# Developing a Regulatory Framework for Fusion Energy Systems

January 26, 2021

| Agenda | |
|---|---|
| Background (12:30-1:00) | NRC Staff |
| | Andrew Holland, Fusion Industry Association |
| Diversity of Designs & Related Hazards (1:00-1:30) | Derek Sutherland, CT Fusion |
| | NRC Staff |
| | General Discussion (All) |
| Regulation as a Utilization Facility (Fission Reactor Model) (1:30-2:15) | NRC Staff |
| | William Sowder, ASME FE.1 Standard |
| | Jeff Merrifield, Pillsbury |
| | General Discussion (All) |
| Break (2:15-2:30) | |
| Byproduct Material Approach (e.g., similar to accelerators) (2:30-3:30) | NRC staff |
| | David Kirtley, Sachin Desai, Helion/Hogan Lovells |
| | Tyler Ellis, Commonwealth Fusion Systems |
| | Agreement State Perspectives<br>Megan Shober, Wisconsin; Jack Priest, Massachusetts |
| | General Discussion (All) |
| New or Hybrid Approach (3:30-4:00) | NRC Staff |
| | General Discussion (All) |
| General Discussion (4:00-4:25) | General Discussion (All) |
| Next Steps/Wrap up | NRC Staff |

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, …

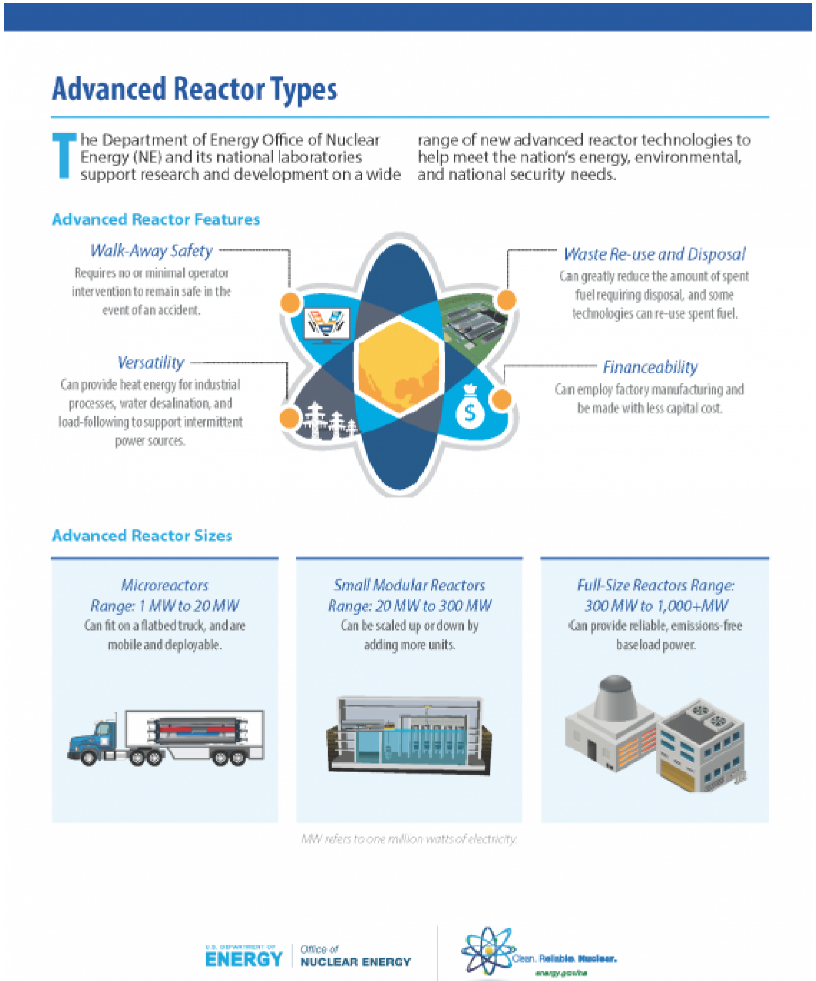
# Commission Direction on Rulemaking Plan

- In SRM-SECY-20-0032, dated October 2, 2020 (ADAMS ML20276A293), the Commission:
  - Approved the staff's proposed approach for the rulemaking
  - 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**
  - 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***

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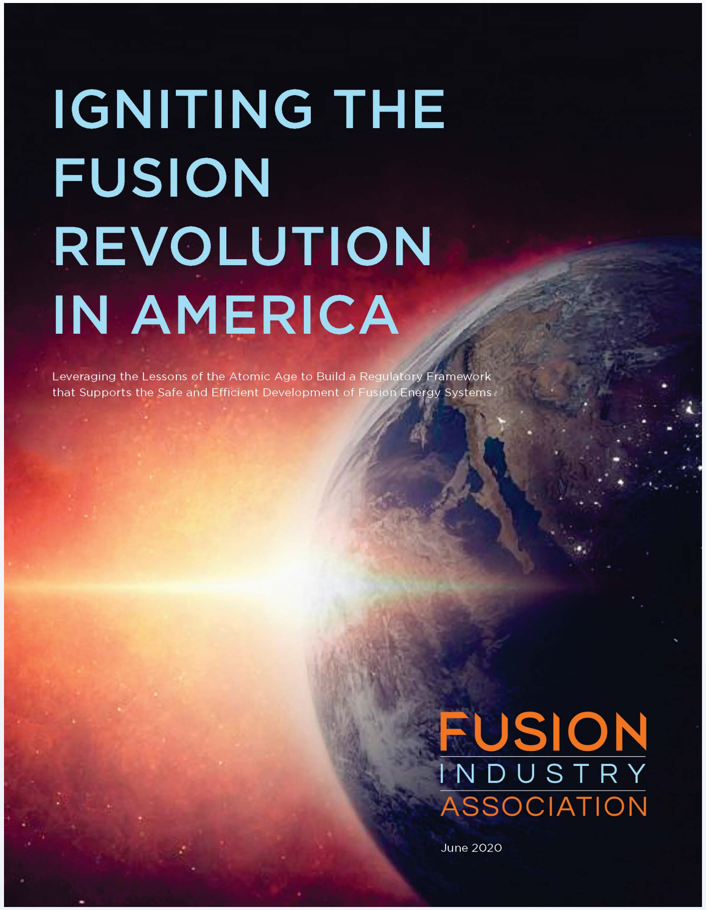
Andrew Holland, Executive Director

Fusion Industry Association



FUSION INDUSTRY ASSOCIATION

# The Voice of a new Industry

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 INDUSTRY ASSOCIATION

*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.*

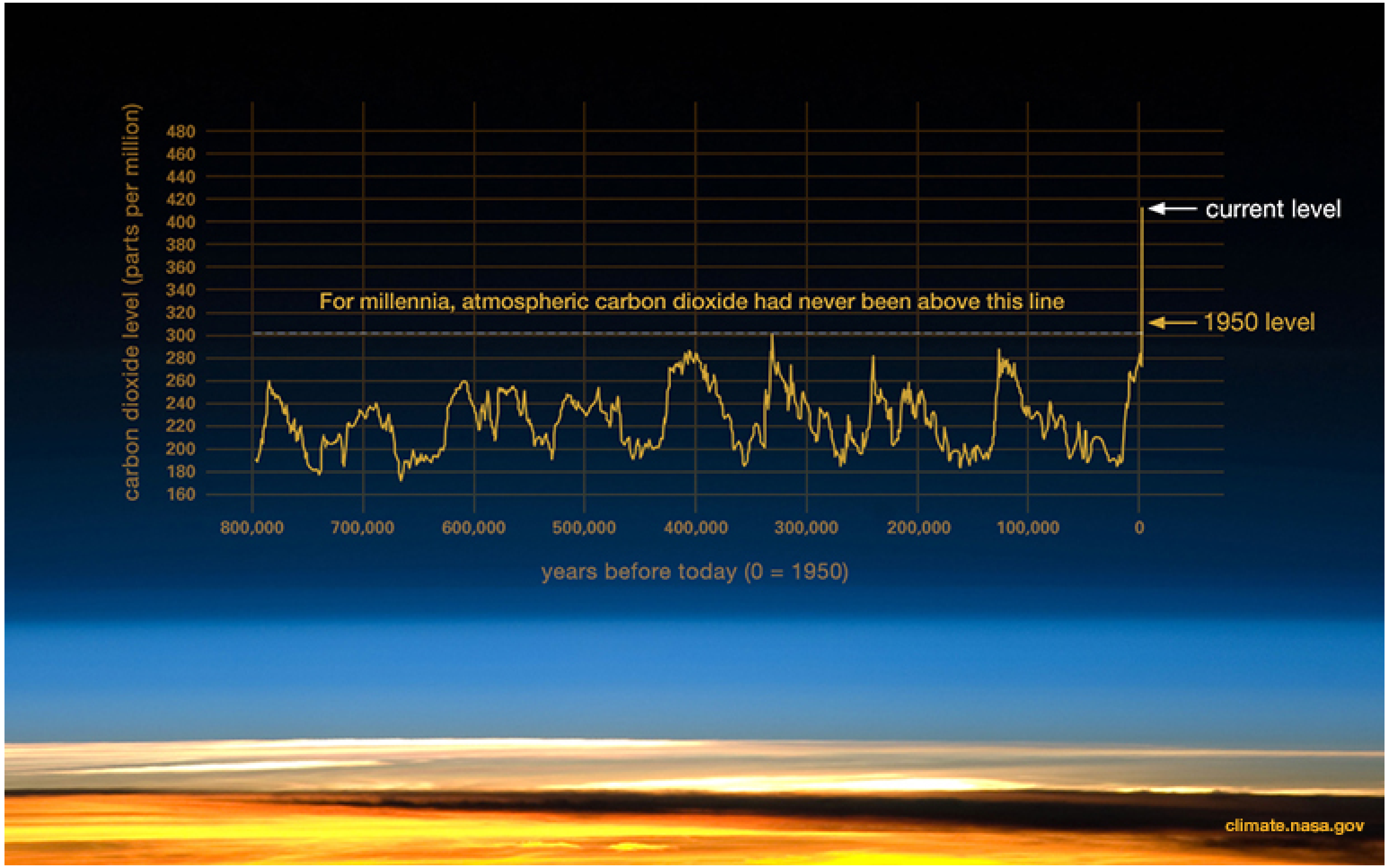
# Why Fusion?

*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.**



# Why Fusion?

FUSION INDUSTRY ASSOCIATION

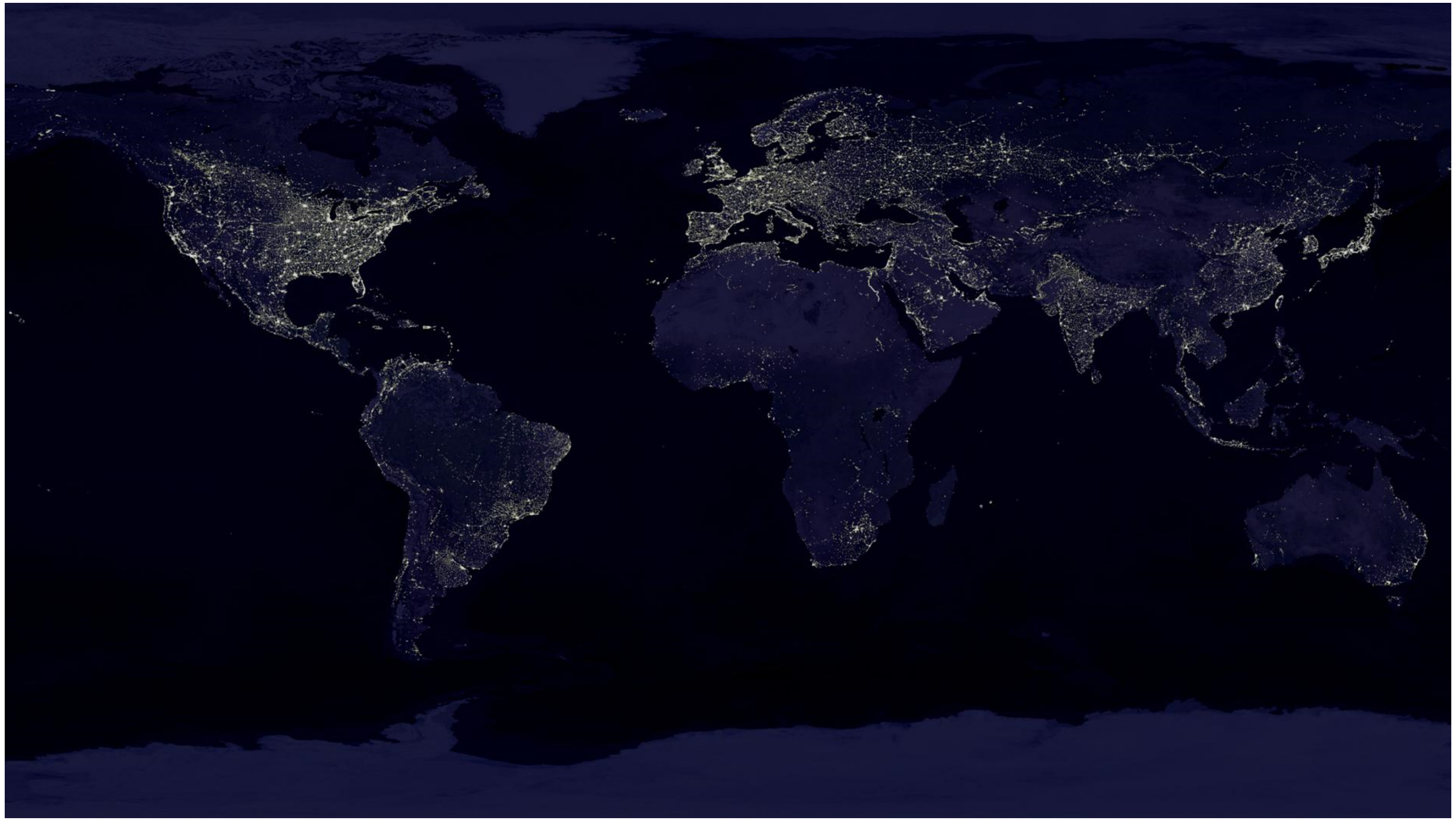
*To solve our species' biggest challenge:*

## ***Resource Scarcity***

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.



