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Nuclear Energy Risk Management Hearing
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Chairman Broun, Chairman Harris, Ranking Member Edwards, Ranking Member Miller, and Members of the Committee, thank you for the opportunity to submit a statement on the Department of Energy's (DOE) Office of Nuclear Energy's R&D portfolio related to the safety of nuclear power plants.

The safety of our nuclear fleet is of paramount importance to this Administration, and we are committed to ensuring that nuclear plants in the United States continue to operate safely. As a former Commissioner of the Nuclear Regulatory Commission (NRC), I can attest to the dedication of the NRC staff and their focus on assuring safe operations. Many parameters tracked by NRC show the excellent safety of our plants and significant improvements in safety over the years.

The safety of nuclear plants is maintained through a series of barriers to prevent exposing the public to health-significant doses of radiation from release of radioactive materials. The principle of Defense-in-Depth is practiced in the industry, wherein multiple barriers are employed to provide this defense. Barriers in typical Light Water Reactors (LWR) include the fuel cladding, the reactor pressure vessel, and the containment building. Improvements in safety may result from increased robustness of existing barriers or from new barriers. Many programs of the Office of Nuclear Energy are focused on improvements in safety of operating and future new plants.

Passive Safety

Current generation II plants rely on extensive operator actions to place the plants into safe configurations in the event of off-normal conditions. In contrast, passive designs require far fewer operator actions and rely on extensive use of natural phenomena, like large quantities of stored water, gravity feed of cooling water rather than pumps, and convective cooling in accident conditions. They do not require operator actions for long periods after an accident, several days in some cases, and do not depend on offsite or emergency diesel generator power to maintain safety. Passive safety is one way of enhancing safety of nuclear plants. Another approach uses increased redundancy of active equipment. However, plants relying on additional active equipment may present challenges with the increased maintenance and operator actions required to keep the additional equipment in optimal condition and to effectively utilize it, and they depend on the availability of adequate power supplies. Plants with passive safety, in my opinion, offer the greatest promise for still safer operations in the future.

The global nuclear industry is currently building a new generation of reactors, most of which are so-called Generation III or III+ plants. These plants, among other features, use either passive safety or increased redundancy of active systems to enhance safety. In the United States, the Nuclear Power 2010 program, now concluded, was focused on bringing two Generation III+ plants, the Westinghouse AP1000 and the General Electric ESBWR, through design certification and issue of Construction and Operating Licenses (COLs). The Nuclear Regulatory Commission (NRC) is now in the final stages of evaluations of design certifications for both systems and COLs for the AP1000. Both of these plants make extensive use of passive safety features. NRC currently expects to be making final decisions regarding the AP 1000 design certification amendment and two combined licenses referencing that design certification amendment by the end of the calendar year. Final decisions regarding the ESBWR design certification are also expected by the end of the calendar year.

Fifteen licenses for these two passive reactor designs are currently pending at the NRC. Four AP1000 reactors are under construction in China. Extensive construction activities, short of safety-grade work, are in progress for two AP1000 reactors in Georgia and two in South Carolina.

Small Modular Reactors (SMRs) are another area of strong interest at DOE, and current designs offer some notable safety advantages. LWR SMR designs incorporate passive safety features that utilize gravity-driven systems rather than engineered, pump-driven systems to supply backup cooling in unusual circumstances. Because of their smaller size, current SMR designs have less water withdrawal requirements and some designs can make use of air cooling options. Some concepts use natural circulation for normal operations, requiring no primary system pumps and providing a still more robust safety case. In addition, many SMR designs utilize integral designs for which all major primary components are located in a single pressure vessel. That feature results in a much lower susceptibility to certain potential events, such as a loss of coolant accident, because there is no large external primary piping. Lastly, because of their lower power level, SMRs have a much lower level of decay heat and therefore require less cooling after reactor shutdown.

