Developing a Regulatory Framework for Fusion Energy Systems

NRC Public Meeting
October 27, 2021

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Agenda

Time	Speaker	Topic
9:30-9:45am	NRC	Welcome/Introductions/Opening Remarks
9:45-10:15am	General Fusion *Michael Cappello*	Updates on plans for Fusion Demonstration Plant in the UK – UKAEA Culham Campus
10:15-10:30am	Oxford Sigma *Thomas Davis*	Overview and establishment of the American Society of Mechanical Engineers (ASME) Section III Division 4 (Fusion Energy Devices) subcommittee "Special Working Group for Fusion Stakeholders (SWGFS)"
10:30-10:45am	Commonwealth Fusion Systems	Updates on the advancement of High-Temperature Superconducting Electromagnet Technology
10:45-11:15am	Fusion Industry Association	Insights on decision-making criteria for a graded approach
11:15-11:45am	NRC	10 CFR Part 30 – Examples of Regulatory Scalability
11:45-12:15pm	NRC	10 CFR Part 53 – Overview of the proposed Advanced Reactor rulemaking
12:15-12:30pm	All/NRC	Questions/Closing Remarks/Next Steps

Fusion Demonstration Plant

NRC Briefing October 27, 2021

Michael Cappello – Senior Vice President Technology Delivery

generalfusion®

*NRC confirmed with General Fusion no confidential information is contained in this presentation.

generalfusion®

Dr. Michel LaBerge founded General Fusion (GF) in 2002 in a local garage

GF has now grown to more than 145+ scientists, engineers, technicians and support staff

One of the largest, most advanced, privately funded Magnetized Target Fusion (MTF) technology companies

Rapid innovation, development and testing laboratories headquartered in Vancouver, Canada, with offices at Oak Ridge and Culham UK

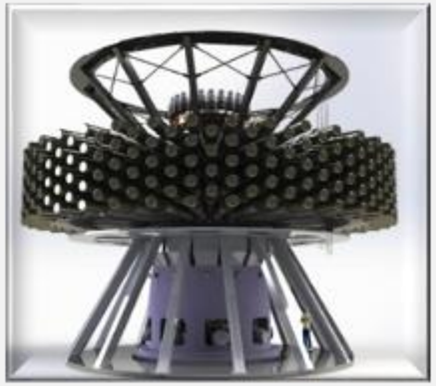
15+ years and 200,000+ fusion plasma experiments conducted to date

Common Fusion Industry Visions and Goals **"…committed to reducing global carbon emissions by transforming the energy supply through clean, safe, economical and abundant fusion energy"**

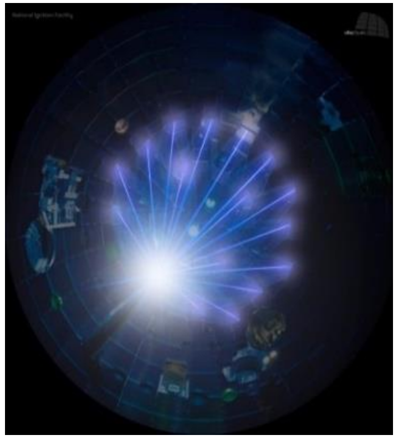
A Spectrum of Fusion Technology Pathways

ITER scale Magnetic Confinement Fusion (MCF)

generalfusion



Magnetized Target Fusion (MTF)



NIF scale Inertial Confinement Fusion (ICF)

All Confinement | Hybrid | All Compression

All Confinement

- Very large, low-density plasma
- Continuous Plasma and Control
- Massive, expensive SC magnets
- 1st wall materials challenges
- External plasma heating systems
- **"Break Even" System:** >$25B (ITER)

Hybrid

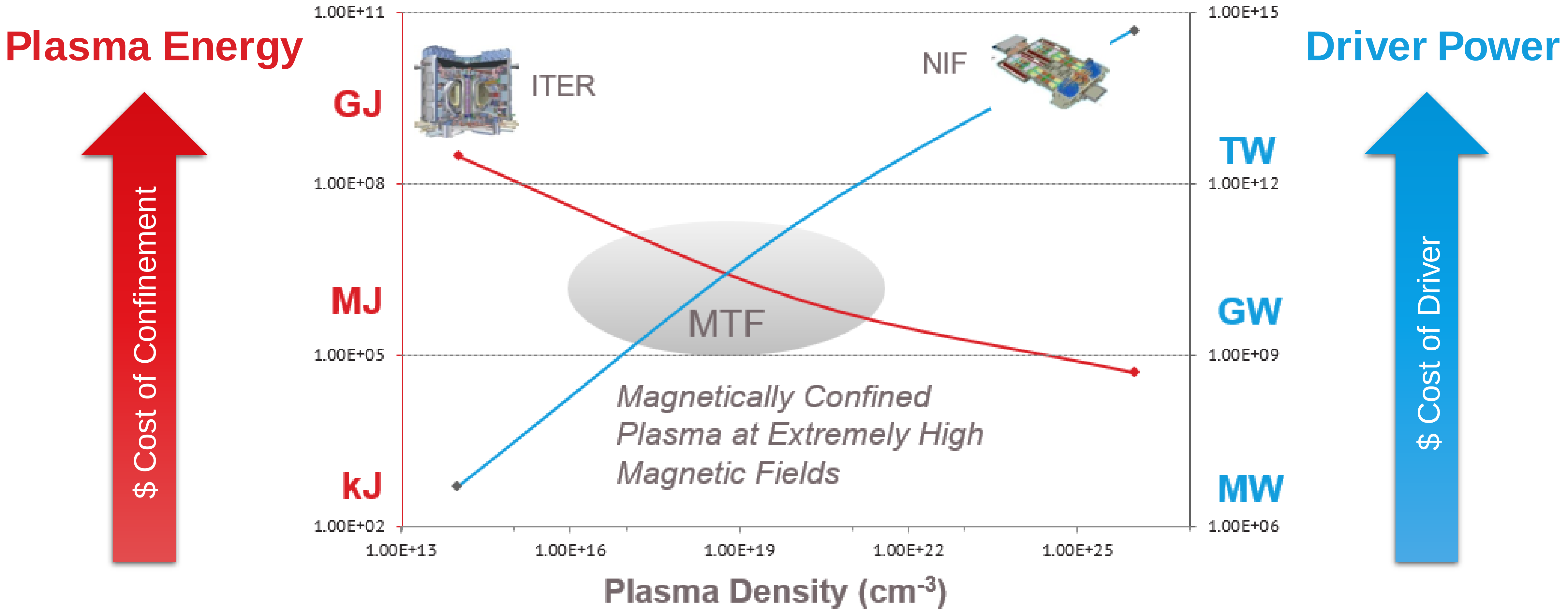
- US Naval Research Labs (NRL) - Linus Program 1971- early research
- Compact, medium density plasma
- Slower compression pulses (ms)
- No large SC magnets or lasers
- Few materials and control issues
- **"Break Even" System:** <$1B

All Compression

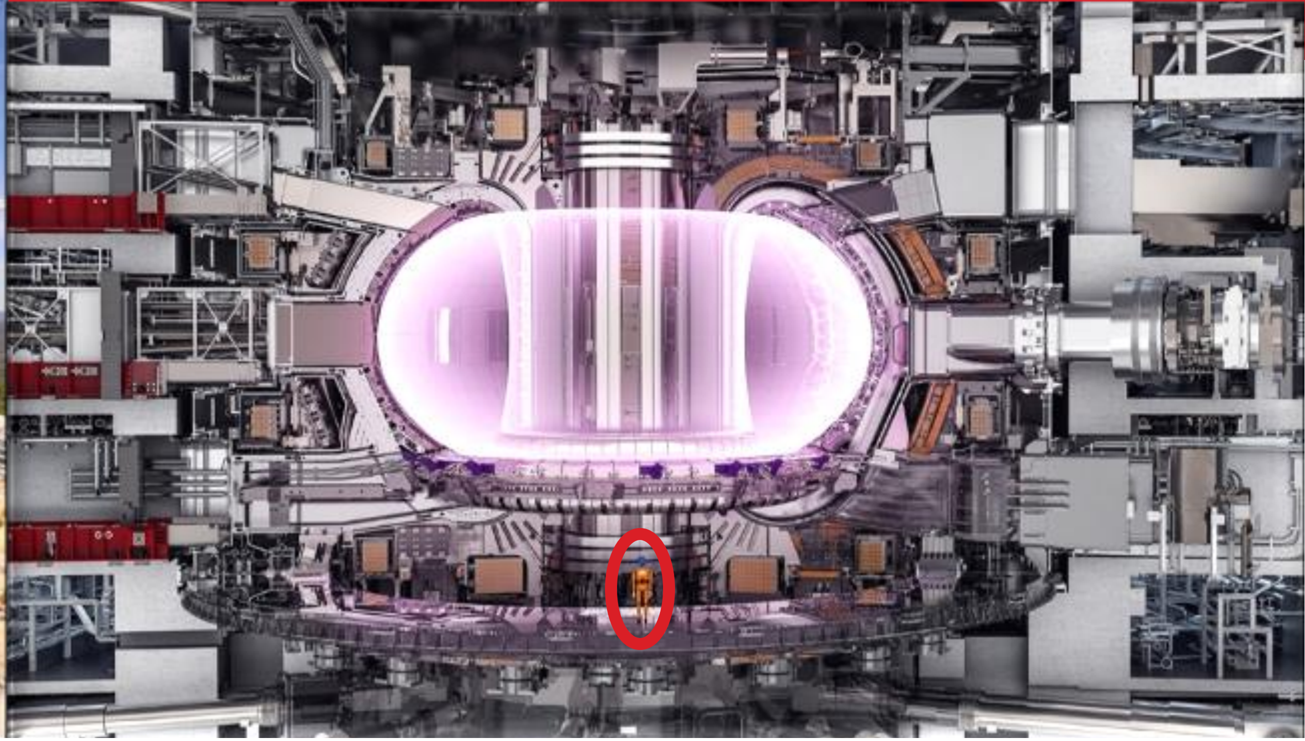
- Very small, high-density plasma
- Super fast compression pulses (µs)
- Expensive high-powered lasers for compression and heating
- Extreme sensitivity to uniformity
- Manufactured fuel targets
- **"Break Even" System:** >$5B (NIF)

MTF technology … optimal hybrid of magnetic confinement and inertial compression

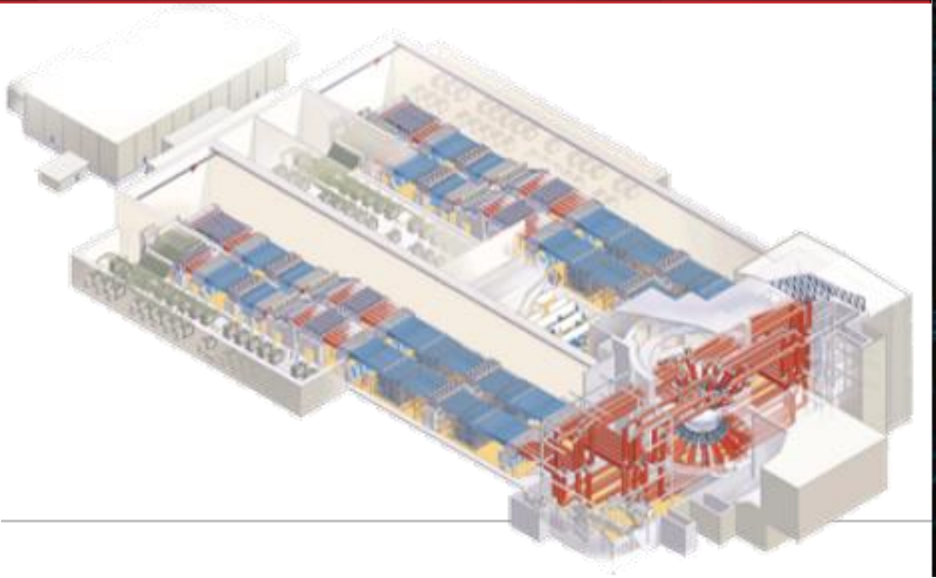
Magnetized Target Fusion (MTF) and GFs Targeted Regime

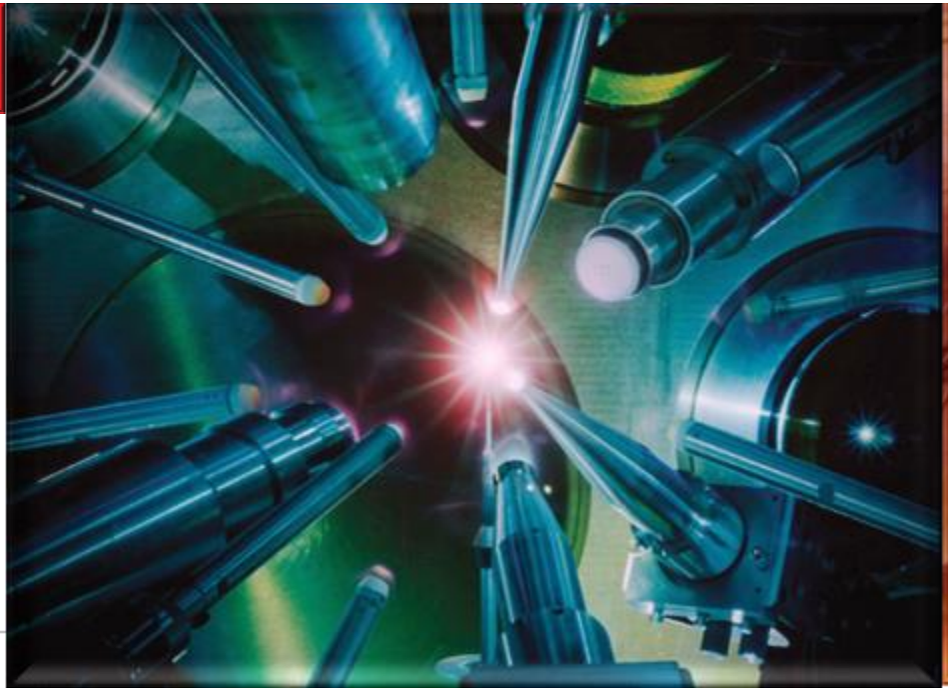


ITER (Magnetic Confinement)



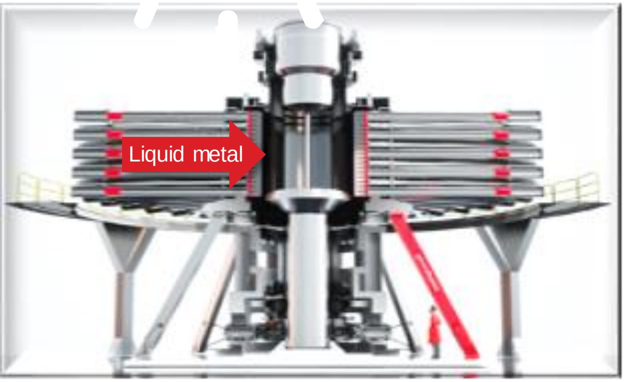
National Ignition Facility- NIF (Inertial Confinement)





How MTF Technology Works

Cavity formation



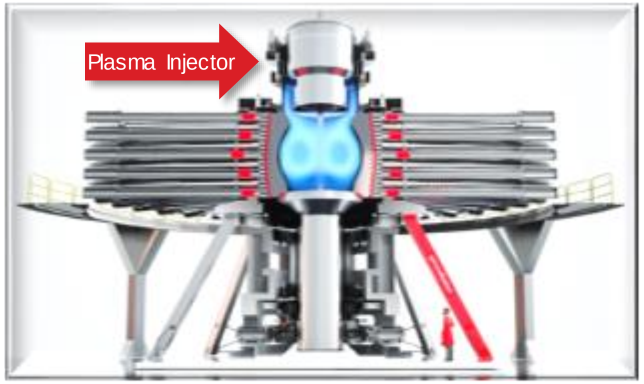
A robustly designed central compression vessel with a rotating inner vessel containing liquid metal. A chamber cavity of approximately three meters in diameter is formed by rotating the liquid metal inside the central vessel, which is surrounded by an array of several hundred compression pistons

Compression system launch

The inner liquid metal liner is quickly pushed inwards by the precisely synchronized array of several hundred compression pistons

Timing control and pressure variations in the piston launch system forms the liquid metal into a spherical cavity for plasma compression

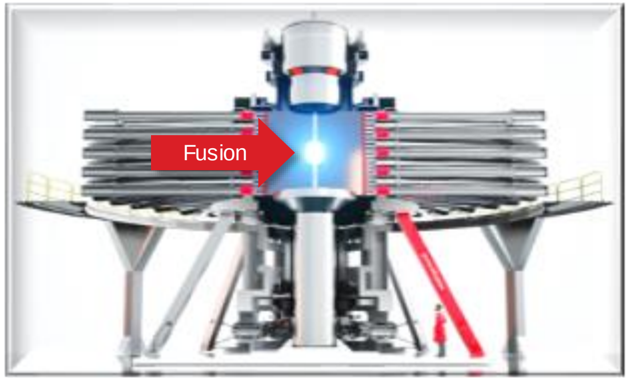
Plasma injection



Simultaneously, a hot magnetized tokamak plasma at 5 million degrees Celsius is formed by a plasma injector and magnetically injected into the compression vessel chamber cavity

Confined within the collapsing metal cavity, the plasma is compressed (~9:1) within 4ms and heated to over 100 million degrees Celsius, creating plasma temperatures and densities with requisite confinement timeframes generating significant numbers of fusion events