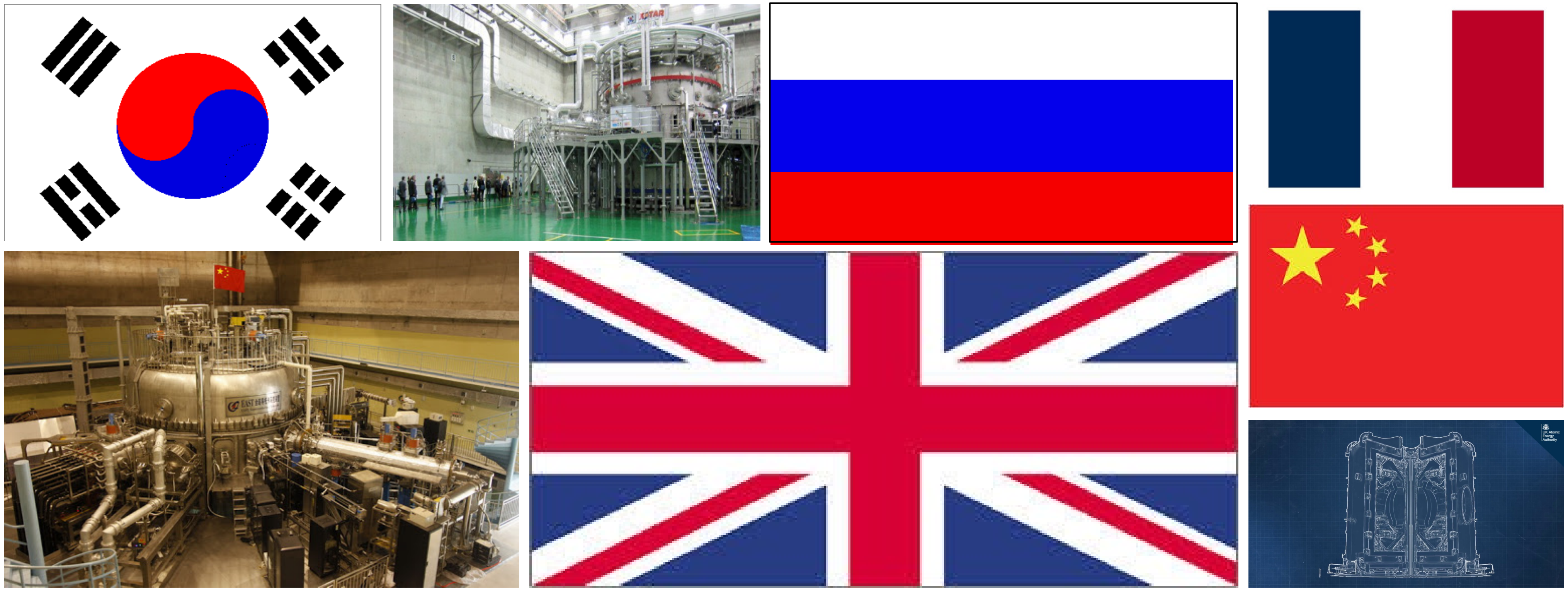
# Mission of the FIA

FUSION INDUSTRY ASSOCIATION

*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.*

FUSION INDUSTRY ASSOCIATION

# A Global Race to Fusion Power



# Membership

FUSION INDUSTRY ASSOCIATION

Helion Energy

Commonwealth Fusion Systems

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tae TECHNOLOGIES

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tokamak energy
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S Innovations

SuperOx

INNOVATIVE SOLUTIONS ABSOLUT SYSTEM

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PEGASUS FUSION STRATEGIES

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

STELLAR ENERGY FOUNDATION

Fusion Energy Base

Kyoto Fusioneering

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K&L GATES

CLEARPATH

AEROSPACE

AMPEGON

OCEM POWER ELECTRONICS

Sapientai

# How does the Fusion Industry Association advance fusion?

*Three strategic priorities for accelerating fusion energy*

# How does the Fusion Industry Association advance fusion?

FUSION INDUSTRY ASSOCIATION

**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**

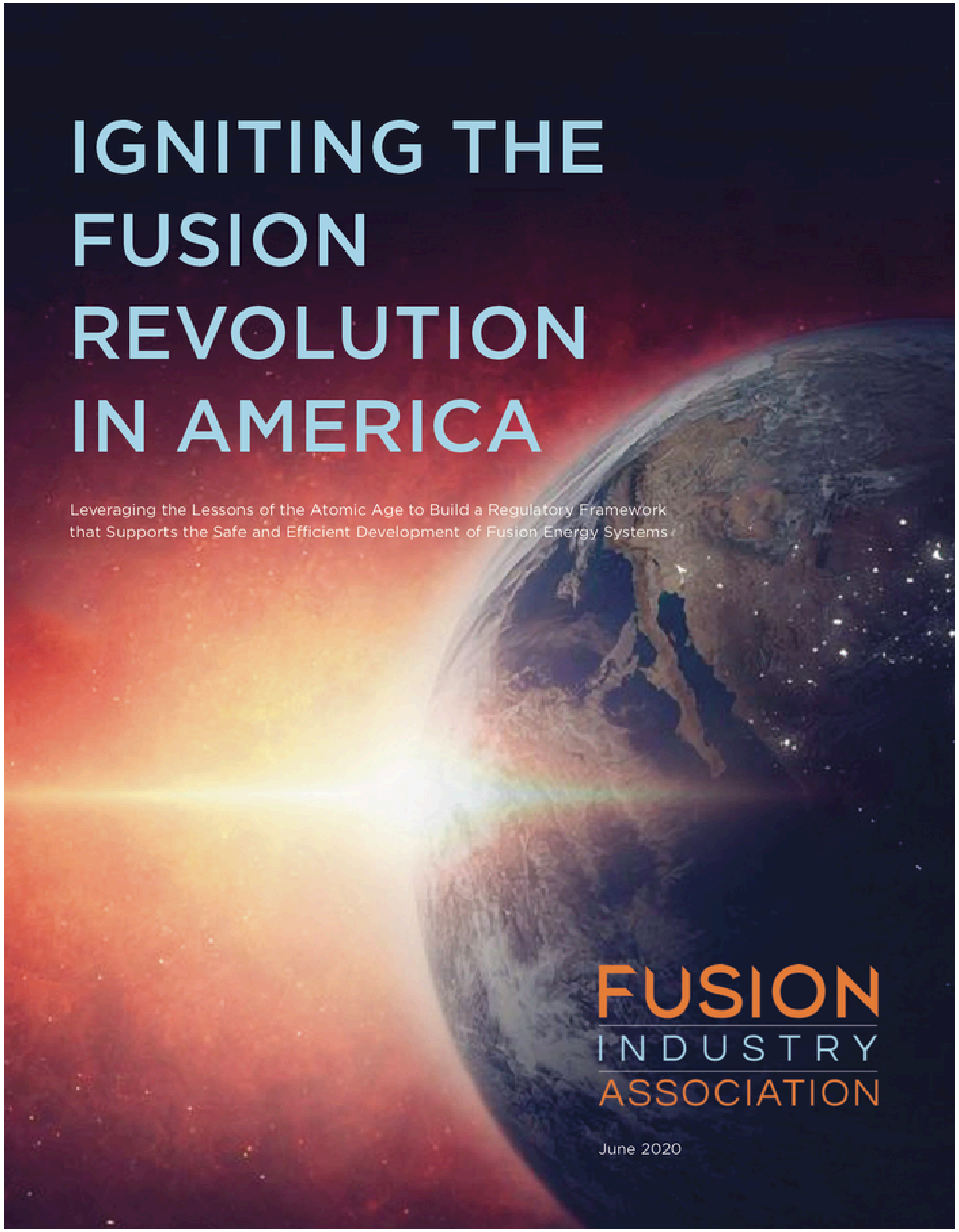
The world should know how important clean, safe, affordable, and secure fusion will be to the future energy system. FIA is educating key stakeholders in the private, public, and philanthropic sectors about the importance of tomorrow's fusion power economy.

