1 Speech: personal representation to HIF-1 inquiry

I am Peter Kirby from Culham village.

I wish to make this representation because I have specific knowlege about nuclear fusion that challenges the basis of UKAEA's case in support of the proposed road development.

Beyond this speech, I have prepared a 10-page written submission.

1.1 Personal credentials

I am a retired physicist.

I have degrees in physics from the University of Oxford. I hold and held memberships of professional institutes. The details are given in my written submission.

I also held a high government security clearance.

I worked for 10 years on fusion in the Theory Division at Culham Laboratory, and was on the site for 28 years. Culham Laboratory became the Culham Science Centre, and has been renamed again just recently.

For my own interest, I undertook a study of the history of fusion research at Culham Laboratory.

I gave several public lectures on the subject.

I have what is probably the most detailed collated record of fusion work at Culham.

1.2 Summary of my position

In recent times, the UKAEA has given a wholly unrealistic description of fusion research.

I believe that this description is intended to promote its property development.

On the basis of that unrealistic description, the UKAEA wishes to force the construction of a £300 million road system in the Oxfordshire countryside.

The road system will lead to damage to the environment, to human health and to people's lives. It may also put the local Councils at financial risk.

My written submission gives a factual and understandable survey of fusion.

A commercial fusion reactor is absolutely impossible in the near term; the practicality may become clearer towards the end of this century.

Any rhetoric to the contrary should not be allowed to influence present-day planning decisions.

My final comment is that if the UKAEA wishes to expand its property portfolio (and to create a centre of employment), the UKAEA can simply expand its operation at Harwell.

There it owns about 300 hectares of land, conveniently next to an *existing* road system (dual carriageway A34) and close to an existing main-line railway station (Didcot Parkway).

1.3 What is fusion?

Fusion is the attempt to exploit certain nuclear reactions as an energy source for humankind.

1.4 Questionable technical claims

In recent years, the UKAEA has mounted an aggressive public relations campaign.

The message to the public is:

1. Fusion is near-term technology.
2. A fusion reactor would produce no radioactive waste.
3. A commercial British fusion reactor will be available in the 2040s.

In the real world, none of this is true.

I and other scientists (without a public-relations department) are critical of this unrealistic promotion of fusion, and dissenting letters appear in the scientific journals.

1.4.1 How to understand fusion

There are two relevant nuclear reactions:

Reaction-1: deuterium + tritium ⇒ helium + neutron + energy

Reaction-2: lithium-6 + neutron ⇒ helium + tritium

(Deuterium and tritium are respectively the 'heavy' and 'super-heavy' nuclear varieties of hydrogen.)

Reaction-1 produces the energy.
Reaction-2 produces ('breeds') a fuel (called 'tritium') for Reaction-1.

Reaction-2 is essential because the fuel 'tritium' does not occur in nature, except as a trace.

The fuel 'tritium' is a radioactive gas. It is likely to be released routinely into the environment by a fusion reactor.

After 70 years of research world-wide:

1. **Reaction-1**: there has been no demonstration of *net* energy production.
2. **Reaction-2**: the technology for breeding the fuel 'tritium' does not exist.

This status is inconsistent with the claims of near-term fusion success.

Furthermore, the UK's national fusion programme has never tried to demonstrate Reaction-1.

1.5 JET: the status of reaction-1

To understand the present state of progress in fusion, consider the achievements of JET:

1. Cost: at least £1 billion.
2. 40 years of operation (1983–2023).
3. Best energy production: 69 units of energy (megajoules) in 2023.
4. The energy produced is only about 1% of the energy *consumed* by the machine.

To understand the practical *insignificance* of the 69 units (megajoules), it is roughly equivalent to the energy from:

1. 30 domestic wax candles.
2. Less than 2 litres of petrol.

A device that costs more than £1 billion, operates once in 25 years for 5 seconds and consumes (not creates) a large amount of energy does not constitute a proof of principle for a practical fusion power plant.

1.6 Some fusion problems

I can only touch on a few issues.

