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Hearing: From Theory to Reality: The Limitless Potential of Fusion Energy

Chairperson Williams, Ranking Member Bowman, and Members of the Committee, thank you for this opportunity to discuss fusion and the international ITER project. I am Dr. Kathy McCarthy, Director of the US ITER Project at Oak Ridge National Laboratory (ORNL). I am a nuclear engineer and National Academy of Engineering member with over 30 years of experience in the fields of fusion and fission nuclear science and engineering. My career has spanned international fusion and fission research, U.S. Department of Energy (DOE) National Laboratories at Idaho and now Oak Ridge, and the Canadian Nuclear Laboratories. I am pleased to participate in today's hearing with this distinguished panel today.

ORNL and DOE commitment to fusion

Fusion has the potential to provide enormous amounts of safe, carbon-free energy to the planet for thousands of years and beyond. Fusion fuels, isotopes of hydrogen, are abundant and could be produced from fusion reactions in a closed cycle. The byproducts of a fusion reaction are helium and energetic neutrons. Low-level radioactive waste from fusion, related to neutron-irradiated structures and tritium fuel, can be managed safely and effectively. Fusion power plants could be productive, non-proliferative sources of clean energy that support strong communities and enable equitable access to reliable electricity.

National laboratories provide translational science to enable new technologies and accelerate commercialization. The unique capabilities and facilities at national laboratories provide a platform for research and development that deliver technology innovation and risk reduction for industry. ORNL is the largest DOE science and energy laboratory, with diverse capabilities including nuclear fission and fusion. We have more than 60 years of experience in fusion. ORNL is recognized as a leader in multiple areas of fusion science and technology, and we contribute to fusion research and innovative fusion systems and around the world. In short, we are a dedicated leader in the national fusion ecosystem as part of the nation's national laboratory system.

US ITER is a multi-lab effort funded by DOE's Office of Science and managed by ORNL with partner laboratories Princeton Plasma Physics Laboratory and Savannah River National Laboratory to deliver the US contribution to the international ITER project. U.S. participation in ITER was authorized by the Energy Policy Act of 2005. In 2006, the United States signed the Agreement on the Establishment of the ITER Fusion Energy Organization for the Joint Implementation of the ITER Project, a Congressional-executive international agreement, along with partners Japan, the European Union (project host), the Republic of India, the People's

Republic of China, the Republic of Korea, and the Russian Federation. The mission of ITER is to demonstrate the scientific and technological feasibility of fusion energy.

ORNL is also building the Material Plasma Exposure eXperiment (MPEX) to support study of plasma-material interactions and plasma-facing materials. Research on MPEX will inform the development of fusion-ready materials for future reactors. Plasma science foundations and fusion technology are also major thrusts of ORNL fusion capabilities. Our expertise in theory and modeling, diagnostic measurements, and fusion technology are also informing public and private sector fusion devices. ORNL's unique array of user facilities, including high performance computing, the High Flux Isotope Reactor, the Spallation Neutron Source, and Manufacturing Demonstration Facility supports fusion research and innovation.

The Office of Science INFUSE program (Innovation Network for Fusion Energy, https://infuse.ornl.gov/), managed by ORNL and Princeton Plasma Physics Laboratory, is an excellent demonstration of the value of national laboratory expertise and facilities for the fusion industry. So far through INFUSE, 21 private fusion companies are engaged in 72 projects with DOE laboratories to advance the technological readiness of their novel fusion devices. DOE laboratories are also supporting projects in the recently announced Fusion Energy Sciences Milestone Program.

I want to especially point out the support of Fusion Energy Sciences in DOE's Office of Science. A strong national program in fusion is crucial to benefit from ITER and realize the potential of fusion energy.

Why do we need ITER?

Achieving a practical fusion energy system is one of the greatest challenges of our times. While the path to fusion energy has benefitted from several recent record-breaking achievements, there remain major challenges that must be resolved to support such a system. ITER is positioned to play a central role in addressing these challenges.

For a practical fusion energy system, we must be able to produce and sustain a fusion power source in a safe and economical manner. At full power operation, ITER will produce a self-sustaining "burning plasma" and demonstrate commercial-scale power over a long pulse lasting several minutes. While fusion power has been demonstrated in the laboratory for a few seconds at a time, we have not yet met the challenge of producing fusion reactions that are self-heating and self-sustaining for minutes at a time.

