Fusion Materials and Codes and Standards for Fusion Energy

Technical Meeting on Experience in Codes and Standards for Fusion Technology

18-21 November 2025 Vienna, Austria

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What is CATF ?

The CATF Fusion Programme

Fusion at the Clean Air Task Force

- The Clean Air Task Force was founded in 1996 with a narrow mission to achieve reductions in smog, soot, air toxics, and carbon dioxide from U.S. power plants.
- This mission has expanded to a broader mandate devoted to a science-driven, solutions-oriented approach to combat climate change and environmental degradation.
- Fusion energy programme was formed in 2023 with the objective of accelerating fusion commercialization in technology-agnostic and evidence-based ways.

"A 25+ year old organization with a startup mentality"

CATF Fusion Scope and Objectives

Our global programme's objective is to advance the policies and technology knowledge necessary to commercialise fusion energy.

We achieve this by:

- Improving options for enabling regulatory frameworks and technology readiness
- Supporting the development of appropriate Fusion Energy policies and standards
- Addressing supply chain challenges
- Providing visibility to Fusion Energy as part of the clean technology sector

This includes four International Working Groups (IWGs) advancing:

- **Fusion safety and regulation frameworks**
- **Cost analysis model for fusion**
- **Standards for fusion**
- **A global fusion materials database**

Four Pillars: Building Fusion's Foundation

Pillar 1	Pillar 2	Pillar 3	Pillar 4
Fusion Energy Policy	**De-Risking Strategies**	**Supply Chain Development**	**Awareness**
Support elected officials on policy formation Advise regulators Monitor alternate fusion approaches Describe new and existing rule sets for neutron management Inform national and regional fusion strategies	Align global safety requirements Create materials catalogue to identify common challenges Provide generic techno-economic cost analysis Create tools for risk assessment	Produce universal catalogue of material needs Maintain technology-agnostic view on workforce needs Evaluate technology enablers such as AI, HPC Codes and Standards development Identify priority materials for supply chain security Workforce development	Increase fusion's visibility in energy sector Articulate fusion's role in the marketplace Support national, regional and international fusion commercialization efforts Demonstrate progress and set expectations for fusion expansion
Inform policies to align global safety and regulatory frameworks and accelerate commercial deployment.	Identify and mitigate the uncertainties in the deployment of fusion.	Inform reference tools to be able to integrate fusion into the net-zero energy mix.	Position fusion as "clean tech" and as part of the net zero solution.

The Future of Fusion Materials Data: Introducing MatDB4Fusion

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Background

- Recent breakthroughs in fusion technology
- Huge investments, also in private companies: Keen to accelerate development towards commercial fusion power, but relying on scientific data
- Development of basic materials suitable for fusion energy, qualified and validated in irradiation campaigns, is a matter of decades and consumes large budgets
- Scientific work of four decades created huge piles of data, however often not public
- Important material manufacturing details are often missing
- The rise of machine learning technology promises even more breakthroughs with enough data

► Urgent demand for a global database for fusion material properties

Formation of the International Working Group in 2023

The Material Database for Fusion

MatDB 4Fusion

Ultimate Vision

► ***Development started in 2024***

A database …

- covering all **materials, properties, supporting data** relevant to fusion device design,
- supplied by many entities from different countries,
- with **quality-controlled** data,
- contains open access data but also restricted data from different stakeholders,
- acts as a **single reference** for all fusion reactor design approaches to
  - ► access wealth of data that did not reach publication or attention
  - ► **assess data gaps** and / or reduce duplication of effort by improving focus of experimental campaigns
  - ► accelerate **creation of codes / standards** for qualification (data quality needed)
  - ► provide sufficient data for **Machine Learning** solutions (data quantity needed)

