Statement of Bernard Bigot
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Before the
Subcommittee on Energy
Committee on Science, Space and Technology
U.S House of Representatives

The ITER Project: a core element of U.S. fusion research
March 6, 2018

Thank you Chairman Weber, Ranking Member Veasey, and distinguished members of the Committee. I am grateful for this opportunity to present to you the status of progress on the ITER Project. I am particularly pleased to present my ITER report in the context of the overall U.S. fusion research program, because I believe it is appropriate that ITER is understood as an essential and integral element of U.S fusion research.

INTRODUCTION

This precise day marks exactly three years since I accepted the position of Director-General of the ITER Organization. In March 2015, as this Committee well knows, the ITER project was in urgent need of reform. The inherent complexities built into the ITER Agreement were widely viewed as liabilities. Much of the focus was on whether it was possible to effectively manage such a complex international construction project.

By April 2016, when I last addressed this Committee, we had begun to answer this question affirmatively. At that time our organizational reforms had been underway for one year, based on an Action Plan designed to accomplish several specific objectives: effective, efficient technological decision-making; profound integration of the work of the ITER Organization with that of the Domestic Agencies; a comprehensive technological understanding of all aspects of the ITER machine; finalization of design of ITER's critical path components; an updated, challenging, reliable schedule; and above all, a project culture capable of reliably delivering on our commitments while maintaining the highest levels of safety and quality.

The Committee at that time offered its congratulations for our efforts to put the project back on track, and we were very grateful for your expressions of support. One month after that hearing, we were also pleased to receive the report of the U.S. Secretary of Energy, which was cautiously optimistic about the ITER reforms. However, it was also clear at that stage that some scepticism remained as to whether we would be able to fully carry out these reforms, and even more, whether we would be able to sustain our commitments to deliver the project in accordance with the demands of the new ITER schedule and resource estimates.

Now, almost 2 years later, I am pleased to report that we have, in fact, remained on track for success according to the agreed schedule and cost. The ITER project is a maturing enterprise. The organizational reforms are fully in place. According to multiple external reviews that have considered the performance of the ITER Project since 2015, we have established a robust project culture, including implementing strong, effective standards for international project management, systems engineering, and risk management. Most significantly, we have continued to deliver on our construction and manufacturing commitments, in accordance with the expected milestones, working within agreed cost constraints, and we have achieved this performance as a fully integrated ITER team. And further, we are committed to continuous improvement.

Last November, the ITER project reached a significant milestone: the completion of 50 percent of the "total construction work scope through First Plasma." This is no small achievement. It represents the collective contribution and commitment of ITER's seven members. So it was with a sense of pride in that collective accomplishment, as well as a sense of deep gratitude to each member government, that we announced this accomplishment. And we were gratified with the attention we received in the international media: more than 750 news organizations, from printed and online articles to TV and radio channels, reported this milestone in more than 40 countries and 16 languages.

"Total construction work scope," as used in our project performance metrics, is a start-to-finish term. It includes design, component manufacturing, building construction, shipping and delivery, assembly, and installation. Globally, these indicators show that the ITER project is progressing steadily. This has not happened easily. A project of this complexity is full of risks; and our schedule to First Plasma 2025 is set with no 'float' or contingency. Effective risk management is a daily discipline at ITER.

ITER's success so far has demanded extraordinary commitment of the ITER members, high performance project management, and almost perfect integration of our work. Our design has taken advantage of the best expertise of every member's scientific and industrial base. No country, not even the most advanced, could have done this alone. We are all learning from each other, for the world's mutual benefit.

But to be clear: in no way are we spending time at ITER focused on self-congratulations. We have many challenges ahead of us. We are continuing to question ourselves, to welcome external scrutiny, and to learn and improve the way we work on multiple fronts; an expectation of constant improvement is a way of life for this exceedingly complex, first-of-a-kind machine.

Today I would like to describe some aspects of our progress in detail, illustrating the inter-connectivity of our work by providing examples of recent contributions made by the U.S. and each ITER Member. I will also explain the series of external reviews we have undergone in the past few years, which have provided validation for our progress and continued to stimulate improvements. With this narrative, I hope to also demonstrate the importance of ITER as an essential element of the U.S. fusion research program.

THE ITER MISSION: collaboration on the world's first "burning plasma" experiment

To set the stage, let me offer a few words about the ITER mission.

Fusion is the mass-to-energy conversion that occurs in the core of the Sun and all the stars. It is the most common source of energy in the universe, and the most powerful. Every second, our Sun fuses a massive amount of hydrogen into helium and releases a huge amount of energy. It is this fusion reaction that gives the Earth light and warmth.

Scientists and engineers globally have been working on the most effective way to harness fusion for more than six decades of research. The U.S. has been a core player in every stage. This includes the multinational fusion research program hosted in San Diego at the DIII-D tokamak, which Dr. Mickey Wade will describe today in more detail; as well as the National Ignition Facility at Lawrence Livermore National Laboratory, to be presented by Dr. Mark Herrmann. It also includes the Tokamak Fusion Test Reactor (TFTR) and the National Spherical Torus Experiment at Princeton, C-Mod at MIT, the Joint European Torus (JET) in the United Kingdom, KSTAR in Korea, T-10 in Russia, JT-60 in Japan, EAST in China, Tore Supra or WEST in France, the ASDEX Upgrade in Germany, and many others.

