資料６
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The United Kingdom, Japan and Canada publish joint recommendations on how to develop a regulatory framework for fusion energy

Summary description: As part of the Agile Nations working group on fusion energy, the UK[1], Japan[2] and Canada[3] have published recommendations on how to develop a regulatory framework for fusion energy facilities. The working group consisted of governments representatives and called upon national technical experts when required.

Description:

The Agile Nations is an inter-governmental regulatory network designed to foster cooperation on innovative regulatory practice. The Agile Nations working group on fusion energy regulation, comprising of the UK1, Japan2 and Canada3 with Singapore4 and Bahrain5 as observers, have drawn on their own experiences to produce five recommendations on how to develop a regulatory framework for fusion energy facilities.

This group recognises the benefits of fusion and the opportunities a globally harmonised approach to regulation could bring. This group recommends that fusion regulation should be proportionate to the hazards of fusion energy while remaining transparent and pro-innovation and nations should consider the public perceptions of fusion when considering regulation.

The working group on fusion energy has also produced two case studies detailing some of the evidence that has been generated by contributing nations to support these recommendations. These case studies are published alongside the group's recommendations:

1. We recommend the recognition of the important contribution that fusion energy could make to the global challenges of climate change and energy security.
2. We recommend all nations start developing clarity on a regulatory framework that would apply to fusion energy facilities independent of the fusion technology.
3. We recommend nations recognise the benefits of a harmonised approach to fusion regulation being adopted by several nations.
4. We recommend the development of a regulatory framework for fusion energy that maintains appropriate protections for people and the environment, proportionate to the hazards of fusion energy while remaining transparent and pro-innovation.
5. We recommend nations recognise the importance of assuring the public that the levels of protection are suitable and consider how this can be achieved.

We encourage other countries starting to think about fusion regulation to reach out to the Agile Nations working group to discuss our recommendations in more detail and share the knowledge we have gained through the development of our own regulatory frameworks for fusion energy.

1 through the Department of Energy Security & Net Zero
2 through the Ministry of Education, Culture, Sports, Science and Technology
3 through Natural Resources Canada

Initial recommendations from the Agile Nations Working Group on Fusion Energy Regulation.

The Agile Nations is an inter-governmental regulatory network designed to foster co-operation on innovative regulatory practice.

The Agile Nations working group on fusion energy is comprised of the United Kingdom, Japan, and Canada as members with Singapore and Bahrain as observers.

The working group has drawn on their own experiences to produce the following recommendations on how to develop a regulatory framework for fusion energy facilities. It is for nations to work with their regulatory body to consider how any framework is implemented.

1. **We recommend the recognition of the important contribution that fusion energy could make to the global challenges of climate change and energy security.**

Climate change and energy security are some of the most prominent challenges the world is currently facing. Fusion energy technology has the potential to be a low carbon, secure, continuous, and effectively unlimited source of energy to provide a lasting solution to these challenges into the next century and beyond. An introduction to fusion energy can be found on the International Atomic Energy Agency's website[1].

There are different approaches to fusion energy that have shown great promise. As exemplified by recent breakthroughs, many technologies could play an important role in commercialising fusion and different technologies could suit the requirements of different nations, markets, and energy applications better than others.

2. **We recommend all nations start developing clarity on a regulatory framework that would apply to fusion energy facilities independent of the fusion technology.**

Over $6 billion has been invested in private fusion industry[2] and over 130 fusion facilities across more than 30 countries[3] are operating or planned through private and public sector organisations. Currently, most fusion facilities are for research, but the purpose of these facilities will become more focused towards electricity generation in the future. The scale of fusion facilities is also due to increase as fusion is commercialised and with the ambition from some private companies to build electricity generating facilities in the 2030s, the urgency to clarify the regulatory framework for fusion is as clear as ever.

To give organisations certainty on investment and planning, and to enable regulators to prepare, nations should start now to develop and/or define a regulatory framework for these facilities. The framework should be technology agnostic to enable all approaches to fusion succeed and allow regulators to adequately assess any new technologies which may arise in the future.

