Developing a Regulatory Framework for Fusion Energy Systems

January 26, 2021
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Times shown in EST
Background

- Nuclear Energy Innovation and Modernization Act (NEIMA) signed into law in January 2019 requires the NRC to complete a rulemaking to establish a technology-inclusive, regulatory framework for optional use for commercial advanced nuclear reactors no later than December 2027
  - (1) ADVANCED NUCLEAR REACTOR—The term “advanced nuclear reactor” means a nuclear fission or fusion reactor, including a prototype plant… with significant improvements compared to commercial nuclear reactors under construction as of the date of enactment of this Act, …
Commission Direction on Rulemaking Plan

• In SRM-SECY-20-0032, dated October 2, 2020 (ADAMS ML20276A293), the Commission:
  o Approved the staff’s proposed approach for the rulemaking
  o Directed the staff to provide:
    ▪ a schedule with milestones and resource requirements to achieve publication of the final Part 53 rule by October 2024
    ▪ key uncertainties impacting publication of the final rule by that date
    ▪ options for Commission consideration on licensing and regulating fusion energy systems
  o Directed the staff to develop and release preliminary proposed rule language intermittently, followed by public outreach and dialogue
Current Activities

- On November 2, 2020, staff submitted a Commission memorandum responding to the SRM direction to provide a schedule with milestones and resources to complete the final rule by October 2024 (ADAMS ML20288A251).
- Continuing interactions such as the public forum in October 2020 with an NRC public meeting scheduled for January 26, 2021.
- Assess potential risks posed by possible commercial deployment of various fusion technologies and possible regulatory approaches for commercial fusion facilities.
- Regulatory framework for advanced reactors (Part 53) being developed to accommodate fusion technologies as much as possible to maintain flexibility for future.
- May recommend separate rulemaking for fusion facilities that would extend beyond 2024 but would be completed before 2027.
Advanced Reactor Concepts

- Light-Water Small Modular Reactors
- Non-Light-Water Reactors
  - Liquid Metal Cooled Fast Reactors
  - Gas Cooled Reactors
  - Molten Salt Cooled Reactors
  - Molten Salt Fueled Reactors
  - Heat Pipe Reactors
    - Microreactors
- Accelerator Driven Systems
- Fusion Reactors
Andrew Holland, Executive Director
Fusion Industry Association
The Fusion Industry Association is an international coalition of companies working to electrify the world with fusion - the unparalleled power of the stars. Energy from fusion will provide clean power for everyone that's safe, affordable, and limitless.
Building the Fusion Economy

Fusion energy will revolutionize the global energy system. It can solve the climate crisis and build energy abundance.

• The Fusion Industry Association is accelerating commercially viable fusion energy by advocating for policies that support our 22 member companies as they develop commercial fusion power.
• The FIA is building a movement to tell the world should know how important clean, safe, affordable, and secure fusion will be to the future energy system. The FIA is educating key stakeholders in the private, public, and philanthropic sectors about the importance of tomorrow’s fusion power economy.

Fusion must be deployed fast enough to meet the world’s challenges.
Why Fusion?

_to solve our generation’s biggest challenge:_

_The Climate Crisis_

Current clean energy technologies will prove insufficient to reduce carbon emissions enough to solve climate change.

Fusion is a breakthrough energy source uniquely suited for rapid, widespread adoption to disrupt and displace fossil fuels around the world.
Clean, safe, affordable, and inexhaustible fusion energy will power the economy of the future. It will raise living standards and meet growing global energy demand without environmental sacrifices. It will break the geopolitics of energy, so a country’s destiny is not determine by the size of its hydrocarbon deposits.
Mission of the FIA

The Fusion Industry Association is the voice of the growing fusion industry. It supports efforts to **accelerate commercially viable fusion research and development**. The Association promotes the interests of the fusion industry around the world by advocating for ways to commercialize fusion power on a time-scale that matters.
A Global Race to Fusion Power
Membership
Affiliate Members

AIR LIQUIDE

Jema

innovative energy

ASG SUPERCONDUCTORS

DAVIS & MUSGROVE LTD.

PHOENIX

TRANSFORMING NUCLEAR TECHNOLOGY

Innovations

SuperOx

INNOVATIVE SOLUTIONS SYSTEM

ENERCON

EPRI

ELECTRIC POWER RESEARCH INSTITUTE

PEGASUS

FUSION STRATEGIES

STELLAR

ENERGY FOUNDATION

Fusion Energy Base

Kyoto Fusioneering

CleanTech Alliance

pillsbury

Hogan Lovells

K&L GATES

CLEARPATH

AEROSPACE

AMPEGCN

OCEM

POWER ELECTRONICS

Sapientα
How does the Fusion Industry Association advance fusion?

Three strategic priorities for accelerating fusion energy
How does the Fusion Industry Association advance fusion?

1. Partnering with Governments

The private sector should have access to the scientific research that governments have pursued for decades. *Public-Private Partnerships* that include government support to private fusion companies can rapidly accelerate fusion development by driving private financial support.