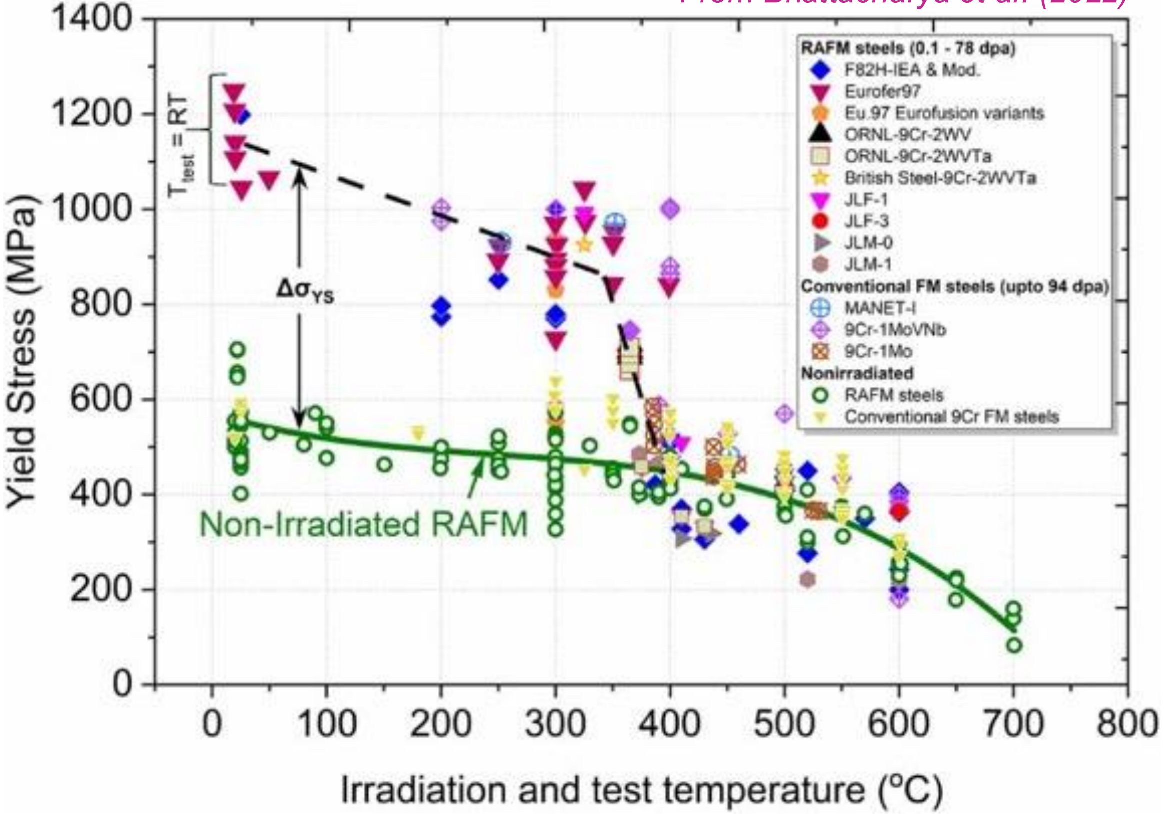
Outline

- Database Content and Structure
- Data Quality
- Hosting of the Database
- Access Models
- Machine Learning
- Web Interface

Database Content and Structure

What should be a single entry in the Database?

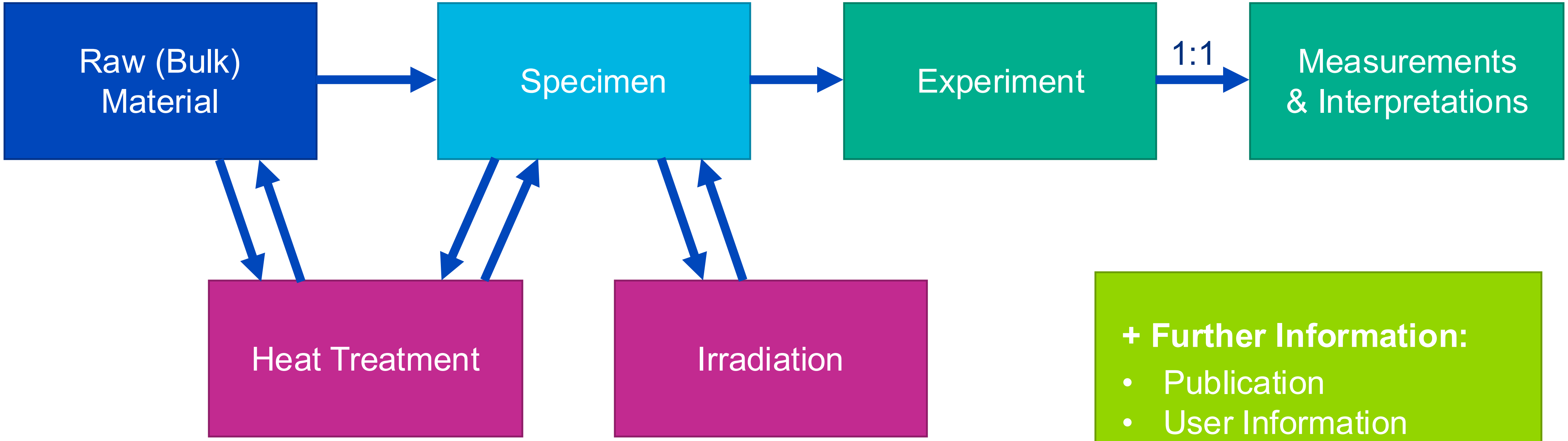
From Bhattacharya et al. (2022)



- Each data point represents a single experiment!
- … What is an “experiment”?

Database Content and Structure

What should be a single entry in the Database?