## 3. Ensuring Regulatory Certainty

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

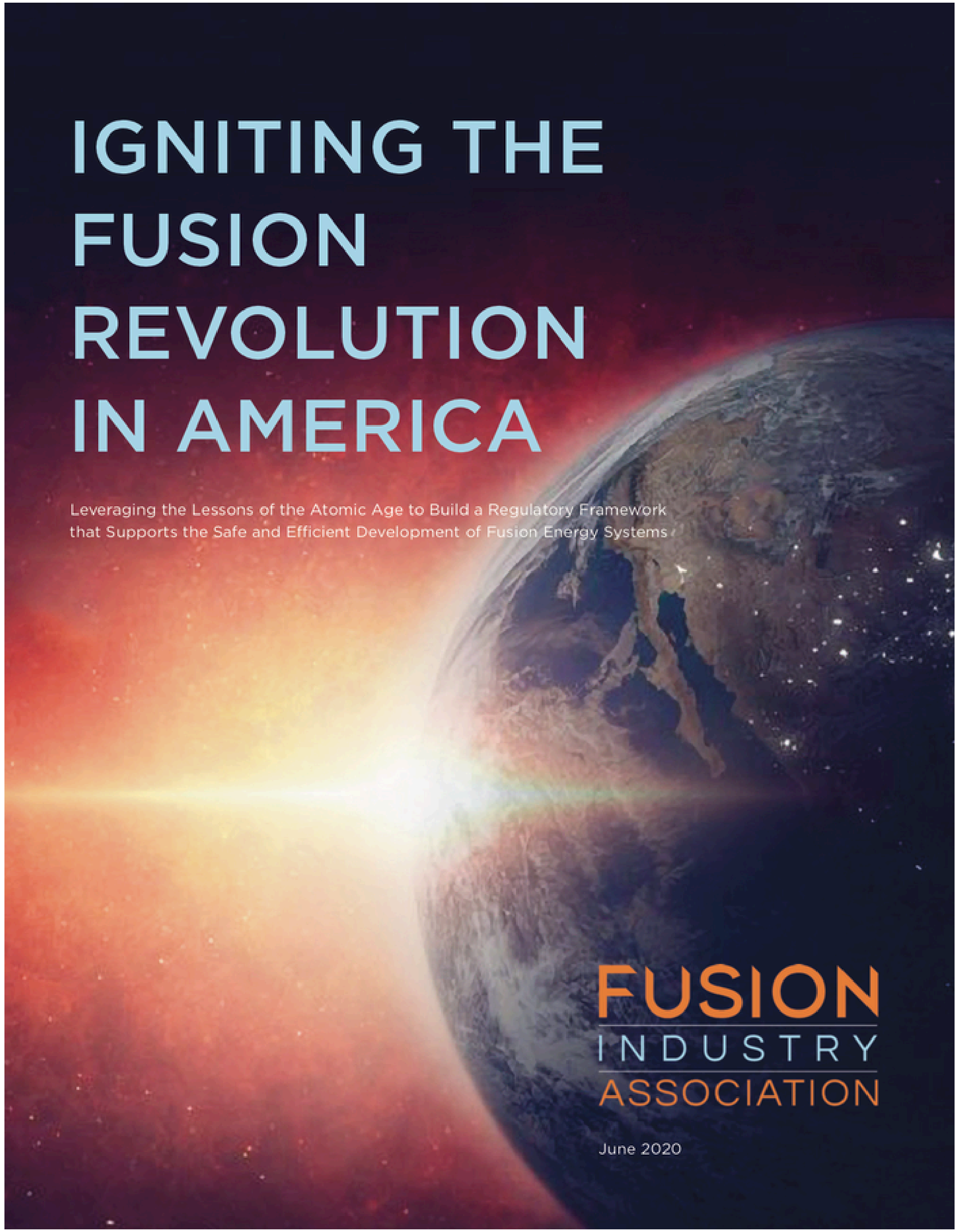
# *Ensuring Regulatory Certainty*

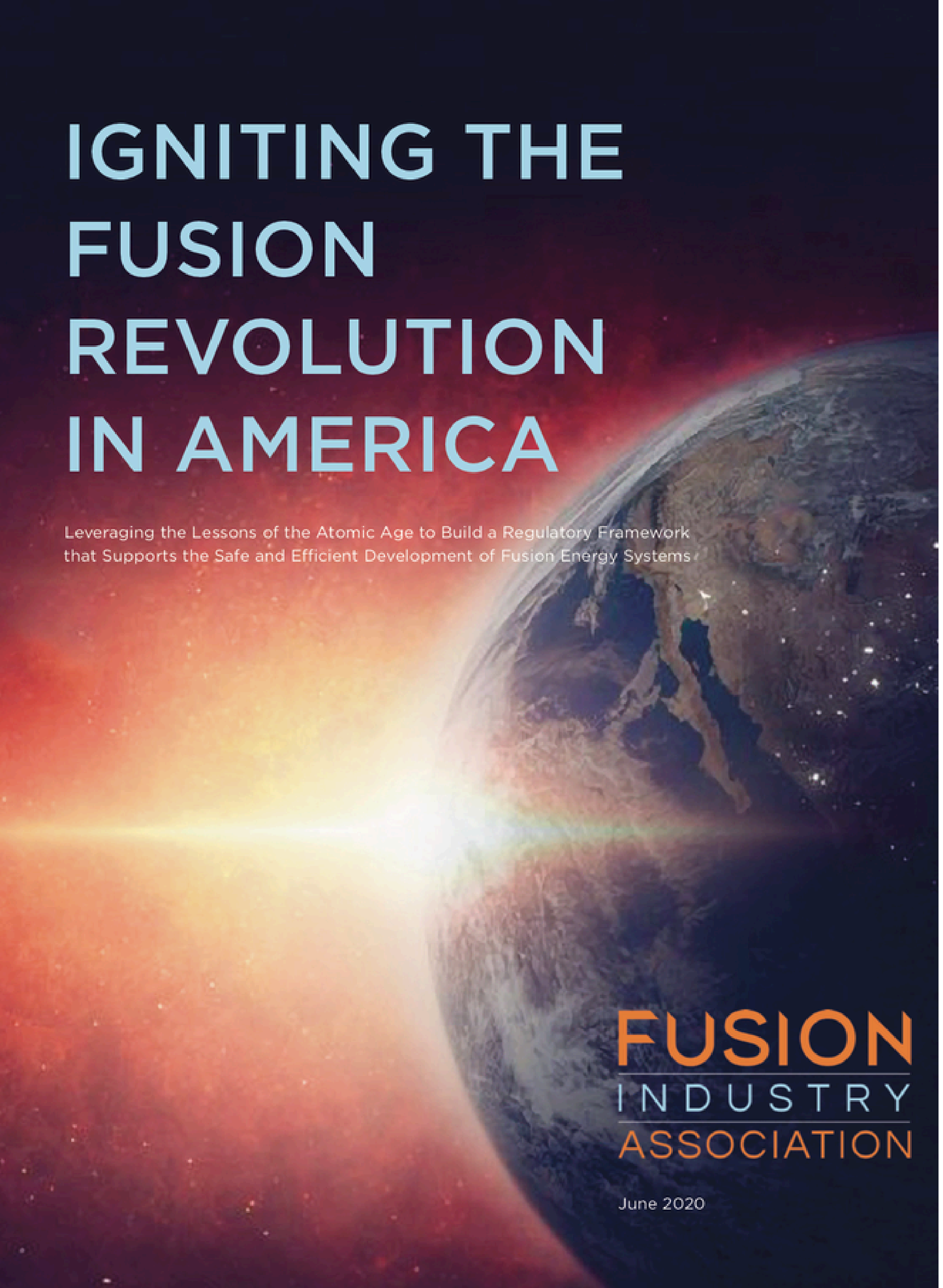
*U.S. policymakers should establish a broad legislative and regulatory framework that* ***explicitly and permanently removes fusion energy from the regulatory approaches that the federal government has taken towards fission power plants.***



# *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

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Derek Sutherland, Chief Executive Officer

CT Fusion

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# Fusion Regulatory Public Forum

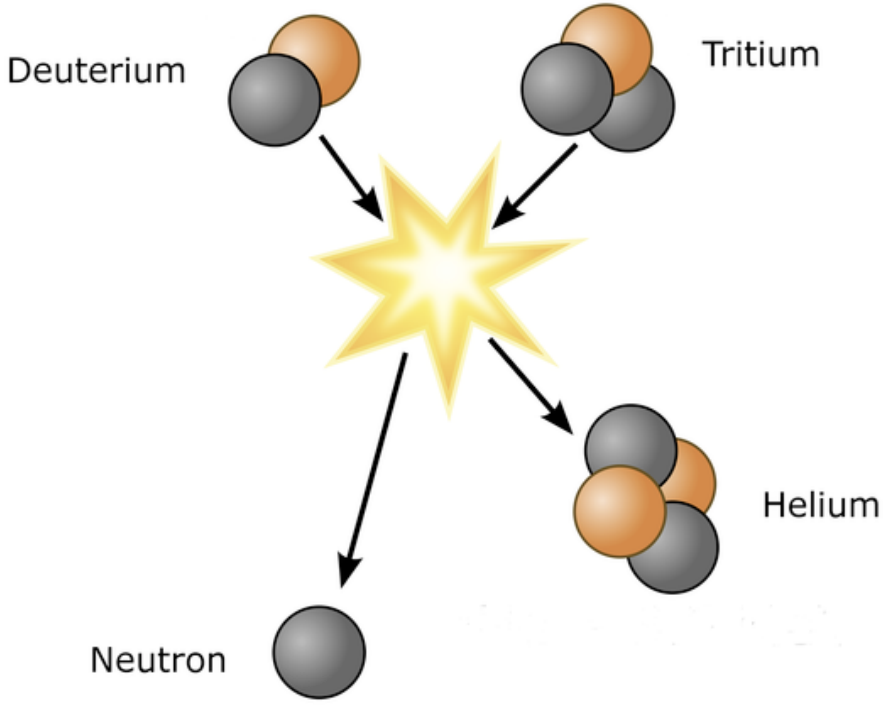
## January 26, 2021

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 $\mathrm{nT\tau_E}$ defines the threshold for ignition for a given fusion type
- The required temperature $\mathrm{T}$ 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, $\mathrm{n}, \tau_\mathrm{E}$, and confinement method to reach Lawson conditions

$\tau_{1/2}$~12.32 yrs




**Can activate materials**

# There are three general approaches to fusion energy

| Magnetic Fusion Energy (MFE) | Magneto-Inertial Fusion (MIF) | Inertial Fusion Energy (IFE) |
|---|---|---|
| Low $n$<br>High $\tau_E$ | Medium $n$<br>Medium $\tau_E$ | High $n$<br>Low $\tau_E$ |

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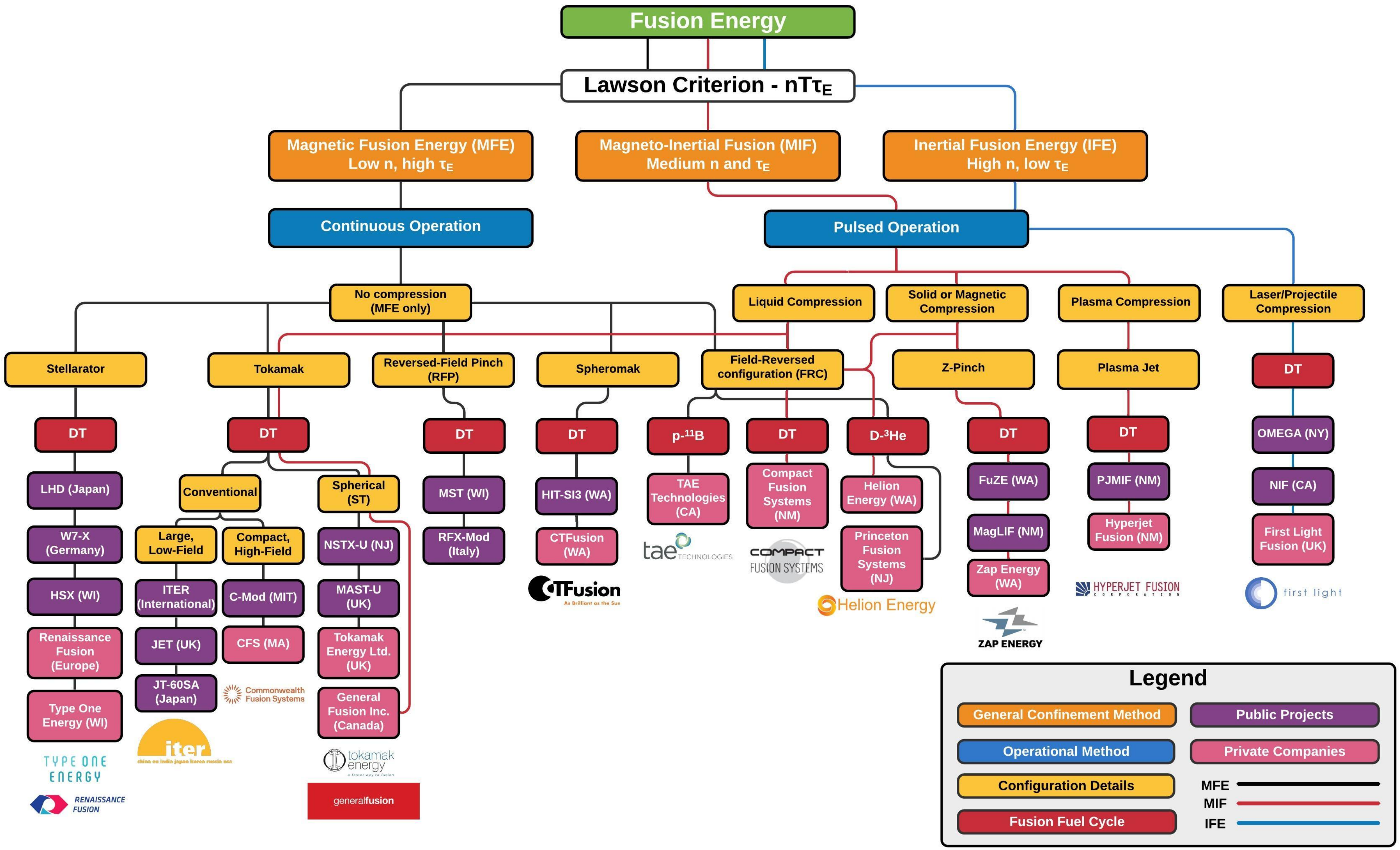
# Partial Fusion Energy Landscape



