Rulemaking: Regulatory Framework for Fusion Energy Systems

NRC Public Meeting

July 12, 2023

U.S.NRC

United States Nuclear Regulatory Commission

Protecting People and the Environment

AGENDA

Time	Topic	Speaker
1:00 pm	Welcome & Meeting Logistics	Dennis Andrukat
1:10 pm	Opening Remarks	Theresa Clark
1:15 pm	NRC Presentation – Rulemaking Overview	Duncan White
1:45 pm	Stakeholder Perspectives	Laila El-Guebaly, Andrew Holland, Sachin Desai, Tyler Ellis
2:45 pm	BREAK	All
2:55 pm	Questions & Feedback	All
3:55 pm	Wrap-up & Adjourn	Dennis Andrukat

WELCOME

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OPENING REMARKS

Theresa Clark, Deputy Director

Division of Materials Safety, Security, State, and Tribal Programs

Office of Nuclear Material Safety and Safeguards

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RULEMAKING OVERVIEW

Duncan White

Division of Materials Safety, Security, State, and Tribal Programs

Office of Nuclear Material Safety and Safeguards

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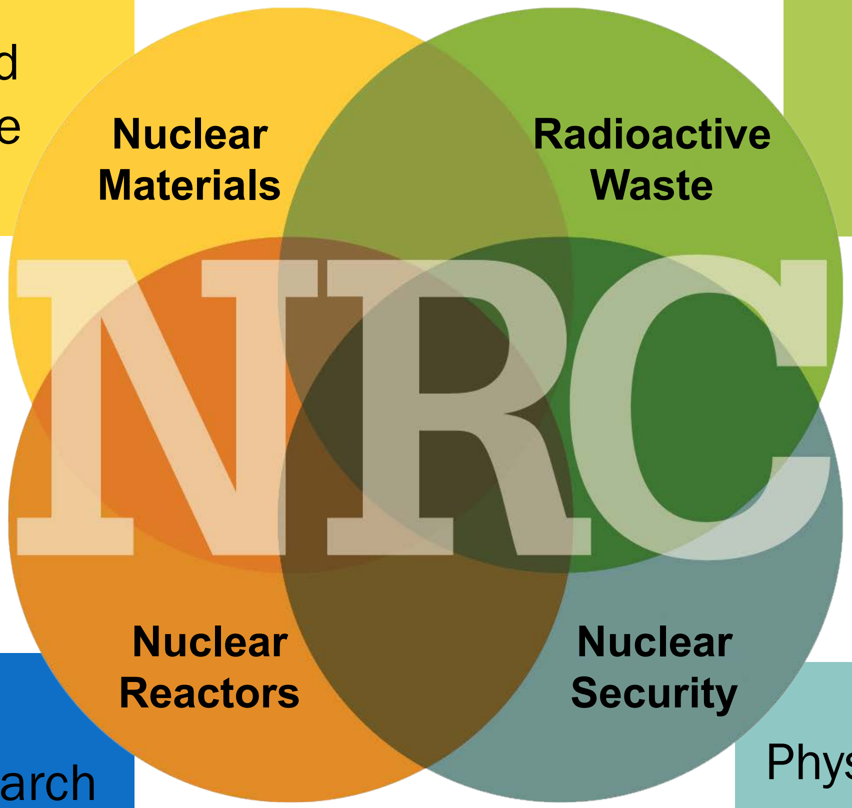
Background

- The Nuclear Energy Innovation and Modernization Act (NEIMA; Public Law 115-439) requires NRC to establish a **technology inclusive regulatory framework** for fusion energy systems by December 31, 2027
    - Definition of advanced reactor includes “fusion reactor”
- On January 3, 2023, staff submitted SECY-23-0001, “Options for Licensing and Regulating Fusion Energy Systems,” with rulemaking plan enclosed (ML22273A178)
    - Three options
    - Proposed rulemaking would be limited in scope to include definitions, content-of-application requirements, and other targeted augmentations

Radioactive materials for medical, industrial and academic use

Transportation, storage and disposal of nuclear material and waste, and decommissioning of nuclear facilities



Commercial power reactors, research and test reactors and new reactor designs

Physical security, source security and cyber security

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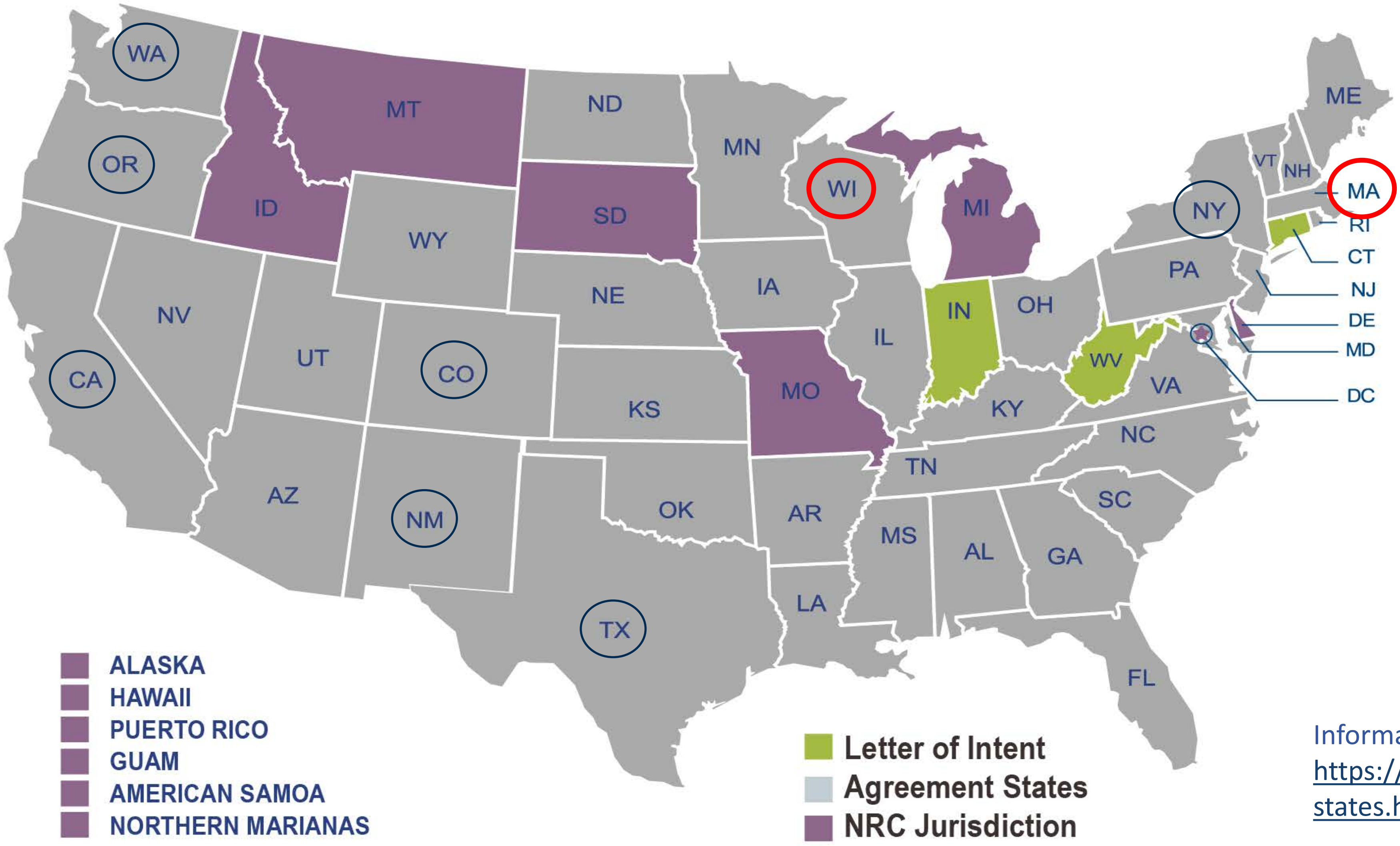
U.S. Agreement States



Information on Agreement State Program: https://www.nrc.gov/agreement-states.html

Note: Data are current as of February 2023. For the most recent information, go to the Agreement State page at https://www.nrc.gov/agreement-states.html. In February 2023, the State of West Virginia submitted a letter of intent to the NRC to become an agreement state.

Source: U.S. Nuclear Regulatory Commission - As of February 2023

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Commission Direction

for Fusion Energy Systems

On April 13, 2023, the Commission issued SRM-SECY-23-0001 "Options for Licensing and Regulating Fusion Energy Systems" (ML23103A449) directing the staff to implement a byproduct material approach to fusion energy system regulation (Option 2)

Byproduct Material Framework

10 CFR Part 30 -Rules of General Applicability To Domestic Licensing of Byproduct Material

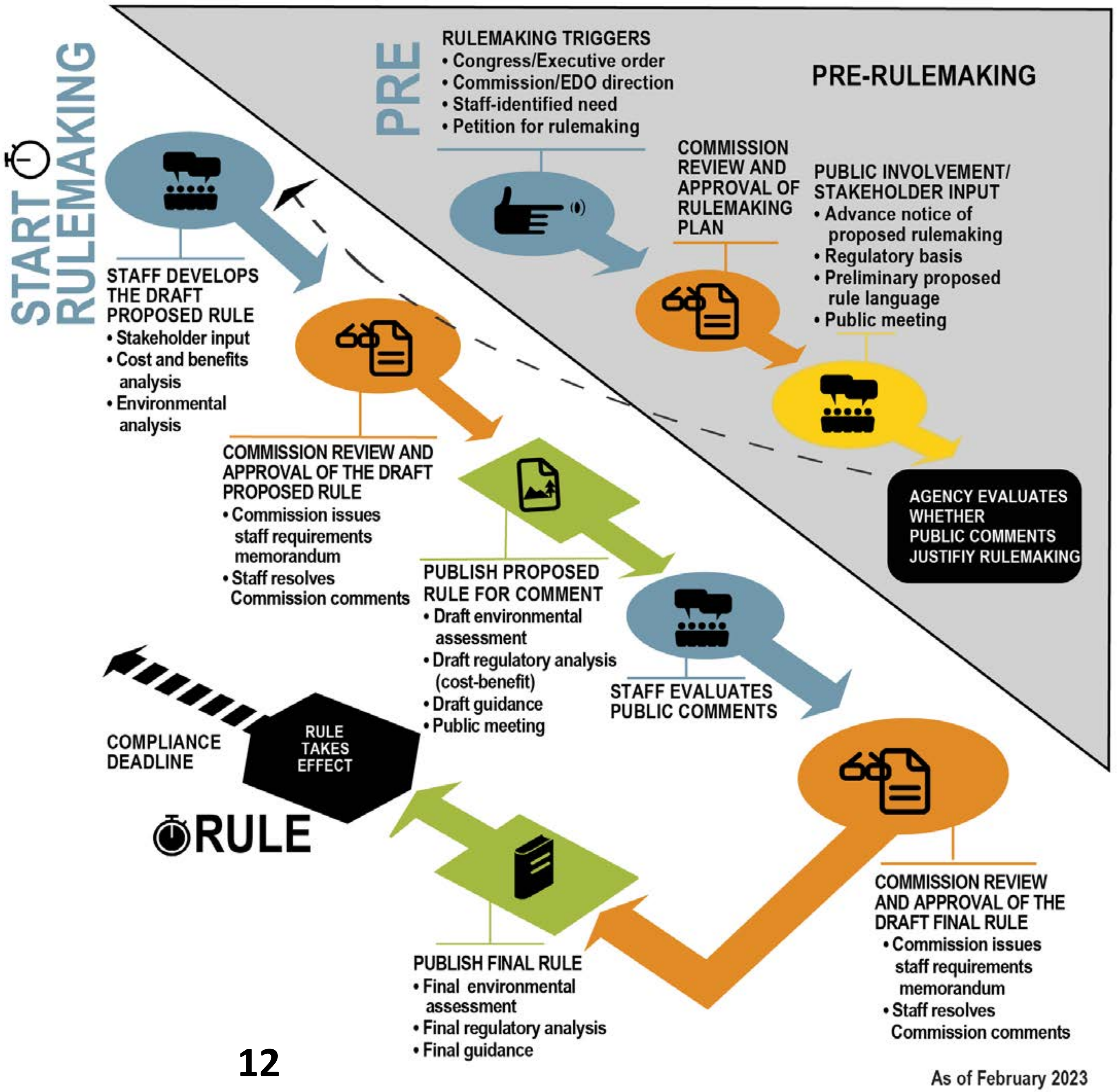
NUREG-1556 Guidance

NUREG-1556, "Consolidated Guidance About Materials Licenses"

Specific Considerations from the SRM

- Scope limited to currently known fusion energy system designs
- The staff should consider existing fusion energy systems already licensed or under review by Agreement States
- The staff should evaluate whether controls-by-design approaches, export controls, or other controls are necessary for near-term fusion energy systems
- If a design presents hazards sufficiently beyond near-term technologies, staff should notify the Commission and make recommendations for appropriate action

NRC Rulemaking Process



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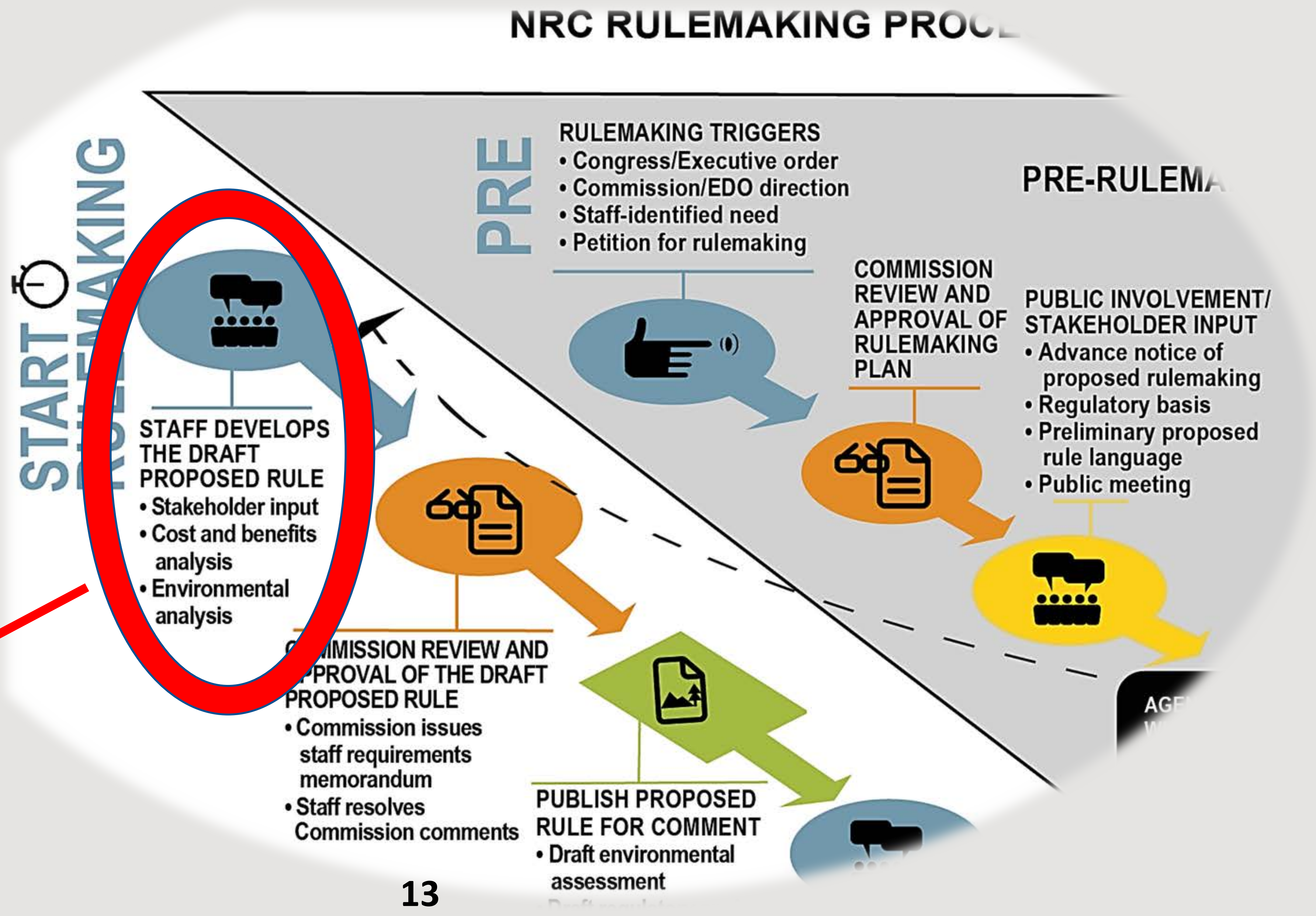
NRC Rulemaking Process

