NRC's Fukushima Near-Term Task Force each issued recommendations for strengthening nuclear safety requirements. Consider the following examples:

—Emergency planning zones around U.S. nuclear plants extend to a radius of 10 miles. Yet significant radiological contamination from the Fukushima accident has been detected well beyond a distance of 10 miles from the plant. In fact, radiation levels high enough to trigger resettlement if they occurred in the United States have been detected more than 30 miles away from the Fukushima site. The discussion we should be having today is whether current emergency planning zones need to be increased, not whether we can shrink them for SMRs.

—As we have seen at Fukushima, nuclear plants with multiple reactors that experience severe accidents present extreme challenges. In its June 2011 report to the International Atomic Energy Agency, the Nuclear and Industrial Safety Agency of Japan (NISA) stated that:

> "The accident occurred at more than one reactor at the same time, and the resources needed for accident response had to be dispersed. Moreover, as two reactors shared the facilities, the physical distance between the reactors was small . . . The development of an accident occurring at one reactor affected the emergency responses at nearby reactors.
>
> "Reflecting on the above issues, Japan will take measures to ensure that emergency operations at a reactor where an accident occurs can be conducted independently from operation at other reactors if one power station has more than one reactor. Also, Japan will assure the engineering independence of each reactor to prevent an accident at one reactor from affecting nearby reactors. In addition, Japan will promote the development of a structure that enables each unit to carry out accident responses independently, by choosing a responsible person for ensuring the nuclear safety of each unit."

The NRC will need to consider these issues in developing its licensing approach for small modular reactor sites, which may host two to four times the number of units present at the largest U.S. nuclear plant site today. The NRC has acknowledged that some of its current regulations and procedures do not account for events affecting multiple units on a site. For instance, according to the NRC, emergency planning regulations focus on single-unit events with regard to requirements for emergency operations staffing, facilities, and dose projection capability. Also, the NRC's guidance for probabilistic risk assessment, an analysis tool which is used in many regulatory applications, does not require the consideration of multiple-unit events. The NRC Fukushima Near-Term Task Force is recommending that emergency preparedness requirements be revised to address multi-unit events, which could have a significant impact on SMR licensing.

—Fukushima also demonstrated how rapidly a nuclear reactor accident can progress to a core meltdown if multiple safety systems are disabled. A well-planned and executed terrorist attack could cause damage comparable to or worse than the earthquake and tsunami that initiated the Fukushima crisis, potentially in even less time. And although Osama bin Laden is gone, the terrorist threat to domestic infrastructure may actually increase over time if al Qaeda seeks to retaliate. This is the wrong time to consider reducing security requirements for nuclear powerplants, regardless of their size. However, SMR vendors have emphasized that reducing security staffing is critical for the economic viability of their projects. Christofer Mowry of B&W told the NRC in March that "whether SMRs get deployed in large numbers or not is going to come down to operations and maintenance (O&M). And the biggest variable that we can attack directly . . . is the security issue." A Nuclear Energy Institute representative said in a presentation in June that "optimal security staffing levels (for SMRs) may appreciably differ from current levels."

UCS is also concerned that reducing safety and security requirements for SMRs could facilitate their sale to utilities or other entities in the United States and abroad that do not have prior experience with nuclear power. Some SMR vendors argue that their technology is so safe that it can be deployed to remote areas, military bases, and countries in the developing world that have relatively low electric demand and no nuclear experience or emergency planning infrastructure. However, SMRs deployed in this manner could raise additional safety and security concerns compared to their deployment by established and experienced nuclear utilities.

The distributed deployment of small reactors would also put great strains on existing licensing and inspection resources. Nuclear reactors are qualitatively different from other types of generating facilities, not least because they require a much more extensive safety and security inspection regime. Similarly, deployment of individual small reactors at widely distributed and remote sites around the world would strain the resources of the International Atomic Energy Agency (IAEA) and its ability to adequately safeguard reactors to guard against proliferation, since IAEA inspectors would need to visit many more locations per installed megawatt around the world. Maintaining robust oversight over vast networks of SMRs around the world would be difficult, if feasible at all.

UCS believes that SMRs are only suitable for deployment where there is an established infrastructure to cope with emergencies, and if sufficient numbers of trained operator and security staff can be provided. It is unrealistic to assume the near-term availability of SMRs that are so safe they can be shipped around the world without the need to ensure the highest levels of competence and integrity of local regulatory authorities, plant operators, emergency planning organizations, and security forces. Fukushima has demonstrated the importance of timely offsite response in the event of a severe accident, so the accessibility of reactors in remote locations also must be a prime consideration. Even within the United States, small utilities with little or no experience in operating nuclear plants need to fully appreciate the unique challenges and responsibilities associated with nuclear power and should not expect that small modular reactors will provide any relief in this regard.

UCS acknowledges the concerns of Members of Congress who fear that the United States is lagging in creation of a robust SMR export market and may lose out to a country like China if it takes too long to develop and license SMRs. However, we believe that the best way for the United States to maintain a competitive edge is to establish American brands with the highest safety standards. If, as some say, NRC design certification is seen as a "gold standard" worldwide, it makes sense to preserve that standard rather than erode it by weakening SMR safety requirements.

To this end, the Congress should prohibit DOE from selecting SMR proposals for its cost-sharing program if their business case depends on a weakening of NRC safety and security regulations or marketing reactors to countries with inadequate safety rules and regulatory oversight mechanisms.

Thank you for your attention. I would be pleased to answer your questions.

Senator FEINSTEIN. Thank you, Dr. Lyman.

Mr. Ferland is representing Westinghouse.

**STATEMENT OF E. JAMES FERLAND, JR., PRESIDENT, AMERICAS WESTINGHOUSE ELECTRIC COMPANY, LLC**

Mr. FERLAND. Thank you. I'm very happy to be here this morning, Madam Chairman——

Senator FEINSTEIN. Could you press your microphone button?

Mr. FERLAND. Chairman Feinstein and Ranking Member Alexander, thank you very much for the opportunity to speak to you this morning.

I am here representing Westinghouse where I serve as the president and oversee our operations in the United States. And what I'd like to do in my few minutes of introduction is see if I can address some of the items that you highlighted this morning in your introductory comments.

So let me start with the success of NP2010. NP2010 was a collaboration cost-sharing program meant to kick start Generation III technologies.

Westinghouse was a participant in that program, and the end result for us was an AP–1000 that's in the final stages of design certification today.

And, as you know, four units in the United States are under preconstruction right now, two in Georgia and two in South Carolina, as a direct result of the success of that program, generating in excess of 1,000 jobs to those sites, and that number will multiply once we receive the design certification and the combined operating license and we move into nuclear construction.

The theory behind NP2010 was as you stated. It was to kick start the design certification on these new passive-safety plants.

And to give you a ballpark feel from a numbers perspective, the cost share received from Westinghouse as a result of NP2010 was about $300 million, which was matched by Westinghouse upfront, and then the cost share stopped, and Westinghouse, on its own, given that we'd proven the viability of that design, spent—and is still spending—several hundred million dollars more on our own with no Government money to take that plant to completion where we have a set of design drawings that are ready to go to the field.

So that program worked very well. Our view is that if we could extend the successes of NP2010 into a SMR program where, again, we used the concept to kick it off and get it going, prove the economic viability, get through the upfront design certification, we can move to a new generation of technology centered in the United States generating thousands of U.S. jobs and putting us in the middle of new nuclear development going forward. So we see an awful lot of benefit in the concept of an SMR collaboration cost-sharing program.

A couple of comments on the Westinghouse SMR from a safety perspective, again, a passive plant, so we're taking advantage of what we learned in NP2010 with the AP–1000s that we're working on today in extending those passive features—smaller plant, single containment with everything inside it.

So that reduces the amount of piping, significantly enhances the safety profile of those units, and, again, we can rely even more on passive technology—gravity, natural circulation—in the event of an incident.

So, for example, on the Westinghouse SMR, in the event of a significant incident—for example, a loss of offsite power, as happened in Fukushima—the Westinghouse SMR would look at 7 days, no operator action, no outside power required, where those units taking advantage of the passive features of the plant would be safe and give us plenty of time to go ahead and respond, so a significant step in safety in that design.

Stand-alone units, I think very good questions. Commissioner Magwood, Assistant Secretary Lyons addressed some of the concerns about multiple units next to one another.

The concept behind the Westinghouse SMR is that each unit is stand-alone, has stand-alone people, and has stand-alone equipment, no common systems. So each unit is able to fend for itself in that matter.

I recognize that we have the detailed design yet to finish to make sure we can stand up to that, and we will receive extensive questioning and scrutiny from the NRC as we go through the design certification process, and from the public, to be able to prove that, but it's my belief that you can safely put stand-alone units next to each other, SMRs, and not magnify a potential problem. So that's our responsibility to prove that to the NRC, but I believe that will be the outcome of this.

From an economic competitive standpoint, the key is to take advantage of modular construction, factory construction, shipping to site, and we do need some scale to make that happen, as you mentioned.

Our numbers upfront show at about 10 units we come down the learning curve to the extent where we believe these are now competitive at or below the price of current units today.

PREPARED STATEMENT

Last comment, on safety, safety is always our number one priority. That's the case at Westinghouse and in this industry as a whole, and we would not ever put forth a design that lowered safety standards, and we would never expect the NRC to lower safety standards. So we expect to live up to the standards that are in place today or will be in the future when we incorporate the lessons learned from Fukushima.

Thank you.

[The statement follows:]

PREPARED STATEMENT OF E. JAMES FERLAND, JR.

Chairman Feinstein, Ranking Member Alexander, and members of the subcommittee. Thank you for the opportunity to provide Westinghouse's views on the importance of proceeding with the Department of Energy's (DOE) program to develop and license light water small modular reactors (LW SMRs). The advancement of this technology is certain to benefit the American energy landscape by offering new investment options for emissions-free, baseload electricity that operates as an increasingly safe and secure generating resource. Westinghouse has appreciated the opportunity to provide input to DOE on the development of the SMR program and will continue to offer our finest scientists, engineers, and analysts in this productive partnership.

Westinghouse has been at the forefront of applying advanced nuclear energy technology since 1953 and approximately one-half of the operating plants in the world today are based on Westinghouse reactor technology. We are currently working with the NRC, and utilities in Georgia and South Carolina, to build four Westinghouse AP–1000® reactors.[1] NRC licensing of these projects is anticipated to be completed around the end of this year and will benefit the nuclear fleet by demonstrating passive safety design.

These projects have already created thousands of jobs across the United States to support engineering, manufacturing, and construction preparation. Thousands more American jobs will be created when safety-related construction begins next year. Moreover, these communities will benefit from the economic multipliers of career employment for thousands of professional and specialized labor personnel who will operate the plants over their lifetime.

As I'm sure you know, the Georgia and South Carolina projects were made possible by the DOE's Nuclear Power 2010 program. We thank the Department, this subcommittee, and the entire Congress for their support of this technology development partnership. We believe that the SMR initiative represents an even more valuable investment because we will be incorporating the improved safety and power performance levels developed with the DOE NP2010 program into the SMR design. Leveraging these technology breakthroughs, and combining them with the customer choice for lower capital cost, significantly smaller footprint, and incremental buildout, will open new markets for emissions-free nuclear energy in the United States.

The DOE's investment in the NP2010 program was an unprecedentedly successful model for collaboration between government and industry that we believe should be reproduced. This public/private partnership provides value to the public, the DOE, utility customers and their rate payers, the NRC, and commercial vendors. The model produces multiple benefits: it allows the DOE to focus on research and technology development that ensures U.S. leadership in safe nuclear technology; it involves the NRC early to result in the highest safety possible in licensable designs;

[1] AP–1000 is a trademark and registered trademark in the United States of Westinghouse Electric Company LLC, its subsidiaries and/or its affiliates. This mark may also be used and/or registered in other countries throughout the world. All rights reserved. Unauthorized use is strictly prohibited. Other names may be trademarks of their respective owners.

it invests in job creation; and it reduces investment and market risk to encourage large private sector investment.

Around the globe, the hunger for emissions-free, baseload electricity supply has invigorated a vibrant export market for Westinghouse technology bearing the stamp of stringent U.S. Federal Government review. Sales of Westinghouse technology and expertise has created thousands more jobs for Americans who are managing the construction, installation, fuel supply, and supply chain for AP–1000 plant projects in China.

The essential technology advancement of the SMR designs being considered for the DOE program is the passive safety system, pioneered and licensed by Westinghouse for its AP–1000 plant design. Passive design means that—in the event of a significant, abnormal event—cooling to the nuclear reactor is produced by the physics of nature using gravity, evaporation, and natural circulation. In contrast, all of the nuclear plants operating in the world today have active safety equipment which relies on pumps and mechanical means requiring uninterrupted sources of electricity to respond to emergencies. Rigorous evaluation proves that passive systems perform as expected with full confidence, without requiring human intervention or back-up electrical sources, and can be sustained for days instead of hours without outside intervention.

The SMR reactor power output is about one-fifth that of our AP–1000 reactor design and uses a dramatically smaller containment vessel to enclose the reactor. The reactor coolant system comprises a single, tall vessel with no need for loop system piping. This simplification and reduction of components cuts costs while it improves safety by eliminating accident scenarios associated with pipe breakage. Moreover, the small, robust containment can be buried underground, adding protection against outside events.

In light of recent events, it's important to note that the Westinghouse SMR design will not require any human operator action for 7 days after a shutdown or accident. And because the Westinghouse SMRs are stand-alone units that will not share equipment, structures, or operating personnel, concerns about response to simultaneous accidents at multiple units on the same site will be avoided. Onsite, used fuel storage will benefit from the same passive safety technology that works much like the reactor safety system.

After safety, the most important factor in our ability to develop a viable SMR market is that it be economically competitive. The Westinghouse design achieves major efficiencies by dramatically increasing the use of factory fabrication for modules that can be used to build the plant.

Almost all of the nuclear plants currently operating in the world today were designed to be unique, assembling every system and structure, one stick at a time. In contrast, the Westinghouse SMR uses a process that fabricates standardized systems and structures into modules in an assembly line, factory environment for installation onsite. Modular design allows tremendous advantages in productivity and schedule controls. Likewise, fabrication, transportation, and construction costs have greater certainty. And because of the compact size, it will allow us to fabricate major components, such as the reactor vessel and steam generator, here in the United States for shipping overseas, creating thousands more high-paying jobs here at home.

