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# A new look at non-proliferation for fusion energy

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Published: August 2026

www.manchester.ac.uk/dalton

# Contents

# List of Acronyms

| | |
|---|---|
| AP | Additional Protocol |
| CSA | Comprehensive Safeguards Agreement |
| DESNZ | Department for Energy Security and Net Zero |
| DT | Deuterium-Tritium |
| EA | Environment Agency |
| ECJU | Export Control Joint Unit |
| HSE | Health and Safety Executive |
| IAEA | International Atomic Energy Agency |
| JET | Joint European Torus |
| NPT | Treaty on the Non-Proliferation of Nuclear Weapons |
| NRW | Natural Resources Wales |
| NSG | Nuclear Suppliers Group |
| NWS | Nuclear-Weapon State |
| NNWS | Non-Nuclear-Weapon State |
| ONR | Office for Nuclear Regulation |
| SEPA | Scottish Environment Protection Agency |
| SQ | Significant Quantity |
| STEP | Spherical Tokamak for Energy Production |
| UKAEA | United Kingdom Atomic Energy Authority |
| VOA | Voluntary Offer Agreement |

# Foreword

## As fusion technology evolves towards commercialisation, it is vital to have in place the appropriate regulatory frameworks to guide designers, developers and operators of fusion facilities.

Progress has already been made in considering the regulation of safety, environmental and security aspects of fusion plants, but our view at the Dalton Nuclear Institute is that the area of non-proliferation has not yet developed to the same extent.

At this nascent and crucial time, there is a risk that, if the regulatory frameworks and guidance for non-proliferation considerations relevant to fusion technology are not addressed and agreed in good time, we could end up in a situation where designs need to be re-configured, projects need to be delayed or investment decisions need to be paused.

This paper aims to add some momentum to these important considerations by assessing the maturity of existing regulation and proposing a measured and proportionate way forward, with clear and specific actions proposed. Importantly, the paper has drawn on input and insight from stakeholders across the UK fusion community and beyond in reaching its recommendations.

Our hope is that this work will be a helpful contribution to aid the formulation of a nationally and internationally robust non-proliferation regime to meet the needs of 21st century fusion technology at both development and commercial scale.

**Professor Phil Edmondson**
**Director, Dalton Nuclear Institute**
**The University of Manchester**

# Glossary

**Additional Protocol (AP)**
A legally binding agreement supplementing a state's safeguards agreement with the IAEA, expanding the scope of declarations and IAEA access rights to strengthen verification.

**Comprehensive Safeguards Agreement (CSA)**
An agreement under which a non-nuclear-weapon state accepts IAEA safeguards on all source material or special fissionable material in all its peaceful nuclear activities, also referred to as a 'full scope' safeguards agreement.

**Enrichment**
The process by which the ratio of a particular isotope of an element is increased, most commonly referring to raising the proportion of uranium-235 in natural uranium.

**Fertile Material**
Nuclear material that can be converted into fissile material through neutron capture, principally uranium-238 and thorium-232, which can be transmuted into plutonium-239 and uranium-233, respectively.

**Fissile Material**
Isotopes capable of undergoing fission by absorbing slow (thermal) neutrons, such as uranium-235 and plutonium-239.

**Fissionable Material**
Any isotope capable of nuclear fission; a broader category than fissile material, encompassing isotopes such as uranium-238 that require fast neutrons to fission.

**Safeguards**
The technical, legal and administrative measures by which the IAEA verifies that nuclear material and facilities are not used for proscribed purposes.

**Significant Quantity (SQ)**
The approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive device cannot be excluded, used by the IAEA as a reference quantity for inspection goals.

**Treaty on the Non-Proliferation of Nuclear Weapons (NPT)**
The cornerstone of the international non-proliferation regime. It is designed to prevent nuclear weapons and related technologies from spreading, encourage peaceful use of nuclear energy, and support progress towards disarmament.

**Voluntary Offer Agreement (VOA)**
An agreement under which a nuclear-weapon state voluntarily offers some or all its civil nuclear material and facilities for IAEA safeguards, concluded with each of the five NPT nuclear-weapon states, including the United Kingdom.

# Executive Summary

Fusion energy is transitioning from experimental research to engineering demonstration. The United Kingdom has positioned itself at the forefront of this shift, committing over £2.5 billion through its 2026 Fusion Strategy, alongside rapidly growing private investment. As the technology matures, fusion is expected to expand beyond electricity generation into applications such as medical isotope production and hydrogen generation, strengthening its export potential.

This document examines a critical dimension of that transition; how fusion energy fits within the global nuclear non-proliferation regime, and whether that regime remains adequate as fusion moves towards commercial deployment. The existing framework, centred on the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), implemented through International Atomic Energy Agency (IAEA) safeguards, and complemented by export control regimes, was not designed with fusion systems in mind. While many fusion-relevant materials and technologies fall partially within this system, its overall suitability for commercial-scale fusion has not yet been fully assessed.

Three considerations underpin this argument: first, fusion reactors generate intense neutron environments capable of transmuting fertile material into significant quantities of weapons-usable fissile material, yet this pathway does not automatically trigger safeguards obligations under the current, material-based regime. Second, the light isotopes essential to the fusion fuel cycles, tritium, lithium-6 and deuterium, fall entirely outside IAEA safeguards despite their direct relevance to nuclear weapons programmes, and tritium inventories in particular are set to grow by orders of magnitude as fusion reaches commercial scale.

Third, commercial facilities will bring these elements together on a single site: a neutron source capable of producing fissile material, alongside significant inventories of weapons-relevant light isotopes. No existing framework assesses the combined significance of this co-location, which creates a risk distinct from any one material considered in isolation.