2. Building a Fusion Movement

The world should know how important clean, safe, affordable, and secure fusion will be to the future energy system. FIA is educating key stakeholders in the private, public, and philanthropic sectors about the importance of tomorrow’s fusion power economy.

3. Ensuring Regulatory Certainty

Fusion research, development, and deployment should be subject to appropriate, risk-informed regulation when experiments are built and sited.
Ensuring Regulatory Certainty

U.S. policymakers should establish a broad legislative and regulatory framework that explicitly and permanently removes fusion energy from the regulatory approaches that the federal government has taken towards fission power plants.
Ensuring Regulatory Certainty

• The NRC’s Part 50, 52 and proposed 53 regulations for large commercial fission reactors address a different suite of risks compared to risks that fusion facilities could create and therefore are not appropriate for fusion systems.

• Rules like the NRC’s Part 20 regulations for general radiation protection and Part 30 rules for handling byproduct material would properly address fusion facilities’ risk profiles.

• The DOE has created a framework for safe construction and operation of experimental fusion energy devices that has worked well for decades.
Thank You

https://www.fusionindustryassociation.org/post/fusion-regulatory-white-paper
Discussion - Background
Derek Sutherland, Chief Executive Officer
CT Fusion
Fusion Regulatory Public Forum

January 26, 2021

Derek Sutherland, Ph.D. – Co-Founder and CEO
All fusion energy approaches are pursuing the Lawson criterion in their fusion power core (FPC)

- Lawson triple product $nT\tau_E$ defines the threshold for ignition for a given fusion type
- The required temperature $T$ is largely set for a fusion fuel choice (e.g. DT)
- The deuterium-tritium (DT) fusion reaction fuses heavy hydrogen and produces helium and a neutron
- Variations between fusion approaches on fuel type, $n$, $\tau_E$, and confinement method to reach Lawson conditions

$\tau_{1/2} \approx 12.32 \text{ yrs}$

Can activate materials
There are three general approaches to fusion energy

- **Magnetic Fusion Energy (MFE)**
  - Low \( n \)
  - High \( \tau_E \)

- **Magneto-Inertial Fusion (MIF)**
  - Medium \( n \)
  - Medium \( \tau_E \)

- **Inertial Fusion Energy (IFE)**
  - High \( n \)
  - Low \( \tau_E \)
Most differences between fusion approaches reside in fusion power core (FPC), but are all qualitatively similar

- Make use of an ionized gas (plasma) and a vacuum region
- Generate some sort of product: neutrons, alpha particles, etc.

- Specific confinement methodology varies between and within each main category:
  - Magnetic Fusion Energy (MFE)
  - Magneto-Inertial Fusion (MIF)
  - Inertial Fusion Energy (IFE)

- The nature of hazards is similar between approaches, which can be reduced by:
  - Reducing tritium inventory and activation volumes by reducing size of system
  - Making appropriate material choices to reduce activation
  - Pursuing advanced fuel cycles to avoid usage of tritium and reduce neutron production
There are similarities in PMI and BOP subsystems for any DT fusion power plant concept

Given a FPC using deuterium-tritium (DT) fuel, the design of PMI and BOP often share these characteristics:

**Plasma-Material Interface (PMI)**
- Made from solid or liquid material
- Directly interacts with plasma
- Neutrons impact interface, which can lead to activation dependent on material choices

**Balance-Of-Plant (BOP)**
- Solid or liquid blanket(s)
- Moderates DT fusion neutrons and cools PMI
- Contains Li to produce T on-site for closed fuel cycle
- Converts heat into electricity
Advanced fusion fuel cycles may reduce challenges associated with DT fusion

The usage of tritium and neutron activation of materials are the two primary hazards to consider for DT fusion.

Advanced fuel cycles (D-D, D-\(^3\)He, p-\(^{11}\)B) require higher plasma temperatures than DT.

Advanced fuel cycles avoid the need for tritium as an input and produce less energetic neutrons.

Multiple private efforts are focusing on the D-\(^3\)He and p-\(^{11}\)B fuel cycles instead of DT.
Ongoing engagement and support of the public is needed to develop effective regulation and enable successful commercialization

• As with any new technology, public engagement and support is imperative to adoption

• Public engagement and support are needed for the successful commercialization of fusion

• Effective regulation will enable the safe adoption of fusion energy worldwide while respecting local and regional viewpoints

• International coordination would help accelerate worldwide usage as part of coordinated fight against climate change
The physics of fusion and fission are different, which encourages different approaches to regulation.

- All fusion approaches have no risk of meltdowns, no long-live radioactive waste intrinsic to the process, and no usage of special nuclear material.

- Risk-informed evaluations recently used by the NRC in the fission sector are recommended to develop the regulatory framework for fusion.

- Emphasis on risk-informed regulatory processes is also encouraged by the Nuclear Energy Innovation and Modernization Act (NEIMA).

