Department for
Business, Energy
& Industrial Strategy

Towards Fusion Energy

The UK Government's response to the consultation on its proposals for a regulatory framework for fusion energy

Consultation conducted 1st October 2021 – 24th December 2021

June 2022

Towards Fusion Energy:

The UK Government’s response to the consultation on its 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

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Foreword

The UK's Fusion Strategy was published last year and set out how the UK aims to support the development of fusion energy for commercial industrial use over the next two decades. Since then, we have already seen real progress. In December 2021 the Joint European Torus – the most powerful fusion facility in the world and operated here in the UK – smashed its own fusion energy record, producing 59 Megajoules of sustained fusion energy. By the end of 2021 the global private fusion sector had raised over $4bn, a $2bn increase on 2020. In April 2022 UK company First Light Fusion achieved fusion using its globally unique 'projectile fusion' approach.

Now is the time to take another step forward. As set out in the Prime Minister's Taskforce on Regulatory Innovation (TIGRR), the UK is helping to lead the global field of fusion regulation. Responses to our 2021 consultation on our proposals for regulating fusion energy in the UK were received from around the world. Input from UK and international experts has been invaluable in helping the Government to reach a decision on how to regulate this rapidly evolving, cutting-edge technology.

After our careful review of the feedback received, the Government can now confirm that future fusion energy facilities will be regulated under the legal framework already in place for fusion. While the hazard and complexity of fusion energy facilities will be greater than current research facilities, we remain confident that existing regulations in the UK will be able to uphold safety standards in a proportionate way. We are also clear that the fundamental differences between nuclear fission and fusion mean that it would be disproportionate and unnecessary to incorporate fusion energy facilities into nuclear regulations.

The Government will now move to implement its proposals on fusion regulation, using the Energy Security Bill to remove any residual uncertainty in the current legal framework. We believe that the decisions in this document – based on the best available evidence and now supported by regulators, the fusion industry and other experts – are the right ones to help move safely and determinedly towards fusion energy.

George Freeman MP

Minister for Science, Research and Innovation

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1. Background

UK Fusion Strategy – Towards Fusion Energy

Fusion is the process that occurs at the centre of stars. It is the source of light and heat emitted by the Sun. Fusion energy technologies seek to harness this process and generate low carbon, secure and effectively unlimited energy on Earth. Fusion energy is expected to play an important role over the longer term to decarbonise global energy production.

The science and engineering involved in fusion energy is now progressing rapidly. The UK is widely recognised as a world leader in the most promising fusion technologies. The UK hosts the Joint European Torus (JET) which in February 2022 announced a breakthrough in fusion energy research, achieving record levels of sustained fusion energy production[1].

The UK Government[2] published its Fusion Strategy[3] in October 2021. This expanded on the aim in the Prime Minister's 10 Point Plan for a Green Industrial Revolution[4] and the Energy White Paper[5], which is for the UK Government to build a world-leading UK fusion industry which can export fusion technology around the world in subsequent decades. The Fusion Strategy describes the Government's approach to delivering this mission.

Designs for fusion energy facilities are being developed by research organisations and private companies around the world, targeting deployment in the 2030s and 2040s. One such plan is the UK Atomic Energy Authority's (UKAEA) STEP (Spherical Tokamak for Energy Production) programme, which aims to build a prototype fusion power plant in the UK by 2040[6].

Consultation on the Government's proposals for a regulatory framework for fusion

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. The Government wants fusion developers to be able to plan with confidence and the public to understand the basis for the UK's approach to the regulation of this emerging technology.

[1] JET announced record levels of sustained fusion energy, of 59 Megajoules. Press release available at: https://www.gov.uk/government/news/fusion-energy-record-demonstrates-powerplant-future
[2] All future references to the Government will mean the UK Government, unless otherwise stated.
[3] UK Government (2021). The UK Government's Fusion Strategy. Available at: https://www.gov.uk/government/publications/towards-fusion-energy-the-uk-fusion-strategy
[4] 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
[5] 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
[6] UKAEA (2020): What is STEP? Available at https://step.ukaea.uk/

In October 2021 the Government published the Green Paper: Towards Fusion Energy[7], outlining its proposals for a regulatory framework for fusion energy in the UK. The consultation, which ran between October and December 2021, provided an opportunity for the public, industry, academia and other fusion stakeholders to share knowledge and offer views. The Government's proposals aim to enable the safe and rapid deployment of fusion energy power plants, promoting innovation while maintaining human and environmental protections. In the Green Paper, the Government sought views on the following broad areas:

- 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, 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.

Objectives for a successful regulatory framework for fusion energy

The Government 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

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 appropriate engagement between regulators and fusion developers is necessary for the regulatory framework to be effective.

[7] UK Government (2021). Towards Fusion Energy: The UK Government's proposals for a regulatory framework for fusion energy. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1032848/towards-fusion-energy-uk-government-proposals-regulatory-framework-fusion-energy.pdf

Devolution

As set out in the Green Paper, the Government wants to maximise the scientific and economic potential of fusion energy in a way that levels up opportunity right across the country.

The UK Government has concluded that the existing regulatory framework for fusion would be appropriate for a fusion energy facility, and that a fusion energy facility would not need to be developed on a nuclear site. Currently, the only major fusion experimental facilities in the UK are in England.

The Government hopes that the conclusions set out in this paper will be used by the Devolved Administrations in considering any changes to policies or regulations related to fusion that are devolved. The Government stands ready to collaborate on fusion regulation with the Devolved Administrations.

All decisions in this document are for England. Some will apply across the UK. 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. Further details on the territorial extent of the proposals are set out in the Green Paper[8].

[8] More information on the relevant regulations that would apply to a fusion experimental facility sited in the UK outside of England is available in Towards Fusion Energy: The UK Government's proposals for a regulatory framework for fusion energy. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1032848/towards-fusion-energy-uk-government-proposals-regulatory-framework-fusion-energy.pdf

2. Overview of responses and the Government's decisions

The Government is very grateful to all those who responded to the Green Paper "Towards Fusion Energy: The Government's Proposals for a Regulatory Framework for Fusion Energy". The consultation on this document ran from 1 October 2021 to 24 December 2021. This chapter summarises the feedback received during this period and sets out the Government's planned next steps to establish a regulatory framework for fusion energy in the UK.

All responses received can be found in Annex A, except those for which consent to publish was withheld by the respondent.

A. Overview of responses received

58 written responses were received. The table below provides a breakdown of the responses. BEIS intends to continue engagement with many of those who responded, as well as key stakeholders who were not able to respond to the consultation.

Table 1: Categorisation of the 58 respondents to the consultation[9]

Category	Responses
Industry (energy, engineering, or technology company)	9
Private Individual	9
Academic	8
R&D Organisation	6
Fusion Company	6
Regulator	5
NGO	5
Local Authority (includes local enterprise partnerships	4
Industry Body	3
Unknown	3

Methods of analysis

Written consultation responses were analysed using mixed methods. Closed questions were analysed with standard quantitative techniques. Open ended questions were analysed using qualitative techniques involving breaking the text down into thematic categories, also considering positive or negative sentiments. Those thematic categories were then grouped and consolidated into a framework to draw out common perspectives among the respondents.

The categorisation of respondents in Table 1 above is used throughout this document to provide a breakdown of responses for those proposals that were supported by less than 70% of respondents, to better understand the range of views received on these particular topics. No breakdown is given in relation to those proposals where they were supported by more than 70%.

[9] 43 responses were from organisations or individuals based in the UK. 3 were from US organisations, 1 was from a Canadian organisation, 1 was from a German organisation, 1 was from a pan-European organisation and 1 response was from an individual based in China. The national affiliation of 8 respondents is unknown.

B. The Government's decisions and next steps

1. Current UK regulators of fusion R&D facilities will retain responsibility for fusion.

Hazard Assessment

The Government's assessment in the Green Paper of the hazard of a fusion energy facility (as projected by existing studies[10]) set out how, although the technology continues to evolve, the overall hazard profile will be comparable with other facilities regulated by the Health and Safety Executive and environmental regulators in the UK, such as a large chemical plant.

Most respondents noted the significant inherent differences between traditional nuclear power (based on the fission process) and fusion energy facilities, with fusion involving no chain reaction, nuclear meltdown risk or the most hazardous category of radioactive waste.

A small number of respondents believed that the Government's approach – to determine regulatory proportionality via a set of hypothetical accident scenarios[11] – did not sufficiently account for all the technical risks or complexity associated with a fusion energy facility. Some respondents also asked for further detail on accident scenarios and the regulatory implications of these. The Government acknowledges that these are important considerations. It has worked with the Nuclear Innovation and Research Office (NIRO) and the UKAEA's Fusion Safety Authority to provide a supporting Technical Annex to this document (see Annex B) in response to the concerns raised.

Implications for Regulators

Some respondents were concerned about the current regulators' technical understanding of fusion and their capability to deal with the complexity associated with fusion technology. Regulatory capability is essential for an effective regulatory framework. The Government is confident that, in line with the proposals in the Green Paper, the regulators can build the necessary capability over the coming years in time to ensure the effective regulation of fusion energy facilities and is ready to offer necessary support. The Health and Safety Executive has provided supplementary information (see Annex C) about its approach to regulating complex facilities with multiple and interconnected hazards.

The Government recognises that, given the nascent state of the fusion sector, information is limited. The Government is clear that the fusion sector should work together on further studies and analysis around potential risks and hazards associated with fusion energy technology. Nonetheless, the safety analysis reviewed used very conservative assumptions to take into account the uncertainties involved in this evolving technology. This means that there is high confidence that the hazards of fusion energy facilities will be bounded by the findings in the

[10] UKAEA Technology Report (2021). Available from UKAEA's website: https://ccfe.ukaea.uk/

[11] The Government is optimistic that the fusion industry, with its increasing focus on more compact or alternative fusion designs, will deliver on its aim of reducing the radiological hazard of fusion energy facilities to even less than the projections in the Government's Green Paper. The Government encourages fusion developers to make public their own assessments on this subject.

Green Paper when subsequent detailed safety analysis is undertaken. This is detailed further in the Technical Annex.

From its analysis of responses received to the consultation, the Government remains confident in its conclusions that the hazard of fusion energy facilities does not warrant a change in regulator. The action regulators propose to take with regard to capability building will ensure that the current regulators will be well equipped to manage the scale and complexity of future fusion energy facilities[12].

This position in the Green Paper was supported by regulators responsible for fusion (the Environment Agency (EA), the Scottish Environmental Protection Agency (SEPA) and the Health and Safety Executive (HSE)), as well as by safety and technical experts (the UK Health Security Agency and the UK Atomic Energy Authority (UKAEA)).

2. This regulatory approach will apply to all planned fusion prototype energy facilities in the UK.

The Green Paper stated that, given the evolving nature of fusion energy technology, the Government will keep the regulatory framework for fusion under review. This was broadly welcomed by many respondents. The majority of respondents also recognised that, despite the developing nature of the sector, action was needed now to clarify how fusion energy facilities would be regulated, to support the rapid commercialisation of this low carbon energy technology.

