UKAEA-CCFE-PR(18)78

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This is a preprint of a paper submitted for publication in
Energy Research and Social Science

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Abstract

The public acceptability of emerging industrial technologies, can affect their chances of commercial success. In large, demographically diverse samples from the United Kingdom ($N = 438$) and Germany ($N = 390$) – recruited to an online questionnaire-based survey study – we show for the first time the stigmatizing impact that the proposed use of depleted uranium as a tritium fuel storage option for nuclear *fusion* has upon public attitudes towards nuclear *fusion*. We also show how this stigmatizing impact can be partially reversed through the provision of a small amount of factual information about the nature and purpose of depleted uranium. The study findings have clear implications for public engagement and communication efforts relating to current and future nuclear fusion demonstration projects.

1. Background

The public and broader social acceptability of emerging industrial technologies can affect their chances of commercial success or failure.[1] By, for instance, lobbying politicians or engaging in other forms of supportive or oppositional protest, publics can influence the decisions made about technologies at a strategic/national level and the ease of deploying facilities at regional and local levels. Indeed, there are a growing number of instances where problems or failures within public engagement and deliberation have led, in part, to delays or curtailments to the introduction of new technologies at both national (e.g. *genetically modified agriculture*) and local levels (e.g. *renewable energy technologies*).[2–5] This raises the importance of engaging publics early in the development cycle of technologies such as these in order to learn more about the nature and antecedents of their attitudes.[1,6,7]

Consistent with this, efforts to understand the nature and antecedents of public attitudes and perceptions of emerging technologies is increasingly considered to be a key component of the research, development, demonstration and deployment process. Moreover, there are growing calls for upstream (i.e. earlier) and participatory involvement of publics early in the development cycle of these technologies.[8,9] This is seen as particularly important within Westernised democracies where policy and institutional change often requires the support of affected individuals and communities.[6]

The current article reports on the findings of a questionnaire-based survey study conducted in two European countries (i.e. the UK and Germany) designed to assess lay-public responses to the use of depleted uranium beds within a tritium processing plant being trialled for use in future planned demonstration and commercial-scale nuclear *fusion* reactors. While depleted uranium beds are a mature and reliable technology, questions remain as to how their intended use might affect public approval of nuclear *fusion*.

1.1. Public perceptions of nuclear fusion and the stigmatizing effect of language

Nuclear *fusion* is seen as a means of generating a secure, safe, carbon- and combustion-free source of energy for use in electric power generation.[10] Thus, nuclear *fusion* is considered as an important part of the energy portfolio for meeting future, growing demand for electricity in a carbon-constrained world.[11] With this in mind, there are ongoing efforts to research, develop and demonstrate the technical and commercial feasibility of the technology.

In Europe, there is an established roadmap for achieving this goal by 2050.[12] This roadmap – designed and curated by *EUROfusion*[13] – begins with the experiments currently being conducted at the Joint European Torus (JET) facility in the UK. The results of these experiments are helping to inform the design and operation of ITER, which will be the world's largest and most advanced experimental fusion reactor. ITER is under construction in France and when complete will be the first magnetic confinement device to produce net surplus energy during operation (equivalent to that of a 500MW power plant). ITER – a joint collaboration between Europe and a number of partners (e.g. China, Russia, India and the USA) – will ultimately form the basis of DEMO. DEMO will be a functioning demonstration power plant capable of supplying electricity to the grid and is anticipated to be the final step between ITER and a commercial power plant.

Crucially, *EUROfusion* also recognises the integral role that the opinions of the pubic (and other key stakeholders) will play in shaping the path to the development of a commercial-scale nuclear *fusion* power plant. Congruently, there is an active social and economic studies team seeking to develop current understanding the roots of acceptance or rejection of nuclear *fusion* at socio-political and local levels.[13]

The existing literature on public (and other stakeholder) perceptions and attitudes towards nuclear *fusion* has begun to reveal much about their nature and antecedents, as well as the discourses used by lay-publics to think about the technology.[14–17] For instance, scepticism about the viability and relevance of *fusion* technology is commonplace due to the reported (and perennially distant) timescales to commercial operation.

One of the key findings arising from this existing research has been the discovery of the negative 'branding' influence that the use of the term 'nuclear' can have upon opinions of *fusion*. In short, the nuclear label has been found to be associated with powerful, rich and detailed collection of ideas and images (e.g. relating to catastrophic nuclear *fission* disasters like Chernobyl and Fukushima, as well as concerns about nuclear proliferation and nuclear war) which can serve to instantly tarnish the things that the term is affiliated with.[15] Indeed, the stigmatizing influence of the term 'nuclear' is thought to have been so pervasive and fear-inducing so as to lead to the decision to drop it from the name (nuclear) Magnetic Resonance Imaging (MRI) – a form of medical imaging technology.[18]

The stigmatization of nuclear *fission* arising from such branding resonates with social psychological concepts relating to human judgement and decision-making such as the 'affect heuristic', the 'risk as feelings' hypothesis and other models of judgement that distinguish experiential and more analytic reasoning.[19,20] All of these point to the prominent role that affect ('gut' emotional reactions) can play in driving perceptions of the risks, costs, benefits and acceptability of unfamiliar hazards.[20] Indeed, research indicates that where people possess little knowledge of a given topic or hazard, they will often rely upon their experiential or 'hot' (i.e. affective) system to evaluate it as opposed to their analytic or 'cold' (i.e. cognitive) system.[19,21,22] With this in mind, it is perhaps unsurprising that a person's attitudinal and behavioural responses to unfamiliar topics or hazards can often hinge upon the terminology that is used to describe them.

A key stigmatizing property of nuclear *fission* is its use of enriched uranium. Enriched uranium is a form of the metal processed to contain a high (i.e. higher than in naturally occurring uranium) proportion of the fissile uranium-235 isotope. Enriched uranium is needed to drive the fission reaction and generate power but simultaneously introduces the risk of nuclear meltdown (through overheating) and is the source of highly radioactive and long-lived legacy waste, both of which are recognized as key issues for fostering public acceptance.[21,23,24]

Nuclear *fusion* does not use enriched uranium but instead reacts two forms of hydrogen isotope (deuterium and tritium) at high temperatures to generate power.[25] As tritium is a radioactive isotope of hydrogen, though, it requires special handling. As part of the experimentation using the Joint European Torus (JET), fusion researchers at the Culham Centre for Fusion Energy are trialling the use of an fuel storage option that utilises depleted uranium beds to store the radioactive tritium.[26–28] Depleted uranium beds are technically favoured for this purpose due to the material properties of depleted uranium, which allow for more efficient storage and retrieval of the tritium fuel than other available options (e.g. Zirconium Cobalt).[29]

Akin to the stigmatizing influence proffered by the use of the term ‘nuclear’, however, we hypothesise that the use of depleted uranium (so called as it is processed to contain less of the radioactive uranium-235 isotope than natural uranium) could stand to exert a similar branding influence on perceptions of *fusion* technology among members of the general population. If such a stigmatizing effect were to be observed, this could stand to compromise public support for nuclear *fusion* as a power generating option for the future. Crucially, we argue that this stigmatizing influence could occur in a number of ways. For example, where people conflate depleted (lower radioactivity) and enriched (higher radioactivity) forms of uranium due to their shared nomenclature; where the term ‘depleted’ is deemed to communicate material weakness or deficiency; and/or where depleted uranium is associated with undesirable historical uses (e.g. the use of depleted uranium in munitions manufacture for armed conflicts like the Gulf War).[30]

1.2 Research objectives

The primary objective of the current research was thus to assess whether the proposed use of depleted uranium as a tritium fuel storage medium would have a stigmatizing influence on lay-public attitudes towards nuclear *fusion*. For the reasons outlined above, it was hypothesised that the prospect of using ‘depleted uranium’ would exert a significant, negative impact upon respondents’ attitudes (Hypothesis 1). Crucially, a secondary aim was to investigate whether the anticipated stigmatizing influence could be lessened by the provision of a small amount of information about the true nature and purpose behind the proposed use of depleted uranium. While one should take care not to assume that the rejection of technologies is simply the product of a lack of the ‘correct’ knowledge about them[31,32], there is growing evidence of the benefits of efforts to educate and inform publics about unfamiliar technologies in order to promote understanding, counter misperceptions and encourage informed discussion about their use. [33,34] Within the current context, we hypothesised that the opportunity to delineate the depleted and enriched forms of uranium via the provision of information should significantly reverse any stigmatizing impact initially observed (Hypothesis 2).

