Virtual Public Forum
A Regulatory Framework for Fusion

Facilitators: DOE, NRC, FIA

Tuesday, October 6, 2020
Meeting Minutes
Teleconference via Zoom Meetings

The Virtual Public Forum: A Regulatory Framework for Fusion was held on Tuesday, October 6, 2020 via teleconference, from 10:00 a.m. to 4:00 p.m. The Forum was facilitated by U.S. Department of Energy (DOE), U.S. Nuclear Regulatory Commission (NRC), and the Fusion Industry Association (FIA).

Presenters:

Mr. Paul Dabbar, DOE Under Secretary for Science
Ms. Kristine Svinicki, NRC Chairman
Mr. Andrew Holland, FIA Executive Director
Dr. Paul Humrickhouse, Idaho National Laboratory Fusion Safety Program
Ms. Joelle Elbez-Uzan, ITER Organization Nuclear Safety Division
Dr. Peter Lyons, Former NRC Commissioner and DOE Assistant Secretary for Nuclear Energy
Mr. Bill Reckley, NRC Office of Nuclear Reactor Regulation
Mr. Kyle Cormier, Canadian Nuclear Science Commission New Major Facility Licensing Division
Ms. Amy Roma, Hogan Lovells
Mr. Michael Cappello, General Fusion Senior Vice President for Prototype Deployment
Mr. Tyler Ellis, Commonwealth Fusion Systems
Mr. Derek Sutherland, CTFusion Chief Executive Officer

*293 attendees were present, names of identified participants are listed in the Appendix.

Moderator: Dr. James Van Dam, Associate Director of the Office of Science for Fusion Energy Sciences (FES), shared opening remarks to attendees and introduced The Honorable Paul Dabbar, The Honorable Kristine Svinicki, and Mr. Andrew Holland.

Paul Dabbar, Under Secretary for Science of the U.S. Department of Energy:

This is a very exciting time for the fusion sector. This conference involves various members discussing the regulatory structure based on the science and uniqueness of fusion versus older energy types and making certain that the U.S. is leading in this area. Part of that goal is making certain that the U.S. has the correct energy structures for risk and safety, as well as informing investors of the regulatory structure being developed and the framework for its implementation. Over the last 3.5 years, leadership at DOE have been highly enthusiastic about fusion. Grants for the overall DOE Office of Science are up 31% compared to 3 years ago, and we enjoy a lot of support from Congress in many areas, including the ITER project in France as it moves toward control of fusion plasma.

Today, the primary focus is to talk about the potential impact of having plants built in the U.S. that can produce power in the long term. The private sector has been dynamic in this effort, raising well over $1 billion for private fusion development for all sorts of physics and confinement types, and we want to make certain to support this as peoples' ideas develop and funding comes in from the public and private sectors. We want to develop a path in terms of the regulatory structure of how to build a demo plant. It is important for us, and the American taxpayers who fund us, that the first commercial fusion plant be built, and deliver power, in the U.S. This possibility is much closer at hand than people perceive because of where the science and technology has moved. We have initiated a number of different aspects of this goal: one has been the Innovative Network for FUSion Energy or INFUSE program that provides private sector companies with access to expertise from the DOE national labs to overcome critical technology and scientific hurdles for the development of fusion energy systems. This approach is based on a similar structure to the DOE Office of Nuclear Energy Gateway for Accelerated Innovation in Nuclear or GAIN program, leveraging what the American taxpayer has already supported at the national lab complex in the areas of fission and fusion energy research. We appreciate Congressional support for the INFUSE program.

Besides increasing support for funding, over the last several years, we have helped to initiate a fusion community's effort to develop input for a long-range strategic planning activity. This planning activity has provided a lot of coherence to the fusion community. The community report was completed in March 2020. That report is now with a subcommittee of the Fusion Energy Sciences Advisory Committee (FESAC) for input in developing a long-range strategic plan for the entire fusion program. The draft plan from the subcommittee will be delivered to FESAC in December 2020. In addition, we have commissioned the National Academies of Sciences, Engineering, and Medicine to provide guidance to DOE on the key goals that need to be established for all phases of operation of a fusion pilot plant in the U.S. that produces electricity from fusion at the lowest possible capital.

Congress, the House Science Committee and both Senate and House Appropriations Committees have provided great support. There is a subset of the Nuclear Energy Innovation and Modernization Act (NEIMA) with a section on fusion, and a portion of the latest House Science Committee bill focuses on fusion. We would like to encourage Congress to pass a fusion bill that contains some components of these for additional guidance and support for the enthusiasm expressed in the DOE, academic, and private communities.

In addition, there is consideration of doing something like the National Aeronautics and Space Administration Commercial Orbital Transportation Services (COTS) program, which was used to support public-private partnerships to produce a U.S. commercial launch capability. SpaceX used COTS to help commercialize their new technology. Last week a report, requested by Congress, about such a cost share program was submitted to both appropriations committees for their review and consideration.

Finally, the NRC regulatory framework is essential in terms of regulation. Globally, fission is considered the benchmark for fusion, but the physics and science as well as the risk issues are quite different. This dialog on a regulatory framework for fusion with the NRC and the whole community, based on the specifics of fusion, is the primary purpose of this public forum.

Kristine Svinicki, Chairperson of the U.S. Nuclear Regulatory Commission

Ms. Svinicki thanked Mr. Dabbar for his leadership. As COVID set in, he said this conference is too important to delay and it needs to be done in some format. The dialog needs to continue; he is right about that.

There has been a long relationship between the DOE and the NRC on possible regulatory approaches for commercial fusion reactors. Ms. Svinicki drew parallels to work that the NRC has been doing on advanced reactors in the fission space. As a regulator, what we are confronted with is suddenly a very heterogeneous community of technologies that need the right regulatory entry point and need a tailored and stylized approach to adapt and commensurate it with the risks posed. Congress is expressing new and wonderful bipartisan support for advanced energy and clean energy technology advancement. Congress has explicitly covered fusion in Nuclear Energy Innovation and Modernization Act (NEIMA) with clear direction to the NRC to include fusion consideration in new regulations being developed in the advanced reactor space. Consistent with that, for some years NRC has been looking at a complement to 10 CFR (Code of Federal Regulations) 50 and 52 which we are using for the fission-based systems. The NRC is in the process of developing "10 CFR 53".

Creating a regulatory construct for fusion is a bit more burdensome and bureaucratic than utilizing fission regulations as a model, but we will bring the minds and skillsets from the work on fission micro reactors to the fusion community. It is so important to make sure the dialog does not go too quiet for too long. There is no obstacle identified today that stops us from having continued work to develop the issues, to have dialog about them in a very transparent way, to find solutions, and to find the next options for moving forward.

Additionally, we will have the involvement of the Canadian counterpart of the U.S. NRC, the Canadian Nuclear Safety Commission (CNSC). The U.S. NRC has signed an agreement with CNSC to continue to work in concert on advanced nuclear technologies. It is not quite co-regulation or the adoption of each other's statutory or regulatory frameworks, but it is a fruitful dialog. Just like micro reactors, fusion is a truly global industry and that international piece is imperative.

Andrew Holland, Executive Director of the Fusion Industry Association, Chief Operating Officer for the American Security Project

Mr. Holland thanked Under Secretary Dabbar and Chair Svinicki for their comments and their leadership in bringing this forum together. Mr. Holland provided a brief overview of the breadth of the FIA and their excitement for being a part of the regulatory environment. FIA is working to build the fusion energy economy. FIA has 22 member companies and is building a movement around the world. FIA's mission is to deploy fusion fast enough to meet the world's challenges. Those challenges are the climate crisis and meet the global energy demand. Clean energy technologies are important but insufficient. Fusion is a breakthrough energy source uniquely suited for rapid, widespread adoption to disrupt and displace fossil fuels around the world. Our species' biggest challenge is our resource scarcity. We need to raise living standards, meet the growing global energy demand, and break the geopolitics of energy so that a country's destiny is not determined by the size of its hydrocarbon deposits. The FIA supports efforts to accelerate fusion research and development (R&D) because it is important, and it needs to be done on a timescale that matters.

We are in a global race to fusion power. The U.S. and our competitors are working fast to get to fusion. I appreciate Under Secretary Dabbar's statement that he thinks it is very important that the first commercial fusion power plant be built in the U.S. FIA members support that. However, the regulatory regime is a part of that international competitive landscape. The U.S. has unique advantages here: capital markets, scientists, and businesses. National regulation will be a factor in international competitiveness.

FIA began 2 years ago and have grown from 15-22 members. All these companies have a huge range of technology, business plans, and ways forward. The consultants, the non-governmental organizations (NGOs), and the members of the supply chain will help build the fusion energy economy. Regulatory certainty is a key goal for the FIA because it's something that our investors and companies care about and what we have been working towards since our start. Fusion research, development, and deployment must be subject to appropriate, risk-informed regulation when experiments are built and sited. To that end, FIA put together a white paper "Igniting the Fusion Revolution in America". This was a multi-year effort including all our companies. The key takeaways are that fusion is explicitly and permanently removed from the regulatory approaches that the federal government has taken towards fission power plants. We believe this because fusion addresses a different suite of risks compared to fission facilities. Rules like NRC's Part 20 regulations for general radiation protection and Part 30 rules for handling byproduct materials would properly address fusion facilities' risk profiles.

We want to give clear support that the DOE has created a framework for safe construction and operation of experimental fusion energy devices that has worked well for decades. This is important that there is enough regime right now to be building experimental devices. A key point to remember as we talk about international competitiveness is that the French nuclear regulator imposed its existing fully deterministic fission facility regulatory approach to evaluate the ITER experiment. This resulted in increased construction costs and timeline because it failed to appreciate the significant difference in risk between fusion and fission facilities.

Panel Discussion/ Q&A

Dr. Van Dam thanked the speakers for their input and assistance putting the forum together. He posed pre-submitted questions from the audience.

Directed to Dabbar – In the U.S. can NRC, DOE, and Environmental Protection Agency (EPA) work together to craft a holistic approach for regulation under current authority or will legislative reform be needed to advance fusion energy, and if so, what kind of legislation? **Dabbar** – The general regulatory framework is authorized by the NRC and it gives authority to execute. DOE has not found any specific need to get new enabling legislation. This forum will help determine if there are things that need to be changed and authorized in legislation. DOE has been working for a while with the Idaho National Laboratory (INL) to consider different regulatory risk factors for fusion. DOE has a body of work that the NRC and NRC staff, as well as commercial sector, could build from. **Directed to Svinicki** – Same question addressed to the NRC about whether legislative reform might be needed. **Svinicki** – There is not a near-term obstacle that requires a legislative fix. The NRC was already reviewing advanced reactors when NEIMA was put in place, so there is a regulatory pathway and system. There is nothing preventing forward progress, but we are learning more as we make progress under the current system. A Congressional law with greater clarity would be helpful. While Mr. Holland suggested that fusion systems should be separated out from Parts 50, 52, and 53, NEIMA specifically puts fusion in Part 53, therefore we are bound to do that by law. However, it is critical to remain agile and continue looking at things as we learn more. **Holland** – Concerning legislation, FIA does not believe additional legislation is necessary at this point, but we stand with our champions in Congress to address it if is needed.

Directed to Holland – How can the fusion industry and regulators work together to craft regulations that address the concerns of the public and experts, and how will those concerns be discovered? **Holland** – The answer begins with transparency. FIA must work with the public through events like this, work with those at DOE/NRC to talk about the risks and risk profile and ensure that we are working with the whole suite of stakeholders. That is why FIA is doing this event and we have planned a series of future engagements. We want this to be open and clear; we are not hiding anything. We want to work in partnership with the NRC. We have already had discussions with staff, we have met with the commissioners, and we feel we have a good partnership and a way forward. **Directed to Svinicki** – Same question addressed to the regulators. **Svinicki** – Appreciated Mr. Holland's comments saying she was in strong alignment. DOE has the statutory obligation to be a technology enabler and promoter of advanced technologies. The regulators at NRC have an obligation to the public's health and safety and are protectors of the environment. A lot of constituencies that care about both of those are participating in the forum today. This type of dialog is how we will put the finishing touches on the regulatory path forward.