The laws of economy-of-scale would say that—all things being equal—a 225 MWe nuclear plant would be much more expensive than an 1,117 MWe nuclear plant, on a per-unit-of-power basis. But our evaluations indicate that making extensive use of inherent SMR features trumps the economy-of-scale penalty.

In the interest of time, I will close my comments by addressing two specific issues that we believe are at the heart of the subcommittee's final approval to move forward with the DOE SMR program.

First, in regard to price and economic competitiveness of SMRs, I can assure you that Westinghouse does not casually guess or estimate the market potential for any of the products or services in any of our business lines. As we designed our SMR, our team focused design on the least-cost engineering solutions and developed new and improved configurations. Our customers want the safest technology with the most efficient design. Both retail and wholesale utilities tell us there will be a substantial market for SMRs if the per-megawatt cost is close to that of large nuclear plants.

In testimony to the this subcommittee on June 7 of this year, Dr. Edwin Lyman of the Union of Concerned Scientists referenced a 2007 paper by Westinghouse employees, which estimated that factors such as passive safety technology and modular fabrication could produce costs for a particular SMR as being only slightly above the cost of a large nuclear plant, when compared on a per MWe basis. Four years later, Westinghouse believes our passive technology and increased modularity can enable SMR delivery at or below the current costs per MWe for today's plants.

Many utilities in the United States and overseas simply cannot afford to invest several billion dollars all at once for a large plant, but they could invest in small portions for one or more SMRs. In an increasingly carbon-regulated world, utilities are looking at nuclear as a preferred, emissions-free, baseload investment. And in many cases, the SMRs are the best business strategy for long-term asset investment and fuel portfolio strategy.

On the second issue, we disagree with, and object to statements made by nuclear power critics that NRC safety standards and regulation will be weakened to accommodate SMRs in order to help them achieve economic competitiveness. Westinghouse, and the entire nuclear industry, has a vested interest in insuring that nuclear energy is supplied in a safe and reliable manner. As such, Westinghouse and others in the nuclear industry support thorough and transparent regulation and oversight conducted by the NRC. We have never asked the NRC to lower its standards or alter a regulation merely to increase the economic competitiveness of SMRs; and we would never make such a request at the expense of safety.

A safety focus is ingrained in our company culture as it is in our customers' culture. There are few business sectors that depend more on maintaining and improving upon safety than the nuclear industry.

As a final note on safety, I want to say that as a leader in the nuclear industry, Westinghouse understands how the events at Fukushima have undermined public confidence in nuclear energy, and the expertise of the nuclear industry. The unique situation in Japan has caused a legitimate review of our own United States nuclear regulatory standards and we are participating fully in those reviews.

At Westinghouse, we believe that a partnership between industry and the DOE is the most effective path for making progress on the policy, regulatory, economic, and infrastructure issues related to deployment of SMRs. We can launch the SMR program and produce the same level of success as we've enjoyed working as investment partners on the NP2010 program. We stand ready to work with DOE on the exciting potential for small nuclear technology.

On behalf of the 15,000 Westinghouse employees, we thank the subcommittee for seriously considering our views. I would be pleased to answer any questions.

Senator FEINSTEIN. Thank you very much.

Mr. Mowry, president of Babcock & Wilcox. Welcome.

**STATEMENT OF CHRISTOFER M. MOWRY, PRESIDENT, BABCOCK & WILSON NUCLEAR ENERGY**

Mr. MOWRY. Chairman Feinstein and Ranking Member Alexander, I do appreciate this opportunity to present testimony today on the promise of SMRs and would ask that my entire written statement be entered into the subcommittee record.

Senator FEINSTEIN. So ordered. All of them will be. Thank you.

Mr. MOWRY. B&W has an ongoing comprehensive effort to evaluate our mPower SMR design in the context of the lessons from the Fukushima event, an effort which is confirming that mPower's safety performance is already extremely robust.

Our SMR design offers significant safety enhancements to current NRC safety goals through the use of inherently safer nuclear plant architecture and significant defense-in-depth systems.

These design features can be summarized in five points. First, an integral nuclear steam supply system with no large penetrations in the primary cooling circuit, a design which eliminates the possibility of typical worst-case-loss-of-coolant accidents.

Second, a small core with low-power density and large water inventory, a design that provides a large buffer against short-term challenges to core cooling.

Third, a containment and reactor building fully imbedded underground, a design that effectively isolates the reactor module and all emergency cooling water and safety systems from natural disasters like what happened in Japan.

Fourth, no requirements for AC power, emergency diesel generators or pumps for any of the safety systems; a design that instead utilizes natural circulation to remove decay heat, and fifth, a fully protected spent-fuel pool with its very large cooling-water volume located deep underground, a design which provides protection for spent fuel similar to that which is provided for the reactor core itself.

Taken together these SMR design features result in a reactor planned to be two to three orders of magnitude safer than current NRC requirements.

The design creates a 14-day safe haven before any outside intervention is required to maintain reactor core cooling and more than 30 days of inherent protection before the spent-fuel pool could experience any exposure of spent fuel.

Furthermore, our SMR design requires zero operator action for the first 72 hours after an emergency shutdown and allows the operators to focus on long-term accident mitigation.

Concerns that multi-module sites are less safe ignore these inherent differences between SMRs and the Fukushima plant. The imbedding of the entire B&W mPower reactor underground, including all necessary cooling and safety systems effectively isolates the reactor from such events. Each module is encased in its own individual containment together with its own independent dedicated safety systems.

Concerns that our industry is pushing the NRC to weaken safety requirements are a complete mischaracterization.

While the way in which an SMR design meets NRC regulations may be different from that of large reactors, the underlying safety requirements are exactly the same. We have no need to change or weaken any underlying NRC safety requirements.

With regard to economics, B&W would not be investing our own company's resources in such an effort if we did not believe we could produce a competitive product and create a viable stand-alone business model in the long term.

Some people are concerned that due to the economies-of-scale paradigm small reactors can't compete with large reactors. This is no longer true. Competitive costs are achievable through factory assembly of integral reactors, but, more importantly, through the simplicity of their design.

Nevertheless, based on our long experience manufacturing reactors for both the Navy and the commercial customer base, we believe we can achieve our cost efficiencies after less than 10 modules.

Recent studies of the economies of SMRs failed to consider that every utility does not have the capital, transmission grid or water resources necessary to build a large reactor, nor does every utility need large- generation capacity additions. In such cases, small, more affordable SMRs offer a better solution.

New EPA regulations are likely to drive near-term retirements of up to 50 gigawatts of coal-fired, base-load generation.

But the industry alone will not be able to develop and deploy carbon-free, base-load replacements for these old coal plants by 2020 without an effective public-private partnership. Such a roadmap to

2020 is also essential to maintain America's competitive edge in the global marketplace.

Our international competitors are largely state-subsidized companies who have already started investing in their SMRs. Failing to move forward with this new DOE cost-share program will not prevent the deployment of SMRs in the United States, but will only ensure that foreign SMRs receive the substantial job and export benefits of selling their reactors to our domestic customers.

Innovative LW SMRs has the near-term potential to raise nuclear safety to the next level while offering America a competitive source of domestically produced clean energy.

In order to meet President Obama's vision of being 80 percent carbon free by 2050, the American energy industry needs a practical nuclear option. Turning this SMR innovation into reality will depend on leadership from industry and government.

PREPARED STATEMENT

We, therefore, ask this subcommittee to support the proposed DOE SMR cost-share program and help maintain our Nation's leadership role in clean-energy technology.

Thank you for the privilege of testifying today, I'm happy to answer any of your questions.

[The statement follows:]

PREPARED STATEMENT OF CHRISTOFER M. MOWRY

Chairman Feinstein, Ranking Member Alexander, and members of the subcommittee: My name is Chris Mowry and I am the president of Babcock & Wilcox Nuclear Energy, a business unit of The Babcock & Wilcox Company (B&W), and chairman of Generation mPower, LLC, which is a majority-owned subsidiary of B&W. I would ask that my entire statement and supplemental information be entered into the subcommittee record. My prepared remarks will be a summary of this statement.

I appreciate this opportunity to present testimony today on the promise of small modular reactors (SMRs) and describe our innovative technology—the B&W mPower™ reactor. I will focus my testimony on the technical, safety, and economic attributes of SMRs and I am happy to respond to any questions.

B&W has more than 50 years of continuous nuclear engineering and manufacturing experience. Today we provide customers with nuclear manufacturing and nuclear-related services from more than 17 facilities across North America. These locations are engaged in activities from manufacturing major components for government and commercial nuclear powerplants, to operating the Nation's nuclear energy laboratories, to fabricating fuel for the High Flux Isotope Reactor at Oak Ridge National Laboratory and the University of Missouri's research reactor, both of which provide critical research and material testing services.

B&W operates significant nuclear manufacturing facilities in Indiana, Ohio, Virginia and Tennessee, as well as Ontario, Canada. We are the only American manufacturer accredited and capable of producing large N-stamped components for commercial nuclear powerplants. We have delivered more than 1,100 Nuclear Steam Supply System (NSSS) components and pressure vessels, including approximately 300 nuclear steam generators worldwide. And, we employ (both directly and through joint venture companies) approximately 12,000 U.S. nuclear professionals. As such, we have significant experience and expertise to validate the technical, safety, and economic value of SMRs.

INHERENT SAFETY OF SMRs—ROBUST DEFENSE-IN-DEPTH

Current and next-generation U.S. large reactor designs operate at a remarkable level of safety, making the United States the global leader in nuclear safety and security. While the current fleet is considered safe, in the wake of the devastating earthquake and tsunami in Japan, and the resultant emergency at the Fukushima—Daiichi nuclear plant, the nuclear community—including the Congress, the Nuclear Regulatory Commission (NRC), the industry and the general public—

is evaluating what additional layers of safety are appropriate to mitigate these types of challenges. Our efforts to work together to learn from Japan's experiences will help make the current U.S. fleet and new nuclear technologies even safer than they are today.

The B&W mPower SMR offers significant safety enhancements to NRC safety goals through the use of an inherently safer plant architecture and significant defense-in-depth safety systems. This enhanced safety performance is achieved through the following design features:

—An integral nuclear steam supply system with no large reactor penetrations in the primary cooling circuit;
—a small core, low-power density and large water inventory that provide a large buffer against short-term challenges to core cooling;
—deeply embedded underground containment, which effectively isolates all emergency cooling water sources and safety systems from natural disasters and external threats;
—safety systems powered by gravity and natural circulation with no dependence on external AC power; and
—underground spent-fuel storage with large cooling water volume, located within the auxiliary containment structure created by the underground reactor service building.

These innovations transcend the design of the reactor at Fukushima-Daiichi. This design results in a reactor planned to be 2–3 orders of magnitude safer than the current NRC requirement or EPRI Utility Requirements Document (URD) safety benchmark, based on core damage frequency (up to $10^{-8}$ vs. $10^{-5}$ NRC requirement or $10^{-6}$ EPRI URD goal). In the unlikely occurrence of an event, the B&W mPower reactor design also creates an extended period of time before outside assistance is required to maintain safe shutdown of the plant. Specifically, our B&W mPower reactor design creates a 14-day "safe haven" before any intervention is required to maintain reactor core cooling through the ultimate reactor cooling water source (ultimate heat sink), and provides more than 30 days of inherent protection before the spent-fuel pool could experience any exposure of spent fuel due to loss of cooling water volume through boiling. Furthermore, our design requires zero emergency operator action for the first 72 hours after an emergency reactor shutdown, which is best in class for all advanced LW SMR designs—large or small. This allows the operators to focus on long-term mitigation of events rather than immediate emergency actions.

The SMR industry is in a unique position to efficiently incorporate both design and regulatory lessons learned from Fukushima into our designs. We have an ongoing, extensive effort to evaluate the B&W mPower SMR design in the context of what we are learning about the events at Fukushima. B&W's evaluation is confirming that the safety performance of our SMR design is extremely robust when confronted by a Fukushima-type event.

*Integral Design and Robust Safety Margins*

The B&W mPower reactor's integral design means that the entire reactor and steam supply system are incorporated into one vessel, rather than multiple vessels connected by large piping. This integral design, with no penetrations in the primary cooling circuit of the reactor vessel below the core, eliminates the possibility of the worst-case design basis accident occurring, an accident in which a loss of cooling water to the reactor is caused by a break in the reactor system piping. In addition, the B&W mPower reactor's small core combined with low density of power and large inventory of reactor coolant, results in operating and safety margins significantly more robust than those required by the NRC.

*Deeply Embedded Underground Containment and Reactor Building*

The integral B&W mPower reactor module is isolated from external events in a steel containment structure, which is itself enclosed within a massive reinforced concrete reactor building that is fully embedded underground. This water-tight underground reactor building contains all emergency cooling water sources (including the refueling water storage tank and ultimate heat sink), isolates all safety equipment from natural disasters, and creates an auxiliary containment for the protected underground spent-fuel pool. In a Fukushima-type event, this means that all systems and cooling water needed to protect the reactor core for an extended period of time are well isolated from the effects of natural disasters. This underground configuration also offers inherent protection against external manmade threats such as aircraft and projectiles.

*Inherent Safety Systems*

The B&W mPower reactor incorporates the most advanced inherent safety system architecture. This means that no AC power, either onsite or offsite, is required to power any safety systems. No pumps are required to inject cooling water to the core. Instead, the emergency core cooling system is powered by gravity—natural circulation removes decay heat and a gravity-drained storage tank supplies make-up water to cool the reactor core. This ultimate heat sink provides up to 14 days of cooling without the need for external intervention. Unlike at Fukushima, no diesel generators are required to provide power for any of these safety systems to perform their intended functions. However, in keeping with our defense-in-depth philosophy, two back-up diesel generators are provided anyway, in seismically qualified structures, for further protection. In addition, a 3-day battery supports all plant monitoring and control for 72 hours without reliance on AC power. After 72 hours, which is the NRC's current regulatory requirement for passive safety designs, auxiliary power units inside the underground reactor building recharge the battery system, again without reliance on external power sources. Finally, passive hydrogen recombiners prevent the build-up of hydrogen, from either the reactor core or the spent-fuel pool, in the containment and reactor building. Most importantly, all of the inherent safety systems, including the ultimate reactor cooling water source (ultimate heat sink), batteries, battery recharging system, and hydrogen recombiners are housed inside the protected underground reactor building, isolated from natural disasters.

