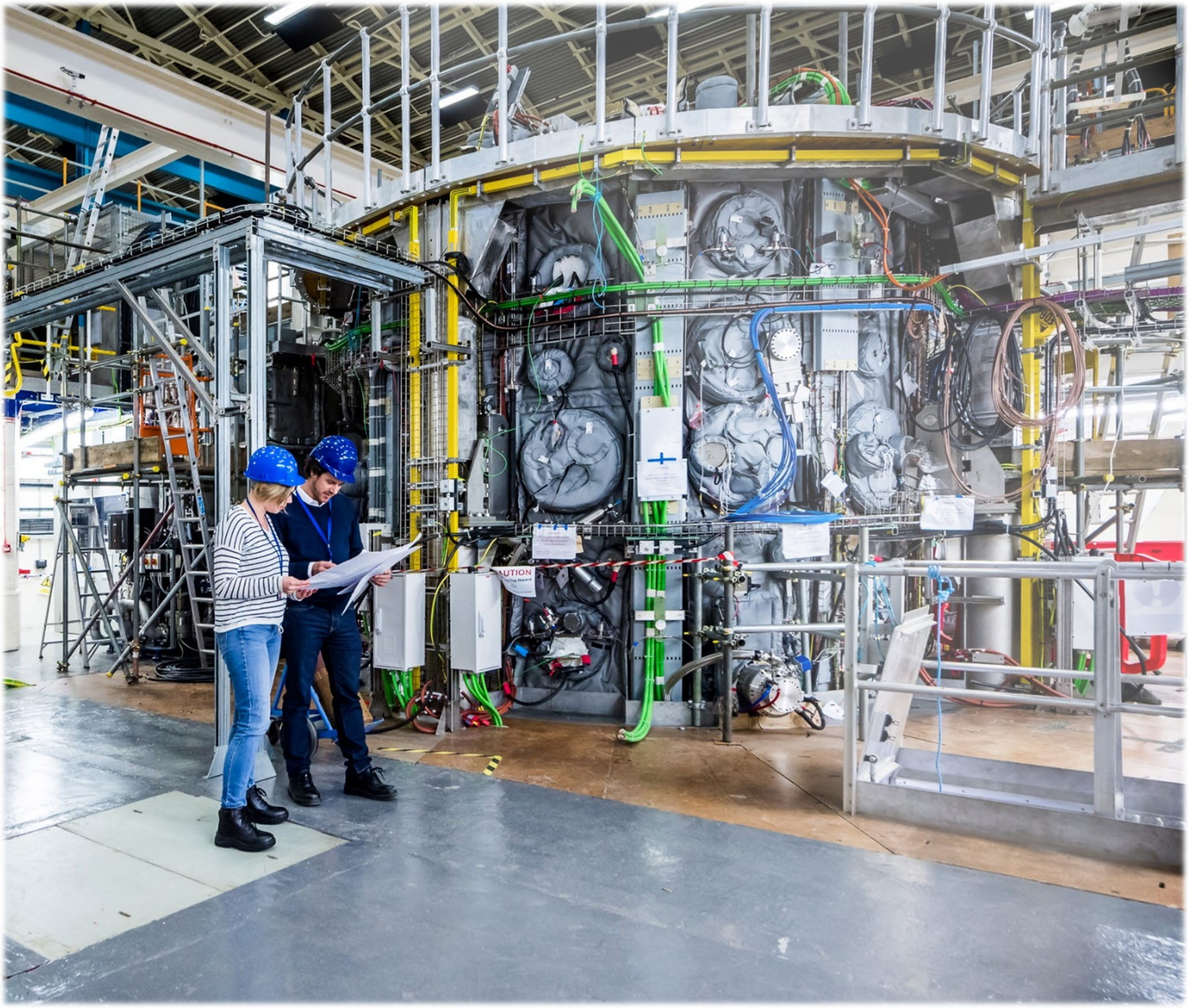
Department for
Business, Energy
& Industrial Strategy

Towards Fusion Energy

The UK Government's proposals for a regulatory framework for fusion energy



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Towards Fusion Energy:

The UK Government's proposals for a regulatory framework for fusion energy

Presented to Parliament
by the Secretary of State for Business, Energy and Industrial Strategy
by Command of Her Majesty

October 2021

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Foreword

The challenges of climate change are some of the most urgent and technically demanding the world is facing. For the UK, the Prime Minister's 10 Point Plan[1] sets out the key measures to help us reach our Net Zero target by 2050. However, given rising energy demand globally we also need to look beyond the next 30 years. The world's future energy generating technologies must be capable of delivering whatever new demands we place upon them. We need to work now to deliver solutions for the long term.

Fusion could be the ultimate clean power solution, representing a low carbon, safe, continuous and sustainable source of energy. The UK is widely recognised as a world-leader in the most promising fusion technologies. We have the potential to capitalise on our scientific and technical expertise and lead the commercialisation of fusion energy.

This is not science fiction but science fact. In the UK, fusion research programmes have supported over £1bn of UK economic activity over the last ten years.[2] Building on decades of study at unique research facilities, the UK Government has launched the world-leading STEP (Spherical Tokamak for Energy Production) programme, to build a prototype fusion power plant in the UK by 2040. At the same time, private companies in the UK are developing their own fusion power plant designs. UK manufacturers and engineers are beginning to form a fusion supply chain to support these programmes.

If the UK is to move from a fusion science superpower to a fusion industry superpower, we need to help the emerging fusion sector to plan with clarity and confidence. It is now time to look at how the regulatory framework for fusion can support this growing fusion industry whilst maintaining the UK's high standards of public and environmental protections.

This paper sets out the UK Government's proposals for the regulation of fusion energy. We want to trailblaze a proportionate and pro-innovation approach and collaborate internationally to maximise fusion's long-term global potential. With this plan, the UK hopes to lead the world on fusion regulation and enable the safe and rapid development of this revolutionary low carbon technology.

George Freeman MP

Parliamentary Under Secretary of State, Minister for Science, Research and Innovation

[1] UK Government (2020). The ten-point plan for a green industrial revolution. Available at https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution.
[2] UK Government (2020). *Impact of the UK's public investments in UKAEA fusion research*. Available at https://www.gov.uk/government/publications/impact-of-the-uks-public-investments-in-ukaea-fusion-research

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General information

Why we are consulting

Designs for fusion energy prototype power plants are now being developed around the world by fusion research organisations and private companies, targeting deployment in the 2030s and 2040s. Fusion energy facilities will need to be regulated appropriately and proportionately in the UK to maintain public and environmental protections, provide public assurances and enable the growth of this low carbon energy industry. We want fusion developers to be able to plan with confidence and the public to understand the basis for the Government's approach to the regulation of this emerging technology.

To inform policy on the regulation of fusion energy in the UK, we want to provide an opportunity for the public, industry, academia and other fusion stakeholders to share knowledge and offer views on the proposals in this paper.

Consultation details

Issued: 01 October 2021

Respond by: 24 December 2021

Enquiries to:

Domestic Fusion Team

Department for Business, Energy and Industrial Strategy

6th Floor, Area A2

1 Victoria Street

London

SW1H 0ET

Email: fusionregulation@beis.gov.uk

Consultation reference: Towards Fusion Energy: The UK Government's proposals for a regulatory framework for fusion energy

Audiences:

The Government would like to engage a wide range of stakeholders on the questions posed in this consultation. The Government seeks views from fusion developers, academia, financial and investment organisations, interested members of the public, the insurance market, international organisations and all other interested parties, including the responsible ministries from other nations. The Government intends to hold engagement events during the consultation period.

Territorial extent:

All proposals are for England. Some will apply across the UK but only where specified. The Government's objective is for fusion energy opportunities to be open to the whole of the UK – so will seek opportunities to collaborate on fusion regulation with the devolved administrations.

How to respond

Your response will be most useful if it is framed in direct response to the questions posed, and with evidence in support wherever possible. Further comments and wider evidence are also welcome. When responding, please state whether you are responding as an individual or representing the views of an organisation.

We encourage respondents to make use of the online e-consultation wherever possible when submitting responses as this is the Government's preferred method of receiving responses. However, responses via email will also be accepted. Should you wish to submit your main response via the e-consultation platform and provide supporting information via email, please be clear that this is part of the same response.

Respond online at: https://beisgovuk.citizenspace.com/energy-development/towards-fusion-energy

Email to: fusionregulation@beis.gov.uk

Write to:

Domestic Fusion Team

Department for Business, Energy and Industrial Strategy

6th Floor, Area A2

1 Victoria Street

London

SW1H 0ET

Confidentiality and data protection

Information you provide in response to this consultation, including personal information, may be disclosed in accordance with UK legislation (the Freedom of Information Act 2000, the Data Protection Act 2018 and the Environmental Information Regulations 2004).

If you want the information that you provide to be treated as confidential please tell us but be aware that we cannot guarantee confidentiality in all circumstances. An automatic confidentiality disclaimer generated by your IT system will not be regarded by us as a confidentiality request.

We will process your personal data in accordance with all applicable data protection laws. See our privacy policy.

We will summarise all responses and publish this summary on GOV.UK. The summary will include a list of names or organisations that responded, but not people's personal names, addresses or other contact details.

Quality assurance

This consultation has been carried out in accordance with the government's consultation principles.

If you have any complaints about the way this consultation has been conducted, please email: beis.bru@beis.gov.uk.

1. The UK Government's objectives for a fusion energy regulatory framework

Background

Fusion is the process which occurs at the centre of stars. It is the source of light and heat emitted by the Sun. For decades scientists and engineers around the world have been developing technologies that seek to harness this process to generate energy on Earth. If it can be successfully demonstrated and commercialised, fusion energy technology would provide low carbon, continuous and effectively unlimited power generation.

The basic science and engineering involved in the production of fusion energy is now well advanced, and fusion energy is expected to play an important role over the longer term to decarbonise global energy production.

The UK is widely recognised as a world leader in the most promising fusion technologies with research capabilities across the technical challenges of fusion. This means that the UK is uniquely well-placed to lead the future commercialisation of this technology.

The UK Government now wants the UK to build a prototype fusion power plant that puts electricity on the grid and demonstrates the commercial viability of fusion, and to establish a world-leading UK fusion industry which can export fusion technology around the world in subsequent decades. These aims were set out in the Prime Minister's 10 Point Plan for a green industrial revolution[3] and the Energy White Paper.[4]

The UK Government's Fusion Strategy[5] contains more information about our approach to delivering this mission.

Purpose and scope of this consultation

Existing regulations for fusion have underpinned fusion research in the UK for decades. In doing so, they have helped the UK to lead the world in pioneering fusion technology.

[3] UK Government (2020). The ten point plan for a green industrial revolution. Available at: https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution
[4] UK Government (2020). Energy white paper: Powering our net zero future. Available at: https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future
[5] UK Government (2021). The UK Government's Fusion Strategy. Available at: https://www.gov.uk/government/publications/towards-fusion-energy-the-uk-fusion-strategy

A number of public and private organisations are now considering designs for fusion power plants with the aim for prototypes to be operational within the next 20 years. One such plan is the UK Atomic Energy Authority's STEP (Spherical Tokamak for Energy Production) programme, which aims to build a prototype fusion power plant in the UK by 2040.

The UK Government believes that any regulatory framework for fusion energy facilities should serve to maintain safety and security in a way that is proportionate to the hazards involved. This consultation sets out the UK Government's proposals for a regulatory framework for fusion energy which are based on this principle. Our proposals aim to enable the safe and rapid deployment of fusion energy power plants, promoting innovation while maintaining human and environmental protections at all times.

Content of this paper

This paper is based around the following broad considerations:

- Whether the existing regulatory framework for fusion will be appropriate and 'fit for purpose' over the next 20-30 years, and whether an alternative approach and/or regulator may be more appropriate
- Whether existing regulatory provisions should be amended and new provisions introduced, in order to ensure that the associated hazard and risks are effectively managed by the fusion sector and to provide clarity and certainty for industry and the public
- How the regulatory framework and related policy areas should evolve as fusion technology is developed

Chapter 1 (this Chapter) sets out the objectives and approach taken by the UK Government in considering this subject.

Chapter 2 provides further detail about fusion, fusion technology and in particular the main hazards involved which have regulatory implications.

Chapter 3 summarises the current regulatory framework for fusion in the UK.

Chapter 4 details the UK Government's proposals that are intended to ensure the proportionate and effective regulation of fusion power plants.

Defining the fusion regulatory framework

Fusion facilities must comply with health and safety regulations for workers and the public and with environmental and public protection regulations. These are detailed in Chapter 3. In England, the responsible regulators for fusion are the Health & Safety Executive (HSE) and the Environment Agency (EA) respectively. Information on the responsible regulators in Scotland, Wales and Northern Ireland is on page 43 in Chapter 3.

These regulations form the core of what, in the context of this paper, the UK Government terms the 'fusion regulatory framework'. The UK Government also includes within this framework the following regulatory areas:

- Land use planning
- Third party liabilities and insurance obligations for fusion developers and operators
- Security and safeguards for nuclear material

Developers and operators of fusion facilities are also subject to regulations that are not specific to fusion, energy production or the use of radiological materials – regulations which apply to other major industrial facilities. These are not considered in detail in this paper which focuses on those regulatory areas that will be affected by the projected evolution of fusion technology as noted above.

Nuclear regulations apply to those facilities which are defined in legislation as "nuclear installations" such as fission power plants. Fusion facilities are currently not defined as nuclear installations and as such nuclear regulations are not currently considered to be part of the fusion regulatory framework in the UK. However, the relationship between fusion and nuclear regulations (and associated policy issues) is described in detail in this paper.

1. **Are there other critical regulatory areas that the government should address when considering the regulatory framework for fusion energy in the UK? Please explain what these are and why they are important.**

Devolution

The UK Government's long-term objective is to maximise the scientific and economic potential of fusion energy in a way that levels up opportunity right across the country. Many elements of the fusion regulatory framework are devolved, with devolved governments being responsible for the policies that underpin these regulations. This paper invites views from across the UK on its proposed approach for fusion regulation, noting that some specific measures would not apply in every nation.

The UK Government will continue to work with the Devolved Administrations to explore opportunities to align fusion regulation where there is policy support to do so.

Hereafter, all references to "the Government" should be taken to mean the UK Government unless otherwise specified.

Objectives

This consultation paper has considered the following three objectives as the means by which to assess whether the current framework is appropriate and/or whether new or amended regulatory provisions are required. Each is based on a core theme that is critical to the Government's thinking on fusion regulation: safety, transparency and innovation.

Objectives for a successful regulatory framework for fusion energy

Safety: Maintain human and environmental protections, in a way that is proportionate to the hazards and risks involved

Transparency: Ensure transparency to enhance public assurance

Innovation: Make the UK the best place in the world for commercialising fusion energy through enabling regulation that offers certainty to fusion developers and investors

In addition to these objectives, the Government is clear that the regulatory framework for fusion must continue to be based on the best available evidence and technical expertise, particularly given that fusion is a developing technology. It must also uphold clear separation between the regulators and fusion developers, whilst recognising that close engagement between regulators and fusion developers is necessary for the regulatory framework to be effective.

Engagement to date

The Government has engaged with fusion, fission and regulatory experts in considering what a proportionate and appropriate framework for fusion energy should look like. This has involved gathering data, evidence and views from regulators and experts across the UK including Environmental Agency (EA), Health and Safety Executive (HSE) and Office for Nuclear Regulation (ONR), the devolved administrations, technical fusion specialists (particularly the UK Atomic Energy Authority (UKAEA)), industry advisory bodies and nuclear risk insurers.

Annex A lists those organisations and individuals with whom the Government has already consulted in developing its proposals on fusion energy regulation.

The Government will continue to engage widely on this subject. This is detailed in Chapters 5 and 6.

The Regulatory Horizons Council

The Government has engaged closely with the Regulatory Horizons Council (RHC) on this topic. The RHC is an independent expert committee that identifies the regulatory implications of technological innovation, and provides government with impartial, expert advice on the regulatory reform required to support the rapid and safe introduction of identified emerging technologies. The RHC identified fusion as such a technology, and sought views from regulators, experts and industry in formulating its recommendations on the regulation of the prototype fusion power plants.[6]

[6] UK Government (2021). Regulatory Horizons Council: report on fusion energy regulation. Available at https://www.gov.uk/government/publications/regulatory-horizons-council-report-on-fusion-energy-regulation

The RHC recommended:

- the evolution of the current regulatory framework under EA (in England) and HSE (in Great Britain);
- the development of guidance to provide clarity to industry and public;
- that the UK Government consults on the regulatory approach for fusion energy as the start of wider public engagement;
- that the UK Government plans and works with the regulators to consider any potential upskilling that might be needed.

The Government welcomes this report and its valuable contribution to this topic. Its recommendations have informed the Government's proposals on fusion energy regulation, which are set out in Chapter 4 of this paper. In accordance with the RHC Charter, the Government will respond formally to the RHC's report following the consultation on its proposals in this paper.

The UK's regulatory strategy

BEIS regulatory strategy

The Department for Business, Energy and Industrial Strategy (BEIS) has developed a regulatory strategy in order to support innovation around rapidly developing technologies, as laid out in its 2019 White Paper on Regulation for the Fourth Industrial Revolution.[7] A clear and proportionate regulatory framework which maintains the confidence of regulators and industry will make it easier for technology developers to innovate while complying with regulations. The proposals on fusion regulation in this consultation are intended to align with this regulatory strategy. The basis for BEIS' regulatory strategy for developing technologies is described in Annex B.

Regulator strategies

The UK already has a world-leading regulatory system that has supported numerous technological innovations. The UK Regulators' Code sets the standard on how all regulators in the UK should work to enable effective regulation. The goal-setting and enabling regulatory strategy of the Environment Agency (EA) and the Health and Safety Executive (HSE) has been able to support fusion and uphold protection of workers, the public and environment. The Government sees these principles as essential for a successful regulatory framework for fusion energy. The proposals in this consultation are intended to align with these existing regulatory strategies for supporting the development of emerging technologies such as fusion. Further details are in Annex C.

[7] UK Government (2019). Regulation for the Fourth Industrial Revolution. Available at https://www.gov.uk/government/publications/regulation-for-the-fourth-industrial-revolution

2. Fusion Technology and Associated Hazard

What is fusion?

Fusion is the process which occurs at the centre of stars. It is the source of light and heat emitted by the Sun. When two light elements are “fused” together, they form a heavier element and release excess energy. Fusion energy can be generated in a variety of ways. All methods need to create an environment with sufficient heat and pressure.

The most common fuels considered for fusion power plants are deuterium and tritium, both of which are isotopes of hydrogen. In a deuterium-tritium fusion reaction, deuterium and tritium fuse together to create a helium nucleus and a highly energetic free neutron, whose energy can be harnessed to produce heat and electricity.

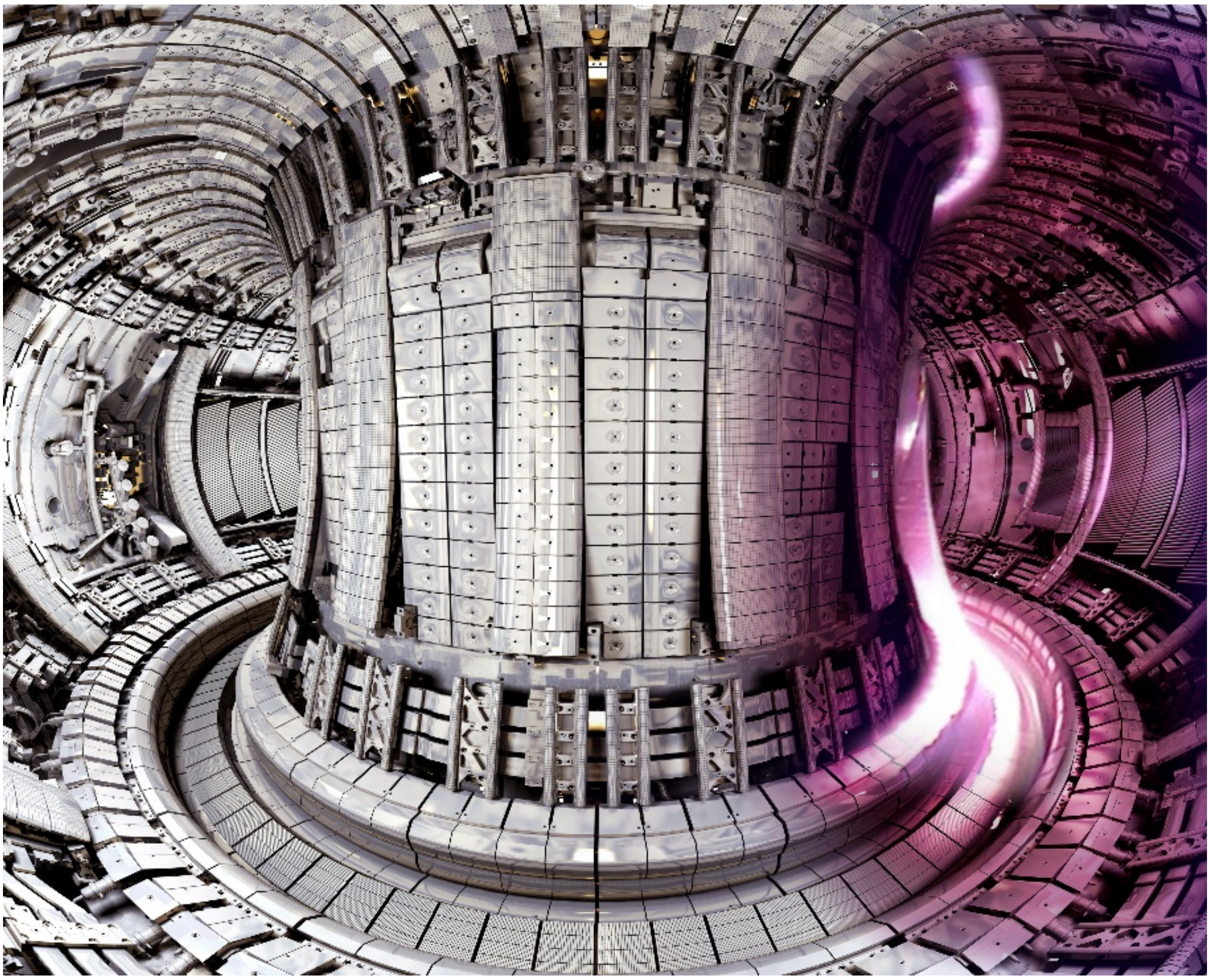

Figure 1 – Inside the Joint European Torus (JET)[8] – The largest and most successful fusion experimental facility in the world, based in Oxfordshire in the UK

[8] https://www.euro-fusion.org/devices/jet/. Picture is available at https://www.euro-fusion.org/media-library/fusion-experiments/ CC BY 4.0