2. Methods

2.1 Participants and Recruitment

Participants were recruited via an online survey-platform provider (Qualtrics: www.qualtrics.com). Demographically representative (in terms of age, gender) samples of participants were targeted in each country using an online participant-panel function provided by the survey-platform provider. Respondents received a small financial reward in exchange for their participation.

Of the N = 1157 UK respondents that began the survey, n = 719 were removed for either failing to complete the survey, ‘straight-lining’ responses to key questions (i.e. Q27 and Q36), indicating that they would not provide their best answers and/or for being a non-national (i.e. UK) resident. This left a final UK sample of N = 438. Of the N = 553 Germany respondents beginning the survey, $n = 163$ were removed for one or more of the reasons stated above, leaving a final Germany sample of $N = 390$.

UK vs. Germany cohort comparison

The UK and Germany respondents were statistically comparable in terms of their trust in science, $t\ (826) = 0.11$, $p = .917$; their environmental values, $t\ (818) = 0.88$, $p = .381$; and their concern with the personal and societal impacts of climate change, $t\ (791.73) = 1.71$, $p = .089$ and $t\ (826) = 0.58$, $p = .562$, respectively. The UK respondents were more concerned by the issue of energy security than the Germany sample, $t\ (819) = 7.05$, $p < .001$.

While the gender distribution in each sub-sample was statistically comparable, $\chi^2\ (3, N = 828) = 2.73$, $p = .435$ (with an approximately 50% split in male and female respondents), there were statistically significant differences on some of the other socio-demographic measures.

Distribution of home vs. foreign nationals: There was a slight overrepresentation of foreign nationals within the UK sample and slight underrepresentation within the Germany sample, $\chi^2\ (2, N = 793) = 6.06$, $p = .048$.

Education level: There was a higher than expected number of UK respondents studying for (or with) undergraduate degrees relative to the number having attained only a Secondary/High or Primary school education. These trends were reversed for the Germany sample, $\chi^2\ (4, N = 828) = 28.61$, $p = < .001$.

Age: There was a higher than expected count in the older age categories (55 years and above) for the UK sample and a lower than expected count for these categories in the Germany sample. These relationships were reversed in many of the younger age categories (25–54 years), $\chi^2\ (6, N = 828) = 19.25$, $p = .004$.

Employment status: There were greater than expected numbers of Germany respondents in paid employment or education, with fewer than expected in retirement. These relationships were reversed in the UK sample, χ^2 (5, N = 828) = 22.28, p < .001.

Taken together, the modal respondent in the UK sample was slightly older, had received more formal education but was less likely to be paid forms of employment (perhaps due to retirement) than the modal Germany respondent. These slight demographic differences should be considered when drawing conclusions from each of the statistical analyses. For the frequencies, proportions, means and standard deviations associated with these socio-demographic analyses, see Table 1.

[TABLE 1 ABOUT HERE]

2.2 Measures and Materials

We used a questionnaire-based survey (QBS) to establish: (a) the nature of lay-public attitudes towards nuclear fusion technology; and (b) to track how the proposed use of depleted uranium (DU) as a fuel-handling option might affect these attitudes. The QBS comprised nine sections (structured as illustrated in Figure 1) and was created in English and German. Below we outline the primary features of each of these nine sections.

[FIGURE 1 ABOUT HERE]

1. *QBS introduction*

A short paragraph introduced the researchers and their affiliations, provided an ethical statement and outlined that the QBS was interested in respondents' initial impressions (including perceived advantages and disadvantages) of nuclear fusion. The distinction between nuclear fission and fusion was drawn and respondents were informed that no prior knowledge was required to complete the survey and that we were interested in their personal opinions based upon what they knew of currently understood at the time of completion.

2. *Section A: Demographics and initial opinions of nuclear fusion + Tracker Questions (Time 1)*

Section A recorded key demographic details of the respondents and their baseline awareness, attitudes and familiarity with nuclear fusion technology. The questions and response options of relevance to the current study are outlined Appendix A, Table A1. Section 1 also included questions to identify respondents that did not adhere to the inclusion criteria for the study, i.e. respondents (a) not living in the UK or Germany at the time of the survey; and/or (b) not agreeing to provide good quality responses to the survey questions.

Tracker Questions

A set of five tracker questions assessed people's attitudes towards nuclear fusion at four key points of the survey (outlined below). These questions (all accompanied by 5-point response scales) assessed respondents' affective response to NFT; how beneficial, risky and worthy of investment they perceived NFT to be; and whether they would be happy to have a facility constructed locally:

1. On a purely emotional level, how positive or negative do you feel about NFT? (very negative - very positive)
2. If developed, how beneficial or unbeneficial do you think NFT could be? (very beneficial – very unbeneficial)
3. Generally speaking, how risky or safe do you think NFT is? (very risky – very safe)
4. How worthy or unworthy of investment do you view NFT as being? (very unworthy – very worthy)
5. How happy or unhappy would you be for a nuclear fusion power plant to be built near you? (very unhappy – very happy).

Scale analysis on these questions for each sample at each time-point (i.e. Time 1: pre-information about fusion; Time 2: post-information about fusion; Time 3: pre-information about DU; and Time 4: post-information about DU) revealed that they had good-excellent reliability (Cronbach's α ≥ .86). Responses to these questions were averaged to form a composite score (i.e. *attitude to nuclear fusion*) for each sub-sample at each time point.

3. *Factual information about nuclear fusion*

Respondents received two short paragraphs of text and simple accompanying diagrams designed to: (a) the key differences between nuclear *fission* and nuclear *fusion* and how they are used to generate power; and (b) outline the current roadmap (and timescales) for moving nuclear fusion from its present (i.e. Joint European Torus or JET) and future (i.e. ITER c.2025) experimental-testing phases to full-scale commercial operation (i.e. DEMO c.2050). Respondents then received brief details of five key advantages (i.e. sustainable and abundant energy; no carbon dioxide and no high-activity or long-lived radioactive waste; no risk of nuclear meltdown; low operating costs) and five key disadvantages (i.e. impact on energy demand; radioactive fuel and low-level radioactive waste products; no full-scale electricity production expected until 2050; high start-up costs).

All information was prepared by the Culham Centre for Fusion Energy (CCFE). The information was designed to be basic, informative and balanced. To ensure this was the case, respondents were invited to evaluate the information on four qualitative dimensions (using 7-point scales; strongly agree - strongly disagree, plus DK). On average, respondents agreed (or somewhat agreed) that the information was understandable (n = 827, *Mean* = 2.22, *SD* = 1.21); balanced (n = 821, *Mean* = 2.46, *SD* = 1.15); of good quality (n = 824, *Mean* = 2.32, *SD* = 1.08); and sufficient for them to make an informed decision about nuclear fusion technology (n = 824, *Mean* = 2.83, *SD* = 1.39). See Supplementary Information for exact wording and diagrams.

4. *Section B: Evaluations of attributes of nuclear fusion technology + Tracker Questions (Time 2)*

Section B was mainly designed to investigate the antecedents of respondents' opinions towards nuclear *fusion*. For example, respondents we asked to respond to 27 statements relating to perceived advantages (e.g. "an attractive low-carbon electricity source for the future") and disadvantages (e.g. "sounds too good to be true") of nuclear *fusion* (7-item scales, strongly agree - strongly disagree, plus DK). The responses to these questions are not analysed further as they are not of focal interest to the current article.

Section B did, though, also contain the section set of Tracker Questions, which are analysed within this article.

5. *Section C: Initial awareness of and attitudes towards depleted uranium + Tracker Questions (Time 3).*

Respondents were asked about their awareness ("Before today, had you heard of depleted uranium?" Yes; No) and self-claimed knowledge ("How much would you say you know about depleted uranium?" Nothing – have not heard of it; Nothing - have only heard the name; A little; A fair amount; A lot) of depleted uranium.