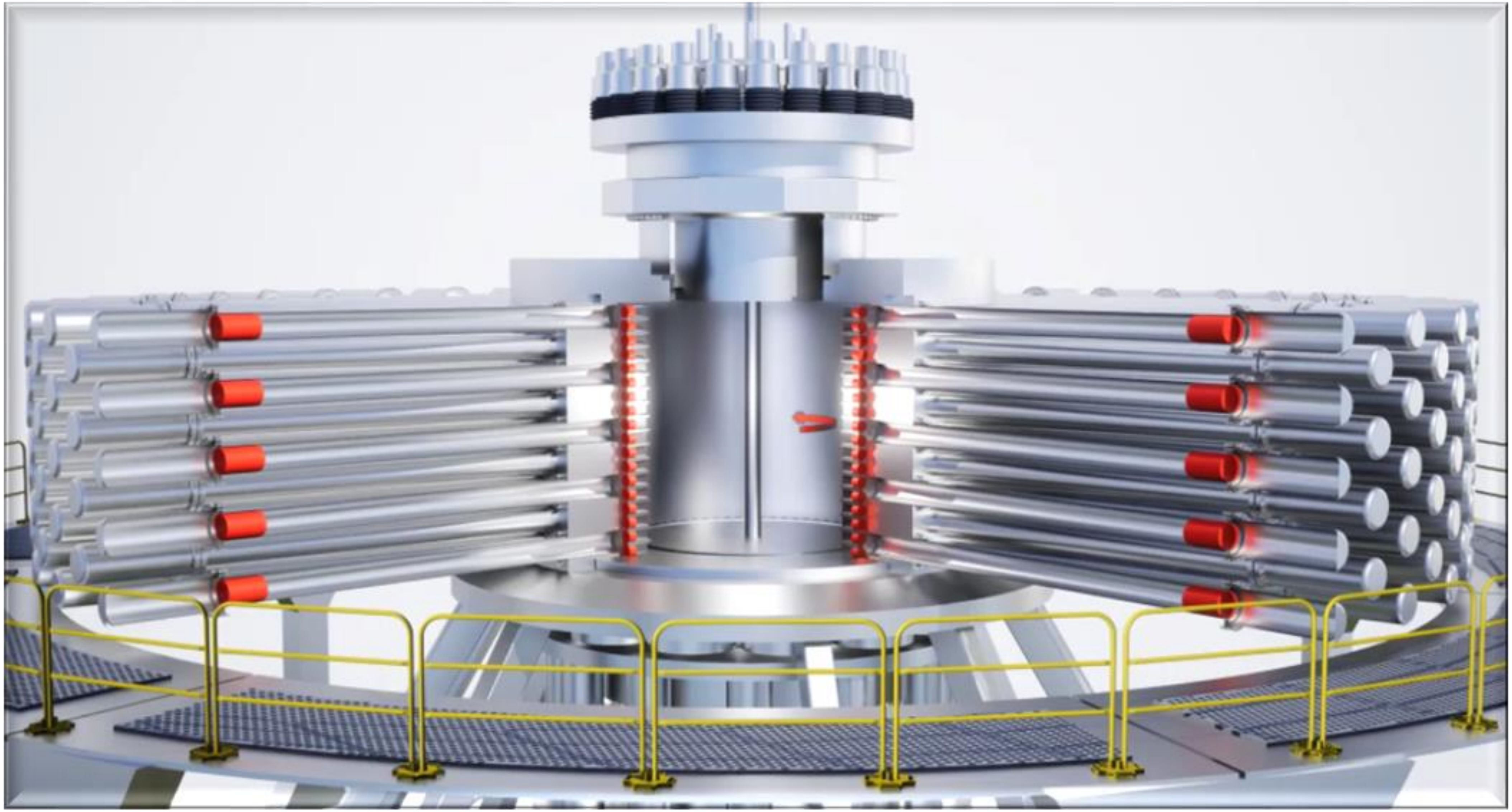
Fusion and energy conversion



Fusion energy is released and absorbed into the surrounding liquid metal liner, heating it to about 500 degrees Celsius

The hot liquid metal is circulated through a heat exchanger and converted to steam. The steam drives a turbine to produce electricity and recharges the pistons for the next cycle

The cavity reopens, pistons reset, and this cycle repeats one time per second for the commercial power plant



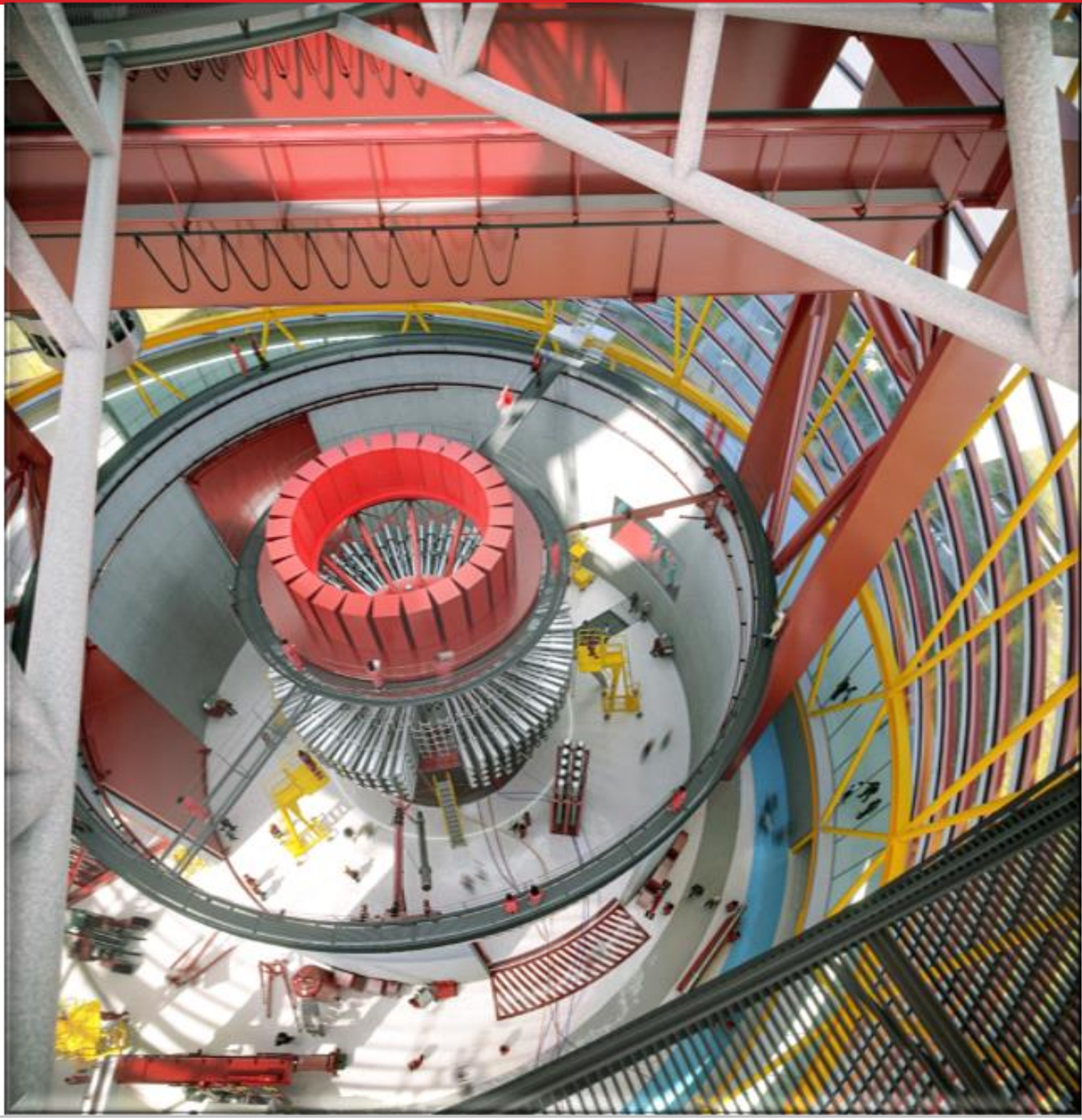
The fusion equivalent of a diesel engine: practical, durable, cost-effective

MTF Technology Advantages

1. Liquid metal liner resolves most high energy neutron challenges for first wall materials, it is also the heat transfer medium, the tritium breeding blanket, dose shielding, etc.
2. MTF does not require fist wall replacements
3. External plasma heating systems are not required (ICRH, RH, neutral beam systems, etc.)
4. Superconducting magnets or liquid helium plants not required
5. MTF has a high-density plasma with strong magnetic field as a result of compressed plasma flux
6. Pulsed approach, does not require complex high speed continuous plasma control systems
7. Diverters are not required
8. MTF has good tritium breeding ratio contained in liquid metal (1.4) allows for very small inventory quantities on site (~2g inventory for CPP vs. 4kg for ITER)
9. High Technology Readiness Levels (TRL) of key components
10. Lower parasitic electrical loads required for power plants
11. Lower capital costs projected for power plants
12. Very competitive LCOE for base load power generation

Biggest Challenges for MTF:

- **Liquid metal wall interface with plasma (interactions?)**
- **Repetition of compressions for CPP @ 1 /sec**



MTF Phased Development and Commercialization Program

Early Experiments	Science and Technology Development	Integrated Large Scale Prototype	Commercial System
2003 - 2008	2009 - Present	Fusion Demonstration Plant (FDP) Operations Start 2025	CPP Unit 1 Construction 2030

Early Experiments (2003 - 2008)

Concept Exploration
Compression Neutronic studies

Science and Technology Development (2009 - Present)

System Development
- Proof-of-Concept
- Prototype Representative

Plasma Compression Science
- Plasma Stability
- Compression Heating

Integrated Large Scale Prototype

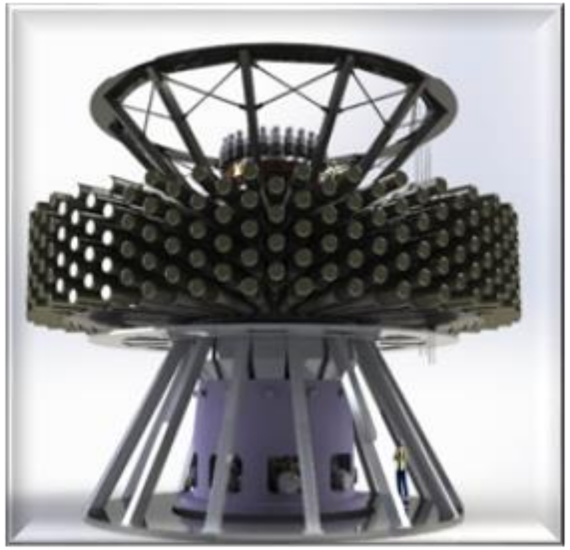
Fusion Demonstration Plant (FDP) Operations Start 2025

Integrated System Solution
Fusion Relevant Temperatures
Repeatability

Commercial System

CPP Unit 1 Construction 2030

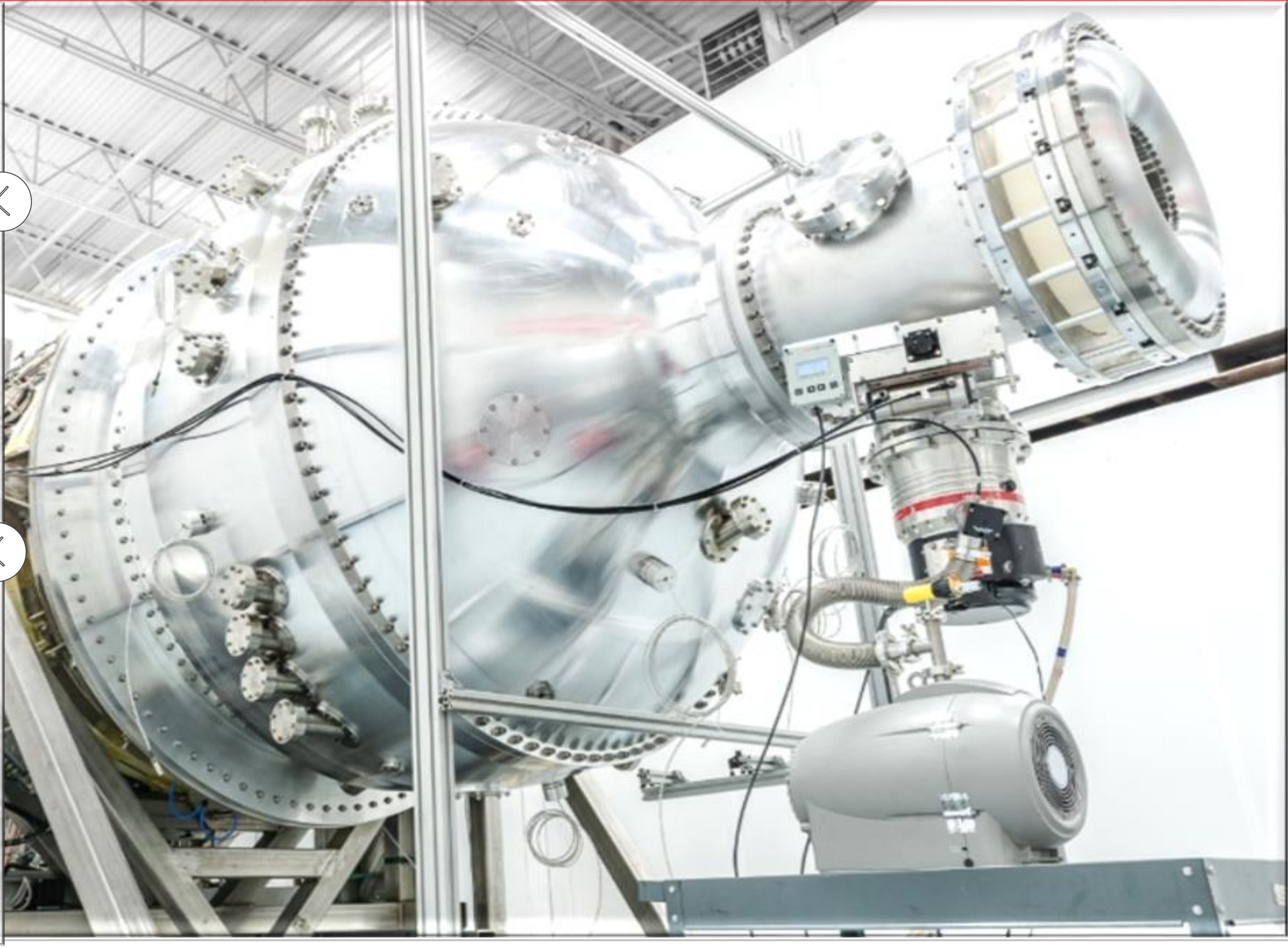
Repetition Rate
Closed DT Fuel Cycle
High Reliability & Availability



Plasma Injection Systems

One of the **largest**, fully operational **plasma injectors in the world**, at 10+ MJ pulsed power supply, 5M°C plasma injection temperatures, and **exceeding 20 ms plasma lifetimes (FDP compression pulse ~4ms)**

High quality plasma's can be reliably generated, and the PI custom designed for optimum plasma performance. Design adjustments available for magnetic fields, high vacuum and purity levels, injected plasma energies and temperatures, plasma density, etc.



Compression Systems

Demonstrated integrated compression technologies at prototype-relevant scale and successfully operated for 2 years of testing

Demonstrating liquid metal liner performance on multiple different test fixtures and configurations

FDP's large central compression vessel and spinning internal rotor under development with top industry partners

FDP compression pistons with accumulator systems in design (>500-unit array)

The MTF Fusion Demonstration Plant’s (FDP) Purpose

Integrate all key technologies for MTF fusion: Plasma injection, compression vessel, rotor, pistons, liquid metal & diagnostics

70% scale
of commercial power plant

1 pulse per day
repetition rate

Off-grid
demonstration prototype

The FDP Program has **3 primary goals:**

- Demonstrate at relevant power plant-scale, that fusion conditions can be practically achieved using General Fusion’s MTF technology
- Refine commercial fusion power plant economics and next steps based on actual FDP performance
- Establish science and engineering collaborations with UKAEA and others, along with establishing General Fusion’s UK and European HQ

FDP MTF Fusion Machine

Approx. 17m in diameter, 13m in height

3 m
Diameter cavity

3.9 ms
Plasma compression time

10.6 m^3
Pre-shot plasma volume

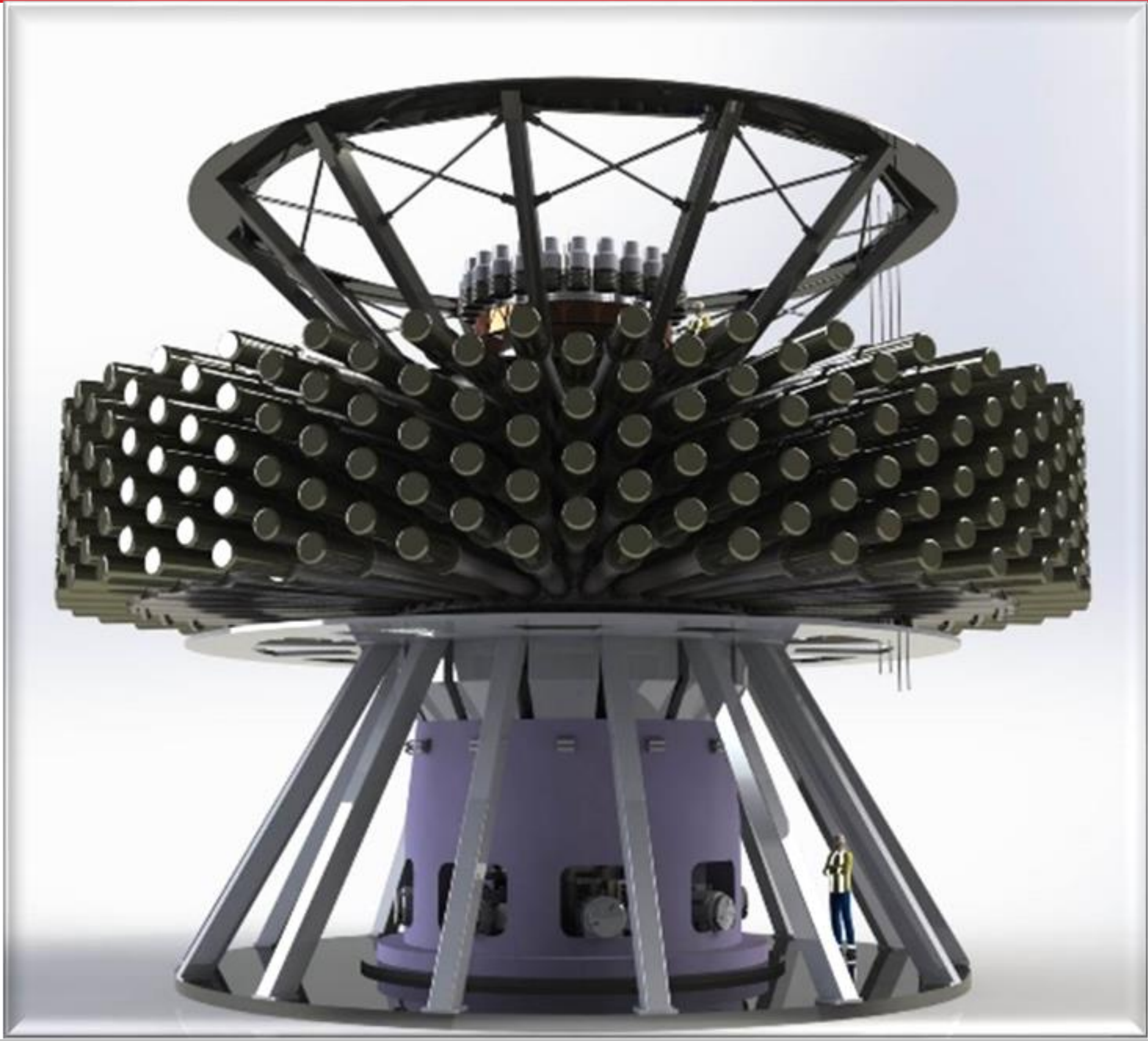
1.06 m^3
Post-shot plasma volume

12MWe
Power Req.

