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Thermonuclear fusion

Summary

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SUMMARY

The development of fusion technology as an energy source is a historically unique undertaking. Between the discovery of its physical mechanisms and the possible availability of commercially usable power stations there will probably be an unusually long period of around 100 years of intensive R&D. It is accordingly not possible to say definitively whether fusion research is still more a matter of fundamental research or has progressed into the stage of development of an energy technology.

THE CONTEXT AND NEED FOR DECISION

Fusion experiments are becoming increasingly large-scale with a high degree of technical complexity, requiring substantial financial investment. In the light of these framework conditions, international cooperation is particularly intensive and stable. The scale of resources needed and very long period to possible implementation, with the resulting extremely great uncertainties in evaluation lead to major complexity in the pending decisions.

The community of fusion researchers believes that the reactor-oriented research programme should be continued with two intermediate phases – ITER (International Thermonuclear Experimental Reactor) and DEMO (Demonstration Fusion Powerplant) – to prepare for construction of the first commercial fusion reactor in around 2050. ITER, which currently requires far-reaching decisions, is a partnership between the EU, Japan and Russia, with other states involved. In parallel to ITER, construction of a special high-intensity fusion neutron source is needed to develop and test low activation materials. DEMO is intended to demonstrate the technical feasibility of a fusion power plant and generate electricity in continuous operation for the first time.

To achieve this programme, very substantial scientific and technical challenges must be mastered. The R&D process required will take several decades and promotional funding on a large scale. In the almost 50-year history of fusion research, the difficulties in developing a fusion power plant were repeparedly underestimated, with the result that the horizon for implementation had to be pushed further and further into the future, becoming in effect a »moving target«.

Nuclear fusion is also a particular challenge for technology assessment. Forecasts of the technological impacts of fusion in more than 50 years are extraordinarily difficult, and require careful interpretation. They are generally no more than heuristic approaches which might give some indication of what requires special attention in the further development process of fusion. The assessment is methodologically complicated by the fact that the quality of the numbers supplied by fusion research is very difficult to judge, given the possible wishful thinking involved and the impossibility of finding »independent« know how.

WHAT IS THE COST OF FUSION RESEARCH?

In the past 30 years, substantial public funding has been invested in promoting plasma research. In the EU almost 10 billion was spent on fusion research up to the end of the 90s. In the last few years, around 130 million a year has been invested in fusion research from German Federal funds. For comparison, German Federal R&D spending on renewable energy and efficient use of energy in 2000 amounted to 153 million. Up to the point of possible implementation of electricity generation by nuclear fusion, the current estimate is that R&D will need further promotion totalling around €60–80 billion over a period of 50 years or so, 20–30 billion within the EU. ITER was redimensioning from the initial 7 billion to 3.5 billion, which will probably be spread over ten years. A decision is needed next year on implementing ITER, its possible location and the division of the costs between the participating countries.

DO WE NEED THERMONUCLEAR FUSION?

The arguments in favour of using fusion energy are primarily determined by providential considerations: first, long-term security against scarcity of energy due to exhaustion of fossil fuels, and second, limiting climatic change by avoiding greenhouse gas emissions. The starting point is the assumption – still unproven – that fusion powerplants will be commercially available from the middle of the 21st century.

All global energy scenarios are based on further growth in demand for energy. On this basis, global demand for primary energy to 2050 will rise to two to three times the level in 1990. Energy saving measures can at best slow this trend. Climate protection requires in the long term the abandonment of the use of fossil fuels. This is also desirable in terms of sustainability, as it leaves the limited fossil resources available for other uses.

In the mid-21st century, the same fuels as today will probably play the dominant role in energy supply, although in a different mix. The gap in energy supply due to the growing scarcity of fossil fuels and rising global energy demand is essentially closed by renewable fuels in many energy scenarios. It is not possible to derive from these scenarios how far the planned progressive expansion of the development and use of renewable fuels combined with the exhaustion of existing potential for energy savings will have effect in practice by 2050. Another open question is how far bottlenecks in the supply of fossil fuels will play a role in this.