To assess how affective responses to the term depleted uranium compared with other terms incorporating the word uranium (i.e. uranium; natural uranium; enriched uranium); respondents were asked to rate how uneasy or calm each of the terms made them feel (10-point scale of 1-10, extremely uneasy – extremely calm). Respondents were also required to rate three other terms related to nuclear *fusion* (i.e. uranium hydride, metal hydride and zirconium cobalt), however responses to these terms are not analysed as part of the current research.

In order to investigate the antecedents of respondents' attitudes towards depleted uranium, they were asked to respond to 16 statements describing the *positive use-value* of depleted uranium (5-items: e.g. "Has important industrial uses"; "Is being put to good use by being used in NFT [nuclear fusion technology]"); the *negative use-value* of depleted uranium (5-items: e.g. "Creates unwanted links between fission and fusion industries; "Unduly increases the risks associated with NFT") and common *negative associations* with depleted uranium (4 items: e.g. "Has negative affiliations with nuclear weapons; "Has negative associations with terrorism"). Two additional items assessed the *positive labelling potential* (i.e. "Sounds less hazardous than uranium") and *negative labelling potential* (i.e. "Sounds more hazardous than uranium") of depleted uranium relative to uranium. A full list of these items is available in Table 4. Items were created based upon the findings of focus groups from a separate study conducted prior to the creating the survey.

Reliability analysis indicated that the items within each sub-scale had acceptable to good reliability for both countries (Cronbach's $\alpha \geq 0.77$) and so they were averaged to form composite variables of *positive use-value*, *negative use-value*, and *negative associations*. The *positive-labelling* and *negative-labelling potential* items (reverse coded) did not form a scale with acceptable reliability (α = .44) and so were treated separately. The section ended with Tracker Questions (Time 3).

Note: An additional question inviting respondents to name the first 3 words or phrases that they associated with the term 'depleted uranium' was included in this section; however, these qualitative data are not analysed within the current article.

6. *Factual information about depleted uranium*

Respondents were provided with two short paragraphs and accompanying diagrams designed to outline: (a) the basic characteristics of depleted uranium (e.g. how it is low-radioactivity form of uranium produced as a by-product of uranium enrichment); and (b) the nature of its use as a means of storing tritium within the current (i.e. JET) and future (ITER c.2025) nuclear fusion demonstration projects. Respondents also received short statements outlining the advantages (e.g. that it can be used to capture and store tritium at room temperatures in a fully-reversible reaction; and that disposal routes for the low-radioactive waste that is produced are already in place) and disadvantages (e.g. that it is chemically toxic if touched, inhaled or ingested; that it is pyrophoric in power form; and that it is classed as a nuclear material which could limit where future demonstration projects could be located).

The information was prepared by the Culham Centre for Fusion Energy (CCFE) and was again designed to be balanced and accessible. Respondents were invited to evaluate the information (using 7-point scales; strongly agree - strongly disagree, plus DK) on the same qualitative dimensions as outlined above. On average, respondents agreed (or somewhat agreed) that the information was understandable (n = 823, *Mean* = 2.55, *SD* = 1.34); balanced (n = 815, *Mean* = 2.68, *SD* = 1.27); of good quality (n = 817, *Mean* = 2.57, *SD* = 1.19); and sufficient for them to make an informed decision about NFT (n = 813, *Mean* = 3.04, *SD* = 1.45). See Supplementary Information for exact wording and diagrams.

7. *Section D: Identifying change to opinions about Depleted Uranium (DU) + Tracker Questions (Time 4)*

In order to check whether the provision of information had changed respondents' opinions about DU; they were again invited to complete the 16 *positive use-value, negative use-value, negative association* and positive- and negative-labelling items. They then completed the final set of Tracker Questions (Time 4).

8. *Section E: Trust in Science, Biospheric Values, and Energy Security and Climate Change Concerns*

Respondents completed the 'Trust in Science and Scientists Inventory' (Nadelson et al. 2014). This 21-item scale measures domain-general trust in science and scientists. Responses are made on a 5-point scale (strongly disagree – strongly agree), with higher scores pertaining to greater trust. Example items include: "Scientists ignore evidence that contradicts their work" (reverse coded); "I trust in the work of scientists to make life better for people". The internal reliability of the scale was excellent for both the Germany and UK sub-samples ($\alpha \geq .90$) and so the items were averaged into one composite measure of '*trust in science and scientists*'.

Biospheric values were assessed using four items taken from De Groot & Steg (2008). Respondents were required to rate how important they viewed: (1) Preventing pollution: protecting natural resources; (2) Respecting the earth: harmony with other species; (3) Unity with nature: fitting into nature; and (4) Protecting the environment: preserving nature. Responses to these items were made on a 5-point scale (Not at all important – extremely important, plus DK). The internal reliability of the items was excellent for both sub-samples ($\alpha \geq .92$) and so the items were averaged into one composite measure of '*biospheric values*'.

Energy security concerns were assessed using a 6-item measure developed by Corner and colleagues (2011). Respondents were asked to register their level of concern (4-point scale: Not at all concerned – Very concerned, plus DK) about the future rationing of energy; affordability of energy; reliance on energy imports; threat of terrorist disruption to supply lines; potential for power cuts and depletion of fossil fuels. The scale had good internal consistency for both sub-samples ($\alpha \geq .82$) and so a composite measure of '*energy security*' was calculated.

Climate change concern was assessed with two items, one registering concern over the potential personal consequences and the other concern about possible societal consequences: i.e. "Considering any potential effects of climate change which there might be on *you personally* [*society in general*], how concerned, if at all, are you about climate change?" (4-point scale: Not at all concerned – Very concerned, plus DK).

9. *Debrief*

Upon completion of the QBS, respondents were fully debriefed as to the aims of the research and provided with links to websites where they could learn more about nuclear fusion.

3. Results

3.1 Awareness and self-claimed knowledge of nuclear fusion and depleted uranium

A. Nuclear Fusion: Fisher's exact tests showed that Germany respondents claimed to hold greater awareness of nuclear *fusion* than UK respondents ($p < .001$) and were less likely to conflate nuclear *fusion* and nuclear *fission* ($p = .046$). Congruently, independent samples *t*-tests revealed that Germany respondents had more self-claimed knowledge of nuclear *fusion* than UK respondents, $t\ (826) = 4.15$, $p < .001$, $d = .29$, despite both samples claiming to have only recently heard of nuclear *fusion*, $t\ (813) = 1.56$, $p = .119$, $d = .11$.

B. Depleted Uranium (DU): Fisher's exact tests revealed that both samples had comparable self-reported awareness of DU ($p = .487$), with around half the respondents in each sub-sample claiming to have heard of it. Both samples claimed to hold similarly low levels of knowledge of DU, $t\ (826) = 0.12$, $p = .915$, $d = .01$, with most indicating that they had only heard of the term. For the frequencies, proportions, means and standard deviations associated with these analyses, see Table 2.

[TABLE 2 ABOUT HERE]

Taken together, the Germany respondents were subjectively more familiar and knowledgeable about nuclear *fusion* than the UK respondents upon commencing the survey. Both sub-samples, however, demonstrated low and statistically comparable levels of awareness and knowledge of DU.

3.2 Uninformed evaluations of uranium terminology

To investigate the extent to which DU might be stigmatizing, we assessed respondents' uniformed evaluations of the term *depleted uranium* relative to other uranium-based terms (i.e. *uranium*, *natural uranium* and *enriched uranium*). In all instances evaluations of the terms were lower than the hypothetical scale midpoint (5.50) indicating a relative unease. For relevant means and standard deviations, see Table 3.

[TABLE 3 ABOUT HERE]

A 2 (Country: UK, Germany) x 4 (Term: Uranium, Natural Uranium, Enriched Uranium, Depleted Uranium) repeated-measures ANOVA with Greenhouse-Geisser correction ($\varepsilon = 0.95$) due to violation of Mauchley's test of sphericity ($\chi^2\ (5) = .91$, $p < .001$) was conducted to see if the terms were evaluated differently both within and between the UK and Germany sub-samples. Significant main effects of Term, *F* (2.84, 2344.64) = 100.07, $p < .001$, $\eta_p^2 = .11$, and Country, *F* (1, 826) = 5.41, $p = .020$, $\eta_p^2 = .01$, were qualified by a significant Term*Country interaction, *F* (3.84, 2344.64) = 12.64, $p < .001$, $\eta_p^2 = .02$.