WE ARE HERE



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SCOPE OF FUSION RULEMAKING ACTIVITIES

Rulemaking:

- Based on 11e.(3) definition in AEA of byproduct material
  - Radioactive material for research, commercial or medical purposes
  - Accelerator-produced
- Limited-scope rulemaking in 10 CFR Part 30 to cover only near-term, known fusion energy system designs:
  - Definitions
  - Content-of-application requirements specific to fusion - Use standard Part 30 processes where applicable
  - Other fusion-specific requirements, as needed, to address specialized topics
  - Compatibility determinations part of rulemaking process

SCOPE OF FUSION RULEMAKING ACTIVITIES

Licensing Guidance:

- New NUREG-1556 licensing volume
  - Well established structure
- Focus on topics that distinguish fusion from other uses of radioactive materials
- Address range of fusion technologies – technology inclusive
- Use standard content from guidance documents to the extent possible
  - NRC, State, and DOE
  - No other licensing guidance development anticipated

Other Related Activities (Non-Rulemaking):

- Technology-specific implementation advice
- Inspection guidance
- Training for NRC and Agreement State staff

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Licensing with NUREG-1556 Guidance Documents

- Wide range of materials uses under Part 30 - regulations would be complex and burdensome to maintain without licensing guidance documents
- Provides specific instructions to *applicants and reviewers* on what requirements are expected to be addressed in an application and information to be provided for a radioactive material license
- Applicant/Licensee submittals to regulatory agency based on licensing guidance documents can be used as ***legally binding requirements (LBRs)*** when incorporated into license as a tie-down condition
  - LBRs can be enforced the same as regulations
  - Provides the licensee flexibility

Fusion-Specific Issues

- Radioactive material inventory challenges due to activation products and tritium production
  - Possession Limits
  - Financial Assurance
  - Potential offsite consequences
- Facility design requirements and shielding
- Tritium form and dosimetry
- Tritium handling systems
- Security
- Offsite emergency preparedness evaluation
- Environmental review

Fusion Rulemaking Activities Since the SRM…

- Program and Technical Lead shifted to NMSS
- Proposed rulemaking efforts underway
  - Identified NRC and Agreement State staff
  - Developing outreach schedule
  - Started work on specific topics
- Start of public meetings and engagement with stakeholders
- Commission receives proposed rule and draft guidance by Fall 2024

NRC Outreach

Leverage Existing Communication Avenues

- State-Tribal Communication letters
- Government-to-Government meetings
- Public Meetings
- User Group(s)

Build Capabilities and Knowledge

- Workshops
- Seminars
- Training
- Staff rotations/details

Engagement Timeframe

- Start of official rulemaking
- Middle of draft development *(before concurrence)*
- After publication of proposed rule

(during public comment period)

Additional meetings as needed

Leverage Existing Regulatory Experience

- Agreement States
- DOE
- ARPA-E
- SDOs (ASME, ANS)
- International

Diverse Stakeholder Engagement

- Agreement States
- Tribal Nations
- Federal Agencies
- Fusion Industry
- Professional Associations
- Utilities
- Universities
- International community
- Non-Government Organizations

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Challenge – Diversity of Designs and Hazards under One Framework

Fusion Reactions (Fuel)
- Deuterium – Tritium (DT)
- Proton – Boron 11
- Deuterium – Helium 3

Radiological Hazards
- Potential Accident Scenarios
- Activation Products
- Neutrons

Fusion Technologies
- Magnetic
- Inertial
- Magneto-Inertial

Design Elements
- Shielding
- Systems
- Access Control, etc.

Programmatic Elements
- Radiation Protection
- Security & Emergency Preparedness
- Waste Management
- Control & Accountability, etc.

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Inquiry to Develop Fusion-Specific Standards to Regulate Radioactive Waste of Fusion Energy System

Laila El-Guebaly
University of Wisconsin-Madison
Consultant to CATF

Sehila Gonzalez and **Joe Chaisson**
Clean Air Task Force
(https://www.catf.us)

NRC Virtual Public Meeting:
Commencing of NRC Rulemaking
for Fusion Energy System

July 12, 2023

Fusion Generates Large Amount of Mildly Radioactive Materials That Needs Serious Effort to Manage

What to do with the sizable fusion waste?

We recommend returning all radioactive materials (mainly steels and concrete) to nuclear and public industries through recycling and clearance.

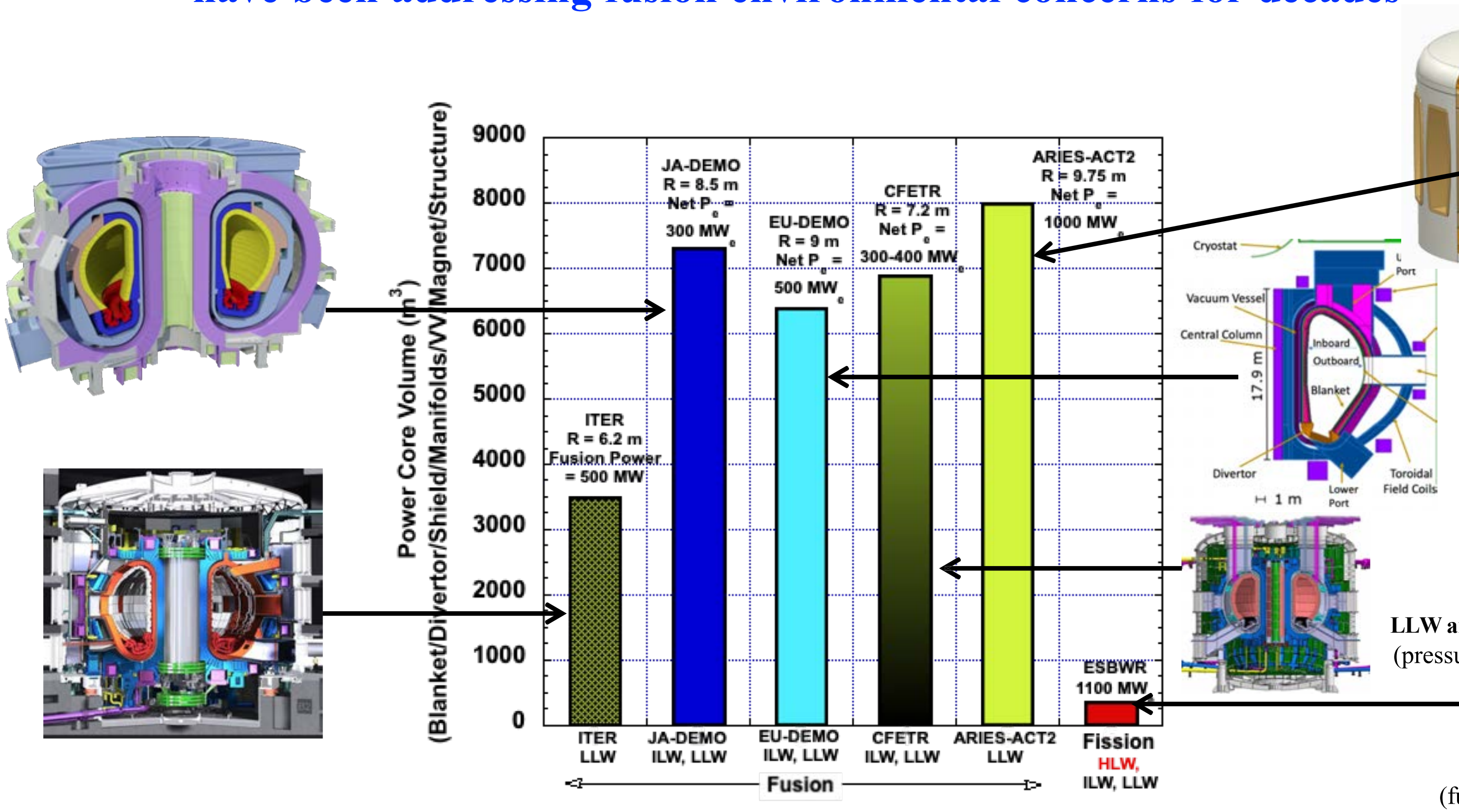
For more details, refer to:
Laila El-Guebaly, "Development of Integral Management Scheme for Fusion Radioactive Materials: Recycling and Clearance, Avoiding Disposal."

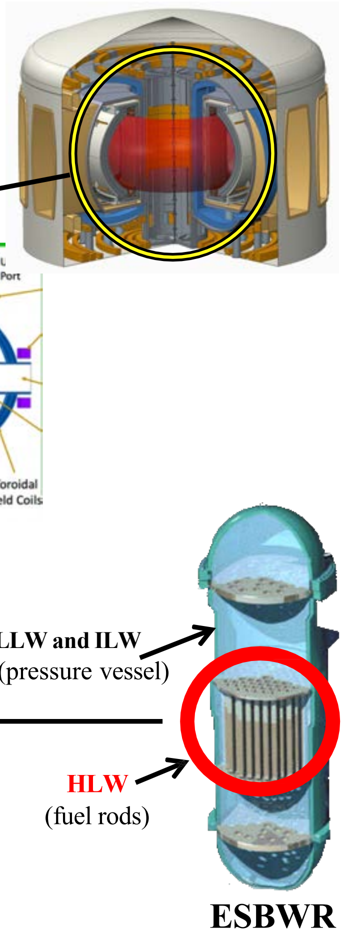
Presented at **June 7, 2022**
NRC Virtual Public Meeting:
Developing Options for a Regulatory Framework for Fusion Energy System.
Available at: https://uwmadison.box.com/s/b5l4y36gj2gi2ukmu7wtojstjhhe3x1a

To recap…

Fusion Generates Low-Level Waste, but in Large Quantity Compared to Fission

Fusion experts (in U.S., Japan, Europe, China, and RF) have been addressing fusion environmental concerns for decades

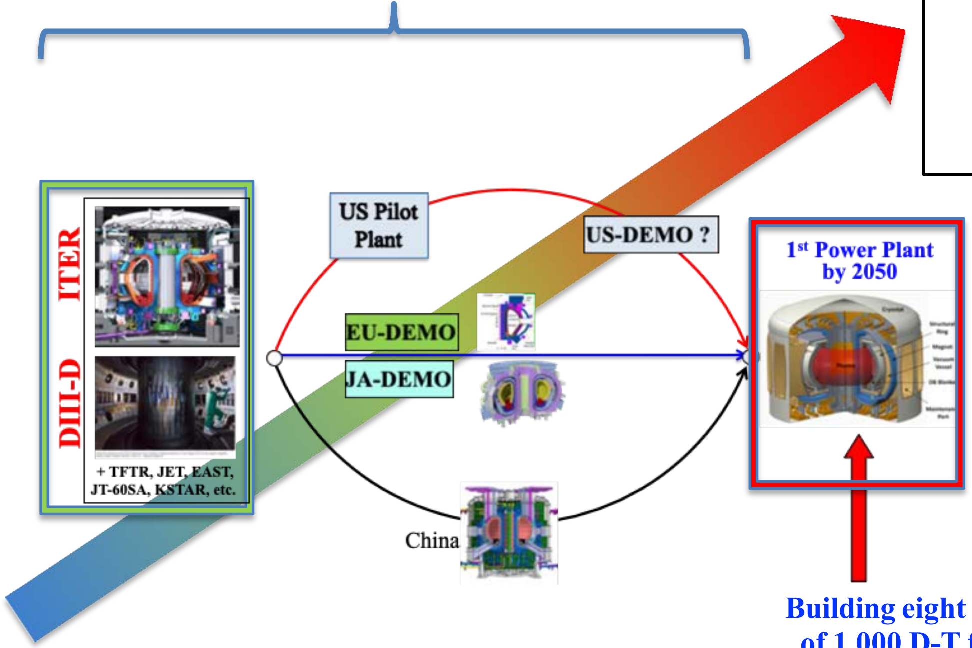




Actual volume of fusion power components in ITER, JA, EU, China, and US ARIES designs; not compacted, no replacements; no plasma chamber; no cryostat/bioshield. EU-DEMO values are only preliminary and will be refined in the next phase of the design.

Radioactivity Level Varies Widely with Fusion Designs

One-of-a-kind Devices



High Radioactivity (Power Plant):

- High radwaste inventory
- High fusion power (2-3 GW)
- High NWL ($\geq$ 1 MW/m^2)
- High availability (85%)
- > 50 y lifetime
- High n fluence ($\geq$ 20 MWy/m^2)

This leads to RWM* challenges that require serious effort to manage radwaste.

Building eight 1-GW$_e$ fusion plants annually, fleet of 1,000 D-T fusion power plants could provide ~10% of world electricity demand by ~2200.

Resources will Eventually be Limited

Luigi Di Pace, "Suitable Recycling Techniques for DEMO Activated Metals." IAEA TECDOC on Fusion RWM, to be published in 2023.

Low Radioactivity (ITER):

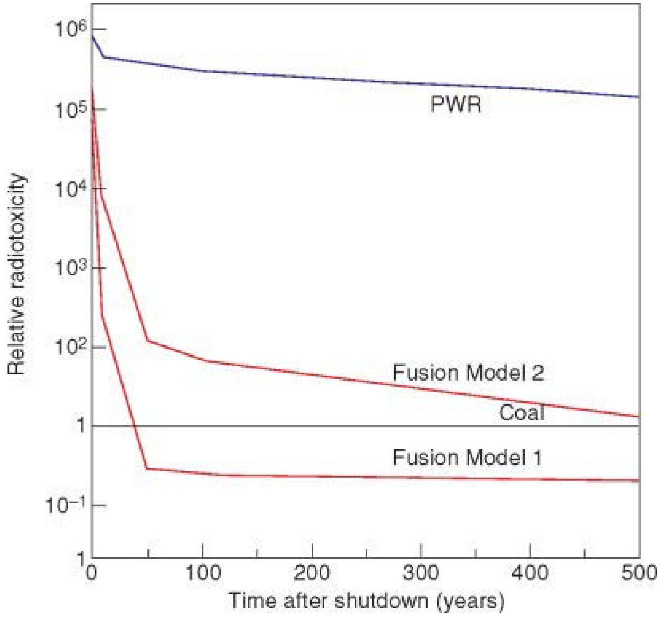
- Relatively low radwaste inventory
- 500 MW fusion power
- Low NWL (0.5 MW/m^2)
- 20 y lifetime
- Low availability
- Low n fluence (0.3 MWy/m^2)

* Radioactive waste (radwaste) management

Fusion Offers Advantages Over Most Other Energy Types

Fusion advantages:

- Not weather dependent (like solar and wind)
- Large amounts of 24/7 energy in small land footprints
- No long-lived byproducts
- Low radiotoxicity* compared to fission.



However, environmental concerns could influence public acceptance to fusion energy, if remains unaddressed.