3000 tons

500+ drivers

20-40 MPa
Accumulator pressures



FDP Facility and BOP Project, Engineering and Design Team

UK Atomic Energy Authority	**Site and Building Owner & Project Sponsor**
generalfusion	**Design Lead,** Canadian HQ, UK office
AL_A	**Architectural Partner,** UK based
HATCH	**Engineering Partner,** Canadian HQ, UK offices
ARUP	**Engineering & Sustainability,** UK based
Turner & Townsend	**Quantity Surveyor Specialist,** UK based

RIBA Stages

0	1	2	3A	3B	4A	4B	5	6	7
Strategic Definition	Preparation and Briefing	Concept Design	Spatial Coordination	Spatial Coordination	Technical Design	Technical Design	Manufacturing and Construction	Handover	Use

FDP Facility Design Principles – "*Form Follows Function*"

Major design drivers

Adequate space to install, commission, operate, service, repair and modify MTF machine

Optimize functionality, adjacencies and efficiencies for testing, process systems, and rapid prototyping

Isolate the hazards - lithium fire protection confinement boundary

Serve GF needs now, and potential future tenants. Flexible capabilities, heavy lift / craning, services, labs, processes, offices, etc.

BREEAM Excellent Standard

FDF Industrial Scale Facility

Major facility parameters

Total area = 9,940 m^2

Highbay height = 32 m

Total steel est. = 914 tons,
concrete est. = 7,875 m^3

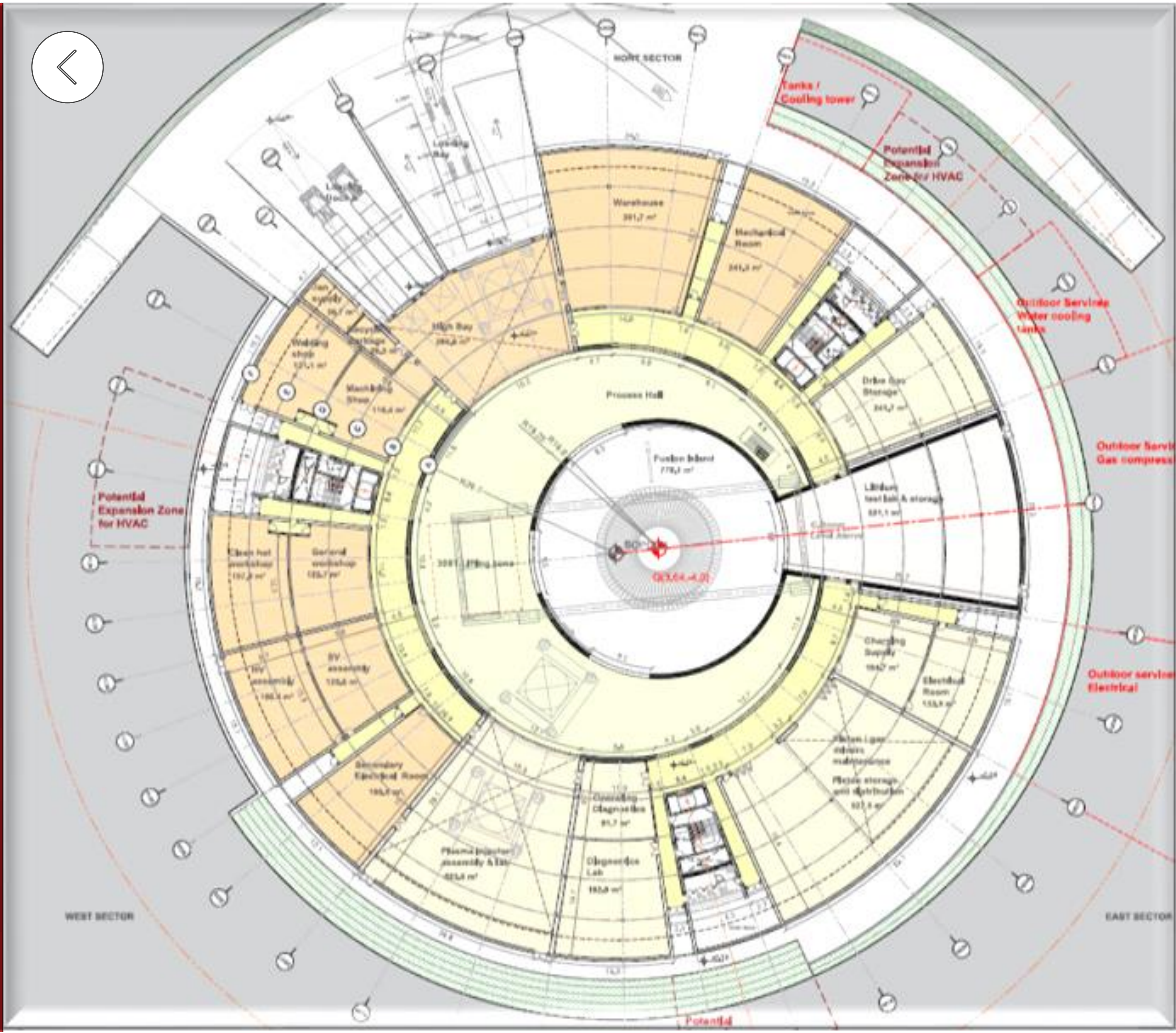
Total est. Lithium = 20 tons, Helium = 5 tons

Site Services, electrical = 12MWe
Service water = 17 L/s, Fire = 126 L/s

60 persons operation staff, 80 parking spots allocated

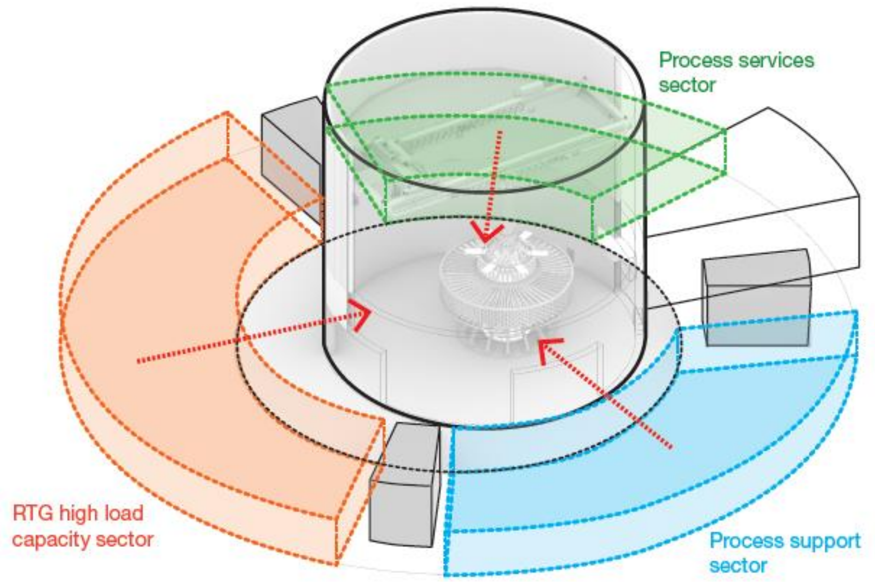
Hazard's analysis, safety case drafted, lithium fire protection primary risk concern

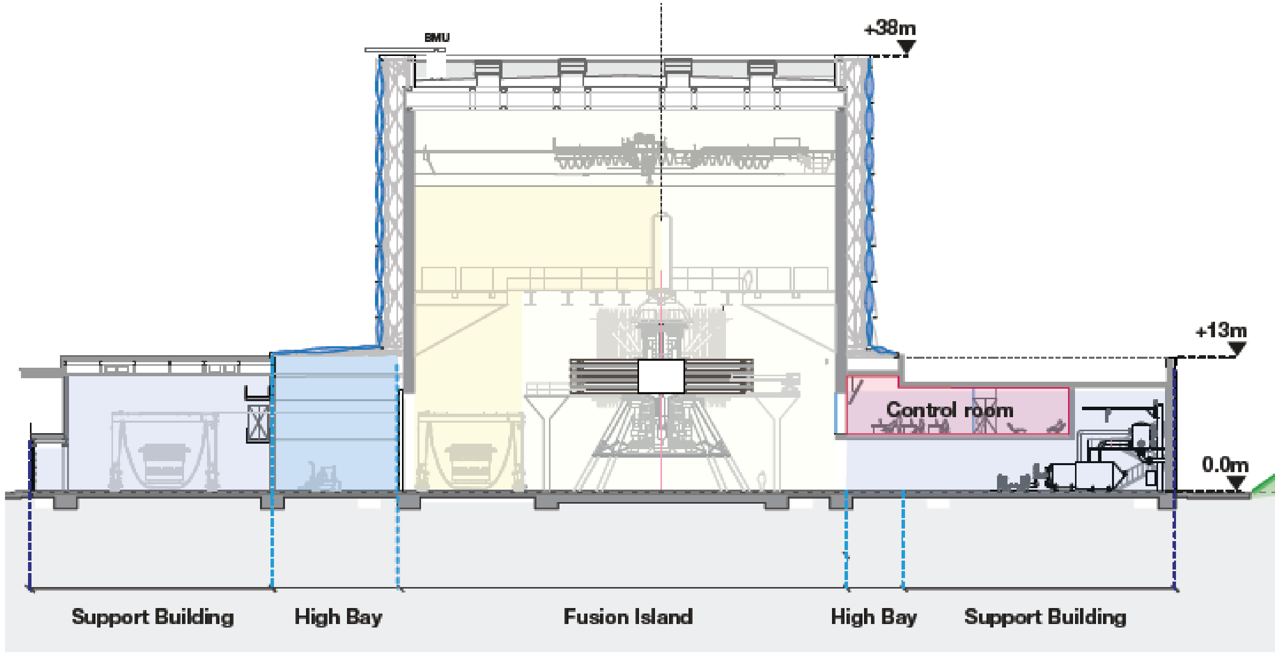
Operations and Safety Plans being drafted



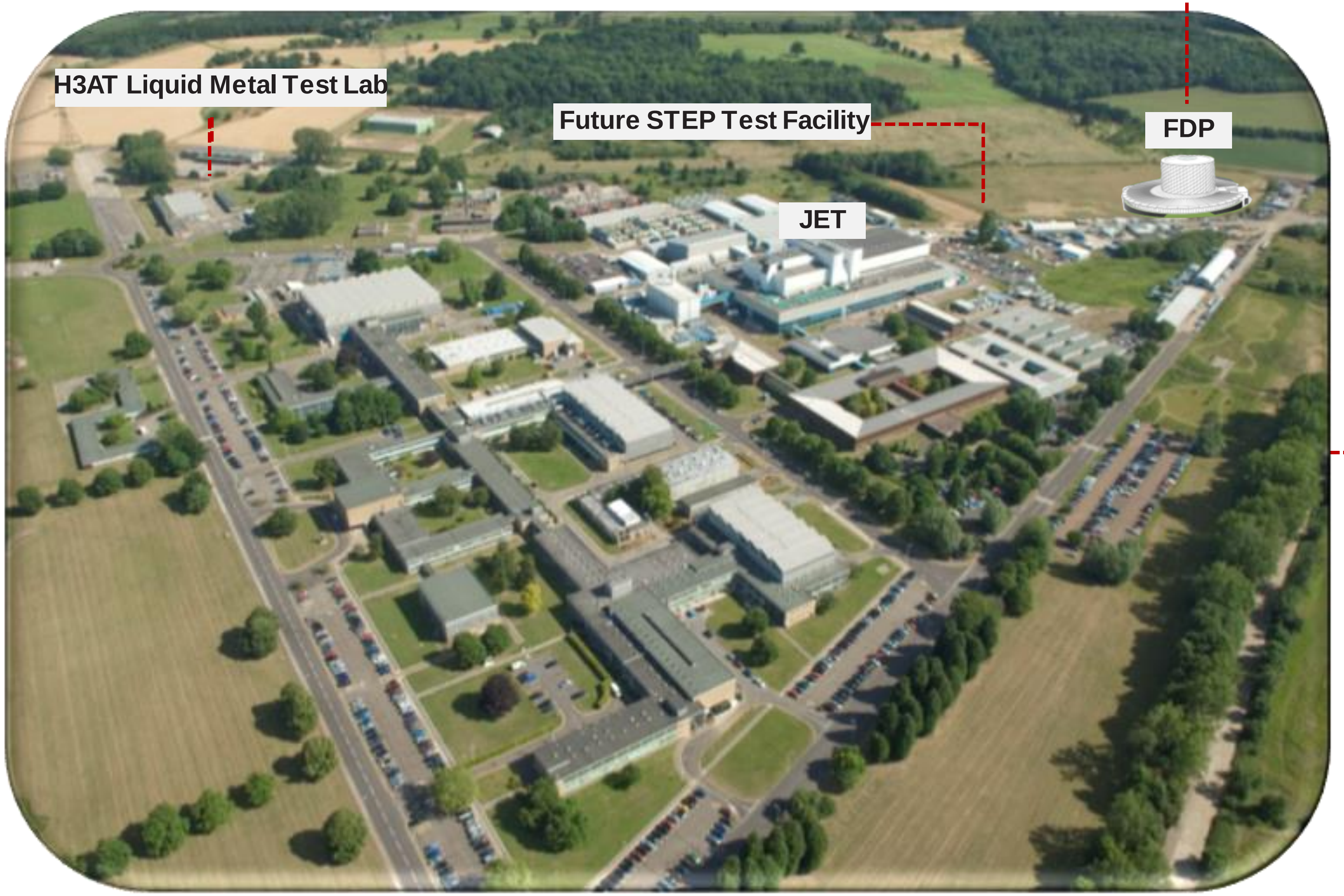
Major Design Efforts Completed:

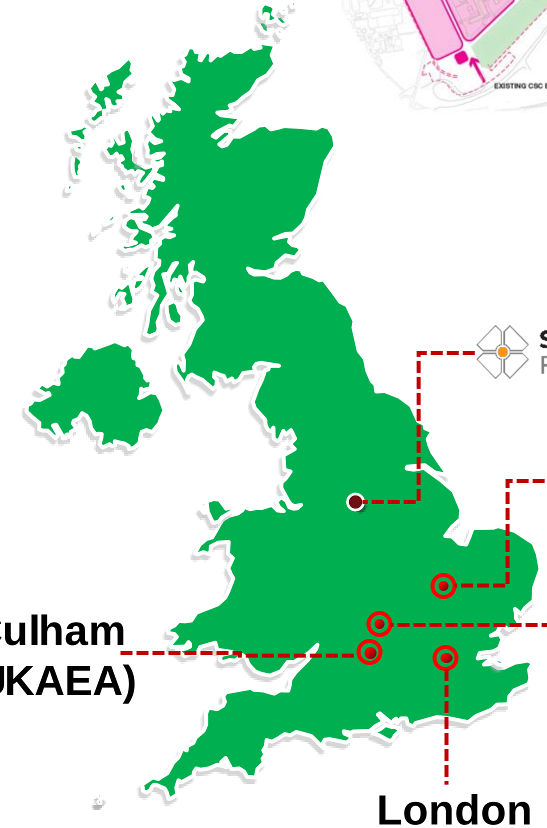
- **RIBA Stage 2.5 Design Report** finalized, approved and distributed
- **Preliminary Safety Case** drafted, submitted and reviewed by UKAEA (HS&E requirements)
- **Preliminary fire mitigation strategy** completed
  - Currently being reviewed by ARUP to ensure we meet appropriate local fire codes and regulations. Consultations with local fire bigrade to follow
- **Preliminary flood risk assessment** report completed
  - Currently working with Hatch, ARUP and McBains to determine flood mitigation requitements
- **Soils Sampling and GeoTech Reports** underway
  - Confirmation on soils loading and for final foundation designs
- **Preliminary noise impact assessment** completed
  - Currently completing the full community noise impact assessment with site samples, in support of planning