*Robustly Protected Spent-fuel Pool*

Our design includes a fully protected spent-fuel pool located within the auxiliary containment structure created by the underground reactor service building, at the lowest point of the structure. Consistent with the design philosophy of an advanced, inherently safe reactor, the B&W mPower SMR provides protection for spent fuel similar to that which is provided for the fuel in the reactor core itself. As shown at Fukushima, protection of spent fuel is most critical in the first few years after it is removed from the reactor core. Therefore, the spent-fuel pool's auxiliary containment structure, inside the underground reactor building, has a similar level of robustness as that protecting the reactor vessel. This ensures an enhanced level of protection for spent fuel recently removed from the core. In addition, it is designed with a large heat sink to ensure more than 30 days of fuel cooling without the need for external intervention, before the loss of water inventory sufficient to uncover fuel could occur—which may have been experienced at Fukushima within 1 week of the accident.

These design safety features are summarized in Figure 1. The underground reactor building is illustrated in Figure 2.

**Design Considerations for "Fukushima-Type" Events** — generation mPower

| Events and Threats | B&W mPower Reactor Design Features |
|---|---|
| Earthquakes and Floods | • **Seismic attenuation**: Deeply embedded reactor building dissipates energy, limits motion<br>• **"Water-tight"**: Separated, waterproof reactor compartments address unexpected events |
| Loss of Offsite Power | • **Passively safe**: AC power not required for design basis safety functions<br>• **Defense-in-depth**: 2 back-up diesel generators for grid-independent AC power |
| Station Blackout | • **3-day batteries**: Safety-grade batteries support all accident mitigation for 72 hours<br>• **Auxiliary Power Units**: Protected inside reactor building for recharging batteries<br>• **Long-duration "station keeping"**: 7+ day battery supply for plant monitoring/control |
| Emergency Core Cooling | • **Gravity, not pumps**: Natural circulation decay heat removal; water source in containment<br>• **Robust margins**: Low core power density and small core limit energy release<br>• **No operator action required**: for 72 hours to mitigate consequences of an accident |
| Containment Integrity and Ultimate Heat Sink | • **Passive hydrogen recombiners**: Prevention of explosions without need for power supply<br>• **Internal cooling source**: Ultimate heat sink inside underground shielded reactor building<br>• **Extended performance window**: Up to 14 days without need for external intervention |
| Spent Fuel Pool Integrity and Cooling | • **Protected structure**: Underground, inside auxiliary containment<br>• **Large heat sink**: 30+ days before boiling and uncovering of fuel with 20 years of spent fuel |

***Multi-layer defense ... mitigates extreme beyond-design basis challenges***

FIGURE 1.

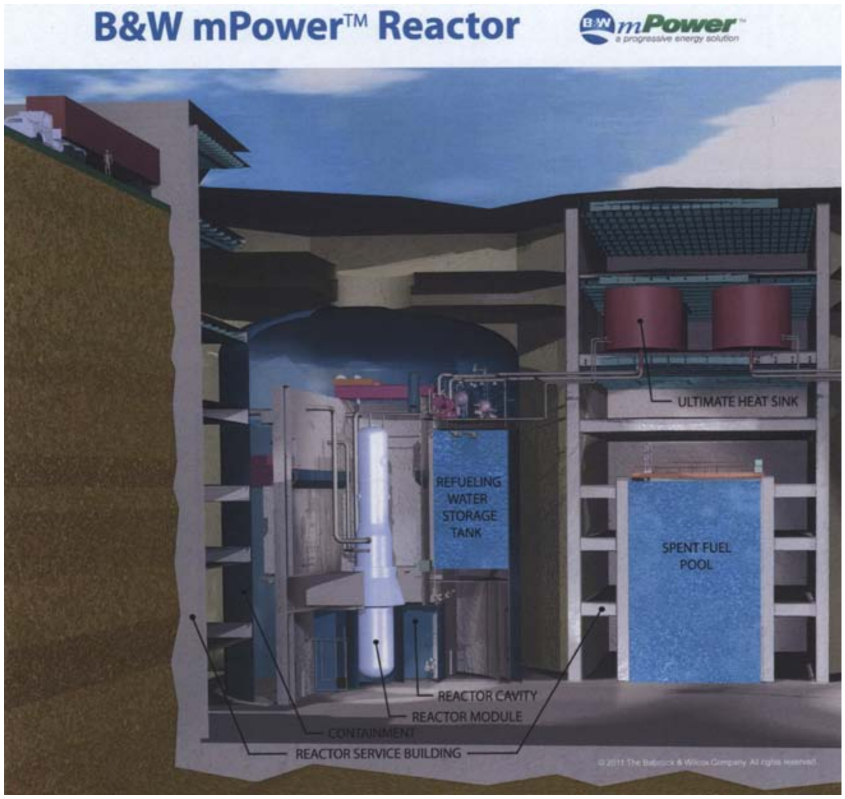


FIGURE 2.

Some groups, including the Union of Concerned Scientists (UCS), have raised concerns related to the safety of SMRs. I agree that we have an obligation to re-examine nuclear safety based on the events at Fukushima. However, the UCS statements regarding SMR safety are unfounded and inaccurate. In particular, I would like to address concerns the UCS has raised related to an alleged "weakening" of NRC regulation to support SMRs, and locating multiple reactors on one site.

*No "Weakening" of NRC Regulation*

In testimony provided to the Senate Energy and Natural Resources Committee earlier this year, the UCS made several statements implying that SMRs require softer regulatory standards to be viable, stating that we as the SMR industry are "pressuring the Nuclear Regulatory Commission to weaken certain regulatory requirements for SMRs." This is a mischaracterization. The B&W mPower reactor design, will meet or exceed all of the NRC's current safety and security requirements. While the way in which an SMR design intends to meet or implement an NRC requirement may differ from large reactor designs, the underlying safety regulations are exactly the same. The B&W mPower SMR will be able to meet regulatory requirements through the robust features of its underground nuclear island architecture, which is being designed to exceed the current NRC safety goal by 2–3 orders of magnitude. In addition, there is no intention or need to weaken NRC regulatory requirements in order to reduce operational and maintenance costs, as the UCS implied. On the contrary, we plan to meet or exceed NRC requirements while simultaneously maintaining competitive costs, by designing the plant itself to be more operationally efficient. For example, we believe the inherently safe and secure design of the B&W mPower nuclear island will require fewer personnel to meet the NRC requirements to safeguard the plant against security threats. Therefore, we have no plans and no need to change or weaken underlying regulatory requirements in order to license the B&W mPower SMR.

*Co-location of Multiple Modules at One Site*

The UCS also stated:

"As we have seen in Fukushima, nuclear plants with multiple reactors that experience severe conditions present extreme challenges. At Fukushima, the need to manage multiple simultaneous crises resulted in what sometimes appeared to be a game of 'whack-a-mole' as the plant operator was forced to shift limited resources from one unit to another as new problems cropped up. These considerations make multiple-reactor sites less attractive from a safety perspective."

The events at Fukushima were more than anything else the result of plant and site configuration. This statement ignores the inherent differences between SMRs and the Fukushima plant. As explained earlier, the embedding of the entire reactor building, including all necessary core cooling and safety systems, in an underground containment, significantly isolates the reactor from the threats of external events. In addition, each module is embedded in its own individual containment with independent, dedicated safety systems. There is no sharing of safety systems. Finally, due to the reactor's inherently safer design, including small size, low-power density, large water inventory and inherent safety systems, reactor safety after a shutdown is not dependent upon immediate assistance from operators or outside help. As stated earlier, for the B&W mPower design, no emergency operator action is required for the first 72 hours to mitigate accidents, allowing operators to focus on managing long-term effects.

*Extensive Test Program*

We are currently engaged in an extensive test program to provide the NRC indepth analytical and physical data to evaluate the safety of the B&W mPower reactor. This includes an Integrated Systems Test facility in Bedford, Virginia, with an unfueled, scaled prototype reactor system to demonstrate the thermo-hydraulic characteristics of the reactor. We expect this testing, which represents a significant investment, to demonstrate to the NRC that the B&W mPower reactor will far exceed current safety requirements. We are working with the NRC to ensure that our design meets or exceeds regulatory requirements, and we will continue to do so as we learn more from the events at Fukushima.

THE ECONOMICS OF SMRs—COMPETITIVE AND FINANCEABLE

Market analysis has concluded that the addressable market for SMRs, both in the United States and globally, ranges from 100–125 GWe through 2030, and that, in addition to benefiting from the factors contributing to the resurgence of nuclear power in general, SMRs directly address the key challenges such as financing risk, cost and time certainty, production bottlenecks and expensive grid upgrades associated with the construction of large-scale, traditional nuclear plants. We would not be investing our company's resources in this effort if we did not believe we could produce a competitive product on both a Levelized-Cost-of-Electricity and per-kilowatt (per-kW) basis to serve this meaningful market.

In addition, we have a Consortium of 15 U.S. utilities and an Industry Advisory Council of 26 utilities, both U.S. and international, which demonstrates broad industry interest. In addition to the investment B&W has made, utilities in our Consortium have also invested resources in the B&W mPower development process. We are working closely with our Consortium, Industry Advisory Council, and our Engineering, Procurement and Construction (EPC) partner to validate the economic value of our reactor and incorporate their valuable input on life-cycle costs.

There has been much discussion surrounding the economics of SMRs, particularly concerns that due to the principle of economies-of-scale, smaller reactors cannot compete with large reactors. This is untrue. The design, size and inherently safe features that ensure that SMRs will raise safety to the next level also enable SMRs to offer the carbon-free advantages of nuclear power in a cost-competitive, more financeable form. This is achievable through a paradigm shift from "economies of scale" to factory assembly of simplified, integral reactors in a manufacturing setting—the next step beyond onsite modular construction. In fact, based on the Navy's successful experience with modular submarine construction, we have engaged a submarine industry leader to provide lessons learned from this effort as part of our B&W mPower design team. Through this paradigm shift, we believe we will be able to offer SMRs to our customers without any cost premium—that we can compete with any new-generation large reactor. In addition, based on our experience manufacturing reactors for both government and commercial customers, we believe we will achieve $n^{th}$-of-a-kind costs in less than 10 modules, rather than thousands as some SMR opponents have implied. Our utility customers require that SMRs be competitive on a per-kW basis with large reactors. This is achievable through:

—modular, integral design and factory assembly for a fully manufactured product;
—the ability to maintain a skilled workforce in a manufacturing setting;
—improved quality, efficiency, and process standardization in factory settings; and
—simplified construction onsite.

In addition, a significant economic advantage of SMRs is the ability to incrementally add individual modules to a site to support load growth and minimize financing risk. Improved financing reduces costs, while individual modules provide utilities the flexibility to replace old fossil plants with carbon-free nuclear power while using existing grid and site assets, further reducing costs. While SMRs require more staff than a similarly sized fossil plant, the replacement of such plants with SMRs simply trades the higher cost of fossil fuels and impact of emissions, as compared to nuclear fuel, for more highly skilled, better paying nuclear jobs.

*External Economic Studies—The Value of a Smaller Option*

There are several studies available on the economics of SMRs, some with widely varying views of the cost-competitiveness of SMRs. Unfortunately, many of these reach erroneous conclusions. For example, a recent study by the OECD Nuclear Energy Assembly, which is currently receiving attention, concluded that "the investment component of the Levelized Unit Electricity Cost (LUEC) for a SMR would be at least 10–40 percent higher than in the case of a Nuclear Powerplant (NPP) with a large reactor". We disagree with this viewpoint. This study was completed without direct input by B&W, and is not consistent with our internal estimates. Any studies that compare estimated SMR costs to large reactor costs are simply comparing estimates to estimates. We have not yet built a new generation large reactor in this country, and therefore it is impossible to compare SMR costs to large reactor costs without making several significant assumptions about the next class of large reactors.

More importantly, this type of comparison assumes that every utility has the same needs, that require the same solution. Not every utility has the capital, grid and water resources to build a large reactor, nor does every utility need capacity of that size. In these cases, which represent numerous utilities across the country, small, more affordable SMRs offer a better solution. In fact, despite the OECD study's inflated comparative cost estimates, it goes on to conclude that SMRs have significant potential for several market segments, including replacing old fossil plants, grid-limited sites, water-limited sites, and those utilities for whom lower upfront capital investment, lower cost of financing and flexibility are important. It also concludes that "SMRs could be competitive with many non-nuclear technologies." In short, it validates our value proposition, which is that SMRs offer utilities a more flexible, financeable, competitive carbon-free option.

## PUBLIC-PRIVATE PARTNERSHIP—INVESTMENT IN CLEAN ENERGY AND U.S. JOBS

I will conclude with a discussion of the critical need for the DOE's proposed SMR cost-share program. This program, which would share the costs and risks associated with developing and licensing any new nuclear technology, is critical to the market development and viability of SMRs. Due to the regulatory and policy environment, there is significant risk associated with developing and deploying any first-of-a-kind nuclear technology. A public-private partnership to develop SMRs is necessary to share these risks and make the long-term, significant investment justifiable to shareholders and investors, by showing the Government's commitment to the future of nuclear power and SMRs. This will provide a level of certainty critical to market development, competition, and long-term associated investment. In addition, broad market adoption of SMR technology is dependent on a successful first-of-a-kind project. Such projects include significant nonrecurring costs, which represent a barrier to deployment of SMRs without a mechanism for public-private partnership.

The DOE has established a goal to reduce emissions from DOE facilities by 28 percent by 2020. In addition, new Environmental Protection Agency (EPA) regulations are likely to drive the retirement of 25–50 GW of coal-fired baseload generation near-term, based on recent industry projections. Most U.S. SMR vendors, while proactively pursuing development of SMRs, are unable to independently invest at the pace needed to deploy the first SMRs by 2020, or potentially at a pace necessary to ensure a viable business case. Without SMR technology available to provide in-kind baseload power sized to replace these old coal plants, utilities will face grid stability and reliability issues. It is critical that utilities have viable carbon-free options to replace old, baseload coal plants by 2020. To reach this goal of deployment by 2020—a goal driven by government policy and regulation—a public-private partnership to share costs and risks is critical.

This timeline is also critical to maintain the U.S.'s competitive edge in the international nuclear power market. Our international competitors are largely state-owned or subsidized companies making large investments in nuclear technology, including SMRs. There are currently several SMRs being developed internationally, in China, Russia, India, Argentina, South Korea, and elsewhere.