1.6.1 Materials

A crucial problem is that Reaction-1 and Reaction-2 act to destroy the fabric of the reactor in a variety of ways.

The development appropriate of materials is likely to take several decades, if possible.

Here is a quote from an old but still relevent conceptual reactor design published by the International Atomic Energy Agency:

"The INTOR study has shown that, with respect to radiation damage, the existing data on different candidate materials are not sufficient for a reliable construction of future fusion devices."

A materials development time of roughly 30 years is suggested, given the appropriate test facilities. Such facilities still do not exist.

1.6.2 JET post-operation

I read that the post-operation analysis of the materials in JET will take 17 years.

That information is necessary to inform the design of a fusion reactor.

However, 17 years takes us to the time when a commercially viable fusion reactor is supposed to be in operation.

Again, the materials analysis is inconsistent with the claims of near-term fusion success.

1.7 Radioactivity

The effect of Reaction 1 is to make all the materials in the fusion reactor highly radioactive because of further, induced nuclear reactions.

In my written document, I describe how, for example, silver and uranium could be pollutants in a reactor.

Silver would form the nuclear variety silver-108, which has a radioactive half-life of more than 400 years.

Uranium would create plutonium. Plutonium-239 has a half-life of 24,000 years.

The question of radioactive waste, or lack of it, is then a question of definition and degree.

The view of European nuclear engineers is that the development of low-activation materials has an earliest possible date of 2060, but is likely to be much later.

This means that sustainable fusion cannot contribute to net zero.

1.7.1 In-service repair

The innermost parts of the reactor will be severely damaged by the intense radiation from Reaction-1.

For that reason, a fusion reactor will have to be dismantled every few years *during* its working life to replace the damaged parts.

That will require large-scale engineering work in a huge, complicated, interconnected, highly radioactive environment, with highly radioactive components.

Such an operation will carry a large technical risk.

The strategy is to use radiation-hardened robots to perform that work.

The failure of the robots (as in the film *Chernobyl*) could threaten a huge financial investment. (*Chernobyl*: robot electronics destroyed by radiation.)

1.7.2 Final words

A commercial fusion reactor is absolutely impossible in the near term. The practicality may become clearer towards the end of this century.

Rhetoric about unlikely, very long-term future developments should not be allowed to influence present-day planning decisions.

That completes my speech.

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1 Personal representation to HIF-1 inquiry

This is Peter Kirby in Culham village. I am making this representation because:

1. I would be directly affected by the proposed HIF-1 road development.
2. I wish to register my objection to the proposed HIF-1 road development.
3. I have specific knowledge about fusion that challenges the basis of the UKAEA's case in support of the development.

1.1 Personal credentials

I am a retired physicist. My academic and professional qualifications are:

B.A., M.A., DPhil. (Oxon), MInstP, ex-MIEEE, ex-DISA†

I worked for 10 years on fusion in the Theory Division at Culham Laboratory (later renamed Culham Science Centre, and recently Culham Campus).

After that, I remained at the Culham Science Centre until 2006, and did contract research work in computational physics for agencies of the Ministry of Defence. As a requirement for that work, I held a high security clearance.

† Defence Industries Security Association

1.2 Specific fusion knowledge

Beyond my 10 years in the subject, for my own interest, I undertook a study of the history of fusion research at Culham Laboratory.

I gave several public lectures on the subject.

I have what is probably the most detailed collated record of fusion work at Culham.

1.3 Context

This document contains much technical information, but it is not an irrelevant scientific lecture.

Its purpose is to provide a factual but understandable description of the issues around nuclear fusion.

The point is that the UKAEA has used, and continues to use, hyperbolic statements about fusion in order to promote its property development. Indeed, in my understanding, the present planning inquiry was instigated by the UKAEA, after the Oxford County Council's planning committee rejected the proposed road development by 7 votes to 2.

In these circumstances, an informed, external technical commentary on fusion is appropriate and desirable. This document provides that commentary.

2 Objections

My objections to the proposed HIF-1 road development are in two areas:

1. I object to the development of the road because of the environmental and social damage that it would cause.
2. I am concerned that an incomplete or inaccurate description of fusion may have affected planning decisions, and may continue to do so.