A number of respondents, particularly fusion developers, noted that the proposal to conduct a full review of the regulatory framework every ten years would introduce new uncertainty. This could undermine the development and deployment of fusion technology, hindering the work of both regulators and fusion developers.

As described above, responses received during the consultation period have reinforced confidence in the Government's views on an appropriate regulatory regime. While the Government will keep many aspects of the fusion regulatory framework under review as the sector matures, the Government has decided that it is not necessary to set a comprehensive or formal review of the framework every ten years as originally proposed. **The Government confirms that the decision for current regulators to retain responsibility for fusion will apply to all prototype fusion energy facilities currently being planned in the UK[13]**. This includes those facilities aiming for deployment in the UK in the 2030s and 2040s.

The deployment of prototype fusion energy facilities provides an appropriate opportunity for a more fundamental review of the regulatory framework, although the Government does not necessarily expect significant change to how subsequent fusion energy facilities are

[12] The EA and the HSE will build on their experience of over 30 years of regulating the UKAEA at Culham.
[13] The Government remains prepared to re-visit its decisions on fusion regulation if compelling evidence is presented that shows the hazard of fusion energy facilities would be far beyond the projected overall hazard as assessed in the Green Paper.

regulated[14]. The Government encourages fusion developers to plan on that basis, and also to develop and evaluate their technologies in a way that will facilitate such a review.

The proposed regulatory approach is appropriate for all those fusion technologies that are currently known to be in development in the UK. The Government believes that fusion technologies that involve much greater use of radiological materials than those set out in the UKAEA's technology report[15], such as fission-fusion hybrids, would require a different approach to that set out in this document.

3. The Government will legislate to make clear in law the regulatory treatment of fusion energy.

The Green Paper suggested that clarifying the regulatory treatment of fusion energy in legislation would provide certainty and confidence to regulators and the industry. As detailed in the following chapter, the Government will proceed with this proposal. **The Government will use the Energy Security Bill to amend the Nuclear Installations Act (1965) (NIA65) to explicitly exclude fusion energy facilities from the regulatory and licensing requirements under NIA65.**

4. Broader Next Steps

The Government is also putting in place a programme of work with safety, security and environmental experts, regulators and industry, to take forward its plans for regulation. This work will ensure the safe deployment of fusion energy facilities in the UK on competitive timescales. The Government is using the responses received to the consultation to develop this programme of work. The central issues raised by respondents of particular relevance to this are summarised below.

- An effective regulatory framework must maintain genuine separation and independence between regulators and fusion developers/operators, as responsibility for managing the risk rests with the developer/employer and not the regulators.
- The diversity of fusion technologies must continue to be appropriately reflected in the regulatory framework, for example in how technical support is provided to regulators and in any fusion-specific regulatory guidance. Many commercial fusion companies are seeking to build compact facilities that would use smaller amounts of radiological material than large-scale demonstration facilities such as ITER[16]. Inertial fusion technologies would likely use even smaller amounts of radiological materials though may involve different non-radiological hazards to magnetic fusion (this is noted in Annex B). Aneutronic fusion has a materially lower hazard profile given the greatly lower levels of irradiation during normal operations.

[14] The Government expects that the proposed regulatory framework will also be appropriate for subsequent generations of fusion energy facilities. The Government believes that the prototype generation of fusion energy facilities represents more of a regulatory challenge than successor generations, by which the technology will have matured and regulators will be more experienced with fusion.
[15] UKAEA Technology Report (2021). Available from UKAEA's website: https://ccfe.ukaea.uk/
[16] ITER is an international collaboration in southern France. ITER is designed to be the first fusion device to produce net energy. More information available at: https://www.iter.org/

- Where suitable guidance does not already exist, fusion-specific guidance could make regulatory compliance simpler for developers, enhancing the overall regulatory framework. The evolving nature of fusion technology makes this particularly relevant.
- Regulatory implications around supplementary systems and infrastructure of a fusion energy facility, as well as those relevant to the fusion supply chain and critical fusion materials such as lithium, will need to be considered.
- Policy and/or regulatory requirements associated with the financing of both the development and decommissioning of fusion energy facilities should also be considered.

Drawing on the “Summary Table of Proposals” from the 2021 Fusion Regulation Green Paper, the table overleaf summarises all the Government’s main proposals, decisions and plans on fusion regulation.

Table 2 – Summary of proposals and next steps

Topic	Why is action necessary?	The Government's Proposals	Intended outcomes	The Government's Decision / Planned Next Steps following consultation
Regulatory Justification of Fusion	Operation of fusion reactors for energy production is not currently a "justified activity".	UKAEA's STEP programme should develop and submit an application for the operation of fusion energy facilities 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.	The STEP Programme is now preparing an application for the operation of fusion energy facilities to be a justified activity. UKAEA will engage with the fusion industry in the coming months.
Fusion and the definition of a nuclear installation	The existing legislative definition of "nuclear installation" could be clearer in whether or not it applies to fusion energy facilities, to remove the risk of inconsistency and disruption.	The Government will legislate to confirm that fusion energy facilities would not be legally defined as nuclear installations.	Provide clarity on the overall regulatory regime for fusion energy facilities in the UK.	The Government will use the Energy Security Bill to legislate to confirm that fusion energy facilities will not be legally defined as nuclear installations.
Planning process for a fusion energy facility	The currently assumed planning process for fusion energy facilities in England would be inefficient and make fusion an outlier compared to the planning process for other electricity producing facilities.	The Government will develop a National Fusion Policy Statement to align the planning process for fusion energy facilities with other nationally significant infrastructure projects and electricity producing facilities.	Establish a more efficient planning process for fusion energy facilities.	The Government will publish its plans for a Fusion National Policy Statement in the coming months.

Topic	Why is action necessary?	The Government's Proposals	Intended outcomes	The Government's Decision / Planned Next Steps following consultation
Fusion and Third Party Liabilities	There is no existing requirement for a fusion energy facility 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).	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.	The Government has concluded that some form of liability regime would be appropriate for fusion. It will publish details in due course.
Regulatory Engagement	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.	Regulators should consider options for formalised engagement processes and guidance specific to fusion energy facilities, using the Government's proposed definition 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.	The Government will support regulators as they develop fusion-specific engagement processes and guidance over the next 2-3 years. The Government will work with regulators, industry and technical experts internationally (such as the IAEA) to refine the proposed definition in the Green Paper of those fusion facilities which should be in scope of any new engagement processes or guidance.

Topic	Why is action necessary?	The Government's	Intended outcomes	The Government's Decision / Planned Next Steps following consultation
Public Engagement	While there are multiple opportunities for the public to engage during the regulatory process, there is no explicit obligation for fusion energy facility 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.	The Government believes that the existing regulatory framework provides broadly sufficient opportunity for public engagement, though the Government expects fusion developers to engage fully and transparently with the public at all appropriate stages.
Cyber Security	Fusion energy facility 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.	The Government will consider what would be proportionate and appropriate cyber security regulations for a fusion energy facility.	Ensure the safe and secure operation of a fusion energy facility, in line with existing cyber security policy around energy infrastructure.	The Government will use responses received to the consultation to develop options on cyber security and will publish details in due course.

Topic	Why is action necessary?	The Government's Proposals	Intended outcomes	The Government's Decision / Planned Next Steps following consultation
Nuclear safeguards (preventing state diversion of source or special fissionable material for military purposes)	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 energy facilities. There also may be other safeguards implications beyond tritium as fusion technology develops.	The Government will keep safeguards in the context of fusion under review, with the planning assumption that the ONR would be responsible. This would be consistent with the ONR's current role in regulating safeguards on other non-nuclear radioactive substances sites.	Uphold UK compliance with international treaty obligations in respect of safeguards.	The Government will use responses received to the consultation to develop options on nuclear safeguards and will publish details in due course.
Radioactive Waste Management and Decommissioning for Fusion	Though there would be no High Level Waste produced by fusion energy facilities, 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.	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 energy facilities is undertaken as safely and as efficiently as possible.	The Government does not believe that changes to regulations on radioactive waste are necessary in relation for fusion. The Government recognises that setting firm expectations around the precise nature of the waste produced by fusion energy facilities is premature.

Topic	Why is action necessary?	The Government's Proposals	Intended outcomes	The Government's Decision / Planned Next Steps following consultation
Export controls	No set guidance or framework for fusion technology generally, though there are existing provisions for particular substances (e.g. tritium) and materials.	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.	The Government will use responses received to the consultation to develop options around export controls for fusion and will publish details in due course.
Regulatory Capacity and Capability	Over the coming decades, regulators would need to build technical capability to regulate fusion energy facilities.	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 energy facilities effectively.	The Government will support regulators to build capability and capacity in fusion.

3. Analysis of Consultation Responses

Question 1. Are there other critical regulatory areas that the government should address when considering the regulatory framework for fusion energy in the UK?

Both questions 1 and 30 sought views on the scope of the Government's proposals on fusion regulation. Comments on both have therefore been combined – this is set out under Question 30.

Question 2. Do you agree with the Government's conclusions regarding the expected hazards of future fusion power plants?

Summary of feedback: The majority of respondents were supportive of the Government's main conclusion, that the overall hazard of fusion energy facilities will be broadly comparable with the overall hazard associated with other major industrial facilities regulated by the HSE and environmental regulators, despite the projected increase from current research facilities.

Of the 49 responses received to this question, **63% agreed with the conclusion on expected hazards, while 27% disagreed and 10% did not know.**

Table 3 – Responses to Question 2

Category	Yes	No	Don't know
Industry	6	1	2
Private Individual	3	6	0
Academic	4	3	1
R&D organisation	4	1	0
Fusion Company	5	1	0
Regulator	3	0	0
NGO	2	0	0
Local Authority	3	0	1
Industry Body	1	1	0
Unknown	0	0	1

Many respondents – both those that agreed and did not – provided supplementary information in support of their responses. The Government is very grateful for this and intends to sustain a dialogue on this topic with respondents.

Several respondents requested more information on tritium – described in the Green Paper as one of the main hazards associated with fusion – and how it behaves in the environment[17]. Some respondents who disagreed with this question suggested that the technical complexities and/or uncertainties[18] around the hazards involved meant that the Government should be more cautious in defining an overall hazard and drawing conclusions regarding regulation. Other respondents described some of the individual hazards that were not detailed in the Green Paper, which primarily focused on overall hazard and its regulatory implications.

BEIS has worked with technical experts at UKAEA and the Nuclear Innovation and Research Office (NIRO) to produce a supporting technical note, produced at Annex B. This will not address every detail raised by respondents, but the Government hopes that it helps to substantiate the Government's conclusions.

The Government's response and intended next steps: As noted by many respondents, the Government acknowledges that the overall hazard of fusion energy facilities will increase compared to existing fusion research facilities[19], and that the radiation hazard in particular is different in its composition than that of other industries regulated by the HSE and environmental regulators. However, after reviewing the feedback received, the Government remains confident that the accident scenarios presented in the Green Paper represent reasonable 'bounding scenarios' with which to identify the overall hazard of fusion energy facilities[20], and that this provides an appropriate basis upon which to make decisions on regulatory proportionality. This is detailed further in Annex B.