Taken together, these gaps do not place fusion outside the non-proliferation regime, but they do expose limitations in how the current system applies to it. The architecture of non-proliferation is in place; its implementation has not yet been extended to fusion. Addressing this now, while facility designs remain flexible, offers a more effective path than retrofitting governance after commercial deployment.

The clearest priority to emerge from this analysis is the need for a coherent mechanism through which these considerations can be addressed together before deployment. This paper's recommendation is therefore the establishment of a technical expert group, under which five specific actions (page 6), prioritised by urgency, should be taken forward.

## Overarching Recommendation

**Establish a Technical Expert Group:**
Department for Energy Security and Net Zero (DESNZ) should establish, as soon as possible, a technical expert group to examine the non-proliferation considerations that arise from fusion energy. The group should bring together fusion engineers and scientists, safeguards and non-proliferation specialists, and regulators, as necessary, and may operate through dedicated subgroups. Establishing the group now allows the UK to develop its technical evidence base around non-proliferation and to shape its position, aligned with the UK fusion strategy.

## Action 1

**Urgent and important**

### Neutron Environments and Fissile Material Production

The expert group should first assess whether energetic neutron sources represent a credible proliferation concern across different fusion designs and operational configurations, considering other intense neutron sources - including particle accelerator-based neutron sources - alongside fusion. The group should define, for various fusion designs, thresholds (energy and source intensity) at which a neutron source becomes safeguards-relevant, and consider the technical feasibility of modification for misuse. This should form the evidence base for any subsequent verification approach or inspection standard ahead of commercial-scale deployment. Should the assessment determine that proliferation risks are credible, the appropriate regulator, identified through the expert group's work, should develop and issue proportionate, fusion-specific safeguards guidance, targeted at clearly evidenced misuse pathways, to clarify how existing safeguards powers apply to fusion facilities.

## Action 2

**Important, not yet urgent**

### Light Isotopes and Tritium Accountancy

The expert group should map the actual risk posed by the presence of tritium, lithium-6, deuterium and associated processing equipment and evaluate the need for tritium accountancy, recognising that the challenge scales with, and is contingent on, the scale of tritium breeding activity. On that basis, tritium accountancy systems should be designed to a standard capable of supporting verification before commercial-scale inventories are established. A voluntary reporting model, comparable to the established arrangements for the voluntary reporting of americium and neptunium, can be considered as a proportionate mechanism the UK could adapt.

## Action 3

**Important, not yet urgent**

### Export Controls for Light Isotopes

The expert group should review whether existing bilateral arrangements and export controls covering tritium, lithium-6 and deuterium remain proportionate in the context of commercial-scale fusion. This review should explicitly cover the associated technologies, including design, production and handling infrastructure, as well as the materials themselves, and should be calibrated to avoid placing disproportionate constraints on fusion development.

## Action 4

**Lower immediate priority**

### Co-location and Facility-Level Assessment

Once Actions 1, 2, and 3 are underway, the expert group should assess the combined presence of neutron sources and weapons-relevant materials at a single site. Rather than prescribing an entirely new framework, this work could adapt existing IAEA frameworks and tools. This should distinguish research and demonstration facilities from full commercial plants, and assessment should be made at the design stage, before facilities are built.

## Action 5

**Lower immediate priority**

### Cross-Sector Collaboration

The expert group should establish a subgroup focused on knowledge transfer across fields. Its role should be to facilitate cross-sector collaboration, transferring existing relevant expertise between fusion, fission, and other relevant sectors. This collaboration could help fusion develop a proportionate regulatory approach, informed by the accumulated experience of other sectors and mindful of the lessons they have already learned.

The UK is well placed to lead this effort, as a major fusion investor, a Nuclear-Weapon State under the NPT, and a key participant in international governance structures. This does not require new treaties or disproportionate constraints on industry, only the proportionate adaptation of existing instruments, pursued now, while the window to act remains open.

# 1 Introduction

## 1.1 Motivation

Fusion energy is moving from experimental science towards engineering demonstration, and the United Kingdom has made a deliberate policy choice to be at the forefront of that transition. The Government's 2026 Fusion Strategy committed over £2.5 billion in public investment over five years, including £1.3 billion to deliver the Spherical Tokamak for Energy Production (STEP) prototype power plant at West Burton in Nottinghamshire [1].

The sector is moving, but it remains at an early stage: no commercial fusion power plant yet exists, and the engineering and governance challenges ahead are substantial. Nevertheless, deployment timelines are shortening. As illustrated in Figure 1, UK STEP is expected to move into construction around 2030 with a prototype targeted by 2040, and Tokamak Energy is targeting a pilot power plant by 2033. Both national and international programmes are receiving increasing levels of funding, influencing the supply chain in the industrial sector.

