Bringing together fusion research

by M. Leiser*

The suggestion that the fusion of nuclei of light elements could be responsible for the energy produced by the stars was first made in 1929. The mechanism envisioned is, in some ways, similar to the more familiar fission process. In fission, the nucleus of an element with large mass-number is induced to split into two lighter nuclei. Since the binding energy of the heavy elements is less than that of the intermediate ones, the resulting mass-difference appears as energy. The binding energy of the light elements is, however, also less than that of the intermediate ones. Consequently, the fusion of two light elements will again lead to the production of energy to account for the mass-difference.

For sustained fusion reactions to occur three basic requirements must be met. The temperature **T** of the ionized gas or plasma must be high enough to ensure that the moving particles come close enough to interact; the density **n** must be great enough for a sufficient number of reactions to occur; and the plasma must be confined for a sufficiently long time **t** to generate energy. Of the various fusion reactions that are possible, the one that requires the most easily attainable values of these parameters is the deuterium-tritium reaction:

$$D + T \rightarrow \text{Helium} + \text{Neutron}.$$

The threshold condition for sustained fusion can be expressed by the so-called Lawson Criterion, which for this reaction requires that

$$n.t \sim 10^{14}\ \text{s cm}^{-3} \text{ at a temperature } T \geqslant 10^{8}\ \text{K}.$$

The great appeal of fusion as an energy source is the fuel it uses. Deuterium is present in sea-water in the ratio of one molecule per 6500 molecules of ordinary water, and is easily extracted. Furthermore, the released neutron can be used to breed tritium in hydrogenous materials, making a fusion power plant independent of external tritium supplies. Fusion power, when achieved, thus represents an essentially inexhaustible source of energy. Although economic studies, carried out on the basis of the current understanding of the physics and technology involved in building a fusion power-plant, raise questions about the near-term commercial viability of such a plant, there is little doubt that, as conventional fuel supplies become scarcer, fusion power will become more and more attractive. In brief, the promise of fusion is such that every technologically developed country today supports an active fusion research programme.

Early research in plasma heating and confinement was performed independently by the USA, the UK, and the USSR, and was treated as secret. In 1958, an international agreement declassified this data, making possible the exchange of information, and raising the possibility of future international co-operation in fusion research.

Since then there has been steady and encouraging progress in understanding the basic processes that govern the behaviour of interacting plasmas. The consensus of opinion in the world fusion community is that, although further work is needed in this and other areas, particularly the technological aspects of fusion, no serious obstacles are foreseen to the eventual successful construction of a power-producing reactor. Some of the major technical issues that are being addressed are the following: impurity control, refuelling, ash removal; scaling laws – the ability to scale from the present generation of machines to the next larger one; plasma physics; reactor choice – although various concepts are currently being investigated to assess their feasibility as the eventual driver for a fusion power plant, the tokamak approach is the leading contender, and each of the major fusion blocs are approaching the completion of a machine of this type (JET – European Community, TFTR – USA, JT60 – Japan, T10 – USSR); technological issues – superconducting magnet development, vacuum technology, materials development.

In the early 1960s, the Agency's involvement in fusion was limited to organizing one or two meetings a year. Thus in 1961 a conference on Plasma Physics and Controlled Nuclear Fusion Research was organized in Salzburg, with approximately 350 people attending. This conference proved to be the first in a series, the next one in 1965, then in three-year intervals until 1976 when a two-year cycle was begun. The next conference will take place in September 1982, with an expected attendance of about 600 people. Over the years these conferences have assumed an increasingly important role in presenting the latest results in fusion research to the international fusion community. The 1982 conference will be the largest meeting of its kind held anywhere.

Increasing Agency involvement

The IAEA's involvement in fusion has kept pace with the growing effort being devoted to this area. Perhaps one of the most important aspects of this involvement is in providing a forum where scientists