3. **We recommend nations recognise the benefits of a harmonised approach to fusion regulation being adopted by several nations.**

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[1] https://www.iaea.org/newscenter/news/what-is-nuclear-fusion
[2] https://www.fusionindustryassociation.org/fusion-industry-investment-passes-6bn/
[3] https://www.iaea.org/publications/15253/world-survey-of-fusion-devices-2022

A consistent framework to regulation across nations would provide operators with predictability regarding the type of safety and environmental protection information they would be required to provide during authorisation. Regulators may then be able to share knowledge to support efficient reviews and allow them to focus on the most important safety and environmental aspects when assessing designs. This is because the information presented by operators is more likely to be at a similar level, making it more easily understandable and relevant. Additionally, if countries are aligned on the risk posed by fusion energy and how to effectively mitigate that risk, this will help build public trust.

Having a predictable, harmonised framework to regulation will also improve investor confidence in the design approval process of the regulators. This would speed up development for fusion facilities and could lower costs for operators and consumers.

Finally, a consistent framework is needed to maximise the export potential of fusion. Reducing barriers to exports through a harmonised approach to regulation will open fusion to more markets, drive competition, lower prices for all and improve global energy security.

4. **We recommend the development of a regulatory framework for fusion energy that maintains appropriate protections for people and the environment, proportionate to the hazards of fusion energy while remaining transparent and pro-innovation.**

The main objective of regulation is to ensure safety and environmental protection, but it is also important that regulation is proportionate, transparent and encourages innovation.

Compared to fission, fusion energy facilities will not produce the same long-lived high-activity radioactive by-products and there is no chance of a runaway chain reaction as the fusion process will immediately stop upon a loss of power or fuel. This presents a difference compared to nuclear fission technologies and suggests that a different regulatory framework may be necessary.

In assessing whether regulation is proportionate, the hazard of the fusion process should be considered in the context of other industrial processes that generate electricity and/or involve radioactive substances. The impact on the public, workers, and the environment of any potential accident scenarios and how this compares to other industries can provide a starting basis for determining how proportional regulation is to the hazard presented from fusion.

Initially, nations should consider peer-reviewed published studies and analyses that provides evidence on possible accident scenarios (examples provided in Annex A) to assess the overall hazard and risk of fusion energy. As new information emerges and facility designs become more developed, nations should review regulation to ensure it stays appropriate.

Transparent regulation is important to give confidence to operators and the public. With early public engagement and if decision making during the approvals process is consistent and openly explained, operators will understand what they need to do to provide the relevant information to assure the design and safe operation a fusion energy facility. The public will be able to understand what safety and environmental protection measures are being taken by the operator and how this will keep them safe.

Finally, the commercialisation of fusion is dependent on technological advances and continued innovation to develop fusion energy and subsequently keep it competitive with other energy source. Regulation that allows innovation will allow new technologies to be developed and could lead to a more cost-effective energy source for the consumer, investor, and operator.

5. **We recommend nations recognise the importance of assuring the public that the levels of protection are suitable and consider how this can be achieved.**

Public knowledge about fusion is generally low which could lead to misconceptions and false information spreading. If the public does not believe that regulation is adequately protecting them, even if fusion is safe from a technical and scientific perspective, then fusion energy will struggle to be accepted by the public and deployed at a meaningful scale. Further evidence about public perceptions of fusion can be found in Annex B.

Nations should work to ensure that scientific evidence is presented in a way that is understandable and accessible by the public, to provide assurances of public safety and that levels of protection are suitable. It is important to recognise that as well as ensuring safety from a scientific point of view, public sentiment needs to be taken into consideration.

Nations should strategically consider how best to raise public awareness of fusion energy technology, including how a communication campaign can be tailored to different audiences. Having an informed public prior to discussions or consultations about an appropriate regulatory framework may be important. Nations, developers, and regulators should also engage in dialogue with the public to learn about and address their concerns.