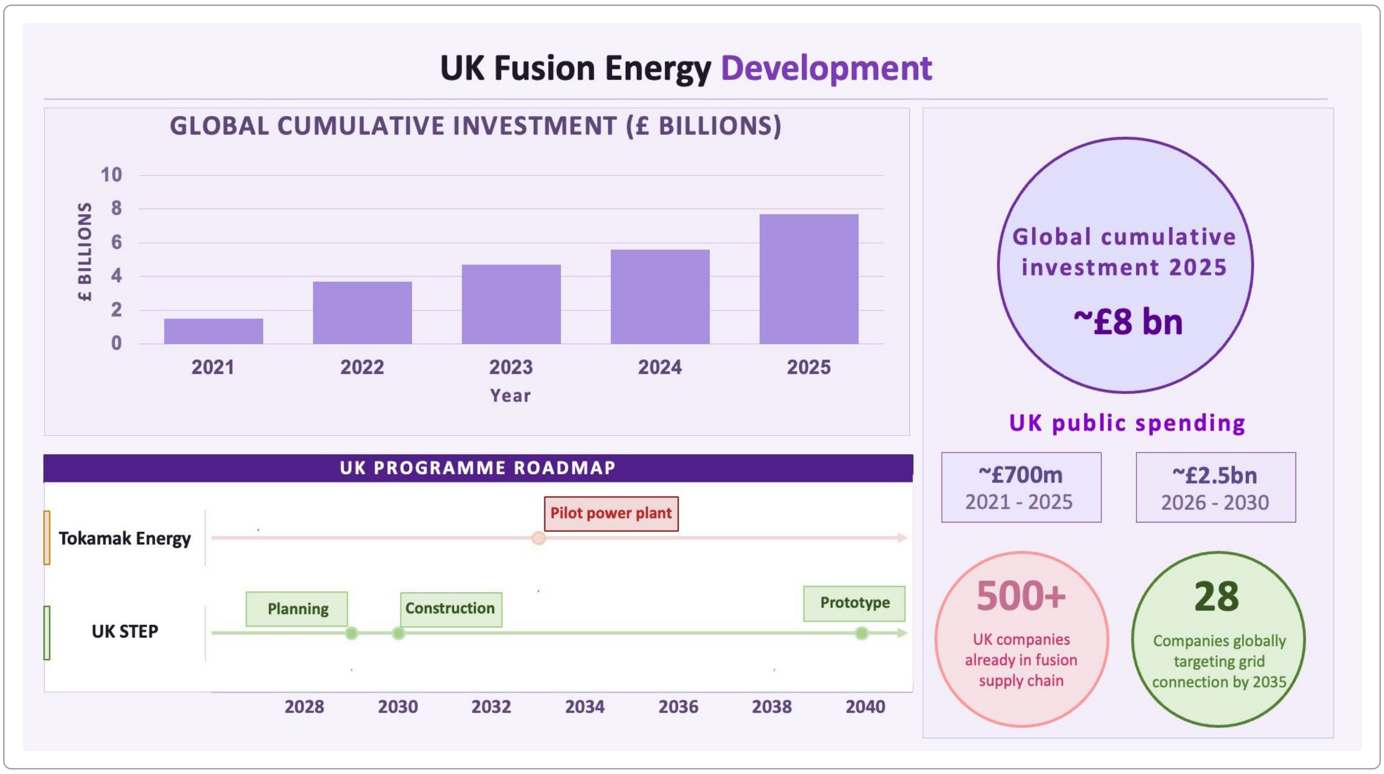


*Figure 1: UK Fusion Energy Development: Global Investment and Programme Roadmap [1], [2].*

As these programmes are developed, the governance frameworks that will shape them need to be developed in parallel, not retrofitted after deployment decisions have been made.

The opportunity extends beyond electricity generation since fusion reactors are a powerful source of high-energy neutrons, which opens the prospect of using fusion technology to produce medical isotopes, as well as for hydrogen production [2]. These adjacent uses could make fusion technology more valuable than a power source alone, and could broaden the markets into which UK-developed fusion technology might be exported.

As fusion technology matures, there is a realistic prospect of the UK exporting it. Exporting a novel nuclear-relevant technology credibly requires demonstrating that the regulatory foundations have been thought through in advance.

This document is concerned with one critical dimension of that foundation: the extent to which fusion energy falls within the global non-proliferation regime, and how that regime may need to evolve as fusion moves towards commercialisation. The global non-proliferation regime is a broader concept than safeguards alone. It encompasses the NPT as its cornerstone, IAEA safeguards as its verification mechanism, and export controls through bodies such as the Nuclear Suppliers Group (NSG) and the Zangger Committee. Many fusion-relevant materials already fall within parts of this regime. The question this paper addresses is whether the current regime is sufficient for the scale and character of fusion's non-proliferation dimensions, and what needs to be strengthened before commercial deployment and export.

## 1.2 Background: The Non-Proliferation Regime and The UK Position

Figure 2 provides an overview of the international nuclear non-proliferation regime and the UK's position within it. The regime is centred on the NPT [3], which distinguishes between Nuclear-Weapon States (NWSs) and Non-Nuclear-Weapon States (NNWSs), and is implemented through the safeguards system of the IAEA.

Under this system, NNWSs are subject to Comprehensive Safeguards Agreement (CSA) covering all nuclear material, while NWSs, including the UK, apply safeguards selectively through Voluntary Offer Agreement (VOA). In both cases,

