Towards a Controlled Nuclear Fusion Reactor

by R.S. Pease

Recently, at Princeton University, USA, plasma temperatures in the region of 60 million degrees Kelvin were attained in a fusion experiment of the so-called tokamak type. This was a significant advance over the temperatures (about 25 million degrees) previously achieved after years of research effort. In other tokamaks record values of the thermal insulation have recently been achieved Consequently there are good prospects of reaching both the temperatures and thermal insulation together needed for power production What then stands between us and the achievement of controlled nuclear fusion power?

During the last decade, growing efforts have been devoted to studying the possible forms an electricity-producing thermonuclear reactor might take and the various technical problems that will have to be overcome. Many conceptual designs of thermonuclear reactors have now been produced and studied and outline solutions to most of the problems have been put forward. Three main categories of reactor can be distinguished; all based on the reaction of deuterium and tritium nuclei which yield a helium nucleus and a 14.1 MeV neutron [$D + T \rightarrow He^4 + n + 17.6$ MeV]. Deuterium is readily available from ordinary water while tritium is bred in a surrounding blanket of lithium

First, so-called batch-burn reactors, in which a batch of fuel is inserted, then heated up and allowed to react and burn out. The reaction products are then pumped away and a fresh batch of fuel loaded for the process to be repeated. An example of this type of design is the laser fusion reactor although some magnetic confinement designs are also based on this system.

A second class of reactor is the so-called energy multiplier reactor, the best known example being the Magnetic Mirror machine. Here, the deuterium and tritium are injected at high energy, held in the magnetic trap sufficiently long to produce a net energy yield from the fusion reaction, and then exhausted out along the lines of force going through the magnetic mirrors. The energy multiplication sought has to exceed about ten if these systems are likely to be useful.

Finally, there are those systems almost exclusively based on toroidal magnetic fields, which are DC or quasi-DC. The cold fuel is injected into an already burning plasma and the reaction products and spent plasma are exhausted through a magnetic divertor.

Considerable numbers of reactor studies have been carried out on this third type and in particular those based on the tokamak geometry. Because of the induced current, for both heating and confining the plasma, these systems are generally planned as quasi-DC, i.e. burn-

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times of 1000 seconds or so There are some theoretical possibilities of making tokamaks strictly DC, but there is little experimental evidence to support these ideas at present

Typically all these reactors are large – usually giving outputs of several gigawatts (thermal) – and plainly are suitable only (as are virtually all fusion systems) for large-scale central electricity generation The physical size of the machines is about twice those of the largest tokamaks now under construction The main increase in size is due to the physical thickness of the blanket regions These have to be thick enough to slow down and absorb neutrons in order both to transform their kinetic energy into heat and to breed tritium Behind the blanket there will be further shielding to screen the superconducting magnetic coils from neutron radiation

THE NATURE OF THE PROBLEMS

On many occasions the various engineering and technological problems of controlled fusion reactors have been listed There are solutions, at least in outline, to all of these problems The greatest uncertainties probably attach to the physics of reacting plasmas, to the means of refuelling and of exhausting the reaction products, to the maintenance of high purity, and to the achievement of long-lived components in view of the (n, α) reactions induced in most of the construction materials by the 14 MeV neutrons

But the central problem is perhaps not that of developing solutions to each of the individual technological issues in isolation, rather it is the fact that to produce a controlled fusion reactor we have together to produce compatible solutions for all the problems We have to combine three major disciplines hitherto somewhat isolated – plasma physics and its associated technology, electromechanical engineering and nuclear engineering

Thus, it seems to me that at an early stage we need to try to build an experimental plant, preferably an electricity generating one, which will show us whether or not we can solve all these problems in a compatible fashion There are good prospects that the tokamaks now under construction will produce tens of megawatts of fusion heat output in the early 1980s, and while we must, under no circumstances, take this outcome as a foregone conclusion, we must at the same time be prepared to exploit such a result should it come about. If it does, the next major question we in the nuclear engineering field have to answer is. can controlled nuclear fusion be used to generate significant and sustained quantities of electric power?