# 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

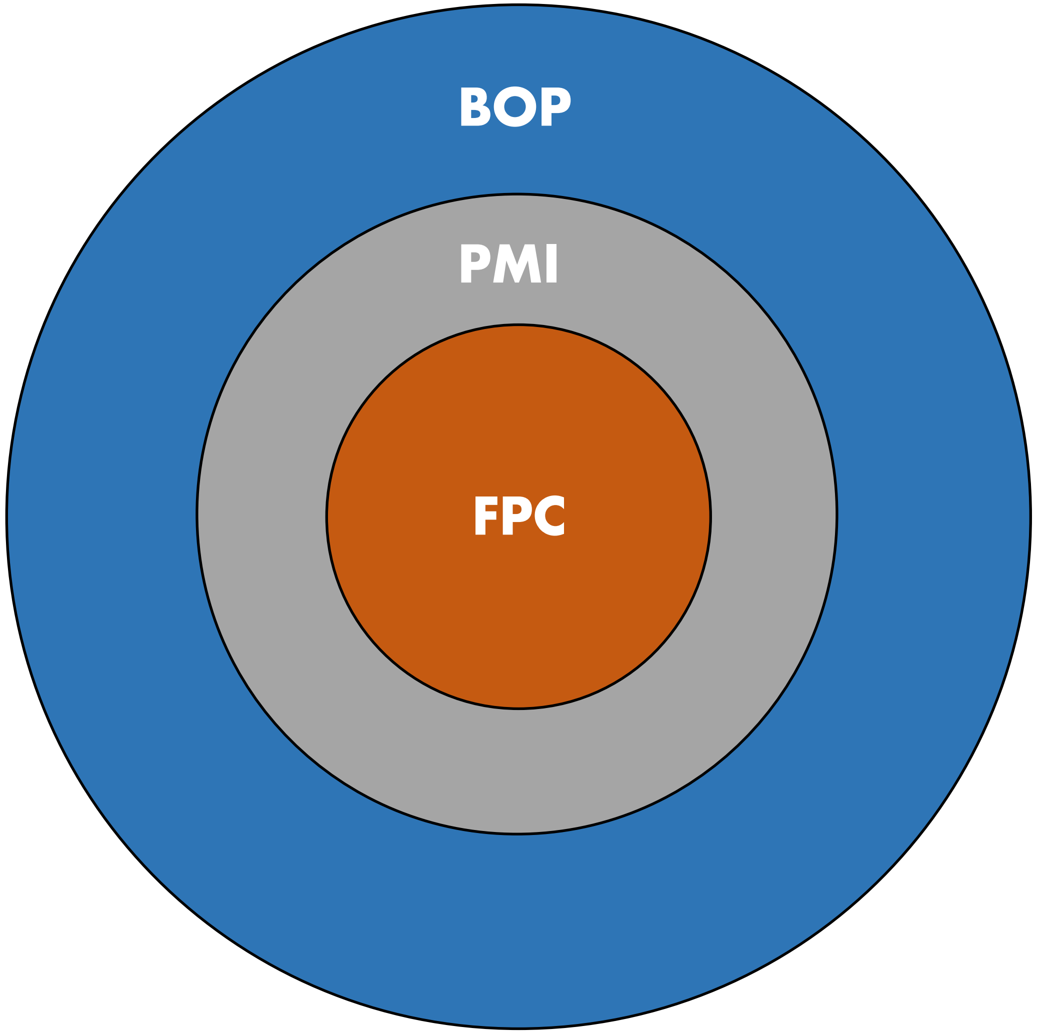
# There are similarities in PMI and BOP subsystems for any DT fusion power plant concept

**Note:** not to scale!

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



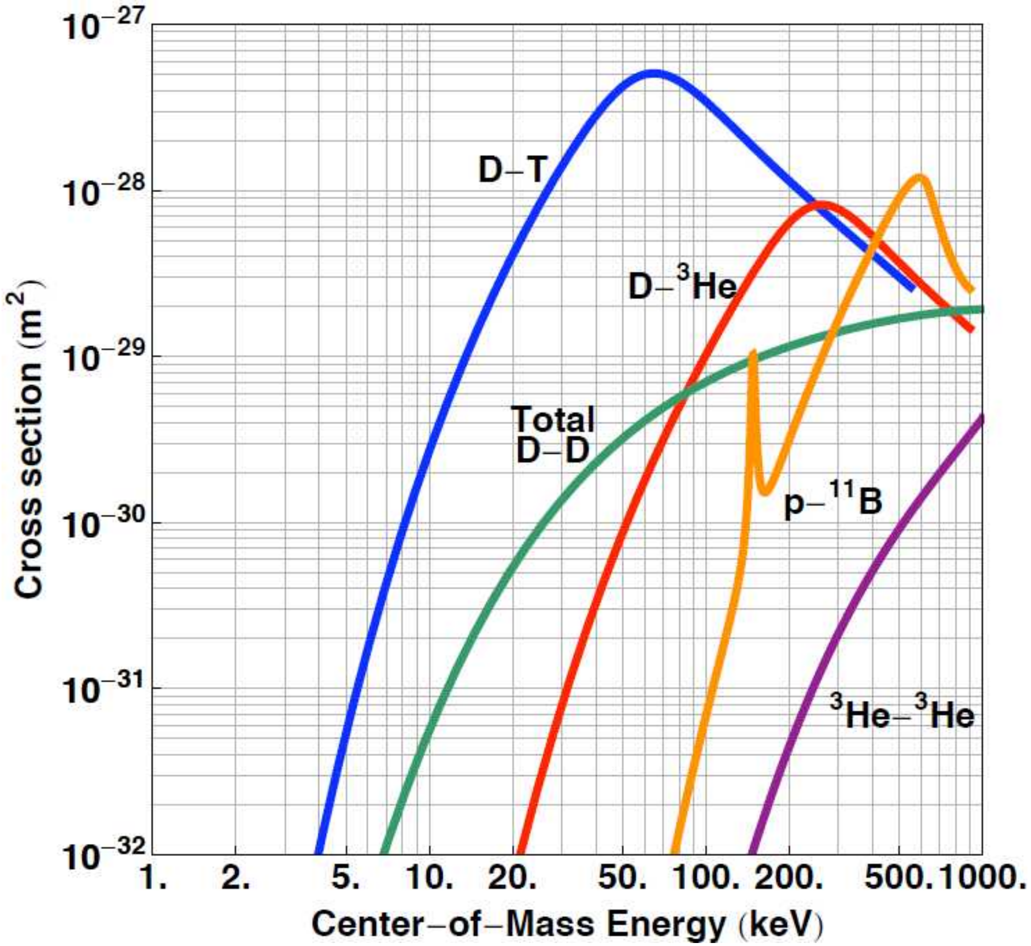
# Advanced fusion fuel cycles may reduce challenges associated with DT fusion

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

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https://www.ctfusion.energy

Email: admin@ctfusion.net

Seattle, WA, USA

# 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**

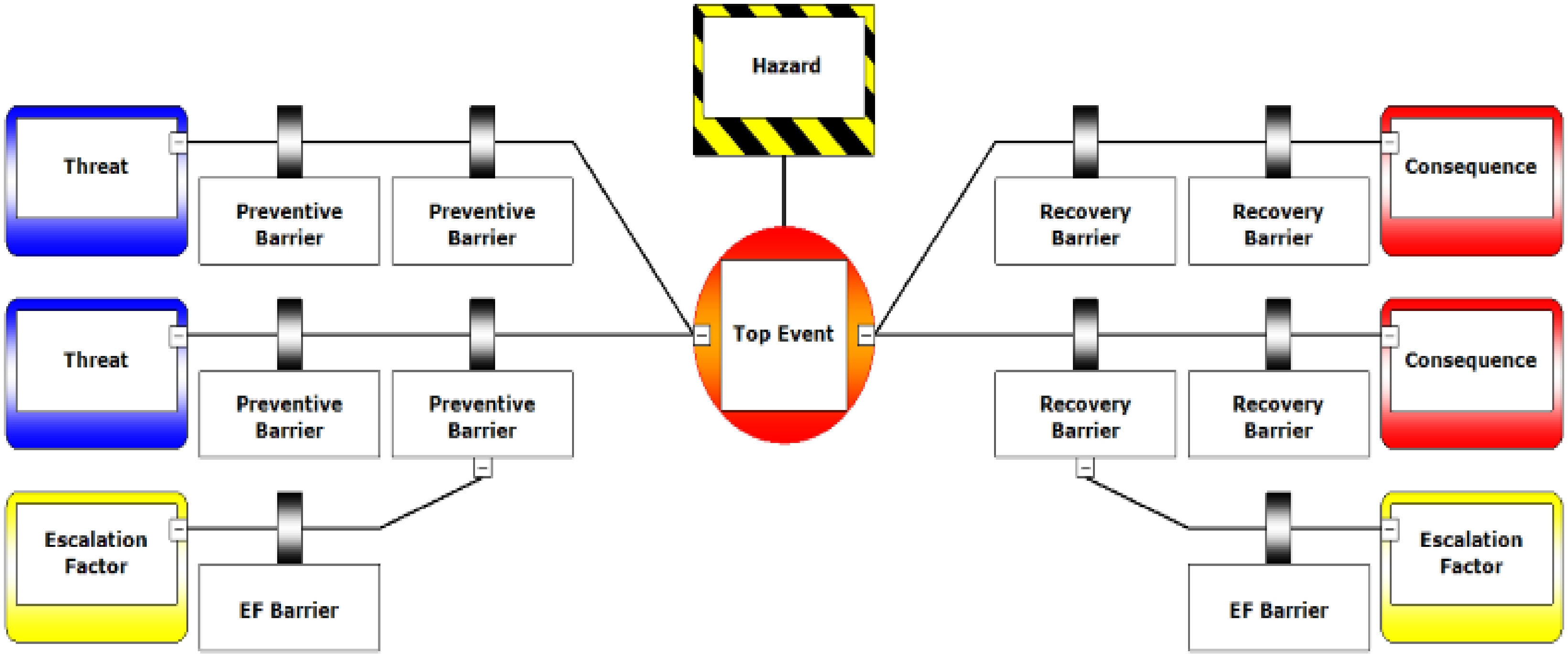
- Magnetic
- Magneto-Inertial
- Inertial

**Fusion Reactions**

- DT
- $P^{11}B$
- $D^{3}HE$

Radiological Hazards
Chemical & Other Hazards

# Integrated Approach (Background)




Bow-Tie Risk Management Figure



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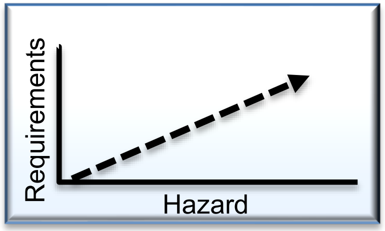
United States Nuclear Regulatory Commission
*Protecting People and the Environment*

# 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



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# 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

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- 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).

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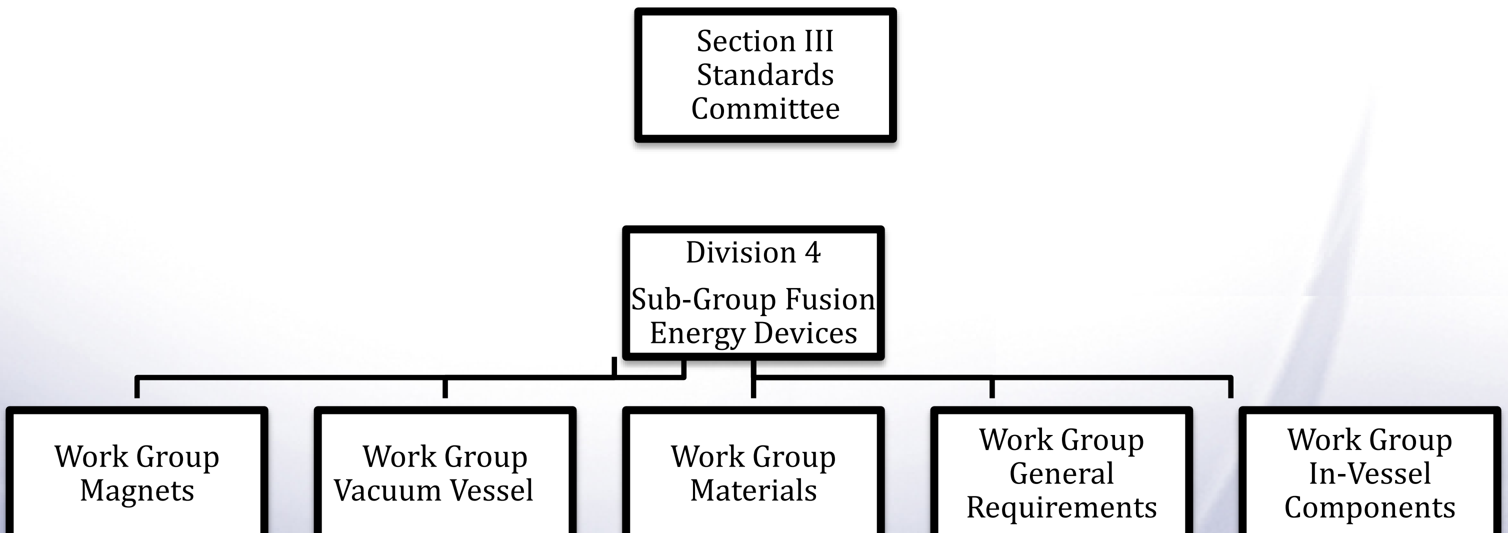
# ASME Section III Division 4 Fusion Energy Devices Sub-Group Organization