From its genesis with President Reagan's invitation in 1985 to consider a large scientific cooperative program, fusion research has been a multinational investment unlike any other science endeavour in history, in terms of its collaborative funding, innovation and brainpower. Globally, fusion scientists agree that the next major step for fusion science and fusion energy is the creation and controlled study of a "burning" or self-heating plasma: a state in which most of the heating of the plasma is coming from the fusion reaction itself.

The Tokamak fusion reactor is the only configuration mature enough to serve as the basis for a burning plasma experiment in the next decades. In order to conduct this experiment with the volume of fusion heating exceeding the surface losses, it must be done at industrial scale—meaning at ITER scale. Thus the ITER Tokamak is the converging next step of all of the magnetic confinement fusion research conducted by all parties, globally, since the late 1950s. The technologies are mature, but there is still much to be gained in terms of industrial expertise and innovation as we push the boundaries of engineering to achieve the necessary combination of scale and precision. And once complete, ITER will enable scientists to observe for the first time, for a duration of several minutes and as often as needed to optimize the process, this state of matter, a "burning plasma" with a fusion self-heating exceeding the external heating power absorbed by the plasma.

The size and timeline of the ITER investment—as well as the past history of fusion research—makes it logical for the world's leading industrial countries to approach this project collaboratively. Seven members, representing 35 countries and more than 80 percent of the annual global GDP and half the world's population, are involved in the construction of this first "star on earth." The ITER Organization serves as owner and coordinator of the ITER facility as well as the nuclear operator. The seven ITER Members are directly providing around 90 percent of the value in the form of procuring and delivering the millions of components that must fit together into a single, functional machine.

This collaboration allows us to continue to pool the best fusion science and engineering minds from around the globe. It lowers the financial and other risks for any one member.[1] And it enables the joint creation and acquisition of industrial capacity and expertise. The spin-off technologies that emerge from ITER's ground-breaking science and technological innovation are applicable to other industries and open significant opportunities for multinational trade.

Two risks also arise from this collaborative approach. First, for an international construction project in which each Member is procuring components that must interface perfectly together,

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[1] Unlike many other U.S. multinational engagements, with ITER the U.S. pays only 9.09% of the cost, with 45.46% of the burden borne by Europe. This makes ITER stand out as a highly leveraged U.S. investment.

we cannot allow differences of perspective or method to lead to divergent priorities or silos of operation. Integration is essential. Each of the ITER Members has a track record of success in high-tech enterprises. But each one approaches project management differently. Cultural and national differences can lend complexities to communication, political decision-making, budgetary processes, labour practices, and other aspects. Thus the organizational complexities built into the project structure, together with the complexities of the machine itself, must be intelligently and carefully managed.

Second, it is absolutely vital that each Member approaches the ITER project with a sense of pride, ownership and responsibility. ITER is an international project, but it is also in every way a U.S. project, an experimental platform for U.S. scientists, an essential element of the U.S. fusion research program—just as it is a European project, a Korean project, a Russian project, a project to be owned and operated by, and for the benefit of, every ITER Member.

The ‘risk’ that arises in this collaboration is that if any ITER Member falls short in meeting its commitments, it jeopardizes not only that country’s fusion program, but the fusion program and roadmap of each of its partners as well.

Looking ahead, we know that we will need the continuing commitment and support of every member to maintain the successful performance of the past 3 years. By choosing to build this machine in an integrated way, we have made our success interdependent. A shortfall in the commitment of any member, if it impacts the delivery of that member’s components or the capacity of the ITER Organization to meet the machine assembly and installation schedule, will have a cascading effect in delays and costs to all other members.

PROGRESS IN MANUFACTURING AND CONSTRUCTION

For the past 36 months, ITER has maintained a rapid pace in manufacturing and construction, in parallel with enhancement of project management. As I mentioned at the outset, we recently passed the 50 percent mark in the completion of “total construction work scope through First Plasma.” Using the same project performance metrics, total average component manufacturing through First Plasma, including building construction, is assessed to be 58 percent complete.

Supported by advances in fusion technology R&D, the production of major ITER components is in full swing. To illustrate both the interdependency of the project and the value being contributed by all Members, I will provide a few selected examples of recent progress made by each Domestic Agency, with a focus where relevant on components that are particularly complex or first-of-kind.

Europe

On-site construction: As part of its 45.46 percent contribution to ITER, Europe is constructing all the buildings of the ITER scientific installation. Today, the European Domestic Agency has completed 42 percent of work on site and signed 74 percent of work contracts.

The Tokamak Complex, incorporating the Tokamak Building, the Diagnostics Building and the Tritium Building, is advancing rapidly (see Figures 1 and 2). The basement levels (B1, B2) as well as the three above-ground levels (L1, L2, L3) of the Tokamak Building and bio-shield are complete. The Diagnostics Building is also nearing completion; whereas the Tritium Building, which is not needed for First Plasma, is currently at the L2 level. Multiple drain tanks have been installed, the first such equipment in the multi-year installation of tokamak and plant systems. The Assembly Building is complete and was turned over for use last year, and installation of the massive Sub-Sector Assembly Tools, manufactured by Korea, is fully underway.