Independent samples *t*-tests confirmed that both sub-samples were comparable in their evaluations of the terms *natural uranium*, *t* (826) = 1.17, $p = .244$, $d = .09$, and *depleted uranium*, *t* (1, 826) = 0.05, $p = .959$, $d < .01$. The UK respondents were significantly less anxious about the terms *uranium*, *t* (826) = 2.11, $p = .035$, $d = .15$, and *enriched uranium*, *t* (826) = 4.80, $p < .001$, $d = .33$.

These findings revealed that the term DU was a source of unease for respondents in both countries and so there was reason to suspect that the term should exert a negative influence on attitudes to nuclear *fusion* when associated with the technology. In the UK, the level of unease felt by the term DU was equivalent to that stimulated by the term *enriched uranium*. Among the Germany sample, the term *enriched uranium* was more negatively evaluated compared with that of DU, however, evaluations of the term DU remained negative.

3.3 Assessing stigmatizing influence of depleted uranium

In order to investigate how participants' attitudes towards nuclear *fusion* had developed over the course of the survey, a 2 (Country: UK, Germany) x 4 (Time: Time 1, Time 2, Time 3, Time 4) repeated measures ANOVA with Greenhouse-Geisser correction ($\varepsilon = 0.75$, Mauchley's test: χ^2 (5) = .82, $p < .001$) was conducted using the composite mean responses to the *Tracker Questions* as the dependent variable. As a result of this analysis, it was possible to investigate how baseline attitudes at Time 1 differed from those following the provision of some basic information about fusion (Time 2). The extent to which these more informed attitudes (Time 2) were affected by the announcement that DU was being considered as a means of fuel storage (Time 3). And the impact that the provision of information about the nature of

DU might have on these attitudes (Time 4). For the relevant means associated with this analysis, see Figure 2.

Analysis of the within and between-subjects contrasts revealed significant main effects of Time, F (2.47, 2042.87) = 37.00, $p < .001$, $\eta_p^2 = .04$, and Country, F (1, 826) = 3.95, $p = .047$, $\eta_p^2 = .01$; however, the Time*Country interaction was not significant, F (2.47, 2042.87) = 1.50, $p = .218$, $\eta_p^2 = .01$.

[Figure 2 ABOUT HERE]

On average, UK respondents were more positive about nuclear *fusion* than Germany respondents throughout the survey. While Germany respondents' attitudes started from a position of true ambivalence (Mean = 3.00; SD = 0.86), UK respondents were generally favourable to nuclear *fusion* (Mean: 3.14; SD = 0.85). Despite this, the trends (i.e. the extent and direction) in attitudinal responses at each key time point was markedly similar – showing a common 'flip-flop' pattern (see Figure 2).

Planned pairwise comparisons on the full-sample means (vs. Time 1) revealed that the information provided about nuclear *fusion* between Time 1 and Time 2 had a significant positive effect on attitudes (Mean Diff. = +0.18, $p < .001$). The news that DU was to be used in the tritium handling system (between Time 2 and Time 3) returned attitudes to their Time 1 (i.e. baseline) levels (Mean Diff. = +0.01, $p = .999$). While the provision of information about the nature and purpose of DU (between Time 3 and Time 4) did improve attitudes to nuclear *fusion* once again (Mean Diff. = +0.07, $p = .018$); they failed to recover to the levels seen before the use of DU was announced (Mean Diff. vs. Time 2 = -0.11, $p < .001$).

These analyses confirmed both our primary hypotheses: (1) that the term DU did appear to have a stigmatizing influence on attitudes towards nuclear *fusion*; and (2) that this stigmatizing influence could be somewhat (although not wholly) reversed by the provision of information about the nature and purpose of DU.

3.4 Explaining the stigmatizing influence of DU

Multiple linear regression (MLR) analysis (using pairwise deletion) was used to predict respondents' evaluations of nuclear fusion at Time 3 (i.e. where the stigmatizing effect of the proposed use of DU appeared to occur). Respondents' subjective evaluations of: (a) the *negative use-value,* (b) the *positive use-value*, (c) the *negative associations*; (d) the *negative labelling potential* of DU; and (e) the *positive labelling potential* of DU, *before* receiving information about the material were included as predictors.

Separate analyses were run for the UK and Germany sub-samples. In both cases, assumptions for MLR were met although three outliers from the UK sub-sample and four from the Germany sub-sample were removed before analysis.

UK analysis: The regression model explained 25.8% of the variance in respondents' attitudes, $R^2 adj. = .258$, $F (5, 385) = 28.17$, $p < .001$. *Positive use-value* (*beta* = -.47, $p < .001$), *negative use-value* (*beta* = .15, $p = .025$) and *negative labelling potential* (*beta* = .13, $p = .014$) were retained as predictors. Stronger evaluations of the benefits of using DU and weaker evaluations of the drawbacks of using DU were associated with more favourable attitudes. Further, the more that people believed that DU sounded hazardous the less favourable they were to nuclear *fusion*.

Germany analysis: The regression model explained 32.9% of the variance in attitudes, $R^2 adj. = .329$, $F (5, 351) = 35.90$, $p < .001$. *Positive use-value* (*beta* = -.42, $p < .001$) and *negative labelling potential* (*beta* = .24, $p < .001$) were retained as predictors. Stronger evaluations of the benefits of using DU were associated with more favourable attitudes, while the more that people felt that the term DU sounded hazardous the less favourable they were to nuclear *fusion*.

3.5 Assessing the influence of information provision on attitudes to depleted uranium

In order to help explain the partial positive rebound in attitudes to nuclear *fusion* between Time 3 and Time 4 (i.e. following the provision of information about DU), a series of 2 (Country: UK, Germany) x 2 (Time: Time 3, Time 4) mixed between-within subjects ANOVAs were conducted. The dependent variables were respondents' evaluations of: (a) the *negative use-value*; (b) the *positive use-value*; (c) the *negative associations*; (d) *negative-labelling potential*; and (e) *positive labelling potential* of the material. For the means and standard deviations associated with these analyses, see Table 4.

[TABLE 4 ABOUT HERE]

Negative Use-Value: There was a significant main effect of Time, F (1, 798) = 32.04, $p < .001$, $\eta_p^2 = .039$, and a non-significant Time*Country interaction, F (1, 798) = 0.08, $p = .778$, $\eta_p^2 < .001$. The between-subjects contrast for Country was not statistically significant, F (1, 798) = 3.61, $p = .058$, $\eta_p^2 = .005$. Respondents' concern with the *negative use-value* of DU reduced to a similar extent in both countries after receiving information about DU.

Positive Use-Value: There was a significant main effect of Time, F (1, 787) = 88.36, $p < .001$, $\eta_p^2 = .101$, and a significant Time*Country interaction, F (1, 787) = 6.22, $p = .013$, $\eta_p^2 = .008$. The between-subjects contrast for Country was not significant, F (1, 787) = 0.02, $p = .890$, $\eta_p^2 < .001$. Respondents' evaluations of the *positive-use value* of DU improved over time, with this improvement being more pronounced in the UK.

Negative Associations: The main effect of Time was significant, F (1, 803) = 46.19, $p < .001$, $\eta_p^2 = .101$; as was the Time*Country interaction, F (1, 803) = 4.06, $p = .044$, $\eta_p^2 = .005$. The between-subjects contrast was not significant, F (1, 787) = 0.02, $p = .250$, $\eta_p^2 = .002$. There was a reduction in the perceived *negative associations* connected to DU in both countries, with a more pronounced effect in the UK sub-sample.

Negative Labelling: The main effect of Time was significant, F (1, 805) = 90.88, $p < .001$, $\eta_p^2 = .101$; as was the Time*Country interaction, F (1, 805) = 4.22, $p = .040$, $\eta_p^2 = .005$.

The between subjects contrast was not significant, F (1, 805) = 2.45, p = .118, $\eta_p^2 = .003$. Respondents' in both countries were less likely to view DU as being more hazardous than uranium after having received information about DU. This effect was more pronounced in the UK sub-sample.