The JET tokamak in the U.K. achieved a fusion power record of 59 megajoules for around 5 seconds in 2021. More recently in 2022, the U.S. National Ignition Facility at Lawrence Livermore National Laboratory demonstrated fusion ignition for the first time ever, surpassing scientific breakeven. Achievements such as these combined with ITER's long pulse mission will contribute to readiness for practical fusion. Experience with and study of a sustained, self-heating plasma will also yield expand understanding of the foundational plasma science essential for fusion energy performance.

A practical fusion energy system must go well beyond breakeven, to the point where the power produced by the fusion reactions is significantly greater than the power applied to the fusion fuel. ITER is a tokamak that uses magnetic fields to contain a large plasma volume; however, the lessons from ITER will be valuable to a variety of fusion architectures. The common denominator for fusion systems is to understand how to capture sustained fusion power from fusion reactions reliably and efficiently.

As a research facility, ITER will offer tools and expertise at the scale of a specialized DOE laboratory and will be a valuable test facility resource for advancement of both private and public fusion systems, and its relevance is related to its flexibility. ITER will be capable of a range of operating scenarios and physics regimes, offering research capabilities that will serve a variety of fusion architectures and technology needs. ITER's long pulse operations (100's of seconds) will provide essential information on extended control of fusion power, including tokamak exhaust processing. The ITER tokamak will have more diagnostics than any existing fusion device, to support measurement of plasma power, optimize machine operations, and assess performance. This range of tools is exceptional and well beyond what private industry could have access to on their own.

For a path to fusion energy—not just fusion science—it is essential to master both the science and the technology required for producing and controlling a power plant-scale burning plasma. ITER offers that opportunity, plus access to ITER intellectual property and a one-of-a-kind scientific facility for research on high power plasmas.

What is ITER already delivering for fusion?

ITER is already delivering value to ITER members, including the U.S. public fusion program and private industry.

ITER is providing us with practical experience designing, fabricating, and assembling a licensed fusion facility. While a fusion pilot plant may be very different in scale than ITER, due to emerging technologies, the lessons learned from ITER will deeply inform the design, assembly and ultimately regulation of a commercial fusion power plant. The recent announcement by the U.S. Nuclear Regulatory Commission that it will separate fusion regulation from fission regulation can be seen as one case of learning from the ITER licensing experience.

ITER is developing fusion supply chains and challenging industry to deliver to fusion's exacting requirements. In the U.S., over 600 contracts in 46 states plus the District of Columbia have been placed with U.S. companies and universities to support delivery of U.S. hardware to ITER. As of the end of 2022, more than $1.4 billion has been awarded to U.S. industry, universities, and national laboratories in support of ITER contributions.

ITER is building a diverse fusion workforce. As a multi-decade international project, ITER is building deep technical, construction, and management experience across its partners. U.S. fusion experts intersect with the ITER project throughout their careers, from internships and post-doctoral programs to advisory boards and senior staff roles. ITER is one of the largest training grounds for fusion in the world.

ITER is already providing information and experience to member nations. In the U.S., fusion industry is expressing interest in various technical systems and manufacturing processes. Information of particular interest to industry include plasma heating systems, plasma fueling, vacuum systems, superconducting magnet manufacturing, and manufacturing qualification approaches—all areas where the U.S. is contributing to ITER. DOE is leading a process to facilitate U.S. fusion access to project information and intellectual property.

ITER is a major contributor to U.S. competitiveness in fusion now and in the future. All ITER members are interested in accelerating their path to a fusion pilot plant. The U.S. has the common advantage of participation in ITER---but also gains a competitive edge from a strong public program in fusion science and engineering and expanding fusion industry field. Intersections between public and private activities, including ITER, give the U.S. major advantages in the race to practical fusion energy in the long-term, and sooner, fusion pilot plants.

What other science and technology support are important for practical fusion?

As noted, ITER will deliver a sustained, self-heated burning plasma for hundreds of seconds. This mission will support the need to understand how to produce and control a fusion power source that goes well beyond breakeven, an important step for practical fusion energy.

However, there are other important challenges that must be addressed to support the realization of practical fusion. We need to develop materials that can perform for extended periods of time in harsh fusion environments. The materials presently available are sufficient for an experimental device such as ITER; however, ITER materials do not need to perform to the degree necessary in a fusion power plant (24/7 operation for weeks or months at a time). As a research facility, ITER will provide some helpful materials information. However, a specialized facility that delivers prototypic fusion neutron exposure for extended periods of time is needed to accelerate the development and testing of fusion functional and structural materials.