FIG. 1: A view of the Tokamak Complex with the Assembly Hall to the back. The Tokamak Pit is in the centre, the Tritium Building on the left and the Diagnostics Building on the right.

FIG. 2: The bioshield is now finalized. Openings in the wall are for cryostat bellows that will connect the machine to the port cells to give access to systems such as remote handling, heating and diagnostics.

Figures 3 and 4 provide an overview of the change in the worksite from February 2015 to January 2018. As these photos illustrate, overall construction has been progressing rapidly, including the ancillary buildings and structures such as the Radiofrequency Heating Building, the Cryogenics Building, and the Magnetic Power Conversion Buildings, as well as the associated civil works and infrastructure elements.

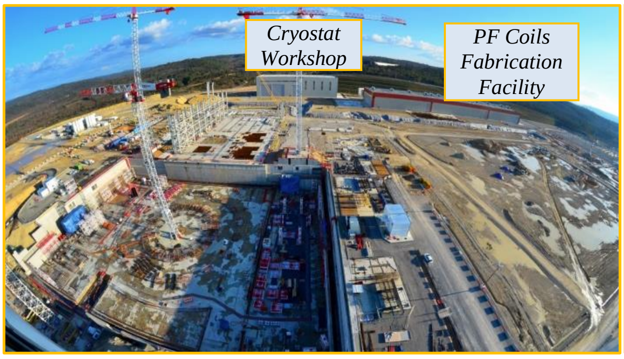

FIG. 3: The ITER worksite in February 2015.

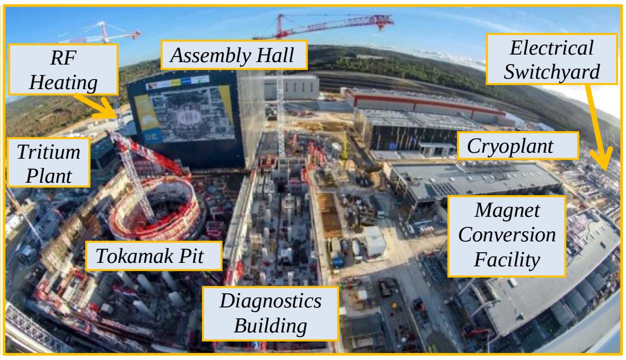

FIG. 4: The ITER worksite in January 2018.

First toroidal field magnet core: Inside the metal torus or donut-shaped vacuum vessel of the ITER Tokamak will be a second, invisible cage created by magnetic fields. These powerful electromagnets will keep the heated plasma in circulation away from the walls. Eighteen of these magnets, called toroidal field magnets, will be integrated around the vacuum vessel. These magnets are being manufactured both in Europe and Japan, using superconductors from six of the ITER Members, including the United States. The first of Europe's toroidal field magnet cores, called a "winding pack" and weighing 110 tons, was completed by the ASG consortium in April 2017 in La Spezia, Italy (see Figure 6).

The magnet core has now been delivered to Italy's SIMIC, the company that will complete cold tests and insert the magnet core into its final case. The completed magnet will then be delivered to the ITER site.

Negative ion beam source: Three systems will be used to heat the hydrogen plasma to 150 million °C, the temperature needed for fusion. The "neutral beam" system will provide more than half the heating for the plasma by injecting two high-energy particle beams of 16.5 megawatts (MW) each into the tokamak vacuum vessel.

The circumference of each particle beam is about 2.5 meters, greatly exceeding the size of previous beams, which had circumference of a dinner plate and a fraction of the power. The size of ITER requires thicker particle beams and faster individual particles in order to penetrate the plasma deeply enough to contribute to its heating. In addition, new high-energy negative ion source technology must be used, instead of the positive ion source technology used in past machines. Years of research have gone into the optimization of these ion sources.

In November 2017, Europe successfully delivered a negative ion source to the SPIDER test bed of the Neutral Beam Test Facility in Padua, Italy. Here the critical components of the system will be tested in advance, before transfer and installation at ITER. Europe, Japan and India are all contributing components. The SPIDER facility will be ready for commissioning later this month.

First cryopump: Six of ITER's cryopumps will maintain an ultra-high vacuum in the 1,400 cubic meter vacuum vessel where fusion takes place. The cryopumps will trap particles on charcoal-coated panels and extract helium ash from the fusion reaction. Each cryopump will weigh 8 tons and stand 3.4 meters tall. Two additional cryopumps will maintain a lighter vacuum in the cryostat, the 8,500 cubic meter chamber that will house the entire tokamak.

After 10 years of intensive R&D in Europe involving 15 high-tech companies—plus four years of fabrication by Germany's Research Instruments and France's Alsyom—the first cryopump was delivered to ITER for testing on 22 August 2017 (see Figure 5). Following mechanical testing at ITER and cryogenic testing at Germany's Karlsruhe Institute of Technology, fabrication of the additional cryopumps will follow.

FIG. 5: The pre-production cryopump was delivered in August 2017. More than 15 companies in Europe were involved in its manufacturing.

FIG. 6: The first toroidal field coil winding pack – the 110-ton inner core of ITER's TF Coils – was completed in April 2017.