The Government does not believe that – either individually or in combination – the specific hazards cited by various respondents (and detailed in Annex B) make fusion energy facilities fundamentally inappropriate for the current regulatory framework. The Government does agree with many respondents that the complexity of fusion technology makes it essential for the regulators to build capability and understanding (this is detailed at question 21) but is clear that this complexity does not change the assessment of overall hazard.

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[17] The UK Health Security Agency, while supporting the overall conclusions, suggested reviewing some of the wording around potential worst-case individual impacts. The Government recognises that, at the highest end of the potential dose range in what is the Hypothetical Accident Scenario, there could be acute effects of radiation sickness such as nausea and white blood cell reduction, which are more serious than the broad description of 'mild-moderate' would suggest.

[18] The Government agrees with Eurofusion (the EU's fusion research delivery body) in its comment that the figures given on potential impacts arising from accident scenarios are "design dependent…the actual figures will strongly depend on design and operation parameters that are not defined yet."

[19] The UKAEA, which has safely operated the Joint European Torus (JET) in the UK since 1983, suggested in its consultation response that "[unexpected failures of prototype fusion energy facilities are] expected primarily to affect the frequency or likelihood of internally generated events, not their severity in terms of radiological impact".

[20] A number of private fusion companies made clear in their responses that they were working to reduce radioactive inventories to levels well below those used in the studies on which the Green Paper's assessments were based. This would further reinforce the position of the accident scenarios in the Green Paper as 'very worst or hypothetical examples', and so as appropriately conservative for drawing conclusions with regards to regulatory approach.

As more detailed design information is produced for fusion energy facilities, other accident sequences may have to be developed and analysed in greater detail, though the accident scenarios presented in the Green Paper are still expected to be bounding worst-case scenarios. The Government expects the fusion sector to build evidence on this subject[21], and to make its findings public wherever possible to build understanding and confidence[22]. This information will be used to inform improvements in guidance as fusion technology increases in scale and complexity.

Question 3. Do you agree with the proposal to maintain the existing regulatory approach?

Summary of responses: The majority of respondents agreed with the proposal to maintain the existing regulatory approach. **Of the 51 responses to this question, 31 (61%) agreed with the proposal (29% disagreed and 10% did not know).**

Table 4 – Responses to Question 3

Category	Yes	No	Don't know
Industry	6	1	2
Private Individual	4	5	0
Academic	3	5	0
R&D organisation	5	1	0
Fusion Company	5	1	0
Regulator	3	0	0

[21]This evidence will be key in demonstrating that risks to workers and the public are as low as reasonably practicable (ALARP) and that safety is being addressed in a proportionate and targeted manner. The safety analyses undertaken could build on a wide range of deterministic and probabilistic analysis techniques as appropriate, such as fault sequence analysis, and fault and event tree analysis, in view of the complexity of systems, structures and components of a fusion energy facility. Many industries conduct these types of extensive safety analyses; the approaches taken for fusion energy facilities would not necessarily have to follow the approaches applied in the nuclear sector. For example, the HSE (which does not regulate nuclear fission) guidance states that “The methods used to generate event sequences and estimate of the probabilities of potential major accidents should be appropriate (eg. fault tree and event tree analysis)” (COMAH Guidance - Predictive Assessment Criteria and Guidance - Criterion 3.4.4), and that “Proportionality is essentially determined by the severity of the worst possible consequences and will influence the type and level of analysis detail” (Safety Report Assessment Guide for Chlorine).

[22] The CoRWM noted in its response “the reasonable use of representative worst case and a hypothetical catastrophic accident scenario in evaluating the expected hazards of fusion power plants, given the significant uncertainty around the radiological inventory. Nevertheless, CoRWM is of the view that public confidence in regulating the hazards of fusion power plants will be strengthened by evaluation of more realistic accident scenarios.”

NGO	1	0	1
Local Authority	3	0	1
Industry Body	1	1	1
Unknown	0	1	0

Many respondents – including UK regulators, engineering companies and overseas NGOs[23] – highlighted that the existing regulatory approach is proven to work effectively.

In most case, those that did not agree with the Government's conclusions on overall hazard (see question 2) did not agree with this proposal. Of those, some suggested that moving fusion to within the remit of the Office for Nuclear Regulation (ONR) would be more appropriate (see question 5).

The Government's response and intended next steps: The Government will, as proposed, maintain the existing regulatory approach, which is judged to be:

- proportionate to the overall hazard (as detailed in the Green Paper and at Question 2 above);
- sufficient for the effective regulation of fusion energy facilities (as detailed in question 4 below);
- preferrable to the alternative approach of nuclear regulation and site licensing (as detailed in question 5 below);
- able to fulfil the Government's objectives of safety, transparency and innovation, as detailed in the Green Paper.

[23] Four selected responses are cited here:
- HSE: "[since the Health and Safety at Work Act 1974] major and sometimes rapid changes in the work environment have been considered and controlled using the same general approach: goals to be achieved rather than absolute standards to be met with those who create the risk best placed to manage the risk. Establishing goals to be achieved rather than unnecessary prescription allows employers to work out what is best for them, so supporting and facilitating innovation. Thus, biotechnology; robotics; established green technologies and energy etc. have all developed within this general framework. As an enabling regulator, the HSE plays a vital role in enabling this innovation."
- SEPA: "the current regulations, and equivalent in Scotland, provide a flexible framework for the regulation of all radioactive substances activities that means that fusion research and power generation will be adequately regulated within an existing regulatory regime that is well-established and provides proportionate regulation."
- Atkins (UK engineering company): "We fundamentally agree that a new regulatory regime is not required for fusion. The existing approach has been successfully (ie no major incidents) applied to fusion facilities in the UK. As suggested in the white paper, further clarifying legislation and guidance is still necessary, but the overall regime is appropriate for the hazards as we currently understand them.
- Clean Air Task Force (US-based environmental organisation): "CATF agrees with the arguments made in the report for staying with expertise developed over years among the regulatory players…Shifting responsibility to the nuclear regulator does seem unnecessary."

Question 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?

Summary of responses: Of the 48 responses received to this question, **27 (56%) agreed that IRR 2017 and EPR 2016 provide for the consenting and permitting (respectively) of fusion energy facilities in a way that is proportionate and appropriate (19% disagreed and 25% did not know)**[24]. In most cases, those that did not agree with the Government's conclusions on overall hazard (see question 2) did not agree with this proposal.

Table 5 – Responses to Question 4

Category	Yes	No	Don't know
Industry	6	0	3
Private Individual	5	3	1
Academic	3	4	1
R&D organisation	2	1	3
Fusion Company	4	0	1
Regulator	4	0	0
NGO	0	0	0
Local Authority	2	0	2
Industry Body	1	1	0
Unknown	0	0	1

[24] Two examples of supportive responses:
- Tokamak Energy (UK-based fusion company): "The three hierarchical tiers of Registration, Notification, and Consent embodied in IRR17 ensures that the HSE regulator is fully engaged prior to any operation involving deuterium/tritium requiring consent, and through the consent process and additional engagement can be satisfied that all necessary risk assessments and procedures/measures are in place to reduce the risk to ALARP. Likewise, the EPR16 permitting process ensures that the EA regulator is able to fully consider radioactivation and waste disposal routes, can be satisfied that all necessary discharge and keeping permits are in place for prior to activities and the quantities of radioactive material present are within radio-isotope specific limits set by legislation, and that all practices to limit the impact on the environment – balanced against other risks – is compliant with the BPEO/BPM philosophy. The risks associated with nuclear fusion are more comparable with the chemical industry and facilities holding large source for industrial radiography than nuclear fission (where run-away chain reaction accident scenarios are credible) – therefore regulation through IRR17/EPR16 as for the chemical and radiography industries is both proportionate and consistent."
- The UK's National Nuclear Laboratory (NNL): "NNL's view is that fusion plants should not necessarily be considered as nuclear installations in line with NIA1965 and they could be regulated under the framework provided by IRR 2017 and EPR 2016 on the proviso that the approach to fusion provides similar levels of protection against risks to workers and the public as fission."
- The regulators and the Government are confident that IRR 2017 and EPR 2016 will achieve this.

The Government's response and intended next steps: The Government will maintain IRR 2017 and EPR 2016 as the key foundations to the UK's regulatory framework for fusion.

HSE is introducing a new consent authorisation process under IRR 2017 which will require an operator (including those of fusion facilities) to submit a safety assessment to HSE. A specialist inspector (radiation) will review this, following which they will inspect the facility. This is much greater regulatory oversight and an enhancement to current requirements.

Question 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?

Summary of responses: The majority of respondents thought that fusion energy facilities should not be considered as nuclear installations under the terms of the Nuclear Installations Act 1965 (NIA 1965)[25] and so brought within the remit of ONR regulation. **Of the 48 respondents who answered this question, 30 (63%) believed that fusion energy facilities should not be considered as nuclear installations (19% thought they should and 19% did not know)[26]**. Those that believed fusion energy facilities should be considered as nuclear installations were in almost all cases those respondents who did not agree with Questions 2, 3 and 4.

Table 6 – Responses to Question 5

Category	Yes	No	Don't know
Industry	1	7	1
Private Individual	2	5	2
Academic	3	3	1
R&D organisation	2	3	1
Fusion Company	0	5	1

[25] NIA 1965 determines how nuclear installations are defined, licenced and regulated in the UK. UK Government (1965). Nuclear Installations Act 1965. Available at https://www.legislation.gov.uk/ukpga/1965/57

[26] Some respondents believed that fusion facilities were already within scope of this framework, negating the need for deliberate action to incorporate fusion into this framework. This is because, under NIA1965, the BEIS Secretary of State is able to prescribe any installation that is "designed or adapted for producing or using atomic energy" as within scope of the requirement to hold a nuclear site licence. The definition of "Atomic Energy" used in NIA 1965 comes from the Atomic Energy Act 1946 where "atomic energy means the energy released from atomic nuclei as the result of any process", which some respondents noted would include fusion energy. These respondents suggested that, for this reason, fusion energy facilities could already be prescribed as nuclear installations and brought within the nuclear site licensing regime. Given that the Government believes that the regulatory requirements of NIA65 are disproportionate to fusion, there are no plans for the BEIS Secretary of State to prescribe fusion facilities as nuclear installations. See Question 7 for further details.

Regulator	0	1	0
NGO	0	1	0
Local Authority	0	2	2
Industry Body	1	1	1
Unknown	0	2	0

Those respondents who disagreed with questions 2 and 3 suggested that fusion facilities should be brought into the remit of the nuclear site licencing framework led by ONR[27]. They suggested that this approach is more appropriate for the nature and complexity of the hazards involved in a fusion energy facility and that the ONR is more able to regulate this technology than the current regulators. They also noted that the nuclear site licensing regime includes lower hazard nuclear sites such as nuclear laboratories and fuel cycle facilities.

The Government's response and intended next steps: The nuclear site licensing regime is a long-established and effective regulatory framework for the UK's nuclear installations, which can offer flexibility based on the nature of the specific facility. The ONR also has deep experience in outcome focused, goal-setting regulation[28] of complex and hazardous technology.