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## SUBGROUP ON FUSION ENERGY DEVICES (BPV III-4)

**W. Sowder, Jr.,** *Chair,* Quality Management Services Co., LLC
**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
**K. Kavanagh,** U.S. Nuclear Regulatory Commission
**K. Kim,** National Fusion Research Institute
**I. Kimihiro,** Toyama Co. Ltd.
**S. Lee,** National Fusion Research Institute
**G. Li,** Institute for Standardization of Nuclear Industry
**X. Li,** Institute for Standardization of Nuclear Industry
**P. Mokaria,** ITER-India
**T. R. Muldoon,** American Exchanger Services, Inc.
**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)

**D. Roszman,** *Chair,* Hayward Tyler, Inc.
**W. Sowder, Jr.,** Quality Management Services Co., LLC

## WORKING GROUP ON IN-VESSEL COMPONENTS (BPV III-4)

**M. Bashir,** *Chair,* Culham Centre for Fusion Energy
**Y. Carin,** Fusion for Energy
**M. Kalsey,** UK Atomic Energy Authority

## WORKING GROUP ON MAGNETS (BPV III-4)

**S. Lee,** *Chair,* National Fusion Research Institute
**K. Kim,** *Vice Chair,* National Fusion Research Institute

## WORKING GROUP ON MATERIALS (BPV III-4)

**M. Porton,** *Chair,* Culham Centre for Fusion Energy
**P. Mummery,** University of Manchester School of Mechanical Engineering

## WORKING GROUP ON VACUUM VESSELS (BPV III-4)

**I. Kimihiro,** *Chair,* Toyama Co. Ltd.
**L. C. Cadwallader,** Battelle Energy Alliance, LLC
**B. R. Doshi,** Institute for Plasma Research
**Q. Shijun,** Institute of Plasma Physics, Chinese Academy of Sciences
**Y. Song,** Institute of Plasma Physics, Chinese Academy of Sciences

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**ASME FE.1-2018**
**Draft Standard for Trial Use**

# 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 resulting 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. Thereafter, 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://go.asme.org/FE1CommentForm.

The American Society of Mechanical Engineers
Two Park Avenue • New York, NY • 10016 USA

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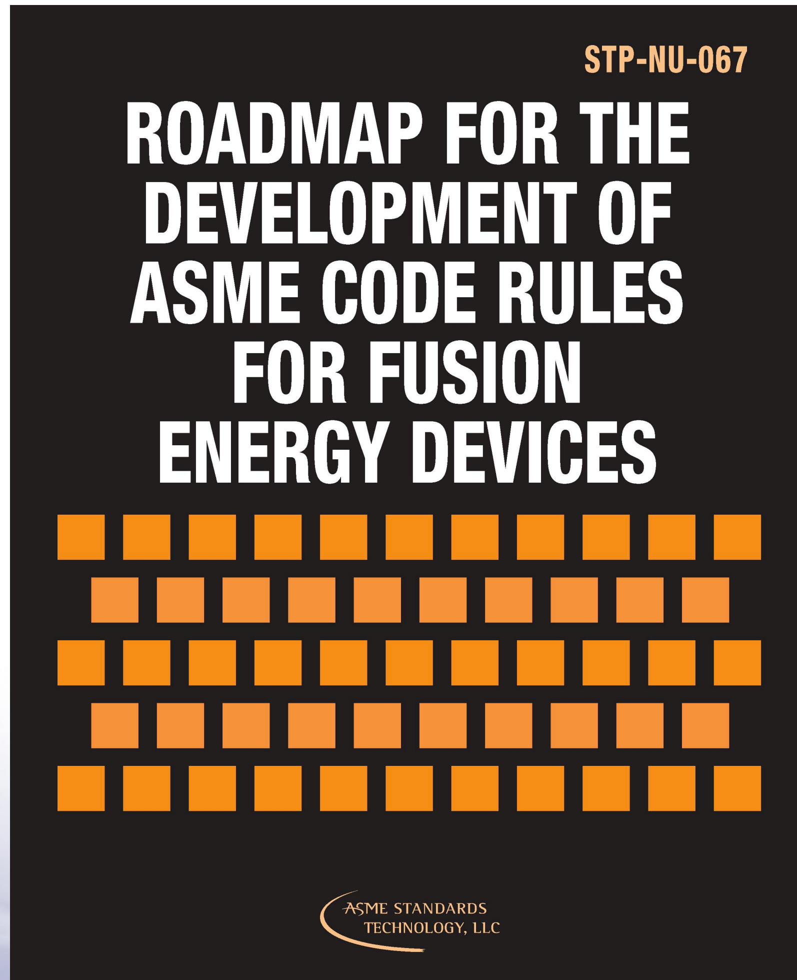

Division 4 FED is also working with the ASME Section XI In-Service Inspection Operations Code in developing for future FED use a type of Reliability and Integrity Management (RIM) Program using as guidance the recently published Section XI Division 2 Code Rules-Requirements for Reliability and Integrity 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).

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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



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# 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"
  - Asserted NRC regulatory jurisdiction over commercial fusion energy devices
  - 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



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# 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



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# Burdens Imposed by "Utilization Facility" Classification

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



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# Regulation of Fusion Reactors under Part 30

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



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# 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



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# 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

MITHRIL

CAPRICORN INVESTMENTGROUP

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# Agenda

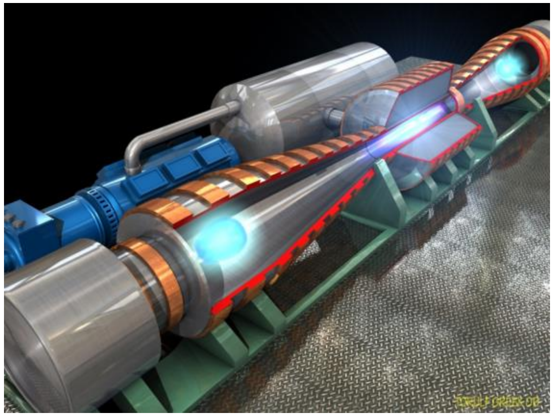
- **About Helion**
- **Fusion Devices as Accelerators**
- **Application of Accelerator Framework**

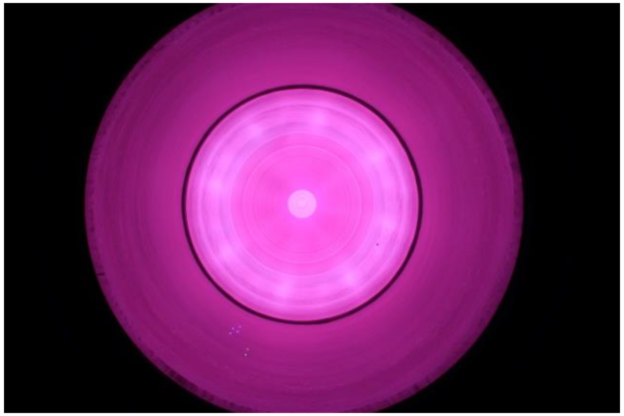
# Agenda

- **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 7$^{th}$ 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

**<u>Energy Policy Act of 2005 Rulemaking (72 FR at 55,868)</u>**
"A particle accelerator is a device that imparts kinetic energy to subatomic particles by increasing their speed through electromagnetic interactions."

**<u>NRC Regulations (10 CFR 30.4)</u>**
"*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.

**Energy Policy Act of 2005 Rulemaking (72 FR at 55,868)**

"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 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."

- ✓ ***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 | Key Inputs |
|---|---|

- 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

- 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]

TECHNOLOGY DEVELOPMENT COMPLETED:
Proven science
Alcator C-Mod
$200M

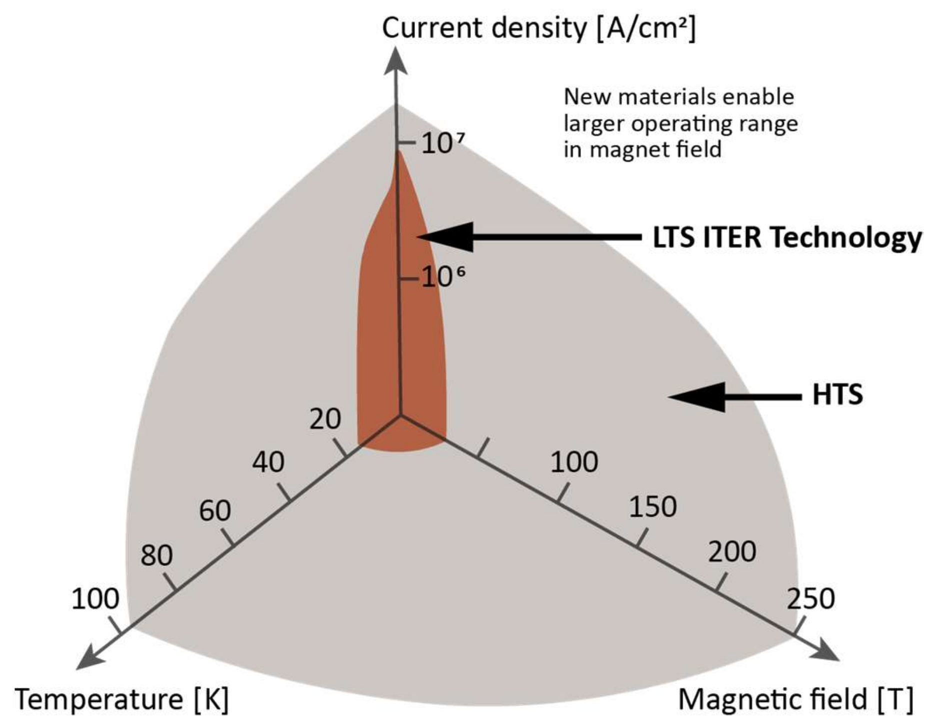
TECHNOLOGY DEVELOPMENT IN PROGRESS
Demonstrate
Groundbreaking
HTS magnets

DEMONSTRATION
Achieve net energy from fusion
SPARC, Q>2

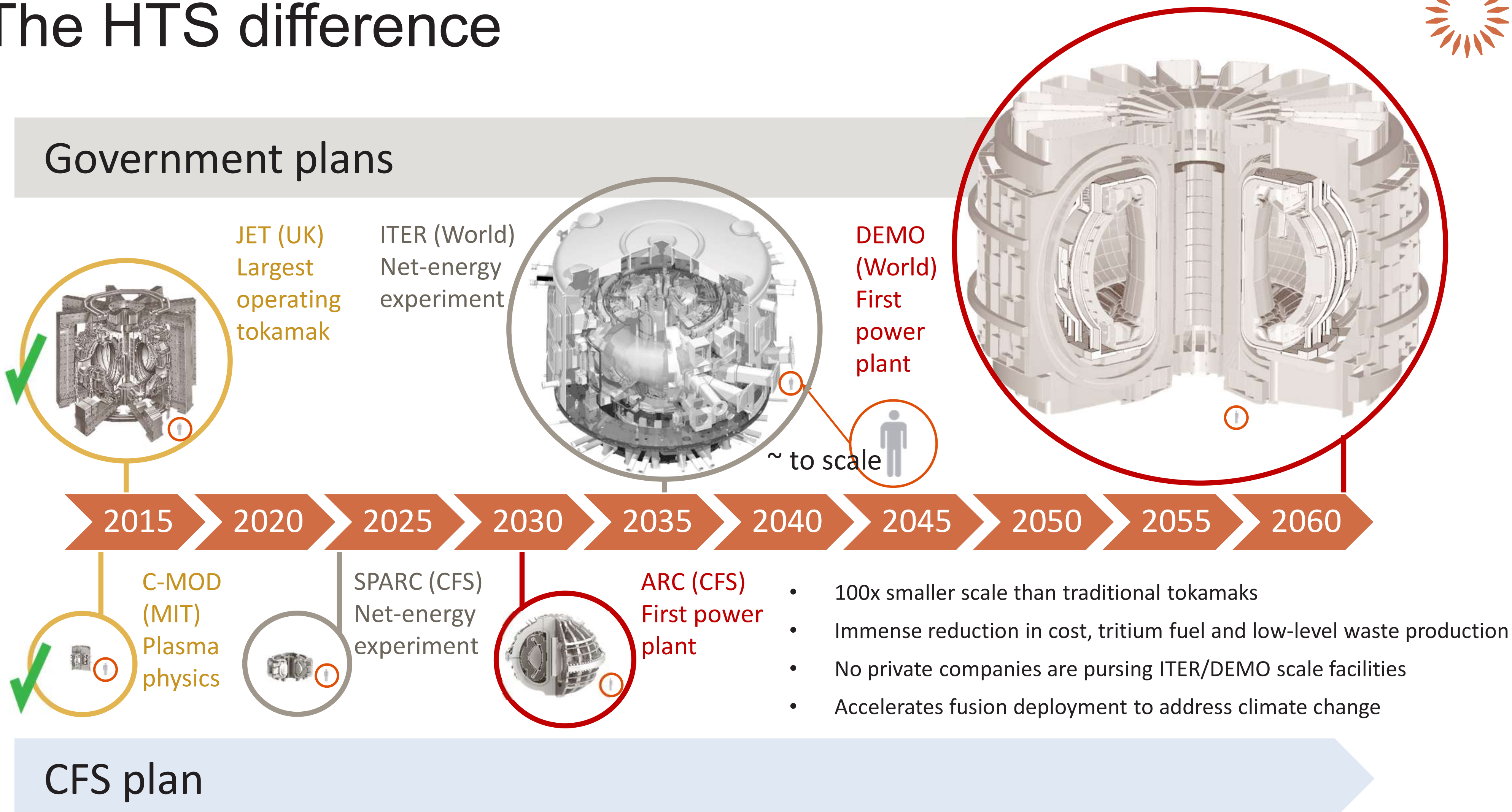
COMMERCIALIZATION
Fusion power on the grid ARC, Q>10, $P_{electric}$~200MW