Failing to move forward with this program will not stall the deployment of SMRs in the United States or worldwide, but will simply stymie the U.S. industry's current early mover advantage in SMR technology and manufacturing leadership. Failure to fund an SMR cost-share program will ensure that foreign SMRs (like the South Korean SMART reactor) receive the manufacturing jobs and exporting benefits by selling to U.S. utility customers. At a time when we need to ensure that public policy promotes U.S. competitiveness in technology innovation and leadership, the SMR cost-share program is the conduit to maintain U.S. leadership and create the manufacturing base here instead of overseas. Conversely, the sharing of risks and costs through public-private partnership will ultimately result in a return on investment to Government by supporting nuclear technology, which can compete in the market without government support or subsidy, while creating U.S. design, supply chain, construction, and operations jobs.

As Ernie Moniz, the Director of MIT's Energy Initiative and Laboratory for Energy and the Environment, testified before this subcommittee, on March 30, 2011, 2 weeks after the events at Fukushima:

"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 . . . 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 10 years lamenting the lack of a technology portfolio needed to meet our energy and environmental needs economically or to compete in the global market."

### CLOSING COMMENTS

Innovative SMRs, like the B&W mPower reactor, have the potential to raise nuclear safety to the next level, while offering America a competitive source of near-term, domestically produced, clean energy. In order to meet President Obama's vision of being 80 percent carbon-free by 2050, industry needs a practical nuclear option. The President has explicitly acknowledged and endorsed that nuclear should and must be part of the generation portfolio. B&W has heard repeatedly from industry that a near-term light water SMR option is essential to a practical nuclear generation solution. Turning this innovation into reality will depend on leadership and foresight from both the nuclear industry and government through a true public-private partnership. We therefore ask that this subcommittee support the DOE cost-share program and help maintain our Nation's leadership role in nuclear power and clean-energy technology.

Thank you for the privilege of testifying today. I am happy to answer any questions the subcommittee may have.

Senator FEINSTEIN. And we thank you for being here. We thank all of you. I know you've come a distance, and it's very much appreciated. So thank you.

Next is Dr. Paul G. Lorenzini, CEO of NuScale Power, Inc. Welcome, doctor.

## STATEMENT OF DR. PAUL G. LORENZINI, CEO, NUSCALE POWER, INC.

Dr. LORENZINI. Thank you, Madam Chair and ranking member. I am the CEO of NuScale Power, Inc., a startup company that is making no profits and is facing a very sizeable investment challenge as a barrier to ultimately commercializing an SMR.

Let me confine my oral remarks to four areas—economics, safety, spent fuel and the importance of an SMR program.

With regard to the economics, we've all known that there are economies-of-scale that would suggest that small reactors cannot be competitive. We challenged that with simplicity and with offsite manufacturing, but we also knew we would need to overcome our skeptics.

So we worked with our engineering and manufacturing partners to develop a credible cost estimate, investing more than 16,000 man-hours over 2 years to develop an estimate in which we had confidence. That estimate showed that our unit costs were not just competitive with large plants, they were actually lower.

We were then challenged, and so we retained an independent firm to review the analysis. They confirmed our estimates to within 10 percent.

We, too, hear all the challenges to the economics of small reactors, but we've done the estimating on an actual design starting from the ground up. The results establish quite clearly that we have a plant that will completely change the economic story for nuclear power, and that, by the way, was for a first plant. And our numbers would agree with the others you've heard, that we reach economies-of-scale for manufacture with about the 8th to the 10th module.

Next, let me address the safety question. When the NuScale concept was first funded by the DOE in 2001, the principal designer, a professor at Oregon State University, Dr. Jose Reyes, set out to design what he hoped would be the safest LW SMR ever built.

He'd spent 10 years in the NRC and he'd been involved in the analysis of Three Mile Island and he understood the importance of making plants inherently safe. The result is the plant we're commercializing at NuScale Power.

First, he revolutionized the containment design. It is factory built and can withstand much higher internal pressures. It's also immersed in a pool of water underground. This pool holds 4 million gallons of water and is sufficient to remove all the decay without ever adding more water to the system.

In our system, the operator doesn't have to do anything. After 30 days, after 7 days there's enough water, followed by air cooling to completely keep these reactors cool. The pool is below ground and the building that holds it is seismically very robust.

Second, he took advantage of simplicity. He designed the reactor to be entirely cooled by natural circulation eliminating pumps and pipes and valves and all the potential failure modes and costs that go with them. He also eliminated by doing this the large break loss of coolant accident.

Finally, he sought out expert advice. Very early in our program he convened two expert review panels, one chaired by Dr. Graham Wallace, a former chair of the Advisory Committee on Reactor Safeguards, and a second chaired by Dr. Michael Corradini, a member of the National Academy of Engineering and a member of the ACRS.

These independent reviews not only validated our belief in the safety of the plant, they also made helpful recommendations to enhance the safety even further.

Now, the question has come up about multi-module configurations, many modules in one building. If you could imagine for yourself taking one Fukushima plant, breaking it up into 12 small pieces, each now a smaller unit, each now with a smaller potential for an accident, separately containing each unit, making it simpler and safer, and then putting it in a pool of water, so you now have an ultimate heat sink, putting it in a common building where you now have a single control room that can watch all 12 at the same time. We believe categorically that we've made that configuration safer by doing that.

Prior to submitting our application for design certification, we will have a complete simulation of the control room and we will test the operators. We will challenge them with every multi-module configuration that we can think of. The NRC will as well. We won't be able to license our plant the way we have it configured unless we can demonstrate that we've made that plant safe and made it safer by doing it the way we've done it.

Let me speak to the question of spent fuel and make three brief points.

First, spent fuel in the NuScale plant is housed in an underground, protected structure.

Second, it has approximately four times the water volume of a conventional spent-fuel pool per megawatt of thermal power.

And, finally, it uses what are called low-density fuel racks that make it much easier to remove the heat from these spent-fuel assemblies.

Madam Chair and ranking member, an SMR program serves the national interest by bringing to market a nuclear option, a non-carbon source of base-load energy that overcomes financial barriers and reaches markets not accessible to larger reactors.

Second, it strengthens the domestic manufacturing base creating jobs and exports.

Third, it enhances the safety of nuclear plants and assures that the NRC will participate in establishing the global regulatory framework for SMRs.

PREPARED STATEMENT

There will be SMRs and they will be marketed throughout the world. The question is whether we are going to be in the game.

Madam Chair and ranking member, I urge your support for this program.

Thank you very much.

[The statement follows:]

PREPARED STATEMENT OF DR. PAUL G. LORENZINI

Madam Chair, members of the subcommittee, thank you for this opportunity to appear before you today. My name is Paul G. Lorenzini. I am the chief executive officer of NuScale Power, Inc., located in Corvallis, Oregon.

NuScale Power was incorporated in 2007 and has been funded entirely from private sector capital. To date just under $40 million has been invested in our company.

The genesis of our 45 MWe "integrated pressurized" small-scale power module began more than 10 years ago with a Department of Energy (DOE) grant through the Idaho National Lab and Oregon State University. This grant came at a time when this very same subcommittee set as a goal to "spin off" more private sector investments from the national lab community and leverage private capital in new companies.

This program included the construction of a one-third scale, electrically heated test facility to validate the safety features of the plant. In other words, our plant design rests on a solid foundation, which involves more than paper studies.

Since our founding in 2007, we have been encouraged by the growing recognition of the value of SMRs in developing a balanced energy policy.

First, we have seen the response of customers. They like several unique aspects of the NuScale SMR—the lowered financial barriers, the elimination of so-called single shaft risks—if a single 45 MWe unit goes down, the rest of the plant continues to operate eliminating the need to find replacement power for the grid; and they especially like the ability to incrementally add new generation to match load growth. All of these features provide significant benefits to their customers. We currently have more than 10 major utilities participating on our customer advisory board.

Second, the NRC's policy guidance issued in March 2010 for potential SMR applicants was a very positive step forward. This key guidance from our safety regulator has given us the preliminary roadmap we needed to submit a high-quality application.

Finally, the inclusion of Federal cost sharing for the development of commercial SMR's in President Obama's budget last February has been critical to our ability to attract the investors who are obviously necessary for our success.

As we now consider the future of that program, let me focus my remarks in four areas:

—First, the economics of small modular reactors (SMRs);

—Second, the ways in which they enhance the safety of nuclear power, a critical question in a post-Fukushima world;

—Third, a few brief comments on spent fuel; and

—Last, the key question—does an SMR cost-sharing program serve the national interest?

Let me speak first to the economic question.

Small nuclear plants have been around for a long time and in recent years they attracted interest because they could serve remote locations and electrical systems with smaller grids.

It was always known that the investment required to build a small nuclear plant would be less. But it was also believed—indeed, it has become almost an article of faith—that the economies-of-scale would make them uneconomic compared with larger plants.

When we first started NuScale in 2007, we knew this is what people believed. Yet we believed those old chestnuts might be wrong.

We saw the economic advantages of the simplicity of our design.

We saw the economic value of taking virtually the entire nuclear system, including its containment, to a factory where they could be manufactured under more controlled conditions.

But we also knew no one—either inside or outside the industry—would believe our assessment of the economics without some kind of proof.

In 2008, working with our engineering and manufacturing partners, we developed a detailed, bottoms-up cost estimate. When we got the results, we saw where we could make improvements in design and construction, so we spent an additional 16,000 man-hours in 2009 to take a second run at it.

We came up with unit costs—meaning $/kw—that surprised even us—they not only compared very well with large plant numbers—they were actually lower. When we showed these numbers to utility executives, they challenged us to independently validate them. We used a firm that has done independent cost estimating on many large nuclear plants, and they confirmed our estimates within 10 percent.

We too hear all the challenges to the economics of small reactors based on scaling and old rhetoric—but we've done the estimating—on an actual design, starting from the ground up. That's the only real way to answer the question. and the results establish quite clearly that we have a plant that will completely change the economic story for nuclear power, by not only lowering the financial barriers, but by doing so with a unit cost that is actually lower than competitive larger nuclear plants.

Next let me speak to the safety question.

When the NuScale concept was first funded by DOE in 2001, the principal designer, a professor at Oregon State University, Dr. Jose Reyes, set out to design what he hoped would be the safest light water reactor ever built. He had spent 10 years in the Nuclear Regulatory Commission (NRC) , he had been involved in the analysis of Three Mile Island, and he knew not only of the importance of safety, but the importance of validating safety through both large- and small-scale tests and experiments.

With the benefit of having designed the test facilities that demonstrated the passive safety features of the Westinghouse AP–1000—a very important advance in the safety of nuclear power and one that, by itself, would have prevented the accident at Fukushima—he asked what more could be done.

The result is the plant we are now seeking to commercialize at NuScale Power.

First, he developed a revolutionary concept for the containment—one that can be factory built, one that can withstand much higher internal pressures, and one that can be totally immersed in a pool of water underground.

The significance of this latter feature is very important. It means we have a very resilient and effective passive system for removing decay heat. About getting rid of the decay heat. This pool holds 4 million gallons of water and is sufficient to remove all the decay heat without ever having to add more water to the system.

This pool of water is housed in a stainless steel lined concrete building that, because it is mostly underground, is seismically very strong. The effect of this pool and the building is not only to provide security for removing decay heat, it also makes it much more difficult for any radioactive release to occur because there are now additional barriers outside the containment structure.

Second, he took advantage of simplicity. Drawing on the natural circulation learning from the AP–1000 tests, he designed the reactor to be entirely cooled by natural circulation—which eliminates pumps, pipes and valves and all the potential failure modes (and costs) associated with that equipment. In so doing, he eliminated the so-called large break loss of coolant accident that largely dominates the safety analysis of large plants.

Finally, he sought outside expert advice. Very early in our program, he convened two expert review panels, one chaired by Dr. Graham Wallace, a former chair of the Advisory Committee on Reactor Safeguards (ACRS), and a second chaired by Dr. Michael Corradini, a member of the National Academy of Engineering and a member of the ACRS. These independent reviews not only validated our belief in the safety of this plant, they also made helpful recommendations to enhance the safety even further.

We have since completed an initial probabilistic safety analysis, which shows that the probability of any event leading to fuel damage in this plant is once every 50 million years. This exceeds the requirements of the NRC by a factor of 5,000.

Because I know it is important to members of this subcommittee, let me speak also briefly to the question of spent fuel.

I will make three quick points:

—First, spent fuel in the NuScale plant is housed in an underground protected structure.

—Second, it has approximately four times the water volume of conventional spent-fuel pools per MW of thermal power.

—Finally, it uses what are called low-density fuel racks that make it much easier to remove heat from these spent-fuel assemblies.

Madam Chair and members of the subcommittee an SMR program serves the national interest in several ways:

—It serves the national goal of bringing to market a noncarbon source of baseload energy—that is, energy available all day, every day. Nuclear power achieves that goal and SMRs further it by overcoming financial barriers, and by reaching markets not accessible to larger reactor designs.

—Second, it builds the domestic manufacturing base, and thus creates jobs and the potential for exports.

—Third, and perhaps most important, it takes the safety of nuclear power to a new level, something that will be demanded in a post-Fukushima world.

—Finally, and most importantly this program assures that our own NRC will be engaged in the safety analysis and licensing of this next generation of reactors and will preserve what is known around the world as the "gold standard" of safety reviews.

Madam Chair and members of this subcommittee, it takes a substantial investment to bring these technologies to market. It may not happen without some kind of assistance. we have an opportunity to move this program forward and capture the unique advantages of this next advance in the use of nuclear energy—both on an economic and a safety front. I urge your support for this program.

Thank you for giving me this opportunity and I would be happy to answer questions.