Positive Labelling: The main effect of Time was significant, F (1, 781) = 70.64, $p < .001$, $\eta_p^2 = .083$; as was the Time*Country interaction, F (1, 781) = 4.10, p = .043, $\eta_p^2 = .005$. The between subjects contrast was not significant, F (1, 781) = .013, p = .908, $\eta_p^2 < .001$. Respondents in both countries were more likely to see DU as less hazardous than uranium at Time 4. This effect was more pronounced among the UK sub-sample.

4. Discussion

The results of this study provide first insight into the stigmatizing influence that the proposed use of depleted uranium (DU) within a planned tritium fuel storage option for nuclear *fusion* has upon public attitudes towards the technology. While objectively less radioactive than natural and enriched form of uranium, depleted uranium was discovered to evoke feelings of anxiety within both our UK and Germany samples. In the UK, this general unease was equivalent to that yielded by the term enriched uranium, while in Germany evaluations of the term were less extreme but still negative. Congruently, and as predicted (Hypothesis 1), the proposed pairing of DU with nuclear *fusion* led to a significant downturn in respondents' evaluations of nuclear *fusion* (Time 2 to Time 3). Interestingly, the magnitude of the stigmatizing impact on attitudes was statistically comparable in both our UK and Germany sub-samples.

Further investigation of the predictors of this downturn in attitudes revealed that a general sense that DU might be more hazardous than uranium *per se* (i.e. *negative labelling potential*) was a key predictor. This was accompanied by evaluations of whether DU was, or was not, perceptively being put to a good and acceptable use by being linked to nuclear *fusion* (i.e. *positive and negative use value*, respectively). By contrast, respondents' awareness of the negative historical associations that DU shares other sectors (e.g. armed conflict) was not found to be predictive.

We argue that this negative 'branding effect' most likely stemmed from respondents initially conflating depleted (unfamiliar) and enriched (more familiar) forms of uranium and/or using their negative feelings about enriched uranium (and its applications) as a guide for their evaluations of depleted uranium. Evidence for this comes not only from the self-claimed lack of awareness about DU in both nations but also the noticeable changes in respondents' evaluations of the *labelling potential* and *use-value* of DU (and associated upturn in attitudes to nuclear *fusion*) following the provision of a small amount of information designed to delineate it from enriched uranium. This explanation is further supported by the failure of respondents' subjective awareness of the historical associations that DU shares with other sectors (e.g. munitions manufacture) in predicting the observed downtown. Arguably, such influence would have hinged more upon respondents' specific (rather than conflated) knowledge of DU.

While clearly evidencing that there is a stigmatizing effect of the proposed use of DU for nuclear *fusion* and yielding indicative reasons as to why this might occur, we argue that future research should seek to learn more about the specifics of the branding influence. This could, for example, be achieved through qualitative or experimental studies designed to learn more about the automatic cognitive and affective associations people draw with the term 'depleted uranium' and the extent to which these are comparable with those derived from the term 'enriched uranium'.[22]

Beyond identifying the presence of a stigmatizing impact of the proposed use of DU on attitudes to nuclear *fusion*; the results also reveal how a small amount of information about the material properties of DU was sufficient to prompt a partial rebound in attitudes towards a position of greater favourability. This rebound would appear to have arisen from respondents clarifying their understanding of depleted uranium and more effectively delineating it from enriched uranium. This was evidenced, for example, by the changes in the extent to which respondents classed depleted uranium as hazardous (relative to uranium per se), as well as increases in the perceived *positive use value* and decreases in the *negative use value* of the of the material.

These findings are consistent with those of other research that speak to the benefits of countering misperceptions and promoting informed public debate about technological innovation through education and outreach.[33,35] This is exemplified, for example, by recent attempts to engage publics in informed discussions about carbon capture and storage (CCS) and is more generally consistent with current shifts towards more participatory-involvement from publics (and other stakeholder) in decision-making relating to science and technological innovation.[36–38] However, while this rebound effect was observable in both the UK and Germany sub-samples, a couple of things are noteworthy. First, in both samples the rebound was only partial and second, the rebound was more pronounced within the UK subsample.

The incomplete nature of the rebound in attitudes is a warning against assuming that attitudes towards innovative technologies, like nuclear *fusion*, are simply a product of one's *objective* knowledge about the technology.[31,32,39,40] In this 'knowledge deficit' scenario, one should have anticipated a full (or even greater) rebound in attitudes following the provision of information about nuclear *fusion*. Rather, attitudes towards science and technological innovation (like other topics) are shaped by manifold factors (e.g. trust, values, perceived norms, etc.) that also need to be accounted for.[41,42] Thus, while the rebound itself could have been the product of respondents delineating enriched and depleted uranium, its partial nature could be a product of residual or raised concerns following the provision of the information. For example, for some the necessary ties between nuclear *fission* and nuclear *fusion* resulting from the use of DU (bearing in mind that DU is a by-product of uranium enrichment) would have been inconsistent with their desires for future denuclearisation and hence negatively evaluated.

Finally, the more pronounced rebound in attitudes among the UK subsample, relative to the Germany sub-sample, arguably reflects qualitative differences in respondents' attitudes within each group. According to our survey, the Germany sub-sample were not only less favourable to nuclear *fusion* from the outset but also claimed to have greater knowledge of nuclear *fusion* than the UK respondents. This combination of less favourable attitudes and greater attitude certainty, likely explains the reduced rebound in attitudes between Time 3 and Time 4. Stronger attitudes are commonly less malleable than weaker attitudes but also by being more certain of their attitudes to nuclear *fusion*, the Germany respondents might have had more motivation to critique or question the clarifying information about DU they were receiving.[43,44]

To some extent, the initial difference in attitudes toward nuclear *fusion* within each sub-sample, might have related to some respondents wrongly conflating *fission* and *fusion.* Nuclear *fission* is a divisive technology in most countries that utilise it for power generation; however, general public opinion is more amenable in some countries rather than others.[45] Typically, UK attitudes to nuclear *fission* are more favourable than in Germany, which could explain some of the initial discrepancy in attitudes towards nuclear *fusion* at Time 1. Crucially, the shift in attitudes towards nuclear *fusion* observed between Time 1 and Time 2 (i.e. where information clarifying the distinction between fusion and fission was provided) arguably provides further evidence of the negative branding influence that nuclear *fission* has on perceptions of nuclear *fusion* before effort is made to delineate these technologies.[15]

5. Conclusion

In sum, the study findings illustrate that in two demographically diverse European samples, the proposed use of DU for storing tritium has significant stigmatizing impact on attitudes towards nuclear *fusion*. While in the current context, this influence was not sufficient to move mean attitudes beyond a position of positivity (UK) or ambivalence (Germany), questions remain. For example, would the nature and extent of the stigmatizing impact observed in this study be different in the absence of initial efforts to delineate *fusion* from *fission*?

The study findings also illustrate the reparative consequences of provisioning clarifying information about the nature and purpose of DU in relation to its proposed use in nuclear *fusion* (as well as perhaps efforts to delineate nuclear *fission* from fusion). While these findings attest to the value of engaging and communicating with publics about nuclear *fusion* (and the role of DU), the observed rebound in attitudes was only partial. This warns against a presumption that any downturn in attitudes to nuclear *fusion* in the context of DU can be fully reversed through the simple provision of information.[31,40]

We have identified a number of potential explanations for the partial nature of this rebound in attitudes, as well as the more general cross-national differences in attitudes to nuclear *fusion* observed within our study. We argue that more research is now required to assess these explanations in order to learn more about: (a) the nature of the stigmatising effect observed; and (b) how this effect might be mitigated.

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Author Contributions

CRJ led the design and distribution of the questionnaire-based survey and the analysis and reporting of the findings. SM and SY assisted in the design and distribution of the survey.

Competing Interests

The authors know of no financial or non-financial competing interests relating to this study.

Materials and Correspondence

All correspondence and materials requests should be directed to the lead author.