Directed to Dabbar – What role can global organizations (including governmental and non-governmental agencies, other regulatory agencies, and industry associations) play in setting precedence examples in standards for such a regulatory environment? **Dabbar** – In the nuclear and fission sectors, standard-setting for regulations around risks has been going on for decades. The NRC is globally recognized as a leader and standard setter. Notwithstanding, fusion is a new technology with risks as Mr. Holland mentioned earlier, and it is important to work with other regulators (in Canada and the United Kingdom (U.K.) in particular) to ensure a consistent, science-based, risk-based approach. If anyone deviates from certain standards of construction for instance, then it will be raised by others in the community. In the U.S., we should be doing this based on the science and the risks. It is important that everyone in the world uses that same benchmark rather than other metrics so there are less questions about those standards. **Same question directed to Svinicki** – It should not be templates from the past or preconceived dogmas about how to regulate fusion as a "nuclear technology". It should be about the hazards and risks. Again, NRC has been working in this way with the diversity of advanced fission reactor types. We have been having some internal dialogs about our own culture about risk acceptance. What are our thresholds on risk? We have an initiative called "be risk smart" meaning gain clear understanding of the risks and hazards and tailor our approach; developing what is truly merited to meet our obligation for public health and safety. **Same question directed to Holland** – FIA recognizes that regulation is effectively and importantly a national prerogative and each country will have their own regulatory regime. But at this early stage, organizations like the NRC could become the gold standard, the one on which other countries base their regulatory standards.

Directed to Svinicki – Could a regulatory environment be created in parallel to the development of the fusion industry so that concerns are addresses as they come to light and would that be prudent? **Svinicki** – This could be done, and it might be the strongest way to develop something that is truly risk-informed and tailored. Drawing a parallel to advanced reactors in the fission area, that is what we have been doing there. There is a lot of pre-review ("regulatory engagement") learning about the technology to be done. Oak Ridge National Laboratory (ORNL) set up a "sodium school" to learn about regulatory engagement in the fission space. NRC is working with DOE and the national labs to develop staff core competencies. Operating in this parallel track allows us to understand the design as it matures. The more we understand the technology, the more we will uncover the hazards and safety risks/concerns it presents. It is the most informed way of preceding. **Same question directed to Holland** – FIA is working towards that and excited to do it. **Same question directed to Dabbar** – On this topic and more broadly, there is a lot of heterogeneous confinement types being developed and doing it concurrently rather than waiting until the end. There are certain risk issues that may be unique, but the science is relatively consistent. To conclude this introductory section, DOE is very excited about this. Harnessing the most dynamic and best funded private sector allows the U.S. to jump on one or more technologies that are under development so that the first plant can be built in U.S. It is important to do this right and be at the front end so that taxpayers' money is getting closer to Q>1. This is much closer than 30 years out. It is exciting that we are moving this portion of the discussion along.

Dr. Van Dam expressed his sincere thanks to all the panelists and attendees.

Morning Session: Introduction to Fusion Safety and Regulations. Dr. Van Dam introduced the morning session and the three speakers, Dr. Humrickhouse, Dr. Joelle Elbez-Uzan, and Dr. Peter Lyons

Overview of US Fusion Safety Program, Dr. Paul Humrickhouse, Research Scientist in the Fusion Safety Program, Idaho National Laboratory

Dr. Humrickhouse talked about origin of radioactive materials in fusion and how it is different than fission, aspects of confinement, radiological hazards (e.g. activation products and tritium), release mechanisms (e.g. dust and permeation), safety analysis, waste, and the DOE Fusion Safety Standard.

Radioactive materials in fusion have a different origin than direct products from a fission reactor. Most of the things we do in the Fusion Safety and DOE programs are generally focused on deuterium and tritium (D-T) fusion (that being the easiest fusion reaction to accomplish). Tritium itself is radioactive and its management has some unique challenges. Eighty percent of the total energy from these D-T reactions is coming out in high energy neutrons (one per fusion reaction) and those neutrons will activate structure, coolants, etc., thus radioactive material will be produced. People may be pursuing alternative fuel cycles, for example ones that are ostensibly aneutronic, and will produce neutrons via side reactions. The production of radioactive materials from these alternative fuel cycles is a substantially reduced hazard compared to D-T fusion. In terms of radioactive materials concerns the extent of the hazard depends on material selection and nature of the device. Historically, we focused on pursuing power-like machines in the end. The selected materials and device will impact how much decay heat will be produced from those radioactive materials. Radioactive waste is an area where fusion can improve on fission reactors. The takeaway is that on a relatively short timescale the radioactivity decays away and are less radiotoxic than emissions from a coal plant, which is an attractive feature of fusion. Because radiation exposure can be avoided by confining the mobilization inventories of the radioactive materials, we focus on understanding what the mobilization inventories are and how they might be transported. Fusion reactors cannot experience the kind of reactivity transients that fission reactors do. But fusion reactors do have significant stored energies. To ensure confinement of radioactive inventories, we must ensure decay heat removal, provide controlled reduction in plasma energy, and control coolants and chemical energy sources, as well as energy stored in the magnets. Most activated materials will be bound in solid structures, making them an insignificant release risk. However, there are certain activated materials and products (e.g. dust, coolants, etc.) that can be released and those must be confined.

Tritium handling poses some unique challenges. For example, tritium can permeate through metals at high temperatures, which is a concern even during normal operations. Also, stored tritium inventories are a concern in that they can be released during an accident. The Fusion Safety Program is devoted to: 1) understanding tritium and activation product transport phenomena through experiments with tritium and other hazardous materials like beryllium; 2) development of accident simulation tools during nucleotide transport, and 3) R&D of technologies (e.g. exhaust systems) that will help minimize inventories and reduce hazards in future plant designs.

Tritium, which makes up half of the fuel for fusion reactions, has a 12.3-year half-life, and undergoes a weak beta decay so it is not an external exposure hazard. The issue is that as an isotope of hydrogen, it is readily incorporated into water, making it hazardous if ingested. Fusion reactors will consume tritium at a rate of 55.6 kg/GW-y. To put that into perspective, molten salt reactors (MSRs) are significant tritium producers among fission reactors. The rate of consumption in a fusion reactor would be a factor of 1000 times that of MSRs and 10^6 times that of a light water reactor. The plasma only burns about 1% each pass, so the fueling rate will need to be 100 times greater. There is no precedent for that in fission. Because of the short half-life there is no natural supply, future machines will have to breed it at least at the same rate it is being consumed and probably higher to bring other machines online. Some concerns are permeation through solid structures (e.g. pipes and vessel walls at high temperatures) and large tritium inventories that might be present in components (e.g. cryopumps) or tritium plants where it is collected and separated for reuse as fuel. The Fusion Safety Program is focused on obtaining data from tritium interactions including irradiated materials to inform transport models such as that in our tritium migration and analysis program (TMAP) code.

The other issue for activation products is dust. A variety of plasma surface interactions will erode material and that will accumulate in the vacuum vessel. This radioactive material could be mobilized in the event of a loss-of-vacuum, for example. The expected quantity from fusion power reactors is uncertain. ITER adheres to a limit of 1000 kg. Historically, there have been attempts to collect dust from currently operating non-nuclear Tokamaks around the world to understand its size distribution, morphology, etc. These particles come in a wide range of shapes and sizes, and this is information that informs aerosol transport models in our safety analysis codes. The primary tool we use for safety analysis is the NRC's code, Methods for Estimation of Leakages and Consequences of Releases (MELCOR), developed by Sandia National Laboratory for application to fission reactors. We originally adopted it for use in fusion because many of the thermal hydraulic, heat transfer, and radionuclide transport phenomena that occur would, in principle, occur in a fusion reactor unit even though initiating events are quite different. For many years INL has developed a modified version of this code and made additions to it to apply it to fusion systems. These modifications include: alternate fluids such as lithium (Li), lead-lithium (PbLi), fluorine-lithium-beryllium (FLiBe), and cryogenic materials that are relative to fusion systems; incorporation of oxidation models; addition of aerosol transport models; enclosure radiation and fire models; and tritium permeation and transport models from the TMAP code. An earlier version of this code, modified by INL, with some but not all the modifications mentioned was used in the ITER safety analysis and licensing documents.

The NRC waste classifications (10 CFR 61.55) outlines high-level waste and low-level waste (HLW and LLW, respectively). HLW being spent fuel as well as highly radioactive things that require permanent isolation. Among the classes of LLW, the highest is Class C, in which the requirement is based on the concept of intruder dose (the intruder being a person who builds a house or lives in a house at the waste site) where the intruder would receive <500 mrem/year after 500 years in the future when this waste is presumed to be no longer recognizable. It has long been an objective of the program, and outlined in our safety standard, that fusion materials meet the criteria for Class C LLW. Reduced-Activation Ferritic Martensitic (RAFM) steel has been developed for this purpose to eliminate some of the longer-lived alloy constituents that would not meet that requirement. While the waste from fusion might be low level, the volume of LLW might be large. However, recycling or reuse of this material for components in the nuclear industry may reduce the disposal burden.

The DOE Fusion Safety Standard was developed in the 1990s recognizing that multi-megawatt power-producing fusion reactors such as ITER might be in DOE's future and acknowledging the fact that these might have significant radionuclide inventories and there was no useful regulatory guidance specific to such a facility. The safety policy states that members of the public will bear no significant additional risk to their health and safety from the operation of a fusion plant beyond the risks to which they are normally exposed. Similarly, for workers there are no more risks than what they would normally be exposed to at a comparable industrial facility. Those risks to the public and workers should be as low as reasonably achievable. The need for an off-site evacuation plan should be avoided, and the amount of waste, especially high-level radioactive wastes, should be minimized. Looking at numbers taken from existing regulations, there are two sets of regulatory limits based on evaluation guidelines for public exposure to radiation and fusion radiological release requirements. For public exposure, the limit is 100 mrem/year from all sources for normal and anticipated operational occurrences and 25 rem/year for off-normal conditions. These are regulatory limits that you must comply with using an evaluation model with conservatisms built into it. Fusion radiological release requirements for normal and anticipated operational occurrences is limited to 10 mrem/yr., which is consistent with standards in the 40 CFR 61 on air pollutants, and the off-normal conditions exposure limit of 1 rem, based on the requirement to have no need for a public evacuation plan. There is also a radiation exposure limit imposed based on drinking water regulations (40 CFR 141.16) set at 4 mrem/yr.

D-T fusion reactors use radioactive fuel (tritium) and produce radioactive materials and waste via neutron activation. The extent of the hazards from these components will depend on reactor design (materials) and operation (irradiation time). The fusion reactor hazards should be lower than fission, but fusion reactors do have some unique stored energies, in the magnets and the plasma and must be managed appropriately. The primary mobilizable materials are tritium and activation products, so understanding these is one of the primary purposes of the fusion safety program. High-level and/or long-lived waste can be avoided if low activation materials are used in the design. Finally, the DOE has a comprehensive fusion safety standard that can help inform licensing efforts.

Discussions via Chat feature:

Sehila Gonzalez, International Atomic Energy Agency (IAEA) commented that regulation is a national issue, but international harmonization in this area would be a great achievement and would be set up as much as possible from the beginning of the creation of an industry. This is a lesson learned from the fission industry which faces problems when moving from one country to other to sell their products.

Tyler Ellis wrote that regarding the waste generation, dust generation and decay heat numbers described are based on either an ITER or DEMO sized device, since no private entity is pursuing a device of this size, these numbers be revisited to reflect the small and compact designs that the private industry is actually pursuing. If the devices sizes shrink 10x, the conclusions should change significantly.

Holly Ray asked if there is an argument that says a fusion plant is NOT a nuclear facility. **Amy Roma** said it depends on the law and regulations of the facility location. The U.S. laws and regulations are set up differently than France. In the U.S, the fusion facility itself is not currently regulated under NRC, only the radioactive materials it uses. In comparison, other types of nuclear facilities are regulated by the NRC, e.g., nuclear reactors, fuel fabrication facilities, uranium enrichment facilities, etc.