However, as set out in questions 2-4 above, the Government believes the case for maintaining the existing regulatory approach for fusion, which is more appropriate and proportionate to the overall hazard of a fusion energy facility, is strong. The Government's position is that the Nuclear Installations Act 1965 is intended primarily to require higher risk nuclear sites, such as those with fissionable materials, to be licenced and regulated by ONR. In line with its decisions above, the Government therefore does not consider fusion energy facilities to be nuclear installations under NIA 1965.

The following two questions are in reverse order to how they appeared in the Green Paper, given that question 7 relates directly to questions 2-5.

[27] One respondent suggested that the ONR would be more relevant for fusion energy facilities on the basis that, as suggested by the illustrative accident scenarios in the Green Paper, these facilities would likely require certain levels of emergency planning in line with the Radiation (Emergency Preparedness and Public Information) Regulations 2019 (REPPIR). REPPIR is structured to exclude most, but not all, HSE-enforced sites. The Government agrees that, as detailed designs of facilities are progressed, more detailed site specific REPPIR 2019 hazard evaluation and consequence reports will need to be generated. The Government's expectations remain that these more detailed site specific reports will confirm the findings of the Green Paper that only an outline plan is required, in line with current REPPIR-relevant facilities regulated by the HSE. Indeed, in all of the actual calculations reviewed, the point estimates were at the lower end of the areas of risk represented on the REPPIR 2019 diagram shown in the Green Paper, generally well below the threshold for an outline emergency plan.

[28] The ONR in its response noted how "operational experience from fission can be used to inform the safety and security of fusion", and has confirmed that it will continue to support the Government's work in this area.

Question 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?

Summary of responses: Of the 47 responses to this question, 27 (57%) agreed that a legislative approach is appropriate (28% disagreed and 15% did not know). Those respondents who agreed emphasised the value to regulators, fusion developers and the wider public of legal clarity on the matter. The ONR was one respondent that agreed that "a legislative approach is appropriate for clarifying that a nuclear site licence would not be needed for a fusion power plant".

Table 7 – Responses to Question 7

Category	Yes	No	Don't know
Industry	4	3	2
Private Individual	5	4	0
Academic	4	3	1
R&D organisation	3	1	1
Fusion Company	5	0	1
Regulator	1	0	0
NGO	0	0	0
Local Authority	3	0	1
Industry Body	2	1	0
Unknown	0	1	1

The Government's response and intended next steps: As set out in the Green Paper and in questions 4-6 above, the Government intends for IRR 2017 and EPR 2016 to continue to provide the basis of the regulatory framework for fusion in the UK, and for fusion energy facilities not to be incorporated into the nuclear site licensing framework under NIA 1965. While fusion facilities in the UK are not currently captured by NIA 1965, this legislation as drafted could see some fusion facilities inadvertently and temporarily meet the legal requirement for a nuclear site licence, based on the source and amount of tritium stored at the facility[29]. This

[29] Tritium is a radioactive isotope of hydrogen that is used as a fuel (along with deuterium) in the most widely preferred method of producing fusion energy. It can be generated by some nuclear (fission) reactors. This source of tritium is expected to be used to initiate the deployment of many prototype fusion energy facilities, which – once fully operational – are designed to produce their own tritium. The link to nuclear fission means that such fission-

would lead to an inconsistent regulatory framework for fusion, where a fusion energy facility could initially require a nuclear site licence but not once the facility is fully operational.

NIA 1965 does enable the BEIS Secretary of State to choose to prescribe fusion facilities as nuclear installations (see footnote 26 for further detail). While the Government has no intention of using these powers in view of its decisions on fusion regulation, this existing provision also contributes to uncertainty on the legal status of fusion energy facilities.

For both of these reasons, and in view of the support from a majority of respondents for a legislative approach to clarify this, the Government will use the Energy Security Bill to maintain in law a consistent exclusion of fusion energy facilities from nuclear site licencing requirements[30] [31].

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

Summary of responses: Most respondents offered support for the Government's proposals on regulatory justification. Many agreed that a justification application for fusion should be based on the 'generation of net energy'. Respondents also felt that a justification application should cover different fusion technologies, though some respondents noted how this may not always be possible or desirable.

The Government's response and intended next steps: Given the support from many respondents for the scope of the proposed justification application for fusion[32], and in particular that this should be for the 'generation of net energy', the Government will take forward its proposals on justification from the Green Paper.

UKAEA has agreed that the STEP application should be developed so that it meets the requirements of the justifying authority while – as far as possible – also enabling other fusion projects to be covered by the resulting justification. UKAEA will engage private sector parties – and the Justifying Authority – in addressing this question.

produced tritium is covered by NIA 1965, and so would trigger the requirement for a site licence if it is stored in large quantities. The storage of fusion-produced tritium – in any quantity – is not covered by NIA 1965 and so would not trigger the need for a site licence.

[30] The Government believes that fusion technologies that involve much greater use of radiological materials than those set out in the UKAEA's technology report, such as fission-fusion hybrids, would require a different approach to that set out in this document.

[31] NIA 1965 applies across the UK and nuclear site licensing policy is reserved to the UK Government. Under Schedule 2 of the Northern Ireland Act 1998, nuclear energy is an excepted matter, the amendment will apply to Northern Ireland. The island of Ireland does not have nuclear fission power stations; this amendment will not change this. As a result of this amendment, if the Northern Ireland Executive decide to build a fusion energy facility in the future, it will not be subject to nuclear site licensing.

[32] The generation of energy from a fusion energy facility must be confirmed as a new justified practice before the operation of any fusion energy facility 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.

Question 8. Do you agree with the proposal to establish a Fusion NPS based on the planning assumptions outlined above?

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

Summary of responses: There was strong support to establish a Fusion NPS. Of the 48 responses to question 8, 34 (71%) agreed[33] with the proposal (15% disagreed and 15% did not know).

The Government's response and intended next steps: Given the strong support for this proposal, the Government will establish a Fusion NPS as proposed in the Green Paper. It will publish its plans in the coming months. Several respondents provided suggestions on the content of a Fusion NPS, in response to question 9. The Government will engage with respondents on these suggestions.

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

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

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

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

Summary of responses: Of the 47 responses to Question 10, 28 (60%) believed that a third party liability regime is required for fusion (11% did not believe this and 30% did not know).

Table 8 – Responses to Question 10

Category	**Yes**	**No**	**Don't know**
Industry	5	0	4
Private Individual	7	0	2
Academic	5	2	1

[33] For example, the EA agreed with the proposal to establish a Fusion NPS, noting that "it is important to have a sector-specific Fusion NPS because fusion energy facilities are a new technology that pose potentially significant environmental risks and hazards for which specific policy guidance is likely to be needed."

R&D organisation	2	1	2
Fusion Company	4	2	0
Regulator	0	0	2
NGO	0	0	1
Local Authority	3	0	1
Industry Body	2	0	0
Unknown	0	0	1

The most common response on the topic of third party liabilities was that any regime needs to be specific to fusion and the hazards it presents.

Respondents who supported a third party liability regime believed one was necessary to give the public, developers, operators, their suppliers and potential insurers confidence that adequate compensation would be provided to the public for damage resulting from an accident. This will allow the industry to grow without being hindered by bearing an intolerable burden of liability. Nuclear insurers and fusion companies were amongst those that stated a clear and comprehensive third party liability regime would help industry to understand the risks involved and to promote the development of suitable commercial fusion insurance.

Some respondents highlighted aspects of the Paris Convention third party liability regime that would be appropriate for a third party liability regime for fusion, such as capped liabilities and strict liabilities. However, many respondents raised the concern that the risk profile of fusion is much lower than that of nuclear fission and so any liability framework for fusion should not have the same liability caps as for fission. Under the Paris Convention, the maximum liability that can be required of a site in the UK is €1.2 bn – many respondents said that this would be disproportionate for fusion[34].

The Government's response and intended next steps: The Government agrees that a third party liability regime for fusion would help to provide confidence to the public, industry and insurers, and support the development of commercial insurance provision for fusion energy facilities. The Government agrees with respondents that a third party liability regime for fusion would need to be specific to fusion and reflect the range of fusion technologies. It would also need to have appropriate liability caps. The Government will develop a regime on this basis and will collaborate internationally to maximise scope for harmonisation where appropriate. The Government will provide further detail in due course.

[34] The Nuclear Risk Insurers (NRI) said:
"The known radiological risks associated with fusion, which stem from tritium and neutron-activated materials, do not correspond with the significant risks associated with a transboundary fission accident that the current civil nuclear liability regime is designed to protect against."

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

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

Summary of responses: There was strong support for the proposal that fusion should be subject to appropriate cyber security regulations. **Of the 45 responses to question 14, 32 (71%) agreed that prototype fusion energy facilities should be subject to cyber security regulations (20% disagreed and 9% did not know).**

The Government's response and intended next steps: The Government will work on developing details for cyber security regulations for fusion energy facilities, drawing on information provided in responses to question 15.

Question 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?

Summary of responses: Of the 44 responses to this questions, **23 (52%) agreed with the proposed definition of fusion energy facilities in scope for enhanced regulatory engagement and new guidance (23% disagreed and 25% did not know).**

Table 9 – Responses to Question 16

Category	Yes	No	Don't know
Industry	5	0	4
Private Individual	5	0	2
Academic	3	4	1
R&D organisation	2	2	1
Fusion Company	2	3	0
Regulator	2	0	0
NGO	0	0	0
Local Authority	2	0	2
Industry Body	2	0	0
Unknown	0	1	1

Several respondents suggested that the focus on net electrical output in the Government's proposed definition[35] did not appropriately reflect fusion energy facilities' high thermal output.

Some respondents suggested that other factors, such as the implications of the pulsed power approach of many proposed fusion facilities, alternative applications of fusion facilities, and/or potential radiation dose levels in accident scenarios, should be taken into account when defining those facilities intended to be in scope.

The Government's response and intended next steps: The Government's aim with the proposed definition was to suggest an approach for identifying those fusion facilities for which – due to reasons of overall hazard, scale and/or complexity – additional regulatory engagement or guidance would be beneficial for both developer/operator and regulator. The Government acknowledges that, following its consideration of responses received, the proposed definition needs to be refined in order for all relevant facilities to be included. The Government's revised definition will take into consideration other factors such as the level of thermal (rather than electrical) power output. The Government will draw on the responses received and work with the fusion sector, technical experts and regulators to consider this further.

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

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

Summary of responses: There was wide support for formal engagement in the design process between fusion developers and regulator(s), including from both fusion developers and the regulators[36]. **Of the 46 responses to question 17, 38 (83%) agreed with the proposal (11% disagreed and 7% did not know).**

The Government's response and intended next steps: Drawing on the suggestions received in response to question 18, the Government will work with the regulators as they consider how best to enable formal engagement with fusion developers in the design process.

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[35] The Government proposed 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".