** The radiotoxicity is calculated by multiplying a dose factor by the ingested activity. The dose factor varies in large proportions; from 1 in the case of beta low energy emitters, such as tritium, to 10,000 in the case of alpha emitters, such as plutonium and uranium isotopes.*
Ref.: Garry McCracken, Peter Stott, "Why We Need Fusion Energy," Chapter 12 in Academic Press Book: Fusion – The Energy of the Universe (2005), Pages 145-154. https://www.sciencedirect.com/science/article/abs/pii/B9780124818514500147

What we Suggest

- **Focus on**:
  - Minimizing the waste by clever design
  - Limiting radwaste requiring disposal
  - Emphasizing recycling and clearance to minimize waste requiring disposal
  - Develop fusion-specific disposal class and regulations for remaining fusion radwaste after recycling.

- **Why?**
  - Fusion generates large quantity of LLW (mostly steel and concrete)
  - Limited capacity of existing LLW repositories
  - Political difficulty of building new repositories (for both LLW and HLW)
  - Stricter regulations and tighter environmental controls
  - Uncertain geological conditions over long time
  - Minimize radwaste burden for future generations
  - Reclaim resources by recycling and clearance
  - Promote fusion as energy source with minimal environmental impact
  - Gain public acceptance for GREEN fusion **(The fusion design stages, commercialization procedures, and use of processes and products that minimize pollution, promote sustainability, and protect the environment and human health without sacrificing economic viability and efficiency)**
  - Support decommissioning goal of U.S., IAEA and international nuclear programs in 21st century.

Recycling/Clearance Approach Supports Goals of U.S., IAEA and International Programs to Manage Nuclear Waste in 21st Century

Main goal of following organizations is to minimize waste volumes, recycle, and clear as much of materials as practical.

Reasons:

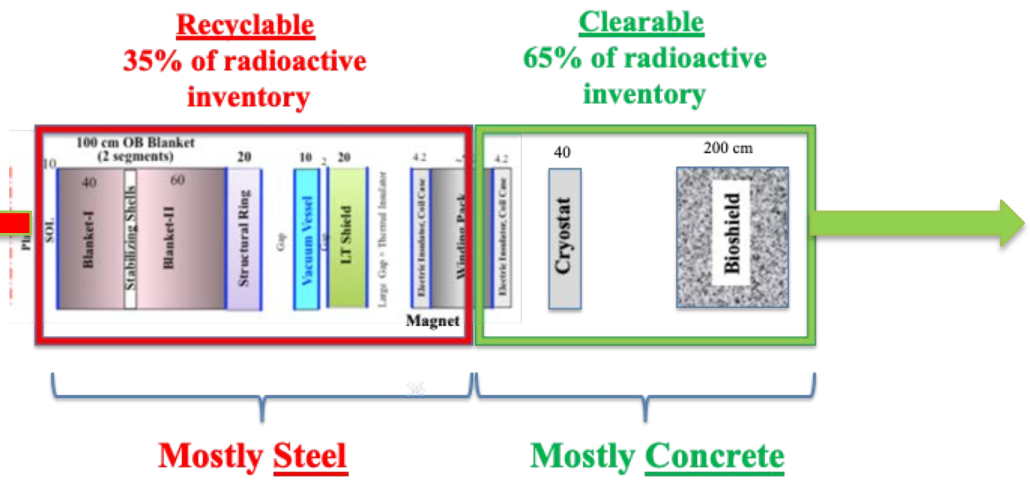
- Reclaim the use of metal resources (through less mining of materials, and maintaining a sustainable environment)
- Reduce volume of waste requiring disposal (free ample space in repositories, and save millions of dollars for high disposal cost).

- **U.S**. DOE: 1996 Fusion Safety Standing Committee, 1999 Snowmass Fusion Report, and 2007 FESAC Fusion Report.
- **ARIES** national project for GW-power plant designs.
- **NAS** 2013 report for Inertial Fusion Energy.
- **IAEA** 2019 Workshop on Novel Trends in Decommissioning.
- **UK** Atomic Energy Authority on Safety Aspects for Fusion Power Plants.
- **JET** fusion experiment at UK.
- **EU** Fusion DEMO (under development).
- **Japan** Fusion DEMO (under development).
- **China** CFETR design (under development).

Applications of Recycling/Clearance to Fusion Power Plants

(Typical Fusion Radial Build – ARIES-ACT2)

Recycle power core materials and return back to nuclear industry



Clear slightly radioactive materials and release to commercial market

Beside Steel and Concrete, Fusion Employs Other Structural and Functional Materials

Structural Materials:

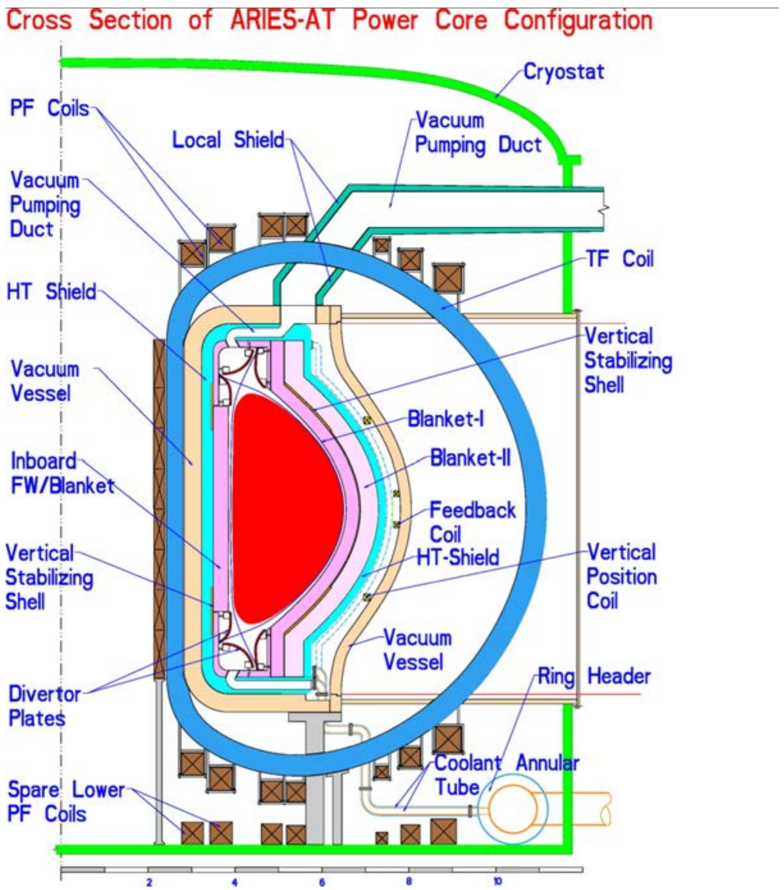
- **Steel** alloys
- Tungsten alloys
- Vanadium alloys
- Copper alloys
- SiC/SiC composites

Recyclable Functional Materials:

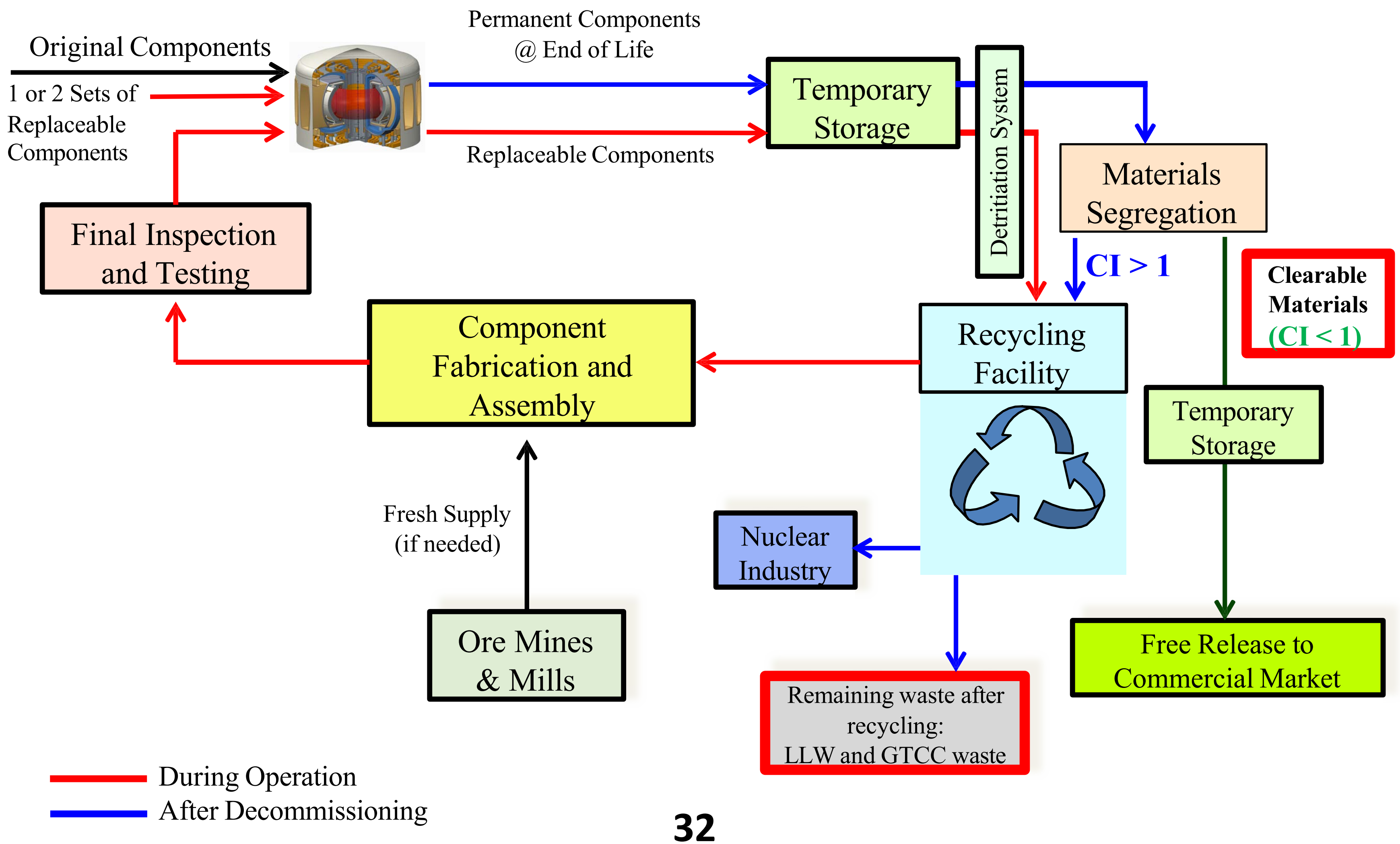
- Liquid metal breeders
- Ceramic breeders
- Molten salt breeders
- Neutron multipliers (Be and Pb)

Others:

- Magnets (largest inventory in FPC)
- Bioshield (largest inventory of entire plant, but its **concrete** is clearable).



Recycling & Clearance Flow Diagram for Fusion Decommissioning



Recognizing the relatively early stages of commercial fusion maturity, lessons learned, worldwide knowledge and recycling/clearance experiences from other nuclear and non-nuclear fields are invaluable resources for fusion.

During decades-long fusion efforts, designers faced problems evaluating designs due to lack of fusion-specific regulations.

Inquiries:

1. ***Expand the list of radioisotopes that define Class A and Class C waste categories in 10CFR61 (and for newly developed GTCC) to include all radionuclides of importance to fusion.***
2. ***Expand the list of clearable radioisotopes in 2003 NRC clearance standards to cover fusion-relevant alloys and functional materials.***

First Inquiry

Expand the list of radioisotopes that define Class A and Class C waste categories in 10CFR61 (and for newly developed GTCC) to include all radionuclides of importance to fusion

- Remaining waste after recycling will require land-based disposal as Class A or Class C low-level waste, and/or GTCC waste.
- The most recent "**NRC plans on possible changes to GTCC, low-level waste regulation**" is of interest.
- Fusion community should be engaged in such RWM effort to outline problems that we faced when applying current 10CFR61 disposal limits to fusion.

NRC Classifications of Radwaste

- Radwaste sources: nuclear industries, utilities (from 104 US commercial fission reactors), university research laboratories, manufacturing and food irradiation facilities, hospitals, healthcare companies, and Department of Energy (DOE) facilities.
- NRC 10CFR61 document* has specific disposal requirement for each type of waste so that LLW and HLW are disposed of properly and safely.
- There are several types of radioactive waste defined by NRC:
  - **HLW** is defined as spent nuclear fission fuel and any reprocessing liquids or residues. It is typically very radioactive and can have high heat generation and requires robust shielding (i.e., such as deep geologic storage) to provide for safety. This HLW class applies only to the fission-fusion hybrid concept. This system meets the definition of a Utilization Facility
  - **LLW** can be safely disposed of in a near-surface repository. It is classified into three classes:
    - **Class A** is the least hazardous type of waste. Waste trenches placed 5-8 m below ground surface.
    - **Class B** is more radioactive than Class A
    - **Class C** waste must meet more rigorous requirements. Intrusion barrier, such as thick concrete slab, is added to waste trenches placed > 8 m deep in ground.
  - **GTCC** (greater-than-class C) waste is LLW that contains radionuclide concentrations exceeding Class C limits. NRC is currently preparing the regulatory basis for disposal of GTCC waste. On May 17, 2023, the NRC had a meeting on possible changes to GTCC, low-level waste regulation – this long-awaited proposed rulemaking will cover both LLW and GTCC waste. https://www.nrc.gov/public-involve/doc-comment.html

- *US Code of Federal Regulations, Title 10, Energy, Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste" (2020).*

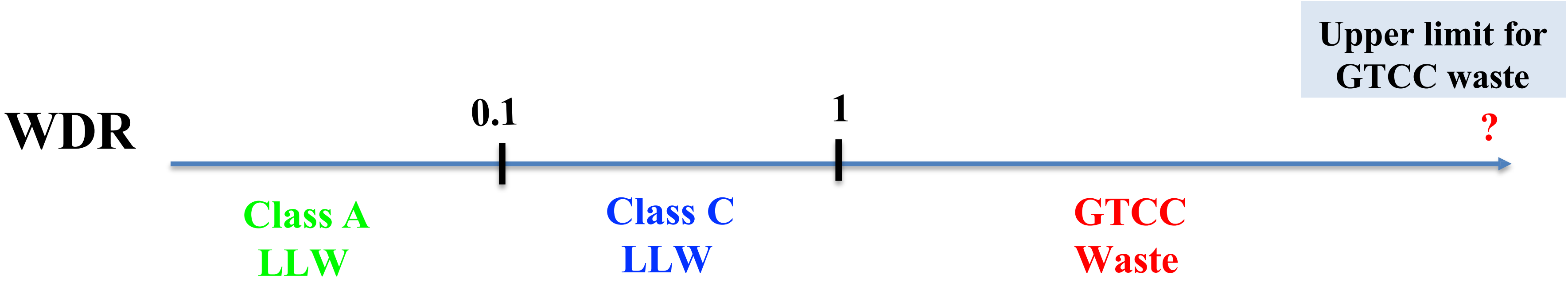
Waste Disposal Rating

(Metric for Waste Classification)

NRC classifies the waste at 100 years after shutdown according to its waste disposal rating (WDR), which is the ratio of specific activity (in Ci/m^3) to allowable limit, summed over only ~10 radioisotopes relevant to fusion:

- **WDR < 1** means Class C LLW (using Class C limits)
- **WDR < 0.1** means waste may qualify as Class A LLW (to be re-evaluated using Class A limits)

- LLW with **WDR > 1** means GTCC waste.



NRC Defined Specific Activity Limits for Class A and C LLW for 9/11 Elements/Radionuclides

NRC 10CFR61 limits for waste classification is based largely on radionuclides that are produced in fission reactors, hospitals, research laboratories, and food irradiation facilities.