Selected Site at UKAEA Culham Science Center





Fusion Demonstration Plant Siting Selection

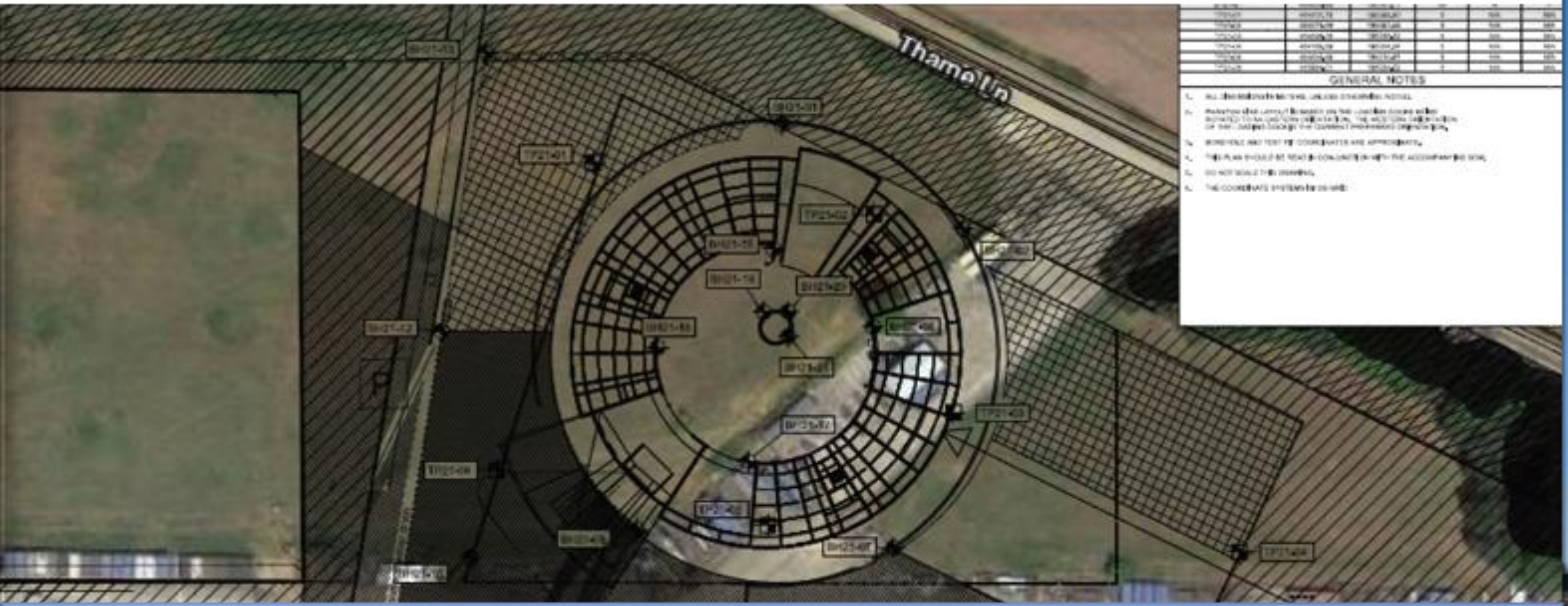
- The UK and UKAEA have an aggressive modern fusion research effort underway with multiple projects, mature supply chain, and a **"fit for purpose"** regulatory environment for commercial fusion technology development companies.

- UKAEA's Culham Science Center and Harwell, along with major universities Oxford, Cambridge, Imperial, etc. have a rich history of fusion research, and current robust fusion sciences education programs for future resources.

- Building the FDP at the UKAEA Culham Science Center affords General Fusion access to significant world-class fusion energy and plasma research expertise in one location. Many science collaborations with UKAEA are being explored.

- Fusion represents a **safe, clean, sustainable, and environmentally friendly process for carbon-free base load energy generation**. Power market studies show there exists **a multi-trillion $ worldwide market** for carbon-free replacement power generation over the next 20 to 30 years – UK is, and near early adopter markets.

Onsite Geotech Drilling Underway

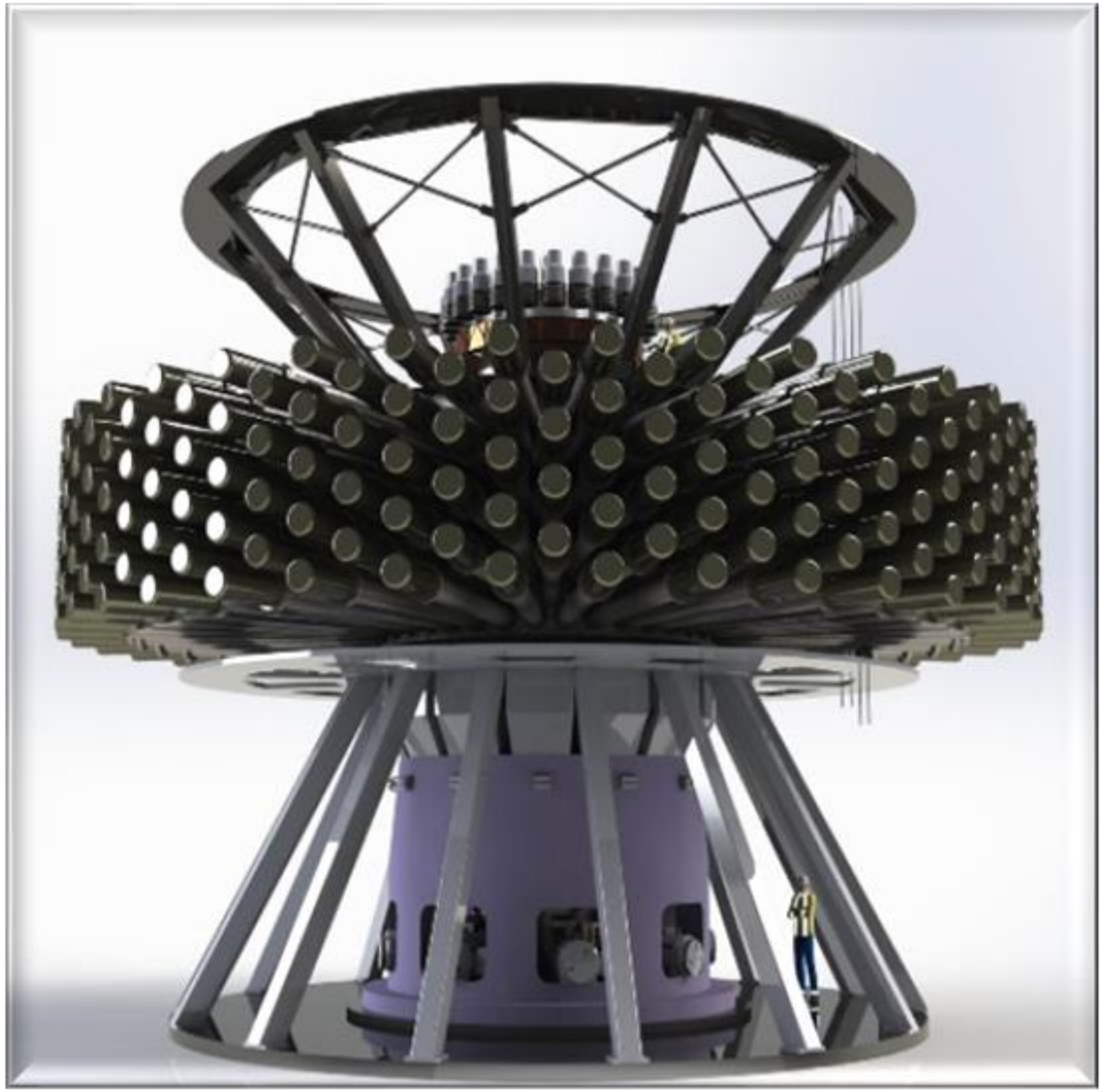



GENERAL FUSION


10.5 M

Regulation Considerations- FDP and Commercial Power Plant (“CPP”)

- FDP- deuterium fueled only plasma
- FDP- @1 pulse/day, lower energies will generate no activated fusion machine components, or dose beyond machine wall
- All particle energies are below 50 MeV
- CPP – high energy neutron pulses are surrounded in 4π by liquid metal (molten lead with small fraction of lithium for tritium breeding)
- CPP- some fusion machine components will experience low-level activation
- CPP- no dispersible first wall activated dusts, or off-site radiological hazards
- An appropriate radiation protection program will be utilized for both facilities (i.e. NCRP Report 144)



Neutron Yields

System	Fuel	Starting Plasma Diameter	Starting Plasma Density	Neutrons per pulse	Operating Frequency
PCS (Plasma Pulse Verification Program)	Deuterium	0.4 m	1e14 cm^{-3}	1e10	1 to 2 /year
Fusion Demonstration Plant (FDP)	Deuterium	3 m	2e13 cm^{-3}	1e13	~1 /day
Commercial Power Plant (CPP)	Deuterium – Tritium	4.4 m	2e14 cm^{-3}	2e20	~1 /s

By comparison: Thermo Scientific P 385 produces 3 x 10^8 n/s.

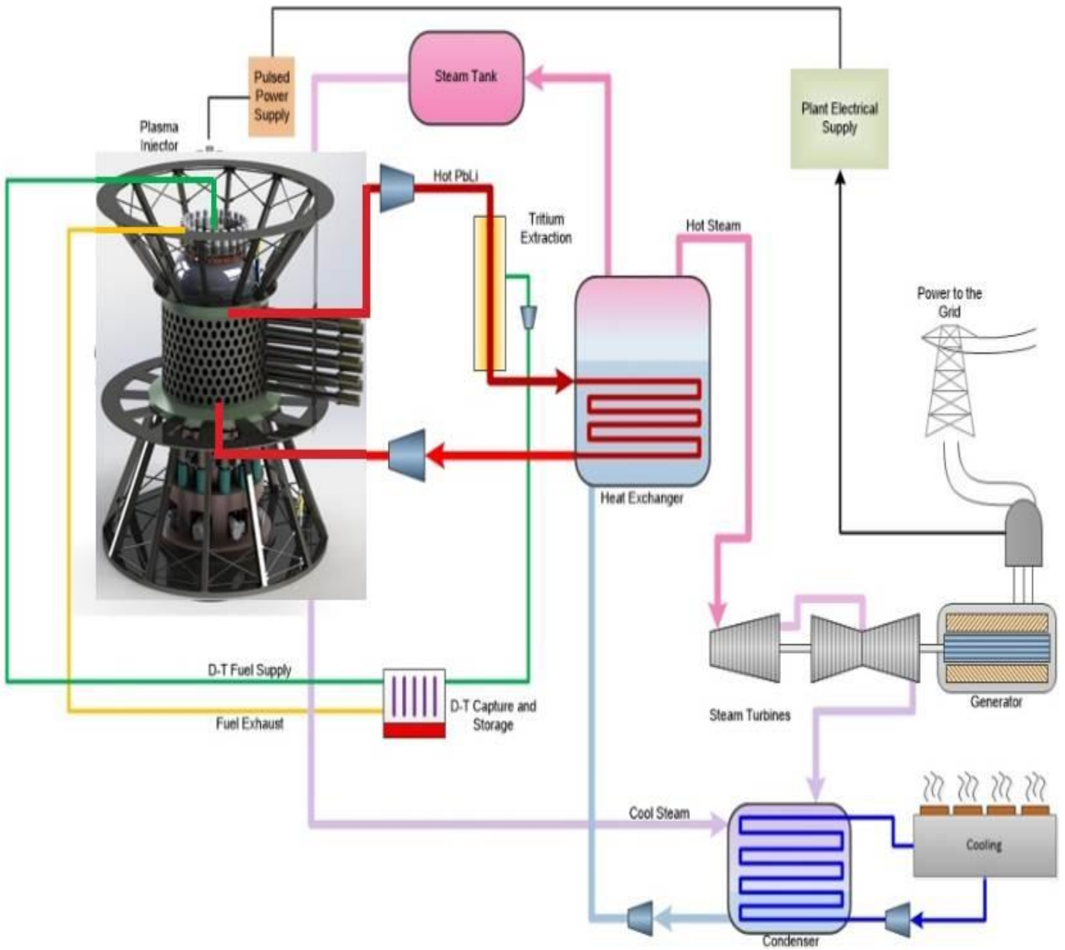
Running for 8 hours it will produce 9 x 10^{12} neutrons in a day

GF has a CNSC Class 2 License for experiments

Regulation Considerations - FDP and Commercial Power Plant (“CPP”)

Tritium management of very low volumes:

- FDP: Deuterium fuel only, one 4ms pulse a day
- CPP: Total inventory of tritium[2] 2g (1.9 x 10^4 Ci)
- CPP: Tritium self-contained throughput 76 g per day (~3oz)
- CPP: High tritium breeding ratio of 1.4, no additional tritium required
- CPP: Tritium is maintained in a closed loop monitored process
- Initial small volume of start-up tritium purchased commercially
- Total tritium inventory of ITER[3] 4 kg (3.9 x 10^7 Ci)
- Bruce Pwr. (A,B,NPP) 2015 Emissions ~37.5 g (liquid/steam)



Mature commercial tritium handling control and monitoring practices exist.

In CPP real time tritium control, monitoring and tracking will be utilized. No planned effluents, off-normal release should be minimal (mg) and below NRC unrestricted release limits of l00 millirem per year, (100 – 500 Ci liquid and 100 Ci gaseous) (EPA drinking water limits for Tritium 20k pCi/liter)

1) High bound estimate on maximum yield for 1,000 shots on FDP.
2) Not including possible additional couple of grams of tritium stored in getter beds for restarts.
*3) http://www.iter.org/faq#What_will_be_the_total_amount_of_tritium_stored_on_site_What_are_the_procedures_foreseen_to_confine_and_control_the_stock_*

Fusion Technology Requirements- Utility Perspective

EPRI Fusion Technology Study and Report - "Criteria for Practical Fusion Power Systems"

"Electric utilities are keenly interested in the promise of fusion: large-scale electricity production anywhere, with virtually no natural resource depletion or environmental pollution. To expedite development of commercially viable fusion systems, the Electric Power Research Institute (EPRI) - the R&D wing of the U.S. electric utility industry - convened a panel of top utility R&D managers and executive officers[1] to identify the key criteria that must be met by fusion plants in order to be acceptable to utilities."

This panel's findings:

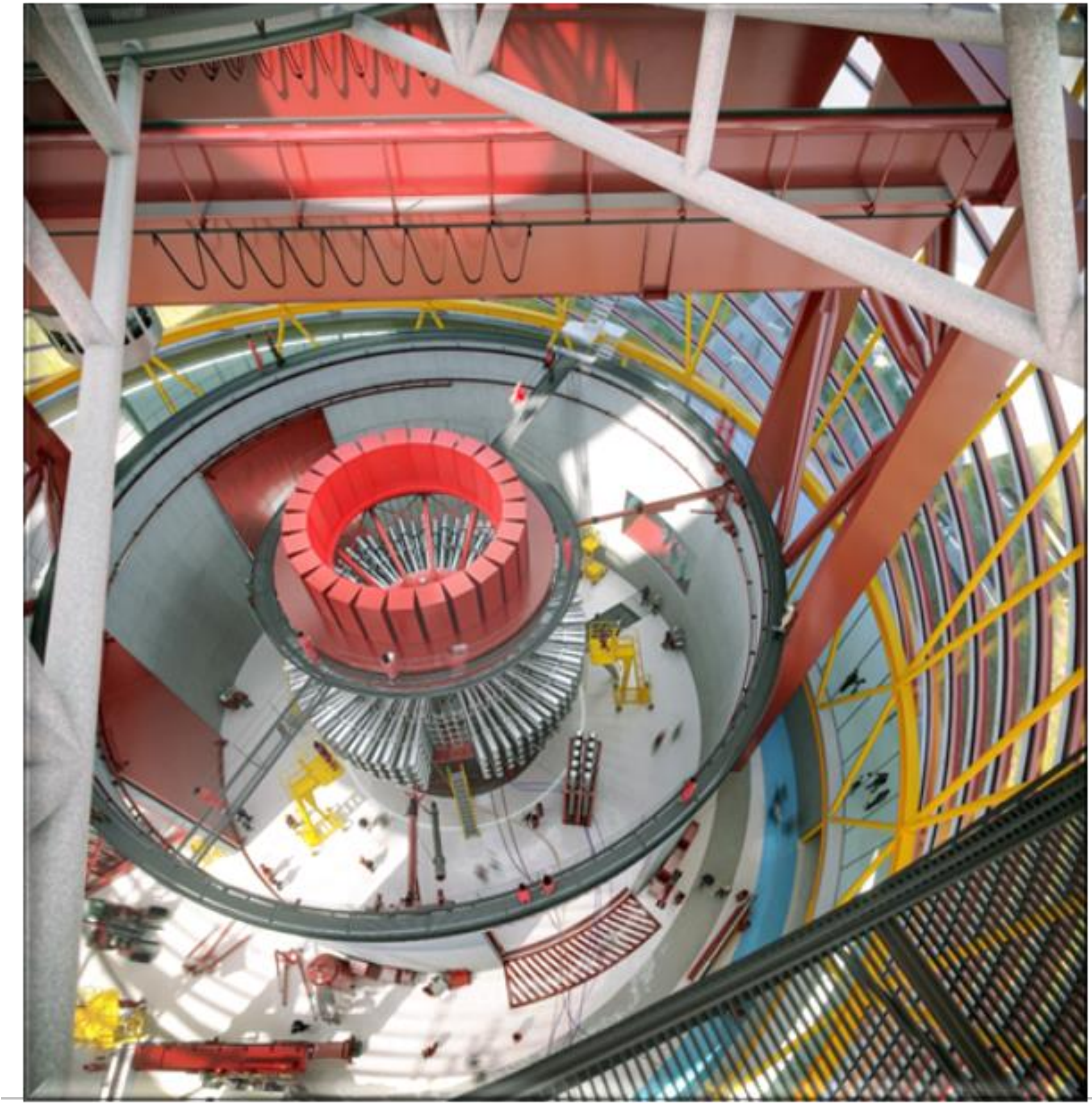
(1) Economics

(2) Public Acceptance

(3) Regulatory Simplicity

[1] Present and former utility industry executives selected for their experience in managing the introduction of major new power generation technologies.