Annex A Fusion Hazards and Accident Scenarios

A.1 Introduction

Unlike fission, fusion energy has inherent safety features, such as no risk of chain reaction or meltdown, fusion does not occur unless specific plasma conditions are met, and no high-level radioactive waste. It is important to consider regulations based on such characteristics related to fusion energy. Many of the globally proposed fusion approaches, however, do involve the use of tritium and the production of neutrons with related material activation hazards. Therefore, it is necessary to identify various events that are assumed as "worst-case scenarios" and to evaluate the hazard and risk of each situation. This Annex provides two Case Studies on accident scenarios in fusion power plant, and the level of hazard in relation to potential public dose from the release of radioactive material.

A.2 Case Study – UKAEA Technology Report

Fusion Hazards

There are several different fusion technologies being developed, including magnetic confinement (eg. tokamak, stellarator), inertial confinement (eg. laser or projectile driven), or using a combination of both in magnetised target fusion. The majority will use deuterium-tritium (D-T) fuel and, therefore, the main radiological hazards for a fusion power plant will be tritium and the activated products created during operations. There are also other industrial hazards that need consideration, such as magnetic fields, lasers and hazardous materials, but existing regulations would be able to manage these hazards for a fusion power plant.

There have been several studies of potential accident scenarios based on evolving conceptual designs of future fusion power plant. Summary information and referenced literature on accident scenarios and analysis of fusion power plants can be found in the UKAEA Technology Report.[1] It is recognised that safety analyses are strongly dependent on the type of fusion technology, design of plant and the materials used. But the assessment of accident scenarios is dependent on the maximum inventory of radioactive material that could be released, so worst-case estimates can be used to identify the upper bounds of impacts.

Accident Scenarios

A key safety feature of a fusion facility is the confinement of the radioactive substances at the facility (known as 'inventories'): the tritium and activated materials described above. The multiple layers of protection provided by the confinement systems at the facility minimise the hazard of these substances to workers, the public and the environment. In an accident scenario, the confinement systems could be damaged, resulting in a percentage of these inventories being released into the environment that exceeds the annually permissible discharge levels set by regulators.

Based on a **conceptual D-T tokamak-design** fusion facility at power plant scale, UKAEA's Fusion Safety Advisors have reviewed independent analysis, already published in the public domain, on the consequence of breaches of the multiple systems of confinement such as the vacuum vessel then the tokamak building. This exercise intended to illustrate the projected worst-case impacts to individuals that could arise from a release of the radioactive inventory from a fusion power plant. Supplementary information can be found in the UKAEA Technology Report.

This exercise identified two representative worst-case accident scenarios. The first Accident Scenario (Acc 1) is a breach of the primary confinement (eg. vacuum vessel) but with the tokamak building confinement and its filtration/detritiation systems intact. The potential worst-case dose is a few micro-Sieverts, which is similar to the radiation experienced on a single transatlantic flight. The second Accident Scenario (Acc 2) is a breach of the primary confinement, with an independent malfunction of the building filtration system, such that there is leakage through the tokamak building confinement. The potential worst-case dose is a few milli-Sieverts, which is similar to the radiation experienced from a CT scan of the chest.

An illustrative hypothetical 'worst-case' scenario (Hypo) resulting from an extreme magnitude earthquake to the facility was also considered. Dose consequence was estimated using an inventory-based approach whereby it

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

was assumed that a large quantity of the tritium and radioactive dust inventory was released into the environment due to total failure of both the vacuum vessel and tokamak building confinement systems (although within the literature reviewed no sequence of events was identified that would lead to such total failure). The potential worst-case dose is less than a Sievert, above which there is potential for some acute radiation effects.