Jeffrey Merrifield Humrickhouse's slides mention that there may be large volumes of Class C materials that are multiples of the same volume produced by light water reactors. He asked if INL analyzed what additional Class C facilities would be needed if fusion systems were to move forward? Also, since much of the material is contaminated by tritium, would that radioactive volume be significantly reduced if the operators were to use safe store to allow the reactors to decay by delaying decommissioning for 40-60 years? **Humrickhouse** responded that a future in which a significant fleet of fusion reactors is operating would indeed challenge the capacity of existing class C disposal facilities. This is one of the reasons why recycling/reuse/clearance of materials is of potential interest. Tritium can likely be removed from these materials to some extent, it is the remaining activation products that will dominate the dose at longer times.

Mike O'Neill asked about the nature of the revisions to the DOE standards and guidance for fusion system design and safety (wholesale re-write or just on the margins and the timeline for releasing the revised version to the public. **Humrickhouse** replied that revisions to STD-6002 (requirements) are complete, and it only remains to publish them. These as minor revisions are mostly updated references to standards and legislation as appropriate. Revisions to STD-6003 (guidelines) are soon to be undertaken.

Matt Moynihan wrote that several phenomena apply to fusion reactors but do not occur in fission reactors, I would like to see a PRA for superconductors that "go normal," something that has happened 17 times in fusion reactors. The corresponding accident in fission might be a Loss of Coolant Casualty (LOCC) in a fission reactor. **Steven Cowley** pointed to Culham for articles on the scenario of failure of the superconductor for ITER. **Matt Moynihan** PRA & CSAU use MELCOR, Cobra and NuPac as three interlocking codes to encompass the whole fission reactor. Fission accidents like PDHR and LOCC are major accidents that must be addressed in kinds of analyses. These codes are trusted because they are so benchmarked, but would be insufficient for fusion physics like superconductivity, plasma, and cryogenic physics. It would be interesting to simulate emergency response in large characteristic fusion accidents like punching holes in the first wall.

Regulatory Approach for ITER, Joelle Elbez-Uzan, Nuclear Safety Licensing Division Head, ITER Organization

Dr. Elbez-Uzan discussed the French regulation context for the ITER nuclear facility and the licensing process. In the ITER agreement between different partners in the project, there is a particular article (14) related to the French regulations on nuclear safety, radiation protection, and environmental protection. The regulator relies on this article to develop its mission in terms of control of ITER.

The French regulatory framework is like the U.S. On the top of the pyramid are the laws voted by the French parliament, followed by decrees and orders issued by the French government, then the Autorité de sûreté nucléaire (ASN) issues regulatory decisions which are applicable to only one nuclear facility or operator, then there are basic safety rules and guidelines applicable to all nuclear facilities, and finally followed by design and construction codes and standards for operators, industry, etc. There are also legally binding domains as well as non-legally binding approaches.

Safety in France is organized following the main principles issued by the nuclear safety authority. The nuclear operator is responsible for the safety of its facility. These principles are based on a limited set of prescriptive requirements with room for a demonstrative approach, and it is up to the nuclear operator to provide the demonstrative approach effectively and to satisfy this objective. This kind of regulation allows room for the nuclear operator to define the set of safety requirements, which are selected through a graduated approach with variable risk. There is also a strong principle in French regulation and environmental code that the entity that pollutes will pay for the safety provisions. Related to radiation protection principles, we must limit the dose to the worker and provide a root level of justification.

The ASN is in charge of the following missions: 1) regulations, to which the ASN contributes its opinion on draft decrees and ministerial orders or issues technical regulatory decisions; 2) inspections to check compliance with the applicable regulations, conformity, rules, and specifications; and 3) information provided to the public and other stakeholders about the state of nuclear safety and radiation protection in France. The ASN is assisted by the Institute for Radiation Protection and Nuclear Safety (IRSN), which acts as the technology support organization (TSO). In France, the Nuclear Safety Authority (ASN), an independent administrative authority and regulator.

In France, there is a strict regulation related to a radioactivity threshold. ITER is above this threshold and therefore is considered a nuclear facility. Basic nuclear installations are submitted to the French nuclear safety regulations and controlled by the ASN. A nuclear facility is named as such depending on: 1) the nature of the facility (e.g. nuclear power plant or research reactor); 2) the amount of radioactive inventory that may be stored/processed/created/used in the facility; and 3) for tritium, the limit is ~27g and different limit amounts for other nuclides. During the ITER site competition, many questions were posed related to the notion of a nuclear facility because of the use of tritium. Under French law, ITER is a civil nuclear facility because its inventory is above 27; ITER is under the regime of “fuel/laboratories” nuclear facilities not under the regime of a reactor. ITER is considered a fuel laboratory because it does not produce electricity and the main safety function is confinement of the radioactive element and the chemical element (Beryllium). ITER does not have any radioactivity issue, there is no nuclear removal as a safety function, and there is no impact if ITER loses the cooling system if the issue is resolved within 10 days. The fact that ITER is a fuel lab presents more relaxed safety requirements. If the Joint European Torus (JET) in the UK was built in France, it would have been classified as a nuclear facility based on the application to French law.

The French regulatory framework was built for a fission plant, power plant, or experimental/fuel laboratory plant. The French regulation is not prescriptive and there are only general principles. Thus, it is up to the nuclear operator to define the set of requirements. Based on the defense-in-depth safety objective principles, such as low as reasonably achievable (ALARA), we have proposed to the regulator that from a different situation (normal to accidental condition) the consequences on the workers and the public is well below the safety objectives as prescribed in the French regulation. The principle of French regulation allows the nuclear operator to provide the demonstration. ITER will provide a very detailed level of demonstration in order to satisfy each requirement proposed to the regulator, but the first analysis of the requirement seemed to be lower than for a fusion plant and was effectively justified by a strong, robust safety demonstration. The French regulator did not know of a fusion installation; therefore, we have frequent discussions to explain safety cases and demonstrate an adequate safety level across the whole life cycle. Because ITER is an international project, we have decided to maintain and rely on a very systematic, transparent approach with the regulator.

Licensing of a nuclear facility in France is governed by several legal codes and notably the Environmental and Public Health Codes. ITER licensing relies on the creation of a safety report that is updated during the life of the facility. This safety report is subject to operational rules which explain how ITER will effectively stay inside the authorized domain which is bounded by ITER's license. In French regulation, there is only one license required for authorization to create the nuclear facility, and this license covers the whole life cycle. There is a specific authorization process after each phase, but there is no new license. In 2008, the first safety report was submitted to the regulator and it was rejected. In 2009-2010, a new set of safety documents were prepared, and the license was secured in November 2012. ITER has passed two hold points: one in 2014 on the pouring of the slab to support the machines, and in 2016 related to the construction of the neutral beam cell (there is a safety issue based on its location inside the tokamak and we wanted to ensure it was robust enough to sustain any type of explosion inside the vacuum vessel). Today, examination has begun to release the last hold point related to assembly of the machine. The welding of the first two sectors of the vacuum vessels is currently authorized. There is currently a deep review by the IRSN, and the goal is to start assembly of the machine and vacuum vessel by the end of 2021. The regulator has asked for a new safety report before the authorization to perform the first plasma. The regulator imposed several appointments to argue before each stepped phase: the pre-fusion step 1, the pre-fusion step 2, and the fusion power operation itself.

The licensing for ITER was very challenging, and the most difficult was to control the level of uncertainties related to the level of maturity of the design. The knowledge of such a machine resulted in France's program of the ITER facility. The regulatory framework needs to be flexible enough to accommodate for uncertainties because this is a long-term project with several steps. For instance, the regulator challenged ITER about the tolerances, which are quite small in detail, regarding the size of the different components. The regulator wanted to know how those tolerances will be controlled and how confidence will be gained about the final feasibility of the assembly and the possible impact on the safety requirements. ITER is using codes and standards defined for fission nuclear power plants. These have been adapted from several sources including Japanese and U.S. codes. Since these codes are not regulatory and ITER has full responsibility to select and demonstrate that a code satisfies the safety requirements. ITER experiences long and intensive program inspections from the French regulator with at least 10 inspections per year.

The regulations and standards must be adapted to a fusion plant, including optimizations and modifications. There are some considerations of emblematic load related to fusion machines (e.g. cryogenic load, electro-magnetic load, plasma events, etc.) that must be continuously characterized and validated. Then validation of the data used for the safety case must be done at early stages with a good level of margin to provide strong configuration and robust demonstration. The confinement function is the most important safety function for ITER. The first and second confinement systems are quite robust buildings, and we must associate the static barrier to general confinement to show that there is confinement efficiency in case of an accidental condition. The design margins are crucial in order to cover the uncertainties because only the ITER program will contain the load and then we have to go to specific, progressive startup to confirm the design input and design margin and to quantify the uncertainties. R&D is also very important to support the fusion safety cases. The robustness of the ITER design is confirmed by the very low impact of releases in normal and accidental conditions. That is one advantage of a fusion facility. The relationship with the regulator is key and must be a trusted relationship. It is difficult to get and very easy to lose. The transparency during the technical discussions has been highlighted by the ASN as a strong value for the ITER organization. In summary, ITER is the first large-scale fusion facility licensed as a nuclear facility. The ITER licensing process is on-going using a staged approach to confirm different assumptions; the ITER licensing experience will help establish a robust regulatory framework.

Thoughts on the Commercial Fusion Regulatory Space, Peter Lyons, Former NRC Commissioner and Assistant Secretary for Office of Nuclear Energy (NE)-DOE

The mission of the U.S. NRC focuses on regulating the use of radioactive materials and to assure adequate protection to the public and the environment. Fusion needs a different regulatory approach than fission because it is fundamentally different. In a fusion energy system, there is no reason to use special nuclear material and if designed correctly there would be no long-lived and no HLW. Fusion power presents a much lower risk profile than fission power. Several classes of accidents that you would carefully consider simply do not apply in a fusion energy system. Fusion uses abundant fuels that do not require mining or fabrication. From the standpoint of proliferation, fusion has no need for enrichment or reprocessing, which are two of the most challenging areas of proliferation risk for the fission systems. But there would be a lot of fusion neutrons generated in a successful fusion power facility. There are much simpler ways to obtain and produce weapons materials than with fusion neutrons. A group at Princeton produced several studies on fusion/fission hybrids and concluded that with appropriate safeguards fusion power plants would present a low proliferation risk compared to fission. In all the considerations of the Princeton group, they could not come up with a proliferation challenge unless further material was introduced into the facility. To my knowledge, there is currently no commercial interest in fusion/fission hybrids, and there has only been interest by one of the national laboratories. With appropriate controls, Part 20 (radiation safety) and Part 30 (regulations on byproduct materials) on tritium will be the primary regulatory concerns for fusion energy systems. There will be a necessity to dispose of low-level activated radiation waste, and this is well understood. The other safety risks can be managed like other industrial facilities.

Amendments to the 1954 Atomic Energy Act (AEA) permitted commercial atomic energy. The atomic energy definition was such that it included nuclear fusion reactions. Pursuant to this authority, the NRC decided, in 2009, to exercise jurisdiction over commercial fusion but the staff were directed not to proceed further until commercial fusion was more predictable based on successful testing of the technology. To develop a regulatory approach for fusion, it is important to note that the NRC and Agreement States already have set precedent for regulating devices that use fusion reactions. The Agreement States enforce Parts 20 and 30. Some states (e.g. Phoenix, LLC in Wisconsin, and Omega at the University of Rochester in New York) are already regulating devices for fusion. DOE has taken steps to support the commercial fusion energy industry through the development of safety standards and increased funding of the INFUSE program and other avenues, such as Advanced Research Projects Agency-Energy's (ARPA-E's) Accelerating Low-Cost Plasma Heating and Assembly (ALPHA), Breakthroughs Enabling THermonuclear-fusion Energy (BETHE), and Galvanizing Advances in Market-Aligned Fusion for an Overabundance of Watts (GAMOW) programs. There is also the potential for a public-private cost share which might be like that which is already used in the fission programs.