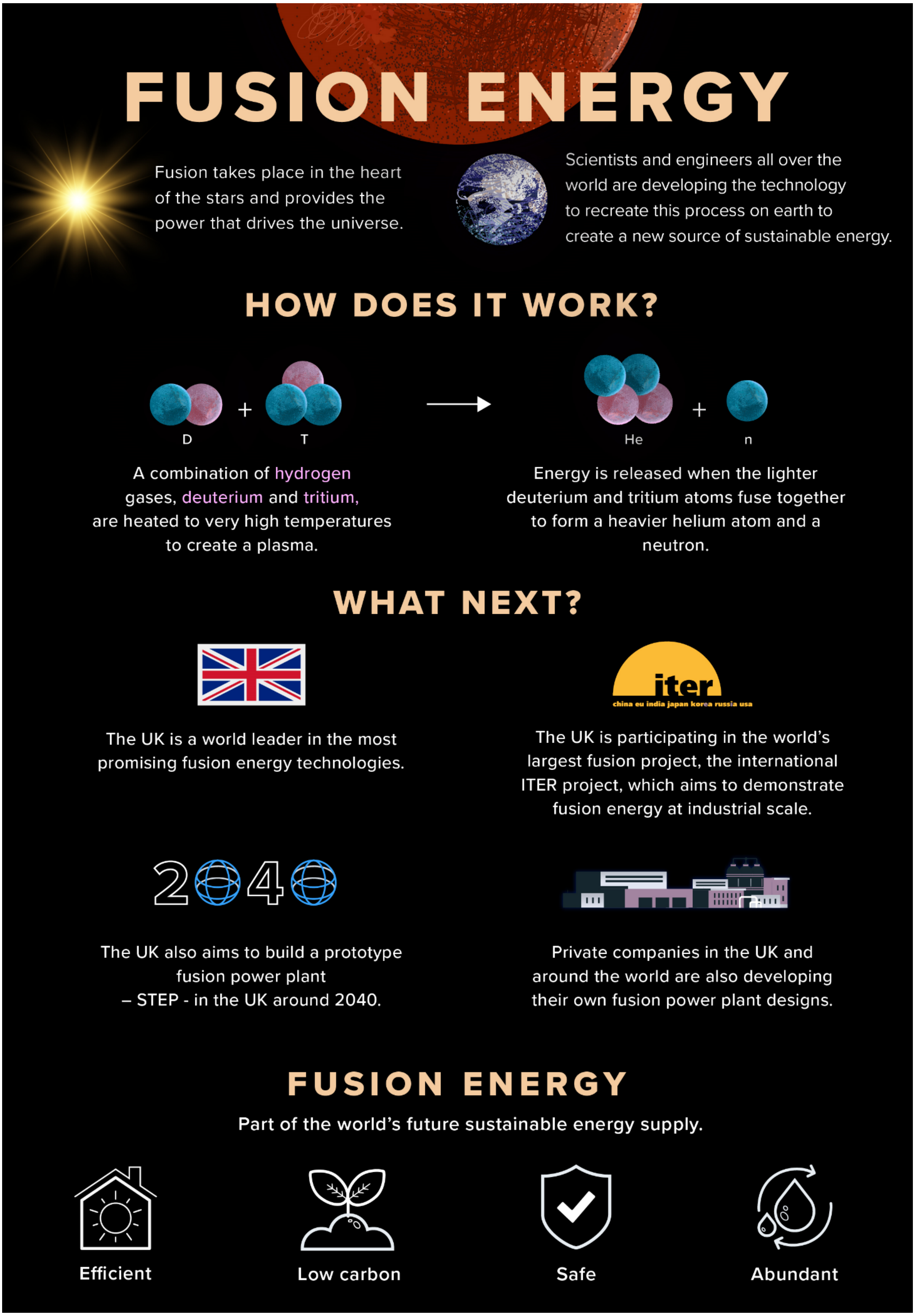

Figure 2 – Summary information about fusion energy

The generation of usable energy using fusion would have six distinct advantages:

- **Fuel abundance**: the fuels used in fusion reactions are effectively inexhaustible. Deuterium is readily extracted from seawater, and tritium is produced using lithium[9]
- **Baseload power**: fusion energy does not depend on external factors such as wind or sun, making it continuously deployable at point of need
- **High fuel efficiency**: fusion produces more energy per gram of fuel than any other process that could be achieved on Earth
- **Carbon-free**: helium is the product of the fusion process – no carbon or other greenhouse gases are produced in the reaction
- **No chain reaction:** fusion is not based on a chain reaction; specific conditions of heat and pressure need to be maintained for fusion to occur. Therefore, if there were any technical problems, a fusion facility could be immediately switched off and the process would stop within seconds or less
- **Shorter lived waste**: fusion power plants are not expected to produce the very long lived, high level radioactive waste associated with nuclear fission

While fusion research facilities have been in operation around the world for many decades, no facility has yet demonstrated net energy gain from fusion.[10] The scientific and engineering challenges in delivering fusion energy are considerable. The design and development of the complex components and systems required remains ongoing – and the integration of these into a highly sophisticated facility that can be operated and maintained at commercially viable levels of productivity and availability will be very challenging. However, advances in fusion science and technology over recent years, coupled with advanced manufacturing and computing capabilities now available, mean that fusion energy is closer than ever before.

A number of public and private organisations are now considering designs for fusion power plants with the aim for prototypes to be operational within the next 20 years. One such plan is the UK Atomic Energy Authority's STEP (Spherical Tokamak for Energy Production) programme, which aims to build a prototype fusion power plant in the UK by 2040.

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[9] Lithium is heavily abundant in the Earth's crust and so there is a plentiful supply of lithium globally. However, many uses of lithium require a high degree of purity. With the increase in lithium demand due to the increase in prominence of electric vehicles, many countries are considering how to increase the global capacity to produce high purity lithium. The projected development of fusion energy in the second half of this century will put further pressure on this supply. The consideration of the lithium requirements of fusion has therefore already begun including recycling of lithium batteries.

[10] Net energy is when the plasma releases more energy than is needed to heat it. The JET facility currently holds the record for energy release, generating 16 MW from 24 MW of heating (a ratio of 0.67).

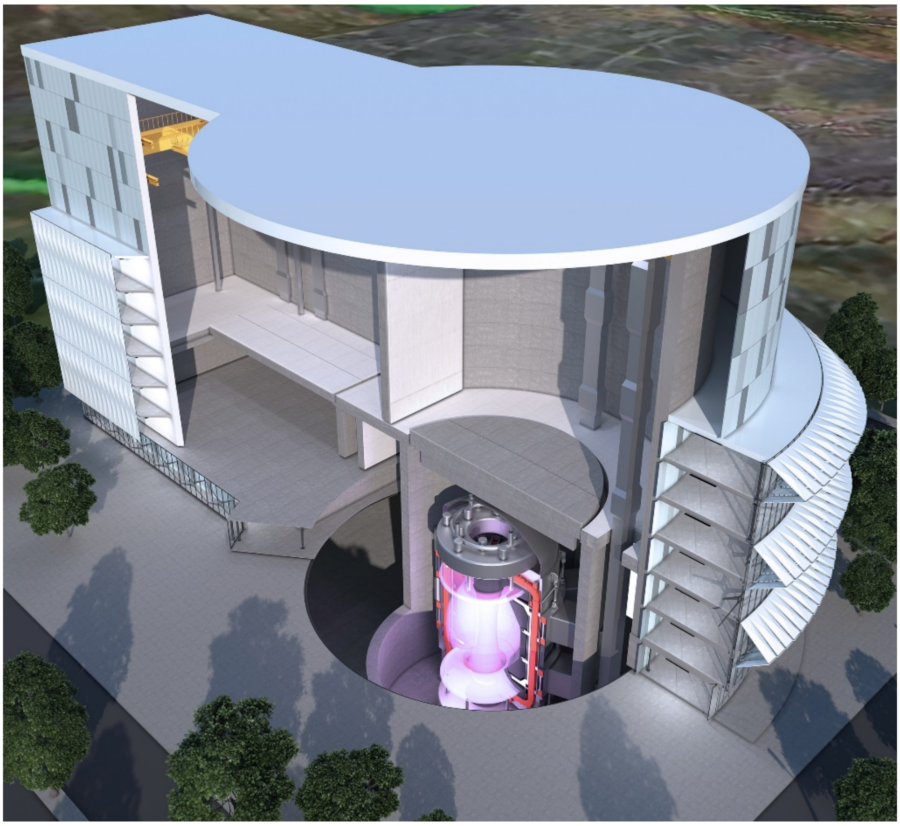

Figure 3 – Illustration of the UK Atomic Energy Authority's STEP (Spherical Tokamak for Energy Production) facility

These intended fusion power plant prototypes are seeking to: produce more power than current experimental fusion facilities; involve the use of more advanced materials; involve additional technologies; use more fuel; and operate continuously for extended periods of time.

To determine the regulatory implications of developing fusion technologies and associated hazards, this chapter:

- outlines some promising technologies expected to be used in fusion power plants;
- identifies the main hazards associated with fusion;
- discusses the magnitude, nature and potential regulatory implications of these hazards in the context of fusion power plants, including in relation to the waste produced.

Fusion technologies

Figure 4 – View of the Joint European Torus (JET) facility[11]

Any machinery that produces or harnesses energy involves hazard, from a kitchen microwave to a power plant. Fusion energy technology is no different and so involves a range of potential hazards to workers and the public. Experimental fusion facilities are currently in use across the world. These are based on various technologies[12] which each bring different associated hazards and risk potential for the operator. The first generation of fusion power plants are expected to involve similar technologies and hazards of the same nature as the experimental facilities currently in operation, albeit at different scale.

The Government has worked closely with UKAEA's Fusion Safety Authority on the following section of this paper. The Fusion Safety Authority is responsible for supplying BEIS with technical expertise and advice regarding fusion regulation based on extensive experience of practical fusion safety. It is organisationally separate from the operational and research parts of UKAEA. See page 60 for more information.

UKAEA has published a Technology Report[13] which provides supplementary detail to the information in this chapter.

There are a number of technological approaches to fusion energy being pursued in the UK and internationally. The fusion technology underpinning most projects around the world is the tokamak design. This uses strong magnetic fields to confine a plasma at an extremely high temperature (over 100 million degrees Celsius) within a sealed structure.

[11] © UKAEA
[12] The goal-setting approach of UK regulation for health and safety and environmental protection requires an operator to identify hazards and minimise risks and impacts, meaning that the UK's regulatory framework can be readily applied to different technologies.
[13] Available from: https://ccfe.ukaea.uk/

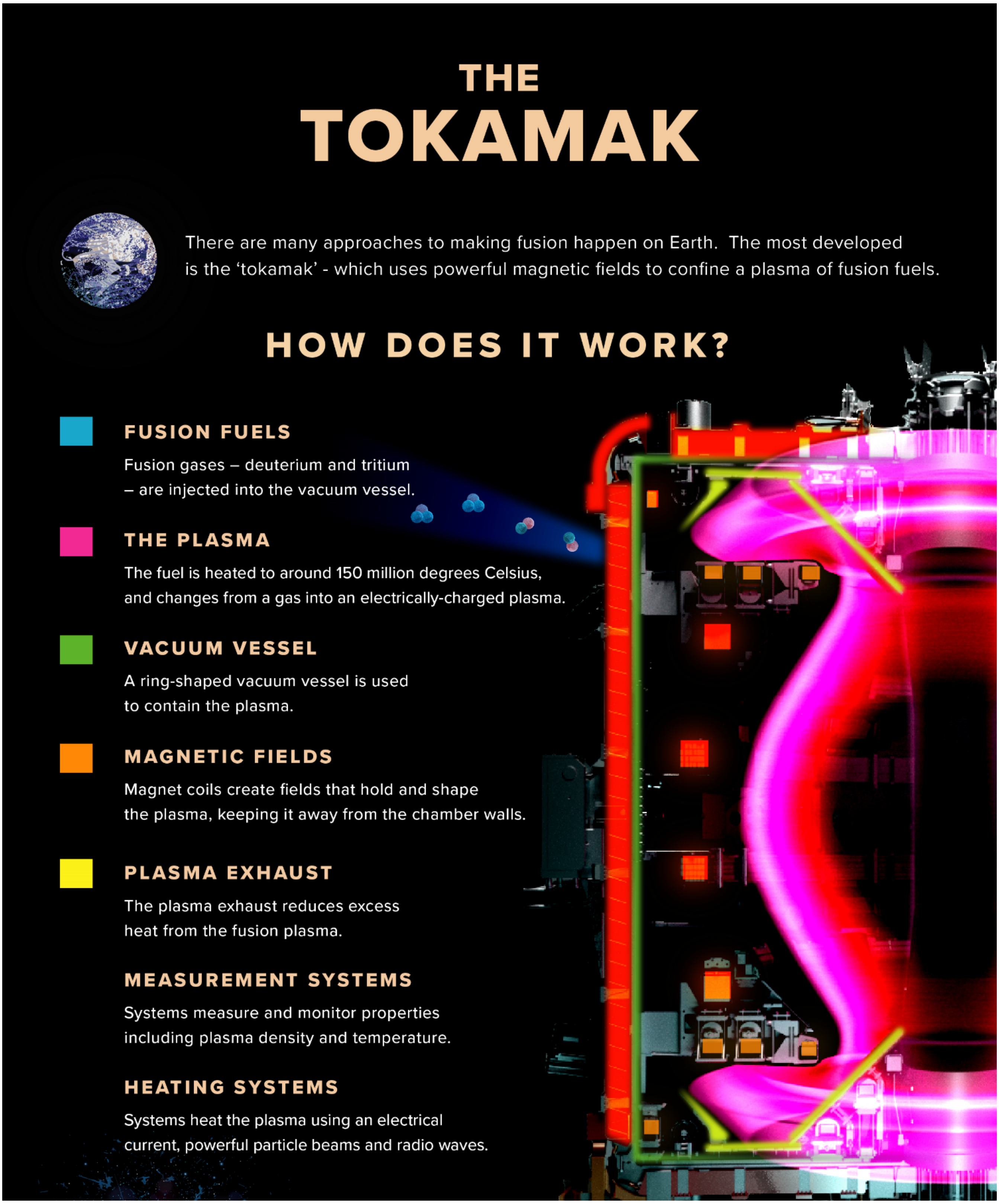

Figure 5 – The tokamak approach to fusion

Alternative technologies are being developed for fusion energy which are based on different approaches to that of the tokamak, with designs using other types of magnetic confinement, inertial confinement, or a combination of both. For example, a stellarator uses magnetic confinement in the same way as a tokamak with complex shaped magnets and a twisted ring shape vacuum vessel. Inertial confinement designs use a pulsed driver to rapidly compress fuel pellets, creating the conditions required for fusion. Drivers include an array of lasers, magnetic fields, or a high velocity projectile. Magnetised target fusion is an approach that combines elements of both inertial and magnetic confinement.

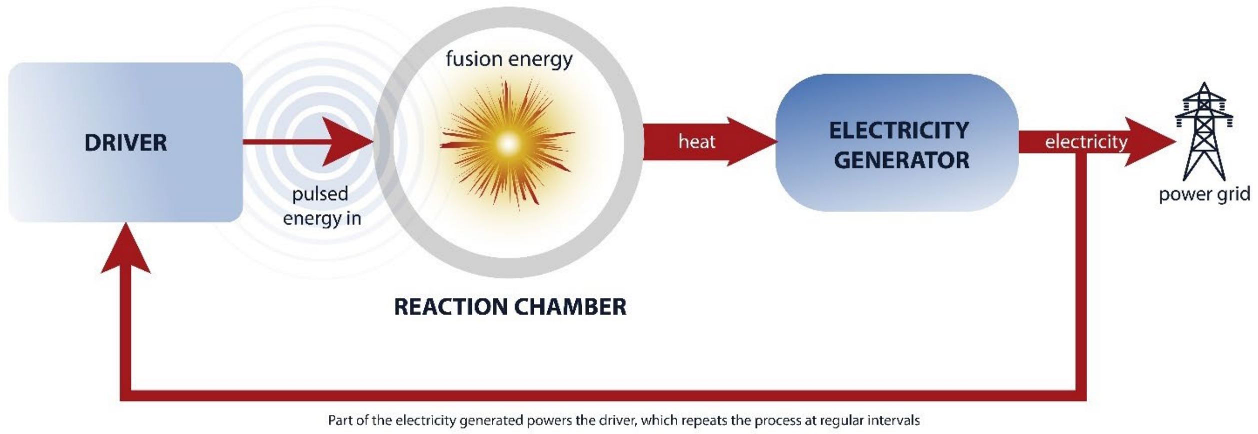

Figure 6 – Illustration of the inertial confinement fusion approach

Fusion fuels and the fusion process

For most advanced fusion facilities or fusion power plant concept designs, the fuels used to create the plasma where the fusion reactions occur are deuterium (D) and tritium (T). These are both isotopes of hydrogen. The D-T fusion reaction results in the creation of high energy neutrons and helium, which is used to sustain the reaction. This is shown in Figure 2 on page 17.

A fusion power plant would produce energy by harnessing the high energy neutrons produced by the fusion reaction. In all concepts these neutrons are captured by a blanket outside the plasma, which converts the neutrons’ kinetic energy to heat energy. This energy is used to drive a turbine, via the heat exchange, which leads to the production of energy. This is illustrated below in Figure 7. Those same neutrons are also used to create more tritium fuel from lithium in the blanket and thus to develop a self-sufficient fuel cycle. There are a range of different technological approaches and materials for the blanket.

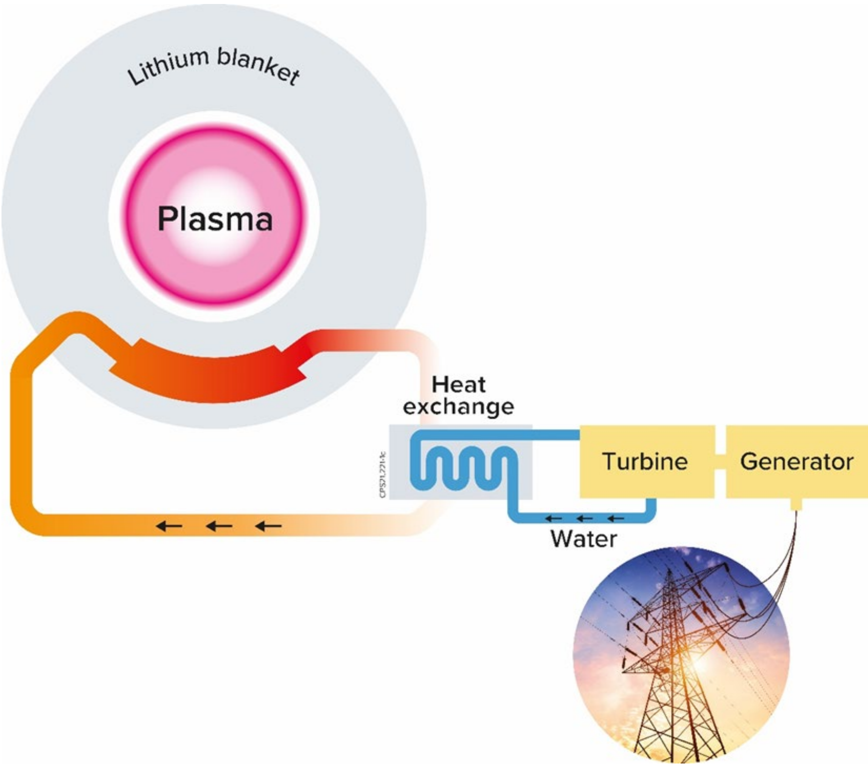

Figure 7 – Illustration of how a tokamak would produce usable energy

While there are different fusion technologies, the fusion process is the same. Crucially, the extreme conditions required to create the fusion reaction mean that any deviation from these conditions cause the reaction to terminate. Therefore, it is not possible to have a runaway reaction, and so the IAEA (International Atomic Energy Agency) notes that the fusion process itself cannot cause a nuclear accident.[14] Whilst there is not an exact distinction between a nuclear and radiological emergency, the IAEA notes that a nuclear emergency is “an emergency in which there is, or is perceived to be, a hazard due to the energy resulting from a nuclear chain reaction or the decay of products of a chain reaction”.[15]

[14] IAEA (2020), Fusion, frequency asked questions. Please see, https://www.iaea.org/topics/energy/fusion/faqs
[15] IAEA (2018) IAEA Safety Glossary. Available at: https://www.iaea.org/resources/safety-standards/safety-glossary

Hazards associated with fusion

Overview

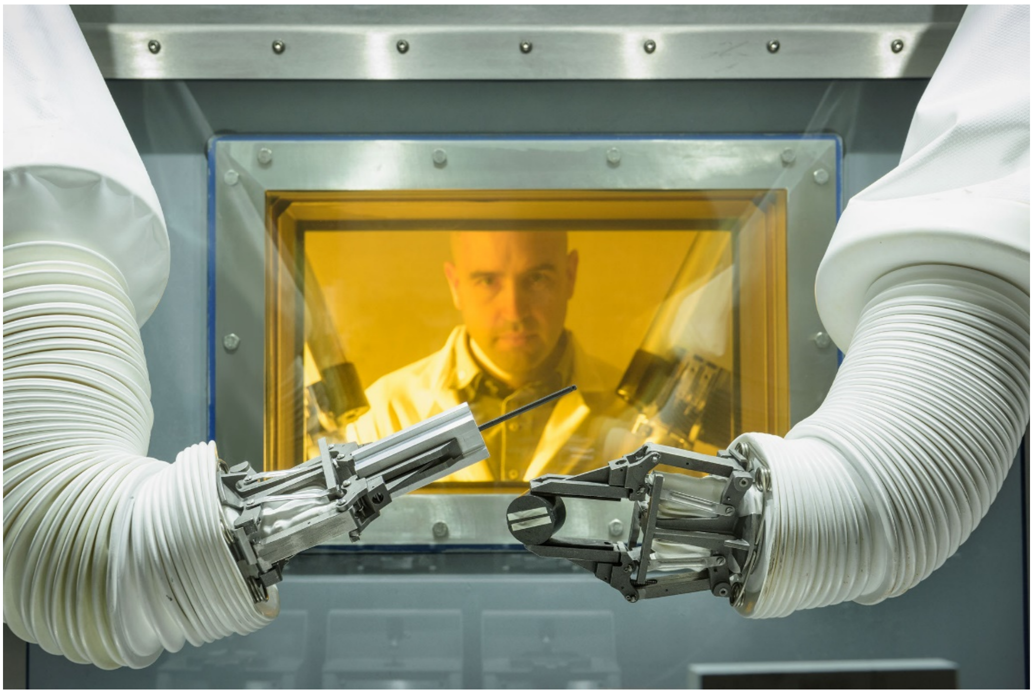

Figure 8 – Representation of UKAEA working with hazardous material[16]

The Government believes that a future regulatory framework for fusion energy should serve to maintain safety, security and environmental protection in a way that is proportionate to the hazards involved and consistent with international standards and the UK Regulators' Code.[17] The Government's work with UKAEA's Fusion Safety Authority has identified that the ionising radiation[18] that results from tritium and activated materials – if there were to be an off-site release – is the main hazard to the public associated with a fusion facility. This is discussed in detail in this section. The regulatory implications of this hazard for a fusion power plant are central to the proposals of this paper.[19] This conclusion is broadly applicable to all fusion technological approaches as described above.

This chapter also addresses the hazard associated with radioactive waste produced by fusion facilities, noting that fusion power plants will not produce the High Level Waste associated with the fuel used in nuclear (fission) power plants. See Annex D for further detail about radioactive waste.