2.1 Environmental and social damage

The proposed development is based on the premise that roads are always beneficial. That view is increasingly unacceptable.

The HIF-1 road may be desired by the UKAEA for its own gain, but it will be a blight on the area, for the environment and the surrounding population.

Consider the health impact of traffic:

1. There are roughly 40,000 deaths in the UK from respiratory diseases caused by traffic pollution (exhaust fumes, brake and tyre dust).
2. HIF-1 will go through Didcot, and cause wilful damage to the health of the population.

Consider the effect of a new road:

1. Any new road attracts more traffic until the road is saturated.
2. That will increase traffic congestion and ‘rat-runs’ through the surrounding villages.

In terms of accessibility:

1. Local access to Culham Laboratory was not a problem during the construction of JET.
2. There has never been a need for a special road link between Culham and Harwell.
3. If the UKAEA wishes to build at Culham but connect to Harwell, much damage would be avoided if the UKAEA simply built at Harwell, where it has about 300 hectares.

I suggest that any claim that only a major new road can bring environmental benefits (such as pedestrian paths, cycle ways and buses) is merely ‘green washing’ and a weakness in transport strategy.

2.2 Inaccurate description of fusion

In recent years, an incomplete or inaccurate description of fusion may have affected planning decisions, and may continue to do so.

2.2.1 Questionable employment claims

Consider the discussion in 2017 about employment at JET:

1. In 2016, UKAEA decided that JET would not be given another extension, Ref [1].
2. That meant that JET would close in the early 2020s.
3. In 2017 (sic), the leader of SODC stated that housing development in the Green Belt was acceptable because of the exceptional employment prospects at JET.

4. That claim was promoted by the catch-phrase ‘the hottest place in Oxfordshire’.
5. The result (put simply) was that the plan for 3500 houses at Culham was adopted.
6. JET closed in 2023.

This is an example of how questionable claims can be made about fusion.

2.2.2 Questionable technical claims

From 2017, the UKAEA has mounted a remarkably aggressive public relations campaign. There has been an extensive media campaign in print and broadcast, with ministerial and royal visits, unlike anything fusion research has seen before.

The message to the public is:

1. Fusion is near-term technology, Ref [2].
2. A fusion reactor would produce no radioactive waste.
3. A commercial British fusion reactor will be available in the 2040s, Ref. [3], [4], [5].

In the real world, none of this is true.

The local Councils have promoted this public-relations message. Indeed, in 2022 they linked fusion with *renewable* energy, Ref. [6], which it certainly is not.

I and other scientists are critical of the unrealistic promotion of fusion, e.g., Ref. [7].

The overriding fact is that the physical world is not influenced by public-relations messages.

3 The problem with fusion

This section presents a simple but accurate explanation of fusion, and justifies the statement ‘none of this is true’ that appears above.

3.1 The basic processes

Fusion attempts to exploit certain nuclear reactions as an energy source for humankind. There are two relevant reactions:

Reaction-1: deuterium + tritium ⇒ helium + neutron + energy

Reaction-2: lithium-6 + neutron ⇒ helium + tritium

Deuterium and tritium are respectively the ‘heavy’ and ‘super-heavy’ nuclear varieties of hydrogen.

Reaction-1 produces the energy. Reaction-2 produces (‘breeds’) the tritium for Reaction-1.

3.2 Intrinsic difficulties

There are several intrinsic difficulties in exploiting Reaction-1 and Reaction-2.

The primary difficulty is that in Reaction-1, the deuterium and tritium must be held at an extremely high temperature (100 million degrees). That alone presents an enormous challenge.

The use of tritium raises technical difficulties because:

1. Tritium is radioactive.
2. It does not exist in nature except in trace amounts.
3. The creation ('breeding') of tritium in Reaction-2 is an essential requirement; the inability to breed tritium would be a terminal failure.
4. Tritium is highly mobile and is easily sequestered in solid materials, which become indirectly radioactive because of the presence of the tritium.