Recommendations for specific actions for fusion should start with the NRC, working closely with the fusion industry and DOE, and should set fusion-focused regulatory directions. Fusion should require a different set of focused regulations different from those for fission plants. NRC has Parts 50 and 52 regulations with the fission plants, but they primarily address risks that are different from most of those covered by fusion energy facilities. Parts 50 and 52 (and perhaps Part 53, when developed) discuss the use of utilization facilities; in my opinion fusion should not be considered a utilization facility under the AEA. The main hazards associated with fusion power plants involve tritium and how it can be managed. For tritium, there already are practices and procedures developed over decades which can be brought to bear. It is interesting that ITER was classified as a nuclear facility based primarily on the fact that the amount of tritium exceeded 27 g. In other words, the focus was on the risks associated with accidents involving tritium. The NRC's Part 20 regulations for general radiation protection and Part 30 rules for handling byproduct material are appropriate for fusion energy systems. DOE has a framework and standards for the safe construction, operation, and decommission of experimental fusion energy devices in DOE facilities. Both should be relied on by the commercial entities working in this area.

The NRC defines a utilization facility as: 1) a nuclear reactor other than one designed or used for the formation of plutonium or U-233, or 2) an accelerator-driven subcritical operating assembly used for the irradiation of materials containing special nuclear material. The NRC's definition of a nuclear reactor is an apparatus, other than an atomic weapon, that is designed to sustain nuclear fission in a self-supporting chain reaction. This is not relevant to fusion and fusion should not be classified under the Utilization Facility guidelines.

The NRC has already signaled openness to the Agreement State approach. In SECY-20-0032, the NRC staff proposed a new Part 53 for advanced nuclear reactors and it was made clear that Part 53 would be more risk-informed, avoid the prescriptive or programmatic criteria already in Parts 50 and 52, and would be focused on reducing the regulatory burden for developers of advanced reactors. The staff memorandum also noted that the NRC could approach regulations for fusion in the same manner as accelerators – such as 10 CFR Parts 20 and 30. Regulating fusion devices pursuant to Parts 20 and 30 would comply with NEIMA, which requires action on a regulatory system for advanced reactions by 2027. Just four days ago NRC moved ahead with a commission vote on the SECY-20-0032. That commission vote called out for an accelerated timeline of 2024 and asked that the staff develop specific options for treating fusion. The NRC recognized that fusion can be treated differently, and they need to see options developed by the staff.

Lyons recommended that the NRC: 1) use only 10 CFR Parts 20 and 30 to regulate the fusion industry; 2) utilize the Agreement State Program already set up for 39 states and operating under the oversight of the NRC so the states can have a significant role in the regulation of fusion energy plants; and 3) federal agencies should take a coordinating role to develop risk- and performance-based regulations allowing states and industry to innovate new technologies to improve fusion.

Panel Discussion/Q&A

Directed to Humrickhouse – What are the largest safety challenges that fusion faces in the current legislative environment? Is this legislation in line with what the actual largest safety challenges really are? What would have to change to fit fusion into a nuclear regulatory space? **Humrickhouse** – The basic issue is in a power plant; the machine might have significant radionuclide inventories and existing regulations do not specifically address those in a fusion plant. The fission regulations may not be addressing concerns relevant to fusion (e.g. lower magnitude than fission, chemical reactions with metal, plasma, magnets, tritium management) in an appropriate way. There is just not specific guidance in the NRC regulations that address these things. The DOE standard was developed specifically to address these kinds of questions, and so it might be useful in adapting to a regulatory framework.

Directed to Elbez-Uzan (Laban Coblentz answered on Elbez-Uzan's behalf). If the regulatory approach for ITER could be done over again, what would you do differently? Is the current nuclear regulation adequate in France and the European Union to incorporate fusion? **Coblentz** explained that he is not the safety expert at ITER but had been an NRC inspector. The biggest lesson is that the transition from fission to fusion is coming from expertise in the academic research communities. As we transition into the regulation community, we pass a threshold (e.g. commercial production of electricity, the inventory of tritium, or some other national regulatory requirement) to coming under nuclear regulation; the experts are not accustomed to that. One of the main challenges is related to managing the level of uncertainty. On a research machine, you may be inclined to be more experimental in the design phase or account for a broader margin in your submission, so the level of maturity of the input data is going to be a key parameter to establish a valid safety case. Commercial machines expect this but for a research machine, such as the case at ITER, the nuclear operator (i.e. the licensee) is compelled to add margins and conservatisms to it to compensate for those uncertainties. Looking back, we would have tried to be more specific at ITER. Secondly, the current regulation is adequate in France. The French regulation is not terribly prescriptive, unlike the U.S. framework. French regulation establishes the safety objectives to be reached, the safety functions to be satisfied, and then the nuclear operator must explain how those requirements will be met. Once those are submitted the regulator reviews the plan for approval. The French system has real advantages because it allows the nuclear operator to demonstrate and articulate how practices will be optimized to protect the public, the workers, and the environment.

Questions

Directed to Lyons – What are the parts in the regulatory process that you think the fusion community needs to work on to be prepared and what will surprise the fusion community in this process? **Lyons** – The regulations, as NRC works through them, should be developed in partnership and cooperation with industry, DOE, and other stakeholders. What would most surprise me would be if fusion plants were labeled as a utilization facility and asked to operate under 10 CFR Part 50 or 52 (and not knowing what Part 53 will be). The industry would be very surprised and concerned if they were treated as a utilization facility under the same framework as used for fission power plants. We need a fusion-focused regulatory structure.

Directed to Humrickhouse –In fission, major accidents include examples such as the loss of coolant causality, which are modeled using established codes, and applying statistics to determine the likelihood that a plant operator can safely shut down the plant (called "probabilistic risk assessment (PRA)" or "cold scaling analysis uncertainty"). A major accident in fusion might be when a super conductor goes normal. Is there a corresponding PRA process for a fusion power plant; are there codes that you would point to and recommend? **Humrickhouse** – We have tried to do some simple uncertainty quantification in the analyses that we have done for MELCOR in the past (e.g. during the original Fusion Nuclear Sciences Facility (FNSF) studies). We are interested in using a combination of MELCOR and RAVEN, a flexible and multi-purpose uncertainty quantification, regression analysis, probabilistic risk assessment, data analysis and model optimization framework, developed at INL, for these uncertainty quantifications. The PRA for a commercial device depends on the regulations. The DOE standard outlines that you need to do a risk assessment with a level of detail commensurate to the hazard. If a facility has inventories that would put it at the highest level of categories, the DOE standard indicates a need for a detailed risk assessment; the PRA is one way to accomplish that.

Questions raised by the Zoom Meeting audience and addressed in the Chat feature:

Lane Carasik (Assistant Professor in the Engineering program at Virginia Commonwealth University) – For newer faculty and nuclear engineering programs, what are the educational areas that are most needed at the undergraduate and graduate level going forward? How can we best support fusion development? **Lyons** recommended the study of plasma physics and understanding the details and history of fusion power systems. Also, radiation transport, different approaches to treatments of severe accidents, and questions on PRA. **Coblentz** said ITER is working with the IAEA and a group in Europe on this knowledge management question called FuseNet. It is a Europe-wide collaboration of students working primarily in PhD level research in fusion related fields. Fusion-related engineering skills are also critical, because fusion has a completely different element than anything in fission, which is that despite the growth in size to larger machines, the particles you are trying to confine do not get any bigger. So, the precision involved in building a power plant becomes based more heavily on advanced engineering fields and expertise than science expertise. There are plenty of science aspects still to be conquered for fusion commercialization, but the critical fields are the detailed engineering disciplines (e.g. cryogenics, robotics, electromagnetism, and supercomputing).

International collaboration is crucial and the fluidity to draw on expertise across cultures to build the plants is an extremely relevant skill.

Tyler Ellis directed to Humrickhouse – The waste generation and decay heat numbers you describe are based on either an ITER- or demo-sized fusion device. Since there is no private company pursuing a device of this size, should the numbers be revisited to reflect the small and compact designs the industry is pursuing? The device sizes are 10+ times smaller than ITER, therefore the conclusions on the waste generation and decay heat might change significantly. **Humrickhouse** – Those are true statements. Those kinds of things (e.g. amount of decay heat and waste) will depend on the designs. This is an important point for any licensing framework that is adopted. The framework should be as general as possible and not make any assumptions about whether a fusion reactor will or will not make x amount of waste.

Steven Cowley directed to Humrickhouse – It is not immediately clear that we should not be restricting some design criteria to make regulating fusion easier and softer. At Culham Center for Fusion Energy, our designs included one requirement that no evacuation beyond the site boundary would ever be needed in any accident scenario. What characteristics should we be aiming for in our designs to make sure that the regulation can be as light as possible? **Humrickhouse** – In the DOE programs and the standard, it is preferable to have passive heat removal systems, but it is not listed as an actual requirement. This is a good design principle, but we want to be careful about being too specific about requirements. If active cooling is needed, then that would most likely bring an additional set of requirements into play (e.g. verifying how that system functions, its reliability, etc.). Certainly, passive cooling should be a design goal. **Lyons** strongly agreed with Humrickhouse. He said he would be nervous in setting up design criteria that must be met by all commercial entities ahead of time, but at the same time it is in their interest to avoid any obvious risks. He is in favor of passive cooling, but wary about regulations that might restrict innovation in the private sector. **Cowley** was not suggesting regulation that one must abide by. But would this make a qualitative difference if designs could be made passively safe in the acceptability for market for instance? **Humrickhouse** wrote that on one hand, we might worry about being too prescriptive, but if there is reliance on any type of cooling systems that would add some complexity to the regulations. Showing that the physics keeps one safe is certainly much simpler than using an active cooling system with additional engineering controls. **Coblentz** cautioned against applying that lesson of fission to fusion because the lack of source term complexity, the improved safety case, etc. are tangibly different for fusion. Putting prescriptive requirements in place at the outset, when fusion plants are trying to get to a reliable design, could very much cripple the discussions. **Lyons** added that it would be wonderful to have passive safety to rely on and a zero-emergency planning zone. Those are obvious to companies; they will be doing their best to do that, and it will simplify the regulation. **Cowley's** concern is that it is hard to reverse course once you start down a regulatory path. For example, we would not want to grandfather in regulations that are not useful in the commercial period. It is hard to backtrack on regulation, at least in the U.K.

Sally Forbes, United Kingdom Atomic Energy Authority (U.K. AEA) to Coblenz posed a question about globalization and harmonization. Currently, JET is the only facility that can operate with deuterium and tritium. It is not a nuclear licensed facility in the U.K. because of the low levels of hazards. JET is regulated by the health and safety executives of the radiological facility. Within the U.K. government, we are reviewing that position, but starting from a place of not automatically if future power plants would fall under a nuclear licensing regime. The safety case process is needed but not necessarily the complexities of nuclear regulations. Global harmonization is important; we have different approaches to regulation, and if we want to solve the global problem of energy, and if fusion energy is that solution, we want to have fusion designs approved in one country and to be able to build in a different country. In fission power stations when designs come from different countries it can take many years. We are starting to have some international meetings about fusion safety and regulations. What is your view on the globalization of regulation? **Coblentz** replied that there is a temptation to focus on what can be done within a country to make the process state-of-the-art but focusing can also mean sharing. In fission, there was no ability to anticipate the potential pitfalls, we did not know what sort of accidents occur. It did show that the global reputation of the industry was heavily dependent on any one operator. Global sharing builds trust in the regulatory regime. The vehicles exist, and the IAEA's ability to share standards is already there. The fusion experience, in the research stage, has been global from the beginning. I see only advantages in building a regime that globalizes the regulatory experience as well. **Sehila Gonzalez** agreed with Forbes and Coblentz. The need of all countries to put regulations in place is understood, but at this point we can take this as a lesson learned from the fission industry. We have the opportunity to internationally harmonize fusion regulation from the beginning, and we cannot miss this occasion. This will favor the fusion industry at end of day where there is a global market. What are your views on that approach? **Lyons** replied that during his time at the NRC, there was tremendous interest on harmonization of regulations among countries as well as globalization in the sense of one licensing code that was applicable everywhere. The harmonization part was and is going well. I would strongly encourage the harmonization in that the regulators talk through many venues and understand each other's perspectives. Globalization means one licensing code for the whole world; that may be a bridge too far at the moment. **Lawrence Williams** added that regulation is essentially law enforcement and the chances of getting a single global framework is impossible. However, it is possible to make sure that the fusion devices of the future are built to the same global standards. Concentrating on the engineering and the standards to deliver a product which every licensing system could adapt is most likely the way forward. This can be accomplished with a non-prescriptive, goal setting regulatory approach that is proportionate to the hazard. Lowering hazard risks involves a lot of engineering and common standards, neither of which are enjoyed at the moment.