Radionuclides	Half-life (y)	Class A Limits (Ci/m³)	Class C Limits (Ci/m³)
H-3	12.3	400	---
C-14	5.7e3	---	80
Co-60	5.3	7e3	---
Ni-59	7.5e4	---	220
Ni-63	100	35	7e3
Sr-90	28.5	0.4	7e4
Nb-94	2e4	---	0.2
Tc-99	2.13e5	---	30
I-129	1.57e7	---	0.8
Cs-135	3e6	---	8.4e3
Cs-137	30	10	4.6e4

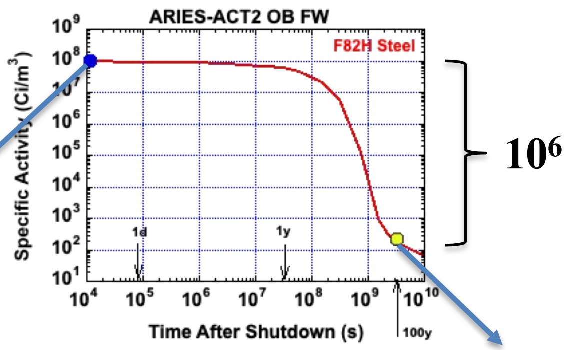
Excluding actinides and fission products. Assuming waste form is activated metal.

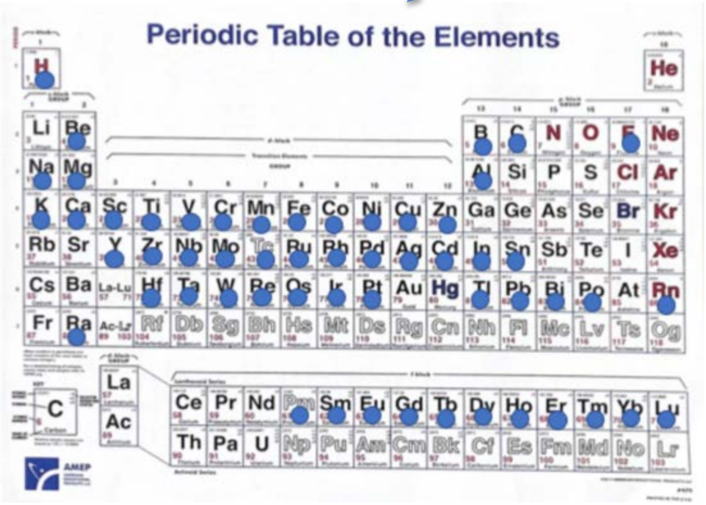
Many radionuclides of interest to fusion are not in the NRC table

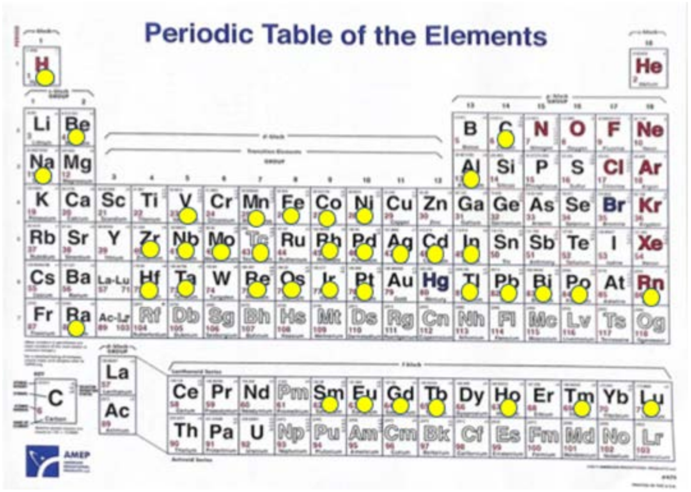
Reason: at the time of original rulemaking in 1980s, no fusion waste was going to commercial sites.

Fusion Generates Numerous Radionuclides
>> 9/11 Elements/Radionuclides in NRC 10CFR61 Tables

Steel First Wall



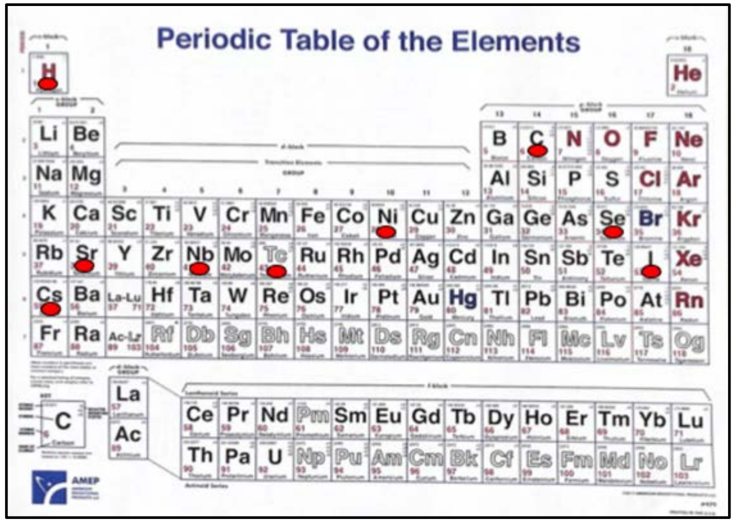




@ shutdown:
56/367 elements/radioisotopes with wide range of activities and half-lives

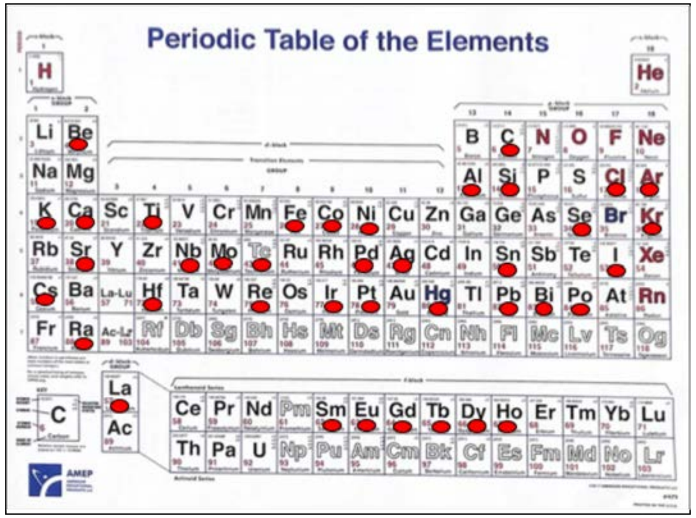
@ 100 y after shutdown:
38/71 elements/radioisotopes with various activities and half-lives

In early 1990s, Fetter Developed Specific Activity Limits for Radionuclides of Interest to Fusion



NRC 10CFR61 provides specific activity limits for **9/11** elements/radioisotopes*

US Code of Federal Regulations, Title 10, Energy, Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste" (2020).

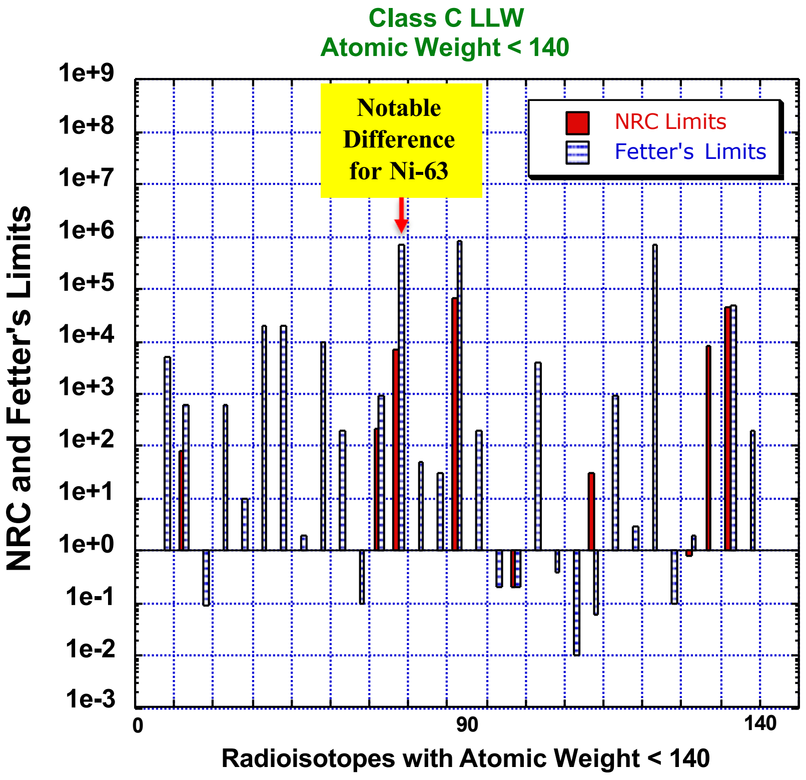


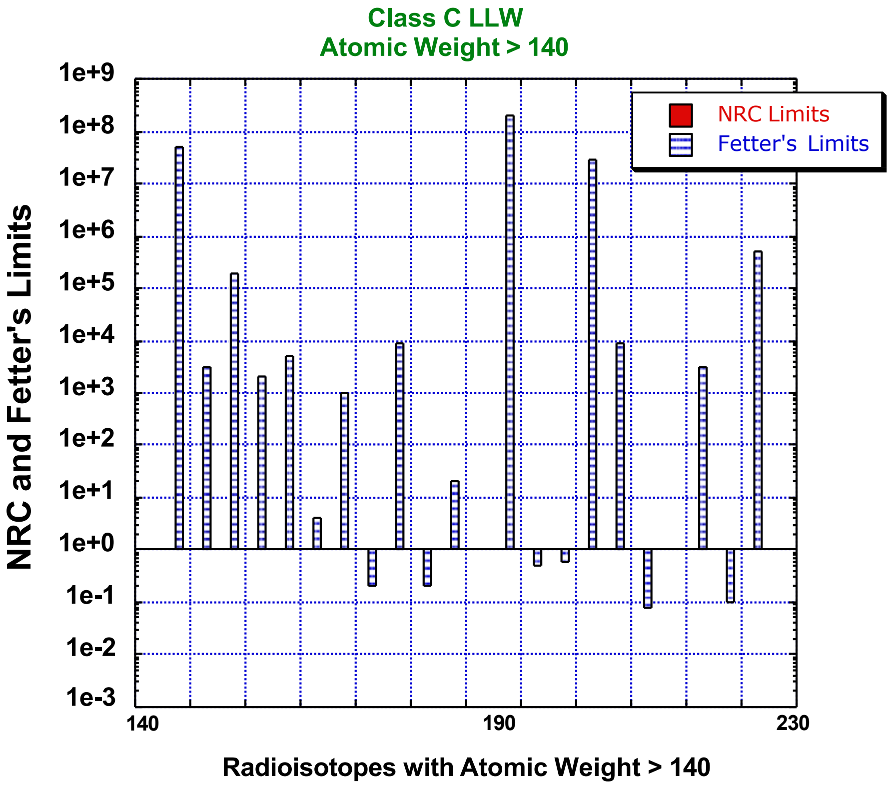
Fetter expanded list of NRC 10CFR61 radionuclides and determined specific activity limits for <u>fusion-relevant isotopes</u> **39/53** elements/radioisotopes*
with 5y < $t_{1/2}$ < 10^{12}y,
assuming waste form is metal.

*S. FETTER, E. T. CHENG, and F. M. MANN, "Long Term Radioactive Waste from Fusion Reactors: Part II," Fusion Engineering and Design, **13**, 239 (1990).*

* Excluding actinides and fission products.

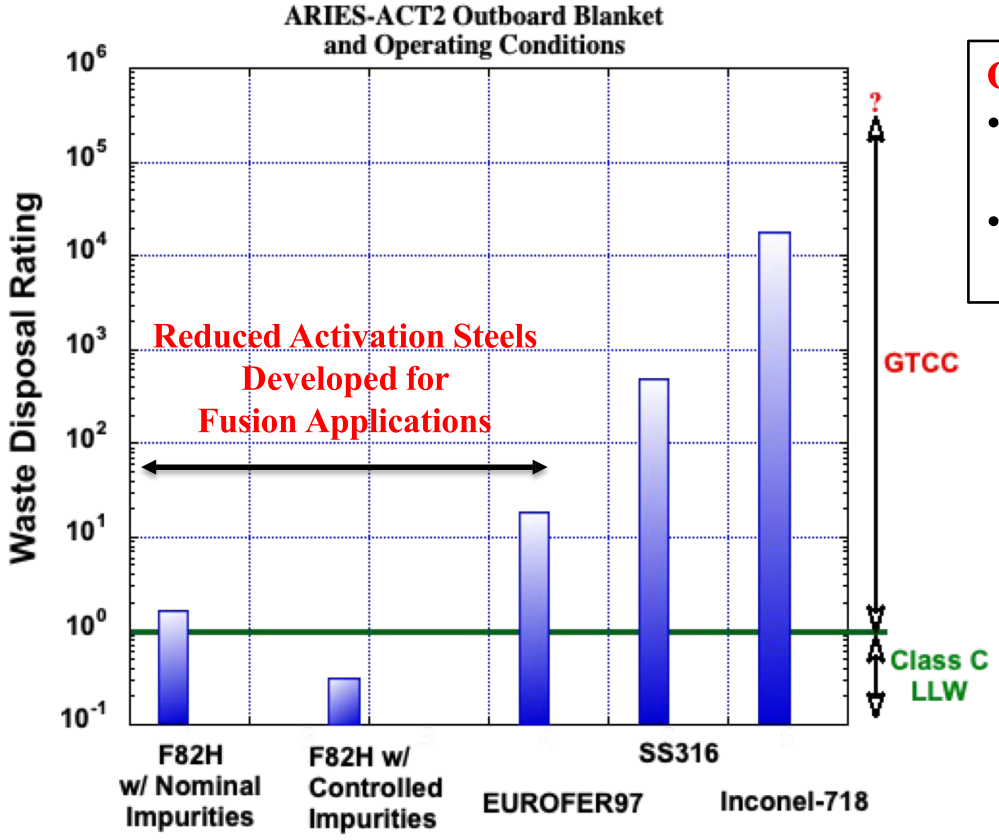
Commonalities and Differences between NRC and Fetter's Limits for Class C LLW





In the absence of fusion-specific regulations, ARIES designs satisfied both NRC and Fetter's limits until NRC develops official guidelines for fusion radwaste.

WDR of Candidate Steels for Fusion Designs



Questions:

- **Could a component with WDR > 10,000 qualify as LLW?**
- **What is the upper limit for GTCC waste?**

To generate Class C (or better) LLW as recommended by National and International Materials Programs:

- Limit Nb impurity to < 1 wppm in F82H and EUROFER97.
- Avoid using two steels: SS316 (of ITER) and Inconel-718 (of MIT ARC design).

Existing NRC LLW disposal limits

(for 11 radioisotopes, excluding actinides and fission products)

present weak basis for evaluating fusion WDR,
calling for fusion-specific limits that cover
all radionuclides encountered in fusion

(> 70 radioisotopes for steel at 100 y after shutdown).

Class A and C disposal limits will need to be expanded considerably to include all radionuclides of importance to all fusion devices that employ different materials and vary greatly in power production level, ranging from 100s of MW to GW of electric power.

Second Inquiry

Expand the list of clearable radioisotopes in 2003 NRC clearance standards to cover fusion-relevant alloys and functional materials

- Clearance fusion campaign could develop clearance standards/guidelines beyond fission*/accelera fields.
- Expand the list of clearable radioisotopes to cover fusion-relevant alloys and functional materials
- **Options for consideration**:
  - NRC could generate clearance limits for individual alloys employed by fusion designs, or
  - Provide a single list of clearance limits for all radioisotopes generated by fusion designs (> 300).

- *Anigstein, R. et al., "Radiological Assessments for Clearance of Materials from Nuclear Facilities," volume 1, NUREG-1640, US Nuclear Regulatory Commission, June 2003. Available at: http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1640/.*

U.S. Department of Energy, "Clearance And Release Of Personal Property From Accelerator Facilities," DOE-STD-6004-2016 (March 2016).