China

Magnet feeders: ITER's magnet feeders will relay electrical power, cryogenic fluids and instrumentation cables from outside the machine into the superconducting magnets, crossing the warm/cold barrier of the machine. These complex systems are equipped with independent cryostats and thermal shields and packed with a large number of advanced technology components such as the high-temperature superconductor current leads, cryogenic valves, superconducting busbars, and high-voltage instrumentation hardware. They will be among the first components installed.

China is supplying all 31 feeders. The first feeder arrived in France in October 2017.

Correction coils: The correction coils are ITER's smallest superconducting magnets. Weighing no more than 4.5 tons each, they are delicate by ITER standards, much thinner and lighter than the massive toroidal field and poloidal field magnets. Yet their role is vital: to fine-tune the magnetic fields to offset any imperfections in the position and geometry of the main magnets.

China is producing these magnets. Eighteen superconducting correction coils will be distributed around the ITER Tokamak at three levels. Qualification activities have been completed and production is underway on the first coils and cases (see Figure 7).

Electrical conversion components: In addition to the steady state network that will supply electricity to buildings and auxiliary systems, ITER will operate a pulsed power electrical network (PPEN) to deliver power to the magnet coils and the heating and current drive systems during plasma pulses. In mid-2017, China delivered the last of the PPEN voltage transformers; and in October, China delivered four 128-ton converter-transformers for the magnet power conversion system.

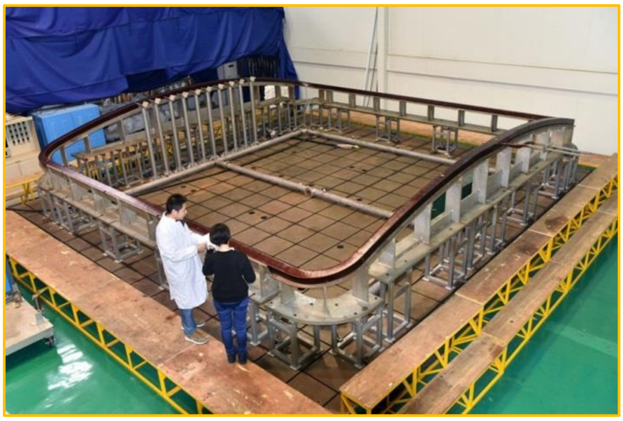

FIG. 7: This full-scale side correction coil prototype was used to qualify winding and impregnation manufacturing steps at ASIPP in Hefei, China.

FIG. 8: The ITER scale is apparent in the Cryostat Workshop, where Larsen & Toubro is supervising the assembly and welding of the lower cylinder.

India

Cryostat assembly underway: The 3,800-ton ITER cryostat will be the largest stainless steel vacuum chamber in the world. It will encase the entire vacuum vessel and all the superconducting magnets, ensuring an ultra-cool, protective environment. India is manufacturing the cryostat, but it is far too massive to be shipped as a whole. Steel segments have been precision-fabricated by Larsen & Toubro in India and transported by sea to Marseille. About half of the cryostat pieces have been shipped so far. At the ITER worksite, the Indian Domestic Agency is supervising a team of German welders in the final fabrication of the first two sections—the base and lower cylinder (see Figure 8). Welding operations on the second tier of the lower cylinder should be complete by the end of this month, and the whole assembly (tiers one and two) is expected to be ready for factory acceptance testing in June.

The cryostat base, at 1,250 tons, will be among the heaviest single loads of machine assembly. It will also be the first major component installed.

Cryoline piping: More than five kilometers of “cryoline” piping will be used to deliver cryogenic cooling fluids—liquid helium and liquid nitrogen—to ITER components. These cryolines will travel along an elevated bridge from the cryoplant to the Tokamak Building. From there, the distributed cryoline network will cool the ITER magnets, thermal shield, and cryopumps. The first batch of cryolines was shipped from India to ITER in June 2017.

Japan

Toroidal field coil magnets and cases: Japan has the responsibility for making 9 of ITER’s 19 toroidal field coil magnets, as well as all of the cases for these magnets. Japan’s first toroidal field winding pack was realized in 2017 by Mitsubishi Heavy Industries Ltd/Mitsubishi Electric Co; a second is underway at Keihin Product Operations/Toshiba Corp.

The steel cases are being made in segments at Mitsubishi Heavy Industries in Futumi, Japan, with some parts contracted to Hyundai Heavy Industries in Ulsan, Korea. They constitute the main structural element of the magnet system—not only encasing the winding packs that make up the core of the toroidal field magnets, but also anchoring the poloidal field coils, central solenoid and correction coils.

In December, the first toroidal field coil case successfully passed all fitting tests. The two sides of this huge component—as tall as a four-storey building and machined from 20-centimeter-thick steel—were matched within gap tolerances of 0.25 mm to 0.75 mm, an accuracy of more than one order of magnitude in relation to conventional high-precision welded structures of comparable size. The case was then shipped to SIMIC in Italy, where the first European winding pack (as mentioned above) has been delivered for insertion.

FIG. 9: This toroidal field coil case was manufactured by Mitsubishi Heavy Industries and Hyundai Heavy Industries, in 2 pieces.

FIG. 10: As of late 2017, Japan has completed the delivery of all niobium-tin superconducting cable to the U.S. for incorporation into the Central Solenoid.