Acknowledgements

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Table 1. Key socio-demographic characteristics of UK and Germany sub-samples

		UK		Germany		Sig.
		N = 438		*N* = 390		
		Freq.	%	Freq.	%	*p*
Gender	Male	214	48.9	202	51.8	= .435
	Female	223	50.9	187	47.9	
	Other	1	0.2	1	0.3	
Age (years)	18-24	58	13.2	54	13.8	= .004
	25-34	75	17.1	81	20.8	
	35-44	69	15.8	79	20.3	
	45-54	80	18.3	86	22.1	
	55-64	97	22.1	60	15.4	
	65-74	50	11.4	29	7.4	
	75-84	9	2.1	1	0.3	
Nationality	Home country	396	90.4	357	91.5	= .048
	Other European	18	4.1	7	1.8	
	Other International	11	2.5	4	1.0	
	Non-response	13	3.0	22	5.6	
Employment Status	Employed (full/part)[1]	248	58.2	251	64.6	< .001
	Seeking employment	21	4.8	19	4.9	
	Homemaker	39	8.9	24	6.2	
	Student	19	4.3	36	9.2	

	Retired	82	18.7	42	10.8	
	Other	29	6.7	17	4.5	
Education	Secondary/High school	199	45.4	211	54.1	< .001
	University (undergrad.)	149	34.0	89	22.9	
	University (postgrad.)	55	12.6	56	14.4	
	No formal/Primary school	8	1.8	24	6.2	
	Other	27	6.2	10	2.6	
		Mean	SD	Mean	SD	*p*
Trust in science and scientists		3.31	0.61	3.30	0.58	= .381
Energy security concern		3.12	0.59	2.82	0.66	< .001
Biospheric (environmental) values		4.07	0.83	4.12	0.86	= .917
Climate change concern	Personal	3.68*	1.25	3.52*	1.33	= .089
	Societal	3.91	1.21	3.86	1.23	= .562

Notes. [1]Includes full and part time paid employment, self-employment and military

Employment Other = unable to work, volunteer work and ‘other’

Education Other = technical college qualifications (e.g. HND, BTEC, City and Guilds); apprenticeship qualifications, emergency services qualifications (e.g. GIFireE) and International educational qualifications (e.g. International Baccalaureate).

*n = 436, n = 385

Table 2. Self-claimed awareness and knowledge of nuclear fusion and depleted uranium (DU)

		UK		Germany		Sig.
		Freq.	%	Freq.	%	*p*
Awareness of nuclear fusion	Yes	219	50.0	248	63.6	< .001
	No	219	50.0	142	36.4	
Confuse fusion and fission[1]	Yes	115	33.2	91	26.1	= .046
	No	231	66.8	257	73.9	
Awareness of DU	Yes	232	53.0	197	50.5	= .487
	No	206	47.0	193	49.5	
		Mean	SD	Mean	SD	*p*
Self-claimed knowledge of nuclear fusion		2.16	0.98	2.43	0.88	< .001
First heard about nuclear fusions		3.22	1.55	3.07	1.21	= .119
Self-claimed knowledge of DU		2.12	0.97	2.13	0.96	= .915

Notes. [1] Figures exclude those answering ‘don’t know’ and non-respondents (n = 92 UK; n = 42 Germany)

Table 3. Mean evaluations of the different uranium terminology among the UK and Germany respondents

	UK		Germany		Overall	
	Mean	SD	Mean	SD	Mean	SD
Uranium	3.95	2.18	3.62	2.23	3.79	2.21
Natural Uranium	4.61	2.27	4.42	2.41	4.52	2.34
Enriched Uranium	3.81	2.28	3.05	2.22	3.45	2.28
Depleted Uranium	3.79	2.19	3.80	2.18	3.80	2.18

Notes. Scale: 1 = Extremely unease; 10 = Extremely calm (hypothetical scale midpoint = 5.50)

Objectively depleted uranium is less radioactive than the other forms of uranium outlined in this table.

Table 4. Mean evaluations of the sub-facets of attitudes towards depleted uranium (DU) at Time 3 (pre-information) and Time 4 (post-information)

	Time 3 (Pre-information about DU)				Time 4 (Post-information about DU)			
	UK		Germany		UK		Germany	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Negative Labelling[a]	3.76	1.21	3.96	1.28	4.32	1.27	4.32	1.17
Positive Labelling[b]	4.06	1.47	3.92	1.60	3.41	1.50	3.52	1.59
Positive Use Value[c]	3.79	1.06	3.72	1.12	3.37	1.14	3.48	1.16
Negative Use Value[d]	3.33	1.01	3.22	1.01	3.51	1.02	3.39	1.10
Negative Associations[e]	2.98	1.08	3.13	1.16	3.27	1.10	3.30	1.25

Notes. Scale coding = 1 Strongly agree; 2 agree; 3 Neither agree nor disagree; 4 disagree; 5 strongly disagree

[a] Negative labelling potential: “Sounds more hazardous than uranium”

[b] Positive labelling potential: “Sounds less hazardous than uranium”

[c] Positive Use Value: “Is not a particularly hazardous substance is used correctly”; “Has important industrial uses”; “Should be used in fuel storage for NFT”; “Would improve my opinion of NFT if it were to be used in fuel storage”; “Is being put to good use by being used in NFT”.

[d] Negative Use Value: “Would negatively affect (tarnish) my opinion of NFT if used in fuel storage”; “Unduly increases the risks associated with NFT”; “Creates unwelcome links between fission and fusion industries”; “Would negatively affect public opinion of NFT in fuel storage”; “Would limit the countries in which nuclear fusion power stations could be built”.

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[e] Negative associations: “Has negative affiliations with nuclear weapons”; “Is an inherently risky substance”; “Has negative affiliations with military ammunition”; “Has negative associations with terrorism”.

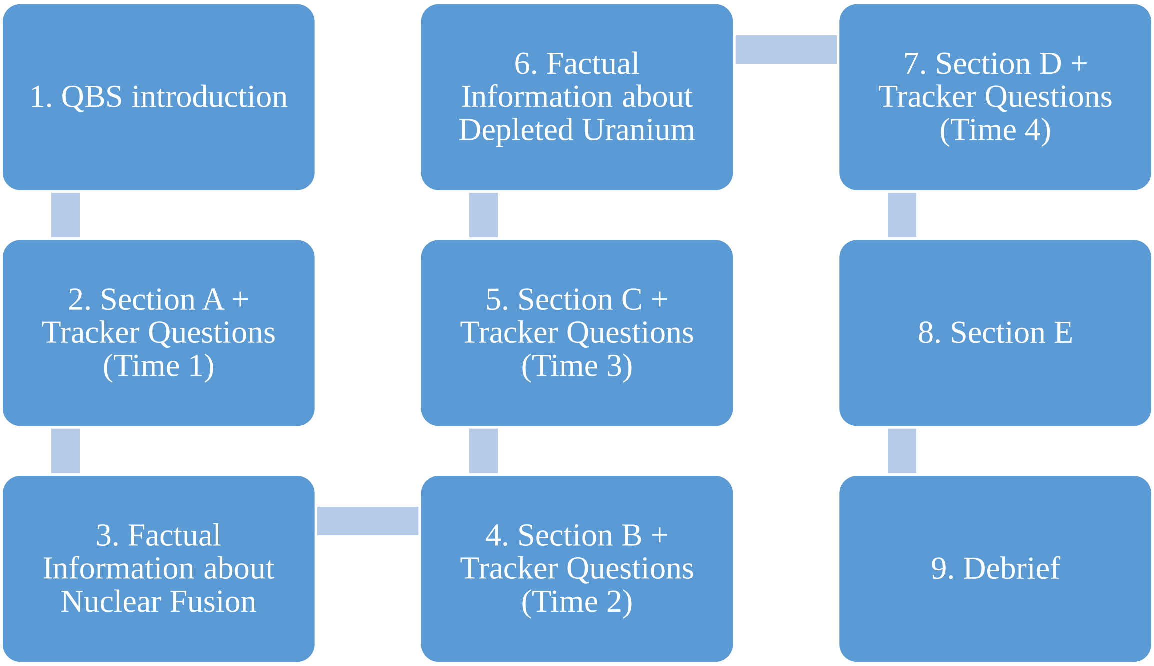


Figure 1. A diagram of the 9 stages comprising the flow of the questionnaire based survey.

Note. The survey comprised five question-based sections (Sections A-E), two sections where respondents were provided with factual information on nuclear *fusion* (3) and depleted uranium (6). These sections were 'book-ended' by a written introduction (1) and debrief (9).