- DOE has already taken important steps to support the commercial fusion energy industry by establishing regulatory precedents for fusion energy devices at DOE facilities.
Conclusions

• There are a variety of fusion energy approaches being pursued in pursuit of the Lawson criterion

• The three main categories of fusion approaches are magnetic fusion energy (MFE), magneto-inertial fusion (MIF), and inertial fusion energy (IFE)

• Advanced fuel cycles being pursued by a few organizations may avoid the need for tritium as an input and reduce neutron activation concerns

• Commonalities between all approaches motivate a unified fusion regulatory framework

• All fusion approaches have no risk of meltdowns from runaway reactivity, no long-live radioactive waste intrinsic to the process, and no usage of special nuclear material – motivates a different approach to regulation than fission power plants using risk-informed methodology

• Ongoing public engagement and support are critical for the successful commercialization of fusion energy as part of the coordinated fight against climate change
Effective regulation is complementary to the efficient deployment of fusion energy as a needed tool in the fight against climate change

• Fusion will work in concert with renewables to deeply decarbonize our energy grids

• Effective regulation can encourage more private sector investment in current and near-term R&D phases

• A risk-informed approach to regulation will be most effective and consistent with NEIMA

• Fusion can have a significant impact on climate change while posing a minimal safety risk to the public

• Effective regulation is needed and complementary with this mission
Challenge – Diversity of Designs and Hazards

**Fusion Technologies**
- Magnetic
- Magneto-Inertial
- Inertial

**Fusion Reactions**
- DT
- P\(^{11}\)B
- D\(^{3}\)HE

**Radiological Hazards**

**Chemical & Other Hazards**
Integrated Approach (Background)

Bow-Tie Risk Management Figure
Regulatory Approaches

- Preliminary assessments left open the regulatory approach for commercial fusion reactors
- Possible approaches include treatment similar to:
  - Nuclear (fission) power plants
  - Materials (e.g., accelerator)
  - Hybrid or new approach
Discussion – Consideration of Diverse Technologies & Related Hazards
Regulation of Reactor Facilities

- Legal and technical framework defined in Atomic Energy Act and NRC regulations for utilization facilities (currently those using special nuclear material (SNM))
  - SNM is plutonium, uranium 233, uranium enriched in the isotope 233 or in the isotope 235
- NRC historical focus on large light-water reactors
- Technical requirements on design, construction, operation and decommissioning
- Extensive licensing reviews
- Environmental Impact Statements
- Mandatory hearings
William Sowder, Chairman
ASME C&S Section III, Division 4
Fusion Energy Devices
Developing the ASME Construction Code and Standard for Fusion Energy Facilities

William K. Sowder
Chairman, ASME C&S Section III, Division 4
Fusion Energy Devices
• The goal is to develop a recognized fusion construction code and standard to be issued by the American Society of Mechanical Engineers (ASME)

• This new construction code would be used in the USA or globally as an acceptable basis for nuclear regulators or nuclear enforcement authorities for the construction, licensing and operating of new fusion facilities, such as the Compact Pilot Plant, DEMO, etc.
• Existing nuclear codes and standards for construction do not adequately cover the design, manufacturing or construction of the magnetic confinement fusion energy devices (e.g. Tokamak devices) that are currently being considered for future DEMO constructions. They also do not provide support for the on-going projects, such as ITER and others.
• As an alternative to just modifying the existing fission design based codes and standards new set of codes and standards are being developed specific for these fusion devices to cover their design, manufacturing and construction activities including the different levels and types of inspection/testing activities.

• In addition, it is anticipated that operation and maintenance requirements for these fusion energy devices will require new Operation and Maintenance (O&M) codes and standards or major modifications to existing ones to utilize the best available methods and technology in each area.
• These new rules for fusion energy devices would apply to fusion-energy-related components such as vacuum vessel, cryostat and superconductor structures and their interaction with each other.

• Other related support structures, including metallic and non-metallic materials, containment or confinement structures, piping, vessels, valves, pumps, and supports will also be covered.
• Division 4 Fusion Energy Devices (FED) issued in November 2018 a Draft Standard for Trial Use of proposed code rules entitled “Rules for Construction of Fusion Energy Devices ASME FE.1-2018

• The issuance of the “Fusion Draft Standard for Trial Use and Comment” is for a 3-y period of time that requires further approvals.

• The Draft Standard is not an approved consensus standard. ASME has approved its issuance and publication as a Draft Standard only.
• To develop this new fusion code and standard a Division 4 Roadmap was written to focus limited resources on areas being considered for development, as well as, providing project management to this development effort.

• The Division 4 code and standard effort are being managed by various project teams within Division 4 of the ASME BPV Committee on Construction of Nuclear Facility Components (III).
• The current membership of the ASME Division 4 Fusion Energy Devices Sub-Group (FED) is global in its participation with 27 members including from the USA(7), several nuclear regulators(2), United Kingdom(5) and other EU member countries(3), South Korea(2), India(2), Japan(1), and China(5).
ASME Section III Division 4 Fusion Energy Devices Sub-Group Organization
SUBGROUP ON FUSION ENERGY DEVICES (BPV III-4)

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D. Roszman, Secretary, Hayward Tyler, Inc.
M. Bashir, Culham Centre for Fusion Energy
L. C. Cadwallader, Battelle Energy Alliance, LLC
B. R. Doshi, Institute for Plasma Research
G. Holtmeier, Lawrence Livermore National Laboratory
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K. Kim, National Fusion Research Institute
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X. Li, Institute for Standardization of Nuclear Industry
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M. Porton, Culham Centre for Fusion Energy
F. Schaaf, Jr., Sterling Refrigeration Corp.
P. Smith, Consultant
Y. Song, Institute of Plasma Physics, Chinese Academy of Sciences
M. Trosen, Major Tool & Machine, Inc.
C. Waldon, UK Atomic Energy Authority
I. Zatz, Princeton University Plasma Physics Laboratory
R. Barnes, Contributing Member, Anric Enterprises, Inc.