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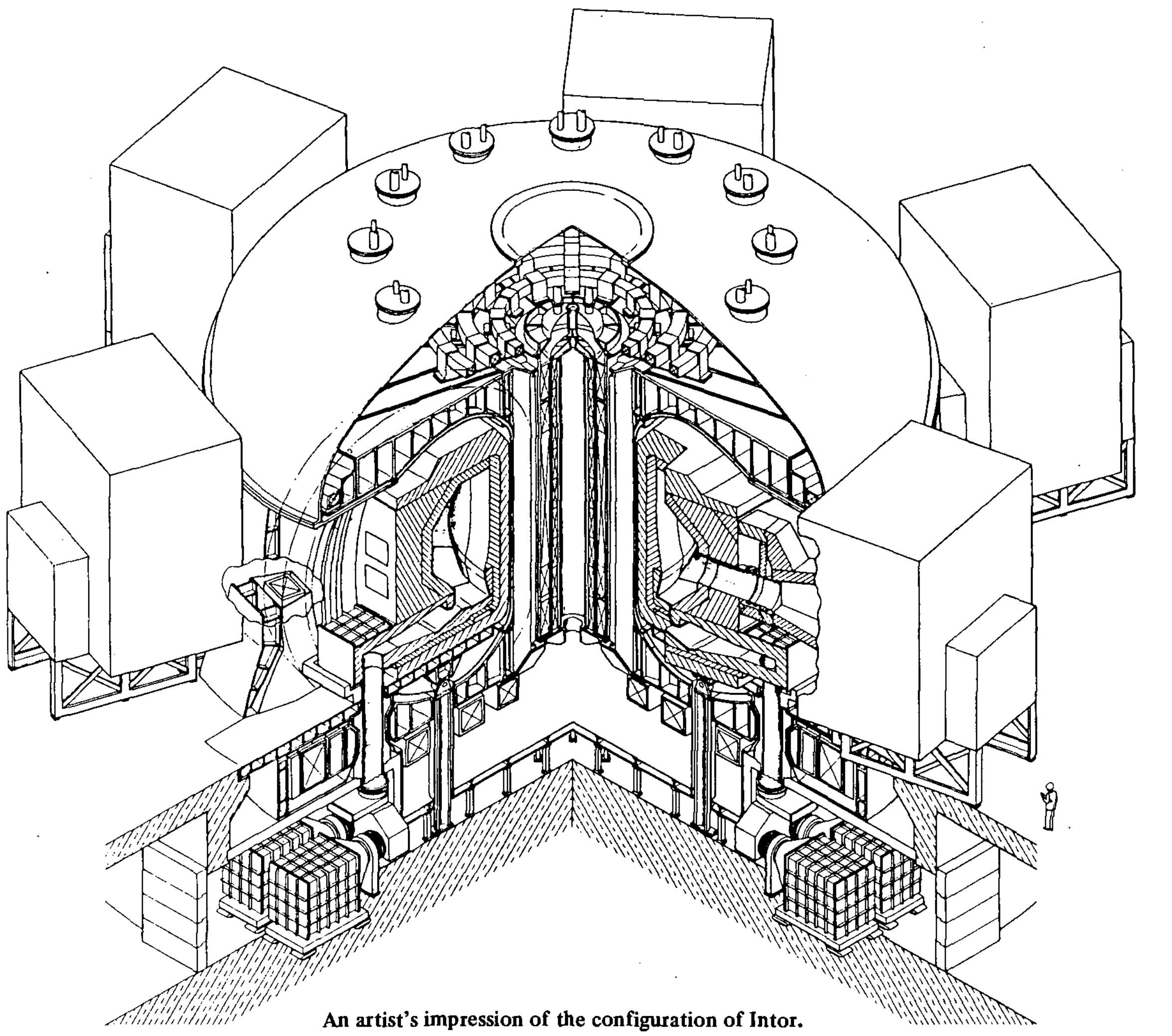

An artist's impression of the configuration of Intor.

from all the major laboratories in the world can meet and discuss their work. Technical committee meetings, workshops and conferences are organized on a wide variety of subjects relevant to fusion. The Agency also provides technical assistance to developing countries in their efforts to develop fusion programmes of their own.

Existing gaps in the research necessary to achieve an eventual fusion reactor are identified and addressed. The Agency publishes *Nuclear Fusion,* a unique journal devoted solely to fusion with contributions from scientists around the world. A list of fusion facilities throughout the world was published in 1976 and an updated version is scheduled for publication in 1982. This publication has been of great value to researchers throughout the world.