Another key challenge fusion must resolve is how to close the fusion fuel cycle and establish sustainable production of fusion fuel. ITER will use deuterium-tritium (DT) fuel for high power operations; that fuel will be provided by sources outside the facility. However, test blankets for fuel production will be installed on ITER to advance understanding of how to produce tritium inside a fusion device. Many other fusion devices and concepts also use or assume the use of DT and will directly benefit from ITER experience with fuel production studies. Some concepts use other fuels, but also face challenges of efficiencies and fuel management. Ideally, fusion fuel would be produced within the fusion power plant itself for efficiency and security. To advance readiness for future fusion systems, an integrated test facility for fusion blankets and fuel production will advance readiness for a sustainable fuel cycle.

Finally, continued investigations in plasma and fusion science are needed to support the foundations of economical fusion systems. Fusion remains at a stage where important discoveries in basic science can transform the options for realizing a practical fusion energy system.

The recent June 1 announcement, describing the selection of eight companies to receive DOE funding to advance the design and research and development of fusion pilot plants, kicks off an important partnership between private industry, national laboratories, and universities.

ITER Update

The start of ITER tokamak assembly in 2020 and continued project progress shows us that it is possible to achieve engineering precision, at the millimeter-scale, on ship-sized fusion components. Even during the pandemic, ITER was able to achieve significant progress. Today, the international site is more than 85% complete for civil construction, and hardware components are being delivered from all of the ITER partners.

After the passing of Bernard Bigot in early 2022, the ITER Council identified a new Director-General of the ITER Organization to lead project assembly and integration. Pietro Barabaschi assumed the Director General role in October 2022. Barabaschi brings fusion and construction experience from multiple large-scale fusion projects, including Fusion for Energy in the EU, JT-60SA in Japan, JET in the U.K., and ITER.

Barabaschi is now leading organizational adjustments to the project to support success with tokamak assembly and appropriate integration with ITER partners. U.S. candidates are among those under consideration for Deputy Director General roles for engineering, construction, and science. Among his initiatives is strengthening communication with private companies. There are many lessons learned from ITER design and construction that will benefit the activities underway in the private sector. We continue to receive and respond to requests for technical information from the private sector.

As a first-of-a-kind power-plant-scale fusion facility, ITER has experienced challenges.

From a technical perspective, the project identified non-conformances in some vacuum vessel sectors which will require repair before assembly. The project also determined that thermal shield manufacturing methods resulted in stress corrosion cracking on these components. After project-wide reviews of the issues and discussion of the best path forward, the ITER Organization is now in process of placing repair contracts for these components. While US ITER was not responsible for any of these components, the U.S. does participate as a member, engaging experts as needed, to advocate for the best resolution of these technical challenges.

The ITER Organization is also working closely with the French nuclear regulator, ASN, to determine an appropriate path for regulation. The project is a strong advocate of a “step-wise” approach, since ITER is a novel device and poses fewer risks than a typical fission reactor.

The ITER Organization is also engaged in preparation of an updated baseline and schedule to address delays from COVID and first-of-a-kind manufacturing and assembly. Efforts are underway to identify opportunities to make activities parallel for greater efficiency and to adapt assembly sequences as needed. The overall project objective is to begin high power operations (DT) in the mid-2030s.

US ITER is also engaged in updating its baseline and schedule, in response to a request by Congress in the FY21 Appropriations Act. An Independent Project Review will be held at the end of June to prepare for DOE action before the end of the fiscal year.

Recent US ITER achievements include the delivery of two central solenoid modules, with a third on the way, for the “heart of ITER”—a 60-foot-tall superconducting magnet at the center of the tokamak. Since its original baseline in 2017, US ITER has completed over 100 deliveries to the ITER site in support of initial operations. Overall, 60% of all US in-kind hardware contributions have been credited by ITER.

The Path Ahead

We are at an exciting moment in the path to practical fusion energy. The ITER project is highly complementary to other government fusion investments and to efforts in private industry.

Our national laboratories, including ORNL, are making crucial contributions to both foundational science and technology development, and are strongly engaged with industry to accelerate the path to practical fusion energy. We appreciate the support that the House and this committee have provided to ITER and fusion over time.

Thank you for your interest and this opportunity to share my thoughts with the subcommittee. I request that my written testimony be made a part of the public record, and I welcome any questions you may have at this time.