# NuScale's Passive Safety Approach

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NuScale Power



## Inherently Safe Reactor Modules

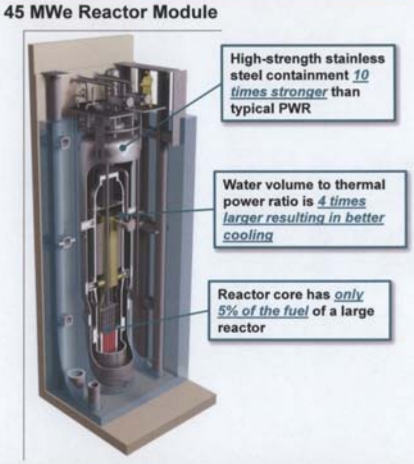
**Natural Convection for Cooling**
- Inherently safe natural circulation of water over the fuel driven by gravity
- No pumps, no need for emergency generators

**Seismically Robust**
- System is submerged in a pool of water below ground in an earthquake resistant building
- Reactor pool attenuates ground motion and dissipates energy

**Simple and Small**
- Reactor is 1/20th the size of large reactors
- Integrated reactor design, no large-break loss-of-coolant accidents

**Defense-in-Depth**
- Multiple additional barriers to protect against the release of radiation to the environment

**45 MWe Reactor Module**





NuScale Power

## Large Pool of Water Holds Reactor Modules

NuScale nuclear power reactors are housed inside ***high strength steel containment vessels*** and submerged in 4 million gallons of water below ground level inside the Reactor Building.

The Reactor Building is ***designed to withstand earthquakes, floods, tornados, hurricane force winds, and aircraft impacts.***

**12-module, 540 MWe NuScale Plant**

***Reactor and containment are submerged in underground steel-lined concrete pool with 30-day supply of cooling water.***

***Any hydrogen released is trapped in containment vessel with little to no oxygen available to create a combustible mixture.***

3 NuScale Power

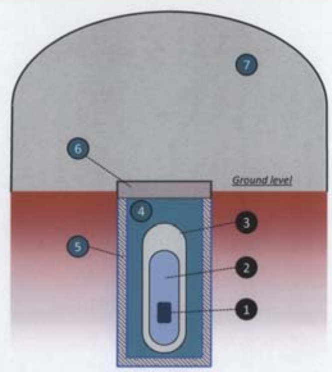
## Added Barriers Between Fuel and Environment

**Conventional Designs**

1. Fuel Pellet and Cladding
2. Reactor Vessel
3. Containment

**NuScale's Additional Barriers**

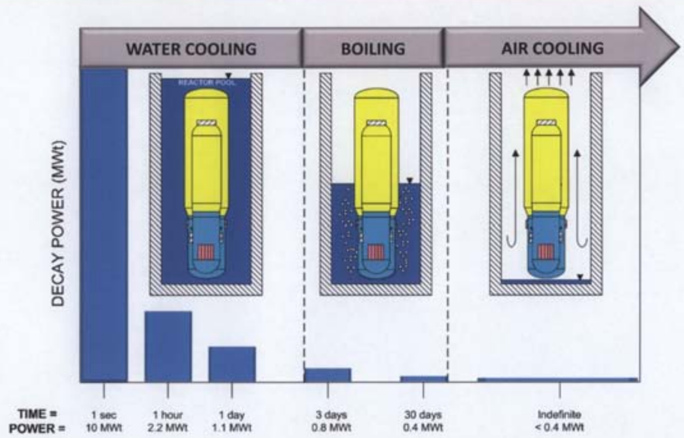
4. Water in Reactor Pool (4 million gallons)
5. Stainless Steel Lined Concrete Reactor Pool
6. Biological Shield Covers Each Reactor
7. Reactor Building




4 NuScale Power

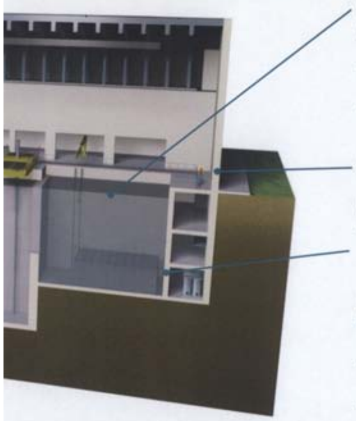
## Stable Long Term Cooling

*Reactor and nuclear fuel cooled indefinitely without pumps or power*




5 NuScale Power

## Spent Fuel Pool Safety



**Increased Cooling Capacity**

- ***More water volume for cooling per fuel assembly*** than current designs
- ***Low Density Spent Fuel Racks*** permit air cooling in the event of loss of coolant
- Redundant, cross-connected reactor and refueling pool heat exchangers provide full back-up cooling to spent fuel pool.
- Stainless steel refueling ***pool liners are independent from concrete structure to retain integrity***

**External Coolant Supply Connections**

- Auxiliary ***external water supply connections are easily accessible*** to plant personnel and away from potential high radiation zones (current problem in Japan)

**Below Ground, Robust Deep-Earth Structure.**

- Below ground spent fuel pool is housed in a ***seismically robust reactor building***
- Pool wall located underground is ***shielded from tsunami wave impact and damage***
- ***Construction of structure below ground in engineered soil limits the potential for any leakage***

6 NuScale Power

## Protection Against Extreme Events

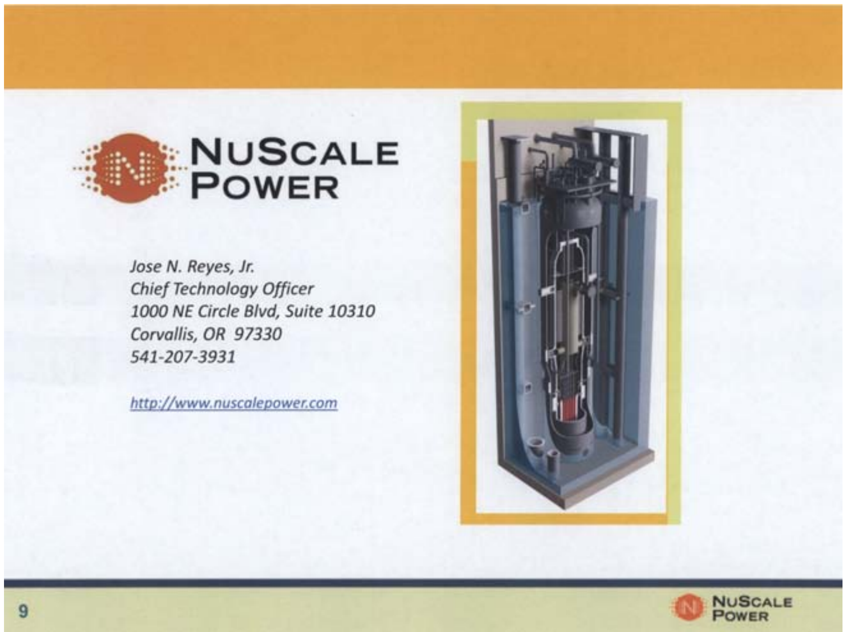
| Events and Threats | NuScale Plant Design Features |
|---|---|
| Earthquakes, Floods, Tornados, Aircraft Impact | • Deeply embedded reactor building provides robust seismic and external hazards protection. |
| Complete Station Blackout/ Loss of Offsite Power | • Passively Safe Nuclear Fuel and Containment Cooling Systems do not require onsite power, offsite power or diesel generators for safety. |
| Emergency Core Cooling | • No external water required for safety.<br>• Containments submerged in underground stainless steel-lined concrete pool filled with 30 day supply of cooling water.<br>• Air cooling adequate for indefinite period of decay heat removal beyond 30 days. |
| Containment Integrity and Ultimate Heat Sink | • No combustible mixture of hydrogen and oxygen inside containment.<br>• Unlimited performance window: No need for external intervention. |
| Spent Fuel Pool Integrity and Cooling | • Housed in underground protected structure.<br>• Has approximately 4 times the water volume of conventional spent fuel pools per MW of thermal power.<br>• Uses low density Spent Fuel Racks that can be air cooled in the event of loss of coolant. |

7 NuScale Power

## Comparison of NuScale to Fukushima-Type Plant

| Fukushima | NuScale Plant |
|---|---|
| ***Reactor and Containment*** | |
| Emergency Diesel Generators Required | None Required |
| External Supply of Water Required | Containment immersed in 30 day supply of water |
| Coolant Supply Pumps Required | None Required |
| Forced flow of water required for long term cooling | Long term (Beyond 30 days) cooling by natural convection to air |
| ***Spent Fuel Pool*** | |
| High Density Fuel Rack | Low Density Fuel Racks |
| Water Cooling | Water or Air Cooling Capability |
| Elevated Spent Fuel Pool | Deeply Embedded Spent Fuel Pool |
| Standard Coolant Inventory | Large Coolant Inventory<br>*4 times the water of conventional spent fuel pools per MW power* |

8 NuScale Power




Senator FEINSTEIN. Thank you very much.

Before we proceed to Dr. Moniz, I just want to thank the three heads of the companies for your straightforward presentations. It's very much appreciated, and I know there's a fiduciary issue here, but it's really appreciated, and I look forward to the Q and A.

Dr. Moniz, welcome back. It's good to see you again, Sir.

**STATEMENT OF DR. ERNEST J. MONIZ, PROFESSOR OF PHYSICS, MASSACHUSETTS INSTITUTE OF TECHNOLOGY**

Dr. MONIZ. Thank you, Madam Chair, Ranking Member Alexander. It's a pleasure to be back in front of you.

Let me start by declaring very clearly what my reference frame is, I think, for the key question before the subcommittee and that is that the core argument for Government support to accelerate new nuclear powerplant construction in the United States is, in my view, the provision of a zero-carbon option for base-load power generation to mitigate climate risks in a timely way.

Obviously, there are issues around what we will or will not do on carbon policy, but let me say that I certainly feel a sense of great urgency and believe that Mother Nature will be giving us increasingly clear signals.

But I do hope that, in any event, we would all agree that it is prudent to prepare the technology options that we will need for the marketplace in the future should we, in fact, have a significant price on carbon dioxide emissions.

In that context, nuclear is one of those many options, and I appreciate the earlier reading of my earlier statement, Senator Alexander, about some of the other technologies as well.

Now, when it comes to the issue of Government support, I do believe there are a number of barriers to the private sector assuming the full risk for the major capital investment needed upfront right now for new plants incorporating new technology, and these include the lack of a price signal on carbon, the absence of end-to-end testing of streamlined licensing procedures at the NRC, new uncertainties about regulatory requirements following in the events at Fukushima and the lack of experience at NRC in licensing reactor technologies other than large light water reactors. So I believe these are market imperfections that do merit considering some public support.

I think it's important for, again, the public to help provide options for this future marketplace that could look quite different from where we are today.

Now, a major factor for nuclear plants is obviously the cost of capital, and, there, a major issue is the financing structure. Our MIT baseline economics evaluation of base-load plants includes a risk premium for any nuclear plant, a higher equity-to-debt ratio and a higher cost of capital.

The question is will SMRs—and, by the way, it has a large impact, that financing risk premium. An issue is will SMRs, smaller cost et cetera help to work down that premium that, in itself, is a very, very large issue as far as the cost of nuclear plants.

In fact, I would note that even if the so-called overnight unit cost of an SMR is larger than that of a large reactor, it does not mean the project unit cost is higher if construction times are shorter and financing is available at a more attractive rate.

The 2020 SMR option, in fact, will be available only if we start now, and even then it will be very, very tight, and it's in that context that I do support the administration's request of $67 million to move toward essentially license or engineering certification studies for these technologies.

In fact, that comes to the safety and security issues. I will not repeat all the issues that had been stated about advantages of SMRs and safety.

I will note that these features need to be certified by the NRC, and there are questions. For example, I would say the long-term integrity and maintenance of steam generators in integral design and the integral system transient characteristics need verification. Judgments about passive safety should be a system judgment, not something around individual technologies.

In that context, I will just note that an emerging very important tool is large-scale simulation, and I would note that, including at CASL, at Oak Ridge and the Nuclear Energy Advanced Modeling and Simulation program, I think we are moving to do that.

I would urge that the NRC should remain very close to these developments to be able to suggest ways in which this helps safety reviews and positions them for rapid adoption of new tools.

I will just also observe that earlier it was stated that—the word "cascading" was used at Fukushima. They should be very careful. There was no cascading of events between reactors. They were essentially independent, driven by a common event, obviously, the tsunami.

What it does raise, however, a point that Mr. Lyman made, is that when we think about the staffing of multi-modular units, we think about staffing in cases where there might be common problems in multiple modules.

My last point involves policy considerations. While I do support moving forward, I want to point out there are, I think, policy risks that need to be addressed.

The first is that we do not want this program to end up with the Government choosing the technologies that go forward. We have many contenders, not only the three at this table, not only LW SMRs, and I believe it's important that we have a transparent program design from the DOE that leaves open the possibility of others coming in for some assistance.

Frankly, we don't want to repeat history and be left with only light water options for the long term, only because it's what we've always done.

The last point I will make is that—In fact, I should add that the SMRs have this very attractive feature, frankly, in comparison to the nuclear business. There has been an unusual amount of innovation. That's what we want to encourage and not suppress, for example, with policies that channel us to one particular technology.

My second and last point is that, as with light water reactors—I mean, conventional light water reactors—there will inevitably arise a request down the road for direct construction support for the SMRs, and I believe the case here—I will put an advance marker on the table—is far less compelling than it was for the light water reactors.

Nevertheless, I would want to emphasize a principal as we go in this direction. For light water reactors, the Congress has approved—as was mentioned earlier, I believe—a substantial loan-guarantee program.

Whereas, in our MIT 2003 report, we emphasized, rather, approaches that reward success and don't provide insurance against failure, which is one way to interpret a loan guarantee.

PREPARED STATEMENT

So, as we go forward, whether it's a production tax credit or a purchase-of-power agreement, we need to have any subsidies be those that reward the production of electricity according to the economics expected with successful construction and operation and not ensuring against failure.

Thank you.

[The statement follows:]

PREPARED STATEMENT OF DR. ERNEST J. MONIZ

LIGHT WATER SMALL MODULAR REACTORS

Chairman Feinstein, Senator Alexander, and members of the subcommittee, thank you for the opportunity to present and discuss views on the economics and safety of Light Water Small Modular Reactors (LW SMRs) and on some policy issues regarding possible Government support for accelerating their deployment. 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, Massachusetts Institute of Technology (MIT).

The core argument for Government support to accelerate new nuclear powerplant construction in the United States is, in my view, the provision of a "zero"-carbon option for baseload power generation to mitigate climate risks in a timely way. Energy security concerns are not a compelling reason, given the substantial coal and natural gas resources of the United States, as well as renewables with expanding deployments, such as wind and solar. Also, material displacement of oil as a transportation "fuel" is quite some time away.