Steven Dolley referred to the statement that fusion is no longer 30 years away, and there is a wide range of projects underway but not a specific timeframe. What kind of timeframe should we be looking at for U.S. NRC regulatory licensing activities? **Lyons** replied that companies today are ready to begin building the next generation of plants; to do that they need regulatory certainty right now. In the case of the U.S., the NRC should move ahead expeditiously to define a regulatory structure that industry can use, perhaps within a year to start construction. **Coblentz** added that there is room to begin right now on a collaboration. We do not think of regulations as being collaborative. It would be surprising if a lot of discussion occurred at this stage between the private sector and the regulator in terms of the different models of fusion plants. Early collaboration regarding what is essential needs to occur now (e.g. French regulation at ITER on the nuclear pressurized system and ways that tritium is treated). These discussions between the private sector and the regulator will add great value. That can be achieved right now by starting that discussion, by identifying the safety cases, and by determine what will need to be regulated and why. **Dolley** agreed that discussions are valuable and interesting but asked who would pay for the NRC staff time. **Lyons** explained that there are certain mechanisms that the NRC can use that do not require billing for staff time. Once a specific design or a technical proposal is being discussed then the NRC must charge the time. But in general, there are many opportunities the NRC has at its disposal to get started.

Holly Ray noted that all kinds of companies develop fission plants, not all safety training and regulations are the same. She asked if there is now an opportunity to keep those more uniform? Can the NRC or DOE start safety training for current workers to maintain coherence between different facilities? **Humrickhouse** responded that is not something that has been done for safety codes, which are geared towards doing safety analysis at facilities. The INL fusion group has not engaged in safety training, but it may be possible to make the contents and principles in the safety standard well-known across complexes working on fusion.

Ed Lyman directed to Lyons – It was suggested that fusion facilities could be regulated as materials facilities and states with agreements with the NRC would be responsible for licensing regulation. How would state authorities have the expertise to conduct that type of licensing and oversight review? Would it make sense to initially assign the NRC with full licensing authority to ensure applications have accident and consequence analysis? **Lyons** stated that he assumes the states had to gain extra knowledge by consulting experts. This state authorization is already being done; it is not a tremendous challenge for a state to gain the knowledge needed to move ahead. **Humrickhouse** proposed that this may be a challenge with fusion licensing in general. Certainly, this will be part of the process in building the framework and the expertise it takes to do that. **David Crowley** added that the Agreement State programs routinely take on new technical challenges and they develop the expertise necessary to overcome them. Not only do the states handle byproduct material with the agreements, we also commonly regulate x-rays, accelerator devices, and other radiological hazards. Some states are already licensing commercial applications of fusion. The Organization of Agreement States (OAS) works with the NRC on a regular basis to take on regulatory challenges presented to the national materials program. The OAS can also work with the states independently if an issue does not pertain to the NRC. Separately, Conference of Radiation Control Program Directors can assist in the matters of developing expertise within the state programs or assisting in creating a regulatory framework.

Jeffrey Merrifield wrote that there has been suggestion of increasing the level of regulations to require passive safety cooling systems or other higher levels of regulation. The U.S. Atomic Energy Act requires the NRC to regulate nuclear facilities to a level that would provide "adequate protection of public health and safety." Creating specific standards that significantly ratchet up the regulatory requirements may be inconsistent with U.S. law. **Steven Dolley** said he was not suggesting more regulatory requirements, rather that there are generic features that will make regulation easier — if we understand what these features are, we can help speed fusion forward. **Matt Moynihan** stated that Phoenix Nuclear Laboratory and SHINE have a large-scale plant in Wisconsin that uses fusion to generate medical isotopes. Both companies have been through a form of NRC licensing. What lessons have been learned from regulating them that can be applied to fusion power plants? **Brad Campbell** wrote that the public already confuses fission and fusion. To gain public acceptance he suggested avoiding equating the two technologies and offer the public a more responsive and transparent process. It is enormously important that the regulatory process for fusion is unlike, and separate and apart from, the regulation of fission reactors. Allowing state primacy under the Agreement State model is an appealing option. **Holly Ray** agreed that it would be nice to separate fusion from fission. Because of fission's history that is equated to nuclear, fusion suffers in relation. Moving away from equating the two would be beneficial for the future of licensing which could otherwise be hindered by strong standing stakeholders or agencies.

A lunch break was called at 12:45PM and the afternoon session began at 1:15PM.

Afternoon Session 1: Regulator Perspectives, Mohamed Shams, Moderator

Director of the Division of Advanced Reactors and Non-Power Production and Utilization Facilities (DANU), Mohamed Shams, began the session stating that an appropriate regulatory framework and footprint for this technology is very important. He welcomed the speakers, Mr. Bill Reckley and Mr. Kyle Cormier, and explained they would review some activities regulators are seeing and how these are being addressed.

Thoughts on NRC Regulatory Approach for Fusion, Bill Reckley, Office of Nuclear Reactor Regulation, Project Manager, Division of Advanced Reactors and Non-Power Production and Utilization Facilities, NRC

The NRC is set up to regulate U.S. civilian commercial, industrial, academic, and medical uses of nuclear materials. The NRC first visited fusion in 2009. At that point, the question was if the NRC would be involved with fusion. The NRC commission asserted that to the degree that fusion devices were significant in either security or public safety, the NRC would take regulatory jurisdiction. Also, the commission directed staff to wait until commercial deployment of fusion was more predictable before developing a framework. With the passage of NEIMA in January 2019, the NRC was directed to develop a technology-inclusive, regulatory framework for advanced nuclear reactors which are defined as either fission or fusion reactors. The preliminary assessment completed in 2009 left the regulatory approach open for commercial fusion reactors. At this point we are considering if such an approach would be like nuclear fission power plants, materials, a hybrid approach, or a new method.

The regulation of radioactive materials by the NRC must address radionuclides, safety and security procedures, doses, waste management, decommissioning, environment, and byproduct materials. The NRC made a conscious decision, in 2009, to not step in. DOE has programs for facilities under their oversight, and to the degree needed NRC has addressed companies that use fusion reactions under the byproduct material requirements. The NRC is trying to determine an appropriate framework for large scale deployment of commercial fusion reactors. The regulation of reactor facilities has a framework built around the use of "special nuclear material" (e.g. plutonium or enriched uranium). The apprehension of the use of a utilization facility model is based on the historical focus on large light water reactors and prescriptive regulations for that technology. It does set up technical requirements on the design, construction, operation, and decommission of the facility, so the focus is on the machine, whereas in the materials realm the focus is on the materials. In a utilization facility, the focus is on the performance of the machine, and if it works well and performs the safety functions required then the material would be contained. A part of the extensive licensing reviews is the traditional environmental impact statements, both on the safety and environmental side. The route of a utilization facility model means it is important to ensure a focus on pre-application discussions to facilitate a good understanding, on the part of the applicant and the NRC, about the nature of the facility. A significant historical implication of utilization facilities is the mandatory hearings under the licensing process in either Part 50 or 52.

Under current activities, NEIMA was passed in part to push the NRC into developing revised processes for advanced nuclear reactors. These include a host of fission technologies that are different than large light water reactors. These include gas cooled reactors, liquid sodium reactors, molten salt reactors, etc. One subcategory is micro-reactors, which are smaller fission reactors (up to 10's of MW versus the 3,000 MW of a typical large light water reactor). With the possible development of those micro-reactors to serve remote locations or be incorporated into a more distributed power system, we needed to see how they would fit in because micro-reactors on the fission side share common goals with some of the fusion discussion (e.g. less emphasis on emergency planning including zones that correspond to the boundary of the site). With the difference in technology goals the question is how might we approach this? The NRC's regulations have been prescriptive while others are more function-based. Whether talking about fusion or fission, there will be radioactive inventory and there are certain measures put in place to prevent its release or prevent its impact on the plant workers. NRC is trying to build off that model in development of Part 53 for advanced fission reactors. Whether the model is a utilization facility or materials licensing, this basic construct still holds. In addition to the NRC developing a framework for fusion, regulatory requirements from other agencies such as EPA, Federal Emergency Management Agency (FEMA), Occupational Safety and Health Administration (OSHA), and Agreement States, as well as the electric supply and rates (Federal Energy Regulatory Commission (FERC), Public Utility Commissions (PUCs)), and land and water use (Environmental Protection Agency, Army Corp of Engineers, State/Local) will need to be addressed.

The NRC is at the beginning and is looking at this as a fact-finding and learning opportunity. We will be creating a framework as directed by NEIMA and will have to decide how to address fusion, which could be included in 10 CFR Part of 53. Our assessment is looking at AEA and other laws to determine necessary changes. There is no immediate need for changes; NRC has handled R&D activities and could handle any pilot plant applications without legislation. However, if commercial deployment of larger number is foreseen, the question becomes whether a framework should be developed and whether the definitions of the AEA should be changed. The ability to change definitions within our own regulations exists when appropriate and necessary, and NRC is looking forward to future meetings such as this.

Thoughts on Regulatory Approach for Fusion – Canada, Kyle Cormier, Project Officer New Major Facility Licensing Division CNSC

The CNSC's mandate is to regulate the use of nuclear energy and materials to protect the health, safety, and security and the environment, to implement Canada's international commitments on the peaceful use of nuclear energy, and disseminate objective, scientific, technical, and regulatory information to the public. In terms of risk-informed regulation, the CNSC has a long history of anticipating the use of innovation in the areas it regulates. When it was enacted in 2000, it anticipated the use of both fusion and fission technologies. From the Nuclear Safety and Control Act (NSCA), CNSC makes informed science-based decisions on the prevention and mitigation of risk and it covers both radiological and non-radiological risks in the conduct of regulatory activities. On the basis for a licensing decision, the CNSC officers are authorized to make a decision on an applicant's activity based on analysis and information from regulatory research, as well as public input. Risks and mitigations need to be well understood to make an informed licensing decision.

Fusion technologies were discussed in a CNSC's published paper on small modular reactors (SMRs). The CNSC position was that the regulatory framework is intended to take into consideration the level of risk suggested by a proposal. The applicable regulations are based on the activities being proposed by the applicant. The licensing processes will be commensurate with the proposed activities and regulations that apply. The safety and control areas that the CNSC uses correspond to the novelty, complexity, and potential for harm. Although the CNSC regulatory documents do not specifically address fusion activities, they do contain fundamental safety principles and objectives that can be applied to fusion activities commensurate with the risk. These regulatory documents are tools to be used by the applicants for information and criteria to consider as they develop safety plans. The CNSC staff is using regulatory framework to engage with proponents of fusion technologies and assessing how proposed activities would be regulated in Canada. Specifically, CNSC staff are engaging an external expert party to review CNSC's framework through the lens of a user considering fusion related activities.

Due to the novelty of fusion technologies, pre-licensing engagement is valuable for feedback on what information is suitable to address the appropriate requirements. CNSC, when talking about current fusion activities in Canada, is thinking about a broad range of activities, but these activities can be regulated using existing licensing processes. The regulations regarding a demonstration or first-of-a-kind facility are based on the different methods of confinement, which could drastically change the hazards and risks. To review this type of facility, the staff would have to use existing tools available in a risk-informed way. Irrespective of fission or fusion, the same fundamental safety principles remain applicable and proposals must be supported by evidence, and the uncertainties must be characterized and addressed by the applicant. Regulatory document REGDOC-1.1.5, Section 4.2.2 (Supplemental Information for Small Modular Reactor Proponents) describes the process for pre-licensing engagement that can be applied beyond fission reactors. It can be used by technology developers for early feedback on information they need to address in development of a licensing application. It also contains high-level safety control information. This process does not result in a decision by the commission, and it can be carried out before a licensing application is made but after describing a project's hazards. This 4-step process ensures a systematic and consistent application of a risk-informed approach while leveraging existing regulatory requirements. The applicant describes a proposed activity, the CNSC assesses the plan and drafts a report providing a suggested strategy, and then the CNSC responds to the applicant with a guidance letter so that the proponent is able to draft an informed licensing application.