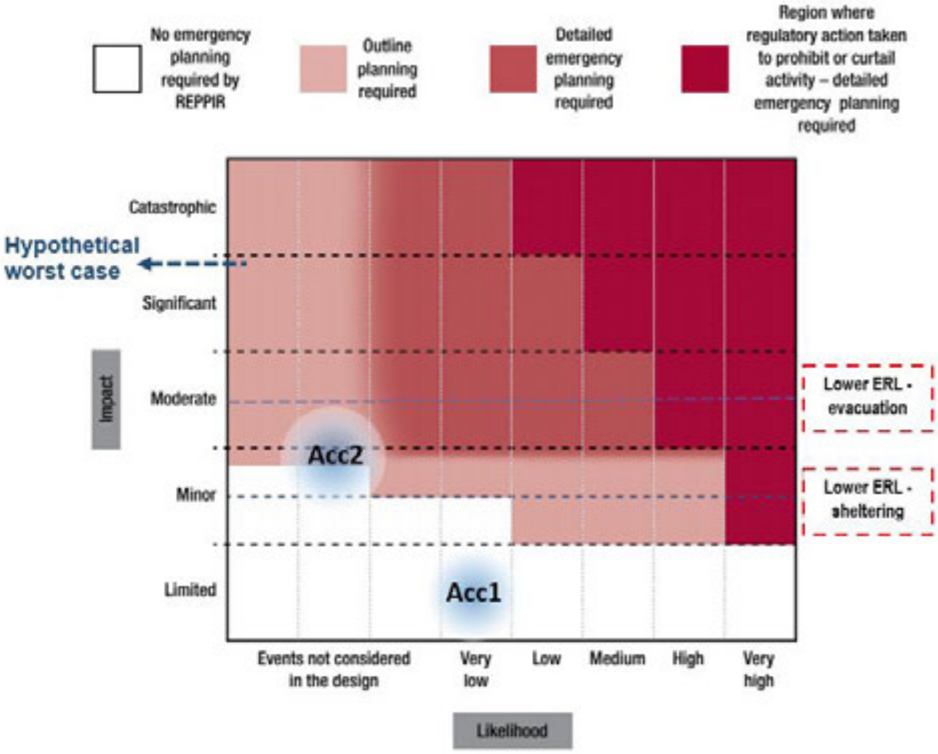
These accident and hypothetical scenarios[2] do not depict wholly realistic situations but serve to illustrate worse-case eventualities in order to identify the maximum potential hazard of a fusion power plant. By way of comparison, unmitigated or hypothetical accident scenarios in the aviation, oil and gas or nuclear fission industries could have similar or worse consequences that those described here for a fusion power plant, involving multiple fatalities and/or severe environmental damage. Worldwide, accident prevention and mitigations measures are put in place that considerably reduce the risks around such events. Such measures would be put in place for a fusion power plant.

Regulation of potential accidents

The Radiation (Emergency Preparedness and Public Information) Regulations 2019 (REPPIR 2019)[3] require facilities in Great Britain which handle specified quantities of certain radioactive materials to undertake emergency planning in proportion to the risks involved, considering both potential impact – in terms of dose to individuals – and likelihood. The way in which operators comply with REPPIR 2019 illustrates how UK regulation addresses hazard in a way that is proportional to that hazard.

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

In summary, this analysis focused on the tokamak approach to fusion using the D-T reaction. However, it is



expected that the findings from this analysis will be applicable to fusion power plant based on different technologies, such as inertial confinement and magnetised target fusion devices using D-T fuel. Although the

[2] Based on indicative radioactive inventory estimates relevant to a DT tokamak-based fusion power plant. The information underpinning the accident scenario assumptions draws on studies of early conceptual designs. As the variables are strongly dependent on the technology, design and materials, as well as the accident scenario itself and any mitigations present, there is significant uncertainty around the maximum amount of inventory that could be released, but worst-case estimates used here seek to identify the upper bound. For all scenarios this analysis is based on worse-case assumptions in terms of estimated doses for the public at 1 km from the source.

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

detailed specifics of many of the accident sequences will be different, the worst-case radiological consequences are expected to be of the same order as those reported for similar accident scenarios.

Future analyses for safety and waste will be underpinned by greater technical certainty and information on inventory levels, which will reduce the uncertainty on the level of hazards. However, the hazards for fusion plant are well understood, and the continuing evolution of designs over the next couple of decades is unlikely to change the overall conclusions of this report.