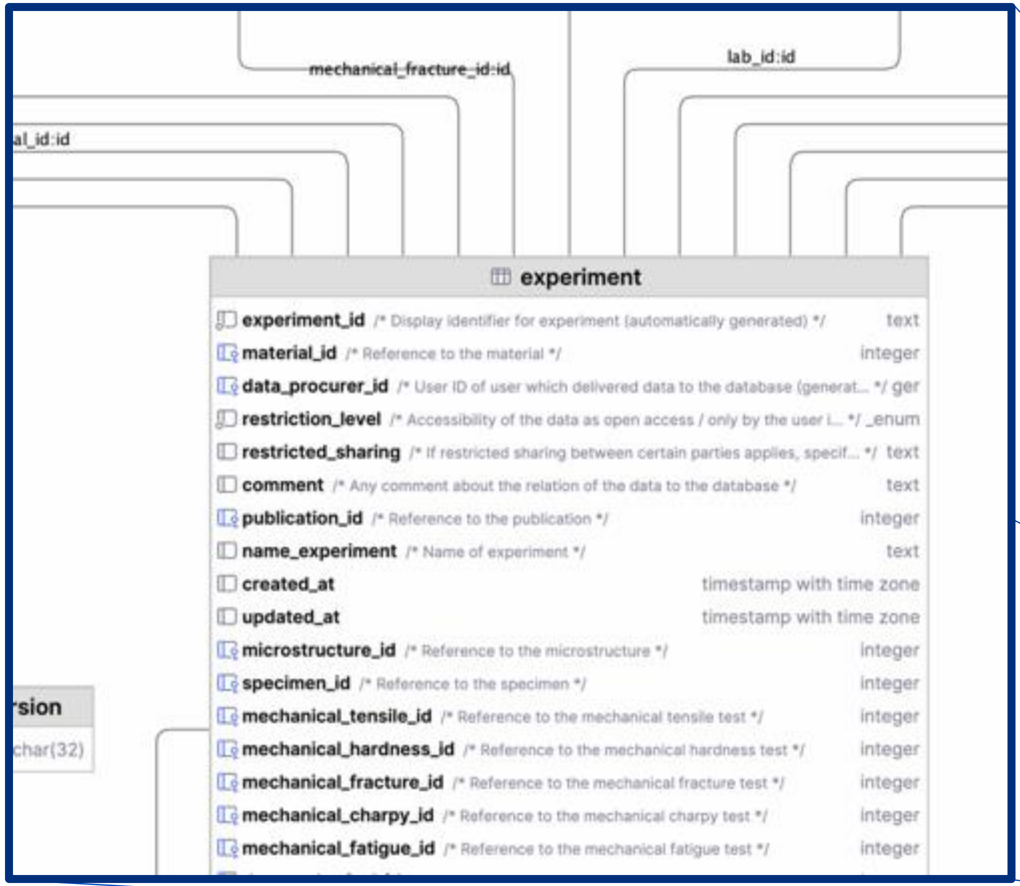


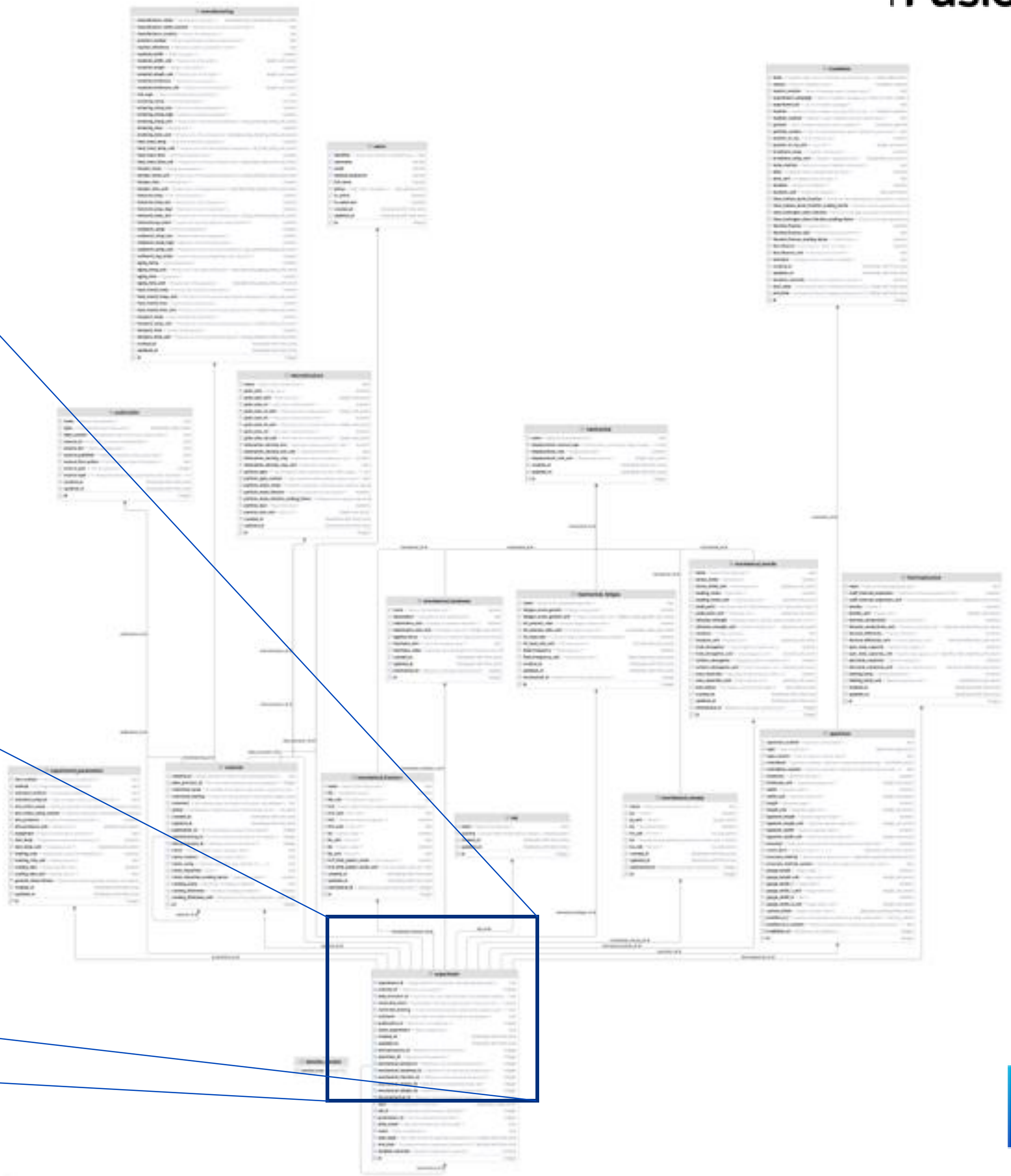
+ Further Information:

- Publication
- User Information
- Data Quality Evaluation

Database Content and Structure

Entity Relations





MatDB 4Fusion

Database Content and Structure

Materials

High heat flux
Different W grades, W alloys, CuCrZr, ODS-Cu, Graphite, …

Structural
Steels (F82Hmod, EUROFER97, ODS-EUROFER, CNAs), Ti6Al4V, SiC, …

Blanket functional
Li, Li-ceramics, Be, beryllides, …

Optical & dielectric functional
Al_2O_3, $MgAl_2O_4$, α-SiO_2, diamond …

×

Preconditions

Mechanical treatment
Type, temperature, degree of deformation, …

Thermal treatment
Annealing, aging, heating & cooling rate, …

Irradiation parameters
Type, spectrum, dose, temperature, …

Coating
Type, thickness, …

×

Properties

Microstructure
Grain size, particles, dislocations, …

Mechanical
Tensile, fracture toughness, charpy impact, fatigue, hardness, creep, …

Magnetic
Magnetic saturation, remnant magnetization, …

Recrystallization
Change in DBTT, hardness, …

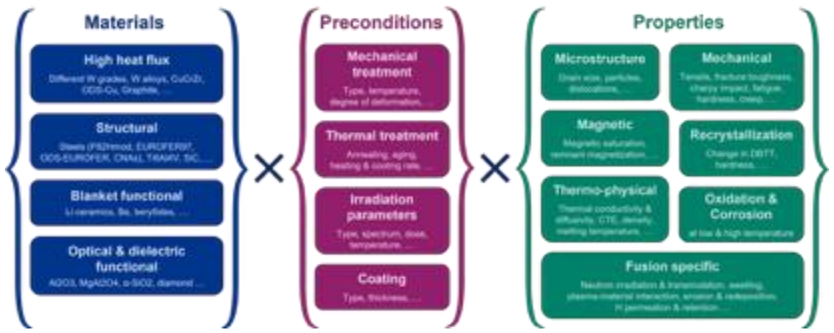
Thermo-physical
Thermal conductivity & diffusivity, CTE, density, melting temperature, …

Oxidation & Corrosion
at low & high temperature

Fusion specific
Neutron irradiation & transmutation, swelling, plasma-material interaction, erosion & redeposition, H permeation & retention …

Database Content and Structure

Analyzed Data



Linkage

Raw Data

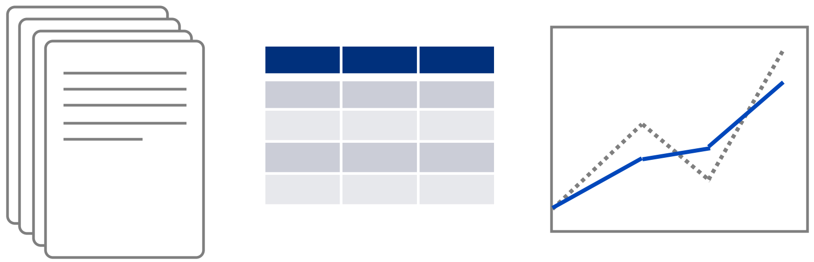
- X-ray spectra
- DSC curves
- SEM / TEM images
- EBSD data
- Stress-strain curves
- Protocols
- Simulation data
- Chemical analysis data
- …

Calculation models

$$\frac{1}{n}\sum_{i=1}^{n} x_i$$

"Compendium"