# 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

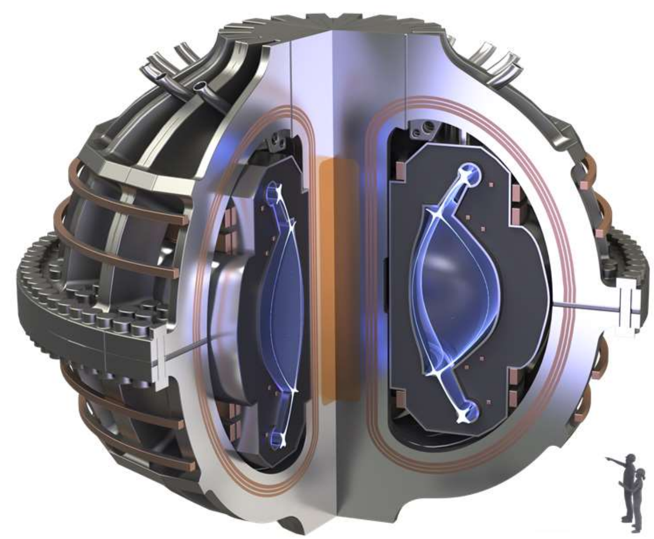


# The HTS difference



# 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."

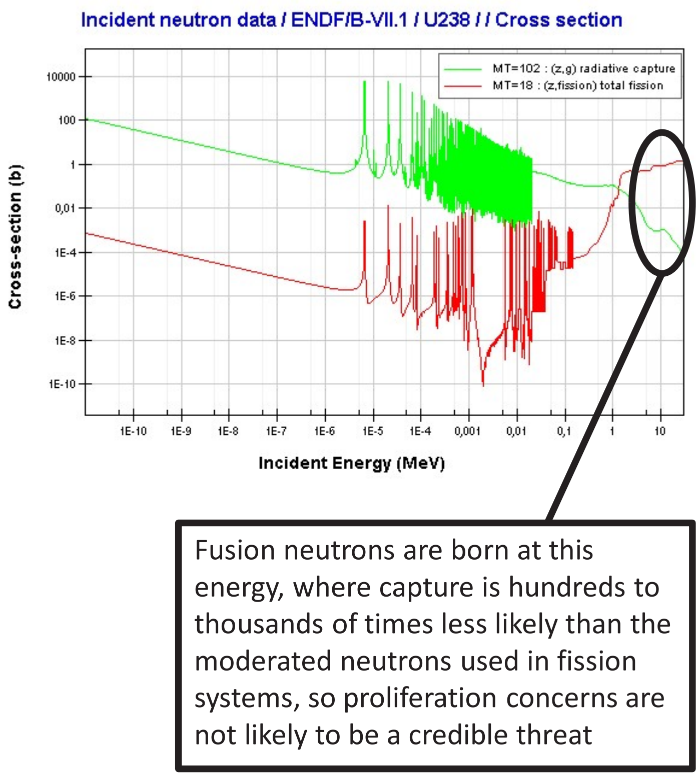
- Fusion energy systems are NOT utilization facilities because they aren't nuclear reactors, nor do they irradiate special nuclear materials
- There are no private fission-fusion hybrid approaches; but if there were, it would qualify as a utilization facility due to the presence of special nuclear material
- 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

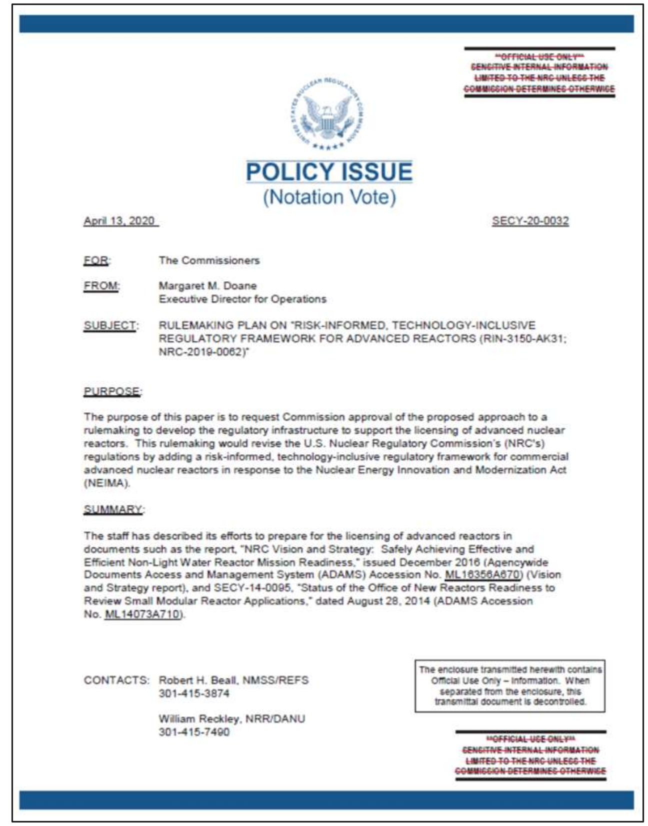


# Additional Considerations for NRC Evaluation

- 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



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**POLICY ISSUE**
(Notation Vote)

April 13, 2020 — SECY-20-0032

FOR: The Commissioners

FROM: Margaret M. Doane
Executive Director for Operations

SUBJECT: RULEMAKING PLAN ON "RISK-INFORMED, TECHNOLOGY-INCLUSIVE REGULATORY FRAMEWORK FOR ADVANCED REACTORS (RIN-3150-AK31; NRC-2019-0062)"

PURPOSE:

The purpose of this paper is to request Commission approval of the proposed approach to a rulemaking to develop the regulatory infrastructure to support the licensing of advanced nuclear reactors. This rulemaking would revise the U.S. Nuclear Regulatory Commission's (NRC's) regulations by adding a risk-informed, technology-inclusive regulatory framework for commercial advanced nuclear reactors in response to the Nuclear Energy Innovation and Modernization Act (NEIMA).

SUMMARY:

The staff has described its efforts to prepare for the licensing of advanced reactors in documents such as the report, "NRC Vision and Strategy: Safely Achieving Effective and Efficient Non-Light Water Reactor Mission Readiness," issued December 2016 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML16356A670) (Vision and Strategy report), and SECY-14-0095, "Status of the Office of New Reactors Readiness to Review Small Modular Reactor Applications," dated August 28, 2014 (ADAMS Accession No. ML14073A710).

CONTACTS: Robert H. Beall, NMSS/REFS
301-415-3874

William Reckley, NRR/DANU
301-415-7490

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# 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


Phoenix Neutron Generator. Source: https://phoenixwi.com/

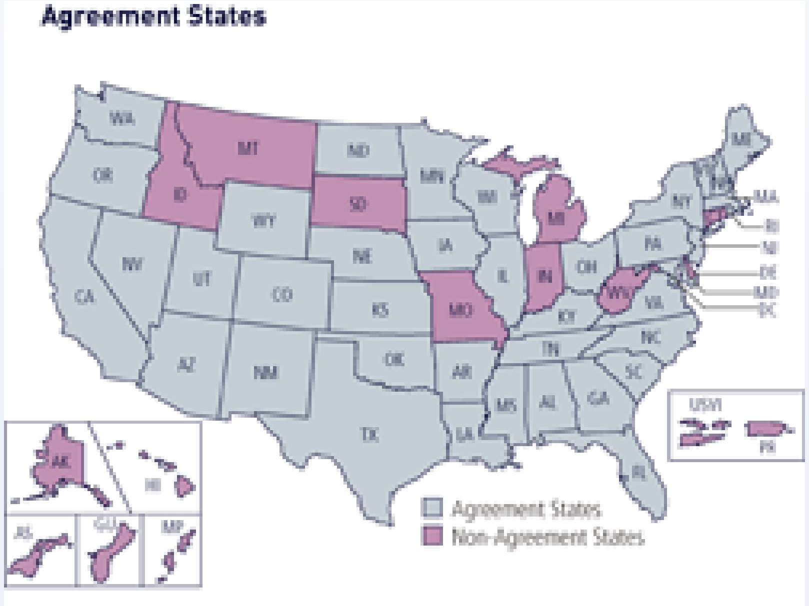
# Recommended NRC Approach

- 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

OAS Organization of Agreement States



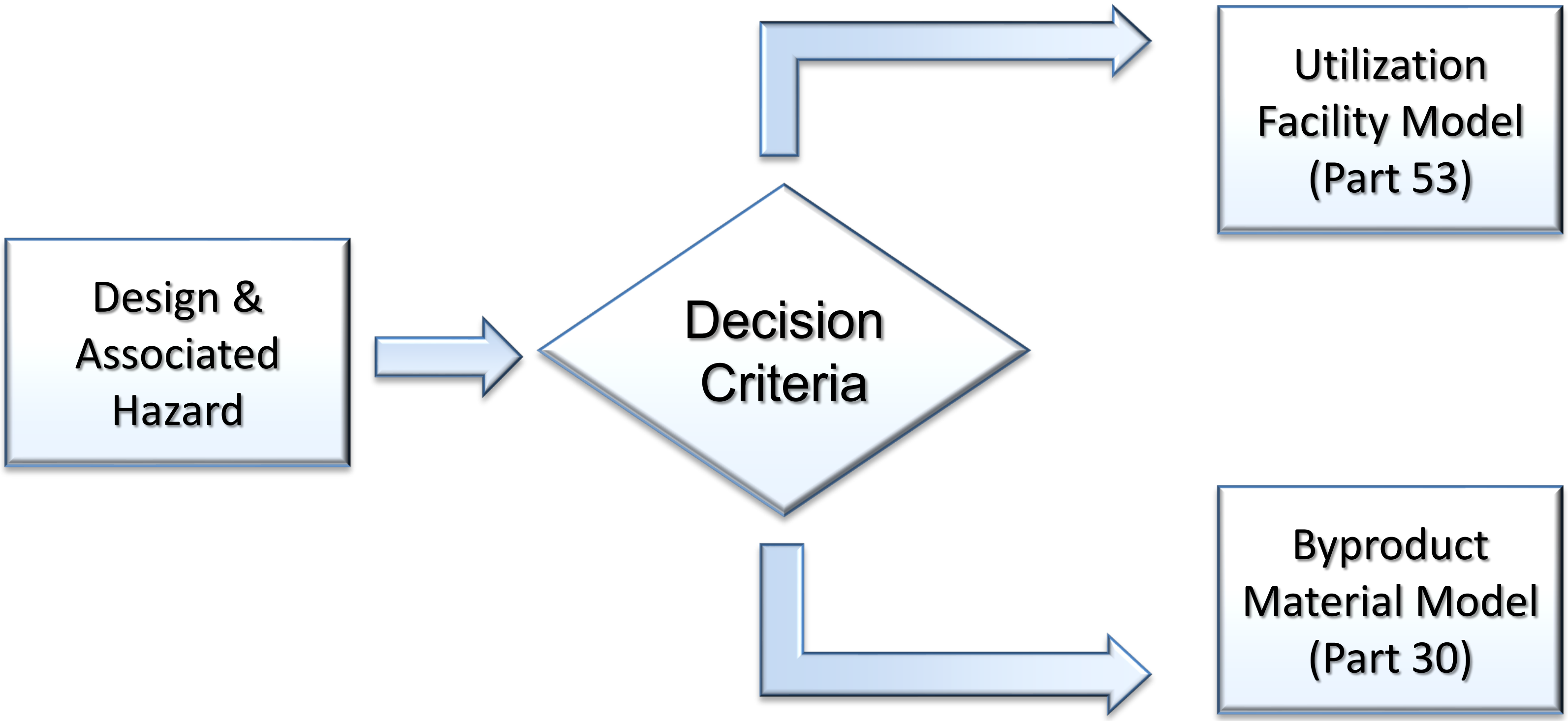
# Discussion – Byproduct Material Approaches