A.3 Case Study – JA DEMO

In order to grasp the safety characteristics of Japan's DEMOnstration fusion reactor (JA DEMO), the Functional Failure Modes and Effects Analysis (FFMEA) has been carried out in National Institutes for Quantum Science and Technology (QST), where postulated initiating events (PIEs) have been selected and safety analysis regarding the PIEs has been performed. JA DEMO is currently designed as a pressurized water-cooled tokamak reactor with a major radius of ~ 8.5 m and a fusion power of 1.5 GW. The enthalpy of the cooling water of JA DEMO is about 5 times higher than that of ITER. Therefore, maintaining the soundness of the confinement barrier during In/Ex-Vessel Loss Of Coolant Accident (LOCA) is important from the viewpoint of ensuring the safety of JA DEMO.

As a result of the FFMEA, 14 events corresponding to system response accident events, and 5 events including superimposed events as the maximum PIEs were extracted. 13 out of 19 events were caused by the LOCA events. In these PIEs, the event with the greatest environmental impact was the guillotine break of the primary cooling pipe for the tritium breeding blanket as Ex-VV LOCA. In order to mitigate the pressurized effects against the Ex-VV LOCA, steam generators and heat exchangers with a large amount of coolant water retention is installed in the vault area, which has higher pressure tightness than other building areas, and a pressure suppression system (PSS) is connected to the vault area. The PSS connected to the vault also plays a role in passively recovering tritium contained in the water coolant vapor by the bubbling effect when the vapor containing tritium passes through during the Ex-VV LOCA.

For the worst-case of the Design Basis Accident (DBA) in the current design stage, which would be the event of the guillotine break of the primary cooling pipe, the use of the PSS against the Ex-VV LOCA brings a small public dose impact with a large safety margin to the evaluation target (< 5 mSv/event) at the site boundary (@ 1 km).

It should be noted that the maximum PIEs and the environmental impact will be revised when necessary according to the future design progress of JA DEMO. Furthermore, QST is considering the need for evaluation of Beyond DBA for the JA DEMO.

Annex B Public Perception

B.1 Introduction

Although there are differences in degree among countries, the current recognition and interest of fusion energy is relatively low. Government surveys, have provided some statistics around awareness and support for fusion energy amongst the public. In the aim of improving social acceptance of fusion energy, lessons can be learned from the nuclear fission industry. Strategic and long-term planning is important, including the promotion of appropriate initiatives and communications for each of the targets and priorities.

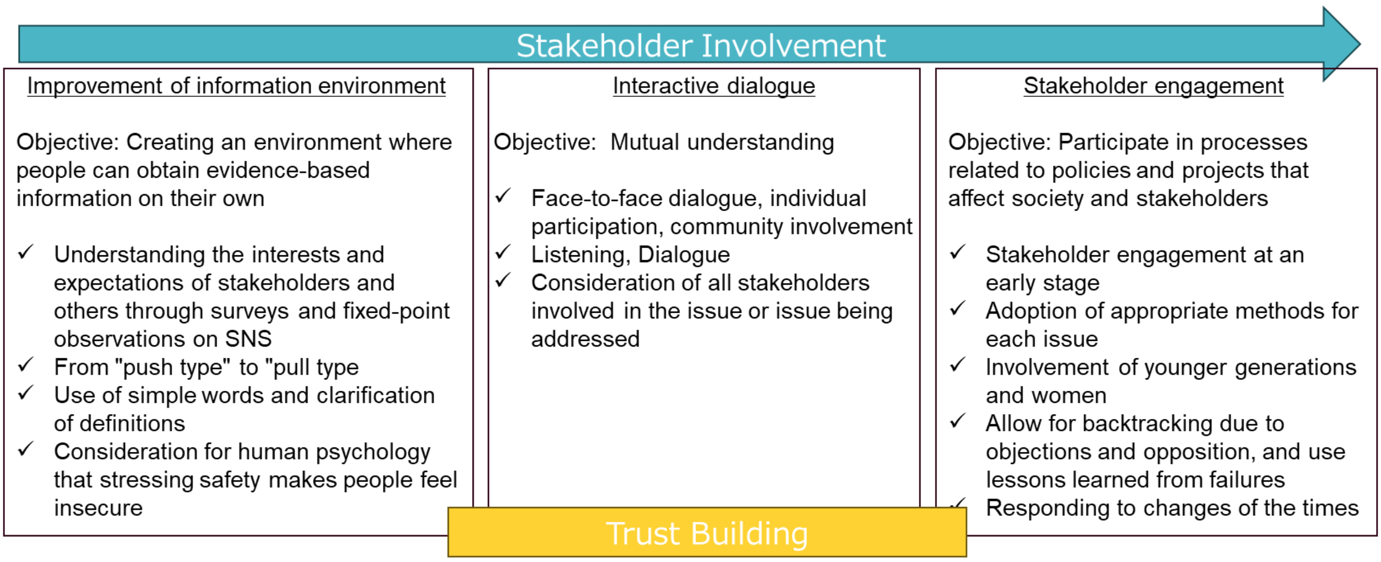
It is necessary to assure scientific safety, of course, but it is also necessary to be aware that people's peace of mind is another matter. Thus consideration of public sentiment and scientific explanations for public understanding are also necessary. This Annex provides two Case Studies based on public surveys in relation to awareness of fusion.