DOE has proposed the LWR SMR Licensing Technical Support program to help improve the timeline for the commercialization and deployment of light water SMRs and also proposed a longer-range program to conduct research on advanced SMR designs.

Improved Fuels and Cladding

All LWRs in the United States utilize uranium oxide pellets contained within zirconium alloy tubes or cladding. The cladding functions as one key barrier to confine the gaseous and volatile fission products that build up during reactor operation. But zirconium will react with steam at about 1,200 degrees C, generating hydrogen. If not properly controlled, hydrogen can ignite with oxygen leading to significant damage, as occurred in the Fukushima accident. Such damage may impair the cladding, releasing gaseous and volatile fission products into the reactor pressure vessel. Additionally, at somewhat lower temperatures, the zirconium cladding can distort and partially rupture, leading to some leakage of these radioactive materials. Similar scenarios can occur in pool storage of used fuel.

The Office of Nuclear Energy has been working with industry to develop a new silicon carbide ceramic cladding technology that could offer improved safety and performance as well as address additional current issues with zirconium cladding (such as rod fretting or abrasive damage to the cladding where cladding tubes pass through support structures) that results in occasional fuel failures in current plants. Ceramic cladding still needs substantial research and development efforts to determine if it can be successful. However, if successful, it has the potential to provide nuclear fuel with a higher tolerance to accidents. For example, silicon carbide cladding would not generate hydrogen in steam at high temperatures.

The sintered ceramic uranium oxide pellets used in current LWRs are very robust, but they do not retain volatile or gaseous fission products – they have significant porosity, and thus depend on the claddings for retention. An alternative fuel type was developed years ago for the original gas-cooled high temperature reactors, like Fort St. Vrain, but that fuel did not perform up to its original expectations. More recently we have revisited this fuel type (so-called TRISO fuel) with impressive results.

TRISO (TRi-ISOtropic) particle fuel has three layers surrounding a kernel of fissionable material like uranium oxide that act as primary, nearly impervious “containment” barrier for fission products during normal operations and accidents. This fuel retains its integrity and confines fission products up to extremely high temperatures. TRISO fuel has been suggested for utilization in other types of reactors, perhaps even in LWRs, because it would virtually eliminate release of fission products from the fuel itself. Significant issues would be associated with use of TRISO fuel in an LWR, and we plan to explore these issues in future research efforts.

High Temperature Gas Reactors (HTGR), as a class of reactors, can offer interesting safety features. Current concepts incorporate additional inherent physical characteristics that enhance safety and do not rely on active engineering systems or operator actions during accident scenarios. In addition to using the TRISO fuel, HTGRs can be cooled without the use of active systems which rely on electrical power for pumps, valves, instrumentation and control systems or operator actions. During such an event, it takes several days (2-4 days) for the TRISO fuel temperature to rise and peak at almost 1600°C, far slower than with LWR loss-of-coolant events. Even if the HTGR’s control rods fail to insert during an accident, the TRISO fuel stays below its fuel failure temperature limits (<1800°C). Future HTGRs will be inherently, passively safe—no electricity, engineered safety systems or operator actions will be needed to control or cool the reactor.

The ongoing research and development (R&D) focuses on: (a) TRISO fuel development and irradiation performance experiments, post-irradiation evaluations (PIEs), and safety heat-up tests to demonstrate fission product retention, and (b) irradiation tests to demonstrate the strength of nuclear structural graphite at high temperatures. All R&D activities are being coordinated with the NRC to support the simultaneous development of regulatory requirements. DOE laboratories, universities, industrial collaborators and international experts are involved in the integrated R&D program activities.