There are currently 104 nuclear plants operating in the United States. The urgency of the climate change risk mitigation imperative argues for a move toward low-carbon power generation, but there are a number of barriers to the private sector assuming the full risk for the major capital investment needed for a new nuclear plant incorporating current technology. These include:

—The lack of price signals for the climate change risks associated with greenhouse gas emissions from fossil fuel combustion;
—The absence of end-to-end testing of streamlined licensing procedures for new nuclear plants; and
—New uncertainties about regulatory requirements following the events at Fukushima.

Policies are in place to accelerate introduction of "conventional" large LWRs (GWe and bigger) through, for example, loan guarantees. Some projects are moving ahead on this basis, but the number is far fewer than were anticipated when the legislation was passed. In this testimony, I will discuss the motivation for advancing SMRs toward design certification and, if the economic case can be made, their licensing and construction.

*Baseload Electricity Economics*

The costs of nuclear powerplants should be put in the context of baseload alternatives. These are illustrated in the table showing levelized electricity costs for new nuclear, coal, and natural gas plant construction. These data are 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. We have however been through many significant excursions in natural gas prices over the last decades, and the recent MIT interdisciplinary study on "The Future of Natural Gas" finds that natural gas prices slowly rise on average over time, suggesting the need for caution about over-reliance on any single fuel source. Furthermore, eventually natural gas itself becomes too carbon-intensive in a few decades if carbon dioxide emissions are severely limited relative to today's levels.

These factors emphasize the importance of providing options for a future marketplace that could look quite different (e.g., a substantial price on carbon dioxide emissions). Nuclear is one such option. The generation portfolio decisions are likely to be different in different parts of the country depending on 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

[In 2007 dollars]

| | Overnight cost (\$/kW) | Fuel cost (\$/MBtu) | Levelized cost of electricity (cents/kWh) | | |
|---|---|---|---|---|---|
| | | | Base case | \$25/ton-$CO_2$ price | Same cost of capital |
| Nuclear | 4,000 | 0.67 | 8.4 | 8.4 | 6.6 |
| Coal | 2,300 | 2.60 | 6.2 | 8.3 | |
| Gas | 850 | 4/7/10 | 4.2/6.5/8.7 | 5.1/7.4/9.6 | |

Coal (without carbon dioxide capture), like natural gas at the low- and mid-range fuel prices, has lower capital and levelized electricity costs than our baseline nuclear costs. However, coal is the most carbon intensive fossil fuel and even a modest carbon dioxide emissions charge of \$25/ton would make nuclear competitive with coal. For reference, \$60/ton is generally viewed as a somewhat optimistic emissions charge to warrant carbon dioxide capture and geological sequestration on economic grounds; such a charge would drive the coal levelized electricity cost beyond 11 cents/kWh.

A major factor is the cost of capital, which hits nuclear powerplant construction particularly hard because of the high capital costs and the longer construction times

(5 years) that are typically required. Our baseline financing model assigns a risk premium for nuclear, meaning both a higher equity/debt ratio and a higher cost of capital. The risk premium has a large impact, as seen in the table. Elimination of the premium brings the nuclear levelized cost into line with coal and with moderately priced gas even with no carbon dioxide emissions price. Of course, there is still the issue for many utilities of the $6–$10 billion project cost for a large LWR.

An entirely different approach to new nuclear powerplant construction lies with SMRs. This has the possibility of addressing the cost/financing 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 10 to 300 megawatts. None have been through a licensing procedure at the Nuclear Regulatory Commission (NRC), 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 means that the total capital cost is more in the $1 billion range rather than an order of magnitude higher. Capacity can be built up with smaller bites, and this may lead to more favorable financing terms—as we have seen, a major consideration for high capital cost projects that take years to license and build. Furthermore, the possibility of bringing part of a larger multi-module plant online means that cash flow can start earlier. This is obviously good for the plant owner, but it can also be important for regulators who are increasingly being asked to place part of the nuclear construction cost into a rate base before electricity is generated. Other benefits lie with more flexibility in providing reserve margins for shutdowns, with grid integration, and with replacement options for fossil plants (which typically are sized well below a 1,000 MWe).

Still, the SMR must come in with a capital cost that is also competitive with LWRs on a unit basis; however, it is quite possible that a higher unit overnight cost can still yield a lower unit project cost because of improved financing terms and a shorter construction time. 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 onsite. 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 enhance the level of activity in bringing SMRs to market. LWR-based technology options would be advanced toward licensing ($67 million request), and other SMR technologies would be supported ($29 million request) for R&D needed to have them follow in the licensing queue. The program is modest, but sensible in light of today's fiscal realities. 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 10 years lamenting the lack of a technology portfolio needed to meet our energy and environmental needs economically or to compete in the global market. We need to get on with the business of providing low-carbon options for a carbon-constrained future, with a principal role of government being to help establish the engineering and economic performance information for credible competitors in a future marketplace conditioned by an explicit or implicit carbon dioxide emissions price. Public investment is too low by about a factor of three (PCAST, November 2010). The 2012 proposal offers a start for SMRs.

*Safety and Security*

The U.S. record for nuclear power safety and security has been a good one for the last 30 years. Nevertheless, Fukushima has clearly raised the stakes. New LWR designs incorporate a greater reliance on passive safety systems that can help ameliorate some of the problems that developed with loss of power and active cooling at Fukushima, but SMRs have mostly been designed to enhance safety further. The designs generally emphasize natural convection cooling such that cooling can be sustained for a considerable time without external power. The small size of the reactors facilitates decay heat removal by natural means. Integral designs, wherein various primary system components such as steam generators are brought inside the pressure vessel, tend to eliminate large loss of coolant accidents. Below-grade construction for both the reactor and spent-fuel storage pools and enhanced seismic protection are also common features of SMRs.

Nevertheless, there is some way to go before these design features are certified by the NRC (this would be supported partially by the DOE program proposed for 2012). This is especially so for non-LW SMRs, since the NRC experience and licensing procedures are almost exclusively based on LWRs. It is very important that an investment be made in diversifying and deepening the NRC technical strength for dealing with multiple nuclear technologies—such as gas reactors, fast reactors, molten salt reactors. Otherwise we will block out or seriously delay innovative technologies for lack of a regulatory basis.

There will be questions for LW SMRs as well. For example, the long-term integrity and maintenance of steam generators in integral designs and the integral system behavior during transients, including startup, needs verification. Judgments about passive safety will need to be made in the context of an integrated appraisal of system design.

An important emerging tool for advancing design and design certification is leading-edge, large-scale computer modeling and simulation. The 2003 MIT report on the "Future of Nuclear Power" placed the highest priority for DOE nuclear R&D on development of such capabilities, with a perspective that the nuclear industry lagged far behind many others in this regard. The latter observation, in my view, remains true, but the DOE now has a focus on rectifying this both through the Nuclear Energy Advanced Modeling and Simulation program and the specific innovation hub Consortium for Advanced Simulation of Light Water Reactors (CASL). The latter is headed by Oak Ridge National Laboratory and involves several other national laboratories and universities, including MIT (I should note that I serve as chair of the CASL advisory board). I believe that these advanced simulation capabilities, when fully developed, will serve as key facilitators of nuclear technology certification and of nuclear science and technology innovation. In particular, such tools can be enablers of SMR deployment at the end of this decade. The LW SMR design certification could benefit specifically from the tools being developed at CASL, but alternative technologies, such as gas and fast neutron spectrum SMRs, should also be addressed. The NRC should remain close to these developments so as to be able to suggest development paths useful to the regulatory challenge and to position for rapid adoption and utilization.

The SMR configuration may have security advantages as well, such as the benefits of below-grade installation. Nevertheless, the safety and security requirements deemed necessary by the NRC remain to be determined and could have a significant impact on the economics of SMRs. Post-Fukushima, the NRC will re-examine seismic, flooding, power cutoff, backup, and spent-fuel management requirements. If the judgment is that various functions, such as security, do not scale with size of the reactor or that operational savings are not realizable for operation of a cluster of modular reactors, then the operational costs for SMRs could be challenging. In the extreme, if the preferred position of nuclear power in the dispatch order based on marginal operating cost is compromised, the value proposition of SMRs would be seriously reduced because of the large sunk capital costs. These issues remain to be clarified in the licensing process.

Nuclear weapons proliferation stemming from misuse of fuel-cycle technologies is another security concern. SMRs do not pose a particular problem relative to "regular" LWRs. Indeed there can be some advantages, for example for technologies that require less frequent refueling. However, apart from possible technologies that have the full reactor module returned to the country of origin or special fuel forms (e.g., TRISO particle fuel for gas reactors), the proliferation issue is not an especially strong differentiator among LW reactor technologies.

Spent-fuel management is also a concern, especially in the absence of a licensed geological repository or suitable consolidated storage sites. The SMRs are generally designed to accommodate a lifetime of spent-fuel storage in below-ground pools. However, especially for a multi-module plant, these design features can equally be incorporated into the design of new large LWRs.

*Policy Considerations*

While I do believe that SMRs represent a sufficiently novel and promising approach to nuclear power to merit public risk-sharing for first movers, much remains to be thought through on the specific implementation plan. There are some major policy risks.

The first, and more important, is that Federal assistance at this stage for two LW SMRs, among the many serious candidate technologies in the U.S., could lock-in these technologies. This is especially so for SMRs (versus large LWRs) since serial production of a significant number of units with an identical design in a manufacturing environment is crucial for the value proposition. This is a challenging issue since, as noted earlier, practical pursuit of serial production will require narrowing down the options—but the Government must be very careful about being the arbiter of technology choice. This tension needs to be addressed transparently. Indeed the smaller scale of SMRs relative to traditional LWRs has encouraged an unusual amount of innovation in the nuclear technology space, and it is important to nurture such innovation, not suppress it. This applies both to LW SMRs and to the other SMR technology pathways that are not part of the initial design certification cost-sharing program. The DOE needs to propose from the beginning a program structure that, subject to congressional appropriations, will leave open the possibility of risk-sharing with promising non-LW technologies that have successfully emerged from the R&D phase. If not we will repeat history and be left with LW options because that is what we have always done. The Quadrennial Energy Review recommended by PCAST, and the first installment Quadrennial Technology Review being carried out by DOE, offers the proper venue for carrying out the underlying analysis, but DOE presently lacks sufficient capacity to carry out the needed level of quantitative analysis for the QER/QTR; rectifying this is central to the Department's future effectiveness in formulating energy technology policy. With regard to SMRs, the marketplace should be left to decide the appropriate time for down-selecting to one or two designs that can be manufactured in serial fashion to very high-quality standards, using the information gained from the Government cost-shared program.

This raises the issue of the degree to which the public benefits from the experience of first movers that are beneficiaries of public support. This issue is not specific to SMRs, but nevertheless deserves emphasis. When all is said and done, the public's investment in the first mover plants should provide information for equipment vendors, users, policymakers, investors, and others. The Government's interest is in stimulating further innovation and competition. This is not to say that specific IP is shared, but to date the pendulum has swung too far toward the cost-sharing company having proprietary rights to control data and information. This needs to be addressed to assure taxpayers that their funds are not being used to cement market control by individual companies.

Second, as with LWRs, there will inevitably arise a request for direct construction support for the first SMRs. The case is less compelling here, given the relatively smaller capital exposure. For large LWRs, the Congress put in place a substantial loan guarantee program. The 2003 MIT report supported a production tax credit (PTC), at least for tax-paying entities, on the basis that such a credit rewards success in the project. In contrast, a loan guarantee can be interpreted as insuring against failure. Clearly, the opportunity to reduce the cost of capital on such a major capital commitment is understandable for the companies involved. For the reduced commitment needed for an SMR, we do not see the need for a major extended SMR construction subsidy beyond the legitimate areas of design certification review and R&D. However, if they are implemented, the principle should be to implement first mover subsidies designed to reward project success for different performers (versus failure insurance); this will help sort out the contenders for Federal support.

*Conclusions*

SMRs represent technology innovation that could change the trajectory of nuclear power deployment in a relatively short period. However, much remains to be understood before they are licensed for material deployment, and the DOE should continue and grow support for key enabling analytical tools. The arguments for public "first" mover risk-sharing are reasonable, and should be pursued to a degree, but the public's interest in gaining and disseminating experience from demonstrations/first movers should be promoted more strongly.

Thank you, and I look forward to addressing your comments and questions.

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NOTE.—The MIT reports "Future of Nuclear Power" "Future of the Nuclear Fuel Cycle", and "Future of Natural Gas" can be found at web.mit.edu/mitei/.

Senator FEINSTEIN. Thank you very much, all of you. There is much to think about.

ECONOMICS OF INDIVIDUAL SMRS

Dr. Moniz you're an academic. You're an expert in this area. Are these things commercially viable on their own?

Dr. MONIZ. I think that's exactly what we need to find out. We have two questions. We need to certify the safety characteristics through a system evaluation, and I believe that's what this program will help accomplish, and then we have to find out—excuse me—if the dog hunts in terms of economic viability.

I do believe that, for this decade, in my context of moving toward lower carbon, natural gas will be a major bridge, but it's only a bridge to what I believe will be a required deployment of zero-carbon options, and we have to see what nuclear's role is in there.

I do believe the SMRs do have a lot of these attractive features that provide them much more flexibility in meeting market demands.

Senator FEINSTEIN. Okay. Let me put this out on the table. My big concern is that they're not cost effective on their own, that they have to be clustered, and, therefore, how many do you cluster? Where do you stop, that kind of thing.

The second point is whether, in fact, they will raise the cost to the consumer of power. That's the 10 to 30 percent.

So let me ask each of the three CEOs if they would care to comment on that question, and then Dr. Lyman, if you would, why don't we begin with you, Mr. Ferland.

Mr. FERLAND. Sure, I'm happy to comment on that.

You know, our view of this is that what you have in the past is economy of scale has been driven by large plant, spread out your costs over a large number of megawatts that are produced.

On the AP–1000, which we're constructing today, we are shifting to more of a module-type design where we manufacture pieces of those units somewhere else and we bring them on site and assemble them. So it's a step in the right direction, but we still rely on—honestly—on the relatively large size of that unit.

And then the big jump on SMRs is true modular construction where we can really gain an assembly line like efficiency, and we think, as I said before, we can do that in the ballpark of about 10 units, ship the units to site and finish them and put them into operation.

Senator FEINSTEIN. Let me see if I understand you. So to be cost effective, you have to manufacture 10 units, but that doesn't mean you have to cluster them all together, right?

Mr. FERLAND. That's——

Senator FEINSTEIN. So it's just the manufacture of 10, and then is one separately operating cost efficient over time?