WORKING GROUP ON GENERAL REQUIREMENTS (BPV III-4)

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Rules for Construction of Fusion Energy Devices

This is a Draft Standard for Trial Use and Comment. This Draft Standard is not an approved consensus standard of ASME nor is it an American National Standard. ASME has approved its issuance and publication as a Draft Standard only. Distribution of this Draft Standard for comment shall not continue beyond 3 years from the date of issuance. The content of this Draft Standard for Trial Use and Comment was not approved through ASME's consensus process. Following the 3-year trial and comment period, this Draft Standard, along with comments received, will be submitted to a Consensus Committee or Project Team. The Consensus Committee or Project Team will review and revise this Draft Standard based, in part, upon experience during the trial term and existing comments. A public review in accordance with established American National Standards Institute (ANSI) procedures is required at the end of the Trial-Use Period and before a Draft Standard for Trial Use is submitted to ANSI for approval as an American National Standard. Therefore, it is expected that this Draft Standard (including any revisions thereto) will be submitted to ANSI for approval as an American National Standard. Suggestions for revision should be directed to the Chair, Subgroup on Fusion Energy Devices, using the following form: http://asp.asme.org/FEICommentForm.
ROADMAP FOR THE DEVELOPMENT OF ASME CODE RULES FOR FUSION ENERGY DEVICES
Division 4 FED is also working with the ASME Section XI In-Service Inspection Operations Code in developing for future FED use a type of Reliability and Integrity Management (RIM) Program using as guidance the recently published Section XI Division 2 Code Rules-Requirements for Reliability and Integrity Management (RIM) Programs for Nuclear Power Plants
What is Reliability and Integrity Management (RIM):

Those aspects of the plant design process that are applied to provide an appropriate level of reliability of SSCs and a continuing assurance over the life of the plant that such reliability is maintained. These include design features important to reliability performance such as design margins, selection of materials, testing and monitoring, provisions for maintenance, repair and replacement, pressure and leak testing, and In-service Inspection (ISI).
Jeffrey Merrifield, Partner
Pillsbury
Fusion Energy: Considerations for Regulation of Fusion-Based Power

January 26, 2021

The Honorable Jeffrey S. Merrifield
Partner, Pillsbury Winthrop Shaw Pittman, LLP
Background

Long sought after, fusion power is finally within reach
- Over two dozen private sector companies actively developing fusion tech
- Strong private and federal support
- Commercialization is now predominantly an engineering and financial challenge

One challenge facing realization of fusion energy is establishment of an appropriate regulatory framework
- Proper regulation is essential for allowing the technology to develop
- Regulatory certainty will allow fusion projects to attract investment
- Ensures public health and safety
NRC Regulation of Fusion Reactors

Discussions have often focused on regulating fusion devices as “utilization facilities”

• SECY-09-0064 – “Regulation of Fusion-Based Power Generation Devices”
  o Asserted NRC regulatory jurisdiction over commercial fusion energy devices
  o One of staff’s bases of jurisdiction was on defining fusion devices as “utilization facilities”

• The Nuclear Energy Innovation and Modernization Act includes both fission and fusion under its definition of “advanced reactors”
  • Does not compel that fusion be regulated as a utilization facility but may create that implication

Fusion could also be regulated under Part 30 based on its use of byproduct material
Problems with Utilization Facility Framework

Utilization facility regulatory framework is designed to address issues more specific to fission power

- Offsite nuclear releases, spent fuel and waste management, proliferation

The utilization facility framework is inappropriate for fusion devices

- Fusion reactors do not present the same threat of offsite radioactive release
- Limited or no proliferation risks
- Limited need for financial assurance for long-term waste management
## Burdens Imposed by “Utilization Facility” Classification

| Economic | • **Subject Fusion Facilities to Price Anderson Act Liability**  
|          |   • Imposes significant insurance and financial protection requirements  
|          |   • Makes fusion facilities potentially liable for accident at a fission facility  
|          |   • Inappropriate given the risks of fusion  
|          | • **Limit foreign investment and ownership of U.S. fusion companies or facilities**  
|          |   • Unnecessarily restricts financing for U.S. commercialization of fusion energy  |
| Regulatory | • **Impose fission licensing process**  
|           |   • Extended process, mandatory hearings, high cost  
|           |   • NRC should not impose such a complex licensing process at this stage  
|           | • **Restrict state involvement**  
|           |   • Precludes Agreement State process  |
| Foreign Trade | • **Subject fusion devices to NRC export licensing requirements**  
|              |   • Restrictions in AEA Sections 127 – 129 (e.g. IAEA Safeguards)  
|              |   • Impose AEA Section 126 inter-governmental consultation process  |
An alternative is to regulate fusion devices under Part 30