# 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

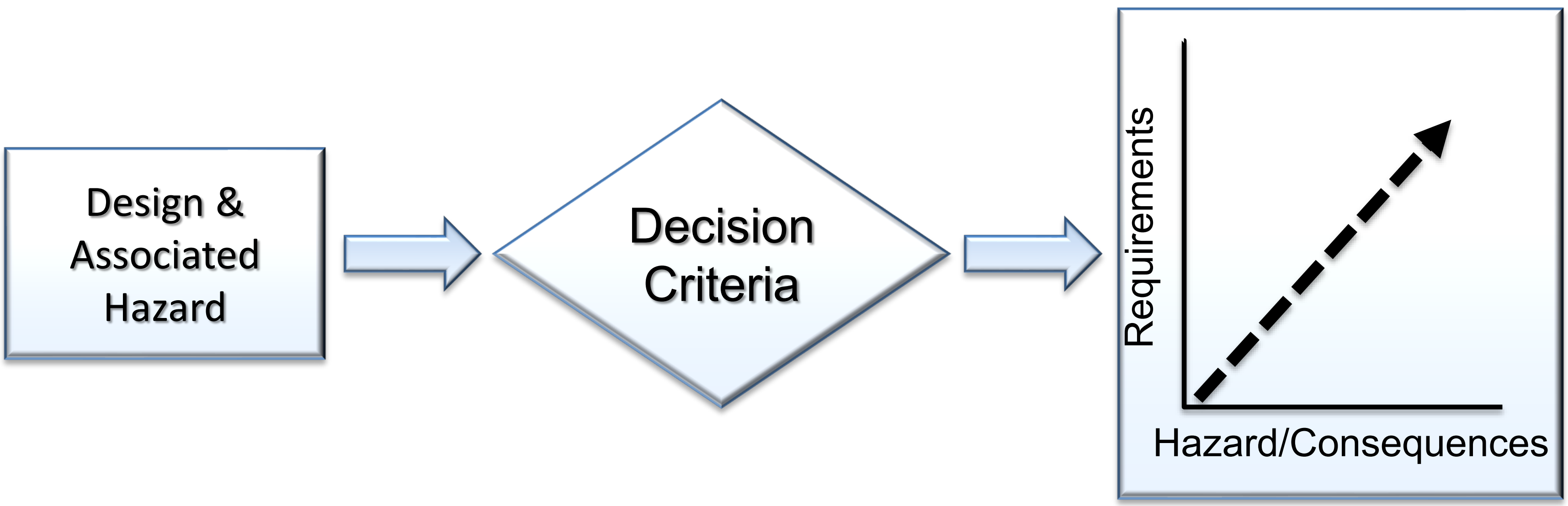
# Possible Hybrid Approaches

- Approach within current frameworks



# 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** | **Subpart C** | **Subpart D** | **Subpart E** | **Subpart F** | **Subpart G**

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

Project Life Cycle

| Design and Analysis | Siting | Construction | Operation | Retirement |
|---|---|---|---|---|
| *System & Component Design* | *External Hazards* | *Construction/ Manufacturing* | *Facility Safety Program* | |
| *Analysis Requirements* | *Site Characteristics* | *Ensuring Capabilities/ Reliabilities* | *Surveillance Maintenance* | |
| *Safety Categorization & Special Treatment* | *Environmental Considerations* | *Change Control* | *Configuration Control* | |
| | | *Environmental Considerations* | *Design Changes* | |
| | | | *Staffing & Programs* | |

Clarify Controls and Distinctions Between

- Plant/Site (Design, Construction, Configuration Control)
- Analyses (Prevention, Mitigation, Compare to Criteria)
- Plant Documents (Systems, Procedures, etc.)
- LB Documents (Applications, SAR, TS, etc.) — **Subparts H & I**

# DOE-HDBK-1224-2018; August 2018
# DOE HANDBOOK - HAZARD AND ACCIDENT ANALYSIS HANDBOOK

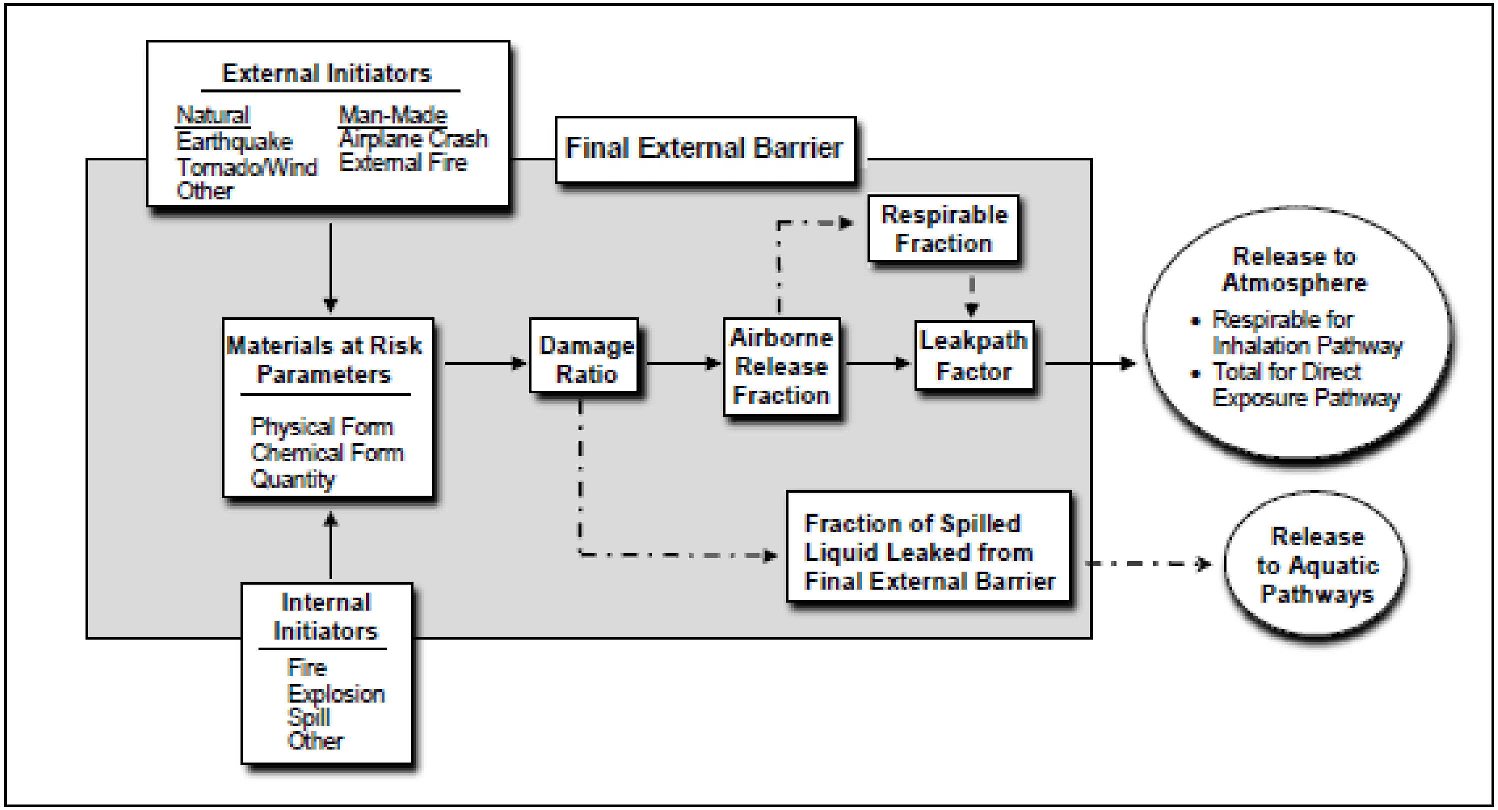



**Figure 5-1. Five Factors Formula.**

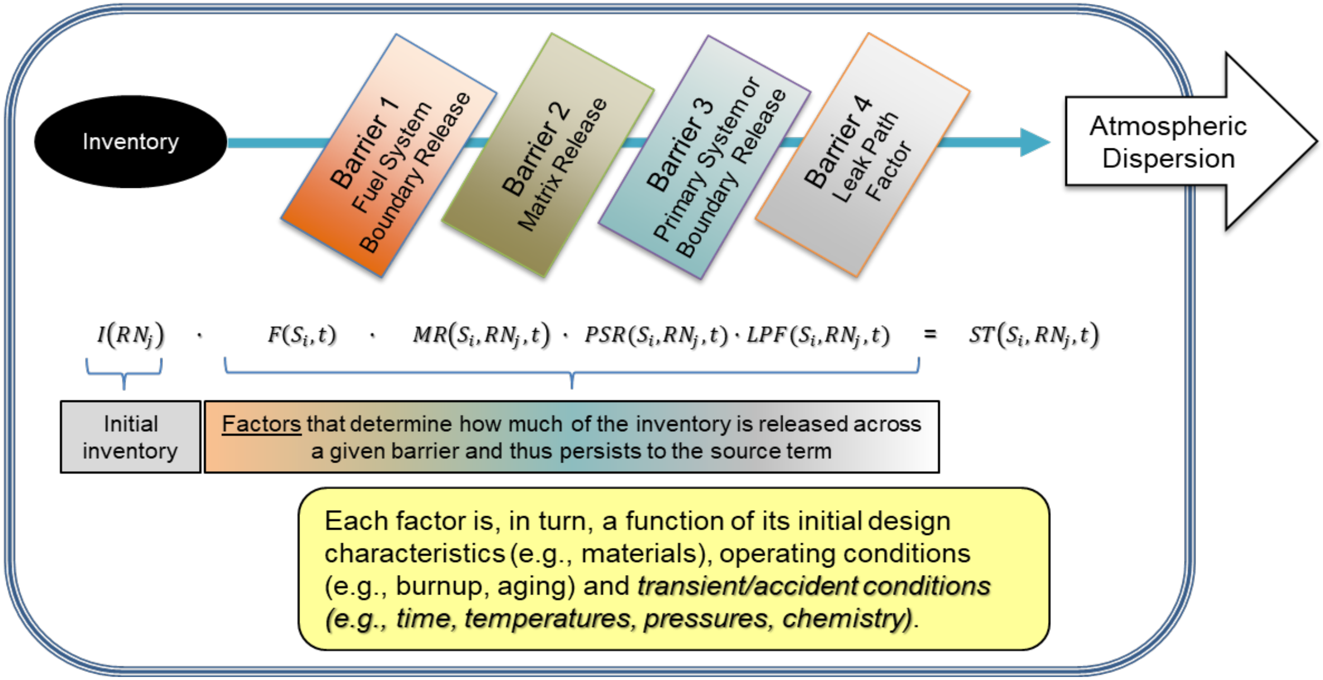
# DOE-STD-1027-2018
# HAZARD CATEGORIZATION OF DOE NUCLEAR FACILITIES

**Table 3.1:** Reproduction of Table 1 in Appendix A of Subpart B of 10 CFR Part 830

| A DOE nuclear facility categorized as… | Has the potential for… |
|---|---|
| Hazard Category 1 | Significant off-site consequences |
| Hazard Category 2 | Significant on-site consequences beyond localized consequences |
| Hazard Category 3 | Only local significant consequences |
| Below Hazard Category 3 | Only consequences less than those that provide a basis for categorization as a hazard category 1, 2, or 3 nuclear facility. |