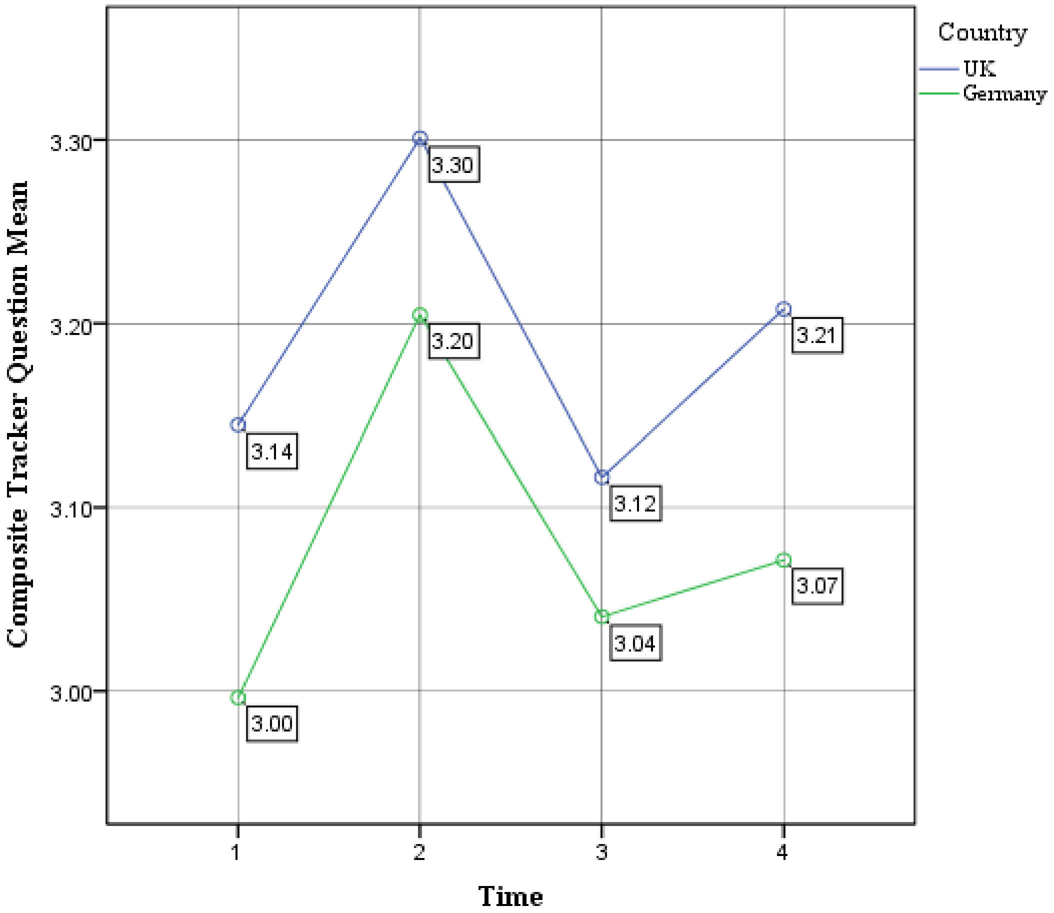


Figure 2. Composite tracker-question means for UK and Germany respondents at each of the four survey time-points.

Notes. 3.00 denotes the scale midpoint (higher values = more favourable towards nuclear fusion). Time 1 = pre-information about nuclear fusion; Time 2 = post information about nuclear fusion; Time 3 = pre-information about DU; Time 4 = post-information about DU.

Appendix A

Table A1.

Key demographic, knowledge and awareness questions (and response coding) from Section A of the survey.

Demographics		
Age	What age bracket are you in?	18-24; 25-34; 35-44; 45-54; 55-64; 65-74; 75-84; 85+
Gender	What is your gender?	Male; Female; Other; Prefer not to say
Education	Please select the option that best represents your level of education	No formal schooling completed; Primary; Secondary/High; UGrad university degree (a) enrolled or (b) awarded; PGrad university degree (a) enrolled or (b) awarded; Other
Employment	What is your current employment status?	Employed (full or part time); Self-employed; Out of work/job seeking; Homemaker; Volunteer; Student; Military; Unable to work; Retired; Other
Nationality	What is your nationality?	Free response

Initial Awareness and Knowledge of Nuclear Fusion Technology (NFT)		
Fission/Fusion Confusion	Before today, did you think that fusion and fission were the same?	Yes; No; Don’t Know
Awareness	Before today, had you heard of NFT?	Yes; No

Self-claimed Knowledge	How much would you say you currently know about NFT?	Nothing (I have never heard of it); Nothing (I have only heard the name); A little; A fair amount; A lot
First heard of NFT	When was the first time you heard about NFT?	A long time ago; Not very recently; Fairly recently; Very recently; Today

Notes: Additional questions included in Section 1 that are not considered in this article assessed: (1) if currently employed, what is your occupation (free response)?; (2) If you had heard of NFT before today, where was this from? (12 source options, e.g. School; Television/Radio News; Social Media); and (2 What are the first three words or phrases you associate with NFT? (Free response)

Supplementary Material

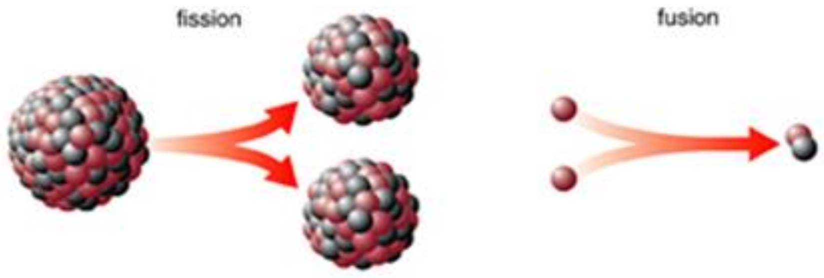
Section 3 (*"Factual Information about Nuclear Fusion"*) and Section 6 (*"Factual Information about Depleted Uranium"*) of the questionnaire-based survey (see Figure S1) comprised the following brief passages of information (including associated diagrams), prepared by nuclear fusion communication experts at the Culham Centre for Fusion Energy (CCFE).

Section 3: Nuclear Fusion Technology

Currently, nuclear power stations produce energy using a process called nuclear fission. This involves splitting large atoms into smaller atoms in order to release energy to power the electricity generating process (see the picture below).

A different process, called nuclear fusion, produces energy inside the core of the sun. This involves fusing smaller atoms into larger ones in order to release energy. Scientists around the world are attempting to replicate this process, developing nuclear fusion technology to be used to generate electricity in future power stations.

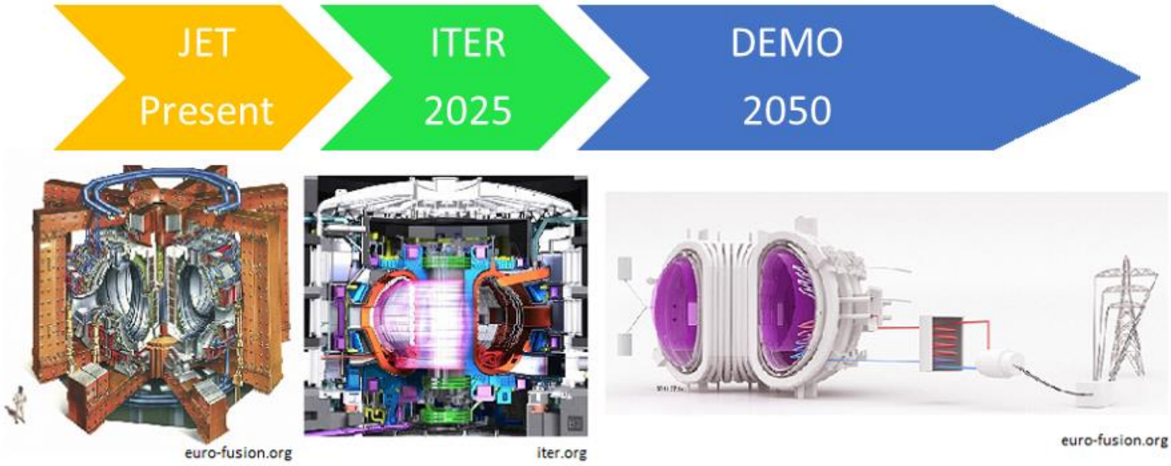
The fuel for nuclear fusion power generation is hydrogen – or more specifically, different types (or isotopes) of hydrogen called deuterium and tritium. In order for nuclear fusion reactions to occur, deuterium and tritium gas must be mixed and heated to temperatures of over 100 million °C within a nuclear fusion reactor.