Data in summarized format with mean values, average curves, …



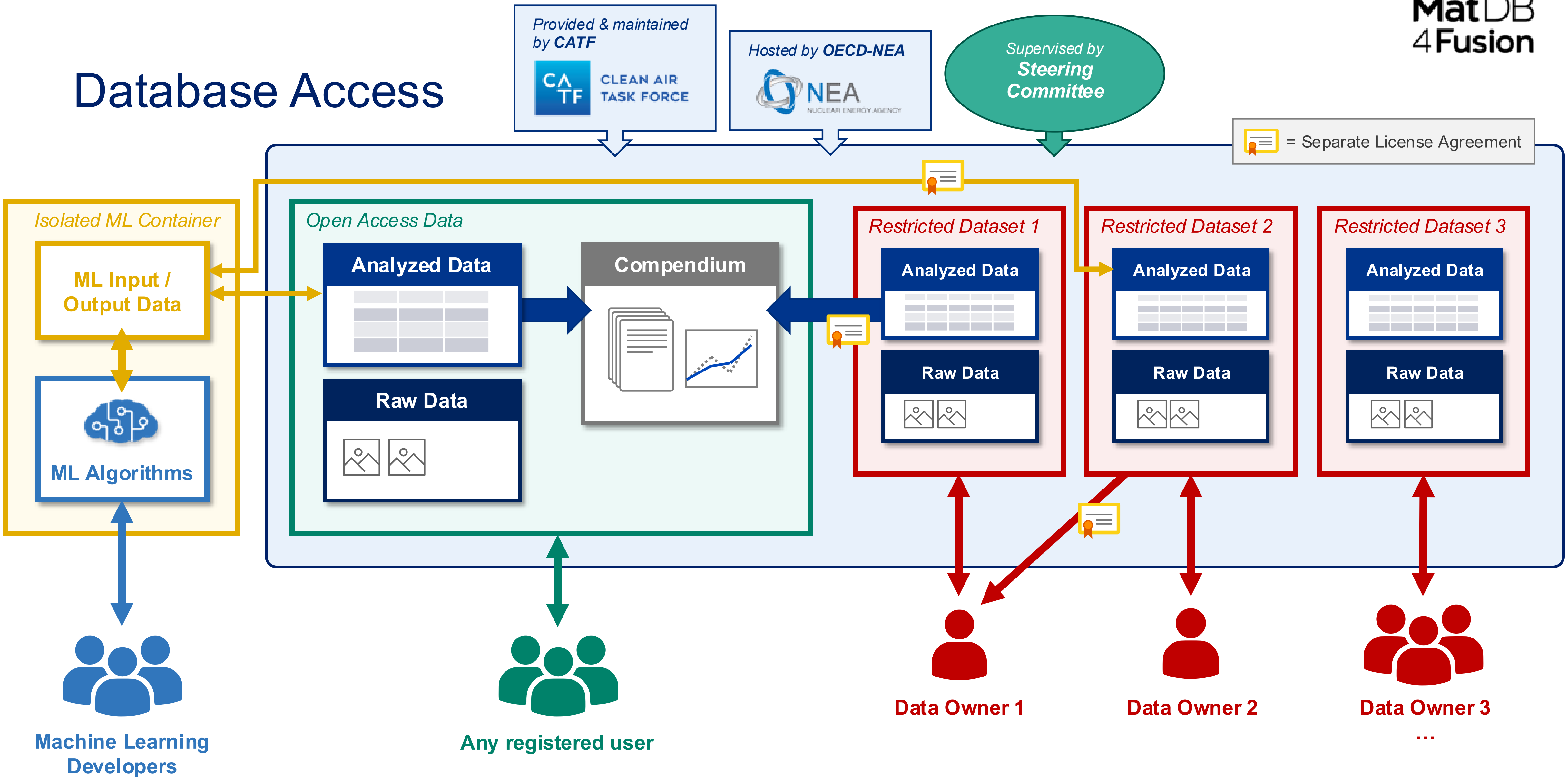
Machine Learning

Where it can make a difference

- Knowledge extraction (collaboration with Google started)
- Property prediction/interpolation to unknown regions of data in terms of important parameters such as irradiation damage and temperature
- Physics-informed models to constrain predictions
- Identification of important features in materials for different applications
- Anomaly identification
- Uncertainty quantification for component design
- Links well with optimization techniques as they can behave as surrogate models