Main Concerns

- The 2003 NRC Clearance document* provides limits for 115 radioisotopes for 3 alloys and concrete:
  - Steel alloy
  - Copper alloy
  - Aluminum alloy
  - Concrete.
- Only 77 radioisotopes (out of 115) are fusion-relevant.
- Many fusion alloys and functional materials cannot be examined with 2003 NRC clearance standards. Examples include:
  - Vanadium alloys
  - SiC/SiC composites
  - Tungsten alloys
  - Tritium breeders
  - Be and Pb neutron multipliers
  - Conductors
  - Electric insulators
  - Thermal insulators
  - Others.
- Large discrepancies exist between NRC* & IAEA# clearance standards.
- Many radioisotopes are missing from ALL clearance evaluations (such as ^{10}Be, ^{26}Al, ^{32}Si, $^{91,92}Nb$, ^{98}Tc, ^{113m}Cd, ^{121m}Sn, ^{150}Eu, $^{157,158}Tb$, $^{163,166m}Ho$, ^{178n}Hf, $^{186m,187}Re$, ^{193}Pt, $^{208,210m,212}Bi$, and ^{209}Po).
- Lack of fusion-specific clearance limits introduces uncertainties in clearance index prediction for fusion materials.

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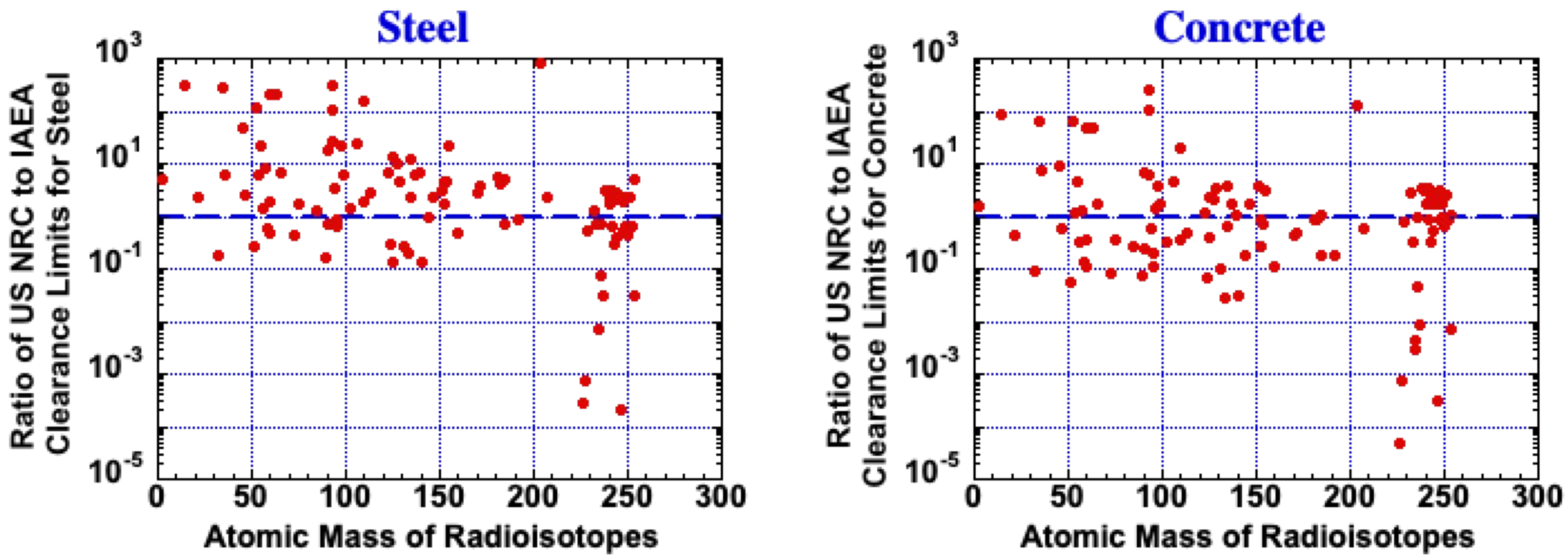
* *Anigstein, R. et al., "Radiological Assessments for Clearance of Materials from Nuclear Facilities," volume 1, NUREG-1640, US Nuclear Regulatory Commission, June 2003. Available at: http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1640/.*

International Atomic Energy Agency, Application of the concepts of exclusion, exemption and clearance, IAEA Safety Standards Series, No. RS-G-1.7 (2004). Available at: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1202_web.pdf.

Discrepancies Between NRC & IAEA Clearance Standards



Such discrepancies impact:

- CI evaluation of components
- Storage period.

Fusion-specific standards are required to build confidence in fusion radwaste classification and clearance of slightly activated materials

Recent publications:

- Laila El-Guebaly, "Managing Fusion Radioactive Materials: Approaches and Challenges Facing Fusion in the 21st Century." Fusion Science and Technology. Available online at: https://www.tandfonline.com/eprint/PKDYQXWAPFSCIQCMD7JE/full?target=10.1080/15361055.2022.2151820
- Laila A. El-Guebaly, "Integral Management Strategy for Fusion Radwaste: Recycling and Clearance, Avoiding Land-Based Disposal," Guest Editorial, Journal of Fusion Energy (2023) 42:11. https://rdcu.be/dbujj
- Laila El-Guebaly, "Fusion Energy Radwaste Management Considerations," ANS Nuclear News magazine – November 2022 – Vol 62, # 12, Page 52-57.
- Sehila M. Gonzalez de Vicente, Nicholas A. Smith, Laila El-Guebaly et al., "Overview on the management of radioactive waste from fusion facilities: ITER, demonstration machines and power plants." Nuclear Fusion 62 085001 (2022) https://doi.org/10.1088/1741-4326/ac62f7

NRC Meeting:

Regulatory Framework for Fusion Energy Systems

July 12, 2023

Andrew Holland
Chief Executive Officer
Fusion Industry Association

The FIA: *Building the Global Fusion Energy Industry*

FIA Mission

The Fusion Industry Association is **the voice** of the growing fusion industry. It is a membership organization that supports efforts to accelerate commercial fusion energy through advocacy and education.

The FIA is an IRS-registered 501(c)6 Membership Association. Its members are the investor-backed fusion developers, and its affiliate members are the companies and organizations that will build the global fusion energy economy.

The FIA's goals are to **accelerate commercially viable fusion energy** by advocating for policies, partnerships, regulations, and industry incentives that support our member companies as they develop commercial fusion power.

The Private Fusion Industry Today

- 43 verified private fusion companies
- **$6.2 billion in investment**
- 13 new fusion companies
- Increasing optimism on timescales
- Growing interest from governments in Public Private Partnerships
- Growing geographical diversity
- But – many challenges remain

FIA Membership

Commonwealth Fusion Systems
HELION
tae
ZAP ENERGY
generalfusion
TYPE ONE ENERGY
GAUSS FUSION
HB11 ENERGY LASER BORON FUSION
AVALANCHE
Tokamak Energy
FOCUSED ENERGY
KYOTO FUSIONEERING
XCIMER ENERGY CORPORATION
first light
EX-Fusion
fuse
THEA ENERGY
MIFTI
RENAISSANCE FUSION
Proxima Fusion
HelicitySpace
ELECTRIC FUSION SYSTEMS
REALTA FUSION
Helical Fusion
LONGVIEW FUSION ENERGY SYSTEMS
BLUE LASER FUSION
SHINE
MarvelFusion
STELLAREX
OPENSTAR TECHNOLOGIES LTD
NOVATRON
nT-tao
LaserFusionX
HORNE TECHNOLOGIES
Princeton SATELLITE SYSTEMS
nearstar FUSION
NK
LPP FUSION

Affiliate Members

COHERENT
SIMIC — since 1975 — A PASSION FOR CHALLENGES
Mitsubishi Corporation
BUTTING 1777
AMPLEON
CleanTech Alliance
eni
Southern Company
THALES
Google
KIND
Sumitomo Corporation of Americas — Enriching lives and the world
FLUOR
equinor
TVA
TWI
framatome
BILFINGER
BILFINGER NOELL GMBH
METOX
ALSYMEX — ALCEN
FARADAY FACTORY JAPAN
CDE ENERGIZING IDEAS
CORNELL DUBILIER
BRUKER
LEONARDO
Sapientai
Cryoelectra — RF Technology for Particle Accelerators
radiasoft
ONTARIO POWER GENERATION
Roland Berger
STELLAR ENERGY FOUNDATION
ENERGY for the COMMON GOOD — Soon enough to make a difference
CLEARPATH ACTION
HTS — HIGH TEMPERATURE SUPERCONDUCTORS
OAK RIDGE CHAMBER OF COMMERCE — In Business For Business
CURTISS-WRIGHT
KINECTRICS
DIVERSIFIED TECHNOLOGIES, INC.
KTC — EST. 1918 — Keller Technology Corporation — We manufacture the future.
Morgan Lewis
TERRA PRAXIS
WOODRUFF • SCIENTIFIC
ARNOLD MAGNETIC TECHNOLOGIES
COSYLAB
American Conservation Coalition
research instruments
ASG SUPERCONDUCTORS
AEROSPACE
AMPEGON
pillsbury
AIR LIQUIDE
INTERLOCK ENERGY
EPRI — ELECTRIC POWER RESEARCH INSTITUTE
STRONG ATOMICS
NEW LIGHT FUSION CONSULTANTS
TRUMPF
FRAZER-NASH CONSULTANCY — A KBR COMPANY
IDOM
ETEC — EAST TENNESSEE ECONOMIC COUNCIL
FUSION ENERGY INSIGHTS
K&L GATES
ENERCON
tecnatom
TELEDYNE BROWN ENGINEERING
ATDG — TRIANGLE DESIGN GROUP LLC
OXFORD SIGMA
OCEM POWER ELECTRONICS

The Commission's decision was clear

- The 5-0 vote by the Commissioners to initiate a rulemaking under the byproduct materials regulatory regime (10 CFR Part 30), and separate the regulatory oversight of fusion from the utilization facilities regime (10 CFR Parts 50 & 52) that regulate nuclear fission energy was appropriate for the technology and the risk.

- This decision will give fusion developers the regulatory certainty they need to innovate as they grow fusion energy into a viable new energy source, while also most effectively protecting the safety, security, and health of the public.

Limited Scope Rulemaking

Commission vote approving Option 2 explicitly called for a "limited-scope rulemaking" to establish a regulatory framework for fusion energy systems that augments the NRC's byproduct material framework in 10 CFR Part 30.

A limited rulemaking should not include a new fusion-specific part at this time. The Commission's decision emphasized the need to near-term regulatory certainty.

“Possible Affected Sections of the Code”

SECY-23-0001, Enclosure 1 stated the primarily affected sections of 10 C.F.R. could be the following:

- 30.4, “Definitions”
- 30.32, “Application for specific licenses”
- 30.33, “General requirements for issuance of specific licenses”
- 30.34, “Terms and conditions of licenses”

FIA agrees that 30.4 should be updated to include new definitions.

However, it is unclear why §§ 30.32-.34 need updating. *These sections are generic and already apply to a wide range of facilities.*

A **Limited Scope Rulemaking** should remain solely focused on § 30.4 definitions for Fusion Energy Systems and particle accelerators.

Specific definitions NRC identifies to address

SECY-23-0001, Enclosure 1 proposed the following definitions for rulemaking:

- Define **"Fusion"**
- Define **"Fusion Energy System"**
- Update the definition of **"Particle Accelerator"**

FIA Principles for Definitions

- Define **"Fusion"**
  - *Fusion is widely understood and a scientific concept. There is no need for a separate definition for fusion. (NRC regulations do not contain a definition for "fission")*
- Define **"Fusion Energy System"**
  - *The NRC has requested a definition of a "fusion energy system" but "system" could be defined too broadly to include auxiliary and subsystems that are seperate from the fusion reaction or are not affected by byproduct materials*
- Define **"Fusion Energy Machine"**
  - *The definition should be limited to those systems that directly use byproduct materials for fusion, and should invoke the commercial purpose of the system, because fusion research facilities are already regulated.*
- Update the definition of **"Particle Accelerator"**
  - *A definition of a "fusion energy machine" should acknowledge that they are particle accelerators. Although it is therefore not necessary for the NRC to also change the definition of particle accelerator to include fusion, it would add completeness.*

FIA Proposed Definition

Particle Accelerator

"*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 megaelectron volt**, including fusion energy machines**. For purposes of this definition, accelerator is an equivalent term."

RED = proposed amendment

*[*10 C.F.R. § 30.4*](#)

Export Controls

SRM: *"The staff should evaluate whether controls-by-design approaches, export controls, or other controls are necessary for near-term fusion energy systems."*

Export Controls

"Nuclear fusion reactors per se" are exempt from NRC Export Controls (10 CFR 810.2(c)(4))

Supporting systems involving hydrogen isotope separation technologies already fall under NRC Export Controls. Tritium is also export controlled.

The Department of Commerce Bureau of Industry and Security has jurisdiction and has reviewed fusion energy systems and subsystems for dual use export controls.

A "limited rulemaking" on export controls should recognize that NRC controls are for Nuclear Suppliers Group Trigger List items, for which fusion is not included.*

**(43 Fed. Reg. 21,641, and 21,642)*

New Guidance Document

SRM directs staff to *"develop a new volume of NUREG-1556, 'Consolidated Guidance About Materials Licenses,' dedicated to fusion energy systems, so as to provide consistent guidance across the National Materials Program."*

Currently, to the extent that fusion energy machines use or create byproduct materials and therefore fall under NRC jurisdiction, licensing is guided by NUREG-1556, Vol 21, *"Program-Specific Guidance About Possession Licenses for Production of Radioactive Material Using an Accelerator."*

FIA **supports** the creation of a new <u>fusion-specific volume</u>

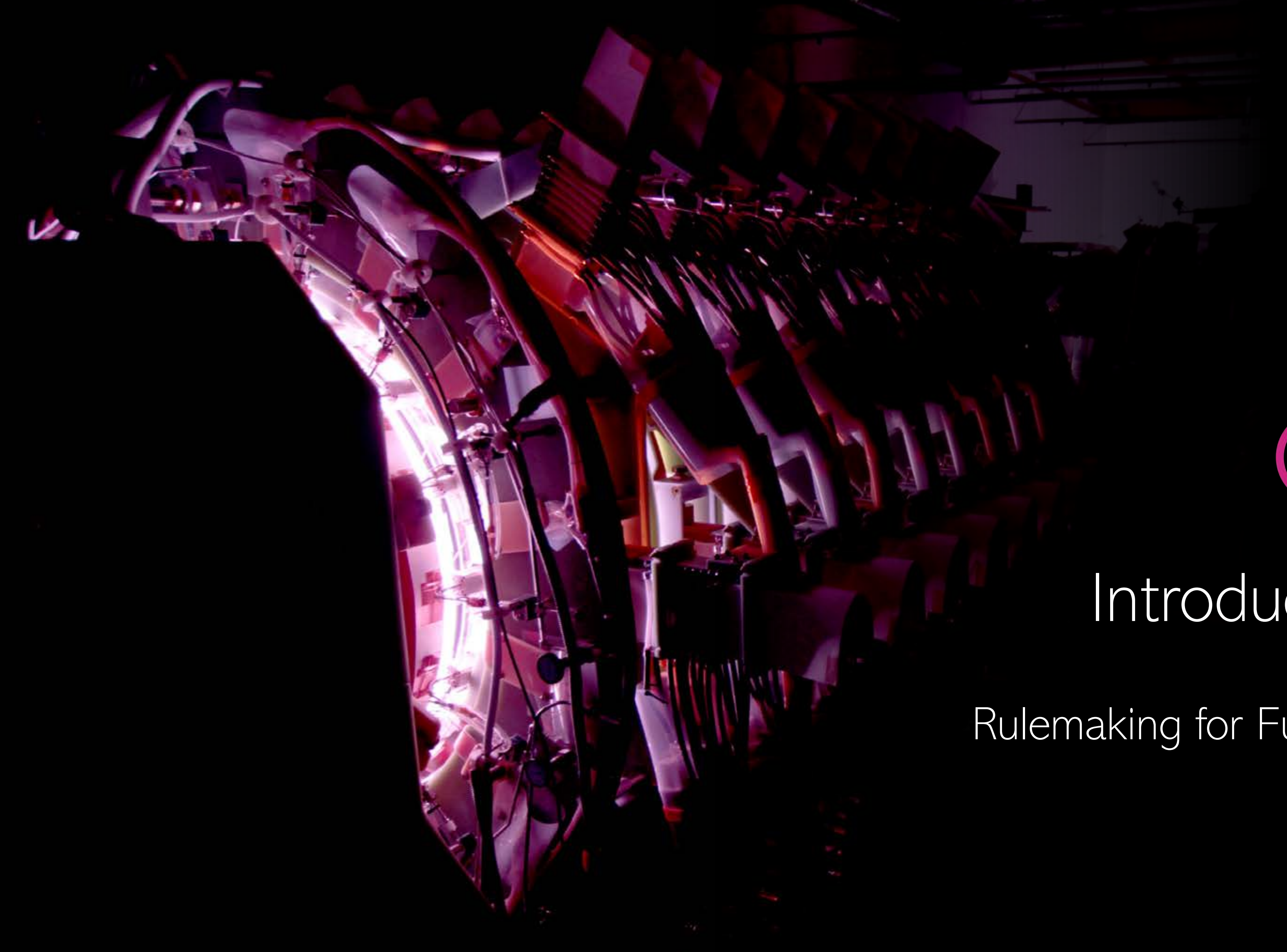
FIA proposes to develop guidance which could be endorsed by the NRC