[36] Regulator responses:

- EA: "We agree there can be advantages for both the Environment Agency and the fusion developers to engage early. For example, it allows us to get involved with developers at an early stage, where we can have maximum influence. Design changes required to address regulatory concerns are more easily implemented while designs are still on paper, rather than when construction has begun, or expensive plant items have been manufactured. It enables us to identify issues early in the process so progressively reducing financial and regulatory risks for potential operators. As the Green Paper notes, engagement also enables us to understand better future technologies and identify potential challenges which could require staff up-skilling and guidance updates /development."
- HSE: "HSE welcomes further discussion on the purpose and benefit of any pre-engagement activity between developers and regulators, and in particular where it can add value to both."

The Government and the regulators will work to ensure that formal engagement in the design stage will not undermine regulatory independence and objectivity, which was raised as a potential risk by a small number of respondents.

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

Summary of responses: There was strong support for additional guidance. **Of the 47 responses to this question, 38 (81%) agreed (9% disagreed and 11% did not know).**

Responses identified possible topics for new guidance to cover, such as: a description of the UK's regulatory approach in relation to that of other countries; which regulations are applicable to fusion energy facilities; which regulatory bodies are responsible for what; and what is involved in the regulation around the handling of radioactive waste and decommissioning of different fusion energy facilities.

Respondents who disagreed with producing additional guidance were largely those who favoured including fusion energy facilities in nuclear site licencing requirements. One respondent stated the application of a nuclear site licencing regime would not require additional guidance on the regulatory approach.

The Regulatory Horizons Council (RHC) in its own report on fusion regulation made a specific recommendation on guidance, finding 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". The RHC recommended that "a joint guidance document is produced to cover this by EA, HSE and BEIS".

The EA confirmed that they will prepare new guidance where gaps are identified or where developers require further clarification of regulatory expectations. The HSE also confirmed that it would consider any fusion-specific guidance on its merits as the technology develops.

The Government's response and intended next steps: The Government will work with regulators to enhance guidance on fusion energy regulation, drawing on the suggestions from respondents. It will continue to consider the case for a single joint guidance document as recommended by the RHC.

Question 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?

Summary of responses: There was strong support for there to be greater opportunity for public engagement in the regulatory process for fusion. **Of the 46 responses to this question, 35 (76%) agreed with this statement (9% disagreed and 15% did not know)[37]**.

The Government's response and intended next steps: The Government will support the regulators to articulate how the public can engage in the regulatory process for fusion and to consider where there should be greater opportunities for this, building on existing processes for sites of high public interest (into which category fusion sites would fall).

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

Summary of responses: Responses to this question mainly suggested that the regulators work with technical experts and engage with a range of fusion developers. The regulators themselves described in their responses how they plan to build the necessary technical capability through training and familiarisation with the technology and radioactive substances involved.

Some respondents suggested using the ONR's expertise in regulating fission to build capability for regulating fusion. Others suggested that the application of fission regulatory strategies and concepts to fusion could be inappropriate given the differences in the technologies and the overall hazard potential.

The Government's response and intended next steps: As noted in question 2, the Government acknowledges that the complexity involved in evolving fusion technology will require the regulators to build further capability and understanding. Indeed, the EA has experience of doing this in respect of advanced nuclear (fission) technologies. The Government agrees with respondents that training and technical familiarisation of regulators will be necessary to build their fusion capability. The Government will draw on suggestions received to the consultation to support regulators to do this.

Question 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?

[37] The HSE agreed that public engagement and explanation is vital for public trust in public institutions and decision-makers. The EA noted that existing arrangements enable sufficient engagement opportunities for the public to interact with fusion developers and the EA. Enhanced consultation is undertaken for 'high public interest applications'. The EA decide whether an application is of high public interest on a case-by-case basis but consider it likely that a fusion energy facility would be in this category. As stated in the Green Paper, the Government expects fusion energy facilities to be in the category of high public interest applications.

Summary of responses: A range of views was provided on how the technical expertise of the UKAEA could be used to support the development of a regulatory framework.

Many respondents commented on the strength of the UKAEA's technical expertise and believed that their knowledge could assist in regulating the expanding fusion sector, such as via the formation of a Technical Support Organisation (TSO) for use by regulators. However, some respondents suggested that, given UKAEA's focus on magnetic fusion, this approach could disadvantage alternative approaches to fusion.

A widely raised concern was that any TSO supporting the regulators would have to be genuinely independent[38] from UKAEA, given UKAEA's mission to commercialise fusion energy.

The Government's response and intended next steps: The Government agrees with respondents' views that regulators must be independent of fusion developers (such as UKAEA) and the Government. The Government will take account of the comments raised on this point in relation to its proposals for using the technical expertise of UKAEA to support the regulatory framework. The Government will set out its refined proposals in due course.

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

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

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

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

Summary of responses: The Government did not make any specific proposals in the Green Paper on radioactive waste arising from fusion nor on how a fusion facility should be decommissioned. The responses received to the consultation on these questions will be used to inform longer-term considerations on this issue[39]. On these topics, the Government is particularly grateful to the Committee on Radioactive Waste Management for their engagement ahead of the Green Paper and their response to the consultation.

[38] In its response the EA cited the IAEA Safety Standards General Safety Requirements, which state that "The government shall ensure that the regulatory body is effectively independent in its safety related decision making and that it has functional separation from entities having responsibilities or interests that could unduly influence its decision making."

[39] For instance, the EA confirmed in its response that it would review guidance in this area to ensure that it remains appropriate.

Of the 40 responses to Question 24, 25 (63%) believed that Government policy should reflect an expectation that radioactive waste from fusion can be disposed in near-surface disposal facilities (18% disagreed and 20% did not know).

Table 10 – Responses to Question 24

Category	Yes	No	Don't know
Industry	5	3	1
Private Individual	6	0	1
Academic	5	0	0
R&D organisation	1	1	3
Fusion Company	5	1	0
Regulator	1	0	0
NGO	0	1	0
Local Authority	2	0	2
Industry Body	0	1	0
Unknown	0	0	1

Those that disagreed with question 24 mostly did so by stating that the management of waste should – as now – continue to be determined by the nature of the waste rather than by the technology that has produced it. Some respondents suggested that it would better to gain a firmer understanding of the nature of the radioactive wastes, the types of radioactivity involved and the amounts of wastes with long half-lives before any such policy decisions are made[40].

Regarding the questions on decommissioning, respondents focused on lessons that could be learned from current nuclear decommissioning principles and approaches[41] and on the issues

[40] CoRWM emphasised that radioactive wastes should be managed in a disposal setting at a depth and with containment appropriate to their radiological risk. CoRWM notes that there is currently considerable uncertainty in the radioactive waste inventory arising from fusion power plants and that this will be different for different technologies. CoRWM considers that some radioactive wastes may potentially be suitable for disposal in a near surface facility. However […] geological disposal may be required for some of the longer lived waste inventory, to provide appropriate isolation and containment at depth.

[41] For example, many respondents advised that plans for decommissioning fusion energy facilities should be fully established from the outset, in line with nuclear industry best practice. Several respondents suggested drawing on experience from fission and research sectors with extensive experience in the decommissioning of facilities where components have become activated by neutrons and/or contaminated by radionuclides.

that should be considered in any new policy position or guidance on decommissioning of fusion facilities[42].

The Government's response and intended next steps: The Government is grateful for the range of views received from responses on how radioactive waste from fusion can be safely managed and on how a fusion facility could be decommissioned. The Government will explore many of the issues raised with CORWM, other technical experts and the wider fusion sector over the coming months.

The Government notes that emerging technologies could reduce the hazards associated with some radioactive wastes produced from fusion, which could offer opportunities for how these wastes are stored and/or disposed of. Nonetheless, the Government's position remains that – as stated in the Green Paper – radioactive wastes produced by fusion are covered by the Government's general policy and strategy on radioactive waste. The Government agrees that a disposal route should not be predetermined based on the technology but should be dictated by the hazard and risk that the waste poses. The Government believes that it would be premature to set an expectation that radioactive waste from fusion should always be disposed in near-surface disposal facilities.

Question 27. Do you agree with the Government's proposals on safeguards for fusion?

Summary of responses: There was support for the Government's proposals on safeguards for fusion. **Of the 40 responses to this question, 28 (70%) agreed with the proposal (15% disagreed and 15% did not know).**

The Government's response and intended next steps: Following its consideration of the responses received, the Government's position at this stage remains that additional regulatory provisions would not be needed on safeguards in relation to a fusion energy facility for the UK to continue to comply with its international treaty obligations. However, many of the points raised by respondents – from technical implications of the increase in scale of fusion energy facilities to related security issues that are outside of the applicable safeguards regime – support the Government's intention to keep this under review. The Government will continue to work with the sector on this subject.

[42] For example:
CoRWM advised that regulatory guidance for decommissioning and waste management should be clear, succinct, and communicated appropriately to engage public understanding and confidence.
UKAEA highlighted that the UK will learn about decommissioning fusion energy facilities from the JET Decommissioning Programme and suggested that more detailed guidance should build on this experience.

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

Summary of responses: Respondents broadly supported the Government's proposals and offered useful suggestions on this topic, with several respondents noting that different fusion technologies[43] may require specific guidance. Some respondents also suggested that the UK should work with the appropriate international organisations to establish common rules needed to enable the global export of fusion technology.

The Government's response and intended next steps: The Government welcomes the suggestions and information provided and will take forward its plans as detailed in the Green Paper.

Question 29. Do you agree with this proposed approach for keeping the fusion regulatory framework under review?

Summary of responses: There was strong support for keeping the framework under review. **Of the 44 responses to this question, 37 (84%) agreed with the proposal (9% disagreed and 7% did not know).** However, although there was strong support for the principle of keeping the framework under review, there were a wide variety of views on how long any review period should be. The fusion industry itself put forward a diverse range of views.

Some responses suggested that a 10-year time frame for reviewing the regulatory framework is too long given the rapidly evolving technology and favoured a review every 5 years. Others raised concerns that a shorter review period would increase uncertainty around the regulatory framework and could disrupt the development of fusion energy facilities in the UK. One response suggested that, if such a review were to result in a change of regulatory approach, the Government should clarify that any future changes to the regulatory program would not affect fusion facilities or machines approved under the prior regulatory regime.

The Government's response and intended next steps: Responses received during the consultation period have reinforced confidence in the Government's conclusions on what would be an appropriate regulatory regime. While the Government will keep many aspects of the fusion regulatory framework under review as the sector matures, the Government has concluded that the framework should not be subject to a set, formal review every ten years. Instead, **the Government confirms that the decision for current regulators to retain responsibility for fusion will apply to all prototype fusion energy facilities being planned for in the UK**[44]. This includes those facilities aiming for deployment in the UK in the 2030s and

[43] For example, inertial confinement fusion may require more specific guidance given the greater relevance for export controls than for magnetic confinement fusion.

[44] The Government remains prepared to re-visit its decisions on fusion regulation if compelling evidence is presented that shows the hazard of fusion energy facilities would be far beyond the projected overall hazard as assessed in the Green Paper.

2040s, including the STEP (Spherical Tokamak for Energy Production) prototype fusion power plant which aims to be built by 2040.