<u>Modeling and Simulation</u>

The Office of Nuclear Energy has extensive programs building and utilizing modeling and simulation of complex nuclear-related phenomena, many of which have significant potential to improve safety. The most visible of these programs is the Energy Innovation Hub for Modeling and Simulation established by the Department through the Consortium for Advanced Simulation of Light Water Reactors (CASL) centered at Oak Ridge National Laboratory. The CASL collaboration is applying leading edge computational capabilities to create a new state-of-the-art in nuclear reactor simulations. The first set of problems to be tackled is related to fuel performance and safety in pressurized water reactors, in particular: pellet-clad interactions, CRUD (a term-of-art standing for Chalk River Unidentified Deposits, which plagued early reactors and occur today to lesser extents) deposition, and support grid-to-rod fretting. By improving our understanding of key mechanical, chemical, and nuclear interactions, the Hub may enable enhanced safety, prolonged life of nuclear fuel, increased power outputs, and enhanced reliability. The goal of the Hub is to have a highly realistic, virtual reactor capable of such simulations within its first five years. Less than one year after being established, the Hub has already released its first version of the virtual reactor code, which will undergo significant refinement in coming years.

As a multi-lab collaboration with industry and academia, the CASL mission is to create a useable tool set that is embraced by industry and researchers to advance the performance and safety of light water reactors. As such, the CASL vision is to embrace the full range of light water reactors including boiling water reactors and the new light-water-based small modular reactors that are being designed. These additional capabilities would be implemented during the first extension of the CASL award. The decision to extend the award or not will be made in 2015, subject to appropriations.

<u>Seismic Evaluations</u>

DOE-NE is currently involved in two projects related to seismic activity on nuclear power plants and plans to conduct further research on mitigating the effects of earthquakes. These two improved computational models will enable nuclear facility operators to determine the probabilistic seismic hazard at any point at ground level in the central and eastern United States with better accuracy:

(1) Generic Seismic Hazard Model for Central and Eastern United States (CEUS).

The objective of the ongoing CEUS Seismic Source Characterization Project, conducted by the Electric Power Research Institute, is to update the consensus seismic source hazards model for the CEUS based on new seismic activity data and comprehensive expert consensus on interpretation of said data. This model will be used to support nuclear plant site-specific Probabilistic Seismic Hazard Analyses (PSHA) anywhere in the CEUS. This project is scheduled to conclude by the end of 2011.

(2) Next Generation Attenuation – East (NGA-East) Seismic Project.
The NGA-East project is being conducted by the Pacific Earthquake Engineering Research Center at the University of California at Berkeley and will develop new ground motion attenuation relationships for the central and eastern U.S. Ground motion and the resultant attenuation of seismic motion is a function of soil type and rock structures at a site or location of interest as well as the location, depth, and magnitude of the seismic event. Ground motion attenuation as a result of an earthquake is a primary source of uncertainty in determining specific site seismic hazards. This project is scheduled for completion in 2014.

In addition to DOE funding, collaboration on these projects involves the Nuclear Regulatory Commission Office of Research, United States Geological Survey, and the nuclear industry through the Electric Power Research Institute.

In FY 2011, the Office of Nuclear Energy will solicit additional research and technology development on seismic isolation systems under its Nuclear Energy Enabling Technology program.

Dry Cask Storage

The present regulatory basis established by the NRC for dry cask storage is 60 years beyond the operating life of a reactor. This mode of storage is an integral part of the nation's current used fuel management and might be useful as an option for longer terms than the current regulatory limits. To evaluate such longer utilization, additional understanding of degradation mechanisms will be essential.

To help resolve issues associated with such extended used fuel storage, DOE is employing a competitive process to fund in Fiscal Year 2011 an Integrated Research Project (IRP) consortium consisting of a lead university, one or more partner universities, and potentially national laboratory and industry partners. Funding will be up to $1.5 million per year for up to 3 years and any potential industry partners would be required to cost share. This competition is now in progress.