Fusion Technology Requirements - Utility Perspective - continued



1. Economics

"To compensate for the higher economic risks associated with new technologies, fusion plants must have lower life-cycle costs than competing proven technologies available at the time of commercialization."

2. Public Acceptance

"Public acceptance and customer satisfaction will be essential to the commercial success of future fusion power plants. A positive public perception can be best achieved by maximizing fusion power's environmental attractiveness, economy of power production, and safety."

3. Regulatory Simplicity

"Because fusion is so different from existing fossil and nuclear power generation technologies, existing regulatory requirements for those technologies are not likely to be relevant to fusion. Appropriate regulation for fusion power plants should be determined by characteristics of the technology, the need for an expeditious and efficient regulatory process, and the obligation to minimize unnecessary barriers to fusion development."

Regulation Summary

Fusion has little to no radiological hazards to the public, as compared to fission nuclear. Fusion technology is much more like accelerators and irradiators – existing regulations are sufficient.

Fusion energy technologies are not “reactors” or “utilization facilities” – no SNM involved.

If required, any new regulations must be simple and “fit for purpose” based on specific technology, appropriate for the specific hazards - generic enveloping or prescriptive regulations, make it easier or more familiar for the regulator, but will hurt the fusion industry.

Safe, carbon-free fusion energy power markets are worldwide. Private companies will migrate to least resistance, early adoption markets.

Time is of the essence for the fusion industry.

CLEAN ENERGY. EVERYWHERE. FOREVER.™

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Overview and establishment of the ASME Section III Division 4 (Fusion Energy Devices) subcommittee Special Working Group for Fusion Stakeholders (SWGFS)

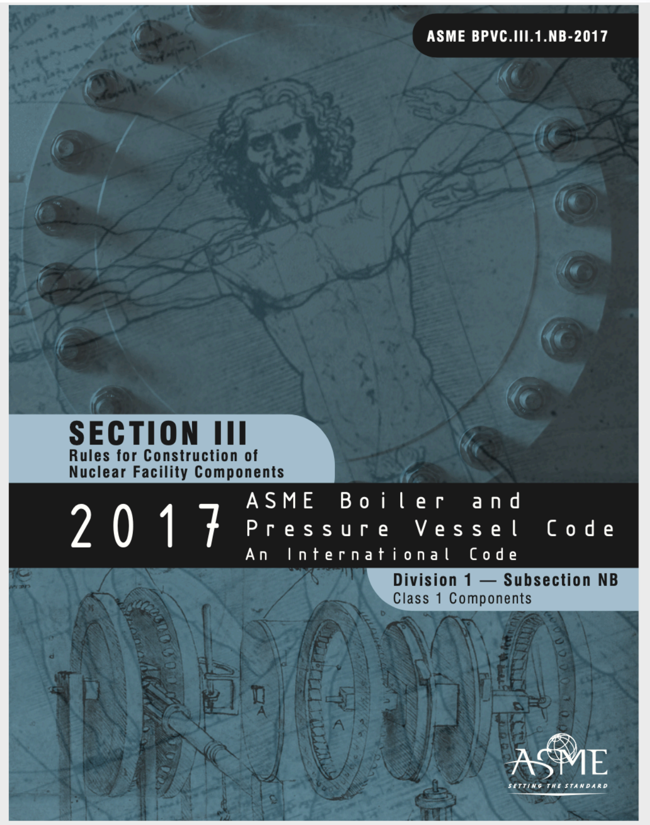
Dr Thomas Davis
Chairman of the Special Working Group for Fusion Stakeholders
Member of ASME Section III Division 4
President & CTO of Oxford Sigma
Email: thomas.davis@oxfordsigma.com

NRC Public Fusion Forum – 27th October 2021 via MS Teams

OS DOCID: R-179

Background – Codes and Standards

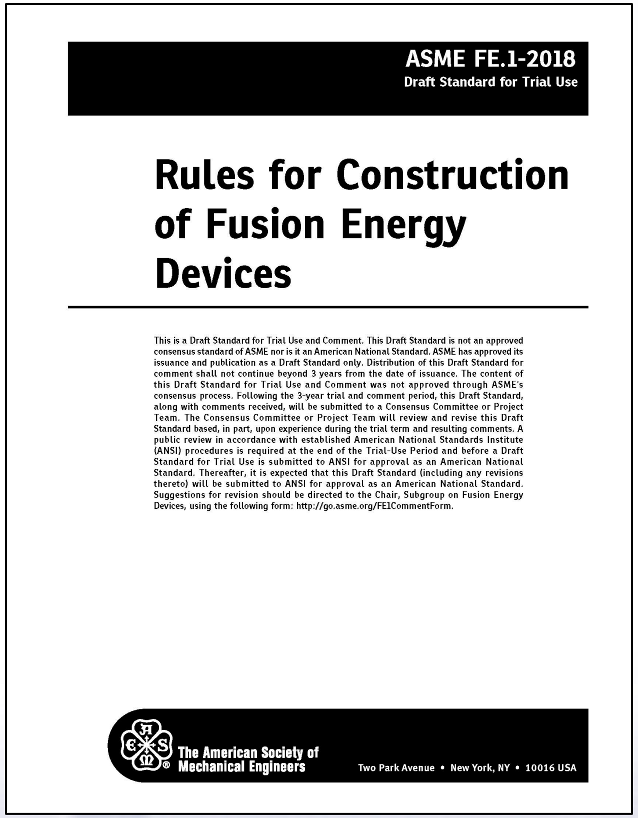
- The purpose of nuclear codes and standards is to establish national or international standards that consist of a set of rules based on state-of-the-art knowledge, experience, and experimental feedback from nuclear facilities.
- The design and construction of any nuclear reactor should make use of appropriate nuclear codes and standards to provide reassurance and quality control for the structural integrity and safety of these plants.
- The codes provide the bridge between different suppliers, participants, researchers, designers, manufacturers, and regulators. The documents can be viewed as a live document that is updated as better operational experience, knowledge, and scientific advancement is made available.
- American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel Code (BVPC) Section III is designed for nuclear reactors since the 1956



ASME
SETTING THE STANDARD

ASME BPVC Section III Division 4

- Existing nuclear codes and standards for construction do not adequately cover the design, manufacturing or construction of fusion energy devices that are currently being considered for future constructions. They also do not provide support for the on-going projects, such as ITER.
- The goal of Division 4 is to develop a recognized fusion construction code and standard to be issued by ASME.
- This new construction code would be used in the USA and/or globally as an acceptable basis for nuclear regulators for the construction, licensing and operating of new fusion facilities, such as the Compact Pilot Plant, DEMO, etc.


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
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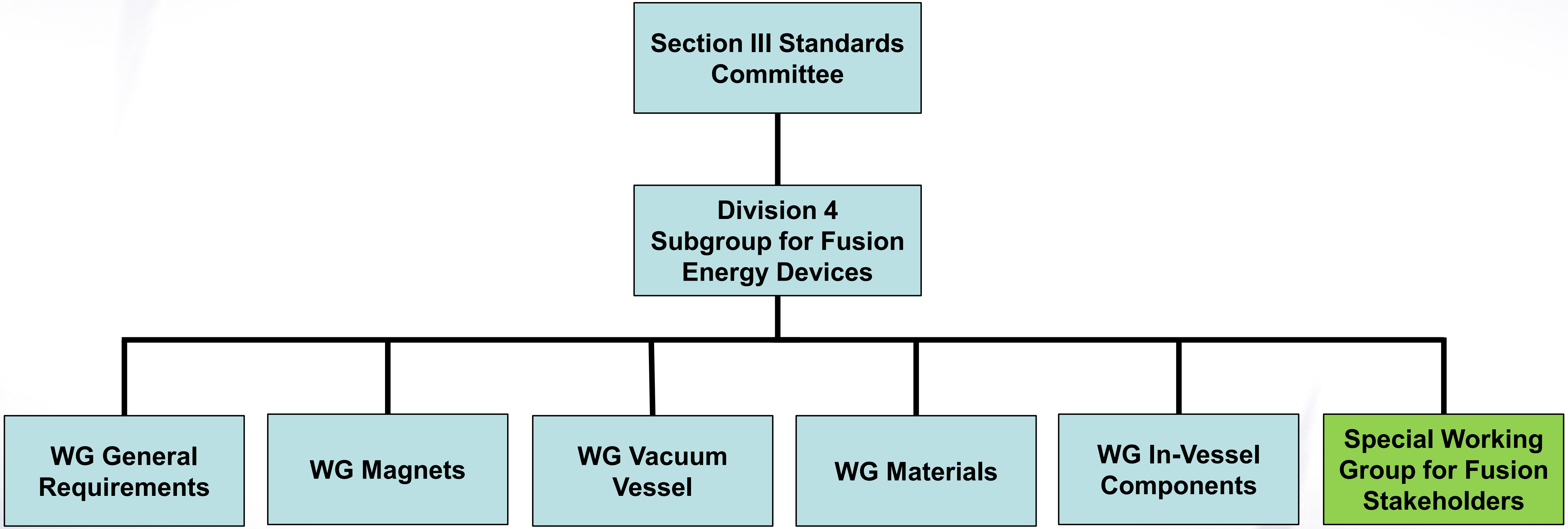
ASME
SETTING THE STANDARD

Organisation



WG = Working Group

Membership of Division 4 as of 27 October 2021

SUBGROUP ON FUSION ENERGY DEVICES (BPV III-4)

W. Sowder, Jr., *Chair,* Quality Management Services Co., LLC
Matthew Ellis, *Secretary,* Hayward Tyler, Inc.
Dan Andrei, Staff Secretary ASME
M. Bashir, Culham Centre for Fusion Energy
James P. Blanchard, Univ Of Wisconsin/Madison
L. C. Cadwallader, Retired Battelle Energy Alliance, LLC
Thomas P. Davis, Oxford Sigma Ltd
B. R. Doshi, Institute for Plasma Research
G. Holtmeier, Lawrence Livermore National Laboratory
K. Kim, National Fusion Research Institute
I. Kimihiro, Toyama Co. Ltd.
Laila El-Guebaly, Retired University of Wisconsin-Madison
David Johnson, UKAEA Culham Centre for Fusion Energy
Christopher J. Lammi, Commonwealth Fusion System
Steven Lawler, Frazer-Nash Consultancy Limited
S. Lee, National Fusion Research Institute
P. Mokaria, India-Institute For Plasma Research
T. R. Muldoon, American Exchanger Services, Inc.
M. Porton, Culham Centre for Fusion Energy
F. Schaaf, Jr., Sterling Refrigeration Corp.
P. Smith, Jacobs
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
Chet Vangaasbeek, Commonwealth Fusion Systems (CFS)
R. Barnes, *Contributing Member,* Anric Enterprises, Inc.
Douglas Roszman, Retired

ASME
SETTING THE STANDARD

ASME BPVC Section III Division 4

- These new rules for fusion energy devices apply to safety classified components such as:
  - Vacuum vessels
  - Cryostats
  - Resistive / superconductor magnet structures
  - In-vessel Components (Divertors, Breeders, First-wall tiles)
  - 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 is also working with the ASME Section XI Division 2 ‘In-Service Inspection Operations Code’ in applying the use of the Reliability and Integrity Management (RIM) program

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

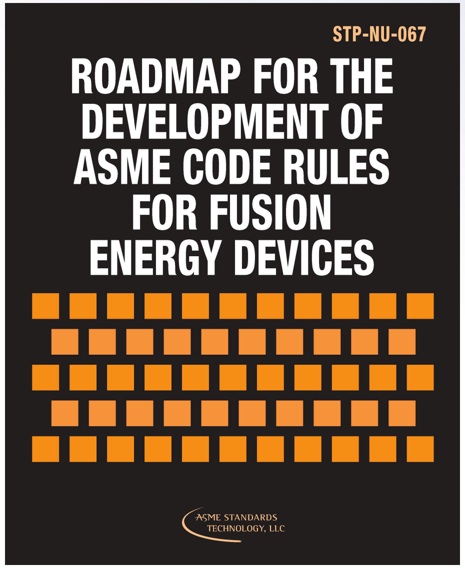
ASME
SETTING THE STANDARD

Division 4 Draft Standard

- Division 4 issued in November 2018 as a Draft Standard for Trial Use of proposed code rules entitled “Rules for Construction of Fusion Energy Devices” ASME FE.1-2018 for 3 years.
- The Draft Standard is not an approved consensus standard. ASME has approved its issuance and publication as a Draft Standard only.
- 3 years will end in November 2021. Consensus approval is expected.

Changes since October 2021

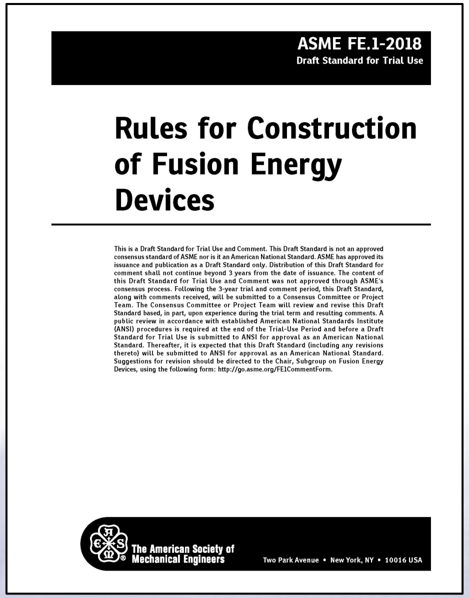
- Discussion on the plethora of approaches to fusion devices:
  - Magnetic confinement fusion
  - Magneto-Inertial Fusion
  - Inertial Fusion Energy
- Based on engineering principles and operational experience (so tokamak focused for now).
- Provide pathway for future edits to develop the code over the decades.
- Preparation for ASME acceptance as a new Division within Section III



STP-NU-067

ROADMAP FOR THE DEVELOPMENT OF ASME CODE RULES FOR FUSION ENERGY DEVICES

ASME STANDARDS TECHNOLOGY, LLC



ASME FE.1-2018
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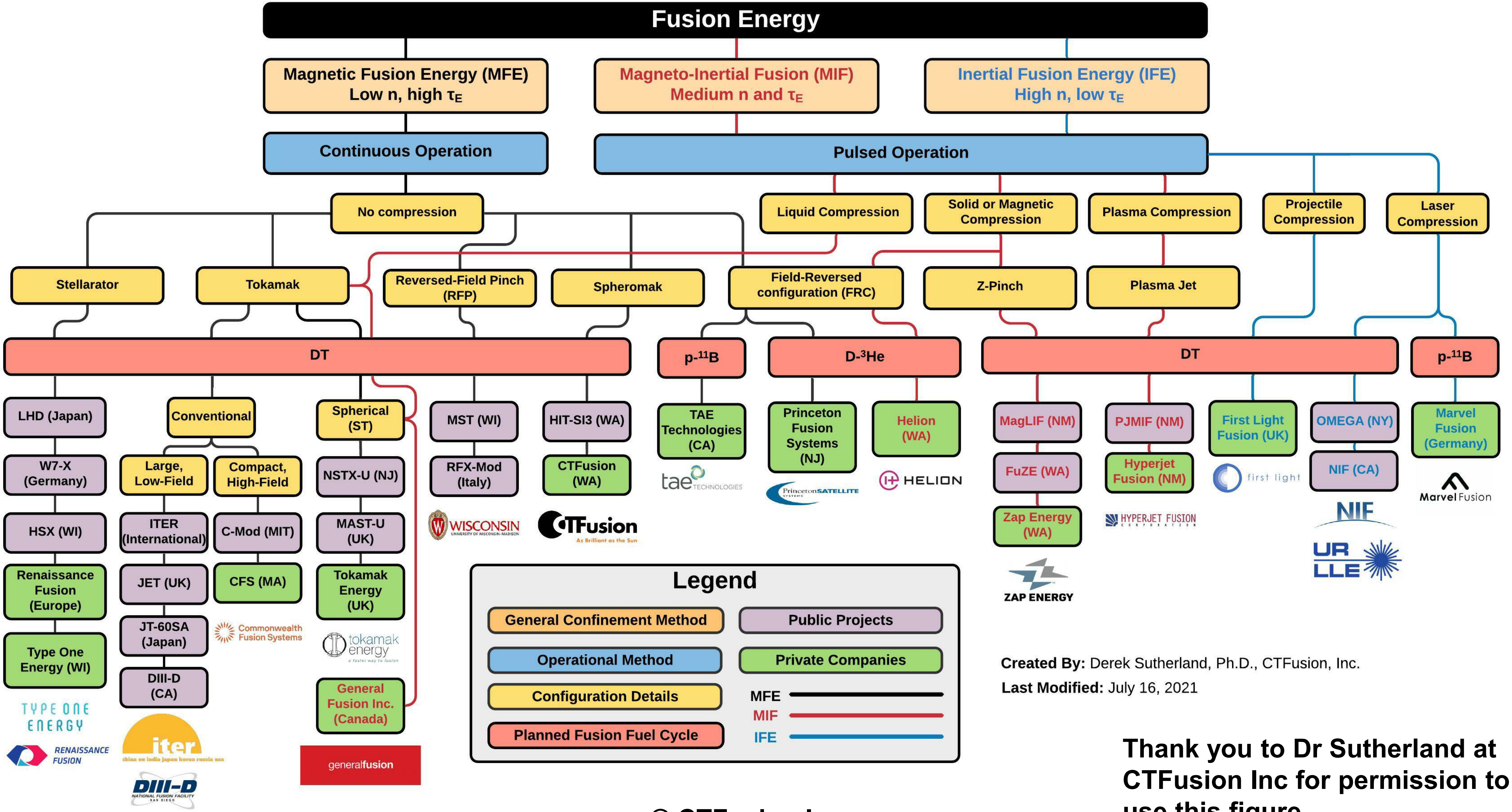
SWG – Fusion Stakeholders

Dr Thomas Davis
Chairman of the Special Working Group for Fusion Stakeholders
Member of ASME Section III Division 4
President & CTO of Oxford Sigma
Email: thomas.davis@oxfordsigma.com

NRC Public Fusion Forum – 27th October 2021 via MS Teams



Thank you to Dr Sutherland at CTFusion Inc for permission to use this figure

SWG – Fusion Stakeholders

Scope

- The SWGFS subcommittee's aim is to provide a venue for stakeholders to voice their needs and development direction, provide comments and suggest input on the development of rules for the construction of fusion energy devices within ASME Section III, Division 4 'Fusion Energy Devices' code.
- SWGFS shall identify the research and development efforts required to support the technical development of the code rules within other subcommittees.
- Interface with BPVC XI Division 2 on Inservice Inspection issues is expected.