The neutrons in Reaction-1 present technical difficulties because:

1. They induce radioactivity in any material that they penetrate.
2. They destroy the physical structure of any material that they hit (like machine-gun bullets fired at a brick wall).

After 70 years of research world-wide:

1. **Reaction-1**: there has been no demonstration of *net* energy production.
2. **Reaction-2**: the technology for tritium breeding does not exist.

This status is inconsistent with the claims of near-term fusion success.

3.3 JET: the status of reaction-1

To understand the present state of progress in fusion, consider the achievements of JET:

1. Cost: at least £1 billion.
2. 40 years of operation (1983–2023).
3. Only four experimental campaigns using tritium (1991†, 1997, 2022, 2023).
4. Until recently, best energy production: 59 megajoules over 5 seconds (2022).
5. The energy produced is only about 1% of the energy *consumed* by the machine.

(† Preliminary demonstration, with reduced tritium to minimize induced radioactivity.)

To understand the practical *insignificance* of 59 megajoules, it is roughly equivalent to the energy from:

1. 25 domestic wax candles.
2. Less than 2 litres of petrol.

Just recently, the final results from JET were announced: the energy production had been increased from 59 to 69 megajoules over 5 seconds. This increase of 17% was announced with hyperbolic publicity, Ref. [8].

However:

1. 117% of *insignificance* is still *insignificance*.
2. The experiments were conducted with no regard to the possible damage to the machine.
3. In fact, the machine was deliberately damaged for diagnostic purposes [9].

A device that costs more than £1 billion, operates once in 25 years for 5 seconds and consumes (not creates) a large amount of energy does not constitute a proof of principle for a practical fusion reactor.

3.4 UK national fusion programme

Experimental fusion work started at Culham in 1961, during site construction. A total of 32 major experimental devices of various types were built. The overall expenditure of this programme was of order £1 billion.

There has been little to show for this expenditure over 60 years:

1. All the experiments concerned the creation of the conditions under which Reaction-1 might proceed.
2. Tritium has *never* been used.
3. The programme has failed to give any proof of principle for a fusion reactor.

3.4.1 STEP

There is currently a major design project for a proposed reactor called STEP ('Spherical Tokamak for Energy Production'). The design is scheduled to be completed in 2024.

Here, 'design' means a 'conceptual design', not a detailed manufacturing specification.

A tokamak is a toroidal (doughnut-shaped) device. It was invented by the Russian physicists Sakharov and Tamm in 1950, to address the containment problem in respect of Reaction-1, Ref. [10].

The essential political position of STEP may be summarized as:

1. STEP is presented as a potential world-leading UK fusion reactor.
2. It is a UK rival to ITER (the huge international machine in France).

The public-relations message must not be allowed to obscure the basic technical issues:

1. 'Spherical tokamak' is merely a tokamak with a smaller central hole than other designs.
2. The purpose is to improve some aspects in relation to Reaction-1 (at possibly the expense of others).
3. The shape of a spherical tokamak does not specifically address the immense difficulties raised by Reaction-2.
4. STEP is subject to the laws of physics and is not technological magic.

There is already a contradiction with the time-scale in the public-relations message and that in reality:

1. The post-operation analysis of the materials in JET (particularly the study of the absorption of tritium into the structure) will take 17 years, Ref. [9].
2. That information is necessary to inform the design of a fusion reactor.
3. However, 17 years takes us to the time when a commercially viable fusion reactor is supposed to be in operation, Ref. [3], [4], [5].

The materials analysis is inconsistent with the claims of near-term fusion success.

3.5 Outline of technical difficulties

This section contains an outline of the wide range of technical difficulties that fusion faces.

The purpose is to demonstrate that the difficulties are entirely inconsistent with the claims of near-term fusion success.

Indeed, fusion may be beyond the boundary of what human ingenuity can achieve in the physical world in which we live, and success (the creation of a practical fusion reactor) may be impossible on any time-scale.

3.5.1 Materials

There are significant problems associated with the intrinsic physical properties of matter.