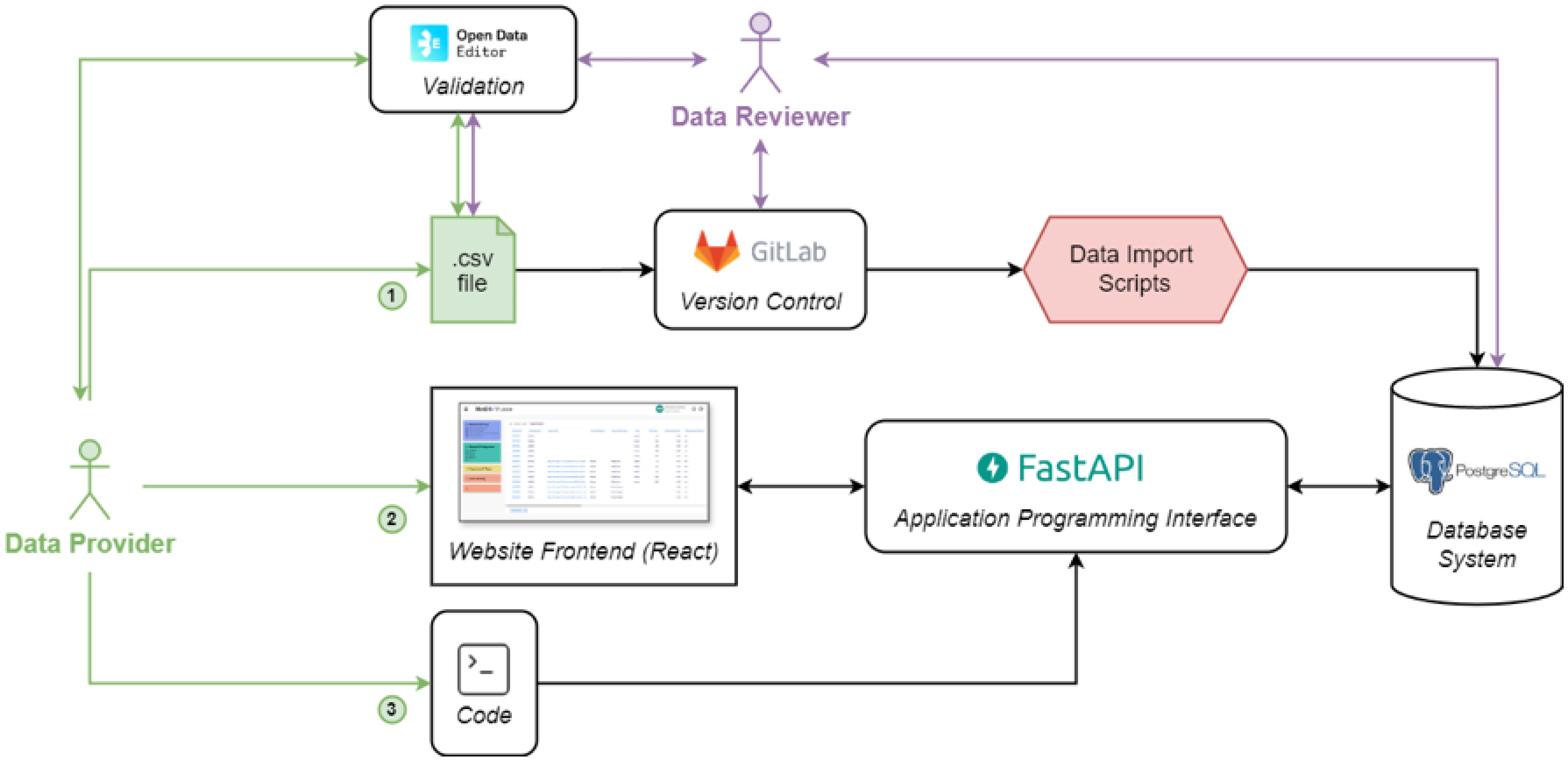
Key Aspects: **Knowledge Extraction** | **Data Analysis** | **LLM Search Function**

Database Access



Contribution to the Database

Three ways to provide data



The Materials Database for Fusion

MatDB4Fusion is being established to consolidate fragmented data on fusion material properties, addressing a key bottleneck in fusion energy development. By providing a centralized, accessible resource, it aims to accelerate research, streamline component design, facilitate collaboration, and ultimately bring us closer to realizing fusion energy's potential.

- Covering **materials, properties & supporting data** relevant to fusion devices
- Support by **International Working Group** and hosted by **OECD-NEA**
- Safeguarding **open access** and **restricted datasets**
- Acting as a **single reference** for all fusion reactor design approaches to
  - access wealth of data that did not reach publication or attention
  - **assess data gaps** and / or reduce duplication of effort by improving focus of experimental campaigns
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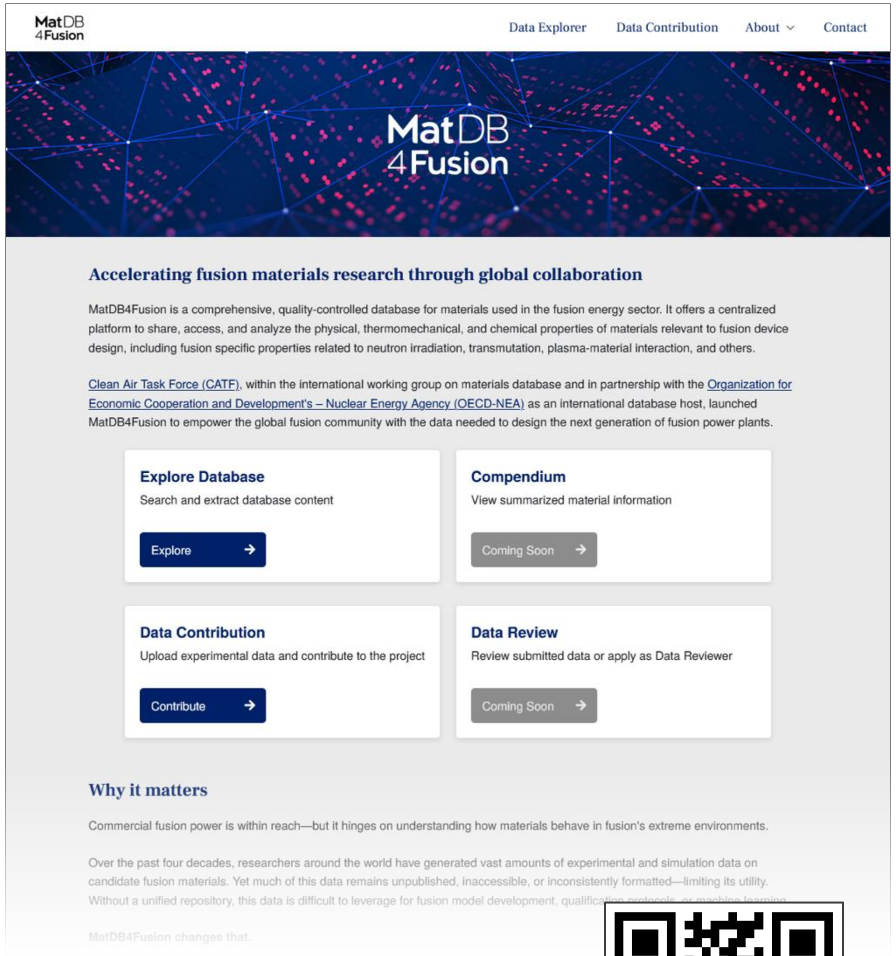