Stakeholders:

- Private fusion companies / Vendors
- Operators
- Supply chain
- National regulators
- National Laboratories
- Government
- Universities

} Balanced and representative view

I am looking for members – please reach out on thomas.davis@oxfordsigma.com

SWG – Fusion Stakeholders

ASME Code Week

- The Boiler Code Week is a forum for business leaders, engineers, scientists, and policymakers to discuss code changes and high-level topics related to the ASME BPVC concerning the design, fabrication, and inspection of boilers, pressure vessels, and nuclear power plant technologies.
- These meetings occur in February, May, August, and November (4 times a year).
- Free and public.
- Held in person in the USA (COVID has made them virtual until May 2022).

Inaugural SWG Fusion Stakeholders Meeting

- 1st November 2021
- 8:30 AM – 10:30 AM EST

https://asme.zoom.us/j/99565408032?pwd=M1VFQWd0N1B6cnhOU2dnVWpZeFRhUT09

ASME
SETTING THE STANDARD

SETTING THE STANDARD

Overview and establishment of the ASME Section III Division 4 (Fusion Energy Devices) subcommittee Special Working Group for Fusion Stakeholders (SWGFS)

Dr Thomas Davis
Chairman of the Special Working Group for Fusion Stakeholders
Member of ASME Section III Division 4
President & CTO of Oxford Sigma
Email: thomas.davis@oxfordsigma.com

NRC Public Fusion Forum – 27th October 2021 via MS Teams

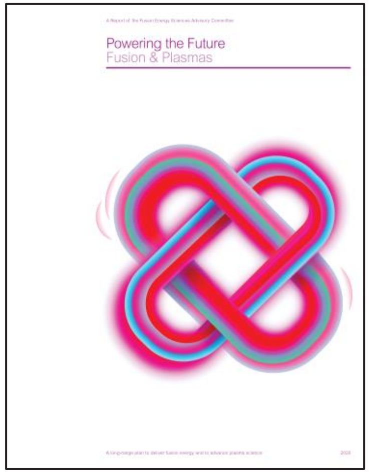
OS DOCID: R-179

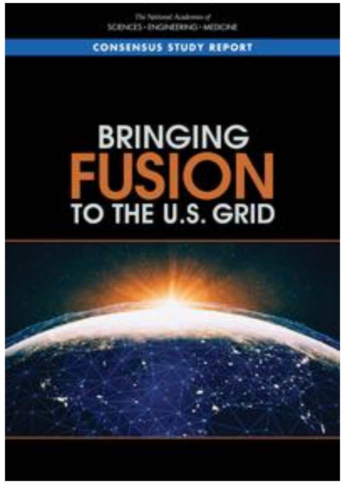
CFS creates viable path to commercial fusion energy with world’s strongest HTS magnet

Tyler Ellis

Importance of HTS magnets for fusion is well established

- 2020 DOE FESAC Report on Fusion
  - “Important technological breakthroughs include high-temperature superconductors (HTS) that enable the advances in magnet technology required to achieve that confinement.” – Page 2



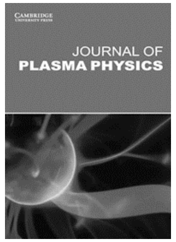


- 2021 National Academies of Science Report on Fusion
  - “… the higher magnetic field made possible by the development of demountable high temperature superconducting magnets was identified as a key enabling technology that provides a potential path, when combined with advanced operating scenarios, to a compact fusion pilot plant with high fusion power density.” – Page 59

CFS path to commercial fusion energy

COMPLETED
Proven science
Alcator C-Mod

COMPLETED
October 2020
Published peer-reviewed SPARC physics basis in Journal of Plasma Physics



COMPLETED
September 2021
Demonstrate groundbreaking magnets

HTS Magnets

CONSTRUCTION UNDERWAY
Operation in 2025
Achieve net energy from fusion

SPARC

Early 2030s
Fusion power on the grid $P_{electric}$~200MW

ARC

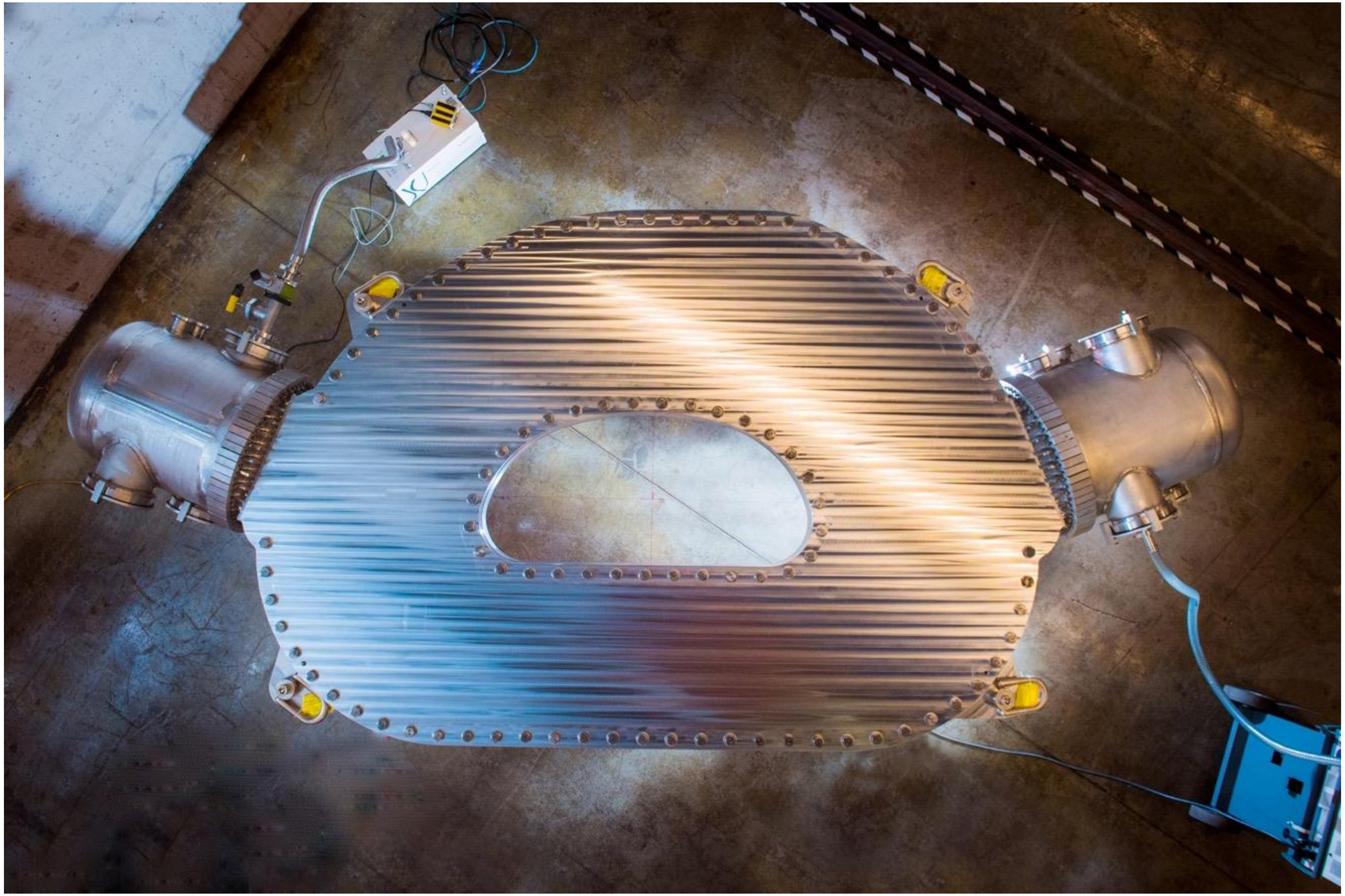
New class of magnets for fusion energy

- CFS is building advanced large-bore, HTS magnets using scalable manufacturing techniques
- Our HTS magnet is made up of 16 staked pancakes; each pancake by itself is the largest HTS fusion magnet in the world
- High field approach reduces fusion power plant size by a factor of 40
- HTS magnets combined with the proven fusion science and engineering of tokamaks enables smaller, lower-cost fusion power plants faster
- HTS magnet technology will be used in SPARC, the world's first net energy from fusion device, and then ARC, the first fusion power plant

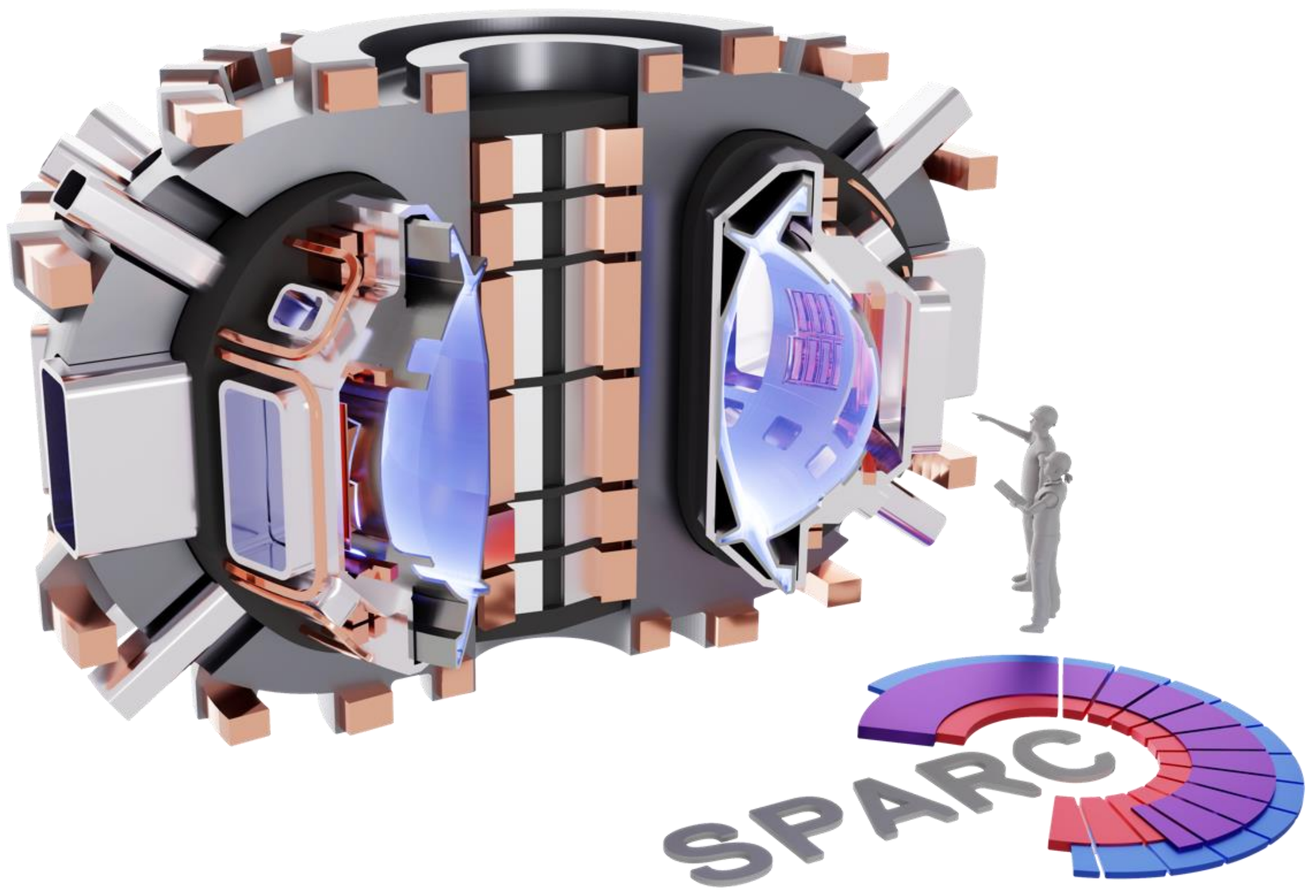
Highly capable integrated coil test stand

Successful test of fusion magnet

- Fully representative of SPARC coil operation
- 20T peak magnetic field on coil, well beyond what LTS can do
- Largest HTS magnet in the world by a factor of 100x
    - >100MJ,
    - >250 km of HTS
    - >100A/mm^2,
    - >2m size
- **Successfully tested on September 5, 2021**



SPARC design has progressed and construction started



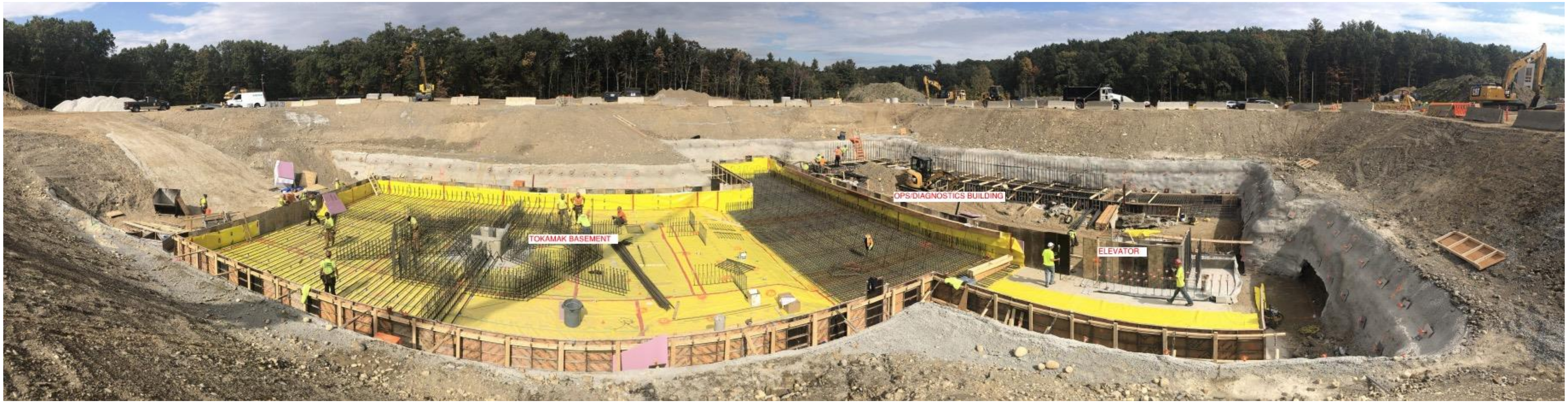
- HTS means smaller tokamaks with lower tritium inventories and smaller low-level waste generation
- This confirms future fusion energy facilities fit comfortably within 10 CFR 30
- Applied agile practices from industries like space – systematic de-risking
- Long-lead procurement begun
- Site settled and build started