The Government believes that the deployment of prototype fusion energy facilities provides an appropriate opportunity for a more fundamental review of the regulatory framework. However, it remains the Government's expectation at this stage that there would be no need for significant change to how subsequent fusion energy facilities are regulated[45]. The Government encourages fusion developers to plan on that basis, and also to develop and evaluate their technologies in a way that will help such a review.

The Government is clear that the current regulators are the correct regulators for those fusion technologies currently being developed in the UK as known to the Government. The Government believes that fusion technologies that involve much greater use of radiological materials than those set out in the UKAEA's technology report[46], such as fission-fusion hybrids, would require a different approach to that set out in this document.

Question 1. Are there other critical regulatory areas that the government should address when considering the regulatory framework for fusion energy in the UK?

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

Summary of responses: Many respondents offered no further areas for the Government to consider regarding fusion energy regulation and felt that the Government had identified the critical regulatory areas of importance to fusion energy in the UK.

Some respondents requested further detail on tritium which is provided in Annex B.

The Government's response and intended next steps: The Government is grateful for the responses provided and is confident that all of the crucial areas that currently need to be considered in regard to fusion energy regulation have been identified.

The Government recognises that there is further work to do on fusion regulation. Next steps are summarised in Table 2 on page 15.

[45] The Government expects that the prototype generation of fusion energy facilities will represent more of a regulatory challenge than successor generations as the technology matures and regulators are increasingly experienced with fusion. On this basis, the Government expects that the proposed regulatory framework will also be appropriate for subsequent generations of fusion energy facilities.
[46] UKAEA Technology Report (2021). Available from UKAEA's website: https://ccfe.ukaea.uk/

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

Summary of responses: All of the 45 respondents who answered Question 31 had at least a little knowledge of fusion energy. The majority of respondents, 84%, knew a lot about fusion. 16% of respondents knew a little.

Option	Total	Percent
Knew a lot	38	84
Knew a little	7	16
Aware of it but didn't really know what it was	0	0
Never heard of it	0	0
Don't know	0	0

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

Summary of responses: There was strong support for the development of fusion technology in the UK. 94% of respondents support or strongly support the development of fusion energy.

Option	Total	Percent
Don't know	0	0
Strongly oppose	1	2
Oppose	0	0
Neither support nor oppose	2	4
Support	6	13
Strongly support	38	81

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

Summary of responses: After reading the Green Paper, 87% of respondents who answered this question knew a lot about fusion.

Option	Total	Percent
Knew a lot	39	87
Knew a little	5	11
Aware of it but didn't really know what it was	0	0
Never heard of it	0	0
Don't know	1	2

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

Summary of responses: After reading the Green Paper, 92% of respondents to this question supported, or strongly supported the development of fusion technology in the UK.

Option	Total	Percent
Don't know	0	0
Strongly oppose	1	2
Oppose	1	2
Neither support nor oppose	2	4
Support	6	13
Strongly support	37	79

Annexes

Annex A. Consultation responses (separate document)

Annex B. Technical annex

Annex C. Health and Safety Executive regulation of complex facilities with multiple hazards

Annex A. Consultation Responses

Annex A provides all responses received to the Government's consultation on its proposals for a regulatory framework for fusion energy with permission to be published. This is available as a separate document at: https://www.gov.uk/government/consultations/towards-fusion-energy-proposals-for-a-regulatory-framework

Annex B. Technical Annex

This technical annex was produced to support the Government's response to the consultation. It seeks to address key technical issues raised by some respondents.

Written by BEIS, UKAEA Fusion Safety Authority and Nuclear Innovation and Research Office (NIRO).

Contents

1. Introduction

This Annex provides additional technical information on radiological hazards and potential causes of radiological impact to the public to support the Government's response to the consultation on its proposals on fusion regulation. It sets out further details on tritium, the radioactive fuel that will be used in many fusion power plants, and on the range of hazards that are considered for fusion power plants[47], the focus being on those that have the potential to cause the release of radioactive material to the environment in an accident scenario. This Annex draws on material from the UKAEA Technology Report[48], with some additional material from the underlying references. The Technology Report mainly focused on magnetically confined tokamak devices, as this was the subject of the majority of the literature available on safety assessment of early concept fusion power plant, although some consideration was given to other technologies. Limited information about safety assessments of other technologies, such as inertial confinement concepts, supports the view that the worst-case "hypothetical" accident scenario described in the Technology Report is still representative of the bounding consequences.

The hazards discussed in this Annex are potential 'initiating events' of damage to one or more of the confinement barriers. This may lead to a release of radioactive material to the environment, and as such will be bounded by the accident scenarios already presented in the Green Paper. Although the focus of the Green Paper was on radiological hazards it is recognised that there are other industrial hazards (e.g. magnetic fields, fire, chemicals) which are already subject to health and safety, and environmental, regulation.

2. Tritium

2.1 Tritium forms, mobility and health effects

Tritium is a radioactive form ('isotope') of hydrogen because it has two neutrons (whereas regular hydrogen has none), making it unstable and therefore radioactive. The production of tritium in nature is rare although some is produced naturally high in the atmosphere by the interaction of cosmic rays with nitrogen and oxygen. The abundance of tritium in the environment is therefore very low compared to hydrogen (and deuterium – a stable isotope of hydrogen). Additional tritium has been created on earth through artificial means, for example as a by-product of activities related to the use of nuclear fission, and tritium is also used in a range of applications including in luminescent devices, medical diagnostics and biomedical research.

As it is radioactive, tritium decays with a half-life of 12.3 years to a stable helium atom, emitting beta radiation (an electron). Tritium is a source of weak beta radiation; the beta particle is of

[47] The term 'fusion power plant' is used in this annex and the UKAEA Technology Report to refer to future fusion devices that produce useful energy, including demonstration and prototype devices.
[48] Fusion Safety Authority Technology Report, 'Safety and Waste Aspects for Fusion Power Plants', UKAEA-RE(21)01, Issue 1, September 2021, https://scientific-publications.ukaea.uk/wp-content/uploads/UKAEA-RE2101-Fusion-Technology-Report-Issue-1.pdf

particularly low energy and can only travel approximately 6 mm in air. It does not have enough energy to penetrate the skin, however it can pose a health risk if taken directly into the body[49]. Tritium can enter the body by breathing air containing tritium or by ingesting tritiated food and water (see below). Tritiated water can also be absorbed through the skin like regular water. Most tritium leaves the body as tritiated water in urine, breath moisture and perspiration with the majority expelled within a month. Most inhaled tritiated hydrogen gas is exhaled immediately.

Around 99% of the tritium produced in the upper atmosphere is oxidised to form tritiated water (HTO); when a tritium atom replaces a hydrogen atom in water (H2O) to form HTO. This has the same chemical properties as water and is also odourless and colourless.

Whether of natural or artificial origin, tritium is extremely mobile in the environment and in all biological systems. Tritium exists in three chemical forms:

- **Tritiated water (HTO)**: the most abundant form of tritium in the natural environment and in living organisms. HTO is extremely mobile in the environment and is quickly integrated into the water cycle. In dry conditions, HTO will exchange with water in the soil; in wet conditions, HTO will enter soil directly as precipitation. In the body it is easily absorbed by inhalation or ingestion where it quickly diffuses through the body.
- **Gaseous tritium (HT):** this form of tritium concerns only a small fraction of tritium currently released into the air. Tritium in the air is deposited in soil by dry deposition or wet deposition (rain), however, there is little transfer of this via rainwater since it is not very soluble. The body does not readily absorb this form of tritium and the majority of that inhaled would be immediately exhaled. HT has a radiotoxicity lower than HTO by a factor of 10,000.
- **Organically bound tritium (OBT)**: some of the tritium released into the environment will be incorporated into nutrients such as carbohydrates, fats or proteins, i.e. ‘organically bound tritium’ (OBT) and this can enter the body directly through ingestion of tritiated foods. OBT poses a slightly greater health risk because, as an organic material, the body will retain it longer than tritiated water, increasing the likelihood that the tritium atom will decay while in the body and possibly cause damage.

Health effects from radiation only occur when radiation comes into contact with biological material. For tritium with weak (low energy) beta radiation, this needs to be taken into the body through inhalation or ingestion (or to a lesser extent absorption of tritiated water through the skin). The magnitude of the health effect depends on the type of radiation, energy level of the radiation, amount of radioactive material, radioactive half-life, whether the radioactive material concentrates in a particular tissue and how long the material is retained within the body (biological half-life). The radiotoxicity of tritium is low because the beta radiation is low energy and it has a relatively short biological half-life (10 days for HTO and 40 days for OBT)

[49] See the following websites for further information and quantitative examples, https://www.irsn.fr/EN/Research/publications-documentation/radionuclides-sheets/environment/Pages/Tritium-environment.aspx, https://nuclearsafety.gc.ca/eng/pdfs/fact_sheets/january-2013-fact-sheet-tritium_e.pdf & https://www.radioactivity.eu.com/site/pages/Tritium.htm

compared to a long radioactive half-life (~12 years). This means that almost all of the tritium leaves the body before it emits a beta particle[50].

Becquerels

The standard international (SI) unit for measuring radioactivity is the becquerel (Bq). 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. It is the radiation released during this decay process that causes biological damage.

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.

Biological half-life

The biological half-life is a measure of the time required for the concentration of a substance in a biological system to be reduced by one half, based on biological process for eliminating substances not the radioactive decay (see radioactive half-life). The shorter the biological half-life, the less time available for the substance to do damage in the body.

2.2 Tritium in a fusion system

Tritium is used as one component of the fuel in a fusion device based on the deuterium-tritium reaction. This is the most prominent reaction in the fusion devices being proposed, as it requires the least temperature for fusion to occur, although devices with other fuels are also under development. In the past, the majority of artificially produced tritium for commercial use has been as a by-product from fission reactors and global supplies are limited. Fusion devices will need a supply of tritium, one way to achieve this is via a self-sufficient fuel cycle, whereby neutrons from the fusion reaction convert lithium into tritium in a so-called ‘breeder blanket’. This will require careful optimisation of the fuel cycle, including tritium extraction processes. Potentially, excess tritium could be produced from a fusion device to provide the initial fuel supply for start-up of a new device.

In a tokamak fusion device, the plasma itself will contain up to only a few tens of grams (~1 x 10^16 Bq) of injected tritium fuel at any one time, however, there will be additional tritium in the materials of the device from (i) tritium created in the tritium breeder blanket, (ii) tritium diffused and trapped in materials surrounding the plasma and (iii) tritium permeated into coolant systems. In addition, a significant proportion of the tritium will be in a fuel handling building (i.e. fuel cycle plant where tritium is recovered from exhaust and waste products,

[50] The authors would like to acknowledge Prof. Gerry Thomas, a senior academic specialising in the molecular pathology of cancer at Imperial College London, for providing BEIS with some of the information on radiation hazards and tritium used in this section of the Annex.

processed for re-use as fuel, and stored in metal hydrides), with smaller amounts in other areas, for example, where maintenance on internal components is performed and in waste processing facilities.