Superconductor for the central solenoid: The central solenoid, the gigantic pillar at the core of the ITER Tokamak, is being built in southern California. But the production of 43 kilometers (745 tons) of special niobium-tin (Nb_3Sn) superconductor that will make up this magnet is the sole responsibility of Japan. In late 2017, Japan completed a major milestone (see Figure 10), shipping the last of this material to the U.S., where it is being wound into the modular coils that make up the central solenoid magnet.

Korea

Vacuum vessel fabrication: The ITER vacuum vessel, a donut-shaped stainless steel chamber heavier than the Eiffel Tower and more than 10 times larger than the next largest tokamak, is being built in nine pieces, like sections of an orange. Each 40° sector is a double walled steel component weighing 500 tons and measuring 12 meters in height and 7 meters in width, with multiple port openings and in-wall shielding contained within its walls in the form of modular blocks. Europe is building five sections, and Korea four. Russia is fabricating the upper ports, and India is making the in-wall shielding.

Korea has recently completed the first segment of vacuum vessel sector #6 on schedule, including non-destructive examination and dimensional measurements (see Figure 11). Sector #1 is nearly half complete, and sector #8 is well underway.

FIG. 11: Korea is nearing completion of the vacuum vessel sector #6. Each sector is made up of four segments. Pictured here is poloidal segment 2.

FIG. 12: The 850-ton thermal shield, made up of 600 components that range from a few hundred kilos to approximately 10 tons, is in mass production in Korea.

Giant assembly tools to pre-assemble the vacuum vessel: The tools ITER will use to assemble the vacuum vessel sectors are truly colossal: six stories high with "wings" that spread 20 meters. Each tool weighs 800 tons. Each is strong enough to hold a 440-ton vacuum vessel sector and two 310-ton toroidal field magnets in its arms, bringing them together to make a unit.

Two of these "sector sub-assembly tools" (SSATs) will work side-by-side in the 60-meter-high ITER Assembly Hall. They will pre-assemble the nine sectors of the vacuum vessel with other components before their transfer to the Tokamak Pit, where they will be welded together to form the ITER vacuum chamber.

Korea delivered the first SSAT to ITER in batches in mid-2017. It is currently being erected in the Assembly Hall. A second, identical, tool is under fabrication in Korea.

Thermal shield: Since ITER's superconducting magnets must be cooled to minus 269°C, they must be heavily protected from any heat source. The toroidal field magnets, which surround the vacuum chamber, require a special high-tech thermal shield: stainless steel electroplated in silver. At SFA Engineering Corporation in Changwon, Korea, the fabrication of the ITER thermal shield is now in mass production (see Figure 12).

Russia

Poloidal field coil #1: Six ring-shaped poloidal field coil magnets will encircle the ITER machine to shape the plasma and contribute to its stability by "pinching" it away from the vacuum vessel walls. Poloidal field coil #1 (PF1) is being built at the Srednenevsky Shipbuilding Plant in Saint Petersburg, Russia (see Figure 13). Specialists from the Efremov Institute and other Russian experts are winding niobium-titanium superconductor material into flat "pancakes." The fifth of eight pancakes that will make up the PF1 magnet is now being wound. The final PF1 magnet, which will weigh 300 tons, will be shipped to ITER and installed at the top of the machine.

Poloidal field coil #6 is also well underway in Hefei, China. The remaining four coils, which will be too large to ship, are being manufactured on the ITER site by the European Domestic Agency.

First completed port stub extension for vacuum vessel: As mentioned earlier, the ITER vacuum vessel, where the fusion reaction occurs, will be encased in a second, much larger vessel, the cryostat. Each of the vacuum vessel's 44 openings will have custom-made "extensions" to create the junction to the cryostat. The upper-level ports are being built in Russia. While the extension pieces are small in relation to the vacuum vessel, they are still quite sizable. Port stub extension (PSE) #12, for example, weighs more than 17 tons, covers an opening of 4 meters x 2.5 meters, and is 3.4 meters in length. In November 2017, Russia completed PSE #12 and shipped it to Korea, where it will be welded onto its vacuum vessel sector.

FIG. 13: This double pancake for poloidal field coil #1 in Russia was the first ITER pancake wound following qualification; it has now completed vacuum pressure impregnation to create a rigid assembly.

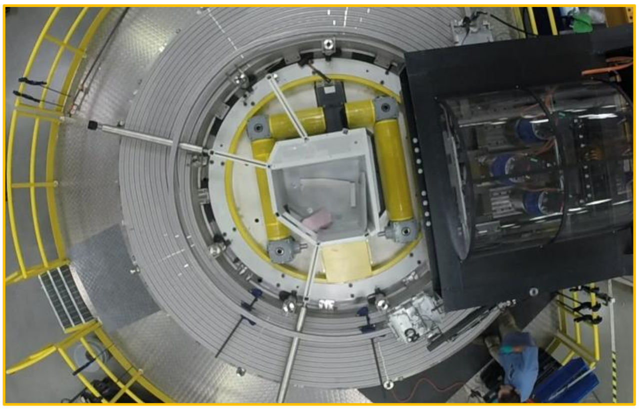

FIG. 14: General Atomics is fabricating the 1000-ton Central Solenoid. Pictured is the first production module. Each module requires approximately 6,000 meters of niobium-tin (Nb_3Sn) conductor.