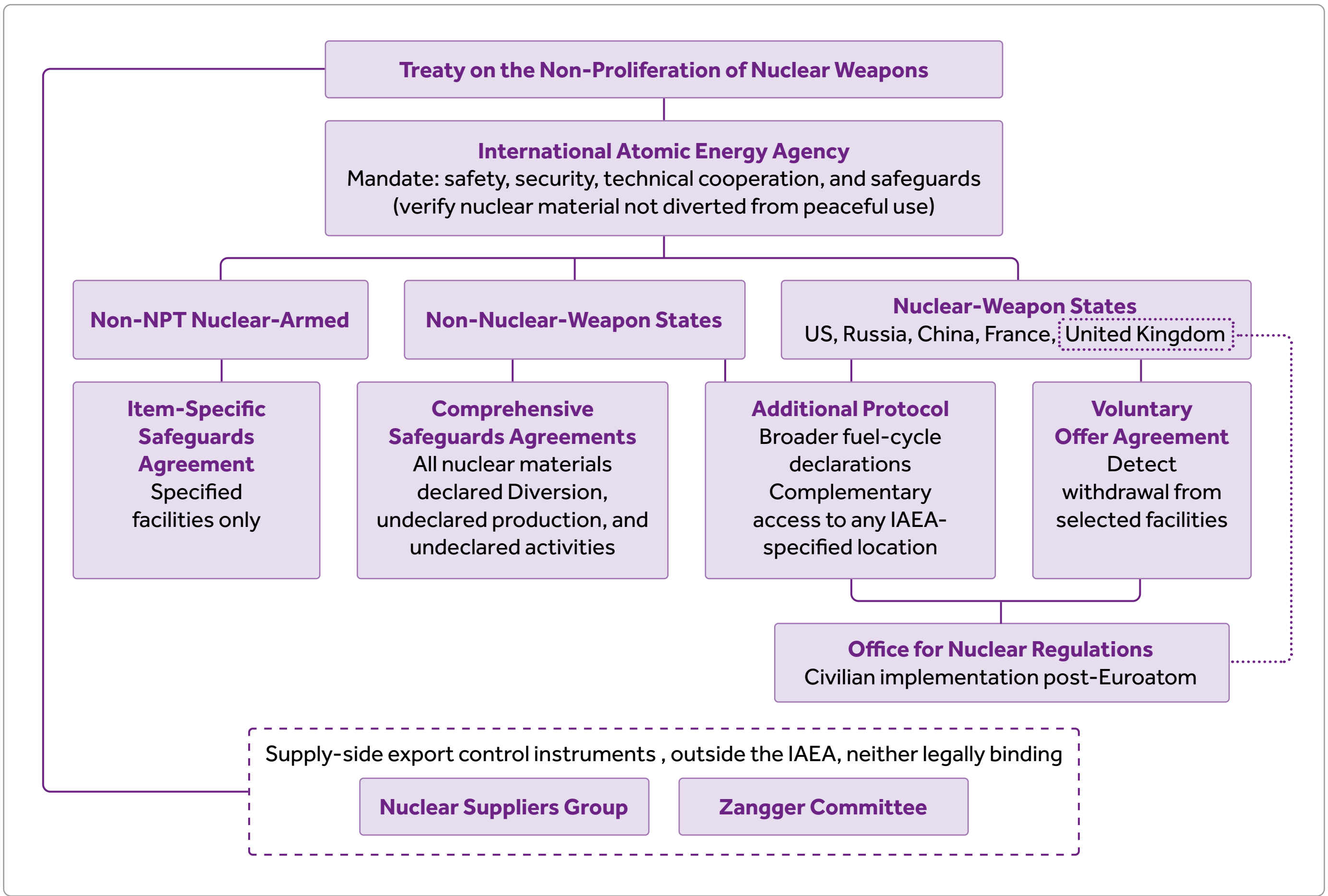


*Figure 2. The international nuclear non-proliferation framework and the UK's position within it.*

the Additional Protocol (AP), which is a voluntary agreement, strengthens verification through expanded declarations and access provisions. Non-NPT Nuclear-Armed States (States that have not signed the NPT) have an item-specific safeguards agreement with the IAEA, which allows access to specified facilities designated by the state. Alongside the IAEA system, export control regimes such as the NSG and the Zangger Committee provide complementary controls on sensitive materials and technologies.

A key feature of this framework is that it is material-based. IAEA safeguards apply to nuclear material: uranium, thorium and plutonium, but do not extend to certain fusion-relevant materials [4]. Light isotopes such as tritium, lithium-6 and deuterium fall outside the formal scope of safeguards, despite their relevance to nuclear weapons programmes. Fusion facilities that handle only these materials and do not contain declared nuclear material therefore fall outside IAEA safeguards as currently defined.

While the design of nuclear weapons is peripheral to this paper, it is necessary to appreciate the roles of fission and fusion reactions within them in order to understand the proliferation significance of the materials and processes that underpin civil applications of fusion. As well as the potential use of a fusion reactor as a neutron source for the breeding of fissile material, fusion power employs a number of dual-use materials. The first nuclear weapons derived their nuclear energy entirely from the fission of $^{235}$U or $^{239}$Pu. However, as weapons developed beyond this first generation, the potential to incorporate fusion components in a multicomponent, 'staged' weapon, initiated by a fission trigger, became clear. Most modern weapons incorporate both fission and fusion components, for example 'boosting' a primary fission stage to increase yield by injecting a Deuterium–Tritium (DT) gas mixture at the point of initiation, or the inclusion in the design of complex 'secondary' stages which utilise both fission and fusion processes in concert. The individual contributions of fission and fusion to overall weapon yield can vary greatly depending on the details of the design.

Despite falling outside the formal scope of IAEA safeguards, fusion is not placed outside the non-proliferation regime entirely. Elements of the system still apply. Export controls under the NSG cover several fusion-relevant items [5], and the AP may provide a basis for IAEA access in specific circumstances [6]. However, these mechanisms were not designed with fusion systems in mind, and their combined adequacy has not been systematically assessed.

This raises a more fundamental question: whether the current regime is sufficient for the scale and characteristics of commercial fusion. DT fusion, the leading technological pathway, relies on tritium as its primary fuel. Fusion systems will inherently combine capabilities and materials of non-proliferation relevance, including intense neutron fluxes, large tritium inventories, and isotopic feedstocks such as lithium-6 and deuterium.

This paper examines where these gaps arise and their policy implications. Its central argument is that the current non-proliferation framework does not fully address the challenges posed by commercial-scale fusion, and that proportionate adaptation of existing instruments is needed. Addressing these issues now, while technologies and facility designs remain flexible, offers a more effective and less disruptive path than retrofitting governance after deployment.