Nuclear Fission vs. Nuclear Fusion
(Source: nuclear.duke-energy.com)

The Joint European Torus (JET) in Oxfordshire, UK, is currently the world's most powerful experimental nuclear fusion reactor. This experimental reactor has been operating for over 30 years and it is an important part of the wider European “roadmap to fusion electricity” (i.e. the journey that we must take in order to build a fully functioning nuclear fusion power station).

The next step on the "roadmap" is the construction of a larger and more powerful experimental nuclear fusion reactor called ITER. ITER is currently being constructed in a place called Cadarache in the south of France. ITER is planned to be up and running by 2025 and will be the first experimental nuclear fusion reactor capable of producing significantly more energy than it uses to create the nuclear fusion reaction.



euro-fusion.org iter.org euro-fusion.org

Timeline for nuclear fusion development

ITER will be a springboard to a full-scale demonstration nuclear fusion power station called DEMO. DEMO will be located somewhere in Europe (the site has not yet been specified) and is planned to be completed and operational around 2050. DEMO will be the first nuclear fusion reactor able to provide electricity to the European electricity grid for use in powering homes and businesses.

Below is a table outlining some of the proposed advantages and disadvantages of nuclear fusion technology (NFT). Please read the text in the table carefully and then answer the questions that follow.

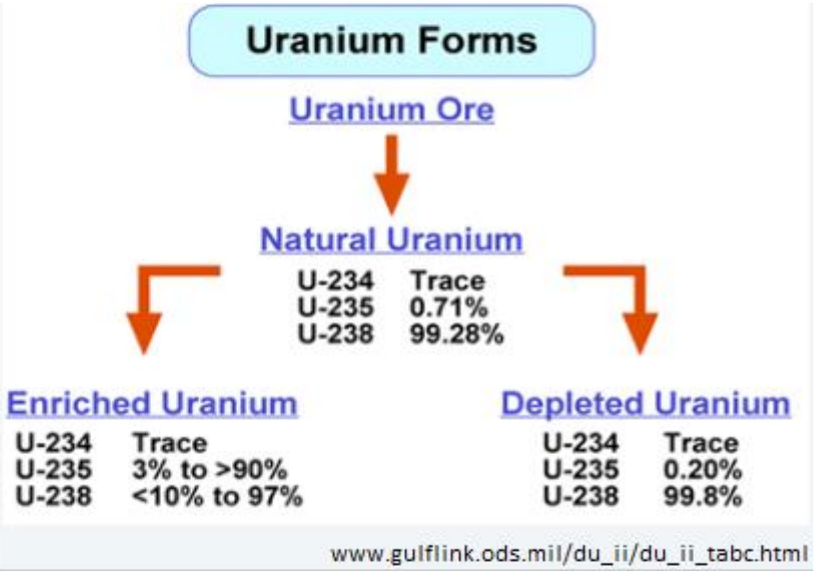
ADVANTAGES of nuclear fusion	DISADVANTAGES of nuclear fusion
Sustainable and abundant energy Fusion fuels are widely available and are nearly inexhaustible. The nuclear fusion reaction releases 4 million times more energy than burning coal, oil or gas and four times as much as nuclear fission reactions.	**Impact on energy demand** As nuclear fusion power would produce large amounts of energy, it is possible that this would remove societal incentives for restraint or reduction of energy use.
No Carbon Dioxide (CO2) and no high-activity or long-lived radioactive waste Fusion power does not emit CO2 or other greenhouse gases into the atmosphere at the point of power generation. The only major by-product is helium, a non-toxic gas. The fusion reaction does not produce long-lived, high-radioactivity waste products.	**Radioactive fuel and low-level radioactive waste products** Tritium (hydrogen 3), a radioactive isotope of hydrogen, is used to power the nuclear fusion reaction. Tritium can be harmful if inhaled, ingested or touched. The nuclear fusion reaction also produces some short-lived radioactive waste products.
No risk of nuclear meltdown Fukushima-type nuclear accidents are not possible in fusion power stations. It is difficult to reach and maintain the precise conditions necessary for the fusion reaction to occur. If a disturbance occurs, the reaction stops within seconds. The quantity of fuel present in the reactor at any one time is only enough for a few seconds of fusion	**No full scale electricity production expected until 2050** Nuclear fusion technology is still being researched and developed. At present there are no operational commercial nuclear fusion power stations. It is anticipated that the first full-scale power station will not be operational until 2050. At present the

as such there is no risk of a runaway nuclear chain reaction.	research-scale demonstrations like JET use more energy than they produce.
Operating costs Similar to nuclear fission (which is used currently in nuclear power generation); when a nuclear fusion power station is up-and-running, the operational costs (e.g. fuel costs) will be cheap, meaning the electricity generated should be affordable.	**Start-up costs** There are high start-up costs associated with bringing nuclear fusion power 'to market'. While these start-up costs will likely reduce over time through research and development, some believe that the money invested in nuclear fusion would be better invested in other options, like renewables.
Adapted from www.ITER.org	

Section 6: Depleted Uranium

What is depleted uranium?

Uranium is a naturally occurring metal found in rocks and seawater. Uranium can be enriched using industrial processes to increase the amount of the isotope U-235 (see the picture below). Slightly enriched uranium is used as fuel in nuclear fission power stations and highly enriched uranium can be used in nuclear weapons. Depleted uranium is left over from the enrichment process. It contains less of the U-235 isotope than natural uranium, so it cannot be used as nuclear fuel. Depleted uranium is 40% less radioactive than natural uranium and it is not classified as a dangerous substance radiologically according to the World Nuclear Association.



Why is depleted uranium used to store the fusion fuel?

Hydrogen is a flammable gas and the hydrogen isotope (i.e. tritium) used as fuel for nuclear fusion is also radioactive. This means that safety is the priority when considering storage options for this fuel. Storing the tritium as a solid chemical compound known as a "metal hydride" is safer than storing it as a gas. By passing the tritium gas over depleted uranium in a secure metal containment vessel (i.e. a depleted uranium "bed" - see the picture below) you create this solid metal hydride.

Due to its chemical properties, uranium is a very suitable metal for storing tritium as all the stored tritium can be easily recovered and reused after storage. Depleted uranium is currently used to store the tritium fuel for the JET fusion experiments taking place at the Culham Centre for Fusion Energy, as it is currently considered to be the safest and most suitable fuel storage method.

Depleted uranium is also the favoured option for use in ITER (i.e. the next nuclear fusion demonstration facility). Alternative storage materials, such as zirconium-cobalt and titanium, are being investigated for use as tritium storage options. Currently these alternatives are not favoured as much as depleted uranium as they are less efficient (e.g. they do not allow you to recover and reuse all of the stored fuel).

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Outlined below are some of the proposed advantages and disadvantages of using depleted uranium as a tritium storage option. Please read the text carefully and then answer the questions that follow.

Advantages of depleted uranium:

- Using depleted uranium is considered to be a safe and reliable means of storing tritium, as tritium can be easily captured and stored at room temperature.
- All stored tritium can be accessed when required. This is due to the fully reversible chemical reaction between uranium and hydrogen. This is not the case with other metals that can be used to store tritium, such as zirconium-cobalt or titanium, in which some of the tritium remains trapped.
- A waste route for disposing of the depleted uranium 'beds' used to trap the tritium already exists. The resulting waste is classed as low-level waste.

Disadvantages of depleted uranium:

- There are some occupational hazards that need to be considered and controlled for when using depleted uranium.
- Depleted uranium is chemically toxic if touched, inhaled or ingested.
- Depleted uranium is pyrophoric (can ignite spontaneously in air) when in powder form.
- Depleted uranium is a radioactive substance. Despite not being used in nuclear weapons or in nuclear fission power generation, depleted uranium is classed as a nuclear material.

Consequently, there are strict regulations and controls applied to the use of depleted uranium. This could be an issue that influences the choice of country for the location of DEMO, the full demonstration fusion power station, intended to be operational in 2050.