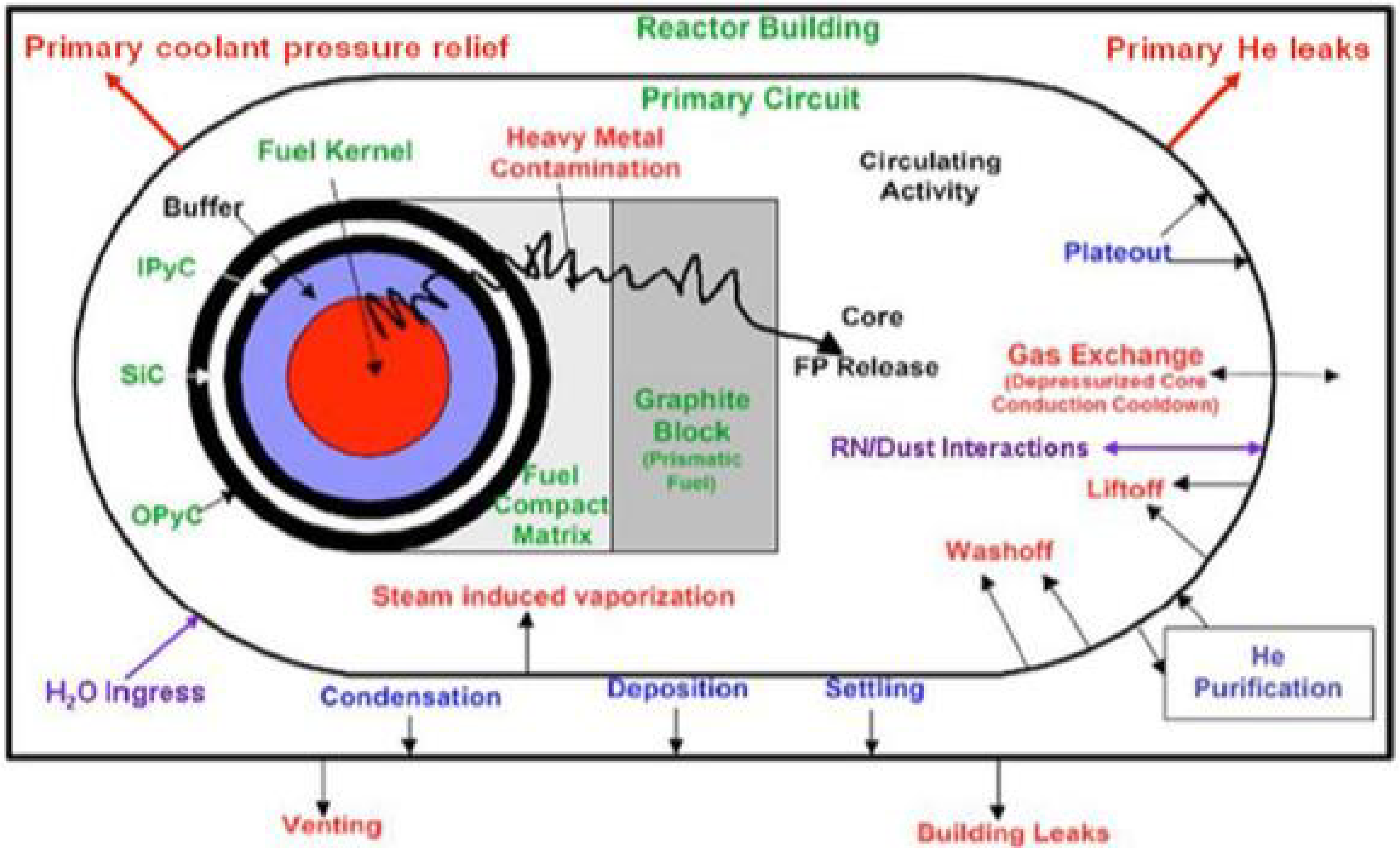
# First Principles

*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*

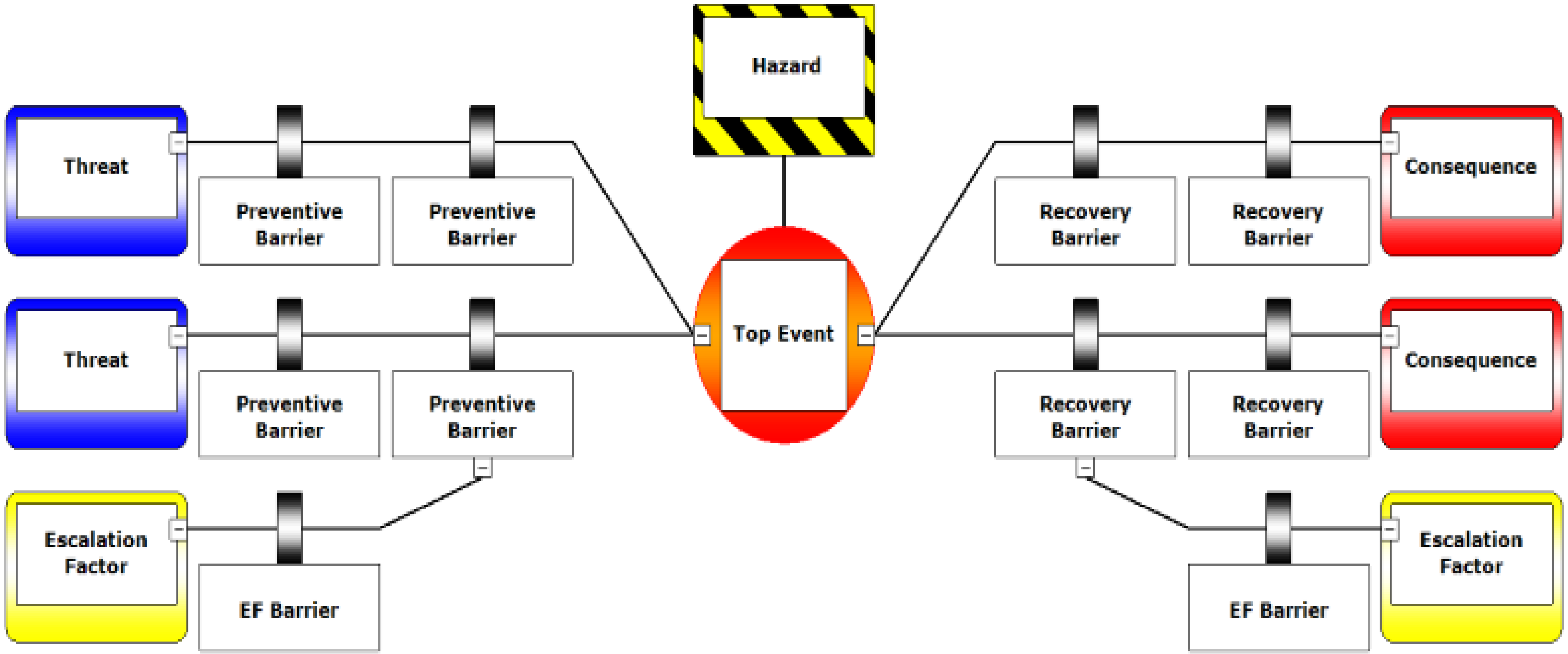



See: SECY-18-0096, "Functional Containment Performance Criteria for Non-Light-Water-Reactors," and INL/EXT-20-58717, "Technology-Inclusive Determination of Mechanistic Source Terms for Offsite Dose-Related Assessments for Advanced Nuclear Reactor Facilities"

# High Temperature Gas-Cooled Reactor (HTGR) Mechanistic Source Term Figure



# Integrated Approach (Background)




Bow-Tie Risk Management Figure

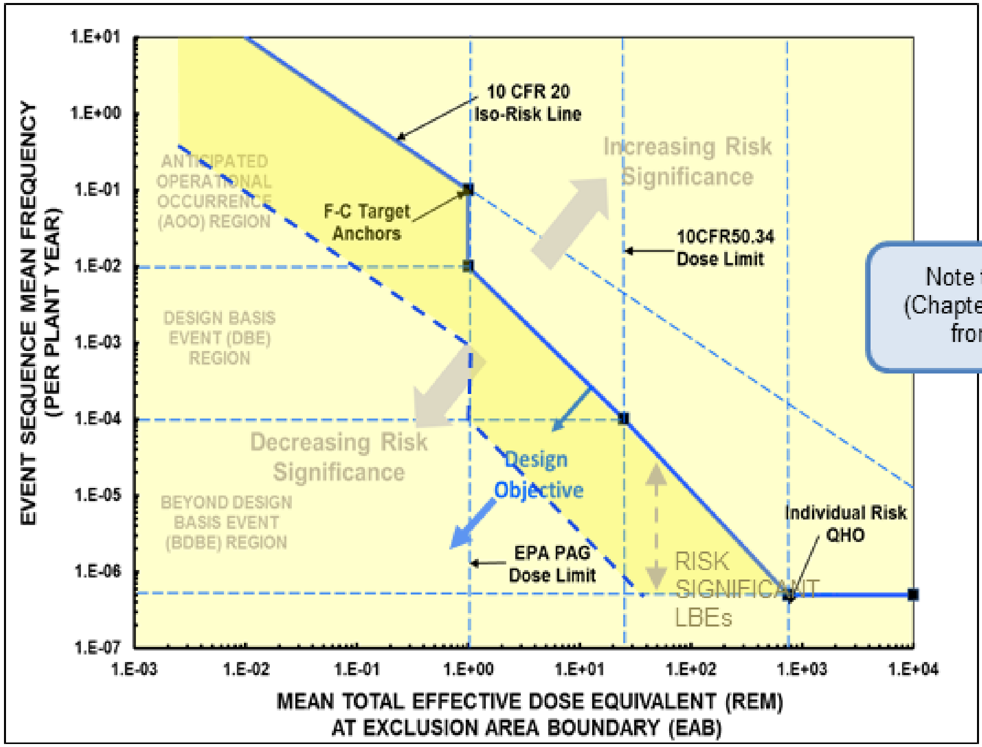
# Licensing Modernization

## (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)




Note that DBAs (Chapter 15) derived from DBEs

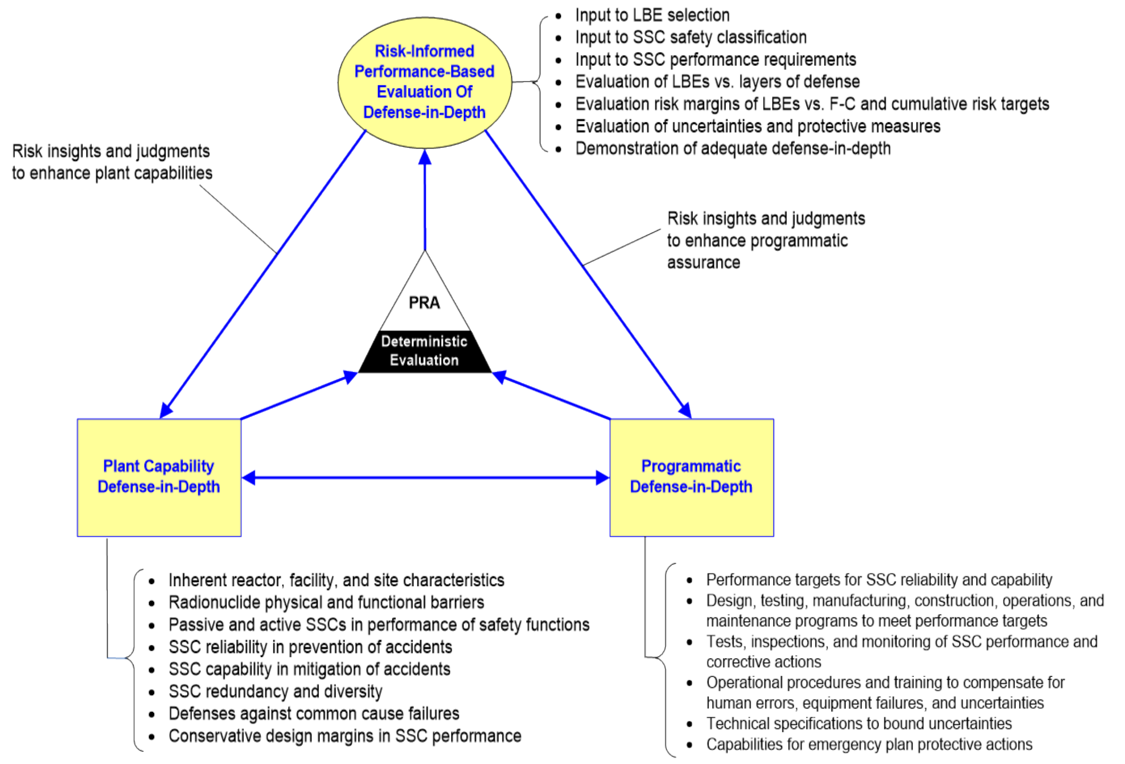
- F-C Target considered along with cumulative risk metrics, safety classification, and assessment of defense in depth

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)