Renewable fuels and thermonuclear fusion are accordingly often discussed in terms of a certain competition between them by 2050. A common feature of both options is CO_2-free transformation of energy and their classification as »future technologies«, making them in principle modules in an energy supply which is independent of fossil fuels. It is entirely conceivable that the two options could coexist in energy supply, for example for reasons of climate protection or in terms of a desired level of security in supply with corresponding diversity of available technologies. There is broad complementarity in the nature of the plants as well: as centralised large-scale installations, fusion powerplants would be primarily suitable for securing the base load in urban regions. They would also fit in well e.g. in future supply infrastructures in countries currently based on coal (e.g. China, India). Renewable energies by contrast are more likely to be used in decentralised and smaller units.

A substantial advantage of energy production through thermonuclear fusion is, as noted above, that the fusion process does not generate any climate-damaging greenhouse gases. A functioning fusion technology would therefore be suitable for contributing towards avoiding climatic change in the second half of the century. However, it cannot contribute to this in the short or medium term. The level and degree of implementation of environmental and climate protection goals also have a significant influence on the structure of energy supply in 2050. If these goals are given comparatively high weighting, fusion powerplants would have to be positioned in an environment which is probably characterised by intensive use of renewable fuels and lower energy demand. This would require powerplants which can be controlled more quickly for energy and network management. Fusion powerplants – designed with more emphasis on steady long-term operation – would hardly be able to perform this function. If the goals were given comparatively less weighting, there would be more demand for low-cost (new) energy sources with rising energy demand. With CO_2-free thermonuclear fusion generation of electricity, it would be possible to supply large quantities of additional energy, but this would not be commercial competitive on the basis of our current knowledge.

Currently, there is no sign of any clear technical line of development to show which energy transformation technology or technologies will play a dominant role in 50 years (e.g. fuel cells, hydrogen technology or thermonuclear fusion). Thermonuclear fusion is one of many options for future energy supply whose use promises an additional possibility of generating base load electricity, and which is accordingly more suitable for supplying densely populated urban regions. The decisive factor in further pursuit of the thermonuclear fusion option is not its immense quantitative potential for supplying energy, but the strategy chosen for energy supply through 2050. Thermonuclear fusion is primarily a providential option for a more distant future in which fossil fuel reserves and resources are largely exhausted. It could contribute to an energy mix which is robust in the face of various political and economic developments.

IS THERMONUCLEAR FUSION SAFE?

Fusion reactors should be intrinsically safe. A crucial difference from nuclear fission is that uncontrolled nuclear chain reactions are ruled out in fusion powerplants by the laws of physics. Even so, catastrophic accident scenarios cannot be excluded. What kind of accidents could occur, with what likelihood, and how far the radioactive materials could be released in this event, is still a matter of dispute, as this requires assumptions about reactor design. There is currently no unambiguous proof or refutation that the goal of intrinsic safety is attainable, and this proof depends on the results of R&D over a period of decades.

Destruction of a fusion powerplant by an act of war or terrorism would probably release a significant portion of its radioactive and chemically toxic materials. Assuming that the easily mobile tritium component of a fusion powerplant was fully released by some violent event, the population over several square kilometres would have to be evacuated.

Tritium is particularly important for the further development of nuclear weapons arsenals, because it is used in various advanced nuclear weapon designs. However, it is also important for the spread of nuclear weapons. Tritium is accordingly a major proliferation risk from the operation of fusion powerplants. The risk of breeding fissile materials which can be used in weapons is, however, lower overall with a pure fusion powerplant than with a fission reactor.

IS ELECTRICITY FROM THERMONUCLEAR FUSION ECONOMICAL?

Evaluating the economic viability of electricity from fusion compared with competing fuels and calculating electricity generation costs are highly speculative exercises. The speed of technological progress alone and trends in costs of competing (e.g. renewable) energy systems are immensely important for their competitiveness, and these are not amenable to long-term prediction. It is regarded as certain that investment will dominate operating costs in electricity generation costs. The cost of a 1,000 MW plant is put at 5–6 billion. Fusion powerplants will accordingly be very capital-intensive major projects. This means they will be primarily suitable for centralised electricity generation for base load. Even the supporters of thermonuclear fusion expect electricity generation costs to be higher than those of competing technologies, on the basis of our current knowledge.