Two existential problems concern physical damage to the structure of the reactor:

1. Erosion of the innermost part of the reactor by the hot fuel (Reaction-1), and by electromagnetic forces in fault conditions.
2. Neutron damage to materials (see Section 3.5.5 below).

Other material issues are:

1. The damage to materials from voids and swellings caused by the absorption of tritium and helium in Reaction-1 and Reaction-2.
2. The creation of long-lived radioactive species (and therefore nuclear waste) by neutron bombardment from Reaction-1 (see Sections 3.5.2 and 3.5.4).
3. Limited natural resources of important chemical elements, such as beryllium, helium, lead, nickel, niobium.

3.5.2 Tritium breeding

The breeding of tritium is crucial to the operation of a fusion reactor. A typical requirement is about 100 kilograms per year, Ref. [11].

As remarked above, the technology for tritium breeding does not exist at the present time; there has been no proof of principle in a hardware demonstrator. A failure to breed sufficient tritium would be terminal.

The concept is that the nuclear fuel for Reaction-1 is surrounded by a ‘blanket’ roughly 1 metre thick. The blanket contains some quantity of lithium-6 (typically tens of tonnes) for Reaction-2.

Other materials may be needed to ‘multiply’ the neutrons (by further nuclear reactions) in order to increase the rate of production of tritium.

There are several uncertainties:

1. The overall strategy is uncertain, unproven and the technical risk is high.
2. The physical extraction of the tritium from the blanket material and the transfer into the reactor is a technically complex, unproven operation.
3. There is uncertainty in the nuclear data that are used in design studies.

Lithium-6 (for Reaction-2) presents in own difficulties, Ref. [12], [13]:

1. Natural lithium contains only about 7% of lithium-6, which is insufficient for the required rate of tritium breeding.
2. There has to be a process of lithium-6 enrichment, possibly up to 90%, in industrial quantities.
3. A crucial issue is how this process can operate, and additionally, how environmental pollution can be avoided.
4. An indicative 20-year development time has been put on this process.

There may be problems if neutron multipliers are needed:

1. Beryllium is a candidate neutron multiplier, Ref. [14].
2. Most of the natural (i.e., mined) beryllium in the world contains uranium (sic).
3. If beryllium is used in the blanket (or elsewhere for structural reasons), any residual uranium will produce plutonium.
4. Plutonium is a dangerous material and remains radioactive for a very long time (the radioactive half-life of plutonium-239 is 24,000 years).

There is a similar issue with lead:

1. Lead is another candidate blanket material.
2. Natural (i.e., mined) lead contains silver.
3. If lead is used in the blanket, any residual silver will become radioactive.
4. One of the nuclear varieties of silver, namely silver-108, has a radioactive half-life of over 400 years.

The degree to which these issues are significant depends on the degree to which the required materials can be refined, from both the technical and economic points of view.

These considerations are inconsistent with the unqualified statement that a fusion reactor would produce no radioactive waste.

3.5.3 Material testing

A crucial aspect of the development of a fusion reactor is the testing of materials. This is certain to be an immense task and take many years.

The design documents for INTOR (International Tokamak Reactor, a proposed machine that tranformed in ITER in the mid 1980s), are illuminating, Ref. [15]:

1. “The INTOR study has shown that, with respect to radiation damage, the existing data on different candidate materials are not sufficient for a reliable construction of future fusion devices.”
2. “It is assumed that the minimum time for a fusion reactor material to accomplish all three phases [of evaluation] is 15 years, provided a high-flux neutron source is available.”
3. “However, the experience with zircaloy in the light-water reactor development and with stainless steel for fast breeders shows that considerably longer times, of the order of 30 years, may be more realistic.”

The crucial points to note are:

1. The high-flux neutron source refers to some laboratory source of neutrons that could be used to represent Reaction-1 in material tests.
2. There was no appropriate source of neutrons in 1983.
3. There *is* no appropriate source of neutrons in 2024.

Given this analysis from the world’s nuclear engineers, the notion that the UKAEA can produce a commercial fusion reactor in the 2040s is clearly highly unlikely.