[16] © UKAEA
[17] UK Government (2014. The Regulators' Code. Available at: https://www.gov.uk/government/publications/regulators-code
[18] Ionising radiation is produced from unstable nuclei as they decay. This radiation can disrupt the structure of other atoms. In a large enough dose, ionising radiation can be harmful to organic life.
[19] This chapter uses the term "radiological" rather than "nuclear" to describe hazard and risk because "nuclear hazard and risk" is widely associated with the fission process, rather than with any form of ionising radiation.

Tritium

Tritium is used as one component of the fuel in a D-T fusion device. Tritium in nature is rare: the vast majority of tritium found on Earth is produced high in the atmosphere by the interaction of cosmic rays with nitrogen and oxygen. The majority of the accessible global tritium supply is currently produced by fission reactors, primarily 'CANDU' reactors in Canada[20] and elsewhere. Annual global production varies but is estimated at no more than a few kilograms per year. STEP and future power plants will breed their own tritium when operational, but the initial tritium fuel to start the first fusion power plants will be sourced from the available worldwide supplies, including from CANDU reactors in Canada. Subsequent fusion power plants are expected to be started with tritium produced in their predecessors.

One of the main commercial uses of tritium is when it is combined with phosphor to create luminescence (as illustrated below). Tritium is also used in medical diagnostics and biomedical research.

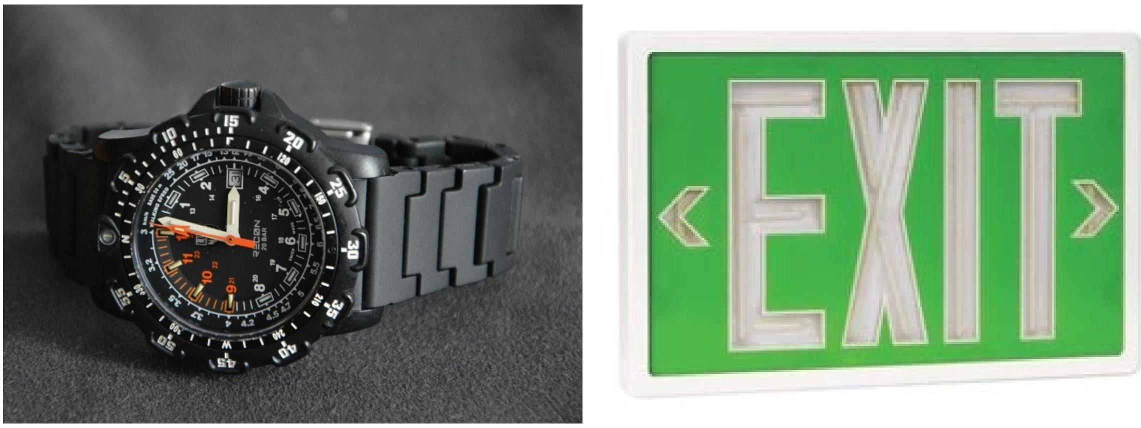

Figure 9 – Examples of everyday uses of tritium to provide luminescence[21]

Tritium is a radioactive isotope of hydrogen, with a half-life (see explanation box below) of 12.3 years, decaying to a harmless isotope of helium. It emits beta particles, which can cause damage to skin or internal organs and cells if inhaled or ingested. Tritium is more likely to give a greater dose in the event that it is released into the environment in significant quantities in the form of tritiated water (water where one or both of the hydrogen atoms has been replaced by tritium), rather than as pure tritium gas. This is because tritiated water is more likely in such an event to enter biological systems, while tritium gas would instead be readily dispersed in the wind. Given these properties, regulators in the UK and around the world require users of tritium to ensure that it is handled and stored safely.

[20] CANDU (Canada Deuterium Uranium) is a Canadian pressurized heavy-water reactor design used to generate electric power. The acronym refers to its deuterium oxide (heavy water) moderator and its use of (originally, natural) uranium fuel.
[21] No radiation is emitted from either the watch or exit sign provided they are not broken.

What is a radioactive half-life?

Radioactive half-life is the time it takes for half of the unstable nuclei in a sample of material to decay, or for the radioactivity of the sample to halve.

The half-life of tritium is 12.3 years. 1 kg of tritium (an indicative inventory of a fusion power plant) would require approximately 10 half-lives – or approximately 123 years – before Health and Safety regulations in the UK would no longer require that site to consider emergency arrangements (schedule 1 of REPPIR 2019[22] sets a floor for quantities of radioactive isotopes held on site above which consideration of emergency arrangements is required).

In the context of a tokamak-based, fully operational fusion power plant, tritium – as one of the fuels in the plasma – will be produced in “breeder blankets” that surround the plasma and processed within a secure (or “closed-loop”) fuel cycle to feed back into the vacuum vessel as fuel. Tritium permeates into materials hence the structural components of a fusion reactor will contain some amounts of tritium. The amount of tritium required on-site for a fusion power plant is estimated to be of the order of a few kilograms of tritium,[23] which equates to around 4×10^{18} Bq. For context, this compares to around 100 g or 4×10^{16} Bq used at the JET facility.

What is a Becquerel?

A Becquerel (Bq) is a unit of radioactivity. One becquerel is defined as the activity of a quantity of radioactive material in which one nucleus decays per second. Radioactive decay is the random process in which a nucleus loses energy by emitting radiation.

Fusion facility exhaust gases pass through detritiation facilities and are monitored to ensure tritium emissions are minimal. Annual dosage estimates for the total residual discharges are at the micro-Sievert level, which is comparable to the dose received from one dental x-ray. No person would be exposed to the entire residual discharge, so any dosage levels for individuals would be much lower than this and so would be negligible.

[22] REPPIR 19 is the Radiation (Emergency Preparedness and Public Information) Regulations 2019. It is available at https://www.hse.gov.uk/radiation/ionising/reppir.htm

[23] Some other fusion technologies are expected to use lower inventories of tritium

What is a Sievert (Sv)?

The Sievert (Sv) is the unit to measure radiation dose. A sievert is the amount of damage that would be caused by the absorption of a set amount of energy, from radiation, per kilogram of body mass.

Units

This paper will explain radiological doses in units of µSv (micro-Sieverts), mSv (milli-Sieverts) and Sv (Sieverts). The table below demonstrates the difference in magnitude between these units. Public Health England dose comparisons are provided at Annex E.

Unit	Relation to a Sievert
µSv	1 millionth of a Sv
mSv	1 thousandth of a Sv
Sv	1

Activated Materials

Figure 10 – UKAEA's Materials Research Facility (MRF) prepares and examines samples of radioactive materials to assess their performance[24]

[24] © UKAEA

The neutrons produced in the fusion reaction will activate (i.e. make radioactive) some of the materials surrounding the plasma, such as in-vessel components and coolant liquids or gases. Dust from erosion or flaking of the in-vessel components over the lifetime of the facility will also become activated.

As well as activation of the materials, neutrons can also cause structural damage. Over time, this can degrade the qualities of the materials such as making them become brittle. The choice of materials is therefore a crucial part of the design to minimise these effects, for instance choosing materials that are not easily activated and/or damaged and using shielding.

Accident Scenarios

A critical safety feature of a fusion facility is the confinement of the radioactive substances at the facility (known as 'inventories'): the tritium and activated materials described above. The multiple layers of protection provided by the confinement systems at the facility minimise the hazard of these substances to workers, the public and the environment. Figure 11 overleaf illustrates the confinement systems at a tokamak-based fusion facility.

In an accident scenario, the confinement systems could be damaged, resulting in a percentage of these inventories being released into the environment that exceeds the annually permissible discharge levels set by regulators.

In line with existing regulations, operators of fusion facilities in the UK make sure that all necessary measures are taken to prevent such accidents from occurring.[25]

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[25] This relates to IRR 2017 Regulation 8: Radiation risk assessments: "an employer must not carry out work with ionising radiation unless it has made an assessment sufficient to demonstrate that:
(a) all hazards with the potential to cause a radiation accident have been identified;
And the employer …. must take all reasonably practicable steps to –
(a) prevent any such accident;
(b) limit the consequences of any accident which does occur".
For example, UKAEA – as a world leader in the operation of fusion facilities – applies in-depth safety analyses to all of its fusion facilities. This is in the form of a written Safety Report, and this evolves and is updated throughout the lifecycle of UKAEA facilities. One of the roles of a safety report is to present the results of a comprehensive analysis of all types of hazards for a fusion or plasma facility. A safety report also provides an in-depth justification of the systems, structures, and components (SSC) designed to provide adequate protection against all types of events and accidents described in the hazard analysis that unprotected could lead to harm to either the members of the workforce or public. A safety report also ensures that the human-human and human-machine interfaces are understood and optimised for the safe and secure construction, operation, routine maintenance and eventual decommissioning of a fusion or plasma facility.

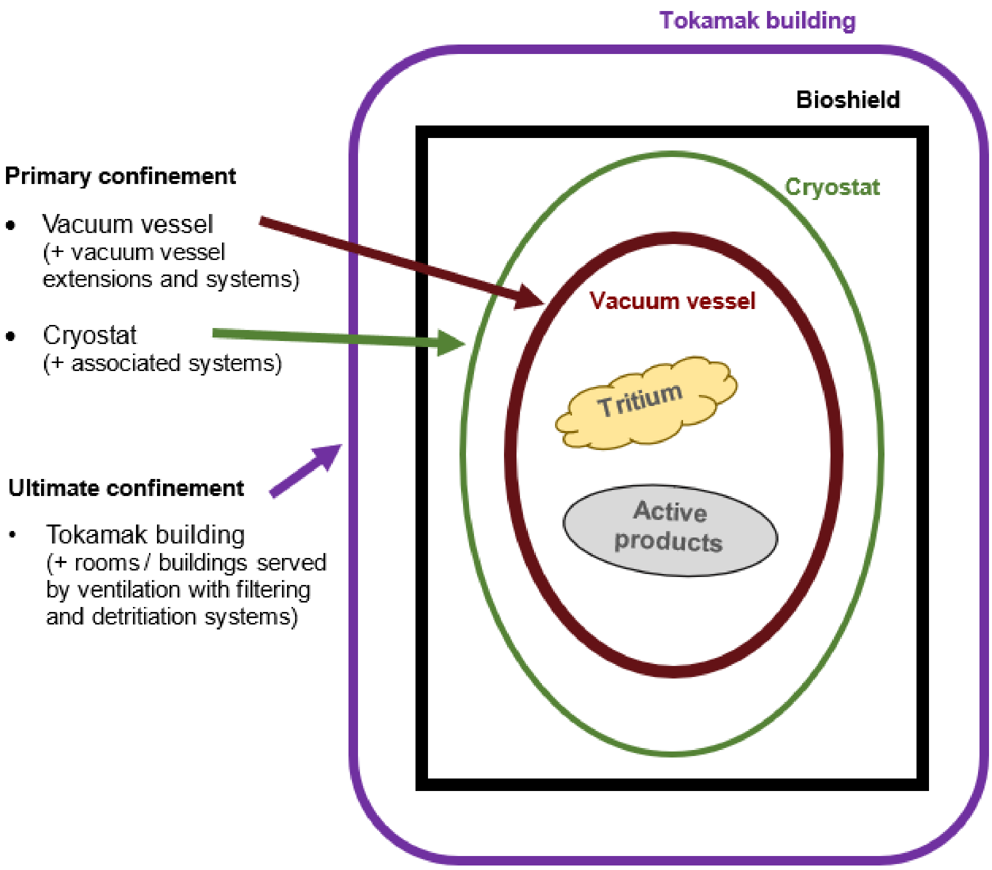

Figure 11 – Representation of multiple layers of protection for a magnetic confinement system such as a tokamak[26]

Analysis

Based on a conceptual tokamak-design fusion facility at power plant scale, UKAEA's Fusion Safety Authority have reviewed independent analysis, already published in the public domain, on the consequence of breaches[27] of the multiple systems of confinement: the vacuum vessel then the tokamak building and intermediate structures (also illustrated in UKAEA's Technology Report). A worst-case hypothetical scenario not based on a known accident scenario is also considered. This exercise is intended to illustrate the projected worst-case impacts to individuals that could arise from any partial or total release of the radioactive inventories of a fusion power plant. Table 1 summarises this exercise on page 31.

[26] The structures mentioned above in Figure 11 show multiple layers of protection. For the purpose of the analysis in this chapter, it is assumed that the vacuum vessel/cryostat and related systems for primary confinement and the tokamak building forms the ultimate confinement. The vacuum vessel will be made from a material such as a specialist stainless steel, in layers a few centimetres thick, well shielded by the blanket. The cryostat, a steel and concrete structure, provides protection to the magnets and vacuum vessel, and the tokamak building will be a concrete structure, of the order of 2-3 meters thick. Additionally, the bioshield is a thick concrete structure providing extra protection to personnel from radiation.

[27] For this report the descriptions of breaches of confinement summarised from published data referenced in the UKAEA Technology Report arise from postulated technical faults or accidents. It is assumed that breaches arising from a security incident would have off-site implications that are comparable with those described in the accident scenarios.

This exercise has identified two representative worst case accident scenarios and a hypothetical scenario. These are based on indicative estimates of the radioactive inventories of tritium and activated dust relevant to a tokamak-based fusion power plant.[28] The information underpinning this analysis draws on studies of potential accident scenarios which are based on evolving conceptual designs of future fusion power plants. As the variables are strongly dependent on the type of fusion technology, the design of the plant and the materials used, as well as the accident scenario itself and any mitigations present, there is significant uncertainty around the maximum amount of inventory that could be released, but worst-case estimates used here seek to identify the upper bound.

For all scenarios therefore, this analysis is based on worst-case assumptions in terms of estimated doses for the public, assumed to be the dose to a member of the public located outdoors and closest to the site (1 km from the source) and remaining there for 7 days after the accident, although the accident release is assumed over 1 hour. For distances greater than 1 km, the doses are lower, reducing by a factor of around 10-100 at 10 km from the site. Future studies are expected to be underpinned by greater technical certainty, particularly around inventory levels. This should reduce the uncertainty in identifying potential dosage levels associated with accidents – this current uncertainty is a primary reason for why the analysis here uses such wide ranges to illustrate potential dosages.

These accident and hypothetical scenarios do not therefore depict wholly realistic situations but serve to illustrate worst-case eventualities in order to identify the maximum potential hazard of a fusion power plant. By way of comparison, unmitigated or hypothetical accident scenarios in the aviation, oil and gas or nuclear fission industries could have similar or worse consequences that those described here for a fusion power plant, involving multiple fatalities and/or severe environmental damage. Worldwide, accident prevention and mitigations measures are put in place that considerably reduce the risks around such events. Such measures would be put in place for a fusion power plant.

Supplementary information and referenced literature on accident scenarios and analysis of fusion power plants can be found in the UKAEA Technology Report.[29]

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[28] Other fusion technologies are expected involve different volumes of inventory. This paper uses a tokamak-design to consider a worst-case bounding scenario.
[29] Available from UKAEA’s website: https://ccfe.ukaea.uk/

Table 1 – Summary of worst-case accident scenario analysis

Accident Scenario	Description	**Potential worst-case** dose to an individual 1km from source building	Potential worst-case individual impact	**Potential worst-case** dose to an individual 10km from source building	Accident likelihood[30]	Regulatory categorisation of accident Impact[31]
"Acc1" - Breach of primary confinement	A breach of the vacuum vessel/cryostat confinement but with the tokamak building confinement and its filtration/detritiation systems intact.	A few micro-Sieverts	**Negligible:** similar to the radiation experienced on a single transatlantic flight.	<1 micro-Sievert	1 in 2,000 to 1 in 20,000 over a five year period	Limited
"Acc2" - Malfunction of ultimate confinement	A breach of the vacuum vessel/cryostat, with additional malfunction of the ventilation system, such that there is some leakage through the tokamak building confinement system.	A few milli-Sieverts	**Very mild:** similar to the radiation experienced from a CT scan of the chest.	<1 milli-Sievert	Less than 1 in 200,000 over a five year period	Moderate

[30] A five year period for accident likelihoods is taken from the likelihood categories used in REPPIR (see below).
[31] These categories are taken from REPPIR which considers the impact of a radiological effect on human life, health & safety, quality of life, property, and environment. These are fully described in the REPPIR Approved Code of Practice and guidance which can be found at this web address: https://www.onr.org.uk/reppir-2019-update.htm

Table 2 – Summary of worst-case hypothetical scenario

Scenario	Description	**Potential worst-case** dose to an individual 1km from facility	Potential worst-case individual impact	**Potential worst-case** dose to an individual 10km from facility	Hypothetical likelihood[32]	Regulatory categorisation of impact[33]
"Hypo"– Hypothetical complete loss of all confinement	Illustrative 'worst-case' scenario resulting from an extreme magnitude earthquake or malicious damage to the facility that results in the entire mobilisable inventory of tritium from the reactor[34] and a large percentage of the mobilisable radioactive dust being released into the environment due to total failure of all confinement systems.	<1 Sievert[35]	**Mild/moderate:** mild radiation sickness, though with some potential for more acute radiation effects depending on the dosage received (see Annex E).	10-100 milli-Sieverts	Less than 1 in 2,000,000 over a five-year period	Significant

[32] A five year period for accident likelihoods is taken from the likelihood categories used in REPPIR (see below).
[33] These categories are taken from REPPIR which considers the impact of a radiological effect on human life, health & safety, quality of life, property, and environment. These are fully described in the REPPIR Approved Code of Practice and guidance which can be found at this web address: https://www.onr.org.uk/reppir-2019-update.htm
[34] In the studies, accident scenarios involving the wider fuel handling system were also considered but the potential radiological hazard is bounded by the reactor accident scenarios described here.
[35] As for other scenarios, the dose would depend on the actual design of the plant.

Regulation of potential accidents

The Radiation (Emergency Preparedness and Public Information) Regulations 2019 (REPPIR 2019)[36] require facilities which handle specified quantities of certain radioactive materials to undertake emergency planning in proportion to the risks involved, considering both potential impact – in terms of dose to individuals – and likelihood.[37] The way in which operators comply with REPPIR 2019 illustrates how UK regulation addresses hazard in a way that is proportional to that hazard.

The two indicative accident scenarios (Acc1 and Acc2) derived from publicly available research can be placed on the REPPIR 2019 Risk Framework matrix, illustrated in Figure 12 below. The range indicated by the boxes take account of the uncertainties that remain in the technology and the fact that the scenarios described are based on conceptual designs, rather than detailed designs. The position of the worst-case hypothetical scenario (Hypo) is also indicated, however emergency planning would be based on the accident scenarios identified and assessed for individual designs.

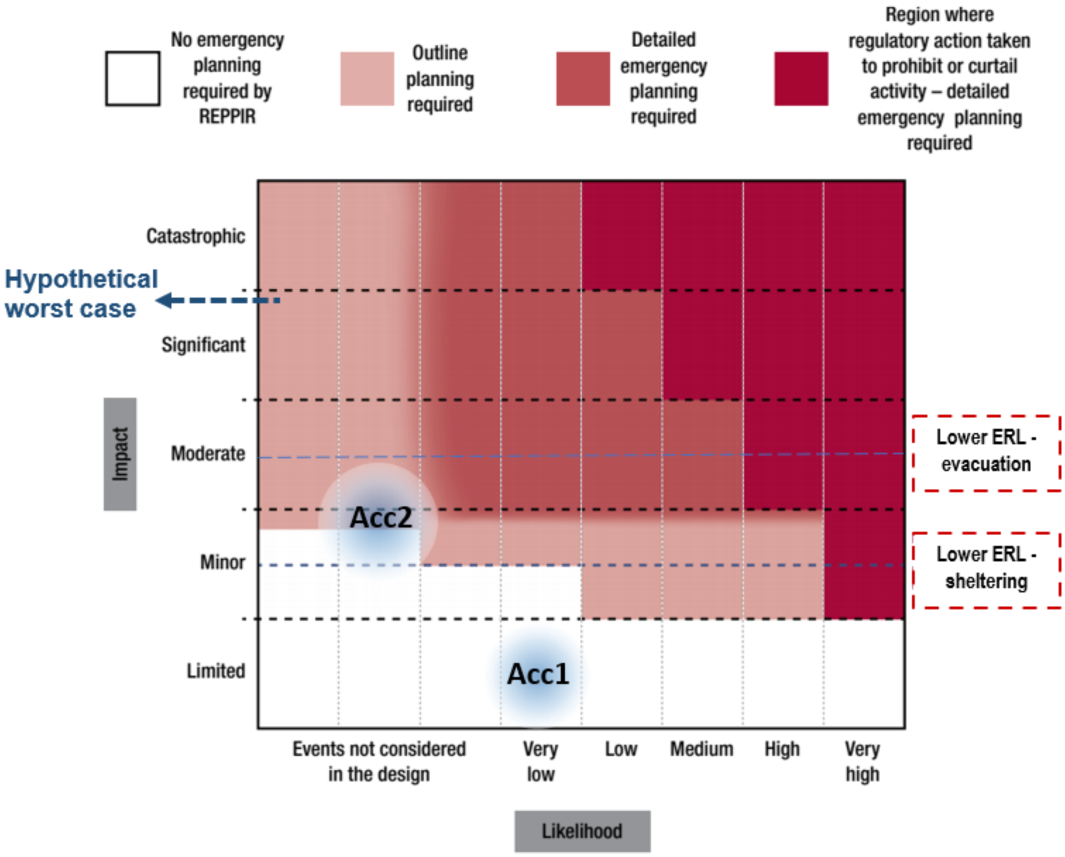

Figure 12 – REPPIR 2019 Risk Framework matrix[38]

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[36] REPPIR 19 is the Radiation (Emergency Preparedness and Public Information) Regulations 2019. It is available at https://www.hse.gov.uk/radiation/ionising/reppir.htm
[37] Environmental Permitting Regulations 2016 does not cover accident scenarios.
[38] ERL is the Emergency Reference Level, related to the does averted by sheltering or evacuation. Whether sheltering or evacuation is needed would be addressed in the emergency plan, considering the transient nature of the release.

The REPPIR 2019 matrix illustrates how, for the two potential accident scenarios described, the likelihood of occurrence is very low, but that the varying impacts of each scenario would involve different requirements in terms of emergency planning.

For an accident such as Acc1, given that there should be no wider impact on the public such as localised sheltering,[39] no advance planning would be proportionate. However, for an accident such as Acc2, the combination of their likelihood and impact could under REPPIR 2019 require a fusion power plant to consider some emergency planning as part of emergency preparedness and response arrangements for both the facility and local public.

For an accident such as Acc2, some emergency preparedness and response arrangements may need to be developed so that these can be triggered should the scenario occur. Whilst this could include localised sheltering for a few days, it might simply require a consideration on what lower level outline planning arrangements might be appropriate.

For the hypothetical worst-case scenario (Hypo), it is likely that any radiological impact arising from that would be eclipsed by the wider impact of the underlying event itself, such as an earthquake of exceptional magnitude. However, as with Acc2 some consideration should be given to whether any outline planning arrangements are proportionate.