The CNSC regulates both radiological and non-radiological risks related to nuclear activities. Hazards can vary greatly depending on the technology proposed. CNSC licenses novel activities with novel technologies by using a benchmark of other activities with similar hazard profiles which points back to the guidance letter in step 4 in the licensing engagement process. Ultimately fundamental safety principles remain central to the analysis provided by CNSC staff. "Proven engineering practices" from the REGDOC-2.5.2 helps with interpretation of requirements, the safety claims must be proven, and adequate provisions must be made around novel activities. On international collaboration, there are three main points: 1) sharing of scientific and technical information can improve regulatory efficiency in the licensing process; 2) fusion is a from-the-ground-up opportunity for regulators to come to an agreement on harmonizing regulatory requirements; and 3) CNSC is open to engaging with the U.S. NRC and United Kingdom (U.K.) Office for Nuclear Regulation (ONR) to further advance cooperation in these areas.

Panel Discussion/Q&A

Directed to both speakers – The hazard potential for a fusion power plant is considerably less than fission, however it is not zero. Do you agree that the proportionate regulatory approach should be adapted based on licensing? This was addressed earlier and essentially both regulators look for a risk-informed approach and one that is proportionate to the hazard of the technology. **Reckley** expressed caution when talking about the risk of a technology. The risk is not related only to the inventory but also the engineering barriers and programmatic controls up to emergency planning. All these go together to determine the risk to the public. In some technologies there is less inventory and more inherent protections because of the physics. The caution we received on reactor safeguards is to resist the temptation to say it is safer. We must formulate how that plays into the regulatory decisions. **Marcel de Vos** said there are claims and then there is reality. CNSC takes a proportional approach and the pre-licensing process allows us to have conversation about specific risks, hazards, and protective measures, to select the appropriate requirements for that level of risk.

Directed to both speakers – Related to potential international collaborations and the development of a more harmonized standard for the technology, who is responsible for developing these standards and guides: industry, regulators, or international organizations like IAEA? **Cormier** said that when it comes to generation of standards or guides, the approach that CNSC takes is dependent on the proposed technologies and activities. There is such a wide range of potential facility types and types of activities that a broad blanket on how to regulate fusion does not make sense, as evidenced from the small R&D laboratory experiments and scaling up to a reactor facility. At this stage, with the pre-licensing engagement, CNSC has to work with the technology developers on what fits with that framework and provide some guidance, but there are opportunities for developers to engage with each other in the generation of standards and approaches. **Marcel de Vos** added that the IAEA tends to lead more in globalization by drawing the experience of the different countries together. However, it is still incumbent on the countries to gather the experience needed to support the regulatory positions to put into documents like technical documents and standards. The IAEA looks for feedback from the member states on the fundamental safety requirements to continue to apply. Defense-in-depth remains valid, the use of ALARA, and handling of substances like tritium, so there is a foundation on which to build fundamental safety principles. Many of the current IAEA safety principles are going to continue to be valid. Member states may bring topics to the IAEA for discussion. **Reckley** explained that regarding consensus codes and standards, NRC looks to the industry, and to some degree DOE national laboratories and academia, to lead the effort in the development of those standards. The NRC participates but does not drive those processes.

Directed generally – Related to international collaboration directed to the U.S. and Canada, the collaborative efforts across North American countries will be a great way to improve national relations and science diplomacy. Are the U.S. and Canadian regulators working together to advance reactive technologies like fusion? If so, what can be learned from ITER and other countries on how to regulate fusion? **Shams** said the NRC is working closely with CNSC counterparts but given the level of resources and activities efforts must be optimized. There is every reason to be working collaboratively on fusion activities such as advanced reactors, risk-informed guidance, technology inclusive guidance for advanced reactors, as well as other activities.

Marcel de Vos shared that the CNSC is willing to start discussions on collaborations. It is early days and we can start sharing information about experimentation in each country, with recognition that there are different technologies coming out. We can find ways to reach consensus on the fundamental safety objectives for fusion.

Directed generally – There seemed to be an urgency for a regulatory framework for fusion, can we start the dialog now to set safety goals and regulatory framework for fusion? **Shams** explained that within the construct of 10 CFR Part 53, NRC is already engaging in discussion for that framework over the next few years and invites different parties and stakeholders to support it. **Marcel de Vos** said there is not a cohesive fusion industry in Canada, but many companies are working in this area. As we engage and learn how the companies understand the requirements and guidance that currently exist to their specific cases, CNSC can write up what might need to be clarified. There are options like discussion papers to explore where changes might be needed; if a good reason to change the regulations is necessary.

Directed to both speakers – Catastrophic failure for fusion can be tested but it is very expensive. How can we move forward in nuclear landscape and test high fidelity concepts? **Reckley** mentioned taking a conservative approach to determine the consequence of a failure? One simple way is to assume just release the inventory with very little credit for any barriers. For large fission reactors that would lead to poor results. The amount of testing needed is proportional to the importance of the model and the computer code that you are relying on to make the safety case. If you can make that case based on inventories and unmitigated releases, the need for complex computational models and testing to confirm modes would be reduced. That is on the safety side. On the operational side, the amount of computer tools and importance of control systems to keep the machine operating might be quite extensive to show the commercial viability. **Cormier** said regardless of fusion or fission technologies, the safety case must be based on proven engineering practices. The safety case should be made by supporting R&D, different programs, and examinations of different experiences from relevant applications. There is also the monitoring and verification of new things as they are being brought into service. **Marcel de Vos** stated that confidence is needed in the design and safety margins and the performance of the workers. In areas with higher uncertainties, there is an expectation to adapt the design and safety control provisions based on people's behaviors. This is normal in a testing environment where it is likely more conservative.

Directed to all – Are there any constraints regarding proliferation from fusion? **Reckley** explained there are some export controls on materials. For ITER, part of the NRC decision in 2009 was to let that remain with the Department of Commerce. But specific constraints would be based on the technology and the degree to which it had other potential uses. **Duncan White** added that controls for tritium and deuterium are evaluated and coordinated with the Department of State. This topic has not been considered from a fusion standpoint, but it is a well-addressed area in fission. **Marcel de Vos** said that export controls focus predominantly on the materials and their alternative uses.

How will the current American Society of Mechanical Engineers (ASME) codes be used for fusion facility construction or will the codes be used at all? **Cormier** said from a regulatory perspective the industry codes and standards complement the CNSC regulatory documents. The applicant is responsible for demonstrating how they will apply the codes and standards to meet their designed facilities. **Marcel de Vos** added that the CNSC does not prescribe specific standards in Canada. The applicant is expected to demonstrate that they are using proven practices. If they select an ASME code they must show why it is relevant in a specific technical situation. There may be areas without any regulations, and thus they will bring information from science and engineering activities until there is enough experience to support development of a standard. **Reckley** noted that the reference to any code is meant provide assurance that a structure is meeting the standards to make regulatory decisions. In terms of whether to use it and how to use it in a safety case is up to the designer. **Anthony McMurtray** explained that ASME put a group together to create codes and standards for advanced reactors and he anticipated similar things will be needed for fusion.

Questions from participants via Zoom Meeting:

Jeffrey Merrifield complimented the CNSC and NRC for work they have underway on fission reactors. Both agencies have made a step-change in their ability to review these applications. In the U.S. moving to Part 20 and Part 30 framework rather than Part 53, is an idea well worth considering and may simplify the process. Merrifield disagreed a bit with Lyons on the issue of transfer control to the state level saying it may seem appealing, but the NRC has a long-standing record of regulation of fission reactors in a unified approach. Imagine if you had a variety of states using different approaches. Each one of those states must have technical expertise to address the complicated regulatory regime. This move to the states could make the process more complicated, more difficult, and more costly. Regarding the material generated in subtitle C, there is variation in the volume provided by the specific fusion reactor design, but this raises questions because there is not a huge amount of subtitle C capabilities. If there are subtitle C costs these will need to be discussed. Merrifield agreed with the former head regulator in the U.K. that international regulations are hard because they become criminal statutes. There was support a decade ago for a multi-national design evaluation process among 10 different countries, but it did not manifest in a unified international regulatory regime. The approach with the CNSC, NRC, and ONR of the U.K. trying to collaborate as a smaller group makes sense. Are there any steps underway to bring those regulators together and unify those approaches? **Reckley** replied that those relationships have been discussed and we are talking about them in this forum. The original regulatory forum to be held in March included a bit more of an international component, including U.K., ASN, and IAEA. There is value in these discussions but harmonizing and achieving on set of standards is questionable. However, the multi-national design program and other activities at IAEA and elsewhere have spent a lot of time trying to address gaps, on the fission side, between regulatory approaches from various countries. To the degree that these discussions are possible, there is an opportunity to improve communications, reach mutual understanding, and avoid future examinations of why countries took different approaches. **Marcel de Vos** responded that there are different starting points for the ONR, CNSC, and NRC in sharing information. IAEA will likely take a greater role and show more interest in fusion technologies, so they may hold a series of consultancies that compare the safety objectives and goals. As regulators there is an advantage in seeing the groundwork happening in the laboratories, where it must start.

Bob Mumgaard said he was struck by the way others do nuclear regulation. Other industries are faced with the similar challenge of an emerging industry with a variety of solutions breaking into an adjacent area. What can we do, as regulators and industry, to pull in the best practices from other emerging industries? An example is the commercial space where the Federal Aviation Administration (FAA) had a mandate to regulate commercial air space. Regulating an experimental rocket is different than regulating a commercial airliner. The FAA worked with industry to develop a framework proportional to both risk and benefit. What work is going on at the NRC to reach out to these other industries such as space, quantum, and intellectual property protection industries? **Cormier** explained that there is a working group at CNSC examining different Disruptive, Innovative, And Emerging Technologies (DIET), which can apply to what is happening in nuclear activities as well as other parallel industries. The point is to develop an evaluation and characterization of these technologies and different regulatory approaches from various industries to generate lessons learned. **Marcel de Vos** added that when presenting a safety case to CNSC, the applicant must demonstrate how their operating experience is valid against the safety case being proposed, as well as identify any gaps in science or other industries. **Anthony McMurtray** expressed that the NRC has not been reaching out to a lot of other industries but is working with Reckley and the fusion working group at the NRC, as well as DOE, to share our experiences and information regarding fusion and INL activities. What Humrickhouse presented today offered great insight into what DOE has been doing in this area for many years. On the materials side, there's a compatibility framework for the regulations that states must meet and the ones where there is more freedom. There are many policy issues that the NRC will need to address.

Scott Krisoloff – What is the best way for private fusion companies to engage with the NRC? **Sham**s suggested that Krisoloff reach out to Shams or Reckley.

Daniel Clark – At what point would a demonstration facility be licensed by the NRC in the U.S.? **Reckley** responded that if a facility is located and controlled under DOE, it likely can be done. On the fission side, there are examples of the Advanced Test Reactor and the Versatile Test Reactor at INL, both facilities would be pursued under DOE safety program and not licensed under the NRC. If the NRC program licensed a facility as a research and test reactor. If so, there are constraints as to how much money can be made. NEIMA changed those provisions, but if it is predominantly a R&D facility it can sell power and electricity up to a certain limit. To the original question about when a facility would be licensed by NRC, it depends on the timing, if there is a framework in place, and whether it is a utilization framework or a materials framework. **Duncan White** added that there have been research facilities licensed by Agreement States, but these do not put power on the grid. They are licensed because they use large quantities of tritium. DOE property, or work done by DOE, would fall under their oversight, not the NRC, but it depends on the regulatory structure and how to pursue licensing.

The meeting was dismissed for a break at 2:29PM and resumed at 2:41PM.

Afternoon Session 2: FIA, Andrew Holland, Moderator

Mr. Holland introduced the afternoon speakers, indicating they would share different perspectives from the industry standpoint.