3.5.4 Low activation materials

A further difficulty is the need to develop materials that have low nuclear activation. This refers to the radioactivity that is induced in materials by bombardment by the neutrons from Reaction-1.

The issues are:

1. Conventional construction materials (and impurities, as above) may give long-lived radioactive products.
2. A *sustainable* fusion reactor must be built of nuclear-qualified low-activation materials.
3. Otherwise, large quantities of radioactive waste will require safe storage for centuries.
4. The problem is that the production of low-activation materials requires the separation on the *atomic* scale of *industrial* quantities of materials.

Consider the time-scales:

1. The development of such materials, if that is possible, and the associated industrial production processes will take decades.
2. The EUROfusion European Research Road Map, Ref. [16], suggests that sustainable fusion:
   (1) cannot contribute to net zero goals by 2050
   (2) has an earliest possible date of 2060
   (3) is more likely in the longer term, i.e., in the next century

Given this analysis from European nuclear engineers, the notion that the UKAEA can produce a sustainable/commercial fusion reactor in the 2040s is clearly highly unlikely.

The crucial point is that the claim of 'no radioactive waste' is inconsistent with the claim of an operational fusion reactor in the near term.

3.5.5 Operation

There are existential problems associated with the operation of a fusion reactor.

A crucial issue is neutron damage:

1. The innermost parts of the reactor will be severely damaged by the intense neutron flux from Reaction-1.
2. For that reason, a fusion reactor will have to be dismantled every few years *during* its working life to replace the damaged parts.
3. That will require large-scale engineering work in a huge, complicated, interconnected, highly radioactive environment, with highly radioactive components.
4. Such an operation will carry a large technical risk.
5. The strategy is to use radiation-hardened robots to perform that work.
6. The failure of the robots (as in the film *Chernobyl*) could threaten a huge financial investment.

Another issue is pulsed operation:

1. A tokamak is intrinsically a pulsed device, but a practical power plant must operate continuously.
2. A pulsed mode of operation is a serious weakness, and will have significant engineering and economic implications, and may not be practical.

3. Indeed, there is a body of opinion that a tokamak is an unsatisfactory concept for a reactor, and that the alternative 'stellarator' device is a better option.

Another issue is thermal efficiency:

1. For electricity generation, the energy produced by Reaction-1 must be used to raise steam to drive turbines.
2. The thermal efficiency of a fusion power plant may be too low for economic operation because of the inability to produce high-temperature steam, Ref. [17].

3.5.6 Nuclear safety

There are some considerations about the nuclear safety of a fusion reactor:

1. In normal operation, tritium (a radioactive gas) will leak into the atmosphere and then into ground water.
2. Whether that leak is acceptable will be determined by the environmental authorities and public opinion.
3. If there is a major failure of the breeding blanket (because of a chemical explosion, for instance), large amounts of tritium could be released into the environment.
4. That would be a significant radiological incident.
5. (The air in the reactor hall would be highly radioactive because of nitrogen-16, but that is short-lived, and is unlikely to affect the general population.)
6. For these reasons, an exclusion zone around a fusion reactor may be needed.

I wonder whether the Councils that offered sites for a prototype reactor were aware of these issues, and whether they tested public opinion.

4 Final remarks

In recent times, the UKAEA has given a wholly unrealistic description of fusion research. I believe that this description is intended to promote its property development.

On the basis of that unrealistic description, the UKAEA wishes to force the construction of a £300 million road system in the Oxfordshire countryside.

The road system will lead to damage to the environment, to human health and to people's lives. It may also put the local Councils at financial risk.

This document gives a factual survey of fusion, and provides many compelling points against the UKAEA's rhetoric. The survey shows that a commercial fusion reactor is absolutely impossible in the near term; the practicality may become clearer towards the end of this century. Any rhetoric to the contrary should not be allowed to influence present-day planning decisions.

My final comment is that if the UKAEA wishes to expand its property portfolio (and to create a centre of employment), the UKAEA can simply expand its operation at Harwell. There it owns about 300 hectares of land, conveniently next to an *existing* road system (dual carriageway A34) and close to an existing main-line railway station (Didcot Parkway).

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