In a fusion device, the most abundant form of tritium will be as a gas (HT), unlike in the environment where HTO is most common. It is important to note that HT has a radiotoxicity lower than HTO by a factor of 10,000. In the accident analysis supporting the Green Paper most used the pessimistic assumption that the form of tritium released was the more radiotoxic HTO form. As an isotope of hydrogen, tritium gas is readily mobilised. Some tritium within the materials will be considered trapped and not mobilisable, even in the event of an accident.

2.2.1 Environmental impact from routine operations

During routine operation of a fusion power plant (i.e. normal operation and expected maintenance), tritium will be discharged (gaseous and liquid), for example due to seepage from valves/seals of coolant systems or fuel cycle equipment. This would be routed through filtration and detritiation systems to limit releases to the environment as a matter of course.

Environmental radiological discharges during routine operation of a fusion power plant will be dominated by the tritium contribution. As an example, the SEAFP report[51] gives an indication of future environmental radiological gaseous and liquid discharges of 255 TBq/year and 23 TBq/year, respectively, from a typical fusion power plant, the majority of which is tritium (either gaseous HT, or liquid HTO). The dose to a member of the public from this level of discharge once dispersed is less than a micro-Sv per annum.

As discussed in the Green Paper, it is the responsibility of the environment agencies across the UK to assess the impact and permit any radiological discharge. Operators of a fusion power plant will be required by environmental legislation to use best available techniques (BAT) to limit discharges and impacts to people and the environment.

2.2.2 Environmental impact from an accident scenario

In some accident scenarios there is potential for confinement systems to be breached resulting in an environmental release of radioactive material (this section is focused on tritium releases, see Section 3 for other radiological hazards). The UKAEA Technology Report[52] describes two indicative accident scenarios through consideration of the multiple layers of confinement, as the confinement systems are the key strategy in prevention and limitation of any releases. The Technology Report uses published studies on early concepts of fusion power plants, and a good indication of the key hazards and ‘worst-case’ type accidents, in terms of off-site releases, can be sought through the safety analyses performed to date.

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[51] J. Raeder et al., Safety and Environmental Assessment of Fusion Power (SEAFP), European Commission Directorate General XII Fusion Programme Brussels, June 1995, https://www.researchgate.net/publication/303252621_Safety_and_Environmental_Assessment_of_Fusion_Power_SEAFP_Final_Report_of_the_SEAFP_Project

[52] Fusion Safety Authority Technology Report, ‘Safety and Waste Aspects for Fusion Power Plants’, UKAEA-RE(21)01, Issue 1, September 2021, https://scientific-publications.ukaea.uk/wp-content/uploads/UKAEA-RE2101-Fusion-Technology-Report-Issue-1.pdf

Due to the environment within the vacuum vessel of a fusion device, this tritium inventory was considered within the Technology Report (and underlying reference material) to be the most vulnerable in terms of accident scenario releases.

A release of tritium in an accident scenario has potential to have public consequences in both the immediate impact (early or short-term dose) and over a longer timeframe (long-term dose). The immediate impact dose consequences from worst case descriptions of Acc1 and Acc2 are given in the Green Paper assuming a 7-day exposure through inhalation and skin absorption. Although the majority of tritium in a fusion device will be gaseous (HT) it is pessimistically assumed that the released tritium in an accident scenario is all oxidised to the higher radiotoxicity HTO form, for example, due to steam interactions if water coolants are used.

As described in 2.1, tritium in the environment can mobilise through various ecosystems and through water cycles as HTO. Some tritium will be incorporated into organically bound tritium (OBT). The different forms of tritium and pathways are taken into account when using modelling to assess the potential longer-term dose. For example, in the SEAFP report[53], the longer-term dose was calculated assuming a 50-year exposure from accidental release including exposure through ingestion of tritiated foods, with doses of a similar order of magnitude to those reported for the early dose.

Confinement

Confinement of radioactive material is the key strategy to prevent mobilisation and limit any releases, protecting the public and environment. The implementation of confinement will vary depending on the type of fusion device and some of the design specifics. However, in general, multiple levels of confinement will be employed (e.g. vacuum vessel and building) and make use of a ventilation system with exhausts routed via filtration and detritiation systems.

Vacuum vessel

The fusion process occurs within a vacuum vessel of some form in all concepts (albeit may have a different name), and the fuel is also held within the vacuum vessel (magnetically, inertially, or both).

3. Key radiological hazards

There are a number of types and forms of radiological materials that are found in fusion plant. The fusion reaction itself does not directly produce radioactive by-products, the deuterium-tritium reaction produces a neutron and the nucleus of helium-4. The neutrons produced in the reaction are a form of ionizing radiation, requiring shielding to be in place during operations.

[53] J. Raeder et al., Safety and Environmental Assessment of Fusion Power (SEAFP), European Commission Directorate General XII Fusion Programme Brussels, June 1995, https://www.researchgate.net/publication/303252621_Safety_and_Environmental_Assessment_of_Fusion_Power_SEAFP_Final_Report_of_the_SEAFP_Project

However, radioactive material in a fusion power plant that could be released to the environment comes from two main sources – the tritium used, bred and processed as a fuel, and materials in and around the fusion plasma that are activated (made radioactive) by the neutrons. The actual amounts of radioactive materials will depend on the technology, design and operation of individual machines. Whilst the majority will use tritium as a fuel, some developing technologies use other non-tritium reactions to create fusion (for example in aneutronic fusion[54]).

This section summarises the key radiological hazards with regards to potential environmental release in accident scenarios.

3.1 Tritium

The different forms of tritium and the potential discharges and accidental release from a fusion power plant is described in Section 2. It is important to minimise the amount of tritium required for operation of a fusion power plant to ensure compliance with the legal requirement to ensure that risks remain as low as reasonably practicable (ALARP) and radioactive wastes are minimised by using BAT. As mentioned already, tritium is in limited supply and so will likely need to be produced as part of the fuel cycle. As well as regulatory requirements to demonstrate ALARP and BAT, operators of fusion power plants will also have economic drivers to minimise the amount of tritium that needs to be bred by minimising of tritium losses within the systems.

3.2 Activated materials

Materials in the vicinity of the plasma become radioactive, caused by interactions with the neutrons produced from the fusion reactions, resulting in activated structural materials, activated dust (resulting from erosion of the plasma facing components) and activated coolant liquids or gases and any corrosion products in them.

The majority of the activated products will be bound within the solid structures (bulk material) of the device and considered immobile, although some activated products can be mobilised through physical or chemical mechanisms.

Within the vacuum vessel, activated products could be mobilised through creation of dust (from erosion and stresses on the plasma facing materials) during routine operation. During some accident scenarios, there could be potential for aerosols to be produced or volatilisation products resulting from oxide-driven mobilisation, depending on the accident conditions, materials used, temperature, etc. Additionally, there can be active corrosion or neutron sputter products within the coolant systems. During routine operation some effluent discharges will result in release to the environment, routed first through filtration systems. As with tritium discharges these releases will need to comply with the facilities environmental permit.

[54] IEEE Spectrum, 5 Big Ideas For Making Fusion Power A Reality, https://spectrum.ieee.org/energy/nuclear/5-big-ideas-for-making-fusion-power-a-reality

The reviewed analyses assumed activated products mobilised in accident scenarios, comprising tungsten dust, aerosols, and where appropriate, corrosion products. Some cases also considered a quantity of volatilisation products due to the conservative temperatures assumed in the accident scenario.

The choice of materials used in the device influences the quantities and types of radioactive isotopes that may be produced via neutron activation, which in turn influences the level of hazard resulting from an accident with some activated product release. Processes such as the minimisation of radiologically hazardous material through the optimisation of design decisions is a legal requirement of the regulatory framework to demonstrate that safety risks are ALARP and that waste is reduced through the use of BAT.

4. Overview of initiating event in-plant energies

The accident scenarios in a fusion power plant can be bounded by assuming a breach of the layers of confinement, with a partial or total release of the mobilisable radioactive inventories, depending on which layers are breached in different scenarios. Damage to the confinement may be caused by a number of initiating events, such as equipment failure, release of energy of different forms from the process causing damage, or external events. In the following subsections the internal hazards particular to a fusion power plant (though not unique, as they are present in other industrial processes) relate to the sources of energy. Although the majority of energy sources are common to different fusion technologies, the specifics and magnitude will have to be assessed depending on the detailed design of individual plant. The appropriate safety controls to prevent and mitigate the hazards would then be implemented as part of the design.

4.1 Energy in the fusion driver

There are a number of different drivers (fusion initiating methods) for fusion energy systems in consideration. As already mentioned, the Technology Report focused mainly on magnetically confined tokamak systems, although some consideration was given to hazards in other technology approaches.

Consideration to potential accidents that could be initiated from the energy in the fusion driver will be different for the various concepts, for example, plasma energies, high-power lasers, compression systems, ion-beams, projectiles etc. In a magnetically confined tokamak approach the key energies related to the fusion driver are the energy in the plasma and magnets. Plasma disruptions, due to loss of plasma control, lead to thermal shocks in the plasma facing materials, resulting in the production of dust and potential increased loads to internal components augmented by electromagnetic forces in some cases. In some cases, it can result in an electron beam focused on a particular area of the structures potentially causing damage leading to an accident scenario, such as loss of coolant.

In some other approaches the misalignment of beams or the unsymmetrical response of targets could cause damage to confinement, in the latter case the target can become a projectile putting a higher than normal load on the impact surface.

In some systems the fuel is contained within a pellet and is compressed creating the conditions for fusion, sometimes referred to as “micro-explosions”. In such systems particular consideration is given to the potential for mobilisation of radioactive material through vaporisation.

4.2 Magnetic energy

In magnetic confinement systems the loss of superconductivity (magnet quench) could lead to an increase in temperature, voltage and mechanical stresses in the magnets, potentially leading to structural failure. In the event of an electric arc caused by a magnet fault, there is the potential for molten material to come into contact with components providing one of the confinement barriers.

Magnets may be also used in other fusion approaches, for example ion beam driven devices will contain magnets for in the beam accelerator and focusing systems. These do not though have the same hazard potential for causing a radioactive release as in a magnetic confinement fusion device.

4.3 Thermal energy

The materials of a fusion device will be hot during operation. A leak from the primary cooling system into the vacuum vessel could cause vaporisation due to these hot components, resulting in a rise in pressure. In an accident scenario the fusion would stop but there will continue to be some heat produced by the materials due to the decay heat from radioactivity (see Section 4.4).

Abnormal thermal loads (such as unexpected high heat loads from plasma disruption) could have potential to damage plasma facing components.

4.4 Decay heat

It is important to consider the heat generated by the radioactive decay of materials within the fusion device, in particular those which are plasma facing (e.g. first wall and breeder blankets), when considering temperature transients in accident scenarios. The temperatures could have a direct impact on the accident (damaged component) and/or affect the mobilisation of tritium and activated products (dusts, aerosols, volatilisation products). In the analyses reviewed the temperatures reached in the modelled accident scenarios were significantly lower than the melting point of the material considered, inferring that the component should not fail at this temperature. Bounding temperatures were used in the conservative assumptions regarding mobilisation of tritium and active products in the accident scenarios.