- Part 30 is an appropriate framework for this stage of fusion development
  - Already used to license many types of large-scale nuclear facilities
    - nuclear medicine centers, cyclotrons, food irradiators
  - Demonstrated track record of protecting public health and safety
- Part 30 already regulates tritium used in some fusion research

Note that it is not clear whether the Atomic Energy Act provides a solid basis for long-term regulation of commercial fusion under Part 30

- While the Part 30 framework is appropriate for fusion regulation, additional legislation may be necessary to provide the most regulatory certainty
Regulation of Fusion Reactors under Part 30

Part 30 avoids the pitfalls of regulating fusion devices as utilization facilities

- Provides a more flexible licensing regime
  - Allows the NRC discretion in holding hearings
  - Avoids the high costs imposed by extended licensing process
- Allows for greater foreign investment in domestic facilities and facilitates exports of U.S. technology
- Avoids cost-prohibitive Price Anderson liability
- Allows state regulatory involvement
Conclusion

• As commercial fusion increasingly becomes a reality, an appropriate regulatory framework is critical to the success of this emerging technology

• Regulation of fusion devices as utilization facilities, while legally permissible, is an inappropriate framework that would impose unnecessary regulatory burdens on fusion development

• Instead, the NRC should regulate fusion devices under Part 30, which will provide the NRC and the industry the needed flexibility to realize the full potential of commercial fusion but still allow the NRC to meet its adequate protection standards

Further information can be found here
Discussion – Utilization Facility Approaches
Regulation of Radioactive Materials

- Application needs to address areas such as:
  - Radionuclides, including maximum possession limits
  - Information on Radiation Safety Program (personnel, monitoring, etc.)
  - Occupational and public doses
  - Procedures for safe use of radionuclides, security of materials, and emergencies (emergency plans, if required)
  - Waste management
  - Decommissioning (including financial assurance, if required)
  - Environmental protection regulations
  - Some usages of byproduct material have additional requirements due to the unique purpose of these materials. Examples include:
    - 10 CFR Part 30 and NUREG-1556, Volume 21 (Accelerators)
    - 10 CFR Part 36 and NUREG-1556, Volume 6 (Irradiators)
Regulation of Radioactive Materials

• Another item to note is that pre-commercial demonstration of fusion may be able to be conducted under DOE oversight and requirements if the private sector fusion company performs pre-commercial demonstration activities at a DOE facility. The company would not be subject to NRC/Agreement State licensing or specific regulations.

• Historically, Agreement States have licensed fusion research facilities. As a general matter, the byproduct material licensing of fusion-related activities have not gone beyond the requirements for possessing tritium or production of neutrons by companies, universities or other research institutions. Examples include:
  – Phoenix Neutron Generators (Wisconsin)
  – Laboratory for Laser Energetics (New York)
  – Planned approach for Commonwealth Fusion Systems' SPARC facility (Massachusetts)
David Kirtley, Chief Executive Officer
Helion Energy
Sachin Desai, Senior Associate
Hogan Lovells
Helion Energy

Dr. David Kirtley
CEO, Helion

Sachin Desai
Attorney, Hogan Lovells

January 26, 2021
Agenda

• About Helion

• Fusion Devices as Accelerators

• Application of Accelerator Framework
Agenda

• About Helion

• Fusion Devices as Accelerators

• Application of Accelerator Framework
Helion's Accelerator Approach

Two ring-shaped plasmas (FRCs) are propelled from opposite ends of the accelerator. They collide at the center and are compressed by a magnetic field, releasing fusion energy.

The whole process takes less than 1 millisecond from start to finish and is repeated every 10 minutes.

Energy is directly recaptured and recycled in a capacitor bank (upwards of 95% energy recovery).

Goal for 7th Gen accelerator is to run 1 Hz for short period.
Helion Runs on Helium 3

- Deuterium-Helium 3 Fusion minimizes many challenges with Deuterium-Tritium fusion
  - Eliminates 14 MeV Neutrons and their materials activation or latent heat challenges
    - *Only 5% of energy is produced as lower energy neutrons*
    - *Minimizes machine rebuild and maintenance issues*
  - Eliminates tritium breeding challenges
  - Eliminates the need for a steam cycle
  - Enables *non-ignition* fusion, further enhancing safety

- Deuterium-Helium 3 Fusion is possible because of advancements in direct energy recovery technology and Helion’s magneto-inertial fusion design.
Agenda

• About Helion

• Fusion Devices as Accelerators

• Application of Accelerator Framework
Two Definitions of Accelerators

“A particle accelerator is a device that imparts kinetic energy to subatomic particles by increasing their speed through electromagnetic interactions.”

NRC Regulations (10 CFR 30.4)
“Particle accelerator means any machine capable of accelerating electrons, protons, deuterons, or other charged particles in a vacuum and of discharging the resultant particulate or other radiation into a medium at energies usually in excess of 1 MeV.”