# 2 Safeguards Considerations in Fusion Energy Systems

## 2.1 Neutron Environments and Fissile Material Production

Fusion reactions generate high-energy neutrons (~14 MeV) during operation, which can, with moderation, transmute fertile materials such as uranium-238 or thorium-232 into fissile isotopes. Under the current material-based safeguards framework, the neutron environment itself carries no safeguards obligation unless qualifying nuclear material is present on site. Where such material is declared, standard material accountancy and control obligations apply under the relevant safeguards agreement. Some fusion facilities may fall within the scope of existing safeguards arrangements depending on their configuration, for example, those using depleted uranium as tritium storage beds, fusion-fission hybrid designs, or facilities where special nuclear material is incidentally produced through uranium impurities in structural or blanket components [7]. Where an AP is in force, the IAEA may in principle seek complementary access to fusion facilities or intense neutron sources to resolve questions about the possible presence of undeclared nuclear material, even where none is declared to be present. For NNWS with a CSA, the AP specifically strengthens the ability to detect undeclared production at declared facilities. For the UK, operating under a VOA, the AP similarly provides a basis for access, though no verification methodology has been developed or validated for the fusion-specific context.

The more significant concern is the potential for misuse of a fusion facility as an intense neutron source through the deliberate introduction of fertile material to breed fissile material under the cover of normal operation. Studies have demonstrated that fertile material could be introduced into a fusion breeding blanket in several ways: dissolved into a liquid blanket coolant, injected as micro-particles into the coolant stream, or incorporated into irradiation test modules. Modelling of a fusion device with fertile material (uranium or thorium-bearing fuel particles) loaded into its blanket suggested that such a system could produce on the order of 20 kg of plutonium or uranium per week [8], more than one IAEA Significant Quantity (SQ). It was also found that with 5-50 metric ton quantities of fertile material introduced into a liquid blanket, one SQ of fissile material could be produced in under a year, with the timeframe dropping to one to two months as the fertile inventory increases [9]. Another study suggests that several hundred kilograms of natural or depleted uranium in a single blanket could yield around 8 kg of weapons-grade plutonium [10].

As fusion facilities incorporate increasingly flexible experimental capabilities, irradiation test modules, variable blanket configurations, and changeable coolant compositions, the question of how regulatory confidence is maintained in the absence of declared nuclear material becomes correspondingly more pressing. The current UK framework provides no explicit guidance on how these configurations are considered from a safeguards perspective, creating uncertainty for developers planning experimental or commercial programmes and for regulators assessing them.

### Overarching Recommendation

**Establish a Technical Expert Group:**
Department for Energy Security and Net Zero (DESNZ) should establish, as soon as possible, a technical expert group to examine the non-proliferation considerations that arise from fusion energy. The group should bring together fusion engineers and scientists, safeguards and non-proliferation specialists, and regulators, as necessary, and may operate through dedicated subgroups. Establishing the group now allows the UK to develop its technical evidence base around non-proliferation and to shape its position, aligned with the UK fusion strategy.

### Action 1

**Urgent and important**

**Neutron Environments and Fissile Material Production**

The expert group should first assess whether energetic neutron sources represent a credible proliferation concern across different fusion designs and operational configurations, considering other intense neutron sources – including particle accelerator-based neutron sources – alongside fusion. The group should define, for various fusion designs, thresholds (energy and source intensity) at which a neutron source becomes safeguards-relevant, and consider the technical feasibility of modification for misuse. This should form the evidence base for any subsequent verification approach or inspection standard ahead of commercial-scale deployment. Should the assessment determine that proliferation risks are credible, the appropriate regulator, identified through the expert group's work, should develop and issue proportionate, fusion-specific safeguards guidance, targeted at clearly evidenced misuse pathways, to clarify how existing safeguards powers apply to fusion facilities.

## 2.2 Tritium, Lithium and Deuterium: Light Isotopes and the Non-Proliferation Regime

Tritium, lithium-6 and deuterium are the principal light isotopes associated with DT fusion. None is classified as nuclear material under the NPT, and none falls within the scope of IAEA safeguards as currently defined [7]. Their relevance to the non-proliferation regime is therefore indirect but valid; each has a role in nuclear weapons programmes, and the presence of these at scales that will grow substantially beyond current research quantities raises questions that the existing framework was not designed to address. It is important to be clear, however, that these materials cannot on their own constitute a weapons threat; the focus of IAEA safeguards remains firmly on special fissionable material, and light isotopes present a concern primarily in combination with fissile material or as contributors to weapons performance enhancement.

Tritium is not classified as source or special fissionable material under the NPT and is therefore outside IAEA material accountancy obligations. This does not mean it is unaccounted for. Bilateral safeguards conditions apply to tritium transfers, for example, the agreement governing the supply of tritium to JET, which passed to the UK post-Brexit and restricts use to peaceful applications [11]. Operational accountancy also exists within fusion facilities for safety and regulatory purposes. What is absent is a formal, nationally and internationally standardised verification framework applicable to the large quantities of tritium at commercial fusion scale.

That gap matters because tritium serves as a booster in nuclear weapons, with only a few grams sufficient to significantly enhance yield [12]. Current research inventories are small, and existing bilateral arrangements and operational disciplines provide oversight. As fusion scales towards commercial operation, tritium inventories will increase by orders of magnitude. Simulations suggest that quantities of tritium could in principle be diverted from a commercial facility without detection using current monitoring technologies [12], and the absence of a standardised accountancy framework means there is no mechanism to provide independent assurance. The technical challenges of tritium accountancy at scale are significant; tritium's high diffusivity causes permeation through materials, real-time monitoring technologies have not yet been fully developed, and determining the complete inventory across a complex fuel cycle involves inherent uncertainty [13].