The temperature transients and the mobilisation of activated products will depend on the accident scenarios identified, the materials and design, the operation schedule etc and assessments will need to be refined as designs mature. Utilising high temperature superconductors there is the potential for tokamaks to be designed with much lower volumes for a given power output than for conventional designs such as JET and ITER. This also means that the power density of the decay heat is likely to be higher and assessments will need to be kept under review as the plant operates. Note that the decay heat depends on how long the materials have been exposed (the decay heat in a component is very low just after it has been installed).

4.5 Explosive energy / fire hazard

Hydrogen or dust explosions could occur with potential to challenge confinement systems and mobilise radioactive material, for example, in the event of ingress of air into the vacuum vessel, or by oxidation of dust / plasma facing materials / liquid metals (if used) by water or steam in a loss of coolant accident.

A flammable or explosible hydrogen/air mixture could result from an accidental leak of hydrogen, deuterium or tritium from fuel cycle equipment. Additional hydrogen inventory could be generated in the vacuum vessel through chemical reactions between plasma facing materials and air or steam (see Section 4.7), for example in the case of an ingress of water coolant in the vacuum vessel (accident scenario).

4.6 Cryogenic energy

A leak of liquid helium or nitrogen can cause a sudden vaporisation of the cryogen, with large volumetric expansions and pressure rise in the area with potential loss of integrity of affected confinement barriers.

4.7 Chemical energy

There will be some materials that are inherently chemically hazardous (such as oils used for vacuum pumping systems) and those which have potential for producing a chemical energy hazard (such as the tungsten-steam reaction).

Chemical energy hazards could result from:

- Hydrogen inventories in systems connected to the fuel cycle (covered in Section 4.5).
- Potential reactions of some materials (such as beryllium, tungsten, and lithium containing materials) with air or steam in the vacuum vessel at elevated temperatures, releasing energy and/or hydrogen.

5. Summary

It is recognised that a fusion power plant will be complex, and that fusion developers will need to carry out rigorous and systematic safety analyses on individual designs as they progress, to assess the full range of technical risks and address the current uncertainties.

It is also acknowledged that there are uncertainties related to the design characteristics of specific machines, materials used in the machine, the level of hazards and detailed fault sequences, and the related inventories and amounts of radioactive material that may be released in an accident scenario.

However, a number of studies have been carried out on concept designs that allow representative bounding cases to be considered, as presented in the UKAEA Technology Report[55], to inform decisions on the appropriate regulatory framework. This Annex has illustrated the range of hazards that could initiate an accident, however the "hypothetical" accident scenario presented in the report and the Green Paper would still bound the consequences.

There are a number of different technologies that may be deployed in fusion power plant, based on different principles such as magnetic, inertial or magneto-inertial confinement fusion, and using different fuels including tritium and deuterium. Whilst the specific hazards related to a particular technology will differ, there are some common features across many of the concepts for fusion power plant.

The main radiological hazard to members of the public in an accident scenario is the potential release of radioactive material into the environment. There are several industrial hazards related to fusion, but this Annex is focused on where these hazards could also initiate a radiological consequence, as the focus with regards to determining what is an appropriate regulatory approach has been on the potential radiological hazards to the public.

Representative radiological accident scenarios leading to breach of the confinement barriers have been assessed to give bounding case potential doses to members of the public, with uncertainties accounted for by the use of conservatism, for example in the radiological source terms and dose modelling. This included a worst-case hypothetical accident scenario, which is not based on a known scenario, but accounts for the range and potential combination of internal hazards or for extremely unlikely external hazards (such as a large magnitude seismic event). It also used other significant pessimisms such as all the tritium released is in the form of the more hazardous HTO.

The published analyses have mainly assessed concepts for magnetic confinement tokamak fusion power plant. However, there is also information about other technologies such as inertial confinement concepts, that support that the worst-case "hypothetical" accident scenario is still representative of the bounding consequences. The consequences would be lower if the amount of tritium fuel is smaller, or the fusion reaction does not use tritium as a fuel (such as in aneutronic or low neutronicity fusion concepts being developed).

The analysis does not present a full risk assessment of a fusion power plant, as a detailed safety analysis would identify a number of design specific accident scenarios with different potential consequences and likelihoods, to build up a full risk profile. This will include internal

[55] Fusion Safety Authority Technology Report, 'Safety and Waste Aspects for Fusion Power Plants', UKAEA-RE(21)01, Issue 1, September 2021, https://scientific-publications.ukaea.uk/wp-content/uploads/UKAEA-RE2101-Fusion-Technology-Report-Issue-1.pdf

events (e.g. equipment failures, release of energy, fires) and external events (e.g. earthquakes, aircraft crashes). As part of the risk assessment, the measures taken to prevent or mitigate the consequences – such as design features, engineering controls and safety devices – will be identified, to ensure that the risks are reduced to as low as reasonably practicable (ALARP). Nonetheless, the "hypothetical" accident scenario, whilst not based on any defined cause, illustrates the magnitude of the worst-case unmitigated accident scenario (i.e. complete loss of confinement), and can thus be used as a basis for consideration of the regulatory approach.

Annex C. Health and Safety Executive regulation of complex facilities with multiple hazards

Currently, experimental fusion facilities are regulated by the Health and Safety Executive (HSE) against the general duties in the Health and Safety at Work etc. Act 1974, the Management of Health and Safety at Work Regulations 1999 and the more specific requirements for workers and others protection in (primarily) the Ionising Radiation Regulations 2017.

HSE recognises that, as the technology develops from experimental to operational facilities over the coming years, regulatory arrangements and expectations will need to reflect an operational fusion power plant's greater complexity and hazard and risk profile. Early work will be needed to understand this and inform whether the current regulatory framework is proportionate for an operational plant that may present many and varied hazards. HSE has, however, significant experience in regulating very complex facilities with significant hazards and associated risk.

HSE is for example, the health and safety at work regulator for all major hazard facilities in Great Britain (GB) other than the licensed nuclear sector. One of HSE's key purposes is to ensure that these major hazards facilities are properly managed in industries where failures in safety management and risk control can lead to catastrophic harm to workers and the public at large. HSE has significant capability and competence in regulating such facilities, developed over many years.

HSE therefore regulates:

- the risks to health and safety arising from work activity in the Offshore Industry on the UK Continental Shelf - ranging from unmanned gas platforms to large oil and gas production platforms, and floating production installations and drilling rigs;
- the natural gas supply industry and industries transporting hazardous substances by pipeline. This includes upstream natural gas transmission and distribution networks; gas import and storage facilities; onshore major hazard pipelines; offshore pipelines; and other associated high hazard sites;
- onshore major hazard chemical manufacture, distribution and storage, and downstream oil refining;
- the manufacture, large-scale storage and transportation of explosives throughout GB and Northern Ireland (in support of the Northern Ireland Office), as well as large-scale ammonium nitrate storage in GB; and,
- work with biological agents across several sectors, including biotechnology and biomedical research, industrial vaccine and pharmaceutical production, healthcare, agriculture and food.

In addition, it has national inspection and enforcement responsibilities for containment, research and commercial laboratories, infectious disease units and all work connected with genetically modified organisms.

HSE also regulates many non-major hazard facilities with the potential for significant offsite effects. These include regulating the risks associated with the Legionella bacterium and the public utilities for example.

Complex facilities are not solely confined to those where there is the potential for significant offsite harm. HSE successfully regulates advanced manufacturing facilities such as car manufacturing plants. Major construction projects of national significance requiring complex risk management arrangements ranging from the construction of the Thames Tideway tunnel, Crossrail and HS2 are all regulated by HSE and involve close collaboration with other regulators

Most of HSE’s regulatory frameworks do not prescribe in detail what measures the dutyholder has to take to prevent an accident or mitigate the consequences. Dutyholders have to determine this for themselves. Dutyholders are responsible for identifying, profiling and managing the risks they create in a systematic way whatever the hazard and associated consequence.

As fusion technology develops to operational power facilities, the regulatory approach will evolve to reflect the hazards and risk and consequence presented. It is likely that any assessment of risk will need a detailed understanding of event sequences and probability estimates. HSE has significant skills and capabilities within its major hazards function to look at these kinds of safety challenges and explore preventive and mitigation barriers.

Illustrating this, HSE expects dutyholders to understand that major hazard risks have to be managed in a multi-layered way and that the layers of protection or control measures will address technical, managerial and procedural arrangements.

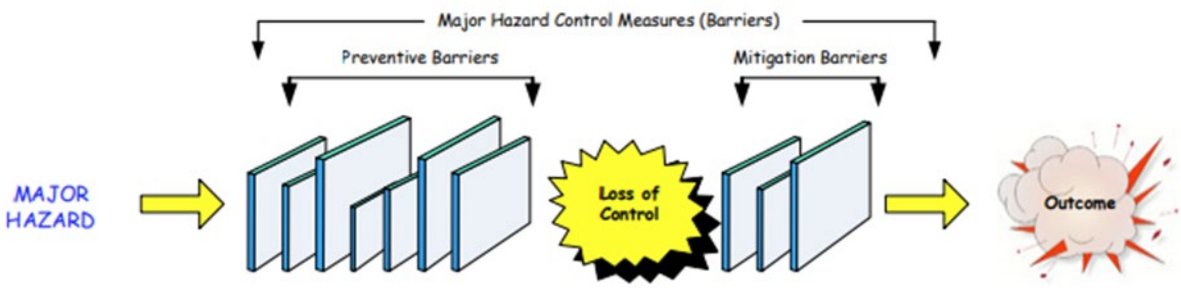

Fig 1: HSE layers of protection

The regulatory model is one of layers of protection. Preventative barriers ensure loss of control is reduced. Mitigation barriers reduce the consequences of any loss of control.

The dutyholder should be able to show a logical and rational flow of analysis leading from hazard identification through to effective risk control, expressed as a set of appropriate ‘barriers’ (or risk control systems).

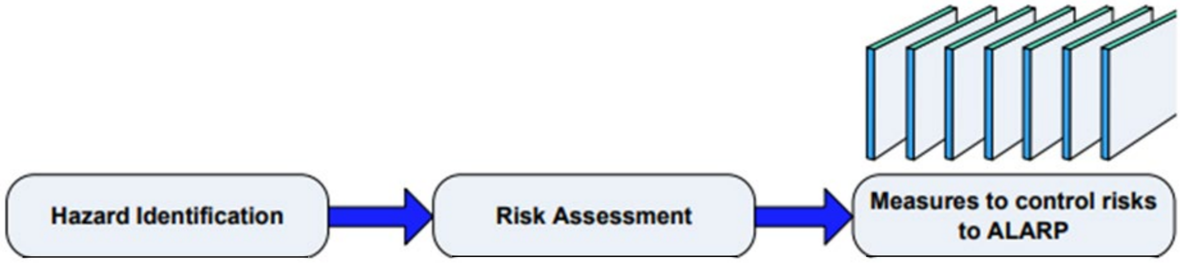

Fig 2: Sequence of analysis to determine the appropriate control and mitigation measures for major hazards.

As with all hazards in all facilities, complex or not, the responsibility for managing the associated risks rests with the duty holder and not with HSE.

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