REPPIR 2019 uses the phrase "Events not considered in the design" to describe very unlikely events. This phrase applies to a wide range of facilities in the UK for which – where the impact of such events would be "limited" – REPPIR 2019 in itself would require no further work to be done in respect of potential events in that impact range, due to the combination of likelihood and impact. However, other applicable regulations (as detailed in the following chapter) require developers and operators of radiation facilities in the UK to ensure that risks to workers and members of the public are as low as reasonably practicable. For future fusion power plants, this means that the design safety analysis and the provision of protective systems would be based on mitigating the risk of events that would fall into this "very low likelihood, potentially moderate to significant radiological impact" range. Reducing risk to a level as low as is reasonably practicable also applies to all other non-radiological hazards.

[39] Sheltering is a protective measure following any accidental atmospheric release from a nuclear power plant that involves staying indoors with windows and doors shut.

Radioactive waste

Radioactive waste is produced by both nuclear and non-nuclear facilities such as medical or research facilities. In the case of fusion, solid, liquid and gaseous radioactive waste will be produced throughout the lifecycle of a fusion power plant (see Annex D for further detail on radioactive waste). This waste will be constituted of components and structures of the reactor that become radioactive and materials within the reactor and fuel cycle plant that become contaminated with tritium. However, the exact quantities and activity of radioactive waste is highly uncertain. The waste produced by a fusion power plant will be heavily influenced by: the choices made in the design stage; the options for detritiation, reuse and recycling; and any regulatory requirements.

UKAEA's Technology Report[40] considers the available literature on the activity and expected quantities of the different categories of radioactive waste for a tokamak design fusion power plant. The information below summarises the main findings of this. However, the Government has not just considered waste implications for tokamak designs when developing the proposals set out in this paper. Although there may be some differences in the waste produced by different fusion technologies, any regulatory framework would be technology neutral and as such would be applicable to any fusion power plant.

In any case, no High Level Waste will be generated from fusion during normal operations, as noted previously.

The quantity of Low Level Waste (LLW) produced is comparable to the quantities produced by a fission reactor producing equivalent power, namely thousands of tonnes of LLW which does not require specialist storage or disposal.

A fusion power plant could potentially produce thousands of tonnes of what is currently defined as Intermediate Level Waste (ILW) if that waste were sent for disposal immediately after operations (e.g. without detritiation or decay storage). This would be less than 1% of the UK's total ILW inventory.[41] This will be a combination of activated reactor components and materials contaminated with tritium. A significant proportion of this ILW is expected to be classed as LLW after a period of decay storage of around 100 years and then disposed of accordingly (see Annex D for more information about decay storage and disposal). However, impurities within the activated materials could result in much longer-lived radioisotopes, meaning that some fusion waste may be classed as ILW for thousands of years.

Waste reduction, handling and mitigation strategies are already established in the nuclear sector to reduce the hazard posed by all levels of radioactive waste. Treatment technologies are being explored to minimise the amount of radioactive waste sent for disposal, for example strategies to remove tritium. The application of these approaches and technological solutions is now being investigated for fusion by UKAEA.

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[40] Available from UKAEA's website: https://ccfe.ukaea.uk/

[41] Nuclear Decommissioning Authority (2016). *Radioactive Wastes in the UK*. Available at: https://ukinventory.nda.gov.uk/document/high-level-summary-uk-radwaste-inventory-2016/

Non-radiological hazards

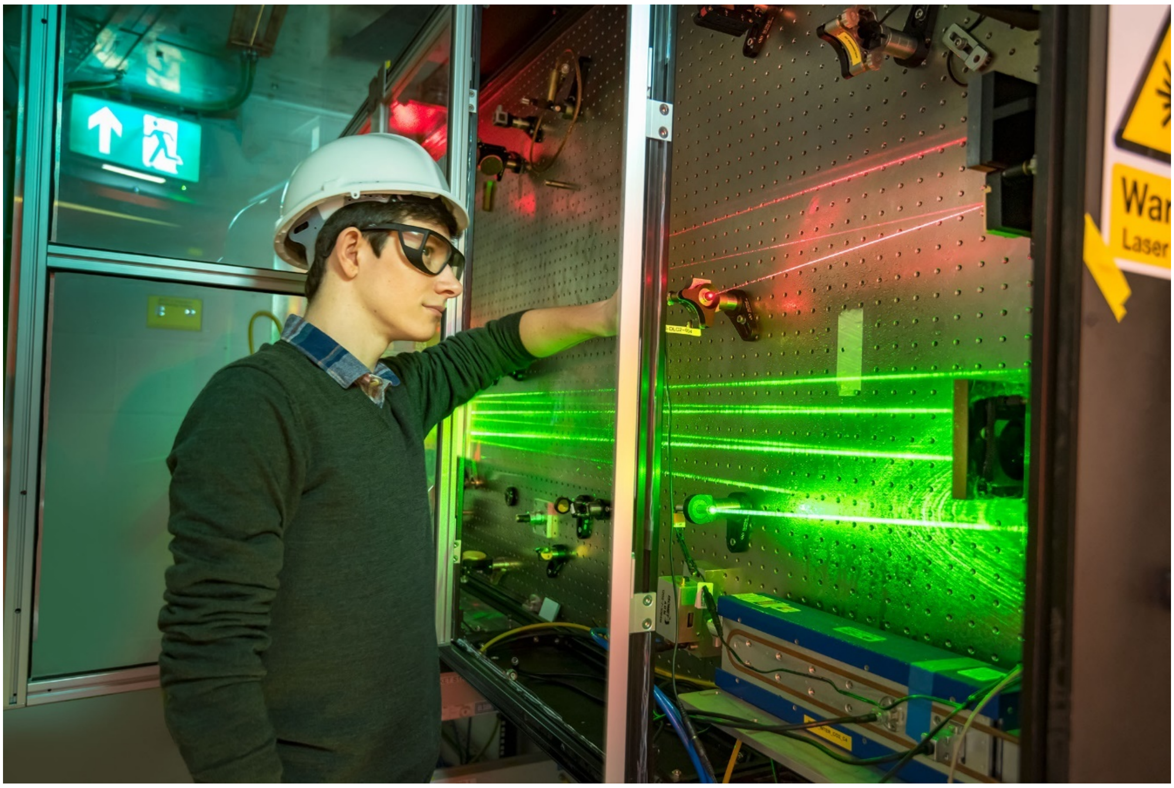

Figure 13 – Representation of non-radiological hazards[42]

There are non-radiological industrial hazards involved in a fusion power plant. As with radiological hazards, they are expected to be greater in a fusion power plant than in current research facilities, though they will be dependent on the design. These hazards include high magnetic fields, microwaves, lasers, high voltages and hazardous materials such as beryllium and lithium.

Such hazards are common throughout the working environment in many other industries. They are generally tolerated by society due to the fact that safety controls are put in place to reduce the risks from these activities to workers and the public to a level that is as low as is reasonably practicable (ALARP), and in recognition of the benefits they bring. In terms of occupational health and safety, these hazards are regulated by the HSE (in Great Britain), using regulations made under the Health and Safety at Work etc. Act 1974. Some aspects may also be subject to additional regulation by the Environment Agency under the Environmental Permitting (England and Wales) Regulations 2016.

[42] © UKAEA

Overall hazard and remaining uncertainty

This chapter has described how a fusion power plant will be of a greater scale than current R&D facilities and that the hazards involved will accordingly be greater than current R&D facilities. The hazards of a fusion power plant will also change from commissioning to operations to decommissioning. Annex F identifies the main hazards at each stage of the regulatory process.

Many industrial and professional activities involve considerable radiological hazards, for instance in scientific research or medical operations, but these are tolerated by society for the benefits they bring. This could be the same for fusion technology, which could produce low carbon and effectively unlimited energy. Indeed, any new activity taking place in the UK that involves ionising radiation must be officially justified on the basis that the social, economic, or other benefits outweigh the risks of ionising radiation. There is a formal assessment process in place for this which is known as Regulatory Justification (more information about how this would relate to fusion energy generation is in Chapter 4).

Fusion power plants will use hazardous radioactive material as fuel and produce hazardous radioactive waste, and that these 'radioactive inventories' would be larger than in present-day fusion research facilities. Crucially however, the likelihood of an accident occurring that would result in any release of these inventories is projected to remain very low as described above. While the impact of an accident could – in a hypothetical worst-case scenario – be significant, the very low likelihood of any accident occurring means that the overall risk of fusion causing harm to workers, the public and the environment is projected to remain very low.

As fusion is a developing technology and fusion power plants are yet to exist to provide safety data, there are still elements of uncertainty[43] around the overall hazard of fusion power plants. Such uncertainty should not itself pose a concern for the effective regulation of fusion in the UK over the coming decades. While it will be impossible to replicate empirically the exact conditions within the first fusion power plants before they begin operation, the risk-based and goal-setting approach of UK regulators (detailed in Annex C) enables them to be adaptable and innovative in determining whether a fusion facility is managing the risks proportionately and effectively in the face of technological uncertainty. There will be an increasing need for regulators to draw on the best scientific knowledge available in their scrutiny of fusion facilities.

In summary, the Government believes that the hazards of fusion power plants will remain of a similar magnitude to those associated with other industrial activities that are currently regulated by the EA and HSE (detailed in Annex G). As detailed further in Chapter 4, this conclusion is central to the Government's consideration of whether the current regulatory framework for fusion R&D activity is an appropriate and proportionate basis for regulation of fusion energy.

[43] Some countries are considering hybrid fission-fusion designs. Such projects are outside the scope of this paper which looks at 'pure fusion' approaches only. However, the presence of nuclear material and higher inherent hazard of the fission process means that, were such a design ever to be developed in the UK, it is assumed that it would fall within existing nuclear regulations.

2. Do you agree with the Government's conclusions regarding the expected hazards of future fusion power plants? Please provide as much evidence as possible to support your view.

The Government will continue to work with fusion technical experts and regulators to monitor the development of fusion technology in case this results in a change in the overall hazard and risk profile of fusion power plants. More information about the Government's proposed approach for this is on page 67.

3. Current regulatory approach

The Environment Agency (EA) and the Health & Safety Executive (HSE) currently regulate fusion research and development (R&D) activity in England as a “radioactive substances activity”. The individual regulations, broad regulatory principles and the implications for devolution in the UK are explained in this chapter to describe what regulation as a “radioactive substances activity” means as applied to fusion research.

The EA and the HSE regulate fusion using a “goal-setting regulatory approach”. This requires regulators to set out broad principles, outcomes or standards that must be achieved or satisfied by the regulated entity – in this case, the operator of a fusion facility. This is different from a more prescriptive process which involves “rules that are highly specific to a regulated action and states what actions are and are not permissible”.[44]

For example, where a goal-setting approach to regulation sets limits on the maximum radiation dose a member of the public may receive over a set period of time, it does not prescribe how this should be achieved. Instead, operators will have to demonstrate that any impact to workers, the public or the environment is ALARP[45] (As Low As Reasonably Practicable) or ALARA[46] (As Low As Reasonably Achievable) to demonstrate compliance. In practice there is no difference between ALARA and ALARP.

The goal-setting approach is more flexible, as how those goals are achieved is unspecified. This is particularly appropriate for an emerging, lower safety risk area of technology which involves ongoing innovation and evolution. As such, the current goal-setting regulatory process is acknowledged by the regulators, and the wider fusion industry, to be fit for purpose for the regulation of fusion R&D activities.

In order for a fusion facility to be developed and operated in a lawful way, it must go through permitting and consenting processes governed by the relevant regulations. These are set out below.

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[44] UK Government (2018). Regulation: goals-setting and rules-based approaches. Available at https://www.gov.uk/Government/publications/regulation-goals-based-and-rules-based-approaches

[45] ALARP is the principle applied by HSE to reduce the risk to workers and the public to As Low As Reasonably Practicable

[46] ALARA is the principle applied by EA to reduce the risk to the environment to As Low As Reasonably Achievable

Table 3 - The principal regulations[47] as currently applicable to fusion R&D in England and the regulatory body responsible for enforcing them

Regulatory Body	Regulations / Legislation	Acronym	Explanation
Environment Agency	Environmental Permitting (England and Wales) Regulations 2016	EPR	EPR requires operators of "regulated facilities" to obtain a permit or to register some activities and so EPR provides for ongoing supervision by regulators of activities which could harm the environment. On non-nuclear licensed sites such as fusion sites, the Environment Agency regulates the keeping and use of radioactive material and the accumulation and disposal of radioactive waste, acting as both an environmental and a security regulator.
Health and Safety Executive	Health and Safety at Work etc. Act 1974	HSWA	Covers occupational health and safety in Great Britain including general duties which employers have towards employees and members of the public.
	Ionising Radiations Regulations 2017	IRR	IRR 2017 applies to a large range of workplaces where radioactive substances and electrical equipment emitting ionising radiation are used (a fusion facility falls within this definition, in addition to many other facilities such as the use of cyclotrons[48] in the medical sector and large-scale industrial irradiators[49] using radioactive material). IRR 2017 requires employers to keep exposure to ionising radiations as low as reasonably practicable.
	Radiation (Emergency Preparedness and Public Information) Regulations 2019	REPPIR	REPPIR 2019 are concerned with preparedness for radiation emergencies. The Regulations establish a framework of preparedness where members of the public might be affected. The Regulations ensure that members of the public are properly informed and prepared, in advance, about what they need to do in the unlikely event of a radiation emergency occurring.

[47] These regulations form a part of the regulatory framework that ONR also use to regulate nuclear sites that come under its remit. Therefore, from a health and safety perspective, the underpinning regulatory principles for fusion sites are similar to that for nuclear (fission) sites. Regulation of transport activities and safeguarding requirements with respect to radiological materials are the responsibility of ONR for both fission and fusion sites.
[48] A cyclotron is circular device which accelerates charged particles to high energy. It will react with a particle beam to create radioactive particles which can be used for medical purposes.
[49] Industrial irradiators emit high levels of ionising radiation. They can be used to sterilise food and medical products.

	Control of Artificial Optical Radiation at Work Regulations 2010	-	Made under HSWA. Aims to protect workers from the risks to health from hazardous sources of artificial optical radiation (AOR) such as high power lasers.
	Control of Electromagnetic Fields at Work Regulations 2016	CEMFAW	Made under HSWA. The CEMFAW Regulations contains a Schedule which explains the effects of EMFs and provides details of safety conditions which must be met.
	Control of Substances Hazardous to Health 2002	COSHH	COSHH is the law that requires employers to control non-radiological substances that are hazardous to health.

A high level illustration of what is involved in the current regulatory process – in terms of approval stages, ongoing compliance and engagement – is shown overleaf. This includes the relevant planning regulations, which are an important part of the regulatory framework for fusion facilities but are not enforced by the EA or HSE.

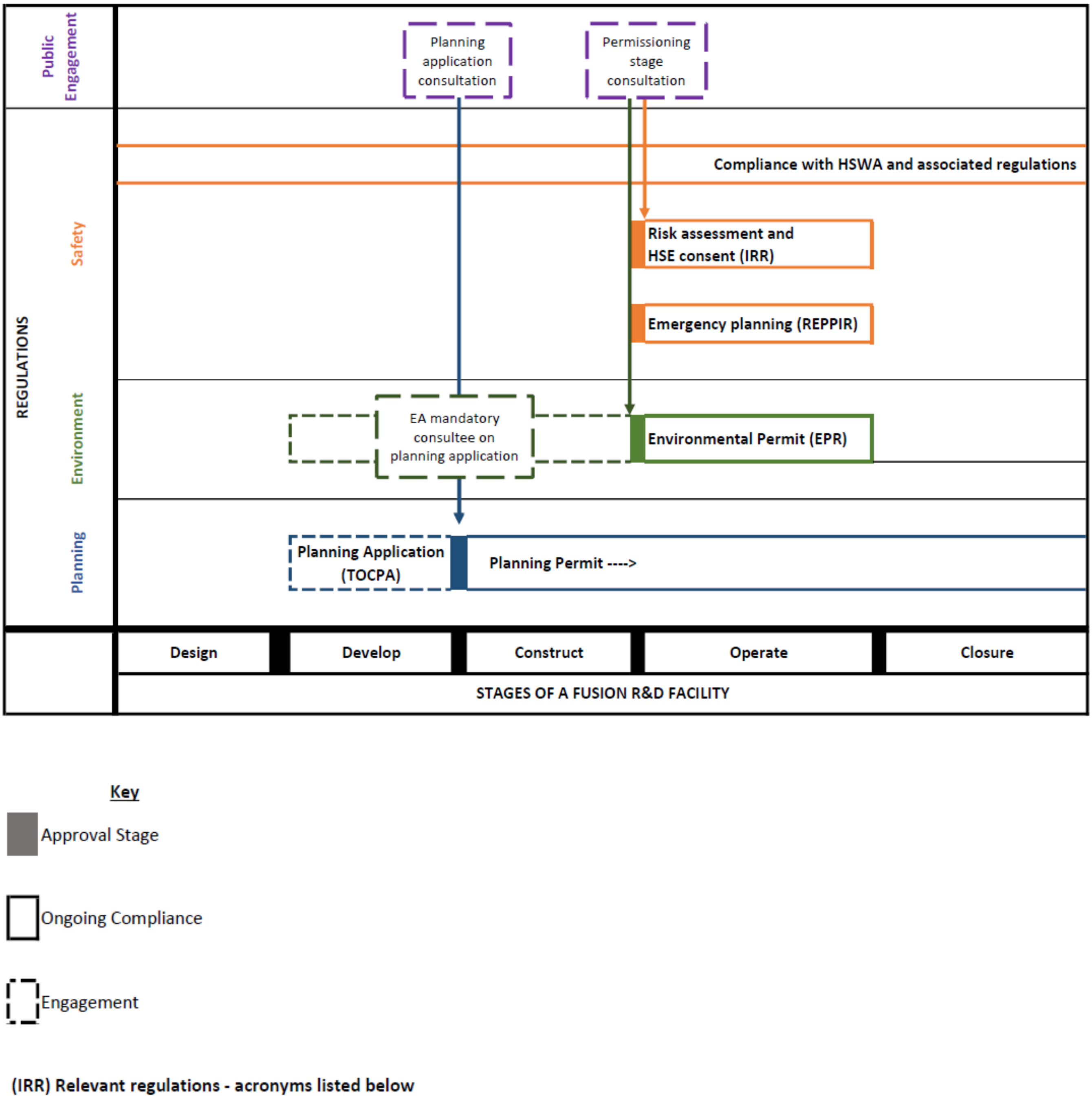

Figure 14 – Illustration of current regulatory process[50] [51] and key

[50] HSWA - Health and Safety at Work etc. Act 1974
IRR - Ionising Radiations Regulations 2017
REPPIR - Radiation (Emergency Preparedness and Public Information) Regulations 2019
EPR - Environmental Permitting (England and Wales) Regulations 2016
TOCPA is the Town and Country Planning Act 1990

[51] An environmental permit issued by EA is not legally required during the construction phase of a fusion power plant. However, it is likely that operators will seek one for major sites such as for fusion to reduce regulatory risks later in the process.

Devolution

While fusion research is taking place across the UK, major fusion experimental facilities are only located in England at the current time. The information below covers the relevant regulations that would apply to a fusion experimental facility sited in the UK outside of England.

Health and Safety is reserved in Scotland and Wales and enforced by HSE. In Northern Ireland, the Health and Safety Executive Northern Ireland (HSENI) has equivalent powers and capability as HSE to regulate fusion R&D under The Ionising Radiations Regulations (Northern Ireland) 2017 (IRRNI 2017) and Radiation (Emergency Preparedness and Public Information) Regulations (Northern Ireland) 2019 (REPPIRNI 2019).

Environmental protection regulation is devolved to each of the UK nations. The Scottish Environment Protection Agency (SEPA) under the Environmental Authorisations (Scotland) Regulations 2018 (EASR), Natural Resources Wales (NRW) (under EPR 2016), and the Northern Ireland Environment Agency (NIEA) (under the Radioactive Substances Act 1993) all have the equivalent powers and capabilities as EA to regulate fusion R&D.

The Town and Country Planning Act 1990 (TOCPA) only applies in England and Wales. In Scotland, energy planning consent is granted through powers set out in the Electricity Act 1989. In Northern Ireland, planning consent is granted under the Planning Act (Northern Ireland) 2011.

Given the close similarities, Figure 14 could be used to illustrate how relevant regulations could apply to a fusion experimental facility in any part of the UK.

4. Towards a fusion energy regulatory framework: the Government's proposals

This chapter summarises the key points made by this paper so far before setting out the Government's overarching proposals on fusion energy regulation.

The UK Government's objectives for a fusion regulatory framework

As set out in Chapter 1, the Government has set a number of objectives against which to assess any new regulatory provisions on fusion energy in the UK. These are:

Objectives for a successful regulatory framework for fusion energy

Safety: Maintain human and environmental protections, in a way that is proportionate to the hazards and risks involved;

Transparency: Ensure transparency to enhance public assurance;

Innovation: Make the UK the best place in the world for commercialising fusion energy through enabling regulation that offers certainty to fusion developers and investors.

Intrinsic hazard and risk of fusion technology

As set out in Chapter 2, while there are still uncertainties around the hazards associated with future fusion power plants, the Government believes that the current regulatory approach for fusion will remain proportionate to the overall risk and hazard associated with future fusion power plants.

The current regulatory approach

As set out in Chapter 3, the current goal-setting regulatory process is acknowledged by the regulators, and the wider fusion industry, to be fit for purpose for the regulation of fusion R&D.

Proposals on fusion energy regulation

The Government's proposals build on work undertaken over the past two years with regulators and other expert stakeholders to identify those issues that need to be addressed in a future fusion energy regulatory framework.

The proposals were also informed by and strongly align with the recommendations of the Regulatory Horizons Council's (RHC) Report on Fusion Energy Regulation (see page 14). The Government will respond formally and fully to the RHC's report following the consultation on its proposals set out in this paper.

The Government's broad proposals are:

1. **To maintain the existing regulatory approach to operational permitting of fusion facilities, given that the radiological hazard of a fusion power plant will be increased but not fundamentally different from current fusion research facilities**
2. **To clarify fusion's status with regards to existing nuclear regulations and introduce new provisions necessary for the efficient, effective and proportionate regulation of fusion power plants**
3. **To work with the regulators to consider whether and how enhanced engagement and new guidance for fusion developers could help support the safe and rapid deployment and commercialisation of fusion energy technology**
4. **To keep related policy under review areas as fusion energy technology develops**
5. **To review the overall regulatory approach to fusion no less frequently than every 10 years, on the basis of the remaining uncertainties around the technologies involved in a fusion power plant**

1) Maintaining the existing regulatory approach

The Government proposes that the current regulatory approach for fusion in the UK – which regulates fusion as a radioactive substance activity – should be retained and developed. This would mean that in England, the regulation of fusion facilities will continue to be led by the Environment Agency (EA) and the Health and Safety Executive (HSE). Fusion operators would not be required to obtain a nuclear site licence and so fusion facilities would not be required to be on a nuclear site regulated by the Office for Nuclear Regulation (ONR).

A key driver for this is the magnitude of the intrinsic hazard and risk of the fusion process in the context of a commercial-scale, energy generating fusion power plant. The hazards associated with fusion (detailed in Chapter 2) will remain around the same magnitude as other hazardous radiological practices regulated by the EA and HSE. This is expected to remain the case despite the uncertainties around some aspects of fusion technology.