Mr. FERLAND. Yes, Madam Chairwoman. You're exactly correct in that we think we need to have 10. They do not necessarily have to be clustered together.

And from that point forward, our goal is to have the cost of these units be at or below the current cost of nuclear today, so it's extremely competitive, and my belief is that we'll get there and exceed those numbers.

Senator FEINSTEIN. Thank you.

Mr. Mowry.

Mr. MOWRY. Thank you, Madam Chairman. With regard to the economics, first of all, we would not be investing our own company's resources, and regardless of the degree of cost sharing that would go forward, we're talking about several multiples of our yearly earnings that we would have to invest on our own after this program, and this represents a significant business risk and business investment, and, clearly, we would not be pursuing this if we didn't believe that, in the long term, we would have a competitive product that we could sell.

And we believe that we are going to have a competitive solution not only because of what Mr. Ferland said with regard to the factory assembly, but there is an inherent simplicity around SMRs because of this idea of an integral reactor design that allows you to simplify all of the other costly systems that you need around this thing to protect it properly.

Senator FEINSTEIN. Stop for a second. Are you essentially saying the same thing that Mr. Ferland said that if you can manufacture 10, from a manufacturing point of view, that's cost effective, but that you can operate one in a cost-effective way?

Mr. MOWRY. Yes, and, in fact, we have a consortium of utilities in the United States that are funding development of policies and other things that are important for the deployment of SMRs.

We have 14 utilities that are called GNTs that are small, regional cooperatives that have in their network less than 2,000 megawatts of generation requirements. They cannot afford and they cannot use large reactors. They don't even need a cluster of small ones.

They're people who need one or two small reactors and they see that the potential economics of an SMR can allow them to basically own one or two of these and supplement their transmission infrastructure with carbon-free generation.

Senator FEINSTEIN. Thank you.

Dr. Lorenzini.

Dr. LORENZINI. Thank you. First of all, I would say that the biggest test for cost effectiveness for us is our investors. They grill us pretty hard, and they're not going to make the investment unless they're satisfied that we have a technology that's going to reach the market. And reaching the market means that it has to be competitive economically with other opportunities and customers have to validate that.

So our investors go back and forth between scrutinizing us, talking to customers and going back and forth with that dialogue. Those are people with skin in the game.

Senator FEINSTEIN. So you're saying the same thing. Is your cost of production at 10 to be cost effective and one will stand on its own?

Dr. LORENZINI. Our model does not involve marketing a single module necessarily. We can market a single module in some markets. We don't think it's cost effective for us to market one module because if you do that you wind up with a 45-megawatt module distributed throughout the system and it's just not practical to do that.

What we think we've done actually by creating this modular design that clusters reactors is create a huge flexibility for customers.

We build a single building and we add modules, each one with its own independent system and each one totally contained in its own system that allows them to increase their load to match demand.

The National Association of Utility—has endorsed small reactors, because they're looking at it from the perspective of customers.

We've got as well an 11-member customer advisory board. All of them are interested because they see this as a huge opportunity for them to serve their customers and lower their cost to customers.

Senator FEINSTEIN. Thank you.

Let me go to Dr. Lyman first. Dr. Lyman, do you have a comment? We've heard the three companies.

Dr. LYMAN. Yes, thank you.

I'm not an economist, but I have to say that I still can't see how they can overcome some of these economies-of-scale hurdles with the kind of deployment they're talking about.

First of all, in my written testimony, I refer to the one study that I'm aware of that tried to quantify the benefits that SMR vendors have been arguing can actually overcome the economies-of-scale disadvantage, and that study found that, at best, they could get it close to the cost of a large reactor, but—you know. So they can't beat the large reactor.

With regards to the clustering issue, it has to do with the economies of scale of the balance of the plant and the infrastructure at the site.

And so this is why I'm concerned that unless—this is why SMR vendors want regulatory relief from certain requirements.

If you need the same number of security officers on every shift for a single 125-megawatt reactor as you need for a 1,000-megawatt reactor that would lead to an excessively high operating maintenance cost.

So this is why I believe that there is a fundamental tie toward improving the economics of SMRs at single sites with some of the relaxation of security and safety requirements that I've been talking about.

So I don't believe unless that kind of weakening of regulatory requirements is granted do they stand a chance of competing with larger reactors.

Senator FEINSTEIN. Thank you very much. Senator?

Dr. MONIZ. Madam Chair, may I just——

Senator FEINSTEIN. Oh, I beg your pardon. Dr. Moniz, I'm sorry.

Dr. MONIZ. I beg your pardon. May I—I have a couple of comments.

Thank you, Madam Chair, because I want to say that I do see how one can draw a conclusion that one cannot beat a large reactor, because there are many variables, including the potential—I'm not predicting this—but the potential for very different financing structures, which has an enormous impact in a technology where it's all upfront capital. So I think that remains to be seen.

Number two, nevertheless, I would say, while I support this early support, as I said earlier, when it comes to construction, risk should remain with the private sector. Let these guys prove it. And if not, well, they and their investors will lose the money.

LOW-CARBON ENERGY OPTIONS

Third, we should note again in this context of options for the future—in particular low-carbon future—that about one-third of our coal fleet is more than 40 years old, less than 300 megawatts and inefficient. Those plants are not going to get any kind of major investment for retrofits. I don't mean only carbon capture. I mean for criteria pollutants and mercury, et cetera.

We are going to need some technologies, which I hope will be very low-carbon technologies, whether it's nuclear or wind and storage, et cetera, but we're going to need those technologies in a 10-to-20-year timeframe in spades.

That's why I feel that even though our finances are pretty stretched at the moment, and I have sympathy for your job on appropriations, we just need to make some low-carbon options available in 10 years. We do not have very attractive options at this stage in terms of cost.

Senator FEINSTEIN. Can you be more precise on whether coal can be a real source for these?

Dr. MONIZ. Well, I think that will be a decision to be made, of course, by the utilities and the plants, but another point about finances, which is why I think we should not make black-and-white statements, is that the cost of a—let's say a green-field plant of any type, it's not just the power source, it's all the balance of plant—hooking up the transmission systems, et cetera, et cetera.

Well, if you're replacing an existing 250-megawatt plant and you can use—you're all set up into the grid, et cetera, that's another huge financial implication.

So all I'm saying is I don't know the answer, but it sure sounds like the kind of option we'd like to have if these guys can produce what they're saying, and if they can't, I'd say put the risk on them.

Senator FEINSTEIN. All right. Thank you very much, Senator, very interesting.

Senator ALEXANDER. It is, and I thank all five of the witnesses for the diversity of views here.

SMR PRODUCTION BUSINESS MODELS

Senator Feinstein has honed in on a very important point. Let me ask the three of you in the middle, Mr. Ferland, does your business model—I'm not asking you to say whether you would turn down Federal money if Senator Feinstein offered it to you. I'm just saying does your business model for SMRs include a Government subsidy after the first 10?

Mr. FERLAND. No, it does not. The assumption is that we use it to kick start the program upfront. It lets us accelerate the R&D spending and the engineering work faster than we normally would, and then we rely, as my colleagues have said, on the fundamental business case——

Senator ALEXANDER. So it'd be the marketplace. So you wouldn't—well, I'm not asking you to say you'd reject it, but you're not moving ahead with the idea that after the first 10 are made that you need Government support to succeed in the marketplace.

Mr. FERLAND. That's correct. We just need the upfront help.

Senator ALEXANDER. Mr. Mowry, what about you?

Mr. MOWRY. Our business model does not include subsidies.

If I could just amplify for a moment here, there was a comment made earlier with regard to a cost premium, and I can say, in discussions with our potential customers, they're not looking necessarily for a relative cost reduction. They would like to have the ability to invest in incremental power generation without a cost premium.

In other words, if you're going to sell me a reactor that's 10 percent of the size, I would like to invest 10 percent of the money.

And this whole discussion about subsidies, a lot of the challenges that we have today are related not to the relative cost of nuclear, but to the—as Dr. Moniz said—to the large magnitude of the investment that's required that, frankly, it's betting the farm for a lot of utilities.

You can cut that investment down by a factor of 10, all of a sudden a lot of the drivers for things like loan guarantees go away and this becomes a more standard economic decision for a utility.

And so we don't see the need for subsidies in the long term. Our goal is to create a carbon-free, base-load option that is competitive in the marketplace without long-term subsidies.

What we are looking for is risk sharing as we try to get a first-of-a-kind option out there by 2020.

Senator ALEXANDER. Mr. Mowry, without—even though Senator Feinstein is chairman of the Intelligence Committee, I don't want to get you in any trouble with classified information, but you already know something about making small reactors, right?

Mr. MOWRY. Yes, we do.

Senator ALEXANDER. Would you say the United States is the world's leader in the production of small reactors today?

Mr. MOWRY. At this point, yes.

Senator ALEXANDER. Yes. And does your company make money?

Mr. MOWRY. Some. Yes.

Senator ALEXANDER. Well, I mean, is it a profitable business?

Mr. MOWRY. Yes, it is profitable.

Senator ALEXANDER. Yes. So you're already in a very profitable—you're already in a profitable business making small reactors for the United States Government.

Mr. MOWRY. Yes, we are.

Senator ALEXANDER. Is that right?

And they're used in 103 nuclear Navy vessels. Is that correct? Or a number——

Mr. MOWRY. They are used in the Navy, yes.

Senator ALEXANDER. Whatever the number might be.

Senator FEINSTEIN. Yes.

Senator ALEXANDER. Mr. Lorenzini, does your business model include subsidies, say, after the first 10 from the Government?

Dr. LORENZINI. No, Sir. Our business model says it requires a substantial front-end investment to develop the design and to get the design licensed and certified before the NRC. Once that's been done, we go to market. We don't need any further subsidies.

Senator ALEXANDER. So Dr. Lyman thinks you may not make money, but that's really your problem, right? I mean, unless the Government decides it wants to create some sort of permanent subsidy for what you're doing, which I think is very unlikely and which I would not be inclined to support.

REACTOR DESIGN IN LIGHT OF FUKUSHIMA

Dr. Moniz, I believe Mr. Mowry said that the design of his SMR would make it such that—well, let me ask this way: What happened at Fukushima was that there was no water to cover the spent-fuel rods, basically, right?

Dr. MONIZ. That was one of many problems.

Senator ALEXANDER. Well, let's say if there had been water to cover the spent-fuel rods from the instant of the natural occurrences, there wouldn't have been a problem. Is that right?

Dr. MONIZ. Both for the spent fuel and for the reactor cores as well if they had remained——

Senator ALEXANDER. So, now, he said that there wouldn't be—with his passive system that nothing would happen for 7 days. Does that sound plausible to you?

Dr. MONIZ. Sounds plausible, but, again, I would rely upon a hard review by the NRC.

Senator ALEXANDER. Now, as I understand your testimony, you're saying that this is not something that we should barge forward with 100 miles an hour today to start building small reactors.

You're saying that we should move ahead with the R&D phase as quickly as we can to see whether we should license the safety of these and the sites upon which they should go.

Dr. MONIZ. Well, I would term it not so much R&D as it is kind of design and engineering certification and an evaluation to get a license.

Senator ALEXANDER. And some of those dollars are spent so that the Government can do its job properly in terms of supervision of such reactors. Is that not correct?

Dr. MONIZ. I agree with that, yes.

Senator ALEXANDER. Now, as I also understand——

Dr. MONIZ. If I may just add, and, again, I think we need to also—and it's not only for LW SMRs. I think we need more investment in the NRC to develop the capability on a broader range of technologies to move promptly into a licensing——

Senator ALEXANDER. I have two other questions, if I may, Madam Chairman.

Senator FEINSTEIN. Yes.

CLEAN ENERGY

Senator ALEXANDER. One is you began with the climate-change point, which is that we're going to need as many good options of clean electricity as we can have. And by clean, that means without sulfur, nitrogen, mercury, carbon, and you mentioned natural gas.

Today, coal is 46 percent of our electricity. Natural gas is 22—going up fast, because that's what utilities are buying, but natural gas has considerable carbon in it. Does it not?

Dr. MONIZ. Well, it's carbon light and——

Senator ALEXANDER. Forty or 50 percent as much as the cleanest coal plant?

Dr. MONIZ. Well, if you factor in efficiencies of the plants, I would call it about 45 percent of the carbon intensity of coal.

Senator ALEXANDER. Yes.

Dr. MONIZ. And if we look—we do have at MIT a recent report on the future of natural gas and fundamentally the analysis comes out confirming the idea of gas as a bridge for a while. If it substitutes for coal, it's a key part of carbon reduction, but, eventually, it itself is too carbon intense and needs zero carbon.

Senator ALEXANDER. And am I correct in saying that nuclear power today is nearly 70 percent of our carbon-free electricity?

Dr. MONIZ. Yes, I would say roughly, yes.

Senator ALEXANDER. And you mentioned the closing of the coal plant, Senator Feinstein, on the TVA region. They've decided to close 18 coal plants, which mean they're too dirty to operate, and they're too expensive to put on the pollution-control equipment. And that means they're going to go from 50 percent to 35 percent coal.

So the question is then what do we do, because we don't want expensive power. Otherwise, our companies go overseas, and the decision we've made in the TVA area is that we're opening new nuclear plants, which is the—so nuclear power is going from 30 percent to 40 percent.

As you envision a future for the United States, Dr. Moniz, do you see a situation where we could do what we need to do to have carbon-free electricity at a reasonable cost as a reliable source without nuclear power?

Dr. MONIZ. Well, my view is we have a limited number of arrows in the quiver. We have nuclear. We have renewable, especially wind and solar, in terms of a possible more ubiquitous deployment, and we have carbon capture and sequestration.

Today, I think that nuclear and wind, obviously are poised to make major contributions, and are. Solar has a ways to come, although I'm very optimistic in the long term for solar, but we have to solve storage problems.

CCS, frankly, of those I must say I would call at the moment the most challenged in terms of the economics.

Senator ALEXANDER. I agree. I think the Holy Grail of—the scientist who figures out how to capture carbon from a coal plant——

Dr. MONIZ. More cheaply.

Senator ALEXANDER [continuing]. Will win many prizes.

ENERGY STORAGE

Madam Chairman, this gets to a discussion we've had before and we're likely to have again.

Dr. Moniz mentioned storage. Batteries we've had a little discussion about, but wind or solar or any intermittent power is not going to be very useful to us unless we have much better batteries, correct?