B.2 Case Study - Japan Government Public Acceptance and Understanding Activities

The Government of Japan’s findings in relation to the public acceptance and understanding of activities regarding nuclear fission, recognise the challenges of how information should be provided to the public. The kinds of activities proposed to address these challenges can equally be applied to fusion.

It is necessary to respond to the public's interest and strengthen efforts and activities by further promoting communication activities such as interactive dialogues and public hearings, while paying full attention to the uncertainties and risks of science. An information system based on scientifically accurate information and objective facts (evidence) must be established to promote an environment in which each citizen can form their own opinions based on a deeper understanding of such information. It is also necessary to respond flexibly to rapid changes in the means of obtaining information, including the Internet and social networking services (SNS), and to make constant improvements in the maintenance of information using various media.

The Atomic Energy Commission has proposed a structure[4] for stakeholder participation, considering the types and means of providing information, through to engagement and dialogue with the public:



[4] Provisional translation of Initiatives Related to Stakeholder Involvement, 2018, The Office of Atomic Energy Policy of the Cabinet Office - Japan. http://www.aec.go.jp/jicst/NC/iinkai/teirei/siryo2018/siryo09/siryo1-1.pdf

In relation to public acceptance of fusion, each of these stages could be expected to take 3-4 years, and target public groups including school and university students, as well as stakeholders related to the industry. It would aim to build public trust by the following, conducting surveys at each step to gauge public attitude:

- Establishing methods of dialogue with the public (including developing content and tools)
- Creating a forum for dialogues with the public
- Building social consensus with the public

In summary, regarding "fusion", people still have a relatively low interest, and the public mood is not matured yet to discuss about the regulation of fusion energy. Thus public consensus needs to be made strategically step by step, considering the importance of inviting public opinion on the policy making process. Considerations include setting up a task force or working groups consisting members of the public alongside industry and regulatory specialists and science communication experts.