Lithium is not subject to IAEA safeguards, and within the non-proliferation regime, its relevance arises primarily through export controls, which apply where the lithium-6 content exceeds natural abundance [14]. Lithium-6, which has a higher neutron capture cross-section than lithium-7 and is often the dominant contributor to tritium production in breeding blanket designs, is the isotope of primary interest, though lithium-7 can also breed tritium, and some blanket designs operate with natural or lower-enrichment lithium [15], [16]. The enrichment of lithium-6 shares methodological heritage with processes that have weapons-programme relevance, and lithium-6 is used in thermonuclear weapon construction [17].

The non-proliferation concern centres on the supply chain; the scale of lithium-6 demand for commercial fusion will drive the development of enrichment infrastructure, and no internationally agreed framework currently exists for verifying the end use of enriched lithium once supplied. Export controls provide a partial response, but controlling transfers does not constitute a verification framework for how enrichment capability is developed or used.

Deuterium is handled as a fuel commodity in fusion facilities and does not fall under international safeguards. Export controls apply to deuterium, reflecting recognition of its dual-use sensitivity. The quantities required for fusion are modest compared to heavy water reactor programmes, and the concern is less acute than that arising from tritium or lithium enrichment. The non-proliferation relevance of deuterium lies primarily in its role as a component of lithium deuteride, a material in thermonuclear weapon construction [18], and in the infrastructure and expertise that large-scale deuterium handling develops.

Across all three isotopes, the pattern is the same: materials with weapons-programme relevance that sit outside IAEA safeguards, governed instead through a combination of bilateral arrangements, export controls and operational practice, none of which was designed with commercial-scale fusion in mind.

**Action 2** — **Important, not yet urgent**

**Light Isotopes and Tritium Accountancy**

The expert group should map the actual risk posed by the presence of tritium, lithium-6, deuterium and associated processing equipment and evaluate the need for tritium accountancy, recognising that the challenge scales with, and is contingent on, the scale of tritium breeding activity. On that basis, tritium accountancy systems should be designed to a standard capable of supporting verification before commercial-scale inventories are established. A voluntary reporting model, comparable to the established arrangements for the voluntary reporting of americium and neptunium, can be considered as a proportionate mechanism the UK could adapt.

**Action 3** — **Important, not yet urgent**

**Export Controls for Light Isotopes**

The expert group should review whether existing bilateral arrangements and export controls covering tritium, lithium-6 and deuterium remain proportionate in the context of commercial-scale fusion. This review should explicitly cover the associated technologies, including design, production and handling infrastructure, as well as the materials themselves, and should be calibrated to avoid placing disproportionate constraints on fusion development.

## 2.3 The Emerging Consideration of Co-location in Fusion

The preceding sections have examined neutron environments and light isotopes individually. Considered in isolation, each raises questions that are tractable within existing or modestly adapted frameworks. What none of these individual assessments address are the emerging safeguards considerations of co-location.. A facility that assembles this combination of materials in normal operation has, as a consequence of its design, potentially brought together on one site the principal materials and technologies required for weapons development: a neutron source capable of transmuting fertile to fissile material, potential fertile material in the form of the depleted uranium storage matrix, tritium for weapons boosting, and the isotopic feedstocks, lithium-6 and deuterium, for thermonuclear weapon construction. No framework currently asks the question: what is the combined safeguards significance of these materials being present together?

**Action 4** — **Lower immediate priority**

**Co-location and Facility-Level Assessment**

Once Actions 1, 2, and 3 are underway, the expert group should assess the combined presence of neutron sources and weapons-relevant materials at a single site. Rather than prescribing an entirely new framework, this work could adapt existing IAEA frameworks and tools. This should distinguish research and demonstration facilities from full commercial plants, and assessment should be made at the design stage, before facilities are built.

# 3 Limitations of the Existing Regulatory Landscape

The considerations identified in Section 2 intersect with a range of existing regulatory safeguards and export control frameworks in the United Kingdom. These frameworks were developed primarily for nuclear fission, radioactive materials management, and dual-use technologies.

Fusion is regulated for safety and environmental protection by the Health and Safety Executive (HSE), the Environment Agency in England (EA), the Scottish Environment Protection Agency in Scotland (SEPA), and Natural Resources Wales in Wales (NRW), through a combination of radiation protection law and environmental permitting.

This is separate from nuclear licensing, which the UK has decided does not apply to fusion. While gaps exist, particularly given the scale of dual-use materials that commercial fusion will require, it is important to note that several of these instruments already carry partial relevance to fusion activities.

Table 1 (page 14) maps each consideration to the regulatory instrument and the responsible body currently applicable.

*Table 1. UK regulatory and export control frameworks relevant to fusion non-proliferation considerations*