The Agency also has several contracts with developing countries to assist them in their own fusion research, as well as providing assistance through the Technical Co-operation Programme. Currently also, a programme directed towards those countries with existing fusion programmes is being considered. This is designed to provide training for their students and to co-ordinate the research of their more senior scientists with a view to integrate their research into the world-wide fusion effort. In order to advise the Agency on all these activities, an advisory group, now known as the International Fusion Research Council, was established. Its initial meeting took place in 1971. The council is composed of senior-level officials from the countries most advanced in fusion research. The IFRC has proved to be an effective body in assisting the Agency in its efforts to co-ordinate world-wide fusion research, providing a forum for the free discussion of national fusion programmes.

Intor workshop

The single most important Agency activity in fusion was the result of a wide consensus that excellent progress had been achieved in fusion research. Because of this perception, the IAEA's Director General in 1978 requested recommendations for an expanded programme that would hasten the development of fusion through international collaboration. The favourable response to the request led to the formation of the International Tokamak Reactor (Intor) workshop. This was organized by the IAEA to identify the nature and the programmatic and technical objectives of the next experiment beyond those presently under construction, and to determine if the scientific and technical bases for this experiment will be available in the near future. As conceived by the International Fusion Research Council, the Intor device would play a major role in establishing the technological feasibility of fusion and in demonstrating the fusion plasma performance needed for the tokamak reactors. The parties to the workshop are the European Community (Euratom), Japan, the United States of America and the Union of Soviet Socialist Republics.

The initial phase of this workshop took place in 1979 and its work was published by the IAEA in a report entitled *Intor – International Tokamak Reactor: Zero Phase.* Widespread interest was aroused by this report and the proposals it contained. With the agreement of the governments concerned, the IAEA set up the next stage of the Intor workshop, the so-called Definition Phase.

In the Definition Phase, the principal objective was the production of a conceptual design supported by a report. This report entitled *Intor – International Tokamak Reactor: Phase One* describes the objectives of the apparatus and its place in the world programme; it presents the conceptual design of the Intor tokamak; and it gives detailed technical discussion of the concepts embodied in the design to meet the overall objectives of the Intor tokamak. It was published in April 1982.

As this report makes clear, Intor, as at present foreseen, would be a large experimental device – a 600 MW(th) experimental reactor. Its construction and operation will, if undertaken, be a very substantial enterprise. It is correspondingly important both to optimize the programmatic information that can come from Intor and to critically review and refine the conceptual design. For this reason, on the recommendation of the governments concerned, the IAEA is continuing the Intor workshop into the so-called Phase IIA, for which the International Fusion Research Council has set the following objectives:

- To carry out a cost-benefit-risk analysis in which the objectives and parameters of Intor are varied to see the effect on costs, risks, and time-schedule both of the Intor device itself and of the fusion development programme.
- To examine the potential impact of foreseeable advances in physics, such as DC-current operation and radio-frequency heating.
- To analyse in greater depth certain critical issues which profoundly affect the design, such as: mechanical configuration and maintainability; tritium breeding and permeation; first-wall design; impurity control; and divertor configurations.
- To outline the design of advanced testing facilities of the torus, such as a combined tritium-breeding and electricity-generation segment, and of complementary non-fusion test facilities.
- To define specific research and development projects required for the design of Intor.
- To produce a report on the optimization of the conceptual design.

Each party to the Intor workshop nominated four participants who met in Vienna several times a year to define the effort of the workshop, to review and discuss the contributions of the four parties, and to prepare the report of the workshop. (When required, these participants were supplemented by experts.) The major part of the work of the Intor workshop was performed by experts working in their home institutions. This home effort involved about 100 senior scientists and engineers and about 10 to 20 man-years of effort for each of the four parties for the Zero Phase, and about 15 to 20 man-years for Phase One.

Some additional features of the Intor workshop series deserve mention. Agency sponsorship has permitted a degree of international co-operation that would otherwise have been difficult to achieve. The availability of expertise from all the major fusion blocks in the world has contributed significantly to the value of the work. The results to date have succeeded in systematically delineating the issues that must be addressed on the road to fusion power, and has focused the attention of the world fusion community on them. Of importance also is the "stand alone" nature of this work. Thus each segment of the activity represents a valuable and useful contribution to the fusion effort as a whole, independent of what decisions are taken with respect to the continuation of Intor. The current activity, the Phase II A referred to above, is scheduled for completion in June 1983, and by that time the participating countries will have arrived at their decision as to the future progress of Intor. The IAEA stands ready to provide the needed support, if requested by the participants, for this important example of international co-operation in the peaceful uses of atomic energy.