B.3 Case Study - UK Government Public Attitudes Tracker

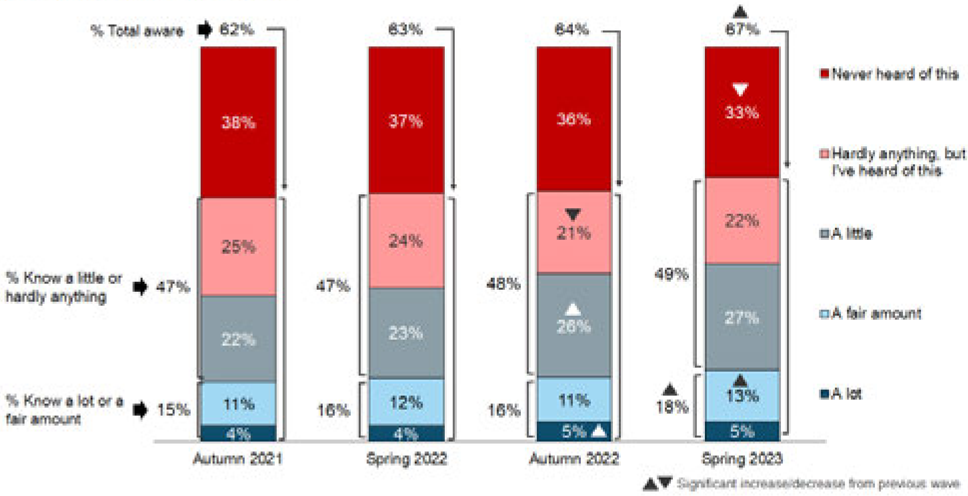
The UK Government Department for Energy Security and Net Zero (DESNZ) has a Public Attitudes Tracker, which since 2021 has included questions on Energy Infrastructure and Energy Sources. The survey includes questions related to fusion energy, and four sets of results have been obtained at six monthly intervals. The surveys are sent to a random sample of addresses, and are then completed on-line, with of the order of 4000-5000 respondents each time. The latest report[5] covers the surveys since 2021.

The questions aim to track the level of awareness and support for fusion energy, and includes the following background and questions:

"*Fusion energy is an experimental technology that works by fusing together atoms in order to release energy. The UK is exploring whether this technology could be used to generate zero carbon electricity.*

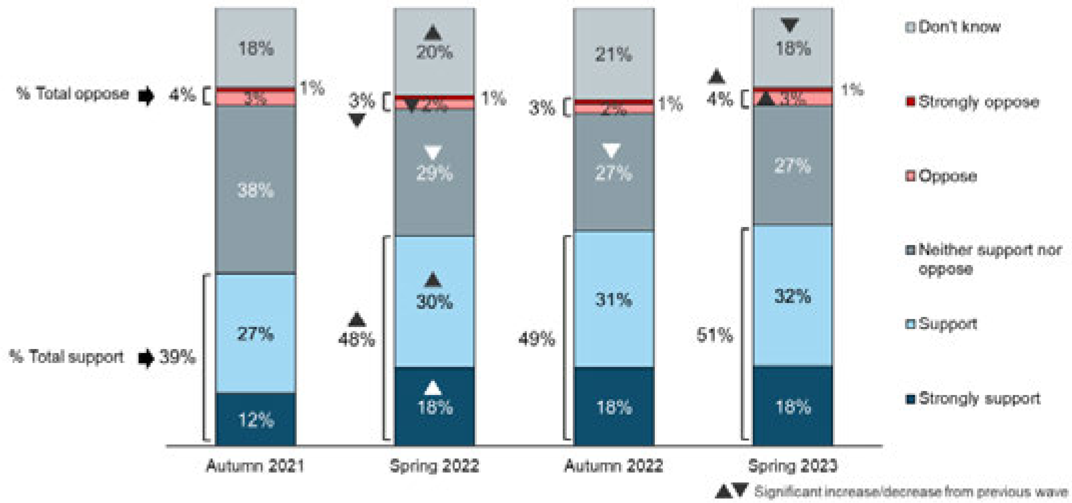
- **Before today, how much, if anything, did you know about fusion energy ? (Figure 4.1).**
- **From what you know, or have heard about fusion energy, do you support or oppose the UK developing this technology ? (Figure 4.2)."**

Figure 4.1: Awareness of fusion energy (based on all people), Autumn 2021, Spring and Autumn 2022, Spring 2023



[5] DESNZ Public Attitudes Tracker: Energy Infrastructure and Energy Sources, Spring 2023, UK. DESNZ PAT Spring 2023 Energy Infrastructure and Energy Sources (publishing.service.gov.uk)

Figure 4.2: Whether support fusion energy (based on all people), Autumn 2021, Spring and Autumn 2022, Spring 2023



In summary of the public attitudes in the UK:

- Around half of those surveyed had not really heard of fusion energy, although awareness had increased by a few percent over the past couple of years.
- Around half of those surveyed did not have a view either way on supporting or opposing fusion energy, reflecting the low overall levels of awareness.
- Only 4% of those surveyed opposed development of fusion energy.