If the present global trend towards liberalising energy markets continues, the high capital intensity would be a major disadvantage for fusion powerplants, as it is not advantageous to tie up capital for the long term in a liberalised environment. An additional factor is that fusion powerplants would have initially to compete with reactors which are at least partly amortised and which can produce at marginal cost. Energy utilities will only accept fusion powerplants if they can expect a clear economic advantage over established technologies, including a risk premium for the still unknown capability and reliability of a young technology. It is accordingly disputed generally whether DEMO can be followed by fusion powerplants capable of economically competitive operation. Initial problems may make further government support necessary. The high level of capital intensity of fusion powerplants would be an important obstacle to use in developing and transition countries in particular.

IS ELECTRICITY FROM THERMONUCLEAR FUSION ECOLOGICAL?

Societal acceptance of fusion technology will depend to a great extent on appropriate consideration of environmental criteria at the point of technology decision-making. A major environmental advantage of fusion technology is that operation does not generate any climate-damaging greenhouse gases.

Conversely, the radioactive waste generated in the reactors are certainly the main radiological problem with nuclear fusion. Evaluation of these depends on the achievement of ambitious goals in further development of the technology and materials used over the next few decades. The second key radiological risk is the tritium fuel. Due to its specific properties, handling this material poses certain difficulties. Tritium is very mobile, and accordingly difficult to deal with in the event of release. The use of tritium in fusion reactors still requires solution of numerous problems and technical advances in process technology (tritium analysis, processes for decontaminating surfaces and cooling water containing tritium).

The resource situation is not an essential problem: deuterium and tritium, are currently the preferred fusion fuels and are available worldwide in large quantities. Deuterium can be extracted from sea water by electrolysis. The corresponding technologies have already been tested on a large scale. Tritium occurs naturally only in minimal amounts, and is accordingly produced by bombarding lithium with neutrons, which also generates helium. As fusion energy is stored at great density in the fuel, hardly any transportation is required. The quantities of deuterium and lithium required annually for a 1,000 MW fusion powerplant could be delivered in a single truck. This would not involve transporting any radioactive substances.

IS THERMONUCLEAR FUSION SOCIALLY SUSTAINABLE?

Development of a virtually inexhaustible source of energy and the universal availability of its fuel makes thermonuclear fusion suitable for avoiding social conflict over resources. In addition, the strong international cooperation on fusion research is contributing to international understanding.

By contrast, major projects tend to arouse scepticism among the general public. Fusion powerplants could also run into problems with acceptance because they contain a significant quantity of radioactive material and require final storage facilities for radioactive waste.

Energy production from thermonuclear fusion will only be accepted by the general public if it meets the needs and concerns of society. Pure information or advertising measures designed to promote acceptance have essentially proved unsuitable. To avoid crises of acceptance and confidence, early and intensive dialogue without predetermined results is required between science, interest groups and the public.

WHAT SHOULD BE DONE?

Despite the shortfalls in knowledge and the problems of evaluation in this specific case, there is no reason to leave development of fusion energy to its own devices. No reliable evaluation is possible at present for many questions regarding if and to what extent fusion energy is compatible with the many facets of the principle of sustainability. However, it is still possible to formulate corresponding requirements and identify the conditions under which fusion development can satisfy these postulates. It is then possible to consider the potential for shaping fusion in social terms. What intervention can influence development so that these conditions can be met? Seen in this way, the following general options for action are possible for research policy. The purpose of these options is to open up the entire space of possibilities for political structuring. Concrete positioning within this space is a matter for political evaluation and decision.

»Continuation« option: further intensive research with the existing key areas, primarily following the ideas of the fusion research community. This option would track the inherent dynamism of this area of research.

»Thorough evaluation« option: comprehensive evaluation of the thematic area of thermonuclear fusion, involving external experts, using the criteria of sustainable energy supply as a guideline. The resulting design requirements could be integrated into subsequent technological development. Here, the inherent dynamism might be interrupted, up to the point of formulating steering or termination criteria if the »moving target« phenomenon persists.

»Reorientation« option: cease focusing on fastest possible development of thermonuclear fusion as an energy technology following the Tokomak route and return to a research programme focusing on a broader understanding of the scientific foundations and alternative containment concepts. This would force termination of the inherent dynamism of this area of research.

The central challenge remains of building up independent expertise and organising broad societal discourse. Given the problem that it is virtually impossible to establish direct involvement of society, due to the remoteness in time and lack of everyday experience of fusion, this is not a simple task.

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