FIA will engage with other stakeholders to solicit feedback as guidance is developed

Thank you

- FIA thanks NRC staff for their dedicated engagement over more than 3 years leading to today’s meeting

- FIA looks forward to continuing productive engagement



HELION

Introduction to Helion

Rulemaking for Fusion Energy Systems

Sachin Desai
General Counsel
July 12, 2023

About Helion

- Fusion power company founded in 2013
- Based in Everett, WA
- 170+ team members
- First private company to reach 100 M°C
- Raised a total of $570M

Helion's technology: How it works

1. Formation

Deuterium and helium-3 are heated to plasma conditions and confined in an FRC.

2. Acceleration

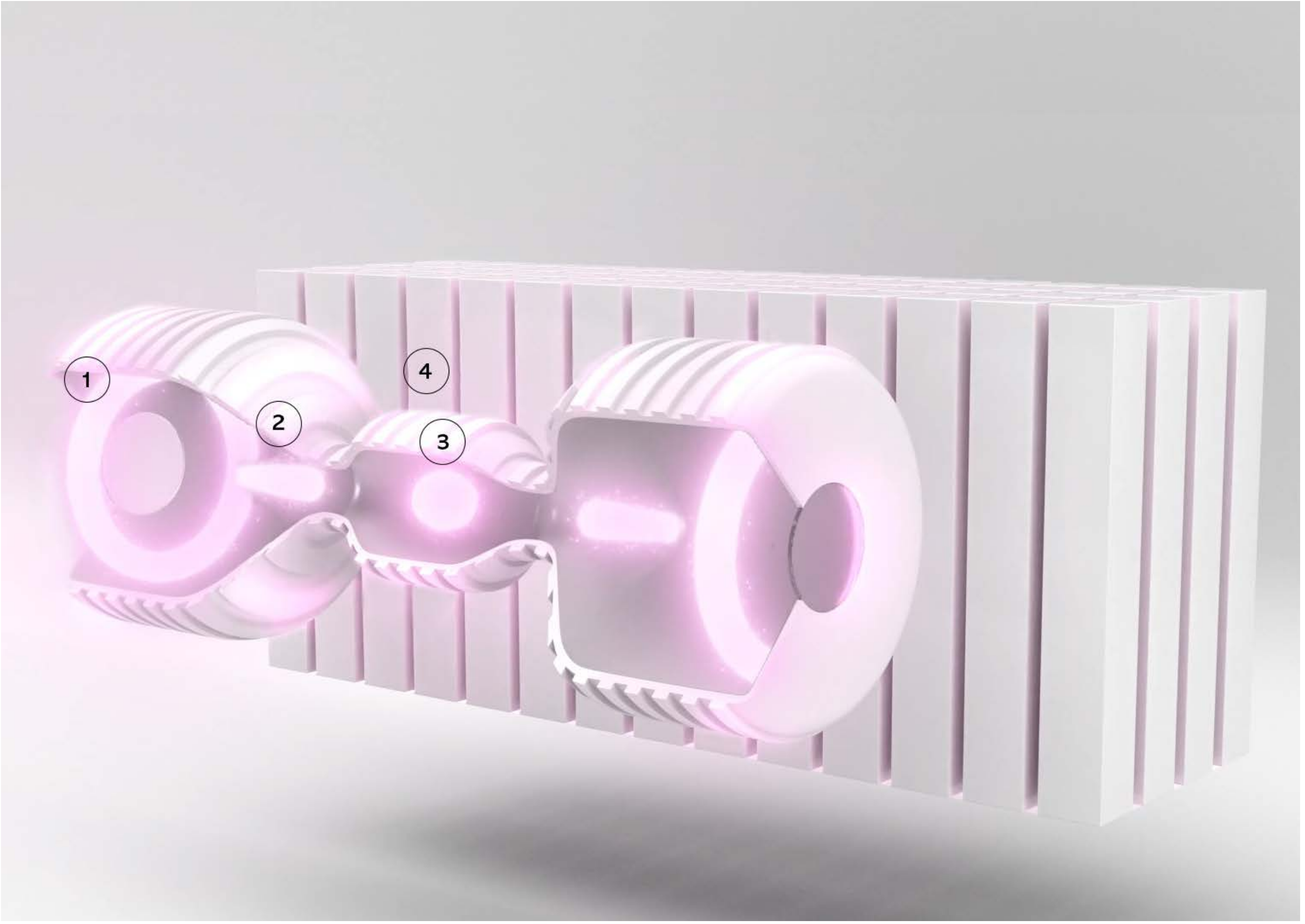
Magnets accelerate the FRCs until they collide in the center of the device.

3. Compression

The merged plasma is compressed by a magnetic field to fusion conditions.

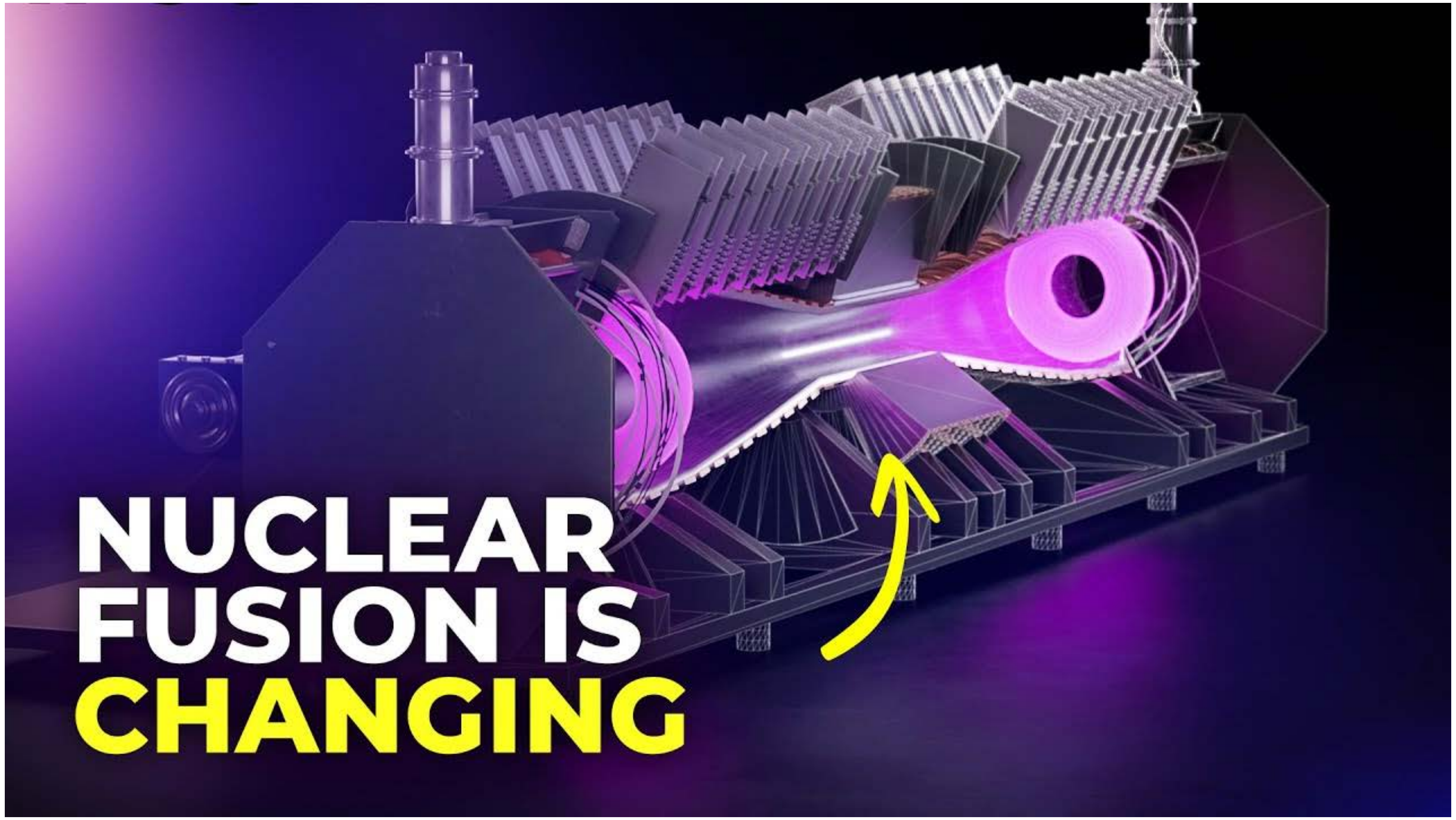
4. Energy recovery

The plasma expands and releases energy, which is directly recaptured as electricity.



More About Helion

- See the video about Helion in Real Engineering



https://www.youtube.com/watch?v=_bDXXWQxK38

Polaris: Helion's 7th fusion prototype

- Machine is currently under construction
- Expected completion: Early 2024
- Regulated by the WA Department of Health
- Goal: Demonstrate electricity from fusion

Ongoing progress: Preparing Polaris

Optimizing fuel injection technology

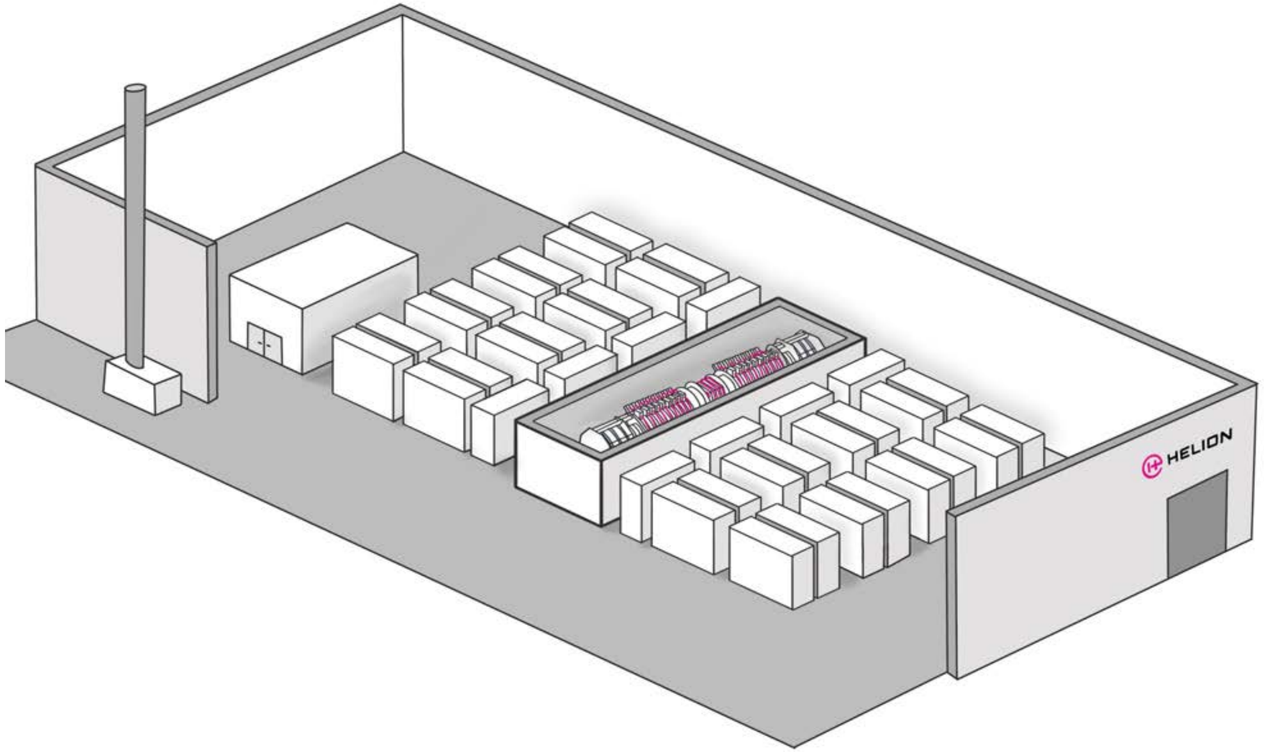
Scaling in-house capacitor manufacturing

Installing our 7th fusion prototype, Polaris

Commercial system: 50 MW

- Fits in 30,000 sq. ft. building
- Borated concrete and BPE shielding
- No secondary steam cycle

- **First customer:** Microsoft with power marketing support from Constellation



NRC Rulemaking Considerations

- How can we continue strong and open engagement?
  - Workshops on key topics
    - *Definitions*
    - *Key technical areas (see also March 2022 presentations)*
    - *Export controls (see also June 2022 presentations & Helion August 2022 letter)*
  - Public meetings
  - Site tours

- How can fusion developers assist?
  - Technology overviews
  - Supporting on guidance

HELION

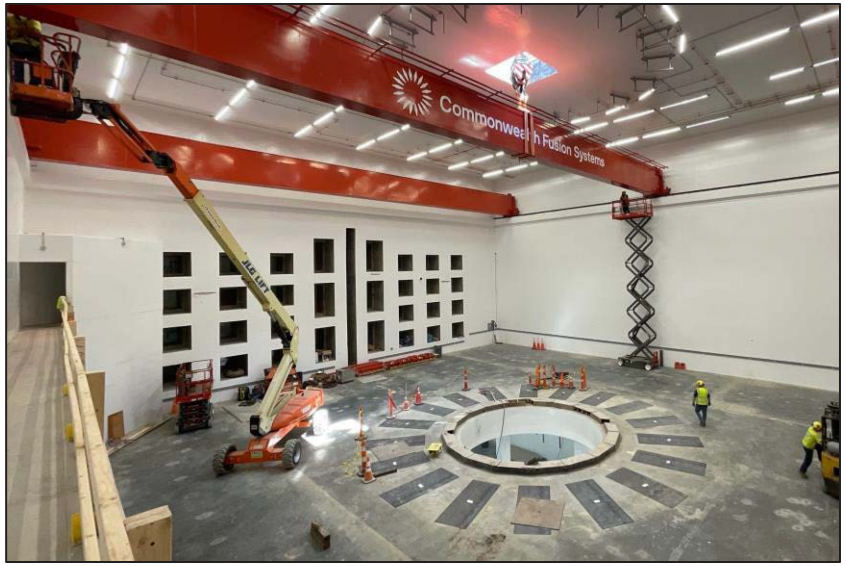
Building the world's first fusion power plant, enabling a future with unlimited clean electricity.