| Consideration | Regulator | Instrument | What It Covers |
|---|---|---|---|
| Neutron environments & fissile material production | ONR | Nuclear Safeguards Act 2018; Nuclear Safeguards Regulations 2019 | Material accountancy for qualifying nuclear material at declared locations.<br>Special arrangements where fertile material is present at unlicensed sites, where activities are known. Reporting is activity-based rather than material-based. |
| Tritium inventory & accountancy | HSE | Ionising Radiations Regulations 2017 | Radiation protection of workers and public. |
| | Environment Agencies | Environmental Permitting Regulations 2016 | Controls on releases of activated/radioactive materials to the environment.<br>Permit conditions require fusion operators holding tritium to prevent theft or loss, and unauthorised access to unsealed sources.<br>Controls on the quantities of radioactive materials and wastes held at a site and require permit holders to keep records of these, with records subject to inspection.<br>Impose permit conditions on users of radioactive substances to minimise holdings of radioactive materials and minimise the generation of radioactive waste, including activation products. |
| | ECJU | UK Strategic Export Control List | Export licence required for tritium. Export controls apply at the point of transfer. |
| | DESNZ | Nuclear Cooperation Agreement (NCA) | DESNZ ensures non-diversion of civil tritium supply. |
| Lithium | ECJU | UK Strategic Export Control List | Export licence required for the transfer of lithium enriched above its natural isotopic abundance (~6.5% Li-6) in any form. |
| Deuterium | ECJU | UK Strategic Export Control List | Export licence required for plant and equipment capable of producing or concentrating heavy water, deuterium, and deuterium compounds. |
| Co-location | N/A | N/A | Not currently considered in any UK regulation. |

Safeguards | Security | Safety

Two observations follow directly from this mapping and should inform the Government's approach:

The first is that for most of the considerations identified in Section 2, the existing regulatory instrument addresses a legitimate but different objective. The Ionising Radiations Regulations protect workers and the public from radiation exposure; they are not designed to verify that tritium has not been diverted. Export controls on lithium-6 restrict the transfer of controlled material across borders; they do not constitute a verification framework for how enrichment capability is developed or used domestically or in recipient states. These frameworks are not inadequate for their intended purposes; they are simply not designed to answer the safeguards question. The safeguards question requires a different kind of instrument, and that instrument does not currently exist for fusion.

The second observation targets co-location consideration, this has no entry in the table because no existing framework addresses it. This requires a new analytical approach: a facility-level assessment that considers the combined inventory of a fusion site rather than evaluating each material stream independently.

# 4

# Non-proliferation Considerations Across Different Fusion Technologies

A natural question following from this mapping is whether the considerations identified in Section 2 are genuinely sector-wide, or whether they arise only in relation to specific fusion technologies.

This matters for policy design; if the considerations are confined to one or two technology types, targeted guidance may suffice; if they arise across the sector, a more systemic response is needed.

Table 2 maps the non-proliferation considerations against the main fusion technology types currently under development. These are illustrative examples rather than an exhaustive list; other technologies exist, and the landscape continues to evolve. The purpose is not to rank technologies by risk or to assess the probability of misuse, but to demonstrate that the considerations are not confined to a single technology or a hypothetical future system.

*Table 2. Non-proliferation considerations across fusion technology types*

| System type | N, Neutrons | T, Tritium | L, Lithium | D, Deuterium |
|---|---|---|---|---|
| Tokamak / Spherical tokamak (ITER, STEP, Tokamak Energy) | ● | ● | ● | ● |
| Stellarator (Proxima Fusion) | ● | ● | ● | ● |
| Field-reversed configuration (Helion, TAE) | ● | ◑ | ◑ | ● |
| Magnetic mirror (Novatron, Lockheed Martin) | ● | ● | ● | ● |
| Z-pinch (Zap Energy) | ● | ● | ● | ● |
| Magneto-inertial fusion (General Fusion) | ● | ● | ● | ● |

● *Present* ◑ *Present in some configurations only; dependent on the specific technology approach adopted by the developer.*

The considerations identified in this paper are not confined to a single technology. They arise now, across the technologies currently attracting the majority of UK and global fusion investment. The tokamak, the technology underlying both ITER and the UK's own STEP programme, presents all four considerations in full commercial DT operation and represents the immediate policy priority. However, governance frameworks must be designed with sufficient flexibility to accommodate the wider technology landscape as it develops. It is also worth noting that fusion is not unique in producing intense neutron fluxes: spallation sources and other emerging neutron-producing technologies face comparable questions, and the governance approach developed for fusion may have broader applicability. This paper does not recommend building an entirely new regulatory framework from scratch. Instead, it proposes adapting and extending existing instruments to address the specific characteristics of fusion, drawing on the institutional knowledge and verification expertise already present across the UK nuclear sector.

### Action 5

**Lower immediate priority**

**Cross-Sector Collaboration**

The expert group should establish a subgroup focused on knowledge transfer across fields. Its role should be to facilitate cross-sector collaboration, transferring existing relevant expertise between fusion, fission, and other relevant sectors. This collaboration could help fusion develop a proportionate regulatory approach, informed by the accumulated experience of other sectors and mindful of the lessons they have already learned.

# 5 Conclusions

The non-proliferation regime is established, its mechanisms exist, and its institutions are mature. What this paper has examined is whether that foundation is sufficient for the scale and character of commercial fusion, a technology expected to move from demonstration to deployment within the next decade.

The answer is that its implementation has not yet been extended to meet the challenges that commercial fusion will present. That gap matters not only for domestic deployment, but for the UK's ambition to export fusion technology globally. A credible export proposition requires demonstrating that the governance foundations have been thought through in advance.

That answer does not reflect a failure of the existing regime. The NPT, IAEA safeguards, the AP, and the export control arrangements of the NSG and Zangger Committee were built for a different era and a different technology. They have now served their purpose. The problem is that fusion sits in the gaps between them in ways that were not anticipated and have not yet been addressed.

### Three reasons underpin that conclusion:

**The first is the neutron environment:** fusion reactors generate intense neutron fluxes capable of transmuting fertile material into fissile material. The current framework only engages when qualifying nuclear material is declared on site. It provides no explicit basis for assessing facilities where that pathway exists, but no nuclear material is formally present, a gap that becomes more significant as fusion facility designs incorporate increasingly flexible experimental configurations.