www.MatDB4Fusion.app
Subscribe for updates! →

Fusion

Codes and Standards for an Emerging Industry

CLEAN AIR TASK FORCE

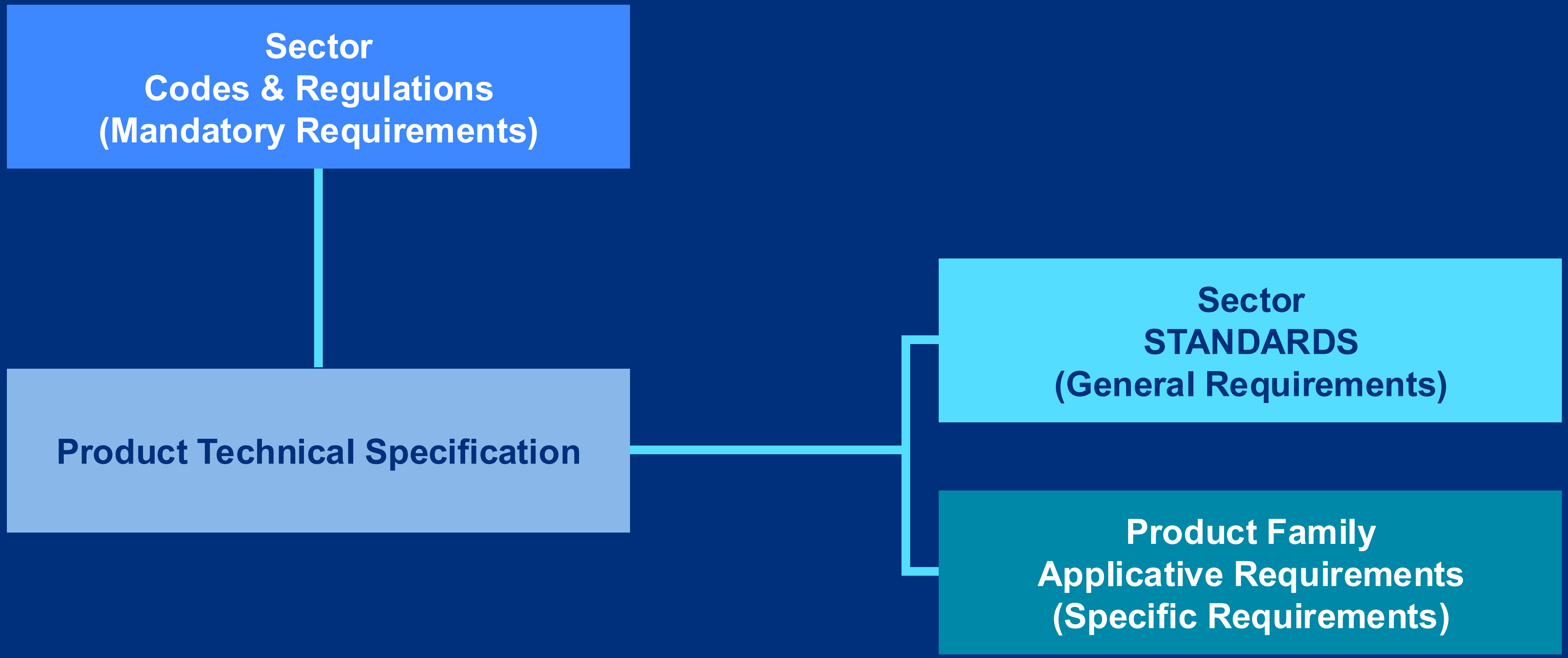
Codes versus Standards

In engineering, "codes" and "standards" are two terms with distinct meanings:

Codes: Often referred to as safety codes, are a set of regulations, rules, and guidelines established by a recognized authority or government agency. The codes are designed to ensure the safety, integrity, and functionality of buildings, structures, systems, and processes. They typically define minimum requirements for design, construction, maintenance, and use of buildings or facilities. Compliance with Codes is mandatory, and failure to adhere to the codes may result in legal penalties or restrictions.

Standards: Standards are specifications developed by a recognized standard-setting organization. Standards are guidelines that establish a consistent and accepted approach to processes, products, services, or systems. Unlike codes, compliance with standards is not mandatory, but adherence to standards contributes to ensure quality, safety, certification and best practices.