Power supply and magnet protection system: Russia is responsible for a wide variety of electro-technical components that make up the switching networks, fast discharge units, DC busbars and instrumentation procurement package. Manufacturing is underway now on the busbars and switching network resistors; and the R&D program is concluding for the fast discharge unit components.

United States

Central solenoid: In Poway, California, General Atomics is creating the ITER central solenoid, a pillar-like magnet standing 18 meters tall, sometimes called "the beating heart of ITER." The central solenoid is made up of six individual coils, each made from approximately 6,000 meters of niobium-tin (Nb_3Sn) conductor fabricated in Japan (see Figure 14). The central solenoid will be among the most powerful electromagnets ever built, strong enough to lift an aircraft carrier. Its maximum magnetic field will be 13 Tesla, equivalent to 280,000 times the magnetic field of the Earth.

The first of the seven central solenoid production coils is now 80 percent complete, with other coils also in fabrication.

U.S. completes electrical deliveries: The U.S. has completed its contribution to ITER's steady state electrical network (SSEN), which will power the pumps and other non-pulsed auxiliary loads of the ITER facility. The 35th and final shipment of equipment arrived at the ITER site in October 2016 (see Figure 15). The global procurement was managed by Princeton Plasma Physics Laboratory. The U.S. is supplying 75 percent of SSEN components; with Europe supplying the remaining 25 percent.

FIG. 15: The U.S. has completed a $34 million, 5-year project to provide 75% of components for the steady-state electrical network at ITER.

FIG. 16: Fabrication of Tokamak Cooling Water System piping is underway at Schulz Xtruded Products in Robinsville and Hernando, Mississippi. A total of 36 kilometers of nuclear grade stainless steel piping is needed.

U.S. completes Toroidal Field conductor deliveries: The U.S. has completed a $73 million project to complete its contribution to ITER's Toroidal Field system, providing more than 40 tons (4 miles) of superconductor to Europe for its incorporation in toroidal field coils. At the height of fabrication, U.S. vendors Luvata and Oxford Superconducting Technologies were each producing more than five metric tons of superconducting strand per month. Before ITER, worldwide production of this wire was 20 metric tons a year.

Tokamak cooling water system: The Tokamak cooling water system will absorb the heat produced by the ITER fusion reaction. More than 36 kilometers of nuclear-grade stainless steel piping for the system is being fabricated in Robinsville and Hernando, Mississippi (see Figure 16).

In October, the final design review was completed for the entire system—which means that more orders for high-tech equipment need to be placed soon.

Additional U.S. procurements: Several other key components also have to be procured by the U.S.: 4 diagnostic port plugs and 7 instrumentation systems (Core Imaging X-ray Spectrometer, Electron Cyclotron Emission Radiometer, Low Field Side Reflectometer, Motional Stark Effect Polarimeter, Residual Gas Analyzer, Toroidal Interferometer/ Polarimeter, and Upper IR/Visible Cameras); Electron Cyclotron Heating Transmission Lines (approximately 4 km of aluminum waveguide lines—24 lines—capable of transmitting up to 1.5 megawatts per line); Ion Cyclotron Heating Transmission Lines (approximately 1.5 km of coaxial transmission lines—8 lines—capable of transmitting up to 6 megawatts per line); the Pellet Injection System, an injector system capable of delivering deuterium/tritium fuel pellets up to 16 times per second; Vacuum Roughing Pumps, a matrix of pump trains consisting of approximately 400 vacuum pumps; the Vacuum Auxiliary System (vacuum system components including valves, pipe manifolds, auxiliary pumps, etc., and approximately 6 km of vacuum piping); and the Tokamak Exhaust Processing System, an exhaust separation system for hydrogen isotopes and non-hydrogen gases.

Summary of progress: an integrated project

The foregoing is only a sampling of the activity currently underway worldwide, as all ITER Members work to the same integrated schedule, fabricating their components for this intricate and interdependent project. This interdependence will become still more apparent this year, as the final preparations for the Assembly Phase are made and assembly contracts are placed. It will escalate even more sharply in 2019, when full-paced machine assembly gets underway and each component must be available in a precisely orchestrated sequence.

INTERNATIONAL PROJECT MANAGEMENT: staying on track for success

To have confidence that the ITER Project is on track for success requires an understanding of the organizational reforms we put in place starting three years ago, the external validation of those reforms, and our performance in relation to agreed milestones.

Initial reforms: In early March 2015, when I took over as ITER Director-General, the organizational deficiencies and management shortcomings of the project were well understood, based on a probing and critical 2013 Management Assessment led by the American expert Bill Madia of Stanford University. The pace of improvement immediately following the 2013 report, however, remained unsatisfactory. My agreement to take on the role of Director-General, after extensive consultation, was contingent on the acceptance by all ITER Members of the Action Plan I mentioned in my introduction today, which I proposed at the time as the way to get the project back on track.