CFS Regulatory Presentation

Tyler Ellis, Ph.D.

Commonwealth Fusion Systems

Construction of SPARC and magnet factory in Devens, MA



10 CFR 30 is an effective pathway for regulating fusion

- CFS supports the unanimous vote by the NRC Commission to regulate fusion energy under a byproduct materials approach (10 CFR 30) which will provide appropriate protection for the environment as well as public health and safety.
- This pathway provides the necessary regulatory certainty to fusion companies to continue developing their next generation facilities towards the goal of putting fusion electricity on the grid by the early 2030s.
- CFS looks forward to engaging with all stakeholders to support NRC's limited-scope rulemaking effort to establish regulatory treatment for fusion energy in 10 CFR 30 as well as provide regulatory guidance for the preparation of a license application.

Limited Rulemaking Proposal

- In SECY-23-0001, Enclosure 1 “Rulemaking Plan” references several potential parts of 10 CFR that could be modified in this rulemaking including:
  - Part 30, “Rules of General Applicability to Domestic Licensing of Byproduct Material”
    - 30.4, “Definitions”
    - 30.32, “Application for specific licenses”
    - 30.33, “General requirements for issuance of specific licenses”
    - 30.34, “Terms and conditions of licenses”
  - Part 50, “Domestic Licensing of Production and Utilization Facilities” – 50.2, “Definitions”
  - Part 51, “Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions”
- In line with the Commission’s desire for a limited rulemaking and previous CFS submissions to the NRC[1], we believe that **minor updates to the definitions in 10 CFR 30.4 are the only changes to the CFR necessary to implement the mandate of the SRM.**

[1] Ellis, T. (August 16, 2022). Letter from Commonwealth Fusion Systems to NRC Chairman Christopher Hanson. ML22230D055

First proposed update to 10 CFR 30.4

- In principle, a new definition for "**Fusion Energy Machine**" should include these aspects:
- **it is a type of particle accelerator,**
- **it is capable of transforming atomic nuclei via fusion processes into other elements, and**
- **it directly captures and uses the resultant products, including particles, heat, or other electromagnetic radiation, for a commercial or industrial purpose.**
- This approach is technology inclusive for all proposed fusion design concepts and fuel cycles.
- "Fusion Energy Machine" is used instead of "Fusion Energy System" because it appropriately focuses on the portions of the plant impacted by byproduct materials, rather than encompassing the entire plant which contains systems that have no impact on radiological public health and safety while avoiding an overbroad change that could create unintended impacts on the segments of the materials licensing framework.

Second proposed update to 10 CFR 30.4

- Edit the current definition of particle accelerator to include the bolded text:
- [Particle accelerator – means any machine capable of accelerating electrons, protons, deuterons, or other charged particle in a vacuum and of discharging the resultant particulate or other radiation into a medium at energies usually in excess of 1 megaelectron volt**, including fusion energy machines**. For purposes of this definition, accelerator is an equivalent term.]
- The first update could be the only one since it does establish “Fusion Energy Machines” as particle accelerators, but the second update does strengthen this point.
- CFS does not think it is necessary to define “fusion” as the concept is widely understood, and “fission” is not similarly defined in 10 CFR 50.2.

Regulatory Guidance Document

- In the Staff Requirements Memo on SECY-23-0001 it states:
- “The staff should develop a new volume of NUREG-1556, “Consolidated Guidance About Materials Licenses,” dedicated to fusion energy systems, so as to provide consistent guidance across the National Materials Program.”
- CFS agrees with this pathway and NUREG-1556 Volume 21 provides a solid basis for the development of this new fusion specific volume[1].
- CFS is ready to work with the FIA on developing a draft volume for the NRC to consider.

[1] Ellis, T. (August 16, 2022). Letter from Commonwealth Fusion Systems to NRC Chairman Christopher Hanson. ML22230D055

Regulatory Guidance Document

- Following extensive conversations with NRC and Agreement state partners, NUREG-1556 Volume 21 is currently being used as guidance for the preparation of the SPARC materials license application and it has been effective so far.
- Given our existing work assembling the SPARC license application and the similarity of subsystems between SPARC and ARC, we believe that volume 21 guidance should be largely applicable for all future fusion energy machines.
- CFS looks forward to sharing lessons learned through the SPARC licensing process to inform the development of this new volume for fusion.

Export Controls

- In the Staff Requirements Memo on SECY-23-0001 it states:
- “The staff should evaluate whether controls-by-design approaches, export controls, or other controls are necessary for near-term fusion energy systems.”
- As per 10 CFR 810.2(c)(4), export controls do not apply to “Nuclear fusion reactors per se, except for supporting systems involving hydrogen isotope separation technologies…”.
- NRC export controls are focused on the Nuclear Suppliers Group Trigger List which does not include fusion energy systems.
- Export controls already exist for both the tritium material itself and associated handling systems, so additional export controls are not needed.

Summary

- Minor modifications to 10 CFR 30.4, adding a definition of "fusion energy machine" and updating the current definition of "particle accelerator," are fully consistent with the Commission's direction to implement a limited rulemaking to bring fusion energy machines into the Part 30 framework more explicitly.
- For writing fusion specific regulatory guidance, NUREG-1556 Volume 21 provides a solid basis and CFS looks forward to working with all stakeholders to support NRC’s efforts to develop a new volume of NUREG-1556, including sharing our recent experience in licensing SPARC.
- Sufficient export controls already exist for fusion and new regulations are not needed.

The fastest path to limitless, clean energy

Commonwealth Fusion Systems

AGENDA

Time	Topic	Speaker
1:00 pm	Welcome & Meeting Logistics	Dennis Andrukat
1:10 pm	Opening Remarks	Theresa Clark
1:15 pm	NRC Presentation – Rulemaking Overview	Duncan White
1:45 pm	Stakeholder Perspectives	Laila El-Guebaly, Andrew Holland, Sachin Desai, Tyler Ellis
2:45 pm	BREAK	All
2:55 pm	Questions & Feedback	All
3:55 pm	Wrap-up & Adjourn	Dennis Andrukat

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Questions & Feedback

Please Note: the NRC is not accepting official comments during this meeting and will not provide any official responses to any feedback provided during this meeting.

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

Thank You!

Contacts

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- Duncan White

Technical Lead

Duncan.White@nrc.gov

Public Information

- NRC Public Website: https://www.nrc.gov/materials/fusion-energy-systems.html
- Docket ID: NRC-2023-0071 (*www.regulations.gov*)

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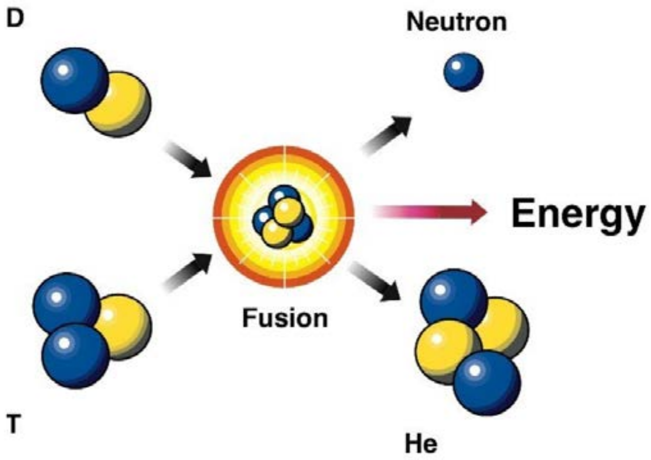
Protecting People and the Environment

BACKUP SLIDES

Fission vs. Fusion

Fission

Fusion



Radioactive Material Considerations

The neutronicity of the fuel is the fraction of the fusion reaction energy that is contained in the neutrons. It has important implications for fusion reactor designs. Less neutrons mean less radiation damage and activation products. Fuels with a small neutronicity are referred to as aneutronic fusion. The downside of less neutrons is that you need to develop a direct power conversion system instead of just running a thermal cycle from a neutron heated blanket.

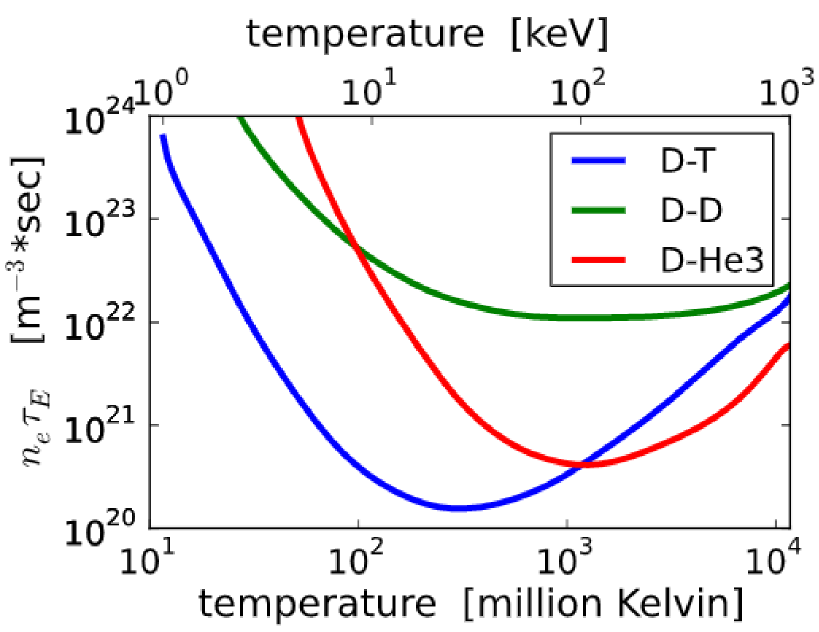
fuel	Z	E_{fus} [MeV]	E_{ch} [MeV]	neutronicity
${}^{2}_{1}D$-${}^{3}_{1}T$*	1	17.6	3.5	0.80
${}^{2}_{1}D$-${}^{2}_{1}D$*	1	12.5	4.2	0.66
${}^{2}_{1}D$-${}^{3}_{2}He$	2	18.3	18.3	≈0.05
p^{+}-${}^{11}_{5}B$	5	8.7	8.7	≈0.001

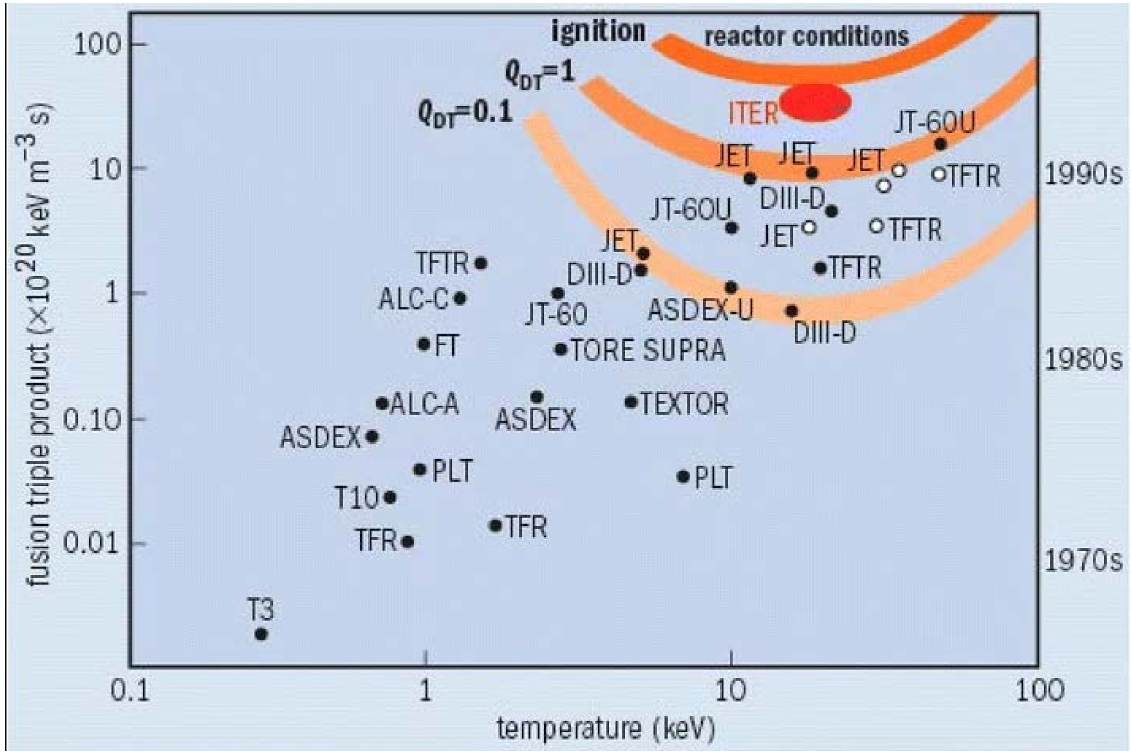
*reaction results in radioactive material

Source: https://en.wikipedia.org/wiki/Nuclear_fusion

Path to Fusion

To initiate a fusion reaction, you must confine the energy long enough in a fuel that is dense enough at a temperature that is high enough. The relationship that quantifies this is called the Lawson criterion.





Sources:
Horvath, A., Rachlew, E. Nuclear power in the 21st century: Challenges and possibilities. Ambio 45, 38–49 (2016). https://doi.org/10.1007/s13280-015-0732-y Figure 4
https://en.wikipedia.org/wiki/Lawson_criterion

Fusion Approaches

Magnetic Confinement Fusion (steady state)

- Creates "magnetic bottles" to confine the plasma using the Lorentz force.
- Low density and long energy confinement times.
- External heating, fueling, and current drive to sustain the plasma.

Magneto-Inertial Confinement (pulsed)

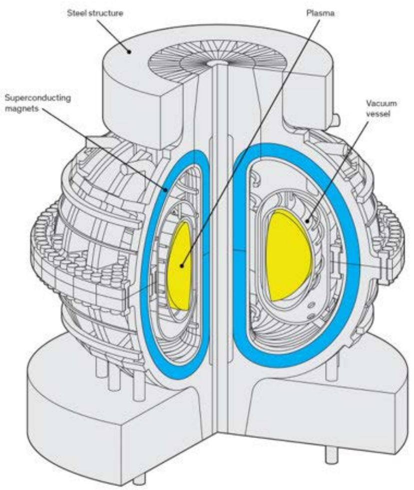
- Forms a magnetically confined plasma and then heats it using magnetic or conducting shell compression.
- Medium density and medium energy confinement times

Inertial Confinement Fusion (ICF) (pulsed)

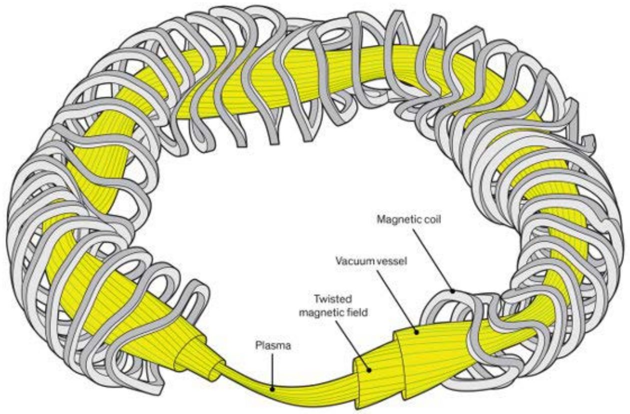
- Uses directed energy in the form of lasers, particle beams or projectiles to heat and compress a plasma to high densities and temperatures.
- Very high density and short energy confinement times.

