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Fusion:

From science to engineering

The engineering questions the fusion industry must answer over the next decade - and what ITER has already taught us about answering them.

A perspective paper from Ekium UK

Engineering for nuclear, fusion and complex industrial environments

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Fusion is no longer just a science project

It is becoming an engineering programme.

01

Public sector is delivering

ITER (International Thermonuclear Experimental Reactor) is in advanced assembly, with operations scheduled from the mid-2030s. The UK's STEP (Spherical Tokamak for Energy Production) programme is moving from concept to design and Europe's DEMO concept work has accelerated.

02

Private sector is scaling

Commonwealth Fusion, Tokamak Energy, Helion, Renaissance Fusion, and others have moved past prototype demonstrations and are now ordering long lead equipment for their next-generation plants: cryogenics, magnets, vacuum vessels, balance-of-plant, etc.

03

The bottleneck has moved

The hard problem is no longer whether fusion can be done. It is how to license, design, build, integrate and operate it - on a schedule, against a regulatory regime and at a cost that allows replication.

The next decade of fusion will not be won in the laboratory. ***It will be in the design office, on the construction site, in the control room and in the licensing file.***

Fusion in plain language.

The reaction.

Fuse two hydrogen isotopes - most notably deuterium and tritium - and you produce helium and a fast neutron carrying around 14 MeV of kinetic energy. That neutron's energy is what eventually gets converted to heat, then steam, then electricity. [1]

The conditions.

To get the reaction running you need a plasma at roughly 150 million degrees Celsius - ten times the core of the sun. You hold it together either with magnetic fields (tokamak) or by compressing a fuel pellet with lasers (inertial confinement). [1]

Why it has taken this long.

The physics has been credible for decades. The engineering - sustaining those conditions for long enough, capturing the energy reliably and managing tritium safely - is what the global fusion programme is now solving in parallel. [2]

ITER BY THE NUMBERS

ITER is the world's largest fusion experiment, under construction since 2010 on a site at Cadarache in southern France and is run as an international collaboration between seven Members: China, the European Union, India, Japan, Russia, Korea and the United States.

150M°C	Plasma operating temperature
6.2 m	Plasma major radius
840 m³	Plasma volume
11	Main buildings, TB04 contract scope
2,000+	Applicable design documents per package

[1] *Fusion Energy, Making it work,* ITER
[2] *Fusion turns to Engineering,* Chris Warrick from the Culham Centre for Fusion Energy

Five engineering disciplines that must converge.

None can be retrofitted. All have their own regulatory regime.

01

Civil & structural

Buildings designed for installed equipment that does not yet exist. Late-stage load and seismic re-validation is the norm.

02

Electrical & power

Backup, redundancy and resilience for systems that cannot tolerate uncontrolled shutdown.

03

I&C (instrumentation and control) & automation

Functional safety, BMS, supervisory layers and integration with central control systems such as CODAC, ITER's central supervisory control system.

04

Fire & safety

Lightning, fire detection, smoke extraction, anoxia protection - each governed by its own code stack.

05

HVAC & containment

Ventilation, gloveboxes, tritium monitoring, dynamic and static confinement under nuclear classification.

Most fusion programme overruns are not physics problems. They are interface problems between these five disciplines.

Civil structures must withstand iteration, not just events.

Fusion buildings are designed once but loaded many times during their build. Equipment plans evolve, contractor sequencing changes and the structural assumptions made years before are tested against revised inputs while installation is already underway. The approach that wins is challenging the calculations, not just running them.

WHAT THIS MEANS IN PRACTICE

- ROBOT© modelling of buildings already constructed and partially equipped
- Design optimisation that minimises retroactive structural reinforcement
- Calculation challenge in line with Eurocode requirements
- Coordination across multiple work-package holders and ITER services

REFERENCE

Structural expertise

Fusion for Energy (F4E) | ITER

Ekium provided Independent expertise on civil engineering studies for the conventional buildings on site. Verification of ROBOT models, calculation notes and deliverables produced by the project's design authority, with optimisation proposals to minimise structural reinforcement while preserving the building commissioning programme.

Eurocodes | Civil & Structures | 2022

Safety on a fusion site is not one discipline. It is several.

Each safety function is governed by a different code stack. Each requires evidence, certification and independent verification. None of them tolerate being added late. The Ekium references below highlight this in practice.

LIGHTNING PROTECTION

Tokamak Complex protection studies

Requirements management against IEC 61513, deliverables prepared and verified to Qualifoudre Level 3 (the highest tier of France's certified lightning-protection scheme) and multidisciplinary interface across more than 2,000 applicable documents.

Engie Axima | ITER TB04 | 2018-2020

FIRE SAFETY

Building Fire Safety System assistance

Contract engineer design and integration support for Fire Safety Systems across seven main and three secondary buildings, including system architecture, functional analyses, wiring schemes and implementation plans.

M+W Group | ITER TB04 | 2017-2019

FUNCTIONAL SAFETY

Anoxia protection - independent verification

Functional safety assessment and independent verification of the operator anoxia protection system in Building 61, performed during commissioning under IEC 61511.

Exyte | ITER TB04 | Building 61 | 2021

FIRE SAFETY DESIGN. OWNER'SREPRESENTATIVE

ITER Buildings – Fire Safety System design study

Owner's engineer support for renewal of the Fire Safety System and the production of the Fire Safety System master plan covering the full set of buildings within the design authority's scope.