Potential threshold question as to how fusion fits within the US radiological protection framework
Two Definitions of Accelerators, cont.

“A particle accelerator is a device that imparts kinetic energy to subatomic particles by increasing their speed through electromagnetic interactions.”

✓ All fusion devices impart kinetic energy (i.e., raise temperature)

✓ All fusion devices use subatomic particles (i.e., plasma)

✓ All fusion devices work via electromagnetic interactions (e.g., magnets, magnetic fields, lasers, plasma “pinches”)
Two Definitions of Accelerators, cont.

NRC Regulations (10 CFR 30.4)

“Particle accelerator means any machine capable of accelerating charged particles in a vacuum and of discharging the resultant particulate or other radiation into a medium at energies usually in excess of 1 MeV.”

✓ All fusion devices accelerate particles (i.e., raise temperature).

✓ All fusion devices work with charged particles (i.e., ions/plasma).

✓ All fusion devices work in a vacuum.

✓ All fusion devices discharge the resultant particulate into a medium (e.g., into the plasma, into walls).

States currently classify fusion devices under this definition
Agenda

• About Helion

• Fusion Devices as Accelerators

• Application of Accelerator Framework
Working an Accelerator Framework into a Model of Fusion Regulation

**Possible Tiered Model of Regulation**

**Tier 1: No NRC Regulation of R&D**
- Industry is here. No real radiological risk from current R&D work.
- Although no formal NRC regulation of fusion, NRC principles still heavily guide and inform state regulatory frameworks.

**Tier 2: State-Led Accelerator Framework**
- Industry is heading here, and needs room for innovation.
- Legally, fusion devices fall under the “accelerator” definition.
- Technically, demo devices and low-impact devices appear to pose no greater risk than current commercial accelerators.
- NRC can assist and guide state regulatory programs.

**Tier 3: NRC Enhanced Regulation**
- Applicable to large-scale commercial devices if their radiological risk profiles run outside what states are able to regulate.
- Would likely need new regulatory regime.
Delineating Between Tiers 2 and 3

Sample Tech-Neutral Factors

- Radiation Flux
- Radiological Inventory
- Accident Release Scenarios
- Need for Ignition Conditions
- Fuel Supply Chain Needs
- Proliferation Concerns
- Capability of States to Regulate
- Need for Uniform Regulation

Key Inputs

- Fuel Type
- Facility Sizes & Designs
- State Regulator Considerations
- Current & Future Accelerators
Tyler Ellis, Founder
Black Hills Partners
Commonwealth Fusion Systems
CFS Approach and the Byproduct Material Licensing Model

Tyler Ellis, Ph.D.

Commonwealth Fusion Systems
CFS Approach

- Extensively studied (since the 1950s), traditional tokamak design which incorporates magnets utilizing high-temperature superconductors (HTS)
- If power is cut or vacuum chamber fails, facility simply shuts down, minimal decay heat to deal with
- No possibility of a melt-down nor production of long-lived nuclear waste due to the lack of source or special nuclear material
- Solid technical basis described in the Journal of Plasma Physics special issue on Status of the SPARC Physics Basis
High-Temperature Superconductors

• New superconducting materials expanded what is possible in magnets

• CFS developed a new generation of superconducting magnets to increase magnetic field in fusion machines
The HTS difference

Government plans

- JET (UK): Largest operating tokamak
- ITER (World): Net-energy experiment
- DEMO (World): First power plant

CFS plan

- 2015: C-MOD (MIT) Plasma physics
- 2020: SPARC (CFS) Net-energy experiment
- 2025: ARC (CFS) First power plant

~ to scale

Government plans

- 2015
- 2020
- 2025
- 2030
- 2035
- 2040
- 2045
- 2050
- 2055
- 2060

CFS plan

- 100x smaller scale than traditional tokamaks
- Immense reduction in cost, tritium fuel and low-level waste production
- No private companies are pursuing ITER/DEMO scale facilities
- Accelerates fusion deployment to address climate change
Tokamaks are effectively regulated under 10 CFR 30

- Like other private fusion approaches, tokamaks:
  - do not contain source or special nuclear material
  - produce no long-lived or high-level waste
  - are driven reactions, so power loss or vacuum failure simply shuts down the facility instantaneously
- Most private fusion approaches utilize tritium in their fuel cycle
- All private fusion approaches produce neutrons and activated materials
- These byproduct materials are already effectively regulated under 10 CFR 30 and fusion should not be treated as a utilization facility
NRC Definition of a Utilization Facility

“Utilization facility means: (1) Any nuclear reactor other than one designed or used primarily 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 described in the application assigned docket number 50-608.”

“Nuclear reactor means an apparatus, other than an atomic weapon, designed or used to sustain nuclear fission in a self-supporting chain reaction.”