With this conclusion, the Government believes that the current regulatory framework (detailed in Chapter 3) is appropriate for the level of hazard of fusion power plants, allowing a proportionate consenting and permitting regime under IRR 2017 and EPR 2016 respectively. While some changes are necessary (as detailed in this chapter), the relevant regulatory bodies have both the necessary legal powers (vires) and expertise to regulate fusion power plants appropriately and proportionately. The ONR would continue to be responsible for the regulation of the off-site transportation of radioactive material and nuclear safeguards.

This approach would also: demonstrate to the world a proven and effective approach to safety and security; support international collaboration on regulation by acting as a basis for sharing key principles and technical information; and provide certainty and clarity that will de-risk commercial investment into the UK fusion sector.

3. **Do you agree with the proposal to maintain the existing regulatory approach? Please explain your response.**

4. **Do you agree that IRR 2017 and EPR 2016 provide for the consenting and permitting (respectively) of fusion power plants in a way that is proportionate and appropriate? Please explain your response.**

An alternative approach

In considering how the regulatory framework led by EA and HSE is appropriate and proportionate for fusion energy, the Government has also considered the regulatory framework led by ONR and EA that applies to fission.

An approach that applied the requirements of the Nuclear Installations Act 1965 (NIA 1965) would require fusion power plant operators to obtain a nuclear site licence and fulfil the obligations accompanying such a licence.

This licence imposes conditions that a licence holder must meet to maintain the safety and security of the site and the appropriate management of radioactive material. These measures are agreed on a safety case basis with the ONR. Applying a goal-setting approach means that the safety case for meeting licence conditions can vary proportionately to the nature of nuclear activities undertaken at a site and associated hazard.

At present, the Government believes that developing a regulatory framework for fusion energy based on the current fusion regulatory approach led by EA and HSE would be better aligned to the activities they currently regulate compared to a regulatory approach based on NIA 1965. However, with the uncertainties involved in fusion power plants, it is possible that the regulatory approach based on NIA 1965 could become more appropriate as the regulatory basis of fusion power plants if fusion design choices in the future involve a considerably higher degree of radiological hazard than is currently expected. As the fusion power plants designs are developed over the coming years, the Government will consider this approach in its regular reviews of fusion regulation (see page 67 for further detail).

5. **Do you think that fusion power plants should be considered to be nuclear installations under the terms of the Nuclear Installations Act 1965 and so be brought within the remit of the nuclear licensing framework led by ONR, either at this stage or in the foreseeable future? Please explain your response.**

2) Clarifying existing regulations and introducing new provisions

There are a number of specific regulatory areas where clarification or the introduction of new provisions is needed to remove ambiguity and provide certainty to fusion developers and the public. The Government's proposals on these issues are set out below.

Regulatory justification of fusion energy

Justification is a process which requires that before any new class or type of activity involving ionising radiation can be introduced in the UK, it must first be assessed to determine whether the individual or societal benefit outweighs any health detriment it may cause. The operation of fusion reactors is currently justified in the UK for R&D purposes. By way of comparison, the operation of certain designs of nuclear reactors is justified for the generation of electricity. The relevant justified practices are reproduced below.

Table 4 – Examples of current practices involving ionising radiation that are justified

Area	**Classes or type of practice**
Research and development	Operation of nuclear fission or fusion reactors for R&D purposes
Generation of electricity by nuclear reactors	Operation of Magnox power stations Operation of advanced gas-cooled power stations Operation of pressurised water power stations

This paper confirms the Government's expectation that the generation of energy from a fusion reactor power plant must be confirmed as a new justified practice before the operation of any fusion power plant in the UK. This would require a successful application to the Justifying Authority which in this case would be the Secretary of State for the Environment via the Justification Application Centre. More information is in guidance published online.[52]

The Government has agreed with UKAEA that the STEP programme, which will develop and build a prototype fusion power plant in the UK by 2040, should develop and submit such an application to the Justifying Authority in collaboration with the fusion industry as necessary (see "Scope" below).

The Government welcomes views on what such an application should cover, particularly on the issues outlined below. For instance, the Government believes, that as part of any such application, the radiological hazards presented by the wastes produced by this activity would need to be justified by reference to the benefits of the activity.

[52] UK Government (2004). The Justification of Practices Involving Ionising Radiation Regulations 2004: guidance on their application and administration. Available at https://www.gov.uk/Government/publications/the-justification-of-practices-involving-ionising-radiation-regulations-2004-guidance-on-their-application-and-administration.

Generation of net energy

Existing justified practices of operation of nuclear reactors are for the generation of 'electricity'. Fusion power plants could have several applications, including producing high-grade heat for hydrogen or carbon capture and storage. To explicitly enable this breadth of application, the Government proposes that a justification application is for the 'generation of net energy by fusion power stations'.

Scope

Existing justified practices regarding energy generation from nuclear reactors are specific to the reactor design in question and the Justifying Authority is expected to require a similar approach for fusion. Some fusion developers are pursuing alternative technological approaches to fusion than STEP, which will be based on the 'tokamak' approach as explained in Chapter 2. The Government wishes to enable the rapid commercialisation and safe deployment of fusion in the UK regardless of technological approach. With that aim in mind, the Government has asked UKAEA to work with other private sector fusion developers to prepare an application to be submitted to the Justification Application Centre.

6. **What are your views on the Government's proposals in relation to the regulatory justification of fusion?**

Fusion and the definition of a nuclear installation

As set out above, the Government proposes that fusion power plants should not be regulated under the same regulatory regime as fission and so will not be subject to nuclear site licensing. How nuclear installations in the UK are regulated and licensed is prescribed by The Nuclear Installations Act 1965 (NIA 1965)[53] and the Nuclear Installations Regulations 1971 (NIR1971).[54]

The Government believes that amending legislation will provide long-term clarity and confidence to industry and send a clear market signal about the Government's intentions for fusion regulation. Amending legislation would also be the most robust and transparent way to ensure fusion power plants are not inadvertently captured by nuclear installation regulations at any point in their lifetime. This would not prevent the Government from changing the fusion regulatory framework in future if it chose to do so. Indeed, by removing this element of uncertainty, the Government seeks to create a consistent basis from which fusion energy regulation can evolve as necessary.

Nuclear legislation such as NIA 1965 and NIR 1971 applies across the UK and nuclear policy is reserved to the UK Government, so any amendments to these would apply in all the devolved nations.

[53] UK Government (1965). Nuclear Installations Act 1965. Available at https://www.legislation.gov.uk/ukpga/1965/57
[54] UK Government (1971). Nuclear Installations Regulations 1971. Available at https://www.legislation.gov.uk/uksi/1971/381/contents/made

7. Do you agree that a legislative approach is appropriate for clarifying that a nuclear site licence would not be needed for fusion power plants? Please explain your response.

National Policy Statement for fusion

In England, a ‘generating station’ (which would include a fusion power plant), with energy output over 50 MW would be designated as a Nationally Significant Infrastructure Project (NSIP). In Wales, a generating station with energy output over 350 MW would be designated as an NSIP. Planning applications for NSIPs can be streamlined by a National Policy Statement (NPS) being published by the Government. A NPS is a statutory document that sets out the Government’s policy on types of NSIPs. It establishes the national need for the infrastructure development which it covers. An NPS provides the framework within which the relevant Secretary of State makes their decisions on NSIP applications for development consent. Where an NPS has effect in relation to an application for an order granting development consent, the relevant Secretary of State must decide on the application in line with that NPS.

Development consent could be obtained without an NPS. However, this is likely to be more burdensome for developers and would not be consistent with other energy producing facilities.

As such, the UK Government intends to establish a Fusion NPS, to provide a development consent framework which gives confidence to developers who wish to bring forwards fusion projects. A Fusion NPS would enable applications for a development consent examination to focus on specific planning issues, not on broader policy questions such as whether there is a need for such infrastructure. The Planning Inspectorate’s Examining Authority would then make their recommendations to the relevant Secretary of State.

Planning policy and regulation is devolved. Scotland and Northern Ireland have fully devolved planning consent processes for energy generating stations. In Wales, planning consent is devolved for generating stations up to a capacity of 350 MW.

The Fusion NPS would therefore have jurisdiction in England and would also have jurisdiction in Wales for fusion generating stations with energy output greater than 350 MW.

The Fusion NPS would not be directly relevant in Scotland and Northern Ireland. The devolved Governments in Scotland and Northern Ireland may wish to decide whether and how to review their own consent processes in relation to fusion, following the establishment of the Fusion NPS in England and Wales. The UK Government is ready to support any such review as appropriate.

The Government proposes that a Fusion NPS (and the accompanying Appraisal of Sustainability) would be based on the following key assumptions:

- The Fusion NPS would be linked to the Overarching Energy NPS.[55] Pending public consultation, the updated Overarching Energy NPS would in future establish the need for fusion energy.
- The Fusion NPS would be applicable for generating stations using any fusion technology.
- The Fusion NPS would not be site-specific. In line with the proposals set out earlier in this chapter, it would confirm that a nuclear licensed site is not required for a fusion generating station.
- Given that fusion technology is still in the development phase, the Fusion NPS would be reviewed as part of the Government's proposed regular review of the overall fusion regulatory framework. Information in the NPS about waste and decommissioning is expected to be reviewed as fusion technology develops.

8. **Do you agree with the proposal to establish a Fusion NPS based on the planning assumptions outlined above? Please explain your response.**

9. **What other issues should a Fusion NPS address?**

Fusion and nuclear liabilities

There are international frameworks that govern the liability obligations of a nuclear (fission) power plant in relation to potential costs arising from a nuclear accident. The international Nuclear Energy Agency (NEA) is currently considering whether fusion should be included within the Paris Convention[56] which is one such international framework to which the UK is party.

There are currently no specific nuclear liability requirements for fusion operators in the UK. As explained in Chapter 2, the impact of a worst-case accident involving radioactive materials at a fusion power plant would not have widespread consequences. The liabilities arising from such an eventuality would be unlikely to have transnational boundary implications.

[55] UK Government (2021). Planning for new energy infrastructure: review of energy National Policy Statements. Available at: https://www.gov.uk/government/consultations/planning-for-new-energy-infrastructure-review-of-energy-national-policy-statements
[56] NEA (2020). Paris Convention on Third Party Liability in the Field of Nuclear Energy. Available at: https://www.oecd-nea.org/jcms/pl_20196/paris-convention-on-third-party-liability-in-the-field-of-nuclear-energy-paris-convention-or-pc

The Government is engaging in international discussions on this topic. The Government aims to confirm in 2022 whether fusion should be subject to a general liability regime, what the terms of such a regime could be, and whether or how this would relate to the Paris Convention.[57] At this stage, the Government believes that, regardless of whether such a regime is developed for fusion, a competitive insurance market for fusion would help to ensure that the development and operation of fusion power plants is not hindered by the burden of (nuclear) liability. In addition, the Government believes that firms supplying key systems and components to fusion power plants should not be precluded from doing so by the potential for third party legal action in the very unlikely event of an accident.

This section considers the principles behind the Paris Convention and their potential applicability to fusion, as well as some additional factors that the Government judges to be important in considering whether and how any fusion liability regime should be developed. The Government believes that any such regime should be one that can be harmonised internationally, to aid the global growth of the fusion industry and international supply chains.

The Government welcomes views on all the points raised.

Capping fusion liabilities

The principle of capped liability is central to the Paris Convention. Capping liabilities means that nuclear fission operators are not over-burdened by having to insure against potentially unlimited liability which would increase costs faced by the nuclear industry, while still ensuring that the victims of a nuclear accident have access to adequate compensation. The Government believes this principle should be central to a third party liability regime for fusion.

Setting the liability cap at an appropriate level

The 2004 amendment to the Paris Convention, applied through the Nuclear Installations (Liability for Damage) Order 2016 which amends The Nuclear Installations Act 1965 (NIA 1965), will set a maximum liability of €1.2 billion for the highest hazard sites. The Nuclear Installations (Prescribed Sites and Transport) Regulations 2018 (NIR 2018) will cap liabilities for intermediate level sites at €160 million and at €70 million for the lowest level sites.[58]

Fusion would not be classified as an intermediate level site as currently defined in NIR 2018 as it does not involve using or storing natural or enriched uranium. To be classified as a low-level hazard site a fusion site would have to store less than the quantities of tritium specified in NIR 2018, shown in Table 5 below.

[57] The UK Government is aware of other established international regimes for nuclear liabilities, for example The Convention on Supplementary Compensation (CSC - https://www.oecd-nea.org/jcms/pl_29288/convention-on-supplementary-compensation-for-nuclear-damage-csc). In considering the application of a liability regime to fusion energy, the Government will consider precedent beyond the Paris Convention though this paper uses the principles of the Paris Convention as a starting point due to current international discussions.
[58] These limits in this paragraph will take effect from 1 January 2022.

Table 5 – Quantities of tritium specified in NIR 2018 under which sites are classified as low-level

Radionuclide	Radionuclide form	Quantity in Becquerels
Tritium	tritiated water	7×10^{17}
Tritium	organically bound tritium	1×10^{18}
Tritium	tritiated water vapour	1×10^{19}
Tritium	gas	1×10^{22}

While a fusion power plant is expected to store approximately 10^{18} Bq of tritium gas, there is uncertainty around the total inventory. If a fusion facility were to store over 10^{22} Bq of tritium, it would therefore be classified under NIR 2018 as a high hazard site, with maximum liabilities of €1.2 billion. In line with the conclusions of overall hazard of fusion in Chapter 2, the Government believes that this would be a disproportionate classification.

The Government is supportive of an approach to capping liability based on the level of hazard of the site in question. The Government will consider options for doing so in a way that can effectively account for the hazards of a fusion power plant as noted throughout this paper.

Strict liability

Liability under the Paris Convention is deemed to be 'strict', meaning that the operator is liable regardless of whether fault can be established. Strict liability ensures someone is held accountable for accidents and the public can seek damages. It is also thought to raise safety standards for an operator if they know they will be liable for an incident. The Government judges this to be appropriate for fusion.

Financial security

In relation to the issue of 'strict liability', the Paris Convention mandates that operators must have financial security up to the amount of the capped maximum liability to ensure they can meet any liabilities. The Government believes that this principle is appropriate for fusion.

Channelling liability

For nuclear power plants, liability is 'channelled' to the site operator i.e., the entity who owns the site licence. This means, for example, any company who must transport radiological material to or from that site does not need separate insurance to cover liabilities, helping to provide confidence to the supply chain and to investors. This provision helps nuclear supply chains to operate together smoothly. Fusion is expected to use similar supply chains to fission. The Government believes that the same approach should be replicated in any fusion liability regime, so there is no new obligation on these supply chains that be a disincentive for diversifying into fusion and helping the fusion sector to grow.

Liabilities across borders

If an accident were to occur which has transnational consequences, the Paris Convention caps and channels the liabilities to the operator and country of the accident. The need for this is established for nuclear (fission) power plants, but fusion is not expected to have long-range consequences in the event of any off-site release, even in a hypothetical worst-case scenario. The Government believes that this principle would only be relevant for fusion in the event of an accident occurring at a fusion power plant that happens to be built on an international border. The Government would expect that any claims in the UK or involving UK-based operators are heard in UK courts.

Timeframe for compensation

Under the Paris Convention, the right to compensation expires if legal action is not brought within ten years of the accident. For personal injury claims this limit will be extended to 30 years. For fusion, the Government will look at best practice in other industries involving hazardous activities to inform its thinking on the appropriate timeframe for compensation in any liability framework.

Regulatory harmonisation

The Paris Convention is intended to provide international harmonisation around nuclear incidents, setting standards for nuclear liabilities to allow operators and supply chains to operate internationally with certainty. The Government believes that this principle would strongly benefit fusion in line with the Government's aim to promote international harmonisation on fusion regulation.

Established rules

The principles of the Paris Convention have been in place for nuclear liabilities for decades and are judged to work well. The Government believes that drawing on established provisions that already broadly classify fusion as 'low risk' could provide confidence to industry that any new liability obligations for fusion are proportional, justified and functional.

Ease of developing a fusion insurance market

Currently there are limited commercial options for insuring a fusion facility which is why UKAEA's fusion activities are indemnified by the Government. By providing a liability framework, the Government hopes to initiate the development of commercial insurance provision that is appropriate for fusion.

10. **Do you believe that a third party liability regime is required for fusion? Please explain your response.**

11. **What are your views on the principles and issues regarding third party liability set out in this paper?**

12. What issues in addition to those described in this paper should any fusion third party liability regime address?

13. How can the Government promote the development of suitable commercial fusion insurance?

Cyber Security

Cyber security of critical national infrastructure (CNI)[59] is regulated under The Network and Information Systems Regulations 2018 (NIS 2018).[60] NIS 2018 would not apply to operators of fusion power plants contributing less than a combined total of 2GW to the grid. Furthermore, nuclear generators are excluded from this threshold and therefore fusion would not be regulated under NIS.

Nuclear Industries Security Regulations (NISR 2003) applies to nuclear installations as defined by NIA 1965 and other locations that hold quantities of fissile materials that are not expected to be present at a fusion power plant. This means that neither NIS 2018 nor NISR 2003 (given the Government's proposal to confirm the non-application of NIA 1965 to fusion) would apply to early fusion power plants such as STEP.

The Government will consider whether and how relevant cyber security provisions should be applied to fusion. Cyber security of chemical sites, regulated under COMAH regulation, is regulated by HSE to ensure protection of the public. Fusion energy is expected to be of a broadly similar magnitude of overall hazard as these sites. The Government believes that fusion power plants should be subject to an equivalent level of cyber security regulation.

As well as the need to maintain resilience and operational safety, the Government notes that prototype fusion power plants in the UK may consist of valuable intellectual property, which could itself pose a risk of espionage, including through cyber vectors. At this stage, while developers of fusion power plants are not legally required to guard against cyber theft of intellectual property and data, the Government encourages them to implement appropriate mitigations.

The Government wants STEP, as the UK's planned prototype fusion power plant, to demonstrate compliance with regulatory principles that may apply to fusion power plants in future. As such, the Government believes that it could be useful for STEP to follow the principles of NIS 2018.

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[59] CNI is defined in the Network and Information Systems Regulations 2018 (NIS 2018) as "Those critical elements of infrastructure (namely assets, facilities, systems, networks or processes and the essential workers that operate and facilitate them), the loss or compromise of which could result in:
a) Major detrimental impact on the availability, integrity or delivery of essential services – including those services whose integrity, if compromised, could result in significant loss of life or casualties – taking into account significant economic or social impacts; and/or
b) Significant impact on national security, national defence, or the functioning of the state."

[60] The Network and Information Systems Regulations 2018 (NIS 2018). Available at: https://www.gov.uk/government/collections/nis-directive-and-nis-regulations-2018

14. Do you agree that prototype fusion power plants should be subject to cyber security regulations, regardless of their energy generating capacity? Please explain your response.

15. What in your view should cyber security regulations for fusion cover?

3) Enhancing engagement and developing new guidance

As noted earlier in this chapter, the Government believes that the current regulatory framework (see Chapter 3) is appropriate for the level of hazard of fusion power plants, allowing a proportionate consenting and permitting regime under IRR 2017 and EPR 2016 respectively. This paper has also previously noted that decisions made early in the design process will determine the level of hazard and risk during operation and decommissioning. The Government has considered whether and how the current regulatory processes should reflect this, such as through formalised regulatory engagement and new guidance.

Early engagement with regulators can help to identify potential areas of risk and maximise regulatory influence over those design choices. For instance, as noted in Chapter 2, materials choices made early in the design process can affect the hazard of activated materials within a fusion power plant.

The Government believes that, for fusion power plants, formalised opportunities for engagement early in the regulatory process, such as at the design stage, could be included in existing processes, building on the approach taken by EA and HSE in other higher-hazard contexts. This would better enable regulators and developers to discuss risk mitigations around critical design choices at the appropriate stage of development. However, the Government has concluded that at this time there is no need to introduce any compulsory pre-commissioning engagement and/or regulatory 'hold points'.

The Government will also work with regulators and fusion technical experts to consider how guidance on the overall regulatory framework for fusion energy as set out in this paper could provide additional clarity and transparency for the fusion industry and the public.

Finally, the Government believes that the overall regulatory framework for fusion energy should enable sufficient engagement opportunities for the public to interact with fusion developers and regulators, to fulfil the Government's fusion regulation objective of transparency.

The following section explores these proposals in further detail.

Defining fusion facilities in scope

Sections 1 and 2 of this chapter related to regulatory proposals that are already clearly defined in scope. With regards to the proposals for formalised regulatory engagement during the design stage and new guidance, the Government intends to establish a formal definition to determine the facilities that it believes should be in scope.

The current regulatory framework for fusion R&D facilities is widely considered to be fit for purpose, so existing facilities are not in scope of these proposals. The Government proposes that those facilities defined as being in the scope of the proposed fusion energy regulatory framework (and specifically the proposed formalised engagement at the design stage and associated guidance) are those that **"are designed with a net generating capacity over 50 MW of energy and/or handle over 7 x 10^{16} Bq of tritium".**

This definition is based on two considerations. Firstly, a facility with 50 MW of generating capacity is that which in England is designated as a Nationally Significant Infrastructure Project (NSIP). Secondly, Schedule 1 of REPPIR 2019 specifies a set quantity of radionuclides derived by Public Health England[61] to identify when assessment of emergency preparedness is required. 7 x 10^{16} Bq of tritium is 100 times the threshold for considering application of REPPIR 2019, so can be considered a significant amount of tritium. This reflects the fact that an increased amount of tritium is the key differentiator in the increased radiological hazard of a fusion power plant: not only because of the increased radioactive inventory that this represents but also the much higher rates of activation resulting from the increased use of tritium in the fusion fuel.

There would be no new legal obligations flowing from this definition in itself. Rather, the Government intends that the definition would be used by fusion developers and regulators to determine those fusion facilities in scope for any enhanced engagement processes and/or new guidance.

16. Do you agree that the proposed definition of fusion energy facilities that should be in scope for enhanced regulatory engagement and new guidance is appropriate? Please explain your response.

Increased developer engagement

A key difference between the current regulatory process for fusion R&D and the proposed regulatory framework for fusion power plants would be the formalised engagement between developer and regulator during the design and development stages of a fusion power plant (in this paper, 'early' or 'enhanced' engagement refers to this proposed type of regulatory engagement). Although early regulatory engagement with EA and HSE is already possible, the Government believes a formalised process for this engagement could be beneficial for industry and the regulators. It would also enhance the overall transparency of the regulatory process in line with the Government's objectives set out in Chapter 1.

[61] Public Health England (2019). Reference Values for Schedule 1 of the REPPIR-2019 Regulations: quantities of inventory holdings for more than 700 radionuclides. Available at: https://www.gov.uk/government/publications/radiation-reference-values-for-schedule-1-of-reppir-2019

This approach was recently followed as part of the Government's Advanced Nuclear Technologies (ANT) programme,[62] with a review process suitable for new advanced reactors early in their design process developed jointly by the EA and the ONR to support the BEIS Advanced Modular Reactor Feasibility and Development competition. The competition included a fusion reactor design. Because ONR does not regulate fusion, in this case the Environment Agency worked jointly with fusion safety specialists from UKAEA and the Atomic Weapons Establishment (AWE).