**The second is the light isotopes:** these materials that make fusion work, tritium, lithium-6 and deuterium, fall outside IAEA safeguards entirely. They are governed instead by a combination of bilateral arrangements and export controls that were not designed with commercial-scale fusion inventories in mind. As fusion moves towards commercial operation, those inventories will grow by orders of magnitude, and the existing frameworks will not provide the independent verification that the scale of the technology demands.

**The third is co-location:** no existing framework asks what happens when a neutron source, tritium, lithium-6, deuterium and potentially fertile material are present together on a single site. The combined picture, which is what a commercial fusion facility will present, is not addressed anywhere in the current regime. Each of these gaps becomes harder to close once technology is deployed and export agreements are in place.

Fusion facility designs are still flexible. Regulatory frameworks are easier to build into a technology than to retrofit onto it. The UK has both the credibility and the opportunity to lead this work internationally, and to do so before commercial deployment makes the choices harder and the stakes higher.

The recommendation and actions in this paper (summarised in Figure 3) are proportionate and actionable. They do not require new treaties or the reopening of international legal definitions. They require the UK Government to assess the risks properly, task its regulators clearly, and engage the IAEA and the export control community with a considered position, before the window to do so cost-effectively closes.

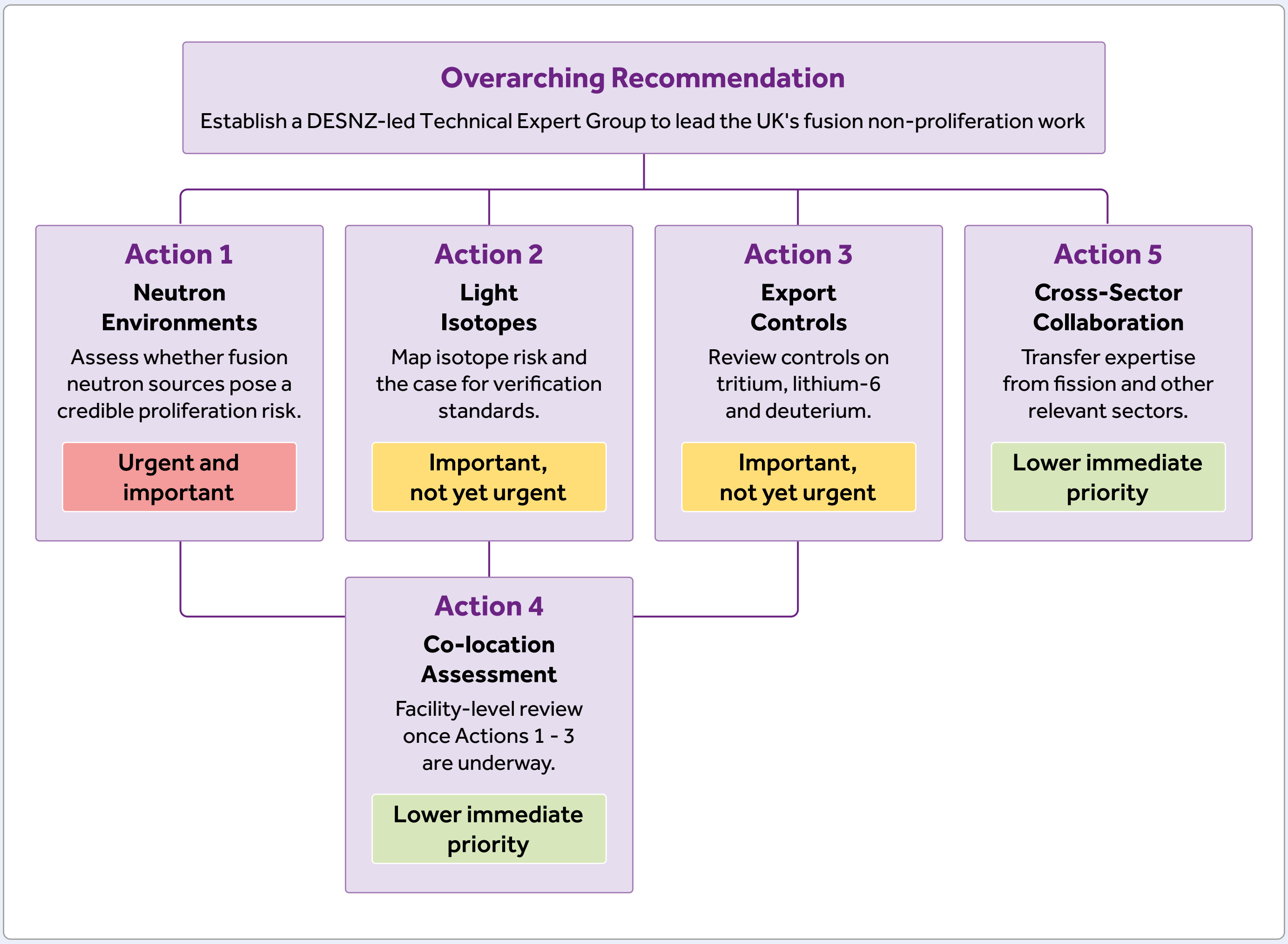


*Figure 3. Summary of recommendation and actions.*

# Acknowledgements

## Contributors

Lee Packer, Francis Livens, Mark Bassett

## Expert Reviewers

Adrian Bull, Aneeqa Khan, Colette Grundy, Clint Sharrad, William Bodel

## Acknowledgments

The author acknowledges the contribution of Magali Rego, Ruairi McCabe, Matthew Warner, Sara Hammoud, and Jeremy Maçon to the stakeholder engagement; and the following organisations: UKAEA, GNSP, The University of Manchester, Oxford Sigma, NIRO, and others to the development of this work.

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