Engage | ITER Buildings | €50M works | 2010-2011

Tritium is its own engineering discipline.

Detritiation, dynamic and static confinement, glovebox handling and ventilation under nuclear safety standards. These are not disciplines fusion can pick up at commissioning. They must be designed in. The Ekium references below highlight this in practice.

TRITIUM-MONITORED GLOVEBOX FEASIBILITY

Implementation of two tritium-monitored gloveboxes

Glovebox ventilation architecture, sizing, equipment definition and detector placement for a post-irradiatory examination facility. Designed to NF ISO 11933-4 and NF M 62-200 with full safety regulation provision against breach of containment and excess vacuum.

CEA Cadarache (LECA STAR) | 2020

TRITIATED DISCHARGE TREATMENT

Increasing tritiated discharge treatment capacity

Detailed design and qualification of modifications to expand effluent storage and treatment capacity ahead of discharge: general installation studies in E3D, civil and steel structure work in ROBOT, qualification of new piping routing in ANSYS and PipeStress and process validation in Flomaster.

Civaux NPP | 2023-2024 | CAPEX €3.5M

Fusion will need tritium engineering at start of life. Existing nuclear has needed it for decades. The discipline is transferable.

The plant is what makes the physics possible.

Power resilience, automation and building services are not the visible parts of a fusion facility. They are what determine whether it runs. The examples below highlight this in practice.

BACKUP POWER

Backup power distribution audit

Independent audit across HVAC, general installations, low-current electrics, I&C and fire detection / protection. Approval of design documents for both conventional and nuclear classified buildings.

VFR (Vinci/Ferrovial/Razel-Bec) | 2019

AUTOMATION

RF heating control - Building 15

Engineering and delivery of automation cabinets and the associated PLC programmes for technical management functions. Local HMI, integration with the central CODAC supervision system, factory testing and on-site commissioning.

Exyte | ITER Building 15 | 2021

I&C ASSISTANCE

Control & Command - 11 main buildings

Multi-year I&C engineering and delivery support for the non-nuclear buildings of the Tokamak complex, covering BMS, ventilation, energy and fluids distribution and fire protection on a Siemens architecture.

M+W Group | ITER TB04 | 2015-2017

Designed and delivered against IEC 61513, IEC 61226, IEC 60880, IEC 62138, NF EN 61508, IEC 62645, IEC 62566.

ITER is the proving ground

The next generation of fusion is what it pays back into

What carries across

- Multi-package interface management
- Functional safety case discipline (IEC 61511, IEC 61513)
- Tritium and confinement engineering
- Civil structural challenges in live-build environments
- Coordination between conventional and nuclear-classified scope

Where it lands next

- STEP - the UK's first prototype fusion plant programme
- DEMO - the European post-ITER reference concept
- Private fusion - Commonwealth, Tokamak Energy, Helion, TAE, Renaissance Fusion
- Compact pilots and SMR-style fusion deployment models
- Existing nuclear plant modifications and lifecycle works

Why it matters

ITER is a single project at vast scale. The next generation will be many projects, often privately financed, on tighter schedules.

Lessons learnt at ITER scale should not have to be learnt again.

The engineering partner most useful to a fusion client is one who has already worked on the regulated, multi-discipline, time-pressured versions of this problem.

Five questions every fusion client should be asking

Less about credentials in the abstract; more about what has been done and what was learned in doing it

1. Evidence of delivery under relevant nuclear safety standards and regulatory expectations (e.g. IAEA, ASN, ONR, NRC).
2. Confirmation of interfaced management across civil, electrical, I&C, HVAC and fire safety on a single regulated programme
3. Have previously worked with tritium-specific containment, monitoring and ventilation under nuclear safety classification
4. Experience of operating across French, British and other European regulatory regimes, with the language and document discipline that requires
5. An understanding - operationally, not theoretically – of the difference between conventional and nuclear-classified scope on the same site

Fusion and tritium engineering - selected references

F4E

Structural expertise

Civil engineering verification and optimisation, ITER conventional buildings.

2022

ENGIE AXIMA

Lightning protection studies

Tokamak Complex, IEC 61513, Qualifoudre Level 3.

2018-2020

M+W GROUP

I&C assistance to design

11 main buildings, Tokamak complex non-nuclear scope.

2015-2017

M+W GROUP

Fire Safety System

Seven main and three secondary buildings.

2017-2019

EXYTE

Anoxia protection - IEC 61511

Independent functional safety verification, Building 61.

2021

EXYTE

Building 15 - RF heating control

Cabinets, PLCs, HMI, integration with CODAC.

2021

VFR CONSORTIUM

Backup power distribution

Independent multi-discipline design audit.

2019

ENGAGE

Buildings – Fire Safety master plan

Owner's engineer, €50M works.

2010-2011

CEA CADARACHE

Tritium-monitored gloveboxes

Feasibility study, NF ISO 11933-4, LECA STAR.

2020

MONTEIRO / EDF

Tritiated discharge expansion

Detailed design and qualification, Civaux NPP.

2023-2024

Each reference is supported by a full project sheet, available on request.

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“The physics has been credible for decades

The industry will be built by the engineers who can turn it into operating power plants.”

Ekium - a partner for fusion programmes from concept to commissioning.

With a strong UK presence and a wider European engineering footprint, Ekium UK combines local delivery with international depth across nuclear, fusion and complex industrial environments.

ekium.com

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