The process involved the assessment of a regulatory submission provided by the vendors to identify areas where there is potential for misalignment with UK regulatory expectations. Based on the advice from EA, UKAEA, and AWE, a programme of regulatory engagement was developed. The engagements included a number of joint sessions with all vendors followed by three individual meetings between each of the vendors and the relevant regulators to discuss regulatory expectations and overview of the vendor's designs. This was used to ensure that vendors understand regulatory expectations in the UK to inform the design process and de-risk any future development and deployment of these designs. These engagements also allowed the regulators to understand better future technologies and identify potential challenges which could require staff up-skilling and guidance updates/development, as well as those with policy implications.

The Government proposes that regulators use this example in considering the development of a similar, non-compulsory process for fusion developers as proposed above.

17. **Do you agree that there should be formal engagement in the design process between fusion developers and regulator(s)? Please explain your response.**

18. **What are your views on how such engagement should work?**

Guidance

There is already existing guidance covering the operation and application of the relevant regulations within the overall regulatory framework for fusion energy, such as for IRR 2017 and EPR 2016. The Government will work with regulators to consider how additional guidance could formalise the enhanced engagement proposed, and how any such guidance could be shared between regulators across the UK.

In its report on fusion regulation, the Regulatory Horizons Council "found that more could be done to clarify, both to the industry and the public, what this regulatory approach is, how it will be enforced and how it could be applied to future fusion projects". It recommended "that a joint guidance document is produced by BEIS, EA and HSE, working with UKAEA as necessary".

[62] More information on the government's Advanced Nuclear Technologies (ANT) programme is available at https://www.gov.uk/government/publications/advanced-nuclear-technologies/advanced-nuclear-technologies

The Government agrees that broader guidance could play a role in providing constructive information, clarity, and transparency. It is important though that any regulatory guidance produced is done so in a way that maintains the regulators' independence from both the Government and from fusion developers. The Government commits to work with the regulators and the fusion industry to consider where additional guidance may be necessary. This could cover regulatory areas where the Government is not proposing changes, such as transport and security.

19. Do you agree that additional guidance for fusion energy facilities should be developed on fusion energy regulation? Please explain your response. If you agree, what should the guidance cover?

Increased public engagement

The Government wants the public to have greater opportunity to engage with the regulatory process, both before operation and throughout the lifetime of a fusion power plant. This would have two benefits:

- Local communities would have more opportunity to provide views to the developer and regulators on proposed designs and regulatory decisions, to increase transparency and confidence in the process
- Developers could better inform and educate local communities on their designs to demonstrate how they have ensured adequate protection for the public and environment

The current framework ensures that there is a public register for all activities permitted under EPR 2016. EA already consult on both an operator's application and the EA's proposed regulatory decisions for sites of high public interest. The Government proposes that sites for fusion power plants are automatically treated as such sites.

HSE are not required to consult the public on regulatory decisions. The Government has asked HSE to consider whether and how HSE should consult on fusion consenting decisions to increase transparency in the regulatory process.

In terms of broader public engagement, fusion developers have acknowledged the substantial benefits of informing and gathering feedback from local communities, the public and non-governmental organisations. For example, UKAEA has undertaken regular engagement with local stakeholders for many years. Nuclear power plant developers adopt a similar approach to public engagement, as do other high hazard or high public interest sites such as chemical plants. This shows that voluntary public engagement is accepted by nuclear and non-nuclear industry as best practice. As such, the Government does not propose to make such engagement mandatory for fusion power plants, though fusion developers will continue to be encouraged to engage with the public through local liaison committees and public forums.

20. Do you believe that there should be greater opportunity for the public to engage in the regulatory process for fusion? If yes, what are your suggestions for how this could be achieved?

Regulator capability

The need to develop enhanced engagement processes and new guidance will require the EA and the HSE to build technical expertise in the production of fusion energy. Both EA and HSE are looking at the potential implications of increased fusion activity in the UK on their capability and capacity. EA and HSE are already experienced in regulating hazardous and dangerous substances (see Annex G for more details), so building capability and capacity will most likely be in the form of upskilling specifically on fusion technology and refinement of processes and resource.

Regulators involved in the Advanced Nuclear Technologies (ANT) programme have developed a better understanding of future nuclear technologies in order to identify potential challenges and opportunities for up-skilling. The proposed enhanced engagement between regulator and operator early in the fusion regulatory process would be similarly beneficial.

The EA is already reviewing processes to consider what is appropriate for regulation of fusion power plants. The EA has consulted[63] on its charging scheme for fusion to bring it in line with other activities regulated by the EA that require specialist staff, such as nuclear fission, medium combustion plants and hydraulic fracking. This is so that the necessary skills required to meet the needs of industry will be available and adequately funded.

If the devolved administrations are supportive of the proposals in this consultation, the devolved regulators would be able to engage through existing relationships with EA and HSE, to ensure the capacity and capability required to regulate fusion energy is in place across the UK.

21. **How do you think regulators can best build technical capability around emerging technologies such as fusion?**

How UKAEA could support the regulatory framework

UKAEA is renowned globally for its fusion expertise and operational experience. The Government believes this technical expertise could play a critical supporting role in a fusion energy regulatory framework.

UKAEA's Fusion Safety Authority

While UKAEA has no regulatory function, UKAEA does have unparalleled expertise for ensuring rigorous safety, security and environmental protection when it comes to fusion operations, with decades of experience operating JET (see page 16).

[63] The Environment Agency (2021). Environment Agency charging scheme proposals from October 2021. Available at: https://consult.environment-agency.gov.uk/environment-and-business/ea-charging-scheme-proposals-from-october-2021/

UKAEA has established the Fusion Safety Authority, which is responsible for providing impartial challenge on UKAEA safety reports and providing BEIS with technical expertise and advice regarding fusion regulation. The Fusion Safety Authority has been set up within UKAEA to enable quasi-independent, technically expert scrutiny of STEP and its regulatory implications. This is similar to 'internal regulator' functions common for operators of nuclear licensed sites. However, this form of separation is different to the formal regulatory independence of independent statutory bodies such as UK regulators, which are subject to set obligations such as public consultation of guidance and processes.

The Government has asked UKAEA to consider whether and how this expertise could form the basis of a 'Technical Support Organisation' providing technical advice to regulators on safety and environmental matters throughout the regulatory process. This could involve UKAEA's Fusion Safety Authority providing technical support to regulators around:

- Assessing a fusion facility design in terms of its risk and hazard mitigations, potentially at both the concept design stage and at the pre-commissioning stage as part of any early engagement process between vendor and regulator;
- Playing a formal, consultee role during the planning consent process – this specific proposal will be expanded on as part of the development of the proposed Fusion NPS.

Along with the regulators themselves, the Government intends that the Fusion Safety Authority would play a key supporting role in in its proposed regular reviews of the fusion regulatory framework (see page 67). The Government is also working with the Fusion Safety Authority to use the international reputation and profile of UKAEA as a focal point for international efforts – which are now underway – to develop globally agreed regulatory codes and standards for fusion technology. In supporting the Government on fusion regulation, it is essential for the Fusion Safety Authority to maintain its separation from UKAEA's fusion development programmes such as STEP, to ensure that technical information provided to the Government is independent and impartial.

22. What are your views on how the technical expertise of UKAEA could best be used to support the development of a regulatory framework for fusion energy in the UK and around the world?

Illustration of the proposed framework for fusion power plants

The illustration of the current goal-setting regulatory process and a representation summarising the Government's outline proposals for a regulatory process for fusion energy (in England) is shown again overleaf:

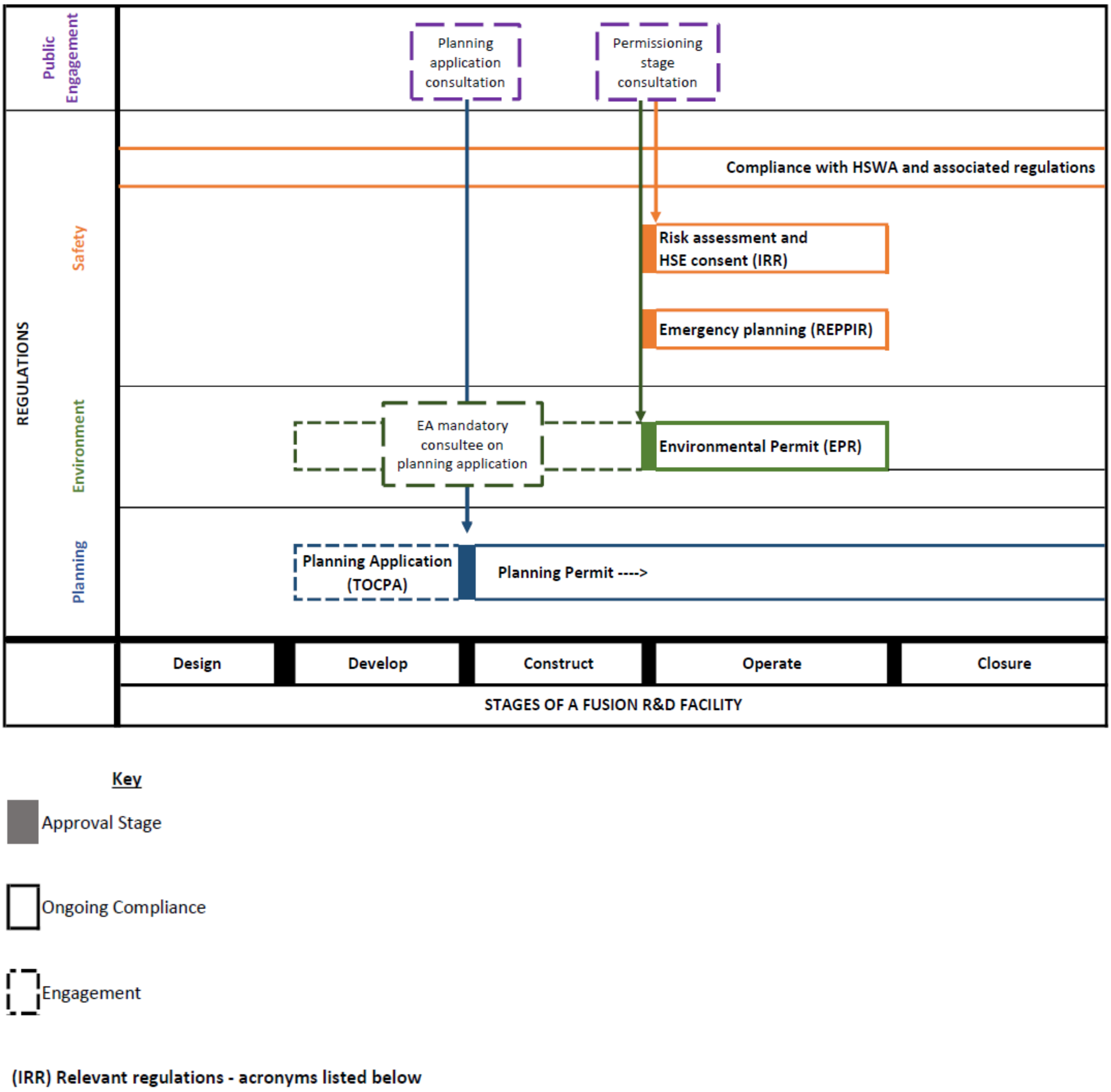

Figure 15 – Illustration of current regulatory process[64] and key

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[64] HSWA - Health and Safety at Work etc. Act 1974
IRR - Ionising Radiations Regulations 2017.
REPPIR - Radiation (Emergency Preparedness and Public Information) Regulations 2019
EPR - Environmental Permitting (England and Wales) Regulations 2016.
TOCPA - Town and Country Planning Act 1990

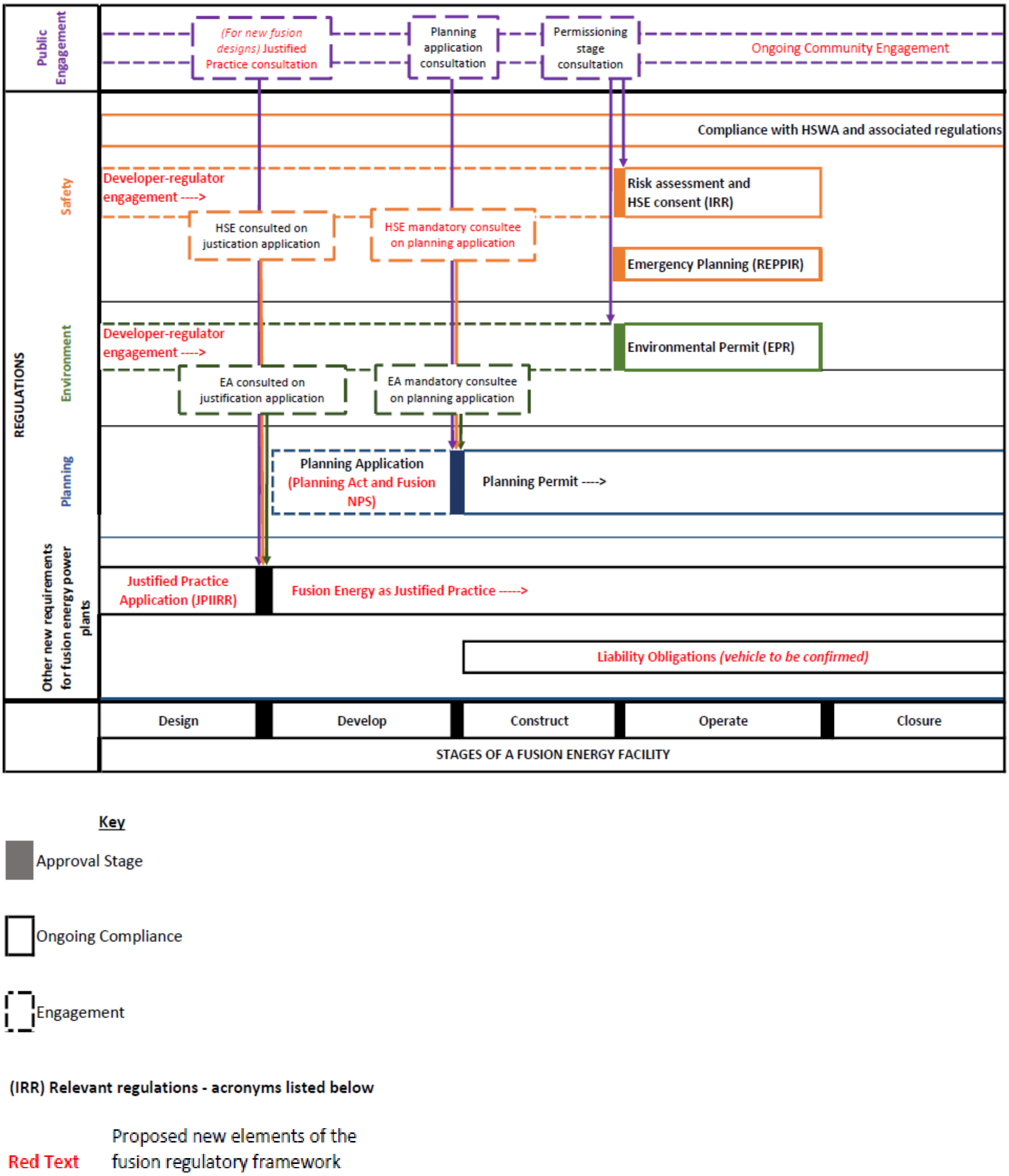

Figure 16 – Illustration of regulatory process with the Government's proposals[65] [66] and key

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[65] HSWA - Health and Safety at Work etc. Act 1974
IRR - Ionising Radiations Regulations 2017
REPPIR - Radiation (Emergency Preparedness and Public Information) Regulations 2019
EPR - Environmental Permitting (England and Wales) Regulations 2016
JPIIRR - Justification of Practices Involving Ionising Radiation Regulations 2004
Planning Act – Planning Act 2008

[66] This notes the potential for HSE to be a mandatory consultee on planning applications for fusion energy facilities along with EA. This will be considered during the development of the Fusion NPS.

In addition to the new proposed opportunities for engagement, Figure 16 also illustrates the proposed requirements for a fusion power plant developer to: secure planning consent in line with the proposed Fusion NPS, applicable in England and Wales; to apply for the production of energy to be classed as a justified practice (if the fusion power plant were based on a previously “unjustified” technological approach); and to comply with a dedicated liability regime for fusion energy.

4) Keeping related policy issues under review

As outlined in this paper, regulatory obligations for fusion developers are either already clear or would be clarified as proposed. There are some policy and regulatory issues in relation to which the Government does not propose to change at this stage, but which need to be kept under review as fusion energy technology develops. The Government believes that these topics however should be appropriately addressed in any new guidance on a fusion energy regulatory framework (as proposed above).

Radioactive waste and decommissioning

A critical issue for fusion is the management of radioactive waste and decommissioning.

Waste

The Government has engaged with CoRWM (the Committee on Radioactive Waste Management) on this topic. CoRWM provides independent scrutiny and advice to the UK Government on radioactive waste management and will be advising Government on areas of consideration around the regulation of fusion radioactive waste. The Government intends that radioactive wastes produced by fusion will be subject to existing policy and strategy on radioactive waste.

As detailed in Chapter 2, the Government believes that the hazard implications of the radioactive waste expected to be produced by fusion power plants do not in themselves require any changes to the regulatory framework for fusion.

Consideration will however need to be given to the treatment, storage and disposal requirements for waste from fusion power plants expected to be developed in the UK (this is detailed in Annex D). As discussed in Chapter 2, even though there is some uncertainty on what waste will be produced by fusion, radioactive waste from fusion is expected to be safely managed within the type of facilities that are already used for storage and disposal of radioactive waste. The Government recognises that there would be some different storage and disposal implications for waste from fusion compared to fission, given that fusion will not produce the High Level Waste (HLW) arising from the spent fuel rods in fission.

The Government will continue to consider regulatory implications for fusion waste as fusion power plants are developed, and how any requirements for operators could be reflected in new guidance. Prototype facilities are expected to trial new materials, which may have varying waste implications. To enable such innovation to take place, the Government does not intend to introduce regulations or guidance prescribing set criteria such as disposal timeframes.[67]

Separately, the Nuclear Decommissioning Authority (NDA) has identified in its latest Strategy report[68] a number of strategic opportunities which would facilitate more effective decommissioning, including exploring the use of near surface disposal facilities for less hazardous ILW. Such approaches would also be applicable to fusion radioactive waste. To maximise the long-term potential of fusion around the world, the Government is considering whether subsequent generations of fusion power plants should be encouraged to only produce waste that could be disposed of safely in such facilities.

Decommissioning

Alongside these proposals on waste, the UK Government and the devolved administrations in Wales and Scotland are considering bringing forward proposals to update the 2004 policy statement on nuclear decommissioning. At this stage, the Government expects the same general principles to apply to the decommissioning of fusion power plants as currently applies to the decommissioning of nuclear facilities. For instance, there should be an emphasis on designing fusion power plants with radioactive waste management and decommissioning in mind from the outset, and, as with any energy generating power plant, a funded plan for decommissioning would be expected before any application for a development consent order.

In terms of the practicalities involved, the Government notes that decommissioning a fusion power plant would be materially different to a fission plant due to the presence of spent fuel in a fission plant. However, after de-fuelling (the removal of the spent fuel from a fission reactor), it is expected that the decommissioning of a fusion power plant would be broadly similar to fission.

Next Steps

The Government invites experts and the public to provide views on how they would expect fusion waste to be safely and sustainably managed. The Government will consider these views as well as the information provided by CoRWM and other fusion technical experts in developing its policy on the management of fusion waste. As noted previously, any new regulatory guidance for fusion developers would – where relevant – be expected to cover issues related to fusion waste.

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[67] Historically, UKAEA has aspired to be able to dispose (see Annex E) of all radioactive waste within 100 years, but this is not necessarily shared across the entire fusion industry.
[68] NDA (March 2021) NDA Strategy 2021 available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/973438/NDA_Strategy_2021_A.pdf

As fusion technology develops and the nature of the radioactive waste that would be produced by fusion power plants becomes clearer, the Government will continue to consider how radioactive waste arising from fusion plants can be managed effectively, learning from best international practice. This would form part of the proposed regular reviews of the regulatory framework no less than every 10 years (see page 67).

23. **What are your views on how radioactive waste from fusion should be safely and sustainably managed?**

24. **Do you believe that Government policy should reflect an expectation that radioactive waste from fusion can be disposed in near-surface disposal facilities? Please explain your response.**

25. **What are your views on how a fusion facility should be decommissioned?**

26. **How should these topics be covered in any guidance developed for the fusion regulatory framework?**

Safeguards

The term ‘safeguards’ refers in this context to the measures to verify that countries comply with their international obligations not to divert certain nuclear materials from civil nuclear (fission) programmes to manufacture nuclear weapons. As of 1 January 2021, ONR is responsible for the regulation of safeguards relating to fusion in the UK.

Tritium does not currently come under safeguards regulations (The Nuclear Safeguards (EU Exit) Regulation 2019).[69] The accounting for tritium in the UK is covered by the Nuclear Cooperation Agreement (NCA)[70] with Canada. This reflects the fact that the UK’s tritium supply is currently sourced from ‘CANDU’ fission reactors in Canada (see footnote 20 on page 25). The UK is only responsible for tritium accounting in the context of this NCA.

In future, fusion power plants will produce their own tritium once operational, though the initial tritium fuel to start the first fusion power plants is still expected to come from fission reactors (later plants are expected to be started with tritium produced in their predecessors). Tritium produced in the UK in this way would not be subject to this NCA or safeguards arrangements regulated by ONR but would still need to be accounted for to maintain compliance with other legislation for safety and security purposes: IRR 2017 requires duty holders to account of radioactive material and to prevent any reasonably foreseeable loss or theft.

[69] UK Government (2019). The Nuclear Safeguards (EU Exit) Regulations 2019. Available at https://www.legislation.gov.uk/uksi/2019/196/contents/made
[70] UK Government (2018). UK/Canada: Agreement for Cooperation in the Peaceful Uses of Nuclear Energy Available at https://www.gov.uk/government/publications/cs-canada-no12018-ukcanada-agreement-for-cooperation-in-the-peaceful-uses-of-nuclear-energy

Whilst tritium is not subject to safeguards regulation, there are possibly other radioactive materials related to fusion power plants that will. For example, there may be a need for depleted uranium in storing tritium.[71] This would need to be accounted for and reported to ONR in accordance with the Nuclear Safeguards (EU Exit) Regulations 2019. Operators holding this quantity of depleted uranium may apply to ONR to become a small holder of nuclear material, which allows reduced safeguards reporting requirements.

At this stage, the Government does not believe that any additional regulatory provisions would be needed on safeguards in relation to a fusion power plant for the UK to continue to comply with its international treaty obligations. The Government will however keep this under review. The Government is planning on the basis that the regulation of any additional safeguards arrangements that may need to be introduced for fusion to ensure continued compliance would be the responsibility of ONR as the competent authority.