Industry Perspective – Legal, Amy Roma, Partner, Hogan Lovells

Roma provided context for the topic of licensing an innovative, new technology. There is a real need and purpose driving the work in the industry. There are important climate change and environmental benefits that fusion would provide. Most power produced in the U.S. is heavily fossil fuel, which emits greenhouse gasses. Fusion, along with solar and wind energy, is a renewable energy with a huge source of carbon-free base load power. Fusion helps for energy independence and security and can raise the global standard of living. There are billions of people with no reliable source of electricity and new power sources can enable them to live a better life. Fusion puts the U.S. back at the top and maintains that position in technological advances. Fusion has both power and non-power applications. The underlying statute, the AEA, is the fundamental U.S. law on the civilian use of nuclear materials and provides for both the development and regulation of nuclear materials and facilities, and requires that civilian-use nuclear materials and facilities be licensed by the NRC (see chat about where the licensing jurisdictional barrier lies). If the technology is for civilian use and not for U.S. government purpose, it falls under the NRC. The Agreement State program is not a matter of who has jurisdiction but rather a question of whether the NRC can delegate jurisdiction down to an agreement state. Can we regulate nuclear materials under the Part 30 program where Agreement States would have jurisdiction to oversee and regulate fusion or does the NRC have to assert a stronger regulatory framework?

The NRC framework includes Part 20, 30, 40, 50/52, 53, and 70. Part 20 applies across the board, in Part 30 the NRC sets fusion across the 30s range, Part 40 does not apply to fusion, Part 70 includes fuel fabrication and uranium enrichment (which does not apply here), Parts 50/52 concerns reactor regulations, and Part 53 is being examined as part of NEIMA for a risk-informed technology inclusive regulatory framework for advanced reactors. NEIMA reactors include fusion and is presently not in Part 53, but it would be easy to say sub-part A: advanced fission, and sub-part B: fusion (see Part 30). In 2009, the NRC staff determined they have jurisdiction over fusion. However, NRC needs greater familiarity with technologies to decide how to regulate them. That is why this conversation today, and this panel, is important for this discussion. Hopefully, this kicks off the opportunity for the panelists to introduce their technology. No matter what anyone is advocating, understanding the risks, and having regulations that are commensurate with the risk the technology introduces is the most important thing. That is impossible if the technology is not understood.

DOE's involvement in fusion includes FES, three ARPA-E programs (ALPHA, BETHE, and GAMOW), as well as recent legislation passed on funding and developing public/private partnerships (INFUSE) to help these entities move further towards commercialization. There has been a lot of federal government support (~$29B so far). The private sector's investment in fusion is rapidly growing and currently exceeds $2B, with a focus on bringing fusion to market. Also, several private fusion companies are looking at demonstrating and scaling commercial facilities soon.

Industry Perspective – Canada, Michael Cappello, Senior Vice President for Prototype Deployment, General Fusion

Thanks to the NRC, DOE, and FIA for hosting such a forum for industry to feel like their voices are heard. While working at the Fort St. Vrain Nuclear Power Plant, one of the U.S.'s only non-light-water nuclear power plants, we dealt with over-burdensome regulations that were due to a lack of familiarity with the technology. I think that it is critical to get this right to avoid discouraging any new technologies being deployed.

General Fusion is not tied to any university or lab. The focus is on building a practical, commercially viable, accelerated path to fusion energy. The founder, Dr. Laberge, looked at all orphan technologies that were bypassed when tokamaks took over as the best fusion device. He looked at a concept from the U.S. Navy Reactor Lab called Imploding-Liner Fusion Reactor (LINUS). A lot of progress has been made by advances in plasma physics and fusion sciences. When the U.S. Navy went after LINUS back in the 1970s, they did not have the advantage of advanced manufacturing, computational capabilities, and high-speed digital control systems. There are also the advancements of high-temperature superconducting magnets. With the advancement of these technologies, it has enabled the private fusion industries to take science and move it into a rapid development pace along a path to commercialization. Although there is a wide variety of approaches and technologies to fusion, the key is that there are a lot of combinations on the Lawson criterion or the triple product. On one side there is the huge magnetic confinement fusion projects like ITER, on the other side there are the inertial confinement fusion projects like the National Ignition Facility (NIF), and in the middle are privately funded companies trying to exploit the Lawson criterion, such as the magnetized target fusion (MTF) that General Fusion is doing. Dr. Laberge saw that government has spent the most money on the extremes but not the middle technologies. The private fusion industries have saturated the middle of the two extremes. All these approaches should be tried. As example, we are most excited about Commonwealth's advances on high temperature superconductors. General Fusion does not use a magnetic array like a Tokamak, but we do use some magnets like in the plasma injector. Advancements with peers and counterparts in the private fusion industry along with the huge companies that have been well-funded by governments has allowed the private industry to take off. A lot of privately funded projects and companies would not be where they are today without the benefit of the large, government funded projects. MTF is a machine in which hot plasma is injected into the center (which is surrounded by a liquid metal), then, the plasma is compressed in milliseconds. A steady state plasma device requires very sophisticated arrays of magnets and plasma control systems. General Fusion is looking for a technology that could bypass that approach but not require the mega cost of gigantic lasers.

General Fusion began in 2003 with early experiments, and the first real funding came in 2009 when General Fusion went into an accelerated mode to develop subsystems and subcomponents. We feel enough experiments have been completed in the lab and we have been given a class II license by CNSC. The U.K. AEA has a different approach to regulation than the NRC. For this technology, the regulations must be risk-based and focused on the activity to be conducted. CNSC and the U.K. AEA have been great to deal with in terms of regulation.

General Fusion is ready to go. One key site selection criterion is regulation certainty. We believe that industry practices with low volumes of tritium and mature technology are headed down the path of making a site selection by 2020-2021.

Industry Perspective – US, Tyler Ellis, Commonwealth Fusion Systems (CFS)

CFS is developing a traditional Tokamak like ITER and JET. The key difference is that CFS is utilizing high-temperature superconductors which makes much more powerful magnets and shrinks the size of the facility significantly. From a safety standpoint, the key considerations are if the power is cut or the vacuum chamber fails, the facility simply shuts down, so there is no decay heat or possibility of a meltdown nor any production of long-lived nuclear waste because there is no special nuclear material. Published in the Journal of Plasma Physics, there are seven papers that go into specific detail about the physics basis behind our approach. Our approach is based on Tokamak technology that has been pioneered at the Massachusetts Institute of Technology (MIT). CFS has raised $200M from private sources to prove out the high-temperature superconducting magnets. All this is feeding into SPARC (the R&D demonstration facility) that we plan to have operational by 2025. CFS was founded to have significant impact on climate change and alleviate challenges.

Back to 2009, the NRC memo on whether it could be looked at as a utilization facility, the NRC would have to find a rule making that fusion constitutes atomic energy, as well as the fusion process is of such quantity to be significant to the common defense and security or effect the health and safety of the public. Commercial fusion facilities should not be treated as utilization facilities because the health and safety impact falls within Parts 20 and 30. Special nuclear materials (SNMs) are only defined as plutonium and enriched uranium, neither of which are used in fusion facilities. To classify fusion facilities as utilization facilities would require reclassifying benign materials as SNMs which is very unlikely.

Significant to the common defense, future fusion facilities can be designed to be incapable of developing nuclear materials because there is no source nor SNM on site. On the tritium front, there are fusion facilities that will be using tritium to start but it is commercially available already. Fusion facilities will eventually be able to create tritium on site and would not need to procure this on the open market.

Fusion energy facilities will not negatively impact safety and security of public because all operations can be confined to the plant site, and they can be constructed to comply with applicable standards for radioactive materials. These facilities will not produce any high-level radioactive waste. Finally, CFS is working towards an emission-free source of electricity (providing cleaner air in the future).

Considering the topic of NRC not establishing a national framework, the Agreement States program already handles radioactive sources under Parts 20 and 30, and the NRC already exerts oversight with audits so it can maintain consistency over the different state programs. The Agreement States program has been quite successful in demonstrating their ability to regulate radioactive sources safely and effectively, including tritium. In the SECY-20-0032, the NRC states it is considering an inter-state agreement approach. Imposing the same fission standards on the fusion sector would be a significant negative cost burden.

On the environmental review, SECY-20-0020 for advanced fission may not be appropriate for fusion facilities. Environmental Review Guidance for Licensing Actions Associated with NMSS Programs (NUREG-1748) is used for guidance, which is proportional to the actual risks that fusion facilities present. Requiring all fusion facilities to complete the proposed generic environmental impact statement would not be appropriate because it is focused on advanced fission systems. Again, this would be an excessive regulatory burden for fusion systems. Finally, the Agreement States program underscores the point that Wisconsin's oversight of D-T fusion devices is a phenomenal example and an appropriate case study of an agreement state's capability to handle a large amount of licenses across the U.S. Wisconsin became an Agreement State in 2003 and they have regulatory jurisdiction over Phoenix, LLC's neutron generators, which use a D-T fusion reaction and the same reaction all of the commercial facilities are looking to utilize. Because of the similarity between those, this case study example of the Phoenix, LLC can be a clear example of an agreement state's ability to regulate fusion devices under Part 30.

Industry Perspective – Small Business, Derek Sutherland, Chief Executive Officer, CTFusion

All fusion energy approaches are pursuing the Lawson criterion. D-T fusion requires the lowest temperatures to proceed. There are three general approaches: Magnetic Fusion Energy (MFE), Magneto-Inertial Fusion (MIF), and Inertial Fusion Energy (IFE). CTFusion was founded in 2015 as a spin-off from the University of Washington (UW). Currently, CTFusion is in the concept exploration (CE) phase of development and funded by ARPA-E and is working with UW to reach the technological readiness level of our fusion energy concept. The CTFusion approach is an alternative approach to MFE and based on the spheromak magnetic confinement with no toroidal field coils or central solenoid. CTFusion pursues a high beta approach to fusion with inductive power injection and current drive for continuous operation. At an early stage, we demonstrated our technology at a small-scale and hope to prove the proof of concept to follow completion of the CE phase of the development path. CTFusion is developing the technology needed for flexible, low cost fusion power plants, called the patented Dynomak technology that simplifies the production of fusion energy by unifying magnetic confinement, heating, and current drive. If this technology allows one to unify all these features, it could result in a simpler compact system than our competitors. Since this is a D-T fusion system it is a heat engine, so heat is being generated first and later turned into electricity.

All concepts have some variety of a fusion power core they are pursing. Provided a particular approach to fusion, like D-T, the plasma-material interface (PMI) and Balance of Plant (BOP) enjoys more technical overlap between the various approaches. Usually this is composed with a solid or liquid material and not intrinsic on the fusion process itself. The BOP of the fusion power core moderates D-T fusion neutrons, cools the PMI, contains lithium to produce tritium on-site for closed fuel cycles and converts heat into electricity. Most regulatory requirements are contained in these two subsystems. The current focus is on developing fusion power cores and the early-stage R&D. Even at this early stage, regulatory considerations already affect the design process for future devices. We design to minimize on-site tritium inventory and make material choices for our PMI and BOP to reduce neutron activation volumes. These design choices, coupled with effective regulations, will ensure fusion power plants will pose a minimal safety risk to the public.

Fusion has no risk of meltdowns, no long-lived radioactive waste, and no usage of SNMs. Risk-informed evaluations recently used by the NRC are recommended to develop the regulatory framework for fusion. This is emphasized in NEIMA as well. DOE has already taken important steps to support the commercial fusion industry by establishing regulatory precedents for fusion energy devices at DOE facilities. Engagement and support of the public is critical for effective regulation and commercial deployment; public support is imperative for success in the competitive marketplace. Effective regulation will facilitate the safe adoption of fusion energy while also respecting local and regional viewpoints. And intentional coordination will help accelerate worldwide adoption as part of the fight against climate change, which is a major motivator for this pursuit. Fusion can also interface with other renewables to decarbonize the energy grids and regulation can encourage more private sector investment in R&D. A risk-informed approach to regulation will be the most effective and consistent with NEIMA. Fusion can have a significant impact on climate change and effective regulation is needed to have a favorable impact on this global problem.