The positive impacts of the Action Plan were rapidly evident. The ITER reorganization that followed created a structure, decision-making protocol, and modes of interaction more suited to this complex, first-of-a-kind project. The Executive Project Board, made up of myself, my two deputies, and the heads of each of the seven Domestic Agencies, has proven effective in resolving the technical questions that arise naturally at the interface of the ITER systems and components contributed by each Member. The Reserve Fund we set up remains an efficient mechanism for financing timely adjustments to the design where necessary. The design finalization for critical path components has been a vital step to prevent further delays and cost overruns. And cross-organizational Project Teams, including all relevant actors in a single entity, have been used to guide progress on the most critical project elements.

By late 2015, after eight months of exhaustive technical analysis and consultation with Domestic Agencies and suppliers, we had successfully compiled a fully integrated schedule with associated resource projections. The cost increases and longer timeline of the new schedule were, in retrospect, inevitable: because previous schedules and cost estimates had been based more on externally imposed conditions rather than on a realistic technological basis and an integration of Members' constraints. The "Best Technically Achievable Schedule" we presented to the ITER Council in November 2015 reflected a comprehensive understanding of a machine with more than 1 million components and correspondingly complex manufacturing, construction and assembly sequences. The integrated analysis that led to this schedule was the essential foundation to give confidence that the ITER Project would be able to progress forward on a realistic and reliable basis, if all Members continued to meet their commitments.

The ITER Council at that time acknowledged the much-improved understanding of project scope, sequencing, risks, and costs achieved by this systematic review. It expressed appreciation for the tangible progress in construction and manufacturing. And it called for an independent review of the overall proposed schedule and associated resource estimates, to validate our methodology and analysis, to suggest adjustments and improvements where warranted, and if possible to identify additional measures for consolidating and expediting the schedule and reducing costs.

External review and validation: In April 2016, when I appeared before this Committee, we had just received the report of the independent ITER Council Review Group, the first time our efforts had received an intensive review by an external body. The Review Group, consisting of 14 international experts, had as chartered conducted a thorough examination of our proposed schedule and resource estimates, and found both to be credible and realistic—although extremely challenging. Based on an intensive drill-down into the project details, they also reported that the project reform efforts had resulted in "substantial improvement in project performance, a high degree of motivation, and considerable progress." They found that collaboration between the ITER Organization and the Domestic Agencies had markedly improved, but still called for "further strengthening" of these internal relationships in a "culture of collaboration"—a recommendation that, as you have seen, we wholeheartedly embraced.

One month later, we received a second significant element of external validation, when the Secretary of Energy reported to Congress with positive statements regarding progress of the project. The Secretary concluded that "ITER remains the best candidate today to demonstrate burning plasma, which is a necessary precursor to demonstrating fusion energy power." The Secretary recommended that the U.S. should remain a partner in the project through FY 2018, but should re-evaluate continued participation prior to the FY 2019 budget submittal.

While as I noted earlier we believe strongly that continued U.S. participation is in the mutual interest of both ITER and the United States, we welcomed this continued scrutiny of project performance. Since that time, we have had regular semi-annual independent reviews by some of the leading world experts on topical issues. In June 2017, we received the report of an independent review of ITER's approach to Risk Analysis and Risk Management. In November 2017, a second review was completed focused on our processes for defining and freezing the design interfaces of the systems, structures and components required for First Plasma. The latest Management Assessment, led by Japan, was also completed in 2017.

Both the Risk Management and Interface Freezing reviews have compared the ITER Project to industry standards, recognized best practices, and best available techniques—while also accounting for ITER's first-of-a-kind nature, which in some cases requires even more sophisticated measures than in past industrial projects. Each of these reviews, as well as the 2017 Management Assessment, has validated ITER's progress and approaches to critical aspects of project management, finding that the project is well-managed, to the best industry standards. Each external assessment and review has also helped us to identify additional refinements of our methods. A new semi-annual external review has begun recently, focused on Configuration Management, and we look forward to receiving the results of that review in the coming months.

Project management and the achievement of a project culture: Changing the culture of a project does not occur overnight. At ITER it has taken us more than two years, and we have continued a rigorous emphasis on self-examination and ongoing improvement. To solidify the gains we made during project reforms, we have emphasized a disciplined approach to applying the best principles of international project management, risk management, systems engineering, and ultimately nuclear safety culture and project culture. Adhering to the revised schedule has not in any sense been automatic or easy; it has required a systematic anticipation and mitigation of risks as well as day-by-day integration and teamwork. Developing and implementing an Earned Value Management system has been a key asset in this regard. And the incorporation of recognized systems engineering best practices has improved the rigor of verifying and validating that safety, quality, and technical performance criteria are incorporated across the full spectrum of construction and manufacturing activities.

Performance to agreed milestones: In November 2015, when we first presented our proposed schedule through First Plasma in 2025, the ITER Council emphasized the importance of maintaining rapid momentum in construction and manufacturing even while external reviews and validation processes were ongoing. For this reason, the Council approved the proposed schedule for 2016-17, together with a set of 29 well-defined technical and organizational milestones covering this two-year period, referenced to this schedule and the hierarchy of associated project activities. These milestones could be used to monitor our ongoing reliability and progress; if achieved successfully and on time, it would demonstrate that the ITER Project was keeping pace.