- Fusion energy systems are NOT utilization facilities because they aren’t nuclear reactors, nor do they irradiate special nuclear materials
- There are no private fission-fusion hybrid approaches; but if there were, it would qualify as a utilization facility due to the presence of special nuclear material
- This is consistent with how the NRC approached regulating SHINE
Additional Considerations for NRC Evaluation

• The 2009 NRC Memo stated “the Commission may be able to exercise regulatory jurisdiction over fusion devices by treating such devices as utilization facilities…”

• To do this, the NRC would have to find in a rulemaking both that:
  • (1) fusion constitutes “atomic energy” within the meaning of the AEA, and
  • (2) the fusion process is of such quantity as to be ‘of significance to the common defense and security, or in such manner as to affect the health and safety of the public’”

• Fusion processes fall within the definition of “atomic energy” since atomic energy is defined to mean “all means of energy released in the course of nuclear fission or nuclear transformation”

• However, commercial fusion facilities should not be utilization facilities because they will not be of significance to the common defense and security and their health/safety impact only falls within 10 CFR Parts 20 and 30
Additional Considerations for NRC Evaluation

- **Fusion energy facilities will not** be of significance to the common defense
  - Commercial fusion facilities will not be capable of producing the fissionable materials because there is no source material nor special nuclear material on site
  - Even though neutrons are produced, using them to produce fissionable materials would be an extremely complex endeavor requiring immense effort and cost, so unlikely to be a credible threat
  - To the extent that fusion facilities use tritium fuel to start, it’s possible to secure tritium on the civilian market so there is no diversion of any material resource from U.S. defense needs
  - Fusion energy facilities are also capable of producing all the tritium fuel that they need on-site
  - Once commercialized, fusion energy facilities will join a mixed electricity grid so it is highly unlikely that any U.S. defense facility or activity will rely solely on fusion for power generation in the foreseeable future

Fusion neutrons are born at this energy, where capture is hundreds to thousands of times less likely than the moderated neutrons used in fission systems, so proliferation concerns are not likely to be a credible threat.
Additional Considerations for NRC Evaluation

• Fusion energy facilities will **not** affect the health and safety of the public in a negative way
  • All effects from abnormal operation of a fusion energy facility would be confined to the plant site and would not have a negative impact on the public
  • Fusion energy facilities would be constructed to comply with applicable standards for radioactive materials, rendering residual risks comparable to risks from existing hydrocarbon power plants or other industrial facilities
  • Fusion energy facilities will not produce high-level radioactive waste and would comply with existing rules for handling radioactive materials like tritium
  • By providing an emissions-free and inherently safe source of electricity, fusion will improve the health and safety of the general public
Additional Considerations for NRC Evaluation

• The 2009 NRC Memo suggested that an “additional consideration involves the potential benefits of the NRC establishing a national regulatory framework for fusion devices instead of requiring various State and local agencies to develop programs to address this new technology”

• States already handle radioactive sources under Parts 20 and 30 through the Agreement State Program (with 39 states participating) and the NRC exerts oversight through regular audits, so national consistency is already maintained

• The success of the Agreement State Program demonstrates that states are fully capable of exercising regulatory oversight for radioactive sources and this program is applicable to the tritium needed for future fusion systems

• NRC Staff suggested in SECY-20-0032 that “development of requirements for fusion reactors potentially includes regulatory approaches similar to those for the regulation of [particle] accelerators, which may include Agreement State considerations”

• Imposing the same fission standards on the fusion sector would create a costly regulatory requirement developed to address risks that will not be present at a fusion energy facility
Tokamaks are very similar to accelerators

- NRC definition of accelerator: “any machine capable of accelerating electrons, protons, deuterons, or other charged particles in a vacuum and of discharging the resultant particulate or other radiation into a medium at energies usually in excess of 1 megaelectron volt.”

- Tokamaks:
  - accelerate deuterons and tritons in a vacuum
  - resultant particulates are helium nuclei, protons and neutrons
  - particulate energies range from 3.3 to 14.1 megaelectron volts
  - particulates can run into the vacuum vessel wall

- Given this strong similarity, it makes sense to regulate private fusion approaches, like tokamaks, in the same way as accelerators under 10 CFR 30
Tokamaks are very similar to accelerators

• Tokamaks have similar hazards to accelerators
  • Direct radiation – addressed through proper shielding
  • Activated materials – addressed through materials selection and operations
  • Tritium – addressed through byproduct material regulations and handling procedures

• Tokamaks have similar operational procedures to accelerators
  • Tritium hazard from vacuum breach – air goes in instead of radioactive material coming out
  • Reaction can always be shut off – accomplished through interlocks, vacuum, magnet controls
  • No chain reaction – purely a driven system for direct radiation hazards

• Previous tokamaks have been regulated as accelerators under 10 CFR 30
  • Alcator C-Mod (MA)
  • DIII-D (CA)
  • Pegasus (WI)
Agreement State Program already regulates fusion facilities under 10 CFR Part 20/30

- Wisconsin’s oversight of a deuterium-tritium fusion device offers a clear example of an agreement state’s capacity to regulate fusion energy facilities and can provide an important precedent for NRC rulemaking actions
- New York’s oversight of a deuterium-tritium fusion device at the University of Rochester’s Laboratory for Laser Energetics offers another example
- 39 states regulate ~17,000 radioactive material licenses under this agreement which is ~86% of all US licenses and NRC oversight assures compliance with federal standards
- This reaction is the same as that proposed in many commercial fusion energy facilities, using the same reactants and demanding the same level of safeguards and regulatory compliance
- Because fusion energy devices will be similar to these facilities, the NRC can look to these case studies as an example of an agreement state’s capacity to regulate fusion devices under 10 CFR Part 20/30
Recommended NRC Approach