Dr. MONIZ. Well, storage, in general. Batteries, but also——

Senator ALEXANDER. Batteries are the leading opportunity——

Dr. MONIZ [continuing]. Or other opportunities, but storage is absolutely critical for intermittent renewable.

Senator ALEXANDER. And here's my last question. Dr. Chu is organizing his Department around objectives which I find very interesting.

For example, R&D to try to get the cost of driving an electric car down to 1 cent a mile for fuel, getting the cost of solar down to $1 per kilowatt, finding new ways to recycle used nuclear waste.

ROLE OF FEDERAL SPENDING IN RESEARCH AND DEVELOPMENT

Does that sound like—and batteries, trying to find ways generally to improve that. Does that sound like an appropriate way to spend Federal dollars as opposed to permanent subsidies to energy companies that might be operating mature technologies?

Dr. MONIZ. I am strongly in favor with your statement that extended subsidies for any technology are just an indication of a failed policy and a failed technology.

So I think there is a role, as you have emphasized, for limited-time subsidies when they offer the real prospect of having the technology become marketplace competitive at the end of that period of support. I think that's the criterion.

I just might add, by the way, earlier you did scare me a little bit when you said jump-start batteries. It reminded me of February in Boston, but anyway, that's—but I think—I totally agree with that philosophy, certainly.

Senator ALEXANDER. Thank you, Madam Chairman.

Senator FEINSTEIN. Thank you very much, Senator.

I want to thank everybody. I think this has been a very good hearing. It's been a very interesting hearing for me.

CONCERNS ABOUT NUCLEAR WASTE DISPOSAL

I think it's fair to say that my colleague, who I have great respect for, has been an enthusiastic supporter, and I think it's fair to say that I am very reticent about this.

I'm reticent about it because if we let this go without a policy for spent fuel, if we close the plant or the repository in Nevada after spending $14 billion on it, we have $13 billion in liabilities because we can't dispose of the waste as we're supposed to. Adding to these problems doesn't seem to me to make good sense.

So I think the question comes—and something that I really want to tackle, and, Lamar, that I hope you'll work with me on is how do we develop a spent-fuel policy for the Nation. Is it a regional system? Is it one repository?

I think the last report I was reading said it should be voluntary on the part of the State. I agree with that, and I gather there is at least one State that's willing to step up.

I think we have to deal with these issues. Otherwise, I feel from my vote that I just compound the problem down line.

I've also come to believe that nobody knows what Mother Nature is capable of in terms of earthquake or hurricane or tornado. I never thought I'd see a nuclear plant encircled by water, but we saw it in Nebraska. I never thought I'd see a tsunami the height of this tsunami, but we saw it. I never thought that the Ring of Fire would be setting off earthquakes of the size that are now happening around the Pacific.

So my own view is that we need to solve that waste issue, and I would certainly welcome any suggestions for anyone that's listening to this or particularly the people at this table.

Candidly, I'm much more—how can I put it? I'm much more persuaded to your point of view by hearing your presentations. And yet I have a certain amount of doubt. You know, are they just saying what we want to hear or do they really mean they won't take a subsidy or what is it really going to do to the cost of electricity for the average Joe and Susie Smith?

And yet what Dr. Moniz—who I have respect for—points out is we have all these coal plants, aging and dirty. What do you replace them with? Maybe this is the logical answer.

So there's a lot to think about, and I'd like to work with you on it.

Senator ALEXANDER. Well, I thank you for the hearing. This has been very helpful. This is the kind of hearing that we welcome here to have such diverse and well-informed views.

AGREEMENT ON FEDERAL POLICY

I think we've identified some things we can work together on, the kind of—you know, what's the appropriate role for limited Federal dollars in terms of energy? I mean, where do we draw the line in terms of what is R&D, what is joint cost sharing, what is a subsidy and what is a permanent—we should tackle that one.

Second, what are we going to do with used nuclear fuel?

And the President's BRC is coming out. I commend President Obama on his approach to this. He appointed a distinguished panel and good NRC board members and I think we can work——

Third, I'll be glad to go with you and talk to Harry Reid about reopening Yucca Mountain if you want to, but I don't think we're going to have any success.

And, finally, I think back when I was Governor. The previous Governor hadn't been able to locate a prison because he wanted to put it somewhere.

So I was not having any success either. So I announced that we only had one and we'd have to have a competition for it. And we actually had four counties compete to get it and we located it and then we located another one.

So I think the idea of having Federal incentives to persuade communities or States either to have a single repository or more than one is the obvious way to go, but I think we wait until we hear from the President's BRC.

In the meantime, though, as you could tell from my comments, I think we should go ahead and make sure we have this option. I mean, all we're talking about is doing the preliminary work to see if industry can make it—in such a way so that they can make money and so that the Federal Government can do it in such a way so they can regulate it safely, and then we get to the point where then we go forward.

That's probably—I mean, the talk is about one or two or three small reactors by 2020. So just having the arrow in our quiver, as Dr. Moniz said, I think is what we're talking about, and obviously we've got a lot more talking to do.

But this—I thank the chairman for her open mindedness and willingness to hear points of view that might not agree with hers. That's——

Senator FEINSTEIN. How many at TVA?

Senator ALEXANDER. Small reactors?

Senator FEINSTEIN. Yes.

Senator ALEXANDER. TVA is thinking of one, which would be—they have a partner with the Oak Ridge National Laboratory, and the Oak Ridge Laboratory—Dr. Chu would like to do that as part of his carbon-free quota for his Department.

And Oak Ridge would like to do it. They estimate that a single reactor of about 125 megawatts would power the entire complex there—the super computers, the nuclear weapons operation and the citizens in the community.

I think they're working with B&W on that. Is that right or are they working with anybody in particular?

Mr. MOWRY. Yes, they're hoping to, yes.

Senator ALEXANDER. But TVA and the Oak Ridge Laboratory have an agreement to explore it, but it would all depend upon this several years of work by the NRC and the companies whether it would come to reality or not.

CONCLUSION OF HEARING

Senator FEINSTEIN. Well, thank you very, very much. We appreciate the testimony. There's much food for thought, and the hearing is concluded.

[Whereupon, at 12:06 p.m., Thursday, July 14, the hearing was concluded, and the subcommittee was recessed, to reconvene subject to the call of the Chair.]

# MATERIAL SUBMITTED SUBSEQUENT TO THE HEARING

[CLERK'S NOTE.—The following testimony was received by the Subcommittee on Energy and Water Development for inclusion in the record.]

## PREPARED STATEMENT OF THE NUCLEAR ENERGY INSTITUTE

In testimony provided to this subcommittee on April 7, 2011, the Nuclear Energy Institute (NEI)[1] supported the administration's request for fiscal year 2012 funding of $67 million for the Department of Energy's (DOE) Small Modular Reactor Licensing Technical Support program. This cost-shared, public-private partnership built on a similar request by President Obama for fiscal year 2011, which the nuclear industry also supported. In its April testimony, NEI noted that this cost-shared development program is the nuclear energy industry's highest priority in the fiscal year 2012 budget request. I urge you to approve DOE's request to begin this program during this fiscal year.

NEI also provided testimony for the record in support of small reactor development to the Senate Energy and Natural Resources Committee on June 7, 2011. NEI's testimony focused on S. 512, the Nuclear Power 2021 Act, which we support broadly. The Nuclear Power 2021 Act also contemplates a cost-shared, public-private partnership to accelerate the development and deployment of small modular reactors (SMRs).

### SMALL REACTOR DEVELOPMENT ADVANCES ENERGY, ENVIRONMENTAL BENEFITS IN NEW MARKETS

Analyses by the Environmental Protection Agency and the Energy Information Administration, and global studies by the UN's Intergovernmental Panel on Climate Change and the International Energy Agency, conclude that a significant expansion of nuclear energy and other carbon-free generation sources is needed to meet the world's growing electricity requirements and reduce the electric power sector's emissions of carbon and other air pollutants.

Small-scale reactors can complement large nuclear plant projects by expanding potential markets in the United States and abroad for carbon-free energy production. Smaller reactors provide energy companies and other users with additional options to achieve strategic energy and environmental objectives.

Their small size—less than 300 megawatts—and innovative features like dry cooling expand the range of sites suitable for deployment, such as remote and arid regions. These and other attributes make them well-suited to replace older coal-fired generating capacity. (Various analyses show that 30,000–50,000 megawatts of older coal-fired generating capacity may be shut down before 2020 as a result of tighter air quality requirements.)

Modular construction will allow these new small reactors to be manufactured in a controlled factory setting, transported to the site by rail, truck or barge, and installed module by module. This manufacturing approach is more efficient than on-site field construction, and should reduce cost and construction time. Modern shipbuilding uses modular construction extensively, and it has been adopted for the construction of large advanced nuclear powerplants, such as the four Westinghouse AP–1000 plants under construction in China and the four reactors in pre-construction today in Georgia and South Carolina. Because they can be manufactured in North

[1] The Nuclear Energy Institute (NEI) is responsible for establishing unified nuclear industry policy on matters affecting the nuclear energy industry, including regulatory, financial, technical, and legislative issues. NEI members include all companies licensed to operate commercial nuclear powerplants in the United States, nuclear plant designers, major architect/engineering firms, fuel fabrication facilities, materials licensees, and other organizations and individuals involved in the nuclear energy industry.

America to meet growing domestic and export demand, SMR deployment will create high-tech U.S. jobs and improve our global competitiveness.

According to a February 2011 Commerce Department study [2] on small reactors, a "robust program of building SMRs could make use of existing domestic capacity that is already capable of completely constructing most proposed SMR designs. This ability could mean tremendous new commercial opportunities for U.S. firms and workers. A substantial SMR deployment program in the United States could result in the creation of many new jobs in manufacturing, engineering, transportation, construction (for site preparation and installation) and craft labor, professional services, and ongoing plant operations."

In addition, small reactors manufactured in America will help the United States re-establish its leadership position in nuclear energy technology around the world. By developing the innovative, clean-energy technologies the world demands, the United States can transfer its safety, security, and nonproliferation culture with the technology.

### SMALL REACTOR SAFETY AND SECURITY—ENHANCED BY DESIGN, REQUIRED BY REGULATION

SMRs being developed today benefit from decades of advancements in materials, design, instrumentation, controls, and operational experience.

SMRs are being designed with separate, independent underground containments for each module, as well as separate, independent safety systems protected within those underground containments. These same features provide the capability to withstand aircraft impacts and, coupled with their small footprint and limited access points, provide improved defense against any terrorist threat.

SMRs rely less on engineered safety features (so-called "active" safety systems like pumps and motors), and rely instead on natural safety features (so-called "passive" safety systems like gravity feed of cooling water in the event of loss of electrical power, and natural convection to carry away heat). This design approach provides significant safety advantages.

In addition, each of the lead light-water SMR designs uses an integral approach where the steam generators, pressurizer, control rod drive mechanisms, and coolant pumps (if used) are contained within the reactor vessel. There are no penetrations into the reactor vessel below the top of the core, which eliminates the possibility of large-break loss of coolant accidents.

Because of their small size, integral design, and reliance on natural convection and gravity-based cooling systems, these small reactors can remain safe, even without onsite or offsite AC power, for 7 days or longer.

### PUBLIC/PRIVATE PARTNERSHIPS ARE ESSENTIAL TO SUPPORT SMALL REACTOR DEVELOPMENT

A number of analyses have documented the potential economic, energy security, and environmental benefits of SMRs. There are challenges to realizing those potential benefits, however, including design and first-of-a-kind engineering costs, Nuclear Regulatory Commission (NRC) licensing costs, and fabrication/construction costs. These challenges inevitably influence the economics of small reactors.

In order to determine the business case for small reactors, NRC design and operational requirements must be finalized. Small reactors must meet or exceed all of the NRC's safety and security goals and requirements. Today's regulations are designed to ensure that large, light water-cooled reactors achieve these requirements. Tomorrow's small reactors may need new or modified regulations to ensure that they also meet or exceed these safety and security goals and requirements.

The nuclear industry and other stakeholders are working with NRC to define the regulatory requirements for SMRs. This work is at a relatively early stage. The NRC and the industry have identified a number of generic regulatory issues—including license fees, decommissioning funding assurance, emergency planning requirements, security, control room staffing, loss of large areas of the plant due to terrorist activity and a number of others—that should be considered when developing the licensing framework for SMRs.

The industry is developing position papers on many of these issues, and discussing them with NRC staff. These interactions between NRC and the industry are conducted in public meetings open to all.

Based on these discussions and its own analysis, NRC will develop the licensing and regulatory requirements for SMRs that, in its view, would protect public health

[2] The Commercial Outlook for U.S. Small Modular Nuclear Reactors, U.S. Department of Commerce, February 2011.

and safety. These requirements will be subject to review by (among others) NRC senior management, the NRC's Advisory Committee on Reactor Safeguards, and the NRC commissioners before they are finalized. Since these regulatory requirements will be promulgated as rules, they will also be subject to public review and comment before being finalized.

Once finalized, these requirements must be factored into the design, licensing, construction and operation of a standardized small reactor. Only at this point will the initial economics be known for the first-of-a-kind or lead plant. Further work will be needed to optimize the factory fabrication and reduce the cost of future SMRs in much the same way our shipbuilding and aerospace industries have done.

The cost-shared, Government-industry SMR program proposed by the President is designed to address these issues and reduce the risk and uncertainty of moving forward. Traditional partnerships among technology vendors, component manufacturers and end users are necessary—but not sufficient in themselves. Industry is prepared to absorb its share of these initial development costs, but revenues from the sale and operation of the first SMRs are some years away, and some level of Government investment in this promising technology is both necessary and appropriate. Absent additional business risk mitigation through Government investment, the potential benefits of these SMR concepts may go unrealized, or may be realized later than desirable.

Leveraging private sector resources through public partnerships with the Department of Energy and other Government entities will help move these new reactor technologies to market, capturing their many benefits while maintaining U.S. nuclear energy technology leadership.

## CONCLUSIONS AND RECOMMENDATIONS

The potential benefits of small, modular, nuclear powerplants are substantial. These technologies should be pursued and supported. These designs expand the strategic role of nuclear energy in meeting national environmental, energy security and economic development goals.

While the United States has the lead today in developing these small reactors, other countries are already developing them. Reducing the time to market is key to ensuring that U.S. companies gain a share of the global market and influence the international safety and security culture. The proposed DOE cost-shared small reactor program will help achieve this goal.

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