Panel Discussion/Q&A

Directed to all – Regarding standards outside of regulatory issues, for fission power plants there are extensive national and international standards that enable designers, operators, and regulators to assess the safety and security of nuclear power plants but there is nothing comparable for fusion power plants. Do you think there is a need to develop such a suite of standards? If so, who is responsible? **Ellis** replied that with fusion facilities, it is important to keep in mind and understand the technology itself. The potential hazards associated with radioactive materials is one small component, it really focuses on the tritium. Other aspects of the facilities, like large power supplies for buildings or fire protection, are taken care of by many existing standards. Because there are a lot of standards that exist to appropriately design these facilities, I do not think there is a need for a fusion-centric standard for every element. **Cappello** added that there are 4,000 particle accelerators in the U.S. alone out of a total of 17,000 world-wide. These are very high energy devices, much higher than what we are talking about for fusion regulations. The radiation source term could be significantly different on a fusion device than what is on a fission device. What happens is we get used to thinking that the fusion nuclear generation industry encompasses the entire radiation world, but it does not.

Jeffrey Merrifield said that a common thread in the discussion today is how to craft a framework that is protective but has the least amount of regulations necessary to ensure that protection. State regulations were mentioned, but the regulations are unpredictable. The goal should be to avoid inconsistencies. **Directed to Ellis** – Clear Path suggested the use of environmental impact statements. This process could be used to eliminate a significant number of elements of the fusion design process. If embraced, the fusion industry would benefit from that, however, 500+ pages of documentation should be avoided, and it is important for fusion to reduce these burdens. **Ellis** replied that there are three pathways offered in regulations (categorical exclusion, environmental assessment, and environmental impact statement). The key thing about reserving optionality is that the risk can be dialed into whatever the facility is. The concern is that by putting it under a generic environmental impact statement means starting in the most intensive type of review process. It is better to provide options for the NRC to pick the most appropriate pathways based on the risks.

David Crowley found it interesting the amount of discussion about the Agreement States, speculations in the regulatory framework of where these states fit, their capabilities, and their desire to be a participant. Some states have more capabilities than others (e.g. Wisconsin). The state programs are adaptable, and development and expertise are nurtured. To Merrifield's comments about the state programs' unique solutions being problematic – the current system and the way the Agreement States are set up drives compatibility and consistency across the national materials program. There are audit and review processes and regulatory review steps to ensure that Agreement States reach at least the lowest bar. The hope is that the Agreement States will have more involvement with DOE, the NRC, and the foreign regulators.

Directed to all – Is legislation needed for regulatory issues? **Ellis** responded that consistent throughout the presentations on the industry panel is that NRC and Agreement States have the tools they need to appropriately regulate fusion through Parts 20 and 30. Legislation is not necessarily needed, but if the NRC sees it might be helpful that conversation can be held. **Roma** agreed stating that when we look at what the NRC can do, they can do whatever the AEA allows them to do and there is a lot of flexibility there. The issue becomes what about the NRC regulatory framework. While it is not a legislative issue, the question is are the existing regulations sufficient for regulating fusion or does the NRC need to undertake rule making?

Bob Mumgaard asked when and what level of certainty the companies, on the panel, need to locate in the U.S. **Cappello** – For the fusion demonstration plant, we are not using tritium, so the risk profile is significantly lower. Any neutrons generated will be absorbed by the liquid lithium, making General Fusion's machine no different than a commercially available thermoscientific neutron generator device. General Fusion is considering a DOE facility site, but the tritium plant decision is a few years away. The current machine will demonstrate that all the subcomponents will work in an integrated manner and that we will not crush the plasma. Canada is a friendly regulatory environment and General Fusion will build the first commercial plants in places where they will pay for them. U.S. power generators love the concept, but they need proof that fusion is a reliable heat source for energy production. Finally, market forces will come into play for the first commercial power plant. **Holland directed to Sutherland** – What does regulatory certainty look like for

CTFusion to present to investors? **Sutherland** said that the nice thing about this technology space is that you can increase the technology readiness level quite a bit without using tritium. During commercialization you will get more money as regulatory uncertainty decreases. In the end, what investors care about is being able to make electricity and sell it to customers. Getting to regulatory certainty sooner than later is preferential because it attracts more private donors for the R&D and commercial phases. If there is a difficult regulatory environment, it is hard to make any difference at all, especially in the private sector.

Reckley raised a question on legislation, specifically the definition of byproduct material and the addition of byproduct materials being something produced by an accelerator. If this byproduct materials provision were used, is there an issue with calling fusion machines accelerators? **Roma** said she would have to look at the byproduct definition as amended in 2005. However, if you define a fusion facility included in the definition of accelerators that might solve the problem. In terms of a legislative fix, does the definition of a utilization facility need to be amended. What other things might need to be changed?

Directed to all – Given ongoing community activities in the National Academy of Sciences (NAS) and FES, what do you feel about broader fusion community support for regulatory aspects, and what can we do to give this further visibility and action? What should we do next? **Ellis** commented that what would be most helpful in the near term, since private companies are looking at constructing and designing their R&D facilities, is to prove out the next level of technology and provide a clear pathway for how regulatory treatment should be handled. Similar discussions would be beneficial for several private companies. Continue the conversation so industry can participate and be involved. **Roma** said that one thing discussed today is ensuring that any regulatory framework is commensurate with the risk and the technologies involved. It is important to a deeper dive in the technology discussion so that the NRC and other stakeholders can get a better understanding of how the U.S. companies are pursuing the technologies.

Sally Forbes asked, with respect to the technology deep dive, within the U.K. government, at a very high level, we are reviewing our regulatory frameworks. While tokamak is a main contender, we want to make sure they will not make the regulatory position difficult for other technologies. **Holland** suggested cross-national regulatory workshop.

Holland encouraged everyone to go to FusionIndustryAssociation.org to download the fusion white paper and all their updates. We are open for membership as well.

General Discussion and Closing Remarks, James Van Dam, Moderator

Dr. Van Dam opened the discussion for public comment.

Seth Hoedl asked how can the regulatory process be seen as facilitating public acceptance? There is a lot of focus on health and safety, but as the industry speakers mentioned there must be a market for the product as well and public acceptance is critical to that. The process of developing those regulations can facilitate that social acceptance and the demand for the product itself – it is important to keep that in mind. **Holland** responded that FIA thinks the public acceptance portion of this is incredibly important. We want to involve stakeholders from the beginning. We did strive to make this event inclusive, and we want to make future events inclusive, as well as outreach to stakeholders. **Roma** followed up saying the fusion industry was excited about this meeting to have a good conversation with the NRC, DOE, and other regulators, but it is also a public meeting to introduce the industry to the public and show the benefits that fusion has, how safe it is, and how technologies work so that people can get more excited about this field.

Richard Nygren noted that the U.S. public has developed a strong anti-science element that may not be present in the U.K. and Canada. Does this make public outreach harder? **Holland** relayed that anti-science biases are a global issue and he worries about the public discussion in that respect. However, he said if the facts are put out there, we will be okay.

Gene Nardella added that the idea of a public forum came from our NRC colleagues. This has been an excellent vehicle to start the process. There was a lot of information, experiences, perspectives, and options shared, and there are lots of ideas to consider on how to proceed. There are many entities we should reach out to who can provide valuable insights. IAEA comes to mind and they have an upcoming meeting in November on fusion safety and radiation protection of which licensing is a subject area. One thing we all want is the right regulatory framework for fusion that is commensurate with the hazards that it presents, and we want it in a timeframe that will allow fusion to continue to proceed. Saying that I would like to thank the speakers, moderators, and attendees and he looks forward to the next discussion and event.

Dr. Van Dam called the meeting to a close. He thanked Oak Ridge Institute for Science and Education (ORISE), the NRC/FIA working group for putting this together, and the speakers. The talks were excellent. The moderators did a great job. This audience has been excellent with great questions, discussions, and comments.

Respectfully submitted October 13, 2020

Tiffani R. Conner, PhD, PMP, AHIP
Jen Tucker, MS
ORISE/ORAU

Appendix: Attendees List

Chris Ajemian
Matteo Barbarino
Cris Barnes
Bob Beall
Jan Berry
Don Beyer
Amitava Bhattacharjee
Ryan Blackwell
John Boguski
Tim Bohm
Scott Brennan
Justin Bresson
Nicole Briggs
Jay Brister
Gil Brown
Brad Campbell
Michael Cappello
Lane Carasik
Emile Carbone
Matthew Carey
Ben Carmichael
Marcia Carpentier
Troy Carter
Sebastian Castrillon
Gabriel Cattrysse
Daniel Clark
Laban Coblentz
Cami Collins
Tiffani Conner
Kyle Cormier
Arlon Costa
Steven Cowley
David Crowley
T.L. Cubbage
Paul Dabbar
Robert Davis
Thomas Davis
Marcel De Vos
Steve Dean
Diane Demers
Floyd Deschamps
Ahmed Diallo
Todd Ditmire
Steven Dolley
Cyril Draffin
Joseph Dumont
Meredith Eaheart
David Edelman
Joelle Elbez-Uzan
Kristen Ellis
Tyler Ellis
Chris Faranetta
Robert Fedosejevs
Nate Ferraro
Sara Ferry
Sally Forbes
Monica Ford
Cary Forest
Alex Friedman
Susan Gallier
Lauren Garrison
David Gates
Wilna Geringer
Yashika Ghai
Alex Gilbert
Sehila Gonzalez
Bryan Greenwood
Brian Grierson
Puja Gupta
Walter Guttenfelder
Malcolm Handley
Robert Harris
Richard Hawryluk
Mark Hinchliffe
Bob Hirsch
Seth Hoedl
Jordan Hoellman
Andrew Holland
Christopher Holland
Leo Holland
Jane Hotchkiss
Natalie Houghtalen
Scott Hsu
Paul Hudson
Paul Humrickhouse
Victoria Hypes
Jason Karcz
Olajos Karoly
Charles Kessel
Jennie Kim
David Kingham
David Kirtley
Kathleen Klausing
Alf Köhn-Seemann
Matt Kriete
Scott Krisiloff
Brian Kryska
Libby Kurz
Robin Langtry
Olivier Lareynie
Ane Lasa
Steve Lawler
Jerry Levine
Edward Lewis-Smith
Grace Li
Luther Loehrke
Arnold Lumsdaine
Ed Lyman
Steven Lynch
Peter Lyons
Tom Magette
Rajesh Maingi
John Mandrekas
Alan Masinter
Chris Matthews
Joseph May
Kathy Mccarthy
Aaron Mcclendon
Mary Mccormick
Adam Mclean
Niko Mcmurray
Dale Meade
Jonathan Menard
Jeffrey Merrifield
Matt Miles
Matt Miller
Ronald Miller
Corinne Mitchell
Ellie Moison
Ross Moore
Saskia Mordijck
Ross Morgan
Matt Moynihan
Matthew Moynihan
Bob Mumgaard
Gerald Navratil
Colleen Nehl
Brian Nelson
Spencer Nelson
David Newman
Richard Nygren
Marty O'neill
Mike O'neill
Augustinus Ong
Donald Palmrose
Matthew Parsons
Mark Paulson
Richard Pearson
Tim Peckinpaugh
Tim Peer
Andrea Peterson
Steve Philpott
Gianluca Pisanello
Nirmol Podder
Lavinia Raganelli
Brett Rampal
Bill Reckley
Justin Redding
Everett Redmond
Will Regan
Don Rej
Alex Renner

Danas Ridikas
Katie Rittenhouse
Kevin Roach
Tom Rognlien
Amy Roma
Alex Rosenberg
Rj Roux
Grace Rubinger
Pierre Sames
Jacob Schwartz
Joe Sebrosky
John Segala
Maxine Segarnick
Jeff Semancik
Mo Shams
Michael Sharpe
Guinevere Shaw
Megan Shober
Chris Smiet
Sterling Smith
Phil Snyder
Wayne Solomon
Caroline Sorensen
Michael Spencer
Don Spong
Bhuvana Srinivasan
Mike Stephens
Martin Stutzke
Derek Sutherland
Kristine Svinicki
Arlee Tamman
Cameron Tarry
Jeff Thomas
Alex Tinguely
Jesse Treu
Nanette Valliere
James Vandam
Tristan Villarreal
Randall Volberg
Gordon Vytlacil
Greg Wallace
Ann Weeks
Duane White
Duncan White
Patrick White
Dennis Whyte
Theresa Wilks
Bradley Williams
Laurence Williams
Melanie Windridge
Brian Wirth
Kevin Woller
Sam Wurzel
Trent Yadro
Dennis Youchison
Andy Zach
Mike Zarnstorff