Domestic burning plasma by 2025

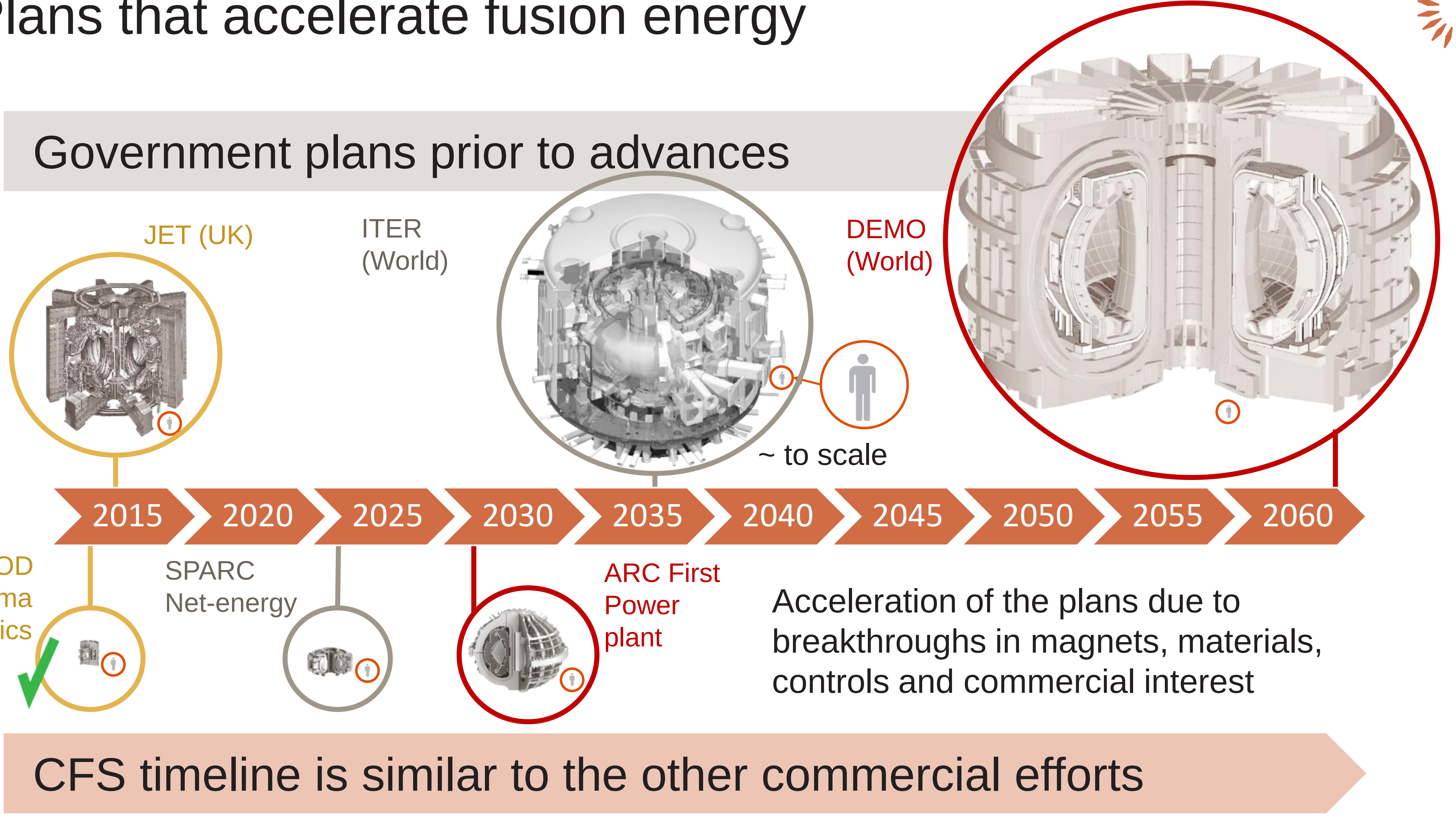
- **Acquired land:** Spring 2021
- **Total size**: 47 acres
- **Location:** Devens, MA
- **Initial magnet manufacturing facility:** 160,000 sf
- **Manufacturing operations:** 2022
- **SPARC operations:** 2025

Construction is underway (progress as of 10-22-2021)

Construction is underway (progress as of 10-22-2021)



Plans that accelerate fusion energy



Summary

- CFS's successful magnet test is a major milestone towards the goal of demonstrating net fusion energy by 2025 and putting fusion megawatts on the grid by the early 2030s
- As noted in the October 2021 PCAST public meeting, successful commercialization of fusion requires appropriate regulatory treatment
- CFS believes the current byproduct material regulatory model (10 CFR 30) is sufficient to ensure a safe and cost-effective fusion energy industry
- Part 30 is inherently flexible and offers a reasonable balance between predictability for developers while providing regulatory flexibility as the fusion industry matures
- Establishing subjective and arbitrary regulatory limits in a hybrid model creates confusion among stakeholders without improving safety or environmental protection

The fastest path to limitless, clean energy

Commonwealth Fusion Systems

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.

FIA Members

FUSION INDUSTRY ASSOCIATION

tokamak energy
a faster way to fusion

Commonwealth Fusion Systems

generalfusion®

tae TECHNOLOGIES

HELION

HB11 ENERGY
LASER BORON FUSION

FOCUSED ENERGY GmbH
Creating the Power of the Stars on Earth

TYPE ONE ENERGY

ZAP ENERGY™

HYPERJET FUSION CORP

HelicitySpace

LPP FUSION

first light

CTFusion
As Brilliant as the Sun

RENAISSANCE FUSION

ALBOT

AVALANCHE

PrincetonSATELLITE SYSTEMS

INNOVEN Energy

fuse

HORNE TECHNOLOGIES

MIFTI

nearstar FUSION

NK

The Stakes of NRC Fusion Decision

FUSION INDUSTRY ASSOCIATION

The world is racing to be ready for fusion energy power plants

- UK Green Paper on Fusion Regulation

- European Commission Study: ”Towards a specific regulatory framework for fusion facilities”

- IAEA TECDOCs on regulation and safety of fusion facilities

The NRC's Four Questions

FUSION INDUSTRY ASSOCIATION

1. **Offsite Consequences**

   What advantages/disadvantages would stem from categorizing Fusion Systems based on estimated offsite consequences as one of the many different decision-making criteria tiers? What are examples of potential tiers based on estimated offsite consequence for staff consideration?

2. **Byproduct Materials Inventory**

   What advantages/disadvantages would stand from categorizing Fusion Systems based on inventory limits of byproduct material such as tritium as one of the many different decision-making criteria tiers? What are examples of potential tiers based on inventory limits of byproduct material for staff consideration?

3. **Power Output**

   What advantages/disadvantages would stem from categorizing Fusion Systems based on power output (MWe) as one of the many different decision-making criteria tiers? What are examples of potential tiers based on power output for staff consideration?

4. **Fusion Reaction Type / Fuel Choice**

   What advantages/disadvantages would stem from categorizing Fusion Systems based on the fusion reaction being applied(neutronic (DT, DD, TY) or aneutronic) as one of the many different decision-making tiers? What would the expected difference in the level of safety systems between fusion facilities for these two types of fusion reactions?

Overall comments on NRC questions

FUSION INDUSTRY ASSOCIATION

- The NRC's questions appear to presuppose the creation of a new regulatory framework with a tiered system of regulation
- Utilizing Part 30 is the most effective, risk informed, and tailored method to address the regulation of Fusion facilities
  - Part 30 has proven itself flexible enough to handle an incredibly wide range of byproduct-based technologies with varying degrees of risk
  - Part 30 is well established and provides regulatory predictability for fusion energy developers
  - Part 30 also provides the NRC flexibility as fusion technologies mature

Overall comments on NRC questions

FUSION INDUSTRY ASSOCIATION

- In general, the Part 30 regime already provides sufficient flexibility to allow the NRC to tailor the requirements to individual fusion designs based on their risk – *This is a graded approach to regulation and risk*

- Part 30 already contains appropriate gradations, and can be adapted to support any gradations needed.

  - Regulatory requirements for emergency planning, decommissioning, and other factors impacting health and safety are contained in Part 30

  - Part 30 requirements already vary depending on issues such as offsite consequences, waste, facility design, and inventory limits

- There are no potential fusion facilities which need a higher grade of regulation than what is already provided by Part 30

  - Imposing a graduated approach to capture hypothetical technologies that no utility or vendor would ever want to order or build drives unnecessary conservatism in the overall regulatory approach

Offsite Consequences

FUSION INDUSTRY ASSOCIATION

- Offsite impact is an appropriate decision-making category for fusion regulation
  - NRC's core mission: protecting public health, safety, and the environment
  - Provides the NRC flexibility to evaluate individual facilities
  - Flexible method that can evolve over time as fusion technologies develop further
- Fusion facilities will present similar offsite impacts to many other byproduct materials facilities. Therefore, this category can build on previous regulatory decisions
  - There is a well-established framework under Part 30 for evaluating offsite consequences for many different types of facilities

Offsite Consequences

FUSION INDUSTRY ASSOCIATION

- There is no need to develop any new regulations for estimating offsite consequences for fusion facilities
  - FIA believes the specific licensing guidance in Part 30 is sufficient for purposes of estimating offsite risk
  - There is no health, safety, regulatory or other advantage in developing a new method for calculating the offsite consequences for fusion energy projects
- Part 30 already categorizes materials licensees based on their potential offsite consequences
  - Part 30 establishes certain offsite exposure limits for members of the public
  - Example: emergency planning requirements contain “grades” depending on the license applicant’s ability to demonstrate maximum offsite dose. Licensees which exceed certain thresholds must create an emergency plan, and the NRC can require additional details or mitigation is necessary to address offsite consequences.

Offsite Consequences

FUSION INDUSTRY ASSOCIATION

- Probabilistic Risk Assessments are not appropriate or necessary for fusion facilities
  - The maximum possible risk presented by fusion facilities is not significant enough to require PRAs
  - The Commission's Policy Statement on Use of Probabilistic Risk Assessment Methods in Nuclear Regulatory Activities (60 FR 42622) recognized that "*there may be situations with material users where it may not be cost-effective to use PRA in their specific regulatory applications*."
  - At its current stage of development, requiring fusion licensees to conduct Probabilistic Risk Assessments would introduce significant regulatory uncertainty, unnecessarily hamper designers, and impose unsustainable costs on developers, effectively precluding many fusion energy developers from building their demonstration devices in the U.S.

Inventory Limits

- Inventory limits are reasonable for consideration in context of evaluating offsite risks, but not as independent criteria
  - One exception – potential to establish exemptions based on certain very low inventory limits
  - An independent focus on inventory limits would not adequately consider differences in facility design or types if inventory
- Part 30 regulations are currently sufficient to accommodate the anticipated inventory limits any potential commercial fusion facility
  - There is no need to create new inventory limits above which a new regulatory regime for fusion facilities would apply

Inventory Limits

FUSION INDUSTRY ASSOCIATION

- The NRC should consider establishing inventory limits below which certain exemptions would be granted, such as for fusion facilities which do not use tritium
    - Some potential designs do not involve any tritium, and should receive broad exemptions as they pose even smaller radiological risks

Power output

FUSION INDUSTRY ASSOCIATION

- There are no advantages to basing regulatory requirements on thermal power output
  - MWt output does not relate to risk, potential offsite dose, decommissioning planning, or any other radiological factor
  - MWt does not consider technological differences
  - Categorizing fusion devices by MWt would impose arbitrary constraints on fusion developers

Fusion Reaction Type/Fuel Choice

FUSION INDUSTRY ASSOCIATION

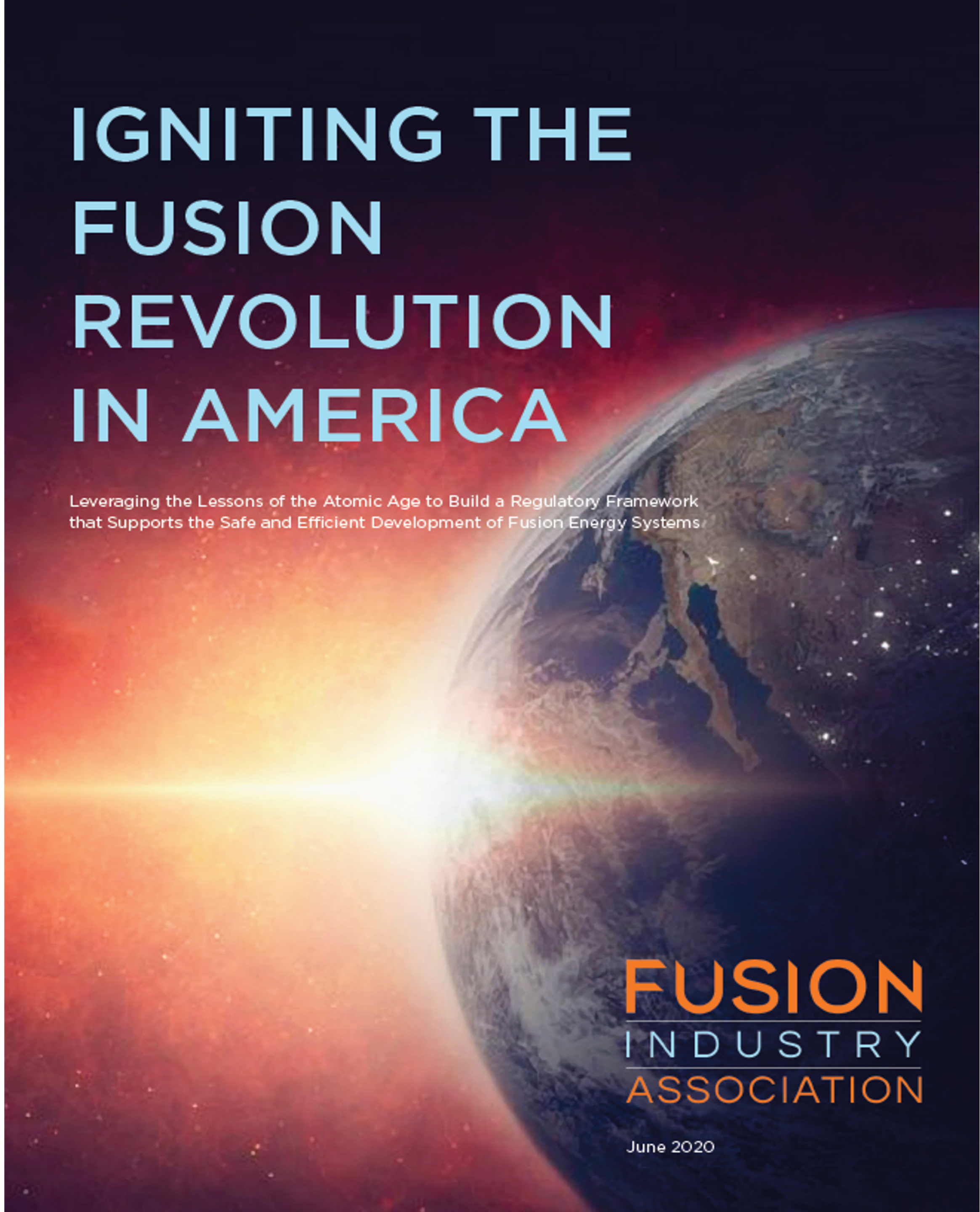
- Other than its relevance to an overall evaluation of offsite impacts or decommissioning planning, fusion reaction and fuel choice are not appropriate methods to categorize fusion devices
  - While some fusion reactions may involve no byproduct material, and be eligible for regulatory exemptions, the level of offsite risk is more inherent in the specific facility design rather than the reaction type
- From a risk-informed perspective, all of the conceived fusion reaction types or fuel choice present risks that can be appropriately regulated under existing Part 30 regulations
- Some types of fusion reactions may involve no byproduct material, and be eligible for exemptions, but there is no basis for establishing more stringent regulatory requirements based on reaction type

Closing

- Even though both technologies are intended to produce electricity, fusion devices and fission reactors share few common risks or radiological hazards
  - Fusion devices do not use or produce special nuclear material, high level waste, or spent nuclear fuel, and cannot have a criticality event
  - Fusion devices fundamentally are not utilization facilities
- Part 30 is the appropriate regulatory framework for fusion devices
  - Fusion devices have much more in common with devices such as accelerators and cyclotrons, which are appropriately regulated under Part 30
  - Although no developers are planning large facilities, even very large fusion facilities would be most appropriately managed under Part 30, rather than being subject to utilization facility requirements
  - Part 30 already contains risk-informed "grades" of regulation, and can be easily amended to incorporate further, that can be applied to specific facilities based on a variety of factors

THANK YOU

- FIA continues to encourage the NRC Staff to engage in monthly meetings with NRC members to further build its understanding of fusion technologies while it works to develop an options paper for the Commission
- Read our FIA Regulatory White Paper at: www.fusionindustryassociation.org/post/fusion-regulatory-white-paper



10 CFR Part 30 - Examples of Regulatory Scalability

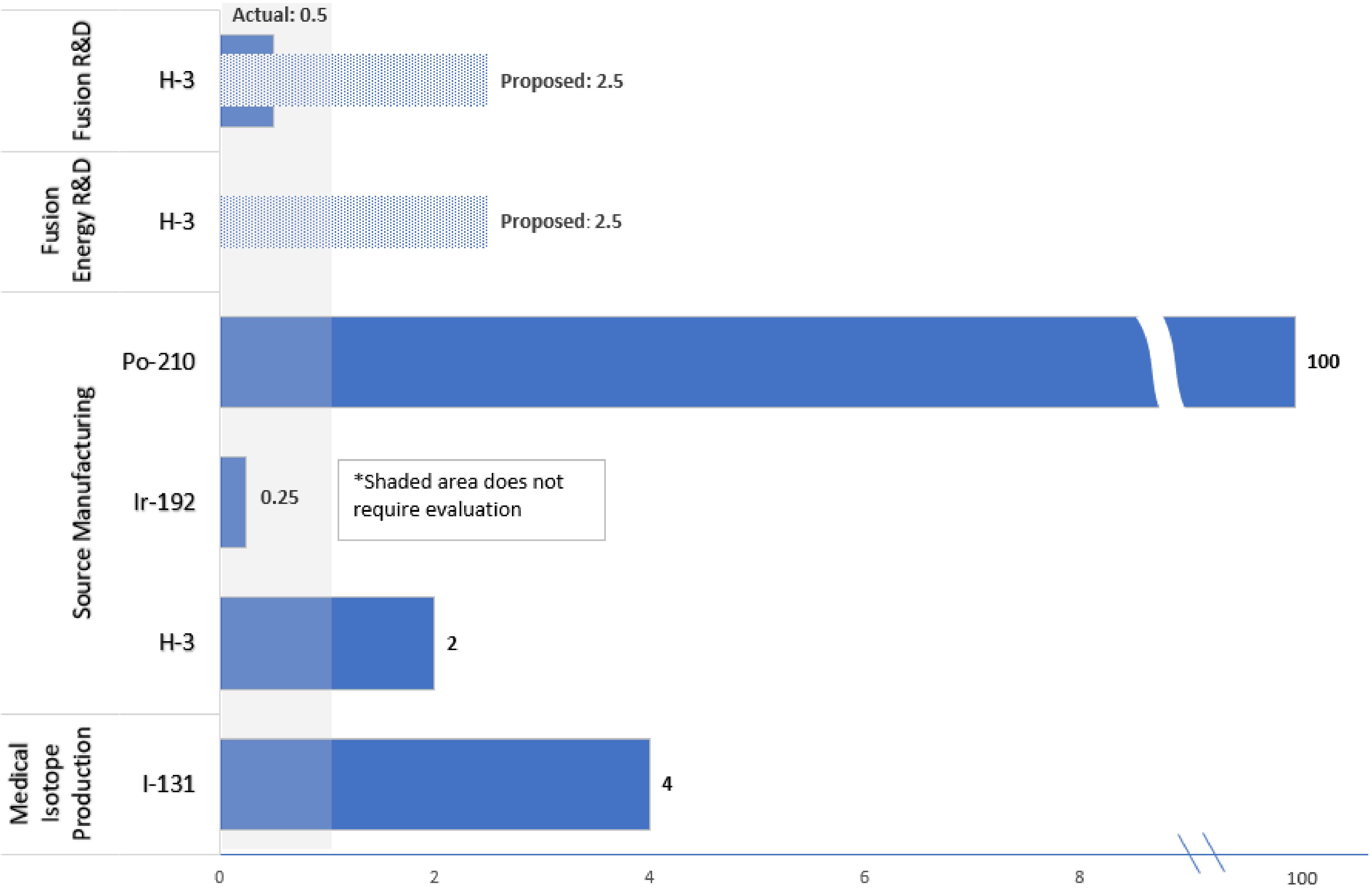
Duncan White (NRC)
Diego Saenz (Wisconsin)
Huda Akhavannik (NRC)
Donald Palmrose (NRC)

October 27, 2021

Overview of a Part 30 Approach

- Part 30 licensing has key frameworks that may be leveraged or extended to license fusion facilities
  - Examples: Emergency Planning, Effluents, Training
- Categorization criteria for fusion facilities
- Could be used in combination with other regulatory mechanisms for a graded approach
- Any scalable approach needs clear and predictable decision-making criteria to ensure consistency and regulatory certainty

Quantities of Radioactive Materials Requiring Emergency Plan Evaluation



Effluents

Facilities with robust radiological effluent control systems are licensed to have less than 10% of the 10 CFR 20, Appendix B, release requirements.