• NRC should use only Parts 20 and 30 to regulate the fusion energy industry
• States, operating within the oversight of the NRC’s Agreement State Program, should have a significant role in regulation of fusion energy plants
• This approach complies with the Nuclear Energy Innovation and Modernization Act (NEIMA)
Agreement State Perspective

- Megan Shober, Wisconsin Department of Health Services
- Jack Priest, Massachusetts Department of Public Health
Discussion – Byproduct Material Approaches
Possible Hybrid Approaches

• Considerations for New/Hybrid Approaches
  – Diversity of designs and related hazards
    • Appropriate for graded requirements
  – Consolidated or Fragmented Framework
  – Development of technical requirements
    • Prevention and mitigation
  – Legal requirements
    • Atomic Energy Act
    • National Environmental Policy Act
    • Other
  – Possible Legislative Changes
Possible Hybrid Approaches

- Approach within current frameworks

Decision Criteria

- Design & Associated Hazard
- Byproduct Material Model (Part 30)
- Utilization Facility Model (Part 53)
Possible Hybrid Approaches

- Dedicated Fusion Framework
Discussion – Possible Hybrid Approaches
General Discussion & Next Steps
Backup Slides
## NRC Staff Plan to Develop Part 53

### Subpart B
- **Requirements Definition**
  - Fundamental Safety Functions
  - Prevention, Mitigation, Performance Criteria (e.g., F-C Targets)
  - Normal Operations (e.g., effluents)
  - Other

### Subpart C
- **Design and Analysis**
  - System & Component Design
  - Analysis Requirements
  - Safety Categorization & Special Treatment

### Subpart D
- **Siting**
  - External Hazards
  - Site Characteristics
  - Environmental Considerations

### Subpart E
- **Construction**
  - Construction/Manufacturing
  - Ensuring Capabilities/Reliabilities
  - Change Control
  - Environmental Considerations

### Subpart F
- **Operation**
  - Facility Safety Program
  - Surveillance Maintenance
  - Configuration Control
  - Design Changes
  - Staffing & Programs

### Subpart G
- **Retirement**

### Project Life Cycle
- **Plant/Site** (Design, Construction, Configuration Control)
- **Analyses** (Prevention, Mitigation, Compare to Criteria)
- **Plant Documents** (Systems, Procedures, etc.)
- **LB Documents** (Applications, SAR, TS, etc.)

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**Clarify Controls and Distinctions Between**

**Subparts H & I**
Figure 5-1. Five Factors Formula.
Table 3.1: Reproduction of Table 1 in Appendix A of Subpart B of 10 CFR Part 830

<table>
<thead>
<tr>
<th>A DOE nuclear facility categorized as...</th>
<th>Has the potential for...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazard Category 1</td>
<td>Significant off-site consequences</td>
</tr>
<tr>
<td>Hazard Category 2</td>
<td>Significant on-site consequences beyond localized consequences</td>
</tr>
<tr>
<td>Hazard Category 3</td>
<td>Only local significant consequences</td>
</tr>
<tr>
<td>Below Hazard Category 3</td>
<td>Only consequences less than those that provide a basis for categorization as a hazard category 1, 2, or 3 nuclear facility.</td>
</tr>
</tbody>
</table>
Recent NRC activities related to advanced reactors (e.g., functional containment performance criteria, possible changes to emergency planning & security, and DG-1353) recognize the limitations of existing LWR-related guidance, which requires a return to first principles such as fundamental safety functions supporting the retention of radionuclides.

Each factor is, in turn, a function of its initial design characteristics (e.g., materials), operating conditions (e.g., burnup, aging) and transient/accident conditions (e.g., time, temperatures, pressures, chemistry).

Integrated Approach (Background)

Bow-Tie Risk Management Figure
Licensing Modernization
(Licensing Basis Events: NEI 18-04 & Reg Guide 1.233)

Event Sequences
- Anticipated Operational Occurrences
- Design Basis Events
- Beyond Design Basis Events

- Design Basis Accidents (relying on safety-related structures, systems, and components)

- F-C Target considered along with cumulative risk metrics, safety classification, and assessment of defense in depth

See: NEI-18-04 (NRC ADAMS ML19241A336) and Regulatory Guide 1.233 (NRC ADAMS ML20091L698)
Licensing Modernization
(Classification & Defense in Depth: NEI 18-04 & RG 1.233)

- Safety Classification and Performance Criteria
  - Safety Related (based on needed capabilities and reliabilities)
  - Non-Safety Related With Special Treatment
  - Non-Safety Related With No Special Treatment

- Defense in Depth Assessment

See: NEI-18-04 (NRC ADAMS ML19241A336) and Regulatory Guide 1.233 (NRC ADAMS ML20091L698)