The IRP focus will be on research and development (R&D) of accelerated aging techniques to better understand long-term degradation mechanisms, especially with high burnup used nuclear fuel (burnups above 45 gigawatt-days/metric ton). Specific issues to resolve include: long-term integrity of fuel cladding and canisters; maintaining fuel assembly configuration and associated components; canister leakage; hydride diffusion and embrittlement; creep, corrosion and stress corrosion cracking; accelerated degradation in a marine environment; and degradation of concrete. Project success will be measured by demonstration of laboratory-scale accelerated aging techniques that may eventually inform the technical basis providing technical justification for extended UNF storage of used nuclear fuel.

Detailed Modeling of the Fukushima Accident

The safety of nuclear power has been improved over the years by, among other approaches, careful learning from any accident or incident. Three Mile Island (TMI) led to major improvements in safety and new requirements for nuclear power plants in the United States. Modeling of TMI has helped enhance the current generation of severe accident modeling codes. Modeling and study of other accidents or near accidents, like Chernobyl or Davis-Besse, have led to further insights. The Fukushima accident must be understood in great detail in order to extract lessons that may further enhance safety or which may inform future regulatory decisions.

The Office of Nuclear Energy is organizing several of the DOE national laboratories for a joint study of accident progression at Fukushima. Our intent will be to learn from that analysis and to supplement any current analysis with future data that will become available once the damaged fuel can be examined. In addition, the implementation plans supporting the 2010 Nuclear Energy R&D roadmap are being studied by federal and laboratory staff to see if adjustments in R&D are needed in the aftermath of Fukushima.

Nuclear Energy University Program

The Office of Nuclear Energy devotes up to 20 percent of its R&D budget for research at universities. Much of this research has a significant nexus with safety issues, frequently related to further enhancement or understanding of the barriers that make up Defense-in-Depth. In addition, this research program plays an essential role in training the future generation of nuclear energy professionals upon whom the safety of future nuclear power systems will depend.

In Fiscal Years 2009 and 2010, NE funded via its Nuclear Energy University Programs (NEUP) a number of university-based safety-related research and development projects, including:

- Improved LWR Cladding Performance,
- Develop Advanced Models of LWR Pressure Vessel Embrittlement for Low Flux-High Fluence Conditions,
- Development of Diffusion Barrier Coatings and Deposition Technologies Mitigating Fuel Cladding Chemical Interactions,
- TRISO-Coated Fuel Durability Under Extreme Conditions,
- Evaluation of materials for interim storage of spent fuel for more than 100 years,

- Failure Predictions for Very High Temperature Reactor (VHTR) Core Components using a Probabilistic Continuum Damage Mechanics Model,

- Fission Product Transport in TRISO Particle Layers under Operating and Off-Normal Conditions,

- Multi-scale Concrete Modeling for Aging Degradation, and

- Investigation of Laser Shock Peening for Enhancing Fatigue and Stress Corrosion Cracking Resistance of Nuclear Energy Materials

In FY 2011, NE has solicited proposals for additional university-based, safety-related R&D projects in many areas, including:

- VHTR TRISO fuel development and qualification activities focused on producing robust fuel particles that can retain fission products during normal and accident conditions and have very low failure rates, as demonstrated by irradiation and accident safety testing programs,

- R&D addressing the Risk-Informed Safety Margin Characterization (RISMC) methodology,

- Development of new reactor concepts using advanced technologies or innovative engineering to provide improved safety and system performance, and

- R&D on sensors and infrastructure technology to address critical technology gaps to monitor and control new advanced reactors.

<u>Conclusion</u>

I began this statement with the well substantiated statement that the nation's nuclear reactors are safe today. But safety of nuclear energy, just as with any mature high technology endeavor, can always be improved through careful study and investigation. The Office of Nuclear Energy will maintain a focus on safe operations and on research and development that will provide still safer systems for future generations.

After the earthquake and tsunami in Japan, Deputy Secretary Poneman stated that: "We view nuclear energy as a very important component to the overall portfolio we are trying to build for a clean energy future." I fully concur with his view, and the programs of the Office of Nuclear Energy are focused on ensuring that the option for safe nuclear power remains open to the nation.