A full set of additional milestones have since been formulated covering the entire period through the realization of First Plasma in 2025. I am pleased to report that, to date, 31 milestones have been successfully achieved. Two of the milestones for 2016-17, both related to civil works in the Tokamak Building, have been decided to be postponed several months ago; in both cases, scheduling sequences have been re-adjusted and mitigation measures put in place to ensure this slippage will not affect the overall schedule. All aspects of the critical path schedule remain on track.

These positive results should in no way be taken for granted; they represent collective effort and teamwork across all project partners, including supplier companies and laboratories. While we have experienced challenges and potential delays with individual milestones, we have in each case mitigated those challenges, offset or reduced the risk of delays and gotten back on track. Overall, so far, there has been no slippage whatsoever in the reference schedule. This reflects substantial improvements in our collective capacity for anticipating and mitigating emergent risks.

Establishing an updated baseline: Following our initial November 2015 presentation of the revised schedule through First Plasma, the ITER Council asked us to initiate a further series of discussions with all ITER Members. The intent was to incorporate the proposed schedule and resource projections into an agreed overall project baseline that would extend through Deuterium-Tritium (DT) full fusion power operation. These discussions were needed to consider the priorities and resource constraints of ITER Member governments, as well as the manufacturing schedules and the interfaces of each Member's in-kind contributions.

The culmination of this schedule iteration was reached one year later, in November 2016, when the ITER Council approved the Overall Project Schedule through First Plasma in 2025 and onward to Deuterium-Tritium (DT) full fusion power operation in 2035. The associated Overall Project Cost was approved *ad referendum*, meaning that it required final consideration by ITER Member governments. For the United States, the Department of Energy subsequently approved the Overall Project Cost in January 2017.

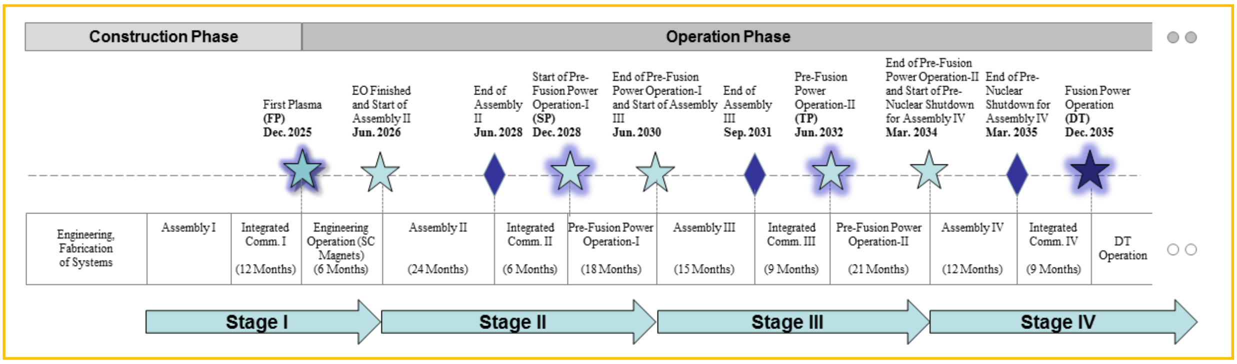

Figure 17: Schematic of the 4-stage strategy from First Plasma to DT operation within the revised ITER baseline.

Putting all of these elements together into an Updated Project Baseline represents a pivotal project-wide achievement, once again requiring integration and teamwork to accommodate the resource constraints of all ITER Members. The result, as depicted in Figure 17, is a 'staged approach' between First Plasma and Deuterium-Tritium Operation.

The staged approach envisages several assembly phases and plasma operation campaigns, in keeping with when ITER Members will be in a position to deliver the associated equipment. In advance of First Plasma, the core tokamak systems will be assembled with the necessary auxiliary systems (heating and current drive (H&CD), diagnostics, fuelling) required to support plasma breakdown. This is consistent with First Plasma as a demonstration of the successful integration of the tokamak core and principal plant systems (power supplies, cooling, cryogenics, vacuum, etc.) and will conclude the first phase of integrated commissioning of the ITER facility.

Subsequently, the magnet systems will be commissioned to full current, and the full set of in-vessel components (including shielding blanket, first wall and divertor) will be installed, together with an expanded subset of the heating and current drive and diagnostic capability. The first physics experiment is planned in December 2028. Two periods of experimental operation with hydrogen and helium plasmas will follow, with a 3rd assembly period to complete the H&CD systems and most of the remaining diagnostic capability. These two experimental periods will commission all tokamak and auxiliary systems with plasma, and will demonstrate full technical performance of the ITER device before the transition to D and DT operation in the 4th stage of the experimental program.

CONCLUSION

At the ITER Organization, we are committed to ensuring the delivery of the ITER machine on time and the full achievement of the associated scientific and technological benefits, as the launching pad for the eventual commercial deployment of fusion-generated electricity. We are committed to delivering the project in a manner that lives up to the trust placed in us by all ITER Members. We are committed to continuous improvement, to make ITER the model for international collaboration on complex science and technology challenges. And we are committed to making ITER a sound investment for the U.S., as for all our partners. These commitments require that all of the seven ITER partners fulfil their own commitments towards the ITER project by providing the needed resources on time (staff, in-kind components and in-cash contribution). This year is critical on this point, since some Members seem not prepared to do so for the first time. We look forward to a long and fruitful collaboration.

Thank you for this opportunity.