Facility Type	Inventory
Nuclear Pharmacy	I-131, Mo-99
Medical Isotope Production	I-131, Mo-99
Fusion R&D (proposed)	H-3, Lu-177, Yb-175, Yb-177
Source Manufacturing	H-3, Co-60, Cs-137, Ir-192, Am-241
Fusion Energy R&D	H-3
Rare Earth Processing	U-238, Th-232

Training Features of Part 30

- Based on role and level of interaction with material
- Individual named on the license could be the supervisor or the primary handler/operator
  - Following table focuses on individuals named on the license or on licensee-maintained list
- Designed to fit industry involved
  - Medical use heavily leverages Medical Boards and Licensure
  - Industrial radiography leverages third-party certifiers such as American Society of Nondestructive Testing, Inc (ASNT)

	Portable/Fixed Gauges	Diagnostic Medical	R & D (incl. Fusion)	Manufacturer & Distributor	Well Logging	Radiation Oncology	Industrial Radiography	Panoramic Irradiators
Transferable	X	X	X	X	X	X	X	X
Refresher Training	X	X	X	X	X	X	X	X
OJT	X	X	X	X	X	X	X	X
Specific number of hours		X	varies	varies		X	X	
Device Specific Training			varies	varies	X	X	X	X
Requires AU's physical presence	C		varies	varies	X	X, C	X	X
3rd Party User Examination		C				C	X (periodic renewal required)	
Review Past Events					X	C	X	X
Simulated Events						X, C	X, C	X

C – Commonly used to meet regulatory criteria or commonly required by licensee tie-downs

X – Required by regulation or included in Licensing Guidance

Categorization Considerations

Tritium inventory already used in regulations

Radionuclide form (gaseous, liquid, bound, unbound) affects offsite consequences, not just activity.

Megawatts electric (MW_e) or thermal (MW_{th}) may not correlate to radiological risk for fusion facilities

Tritium handling system may account for a large fraction of tritium inventory and inventories could widely vary

Wide range of facility types, including aneutronic fusion

Agreement State Considerations

- Agreement States may be willing and able to maintain on-site inspection staff (e.g., Resident Inspectors)
  - Illinois Emergency Management Agency currently maintains Resident Inspectors at their nuclear power plants
- Agreement States may follow NRC practice of consulting with DOE National Laboratories and other contractors for portions of licensing review

Conclusion

STAFF IS CURRENTLY CONSIDERING PART 30 AS A POTENTIAL APPROACH.

CURRENT APPROACH TO TRAINING, EFFLUENTS, AND EMERGENCY PLANNING ARE ALL APPLICABLE TO FUSION FACILITIES.

CATEGORIZATION CRITERIA MAY BE APPLICABLE TO FUSION LICENSING UNDER PART 30.

AGREEMENT STATES WOULD BE KEY PARTNER IN REGULATION OF FUSION FACILITIES.

10 CFR PART 53

Overview and Status

Part 53 Relationship to Fusion Energy Systems

Nuclear Energy Innovation and Modernization Act (NEIMA) and Commission Direction

- "advanced nuclear reactor" means a nuclear fission or fusion reactor, …
- SRM-SECY-20-0032 approved staff's approach for Part 53 rulemaking and directed the staff to consider the appropriate treatment of fusion reactor designs in our regulatory structure by developing options for Commission consideration
- July 15, 2021, NEIMA Section 103(e) Report to Congress on Part 53 Rulemaking

Staff's Response to SRM-SECY-20-0032 and Path Forward

- Continue interactions in public forums with U.S. Department of Energy (DOE) and Fusion Industry Association (FIA)
- Develop options for regulatory approaches for fusion in parallel with Part 53 rulemaking
- Part 53 primarily fission-based; technology-inclusive concepts may accommodate fusion technologies—maintain flexibility for future Commission direction
  - Part 53 is an option to be presented to the Commission

Transformative Aspects of Part 53

- Establishment of technology-inclusive safety criteria
- Risk-informed approach to safety criteria to provide predictability for the classification of plant equipment and controls over that equipment during operation
- Approach to the selection of design basis accidents (DBAs) that provides flexibility to designers to designate which equipment will be classified as safety-related
- Allowances for applicants to credit analytical safety margins in their design to gain operational flexibilities in areas such as EP and plant siting
- Quality assurance requirements that would allow use of a broader set of codes and standards
- Proposal to address manufactured reactors that would be fueled at the manufacturing facility and transported to the reactor site

Part 53 Development





Publishing

The staff continues its novel approach of releasing preliminary rule language to facilitate early stakeholder engagement

Engaging

Optimizing future public and ACRS meetings to be more topic-specific to enable richer focused dialogue on specific issues (e.g., staffing, role of PRA)

Responding

Continuing to consider input from numerous stakeholders, the public, and ACRS, as we evaluate changes to the preliminary language

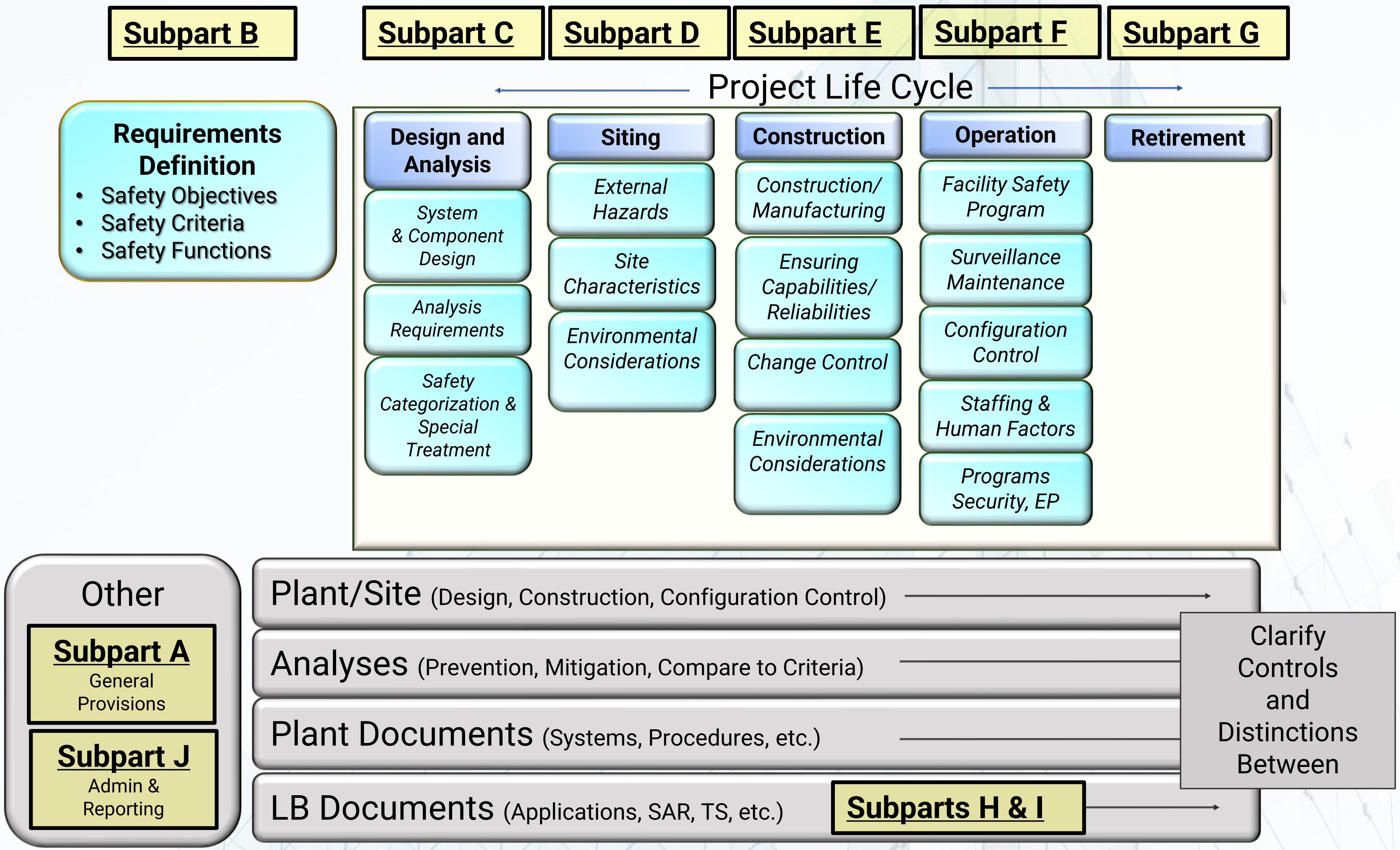
Evolving

Developing options for technology-inclusive alternatives that do not rely on PRA in a leading role to address stakeholder comments

Assessing

Developing the path forward to achieve the objectives of the approved rulemaking plan while addressing stakeholder comments

Part 53 Outline



Part 53—Rulemaking Status

Rule Language

- Early Release: (A) definitions, (B) safety criteria, (C) design and analyses, (D) siting, (E) construction & manufacturing, (F) operations, programs, (Part 73) security and EP.
- Recent Release: revision to (B) safety criteria and (C) design and analyses; new language for (H) licensing processes, (I) maintenance of the licensing basis, and (J) reporting and financial
- Nearing completion of 1st iteration of all Part 53 subparts and Technology-Inclusive Deterministic Alternative

Recent Industry Input

- NEI letter presenting unified industry positions (July 14)
- USNIC letter (July 15)
- NEI Manufacturing Licenses white paper (July 16)
- NEI comments on security sections (August 31)
- NEI Role of PRA white paper (September 28)

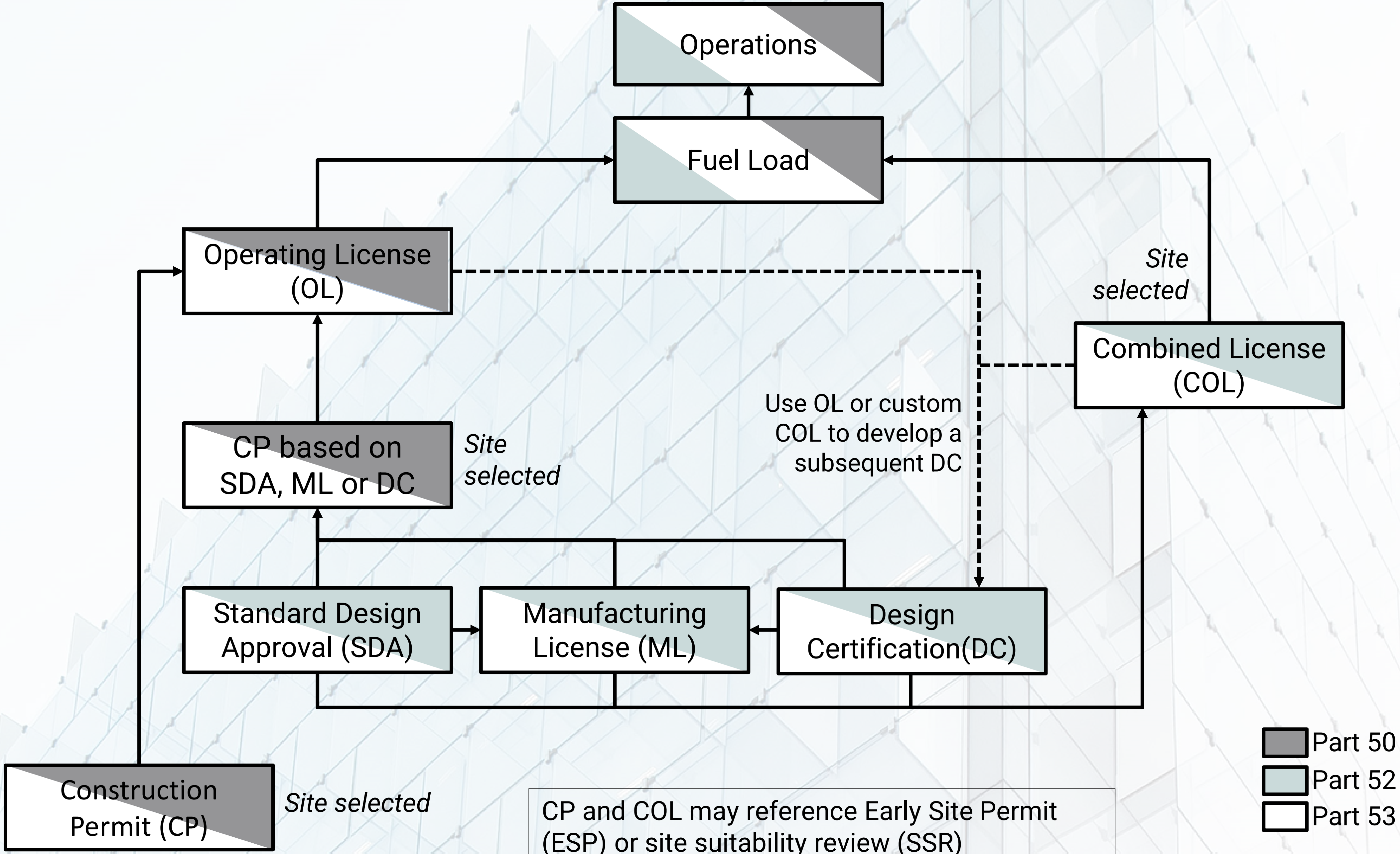
Stakeholder Engagement

- 8 public meetings and 9 ACRS meetings
- Future meetings will be topic focused
- Recent meetings:
  - This week: 10/26 on Personnel (Subpart F); 10/28 on Technology-Inclusive Deterministic Alternative
  - Public: 9/15 on 50.59-like change process; 8/26 on graded PRA; 6/10 on Security and EP
  - ACRS: 9/23 ACRS meeting; 7/21 on EP/Licensing Modernization Project

Focus Areas

- Continue stakeholder engagement
- Continue preliminary release of rule language
- Develop the rule package
- Work on the supporting guidance

Leveraging and Combining Existing Licensing Processes



CP and COL may reference Early Site Permit (ESP) or site suitability review (SSR)

Next Steps

- Continue ongoing activities
  - Part 53 development and stakeholder engagement
  - Continue public forums with DOE and FIA
- Deliver options paper to Commission – informed by stakeholder interactions
- Incorporate fusion technologies into a technology-inclusive regulatory framework by 2027 in manner directed by Commission
- Key documents related to the Part 53 rulemaking, including preliminary proposed rule language and stakeholder comments, can be found at Regulations.gov under Docket ID NRC-2019-0062


Thank You


Discussion/Questions

Schedule/Next Steps

- The timeline for providing options to the Commission on the licensing and regulations of Commercial fusion power plants is being done in parallel, but on a separate schedule from the development of the draft proposed 10 CFR 53.

- A separate schedule means that if the NRC pursues rulemaking to address fusion facilities, the schedule could extend beyond 2024, but would be completed before 2027 to comply with the Nuclear Energy Innovation and Modernization Act.

- Rulemaking is done via a comprehensive, multi-step process. Additional information:
  https://www.nrc.gov/about-nrc/regulatory/rulemaking/rulemaking-process.html

- The NRC would consider extending the May 2022 SECY paper target date should an extension to the 10 CFR 53 schedule occur.

- Extending the proposed SECY aligns well with industry's desire to have a series of workshops to allow for greater engagement and understanding of fusion technology, risk, and legal requirements.

THANK YOU!

Closing Remarks