27. Do you agree with the Government's proposals on safeguards for fusion? Please explain your response.

Export controls and technology licensing

Tritium production and the technology needed to handle tritium are defined as dual-use (they have both military and civilian uses) under the Nuclear Suppliers Group (NSG) guidelines.[72] [73] These guidelines ensure that trade of materials or technology for peaceful purposes does not contribute to the proliferation of nuclear weapons. Currently there is no fusion specific guidance for industry on what fusion technology will be subject to licensing or export controls.

In addition to nuclear-related export controls, potential future applications of fusion technology may make the exports subject to controls for being designed or useable in specific applications. These include both military power generation and dual-use technologies. Such controls would typically be agreed internationally through the Wassenaar Arrangement[74] which is responsible for sensitive military and related dual-use technologies.

The UK Government wants UK industry to export fusion technology around the world in coming decades. At this stage the Government does not expect there to be any specific policy changes around export controls related to this, though this will be kept under review. The Government will consider what guidance specific to fusion may be appropriate, to provide clear regulatory expectations and ensure that controls will be suitably robust to ensure the civil use of fusion technology. The Government will work with the regulators and relevant experts in developing any such guidance.

[71] Depleted uranium is fissionable but not fissile. This means it cannot sustain a chain reaction and therefore poses no danger of causing a nuclear accident. It would be stored remote from the area where fusion takes place and so is in no chance of being exposed to neutrons from fusion. The amount of depleted uranium-238 beds required to store the tritium is expected to be around 200 kg

[72] Nuclear Suppliers Group. Guidelines for transfers of nuclear-related dual-use equipment, materials, software, and related technology. Available at: https://www.nuclearsuppliersgroup.org/en/guidelines

[73] Any export of certain potentially sensitive fusion related technology may already be subject to export controls based on the intended end-use or concerns with a specific end-user under WMD End-Use or WMD Technical Assistance controls.

[74] More information on the Wassenaar Arrangement can be found here: https://www.wassenaar.org/

28. What should the Government consider in developing guidance for export controls and technology licensing?

5) Reviewing the UK's regulatory approach to fusion

The conclusions on fusion technology and hazard as set out in Chapter 2 should apply to all fusion prototype power plants expected to be developed in the UK in the next 20 years, such as the planned STEP facility. They would also apply to planned fusion prototypes around the world, though the regulatory implications would be specific to national regulatory frameworks.

As fusion facilities develop increasingly detailed engineering designs, choices in the design process that may affect the overall level of hazard of fusion power plants will become even clearer.

If compelling evidence is presented to the Government or regulators that shows prototype fusion power plants would in fact be far beyond the hazard profile of fusion R&D facilities and other comparable industrial facilities such as chemical plants or particle accelerators, the Government would re-visit the conclusions and proposals outlined in this consultation.

Regardless of whether this occurs or not, in view of the uncertainties involved, the Government will review the fusion regulatory framework **no less frequently than every ten years.** The Government plans to continue to do this until it is internationally recognised that fusion technology has reached maturity, which is not expected until the 2050s at the earliest.

The Government believes that this approach is an appropriate balance between the needs of providing certainty to fusion developers and the public and maintaining flexibility in the face of a developing technology.

29. Do you agree with this proposed approach for keeping the fusion regulatory framework under review? Please explain your response.

Implications for Devolution

The UK Government has concluded in this paper that the existing non-nuclear regulatory framework would be appropriate for a fusion power plant, and that a fusion power plant would not need to be on a nuclear site. Currently, the only major fusion experimental facilities in the UK are in England.

Nuclear regulation is reserved to the UK Government. Environmental protection is devolved to each administration in the UK with health and safety regulations reserved except in Northern Ireland. Planning is devolved to each administration except in the case of Wales where planning for facilities generating over 350 MW of energy is reserved.

The UK Government hopes that the Devolved Administrations would be supportive of fusion facilities being developed across in the UK in future. With that aim in mind, and in line with specific proposals in this paper regarding the regulation of fusion power plants in England, the UK Government has identified a number of issues that the Devolved Administrations and regulators may wish to consider ahead of any fusion power plant being developed in the UK outside of England. These include: the capability and capacity of (devolved) regulators to regulate fusion power plants; the case for tailored guidance (and whether any guidance developed in England could be used for this); and the suitability of existing planning regulations in Scotland, Wales and Northern Ireland for the planning consenting of a fusion power plant. The UK Government is ready to work with the Devolved Administrations on these issues as is appropriate.

In summary, the UK Government is keen for these proposals to apply across the UK to maximise the opportunities of fusion energy for the whole country, though some of the specific proposals detailed above would apply only to England. The Government hopes that the conclusions set out in this paper – such as the current "non-nuclear" regulatory framework being appropriate for fusion power plants – will be used by the Devolved Administrations in considering any changes to policies or regulations related to fusion that are devolved.

Summary Table of Proposals

The table overleaf provides a summary of the Government's proposals and the applicability of these to each part of the UK. It rates these proposals in order of importance, from a red rating - where inaction would effectively prevent the commercialisation of fusion in the UK - to a green rating - where no urgent action is required although there is a need for further policy consideration.

As detailed in Chapter 6 (International engagement), the UK wants to collaborate with other governments and international organisations to consider regulatory harmonisation and maximise the global benefits of fusion. As such, the table below also identifies the potential international applicability of the proposals in this paper.

Table 6 – Summary of the Government's Proposals

Topic and page number	Why is action necessary?	Relevant Legislation / Regulations	RAG rating of the impact of inaction on UK development of fusion energy	The Government's Proposals	Intended outcomes	Applicable to	Could the principles of the UK's proposals be applied internationally?
Regulatory Justification of Fusion (pg. 47)	Fusion energy production is not currently a "justified activity".	Justification of Practices Involving Ionising Radiation Regulations 2004		UKAEA's STEP programme should develop and submit an application for the operation of fusion power plants to be a justified activity, working with the wider fusion industry in doing so.	If approved by the Justifying Authority, fusion energy production becomes a justified practice, and therefore is a permissible use of ionising radiation in the UK.	UK	Yes – though justification decision is specific to UK, other countries could draw on UK approach in their own decision-making.
Fusion and the definition of a nuclear installation (pg. 48)	The existing legislative definition of "nuclear installation" was not developed with fusion in mind and could be clearer in whether or not it applies to fusion power plants, to remove the risk of inconsistency and disruption.	Nuclear Installations Act 1965 / Nuclear Installations Regulations 1971		The Government will legislate to confirm that fusion power plants would not be legally defined as nuclear installations.	Provide clarity on the overall regulatory regime for fusion power plants in the UK.	UK	Yes, underpinned by a globally agreed set of technical codes and standards for fusion – see chapter 6.
Planning process for a fusion power plant (pg. 49)	The currently assumed planning process for fusion power plants in England would be inefficient and make fusion an outlier compared to the planning process for other electricity producing facilities.	Planning Act 2008		The Government will develop a Fusion Policy Statement to align the planning process for fusion power plants with other nationally significant infrastructure projects and electricity producing facilities.	Establish a more efficient planning process for fusion power plants.	England and Wales	N/A – specific to UK
Fusion and Third Party Liabilities (pg. 50)	There is no existing requirement for a fusion power plant operator to hold insurance provisions that could sufficiently cover costs arising from accidents to guarantee third party claims can be met (although claims could still be brought).	Paris Convention (international treaty) The Nuclear Installations Act 1965 The Nuclear Installations (Prescribed Sites and Transport) Regulations 2018		The Government will consider whether and how to introduce an appropriate liability regime for fusion.	Make sure that third party costs arising from any fusion accident would be met by the fusion operator, and that the cost of the necessary insurance provisions is proportionate to the liabilities involved.	UK	Yes

Topic and page number	Why is action necessary?	Relevant Legislation / Regulations	RAG rating of the impact of inaction on UK development of fusion energy	The Government's Proposals	Intended outcomes	Applicable to	Could the principles of the UK's proposals be applied internationally?
Regulatory Engagement (pg. 56)	There is no formal process for additional engagement in the design phase between fusion developers and regulators, nor specific guidance to ensure fusion developers' understanding of regulatory obligations.	See Chapter 3 for the main environmental and health and safety regulations that apply to fusion		Regulators should consider options for formalised engagement processes and guidance specific to fusion power plants, using the Government's proposed definition on page 56 to identify the facilities in scope.	Ensure regulatory compliance, build technical capability of regulators and reduce the costs of commercialising fusion technology in the UK.	England (though devolved regulators may also choose to consider similar measures)	Yes, underpinned by a globally agreed set of technical codes and standards for fusion – see Chapter 6
Public Engagement (pg. 58)	While there are multiple opportunities for the public to engage during the regulatory process, there is no explicit obligation for fusion power plant developers to engage with the public about their designs or facilities to enhance transparency.			Regulators should consider whether there should be additional opportunities for the public to be consulted during the regulatory process. Fusion developers should ensure that they engage fully and transparently with the public at the appropriate stages.	Maximise public confidence in the regulatory framework for fusion.	UK	Yes
Cyber Security (pg. 54)	Fusion power plant developers would not be legally required to adhere to current cyber security regulations for energy infrastructure or nuclear installations, potentially leaving operators vulnerable to cyber attacks.	Network and Information Systems Regulations 2018 (NIS) / Nuclear Industries Security Regulations 2003 (NISR)		The Government will consider what would be proportionate and appropriate cyber security regulations for a fusion power plant.	Ensure the safe and secure operation of a fusion power plant, in line with existing cyber security policy around energy infrastructure.	UK	Yes
Nuclear safeguards (preventing state diversion of source or special fissionable material for military purposes) (pg. 65)	Tritium is not defined as a source or special fissionable material by the IAEA and is not covered by nuclear safeguards. Tritium sourced from Canada is covered under UK-Canada nuclear cooperation agreement. This would not apply to tritium produced in future fusion power plants. There also may be other safeguards implications beyond tritium as fusion technology develops.	UK-Canada Nuclear Cooperation Agreement (NCA)		The Government will keep safeguards in the context of fusion under review, with the planning assumption that the ONR would be responsible.	Uphold UK compliance with international treaty obligations in respect of safeguards	Great Britain	N/A – nuclear safeguards already determined by international frameworks.

Topic and page number	Why is action necessary?	Relevant Legislation / Regulations	RAG rating of the impact of inaction on UK development of fusion energy	The Government's Proposals	Intended outcomes	Applicable to	Could the principles of the UK's proposals be applied internationally?
Radioactive Waste Management and Decommissioning for Fusion (pg. 63)	Though there would be no High Level Waste produced by fusion power plants, there is uncertainty on how much waste will be produced and what classification that waste would fall under. However, no major changes are directly required to existing policies or regulations on waste or decommissioning.	n/a		The Government will keep policy on fusion waste and decommissioning under review as fusion develops.	In line with existing policies, ensure that radioactive waste from fusion is minimised and handled safely and in proportion to the hazards involved, and ensure that the decommissioning of fusion power plants is undertaken as safely and as efficiently as possible.	England	Yes
Export controls (pg. 66)	No set guidance or framework for fusion technology generally, though there are existing provisions for particular substances (e.g. tritium) and materials.	Nuclear Suppliers Group (NSG) guidelines		The Government will work with experts, regulators and other organisations to consider whether further guidance should be developed.	Enable UK industry to export fusion technology and promote best practice to international partners.	UK	Yes – export controls require international collaboration.
Regulatory Capacity and Capability (pg. 58)	Over the coming decades, regulators would need to build technical capability to regulate fusion power plants.	n/a		Regulators should monitor the growth of the sector and increase capability accordingly, bringing in specialist expertise as required.	Ensure regulators have the technical capability to regulate fusion power plant effectively	England (though devolved regulators may choose to consider similar measures)	Yes – UK regulatory expertise in fusion could be offered to support regulator capability growth in other countries.

30. Do you believe there is anything else the Government should consider with regard to fusion energy regulation?

5. Domestic engagement

Industry

This consultation represents an important stage in the Government's engagement with the fusion industry. Chapter 4 proposes new formalised engagement between regulators and fusion developers during the design stage of a fusion power plant. It is important that industry engages with the Government both through this consultation and subsequently with the regulators during the development of any new processes. After this consultation, the Government will continue to engage with industry and regulators as fusion technology and power plant designs mature.

Public

In September 2020, the BEIS Public Attitudes Tracker[75] contained questions on fusion energy for the first time. As shown in figure 16, 50% of the public as surveyed had at least some awareness of fusion energy but 46% of people had never heard of it. Awareness increased with decreasing age, from 40% in people aged 65+, to 69% in those aged 16-24.

Furthermore, the same survey found a third of people (34%) supported the UK developing fusion technology. Just 5% of people opposed it while the rest had no opinion.

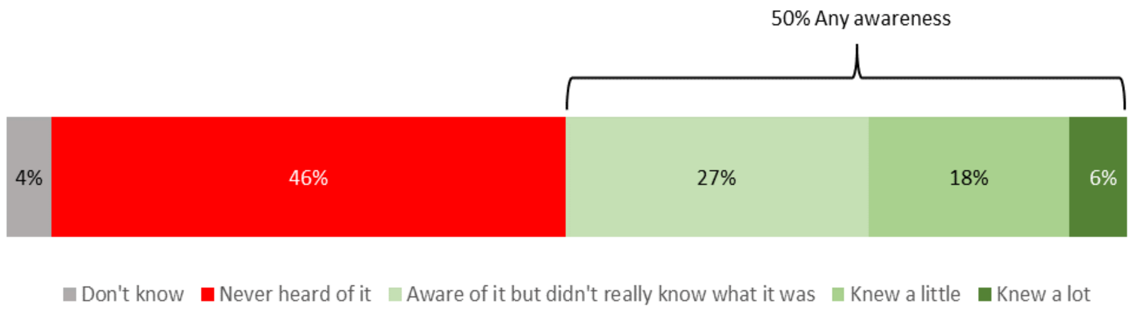

Figure 17 – Public Attitudes Tracker, September 2020 – Responses to the question: "Before today, how much did you know about fusion energy?"

As shown in figure 18, those who had greater knowledge of fusion energy were more likely to support than oppose it. Of those that know a little about fusion, 65% support. Of those that know a lot about fusion, 83% support. This indicates the importance of public information to public acceptance.

[75] UK Government (2020). BEIS Public Attitudes Tracker: Wave 35. Available at https://www.gov.uk/government/statistics/beis-public-attitudes-tracker-wave-35

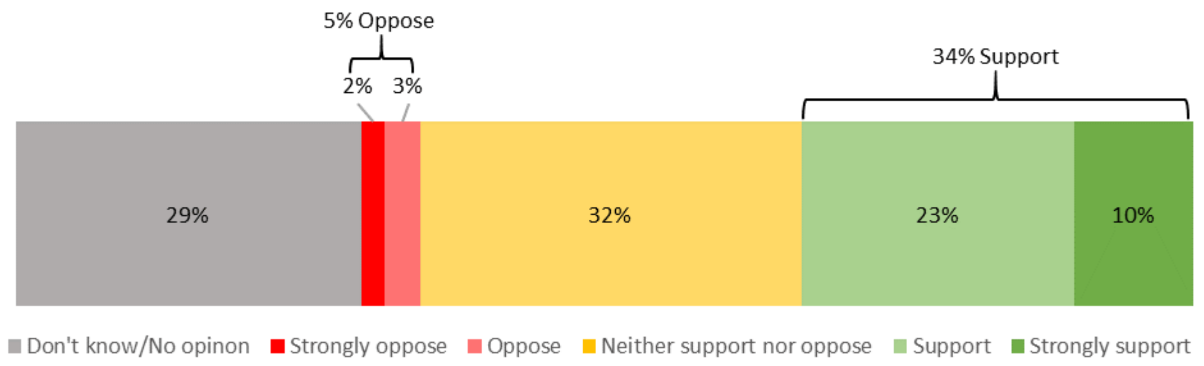

Figure 18 – Public Attitudes Tracker, September 2020 – Responses to the question: "From what you know, or have heard about fusion energy, do you support or oppose the UK developing this technology?"

Although these are only the results from a single exercise, these findings suggest there is a need for the Government to help build public understanding of fusion energy, particularly in view of the ongoing public investment into fusion R&D programmes in the UK. Crucially, if fusion is to be commercialised successfully in the UK, it is essential that the public: understands what fusion is; supports the deployment of fusion energy technology in the UK; and trusts the UK's regulatory framework for fusion.

BEIS will carry out further Public Attitudes Trackers with questions on fusion in the future to develop its understanding of public perceptions of fusion. At this stage, in response to this paper, the Government encourages views from the public on fusion more generally. There are broader questions aimed at members of the public immediately below, though all views, comments and submissions will be welcomed. Given that these questions are about fusion more broadly, respondents may also wish to refer to the Government's Fusion Strategy, published separately alongside this paper.[76]

In terms of the regulatory framework, Chapter 4 explained how the public would be able to engage during the regulatory process. The Government hopes that, as fusion energy technology moves towards commercialisation, the UK public will be motivated to engage fully, so that fusion is taken forward in the UK in a way that is fully reflective of the public's views and interests.

[76] UK Government (2021). The UK Government's Fusion Strategy. Available at: https://www.gov.uk/government/publications/towards-fusion-energy-the-uk-fusion-strategy

31. Before today, how much did you know about fusion energy?

A. Knew a lot

B. Knew a little

C. Aware of it but didn't really know what it was

D. Never heard of it

E. Don't know

32. From what you know, or have heard about fusion energy, do you support or oppose the UK developing this technology?

A. Don't know

B. Strongly oppose

C. Oppose

D. Neither support nor oppose

E. Support

F. Strongly support

33. What is your level of knowledge about fusion after reading this paper?

A. Now know a lot

B. Now know a little

C. Now aware of it but still don't really know what it is

D. Never heard of it

E. Don't know

34. What is your level of support for the development of fusion energy technology in the UK after reading this paper?

A. Don't know

B. Strongly oppose

C. Oppose

D. Neither support nor oppose

E. Support

F. Strongly support

6. International engagement

The Government wants to make the UK a science superpower. The UK's fusion R&D programmes will play a role in realising that objective. The Government hopes that the proposals set out in this paper for a proportionate and transparent regulatory framework for fusion energy will also work towards that goal. We want the UK's pro-innovation approach to represent global best practice on fusion regulation, encouraging other nations to follow in our footsteps.

The UK welcomes comments on the proposals in this paper from governments, research organisations, fusion developers, regulators and other interested parties from around the world.

Regulatory harmonisation will be essential for the establishment of an international fusion energy market, allowing the world to realise the benefits of commercial fusion energy. To that end, the UK will engage internationally, collaborating with partner nations and international organisations such as the International Atomic Energy Agency (IAEA) to develop common codes and standards for fusion and harmonise regulatory approaches where appropriate. This will help to reduce barriers to global trade in fusion technology while ensuring its safe and proper use.

In many other countries, fusion is regulated by the same regulator that regulates nuclear (fission) power plants. This is because in many countries lower hazard radiological sites and fission sites are regulated by the same regulator. In the UK, lower hazard radiological sites are separate in legislation to fission and are regulated by EA and HSE. This difference in approach is not viewed as a barrier in any way, as common international standards for fusion technologies can be established which are not dependent on domestic regulatory frameworks.

The UK is already involved in a number of international fora looking at fusion regulatory issues. The IAEA is seeking to foster collaboration on fusion and develop a set of common codes and standards – the UK is working with the IAEA and assisting in developing shared knowledge around the hazards of fusion. The Nuclear Energy Agency (NEA) is considering whether fusion should be brought within the scope of the Paris Convention, which sets liability requirements for fission, with the UK providing technical information to inform those discussions (see page 51). In these and other fora the UK will continue to advocate for evidence-driven, pro-innovation and proportionate regulation that effectively upholds safety and security. The UK is ready to consider recommendations arising from these international expert organisations for implementation in the UK.

The UK also participates in international expert peer reviews to share its regulatory experience and ensure compliance with international standards. For example, in 2019 the IAEA Integrated Regulatory Review Service[77] (IRRS) mission reviewed the existing UK framework for nuclear, radiation, radioactive waste and transport safety, and provided a number of recommendations on how this could be enhanced.[78] Work is well underway to address the mission team's findings in advance of the follow up mission, which will take place in early 2024.

The Government would like to identify new opportunities to engage and collaborate internationally on fusion regulation, either bilaterally or multilaterally. The UK stands ready to work on this subject with partner nations and international organisations, with academia and technical experts, and with businesses and industry groups, in order to maximise the global potential of fusion energy.

35. What is your country's / organisation's planned approach to regulating fusion energy?

Please provide appropriate contact details to enable further discussion and collaboration with the UK Government on this subject (this information will be treated confidentially).

[77] The IRRS provides a peer review of a State's national, legal and governmental framework and regulatory infrastructure for safety against IAEA safety standards.
[78] UK Government (2019). Integrated Regulatory Review Service (IRRS): 2019 mission report. Available at: https://www.gov.uk/government/publications/nuclear-and-radiological-safety-review-of-the-uk-framework-2019

7. Conclusion and next steps

This paper represents a critical stage in the development of fusion energy technology in the UK. It presents for the first time important conclusions and planning assumptions that would underpin the regulation of fusion energy in the coming decades.

The Government believes that this paper represents the first time that any government around the world has set out its regulatory intentions for fusion energy and the relevant technical information that underpins this. The Government hopes that this paper will serve to contribute towards global understanding of fusion and how it could be best regulated.

The Government will consider responses received during the consultation period ending 24 December 2021 and will publish its response in early 2022, summarising the received responses and setting out the actions that will be taken.

Consultation questions

1. **Are there other critical regulatory areas that the government should address when considering the regulatory framework for fusion energy in the UK? Please explain what these are and why they are important.**

2. **Do you agree with the Government's conclusions regarding the expected hazards of future fusion power plants? Please provide as much evidence as possible to support your view.**

3. **Do you agree with the proposal to maintain the existing regulatory approach? Please explain your response.**

4. **Do you agree that IRR 2017 and EPR 2016 provide for the consenting and permitting (respectively) of fusion power plants in a way that is proportionate and appropriate? Please explain your response.**

5. **Do you think that fusion power plants should be considered to be nuclear installations under the terms of the Nuclear Installations Act 1965 and so be brought within the remit of the nuclear licensing framework led by ONR, either at this stage or in the foreseeable future? Please explain your response.**

6. **What are your views on the Government's proposals in relation to the regulatory justification of fusion?**

7. **Do you agree that a legislative approach is appropriate for clarifying that a nuclear site license would not be needed for fusion power plants? Please explain your response.**

8. **Do you agree with the proposal to establish a Fusion NPS based on the planning assumptions outlined above? Please explain your response.**

9. **What other issues should a Fusion NPS address?**

10. **Do you believe that a third party liability regime is required for fusion? Please explain your response.**

11. **What are your views on the principles and issues regarding third party liability set out in this paper?**

12. **What issues in addition to those described in this paper should any fusion third party liability regime address?**

13. **How can the Government promote the development of suitable commercial fusion insurance?**

14. Do you agree that prototype fusion power plants should be subject to cyber security regulations, regardless of their energy generating capacity? Please explain your response.

15. What in your view should cyber security regulations for fusion cover?

16. Do you agree that the proposed definition of fusion energy facilities that should be in scope for enhanced regulatory engagement and new guidance is appropriate? Please explain your response.