Magnetic Confinement Concepts

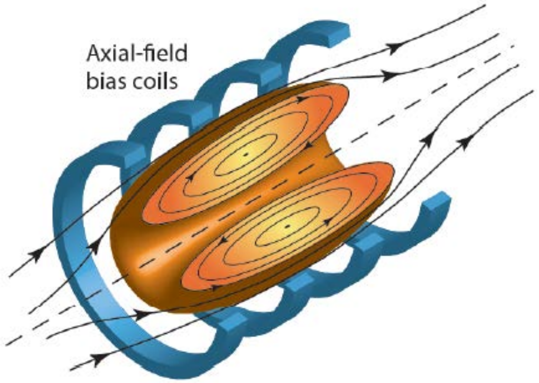
Tokamak



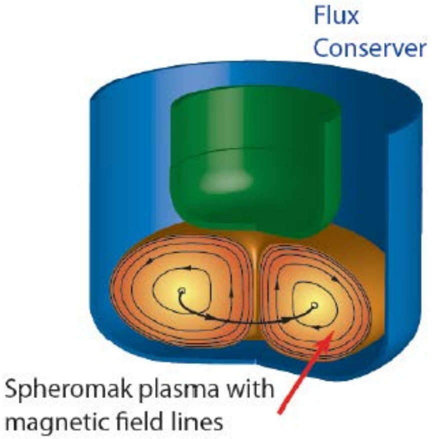
Stellarator



Field Reversed Configuration (FRC)

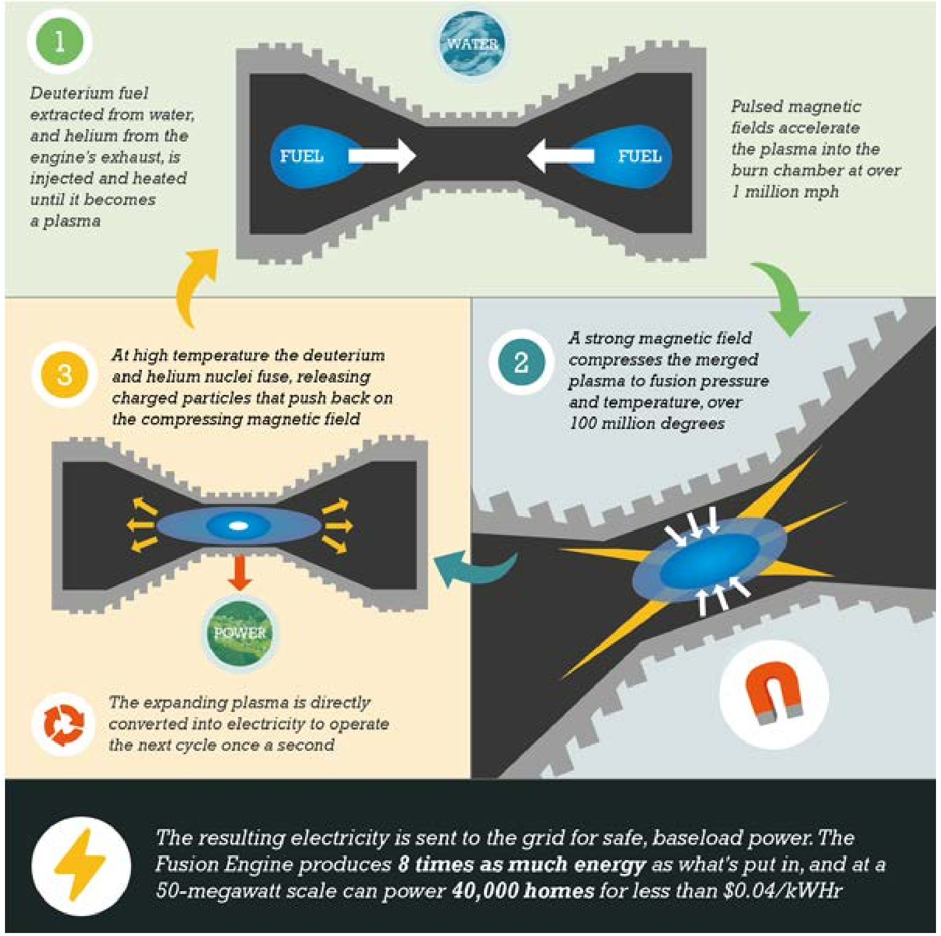


Spheromak

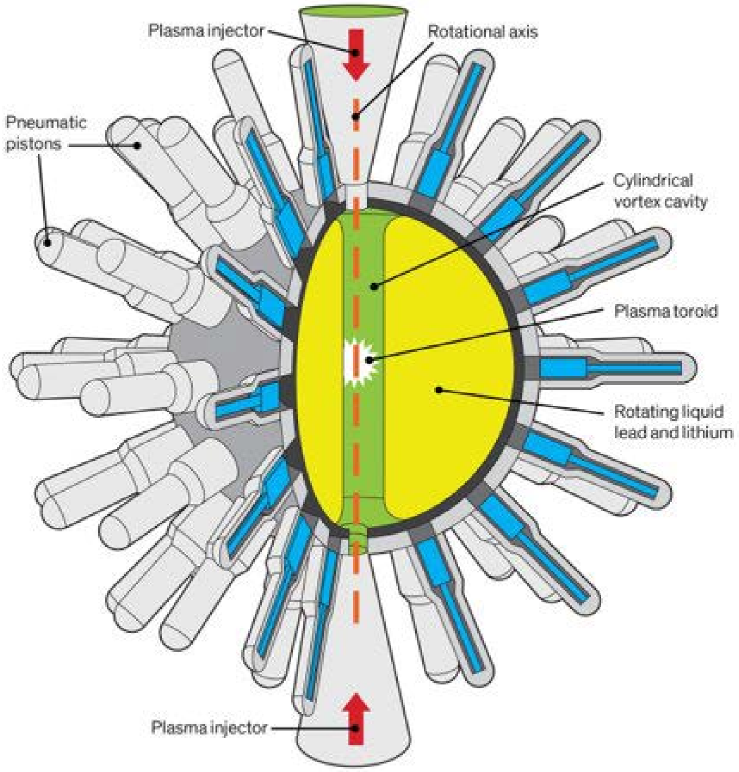


Magneto-Inertial Confinement

Magnetic Compression



Liquid Wall Compression



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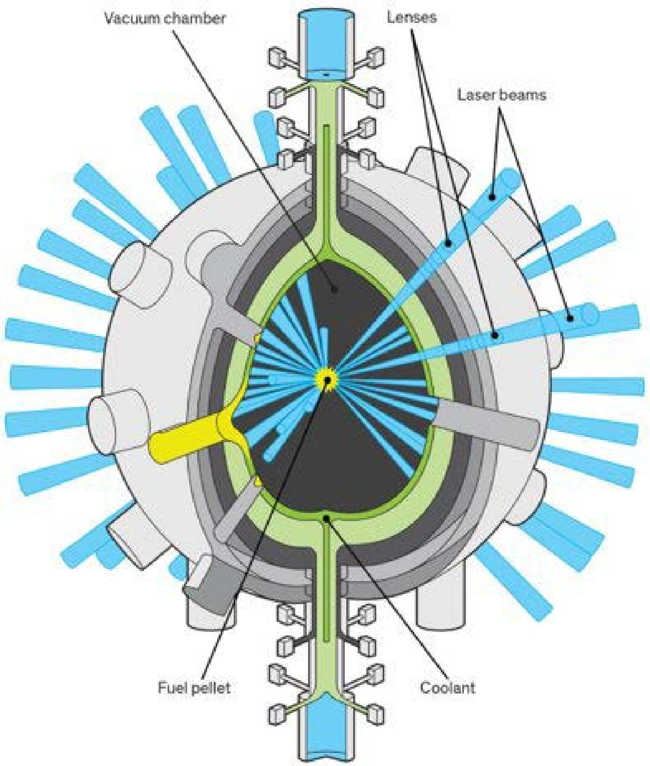
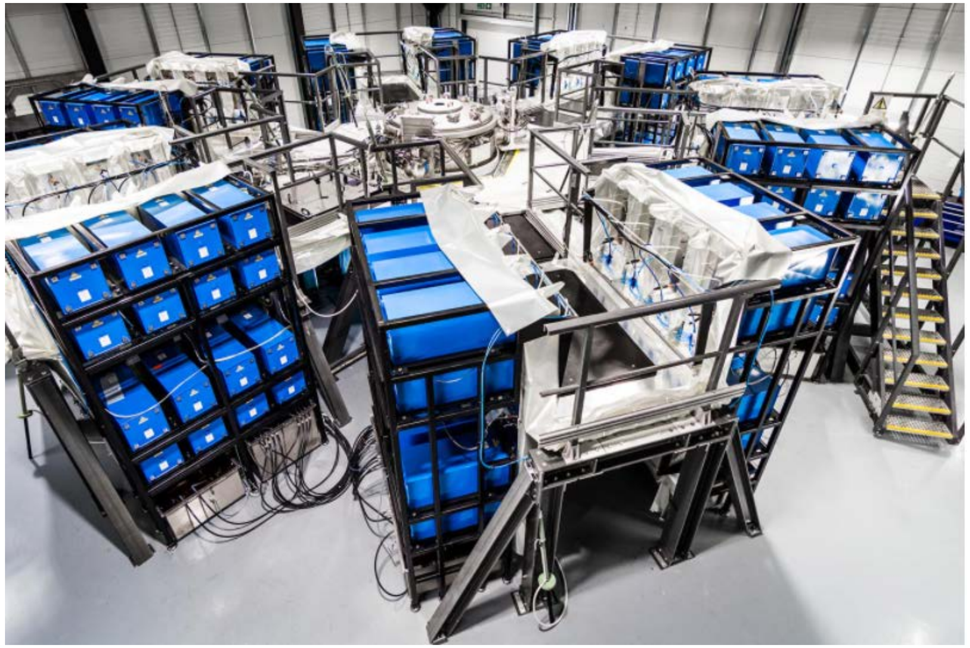
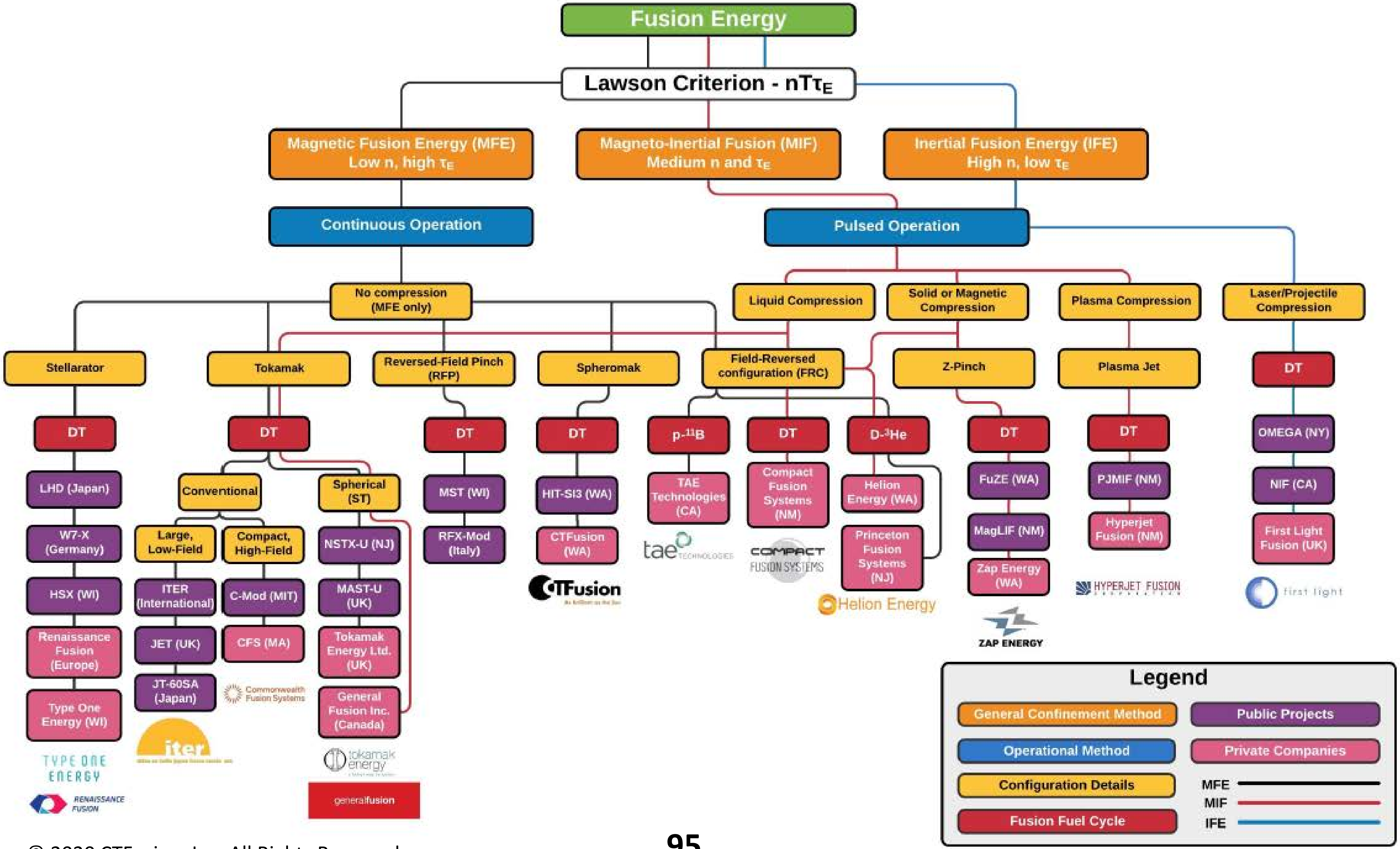
Inertial Confinement

Laser Driver



Projectile Driver





Fusion Energy
Lawson Criterion - nTτE
Magnetic Fusion Energy (MFE)
Low n, high τE
Magneto-Inertial Fusion (MIF)
Medium n and τE
Inertial Fusion Energy (IFE)
High n, low τE
Continuous Operation
Pulsed Operation
No compression
(MFE only)
Liquid Compression
Solid or Magnetic Compression
Plasma Compression
Laser/Projectile Compression
Stellarator
Tokamak
Reversed-Field Pinch (RFP)
Spheromak
Field-Reversed configuration (FRC)
Z-Pinch
Plasma Jet
DT
DT
DT
DT
p-11B
DT
D-3He
DT
DT
DT
LHD (Japan)
W7-X (Germany)
HSX (WI)
Renaissance Fusion (Europe)
Type One Energy (WI)
Conventional
Spherical (ST)
Large, Low-Field
Compact, High-Field
ITER (International)
JET (UK)
JT-60SA (Japan)
C-Mod (MIT)
CFS (MA)
NSTX-U (NJ)
MAST-U (UK)
Tokamak Energy Ltd. (UK)
General Fusion Inc. (Canada)
MST (WI)
RFX-Mod (Italy)
HIT-SI3 (WA)
CTFusion (WA)
TAE Technologies (CA)
Compact Fusion Systems (NM)
Helion Energy (WA)
Princeton Fusion Systems (NJ)
FuZE (WA)
MagLIF (NM)
Zap Energy (WA)
PJMIF (NM)
Hyperjet Fusion (NM)
OMEGA (NY)
NIF (CA)
First Light Fusion (UK)
TYPE ONE ENERGY
RENAISSANCE FUSION
iter
Commonwealth Fusion Systems
tokamak energy
generalfusion
CTFusion
tae TECHNOLOGIES
COMPACT FUSION SYSTEMS
Helion Energy
ZAP ENERGY
HYPERJET FUSION
first light
Legend
General Confinement Method
Operational Method
Configuration Details
Fusion Fuel Cycle
Public Projects
Private Companies
MFE
MIF
IFE