Relationship between Codes, Standards and Product Technical Specifications

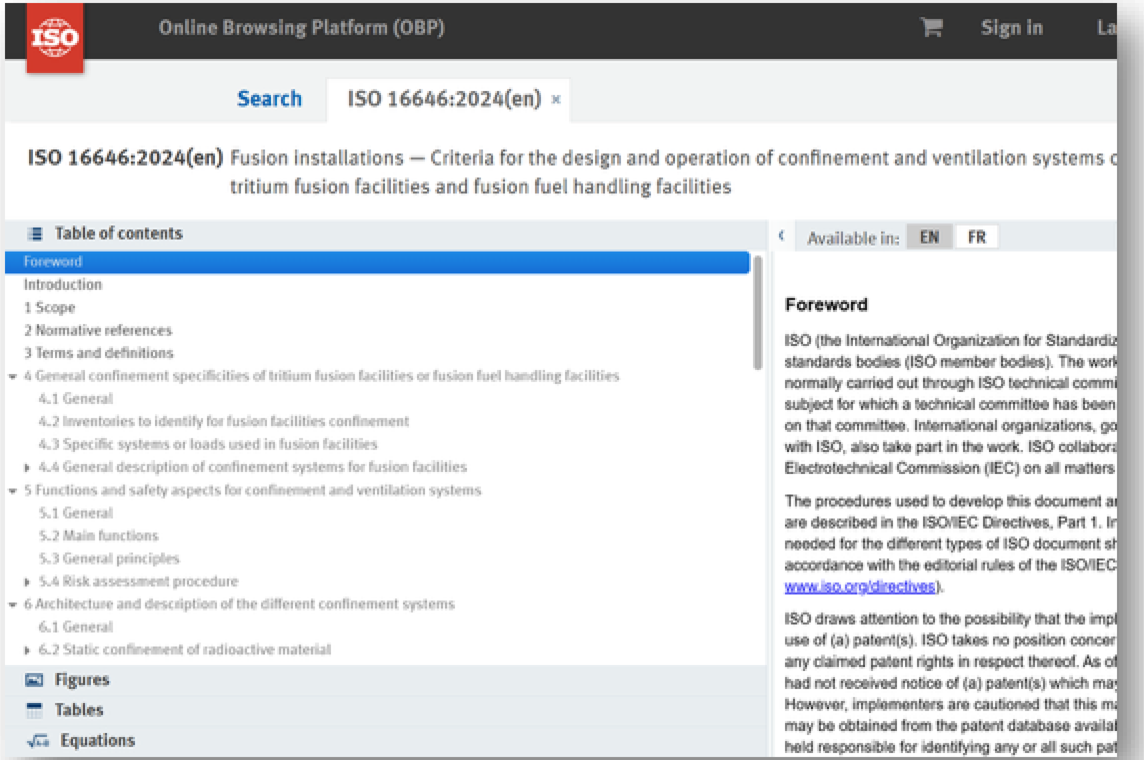


Why Standardisation?

1. Achieve more **cost-effective** Fusion projects in terms of technical performance, life cycle cost-effectiveness, and on-time deliveries;
2. Improve the **quality and safety** of Fusion projects and products;
3. **Reduce risk** and guarantee interoperability and interface compatibility by applying proved and recognized requirements and methods;
4. Facilitate clear and unambiguous **communication** between all parties involved in Fusion systems development and operation;
5. Reflect user needs and **feedback of experience** from projects and other appropriate sources to develop and improve Fusion Standards;

Fusion Sector International Standardisation Status

- **ISO 14152:2001** Neutron radiation protection shielding
  Design principles and considerations for the choice of appropriate materials
- **ISO 4233:2023** Reactor technology - Nuclear fusion reactors Hot helium leak testing method for high temperature pressure-bearing components in nuclear fusion reactors
- **ISO 16646:2024** Fusion installations — Criteria for the design and operation of confinement and ventilation systems of tritium fusion facilities and fusion fuel handling facilities
- **ISO 18518:2025** Magnetic fusion facilities — Requirements for the safety systems raised by the application of the superconducting technology



Learning from Other Sectors and Working with Industry

- Industries with huge societal benefits have established platforms to further a uniform commercialization of their technologies by aligning around common standards for the delivery of the technologies…aviation, semi-conductors, etc.

- Independent international organizations, funded by government and private sector have been established to administer the standards

- Fusion is very similar in its potential for societal benefit and harmonization of standards supporting the most rapid commercialization of the technology is warranted

- The Clean Air Task Force is leading an effort to establish a first of a kind **international working group** on the development of standards for fusion technology.
  - This position can lead to an independent organization that will administer fusion standards
  - Working with government, fusion technology developers, industry and international organizations today to get this important next step for fusion started
  - Working with Industry to meet the evolving needs of this developing technology

- The Clean Air Task Force is also on the ASME Division III Section 4 Special Working Group for Fusion Stakeholders and is chairing the Codes and Standards Committee for the Fusion Industry Association

CATF Upcoming Activities

Webinars

- The Future of Fusion Materials Data: Introducing MatDB4Fusion
  19 Nov 2025

Coming soon…

- Webinar
  Cost Model for Fusion Power Plants
- EU Fusion Safety and Regulation Training Course 2026
  17-19 Feb 2026

Publications

- **US State** Policy Options for Fusion Energy Deployment
- A Fusion Engine for Growth: A **European** Industrial Strategy for Fusion Energy
- A Survey of **Artificial Intelligence** and **High Performance Computing** Applications to Fusion Commercialization

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