17. Do you agree that there should be formal engagement in the design process between fusion developers and regulator(s)? Please explain your response.

18. What are your views on how such engagement should work?

19. Do you agree that additional guidance should be developed on fusion energy regulation? Please explain your response. If you agree, what should guidance cover?

20. Do you believe that there should be greater opportunity for the public to engage in the regulatory process for fusion? If yes, what are your suggestions for how this could be achieved?

21. How do you think regulators can best build technical capability around emerging technologies such as fusion?

22. What are your views on how the technical expertise of UKAEA could best be used to support the development of a regulatory framework for fusion energy in the UK and around the world?

23. What are your views on how radioactive waste from fusion should be safely and sustainably managed?

24. Do you believe that Government policy should reflect an expectation that radioactive waste from fusion can be disposed in near-surface disposal facilities? Please explain your response.

25. What are your views on how a fusion facility should be decommissioned?

26. How should these topics be covered in any guidance developed for the fusion regulatory framework?

27. Do you agree with the Government's proposals on safeguards for fusion? Please explain your response.

28. What should the Government consider in developing guidance for export controls and technology licensing?

29. Do you agree with this proposed approach for keeping the fusion regulatory framework under review? Please explain your response.

30. Do you believe there is anything else the Government should consider in regard to fusion energy regulation?

31. Before today, how much did you know about fusion energy?

A. Knew a lot

B. Knew a little

C. Aware of it but didn't really know what it was

D. Never heard of it

E. Don't know

32. From what you know, or have heard about fusion energy, do you support or oppose the UK developing this technology?

A. Don't know

B. Strongly oppose

C. Oppose

D. Neither support nor oppose

E. Support

F. Strongly support

33. What is your level of knowledge about fusion after reading this paper?

A. Knew a lot

B. Knew a little

C. Aware of it but didn't really know what it was

D. Never heard of it

E. Don't know

34. What is your level of support for the development of fusion energy technology in the UK after reading this paper?

A. Don't know

B. Strongly oppose

C. Oppose

D. Neither support nor oppose

E. Support

F. Strongly support

35. What is your country's / organisation's planned approach to regulating fusion energy?

Please provide appropriate contact details to enable further discussion and collaboration with the UK Government on this subject (this information will be treated confidentially).

Annexes

Annex A – List of participants in the development of this paper

Annex B – Background for BEIS' regulatory strategy

Annex C – Background for regulator strategies

Annex D – Further information on radioactive waste management in the UK

Annex E – Extracts of Public Health England guidance - Ionising radiation: dose comparisons

Annex F – Hazards of a fusion power plant during its lifetime

Annex G – Regulatory experience of the Environment Agency and the Health and Safety Executive

Annex H – List of figures

Annex I – List of tables

Annex A – List of participants in the development of this paper

In developing this consultation, the Government has engaged with:

Regulators:

Health and Safety Executive

Environment Agency

Office for Nuclear Regulation

Scottish Environment Protection Agency

Natural Resources Wales

Devolved Administrations:

Scottish Government

Welsh Government

Department for Agriculture, Environment and Rural Affairs (Northern Ireland)

Other Technical, Fusion and Nuclear Experts:

UKAEA's Fusion Safety Authority[79]

Committee on Radioactive Waste Management (CoRWM)[80]

Regulatory Horizons Council

Nuclear Risk Insurers – a nuclear insurer

ELINI – a nuclear insurer

Tim Stone – Chairman of the Nuclear Industry Association

Fiona Reilly – Non-Executive Director of the Nuclear Industry Association

[79] See page 59.

[80] CoRWM produced a short paper for BEIS on potential ways forward for the management of fusion waste. CoRWM have agreed to produce a position paper for BEIS' consideration during policy development.

Annex B – Background for BEIS' regulatory strategy

In 2019, the Department of Business, Energy and Industrial Strategy (BEIS) published its White Paper on Regulation for the Fourth Industrial Revolution[81] announcing a plan to maintain the UK's world-leading regulatory system during rapid technological change to support new technologies, uphold safeguards for people and the environment, and engage the public. It identifies some key principles the UK will adopt to ensure regulation is fit for purpose:

- We need to be on the front foot in reforming regulation in response to technological innovation
- We need to ensure that our regulatory system is sufficiently flexible and outcomes-focused to enable innovation to thrive
- We need to support innovators to navigate the regulatory landscape and comply with regulation
- We need to build dialogue with society and industry on how technological innovation should be regulated

BEIS has conducted research into regulatory approaches to facilitate, support and enable innovation[82] which found compelling evidence that by supporting business-led innovation, regulators can build knowledge and expertise around types of emerging innovations and their potential impacts. This improved knowledge allowed regulators to adapt or develop new regulatory frameworks that are more robust, support innovation and improved quality of service when providing advice.

The UK is a member of the 'Agile Nations', an inter-Governmental network foster co-operation on rulemaking, with a mission to make it easier for businesses within their jurisdictions to introduce and scale innovations across their markets while upholding protections for citizens and the environment. In 2020, the World Economic Forum launched a Toolkit for Regulators on Agile Regulation for the Fourth Industrial Revolution[83] setting out key foundations for good regulatory practice of openness, proportionality and fairness.

In May 2021, the National Audit Office published its 'Principles of effective regulation'[84] which sets out how regulation can continue to protect and benefit people, business and the environment and to support economic growth by keeping pace with developments in technology.

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[81] UK Government (2019). Regulation for the Fourth Industrial Revolution. Available at https://www.gov.uk/Government/publications/regulation-for-the-fourth-industrial-revolution

[82] UK Government (2020). Regulator approaches to facilitate, support and enable innovation. Available at https://www.gov.uk/Government/publications/regulator-approaches-to-facilitate-support-and-enable-innovation

[83] World Economic Forum. Agile Regulation for the Fourth Industrial Revolution: A Toolkit for Regulators. Available at https://www.weforum.org/about/agile-regulation-for-the-fourth-industrial-revolution-a-toolkit-for-regulators/

[84] National Audit Office (2021). Principles of effective regulation. Available at https://www.nao.org.uk/report/principles-of-effective-regulation/

In July 2021 the Better Regulation Executive (BRE) published a consultation on the UK's Better Regulation Framework to ensure it remains fit for purpose.[85] This framework aims to unleash innovation, propel start-up growth and level up every corner of the UK through the following five principles:

- A sovereign approach: the UK will use its freedoms to take a tailored approach to setting rules in a way that boosts growth and benefits the British people
- Leading from the front: we will act nimbly to support the development of new technologies
- Proportionality: we will use non-regulatory options where we can, while acting decisively to put in place strong rules where they are needed
- Recognising what works: regulations will be thoroughly analysed to ensure they work in the real world
- Setting high standards at home and globally: we will set high standards at home and engage in robust regulatory diplomacy across the world, leading in multilateral settings, influencing the decisions of others and helping to solve problems that require a global approach

[85] UK Government (2021). Reforming the framework for better regulation. Available at: https://www.gov.uk/government/consultations/reforming-the-framework-for-better-regulation

Annex C – Background for regulator strategies

The Regulators’ Code sets the standard on how all regulators in the UK should operate to reduce regulatory burdens and support business growth, by adhering to principles of being proportionate, consistent, accountable, transparent and targeted. This provides a flexible, principle-based framework for regulatory delivery. The specific requirements of this code are that regulators should:

- Carry out activities in a way that supports those they regulate to comply and grow
- Provide simple and straightforward ways to communication with those they regulate
- Base their regulatory activities on risk
- Share information about compliance and risk
- Ensure clear information, guidance and advice is available
- Ensure their approach to their regulatory activities is transparent

The Environment Agency (EA) have published “Regulating for people, the environment and growth” which sets out their regulatory principles and ways of working. The EA outline how their framework aligns with the principles of the Regulators’ Code. The principle of being customer-focused is included which is to support business by providing clear guidance and advice as well as being open to new ideas and proposals, supporting innovation and sustainable growth.

For regulation of radioactive substances, the EA has set out fundamental principles to ensure effective regulation. Most importantly, these are that radioactive substances are managed to ensure: an optimal level of protection to human health and the environment; that regulation is transparent, accountable, consistent and targeted; that the best scientific knowledge is used when making decisions; and that decisions should take into account uncertainties. As fusion is a developing technology, being able to deal with uncertainty will be a particularly important part of a regulatory framework.

The Health and Safety Executive (HSE)’s regulatory activity is conducted in line with the principles of the Regulators’ Code – targeted, proportionate, transparent, consistent and accountable, having due regard to economic growth. The goal-setting and outcome approach of the HSE allows flexibility in its regulatory options and decision-making to tailor approaches to hazard and associated risk.

The Health and Safety at Work Act 1974 etc. (HSWA) provides for a range of regulatory instruments. It allows for modernising health and safety law according to a particular structure. HSE’s policy goal is to ensure that regulations, like HSWA itself, should, so far as possible, express general duties, principles and goals, with subordinate detail set out in guidance. This architecture is designed to keep the need for intervention by the regulator to a minimum and has allowed HSE to regulate proportionately new and emerging sectors such as biotechnology, nanotechnology and green energy.

HSE uses horizon scanning, knowledge-sharing and foresight activities to anticipate and keep pace with change to anticipate health and safety challenges so that the HSE can continue to regulate proportionately and effectively. As mentioned, fusion is a developing technology, so keeping pace with change is crucial for a regulator.

The Office for Nuclear Regulation (ONR) currently have a regulatory role in transport and safeguards for radioactive material involved in the fusion process. Like HSE and EA, they adopt good regulatory principles in line with the Regulators' Code for enabling regulations. These principles are outlined in "Holding to Account and Influencing Improvements - Enabling regulation in practice",[86] and show how the ONR's outcome-focused regulation can apply across the nuclear industry to achieve effective regulation of safety and nuclear security, and how their approach can be adapted as new and developing technologies develop. In "Approach to regulating innovation",[87] ONR sets out how it can adopt a more agile approach to regulation through practices and behaviours, which can support innovation and meet the Government's challenges set out in its White Paper 'Regulation for the Fourth Industrial Revolution'.

[86] ONR (2018). Explaining the principles of enabling regulation. Available at https://news.onr.org.uk/2018/03/new-guide-explains-principles-of-enabling-regulation//
[87] ONR (2020). Approach to Regulating Innovation Available at: https://news.onr.org.uk/2020/09/approach-to-regulating-innovation/

Annex D – Further information on radioactive waste management in the UK

The Strategy for Hazardous Waste Management[88] in England is underpinned by the waste hierarchy which sets out the principle of adopting options for managing waste that start with those that have least impact on the environment. The waste hierarchy will apply to all waste from fusion regardless of whether it is radioactive.

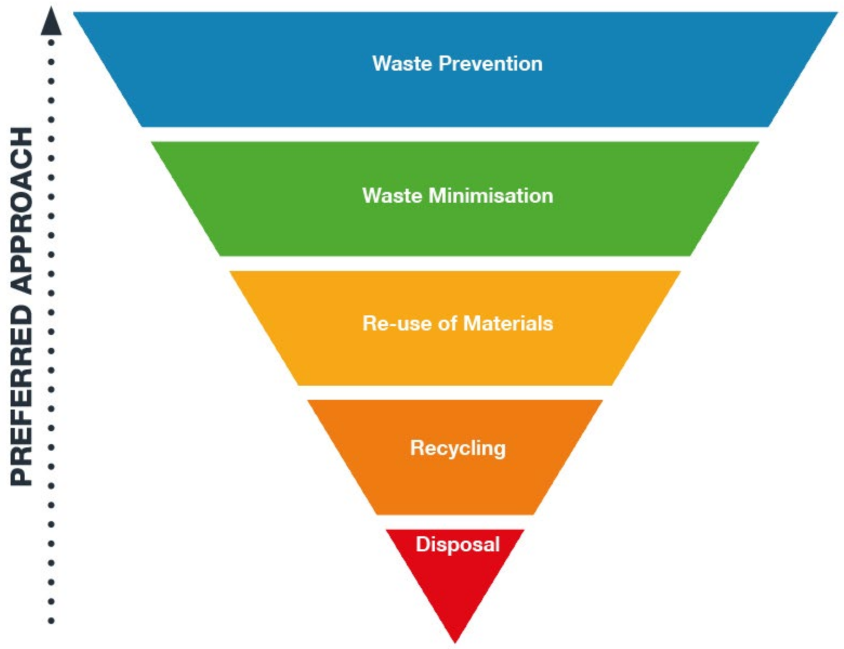

Figure 19 – The UK waste hierarchy[89]

As described in Chapter 2, some radioactive waste from fusion will require specialist disposal. In the UK there is a range of disposal facilities available and planned for radioactive waste from both the nuclear and non-nuclear sectors. The disposal facilities range from those that accept the most hazardous radioactive waste that needs to be isolated and contained for many hundreds of thousands of years, to facilities where no special controls are necessary, suitable for less hazardous radioactive waste.

The disposal options currently available to waste producers include:

- landfill sites for the least hazardous Low Level Waste (LLW);
- specialised near surface disposal facilities for LLW that is not suitable for disposal at municipal or permitted landfill sites.

[88] UK Government (2019). Radioactive Waste Strategy September 2019. Available at https://www.gov.uk/government/consultations/nda-radioactive-waste-management-strategy/outcome/radioactive-waste-strategy-september-2019

[89] The waste hierarchy applies across the UK. Each nation is the UK has developed their own waste management strategy underpinned by the waste hierarchy.

In future more disposal capacity will be needed for the management of radioactive waste across the nuclear, non-nuclear, oil and gas industries, as well as fusion. The UK Government and the Welsh Government have already set out processes for identifying a suitable location for a geological disposal facility (GDF)[90] in either England or Wales. More near surface disposal facilities, similar to the LLWR, could also be developed across the UK for the disposal of ILW.

Consideration will need to be given to the treatment, storage and disposal requirements for waste from fusion power plants that are expected to be developed in the UK. This should reflect the current uncertainties around the nature and quantities of this waste.

Decay storage

Decay storage enables waste producers to take advantage of radioactive decay to allow a specified retrieval or treatment step, or to allow a change in disposal route. This management step can occur at the outset of packaging for storage, or it can be a management step that is selected after a period of interim storage.

Disposal

Solid radioactive waste can range from waste that can be safely disposed to conventional landfill sites, to items that need to be isolated and contained deep underground in a highly engineered disposal facility. It is the UK's policy to make the best practicable use of resources, by encouraging the disposal of radioactive waste to facilities designed to provide the isolation and containment of radioactive waste appropriate to the hazard posed by that waste, so that people and the environment are protected.

The UK's policy is to enable and encourage waste producers and waste owners to dispose of their radioactive waste in an optimal manner, that takes account of the radioactive and non-radioactive properties of the waste. Waste producers should consider the properties of the waste and the waste acceptance criteria for disposal facilities to enable them to choose the optimal disposal route for their waste.

[90] GDFs are specialist facilities up to 1 km underground used to dispose of the most hazardous radioactive waste inside a suitable rock volume, to ensure that no harmful quantities of radioactivity ever reach the surface environment.

Waste Classification

Table 7 – Waste classification and definitions[91]

Waste Classification	Definition
High Level Waste	Waste in which the temperature may rise significantly as a result of its radioactivity
Intermediate Level Waste	Waste exceeding the upper boundaries for low level waste, but which does not generate sufficient heat
Low Level Waste	Wastes having a radioactive content not exceeding 4 GBq per tonne of alpha activity or 12 GBq per tonne of beta or gamma activity

[91] UK Government (2019). Radioactive waste strategy September 2019. Available at: https://www.gov.uk/government/consultations/nda-radioactive-waste-management-strategy/outcome/radioactive-waste-strategy-september-2019#background

Annex E – Extracts of Public Health England guidance - Ionising radiation: dose comparisons

The health effects of ionising radiation depend on the dose received. In most cases, the risks to health are low, and ionising radiation is in fact widely used for medical purposes. However, low doses do increase the risk of cancer later in life, while very high doses can be fatal.

In the UK, Public Health England has calculated that on average people are exposed to about 2.7 millisieverts (mSv) of radiation a year. A millisievert is a measure of radiation dose which accounts for the fact that ionising radiation can affect different parts of the body to differing degrees. The millisievert dose also allows for the different effects of different types of radiation, x-rays, gamma rays, neutrons, alpha particles and beta particles.

The 2.7 mSv dose that people in the UK are exposed to comes from a number of sources. Many building materials contain low degrees of natural radioactivity and radon gas seeps from the ground into all buildings, so the largest exposure is to naturally occurring radiation in homes and workplaces. There are also significant contributions from naturally occurring radioactivity in food and from medical exposures.

Table 8 – Ionising radiation dose comparison[92]

Source of exposure	Dose
Dental x-ray	0.005 mSv
100g of Brazil nuts	0.01 mSv
Chest x-ray	0.014 mSv
Transatlantic flight	0.08 mSv
Nuclear power station worker average annual occupational exposure (2010)	0.18 mSv
UK annual average radon dose	1.3 mSv
CT scan of the head	1.4 mSv

[92] UK Government (2011). Ionising radiation: dose comparisons. Available at https://www.gov.uk/Government/publications/ionising-radiation-dose-comparisons/ionising-radiation-dose-comparisons

Source of exposure	Dose
UK average annual radiation dose	2.7 mSv
USA average annual radiation dose	6.2 mSv
CT scan of the chest	6.6 mSv
Average annual radon dose to people in Cornwall	6.9 mSv
CT scan of the whole spine	10 mSv
Annual exposure limit for nuclear industry employees	20 mSv
Level at which changes in blood cells can be readily observed	100 mSv
Acute radiation effects including nausea and a reduction in white blood cell count	1000 mSv
Dose of radiation which would kill about half of those receiving it in a month	5000 mSv

Annex F – Hazards of a fusion power plant during its lifetime

Table 9 – The different stages of a fusion power plants and the main hazards at each stage

Stage of a fusion power plant's lifetime	Major hazards
Design	No major hazards
Development	No major hazards
Construction	Industrial hazards Potential handling of beryllium, lithium and lead
Pre-operation	Handling of tritium
Operation	Non-radiological hazards Potential for an accident scenario Potential use of beryllium, lithium and lead Handling of tritium and activated dust Management of activated and contaminated structural components
Closure	Radioactive waste Activated dust

Design – There are no major hazards expected in the design process.

Development – There are no major hazards expected in the developments of designs.

Construction – Hazards during construction are expected to be similar to those occurred in any large infrastructure project. Fusion power plants will use large lithium blankets to breed tritium so there will be additional handling of lithium compared to JET.

Pre-operation – Tritium will be handled and stored but not used for fusion.

Operation – During operations, the industrial hazards outlined in chapter 2 will be present including the use of high voltages, cryogenics, electromagnetic fields, microwaves and lasers. This will also be when a severe accident scenario could hypothetically result in an offsite release of tritium or activated dust. Breeding blankets will produce tritium and other in-vessel components will become activated, both of which will need to be safely handled.

Closure – Activated dust is expected to be removed from the vacuum vessel during operations and some activated large components will be also removed. However, after final closure of the plant is when the highest amount of radioactive waste is expected to materialise largely from the decommissioning of major components and from structural and other materials. Fusion operations will have ceased, so the waste would involve the most significant hazard.

Annex G – Regulatory experience of the Environment Agency and the Health and Safety Executive

The Environment Agency (EA) and the Health and Safety Executive (HSE) have decades of experience effectively regulating extremely hazardous and dangerous substances using the Control of Major Accident Hazards Regulations (COMAH) regime. This regulatory regime aims to prevent and limit the consequences of major accidents at approximately 1000 establishments which use or store significant quantities of dangerous substances, such as oil products, natural gas, chemicals or explosives. The EA and HSE are the joint Competent Authority on these sites. Examples of the type of sites EA and HSE regulate can be found below.

Inorganic Chemicals

The EA and HSE regulate a number of inorganic chemical installations, including the Runcorn Membrane Chlorine Plant (MCP). The MCP has been designed to produce circa 500,000 tonnes of chlorine per year. Chlorine, together with the other hazardous products (caustic soda, sodium hypochlorite and hydrogen) from the process, is used in the water industry and for other industrial processes. EA regulation addresses significant issues associated with protecting people and the environment, including air quality (e.g. chlorine, hydrogen); protection of soil and groundwater; water quality (e.g. brine, available chlorine, bisulphite) and waste management. This also covers the management of elemental mercury and mercury containing wastes arising from the decommissioning/demolition of the redundant chlor-alkali process on-site.

Refineries

The EA and HSE regulate the big four oil refineries in England (Philips 66 – Humberside; Total SA – Lindsey; Essar – Stanlow; Esso – Fawley). Together these complex and physically extensive installations produce around 50 million tonnes of petroleum products each year. EA regulation addresses significant environmental and health issues including air quality (e.g. sulphur dioxides, NOx (nitrogen oxides), Volatile Organic Compounds); soil and groundwater (e.g. hydrocarbons and metals); water quality (e.g. metals) and waste management.

Preparing for the hydrogen economy

EA technical support contractors are developing the UK Best Available Techniques (BAT) Guidance for large scale hydrogen production from methane with carbon capture and storage (CCS), and they expect a permit application this year for the Stanlow Refinery which is receiving phased BEIS funding as part of the HyNet decarbonisation cluster project competition. They are also supporting other UK industrial clusters, including Humber, Tees Valley, and South Wales where they have plans for hydrogen production at similar scale as part of their Net Zero ambitions.

Integrated Regulatory Review Service

The Integrated Regulatory Review Service (IRRS) conducted a review into the UK's regulatory framework for nuclear and radiation safety against the International Atomic Energy Agency (IAEA) safety standards. As noted in Chapter 6, this review concluded that both EA and HSE have the capability for activities that they currently regulate and are capable of building capability for the future.

The review also described how EA and HSE work together to ensure risk-based, proportionate regulation, with joint inspections, regular discussions and interactions to share knowledge; and the memorandum of understanding between EA and HSE which covers working together practices. The IRRS review pointed to the regulation by EA and HSE of large-scale industrial irradiators which use very large quantities of cobalt-60 (approximately 10^{15} Bq of activity) as an example of good working practice.

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Figure 14 – Illustration of current regulatory process and key

Figure 15 – Illustration of current regulatory process and key

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Figure 17 – Public Attitudes Tracker, September 2020 – Responses to the question: "Before today, how much did you know about fusion energy?"

Figure 18 – Public Attitudes Tracker, September 2020 – Responses to the question: "From what you know, or have heard about fusion energy, do you support or oppose the UK developing this technology?"

Figure 19 – The UK waste hierarchy

Annex I – List of tables

Table 1 – Summary of worst-case accident scenario analysis

Table 2 – Summary of worst-case hypothetical scenario

Table 3 – The principal regulations as currently applicable to fusion R&D in England and the regulatory body responsible for enforcing them

Table 4 – Examples of current practices involving ionising radiation that are justified

Table 5 – Quantities of tritium specified in NIR 2018 under which sites are classified as low-level

Table 6 – Summary of the Government's Proposals

Table 7 – Waste classification and definitions

Table 8 – Ionising radiation dose comparison

Table 9 – The different stages of a fusion power plants and the main hazards at each stage

This consultation is available from: https://www.gov.uk/government/consultations/towards-fusion-energy-proposals-for-a-regulatory-framework

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