A number of outline studies of possible tokamak experimental reactors have been carried out, notably in the United States and in Italy. Perhaps it is fair to say that these studies were carried out without any prospect of the immediate construction of the reactors. And indeed my advocacy is presently limited to urging vigorous paper studies to establish the basis of such a plant. However, the IAEA's International Fusion Research Council (IFRC) has recommended in its 1977 Status Report to the Director General that the time is ripe for an aggressive attack on the fusion problem It is my thesis that the early construction of an experimental electricity generator might turn out to be the most direct and cost-effective point of attack. We can take encouragement for such a bold step from the achievements of nuclear engineering in the pioneering phase of fission power development. During the decade 1950–60, the major new applications of nuclear fission energy to power production were all demonstrated, yet in 1950, it required some confidence to predict that by 1960 fission reactors would be producing electricity for the utility companies, and that they would also be operating in surface ships and submarines.

INTERNATIONAL CO-OPERATION

The IAEA has, of course, the special responsibility to promote co-operation in the development of nuclear energy for peaceful purposes. Perhaps I may be permitted to take this opportunity to pay tribute to the effectiveness of the IAEA and of Dr. Eklund's leadership in promoting international co-operation in controlled nuclear fusion research . In May 1978, following the 1977 Status Report, the IFRC met to formulate further recommendations. In particular, our Soviet colleagues concretely formulated the proposition that "the next big step" in tokamak research should be planned on a multinational basis under the auspices of the IAEA. The Soviet Government has also offered, if desired, to provide a site for the project on Soviet territory. The merits of such a proposal are that we can consider a more ambitious step forward than would be possible within the existing fusion research resources of individual nations or of existing groupings

The IFRC has consequently recommended that the IAEA promtly set up an international specialist workshop to prepare a report describing the technical objectives and nature of the next large fusion device of the tokamak type which could be constructed internationally.

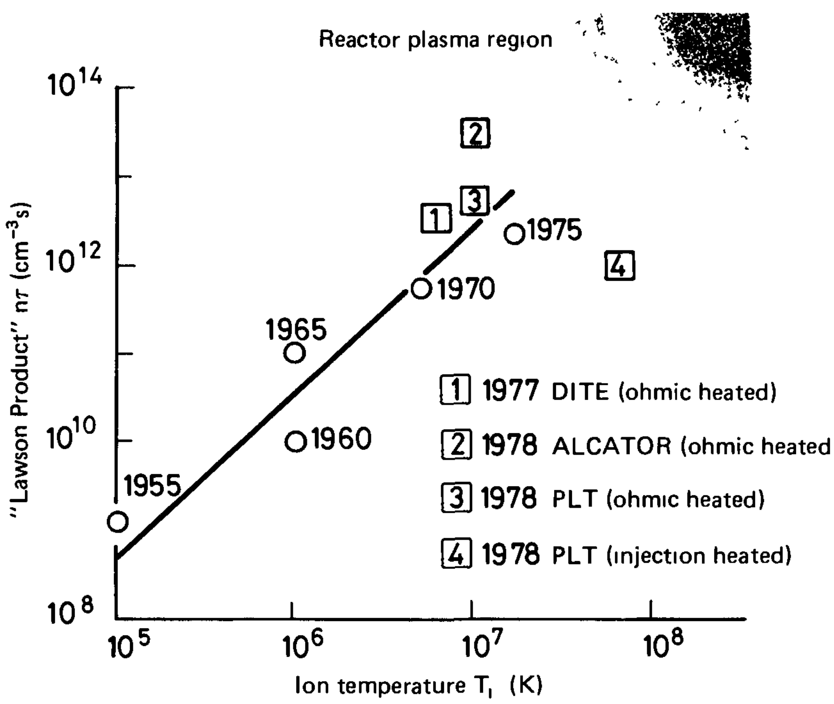

Figure 1. Progress in fusion research has been rapid and remarkably steady. The high temperature conditions needed for a reactor now appear to be almost within our grasp.

The IFRC has specifically in mind that the objective of the next major installation could be to take the maximum reasonable step beyond the present generation of experiments, to demonstrate the scientific, technical and engineering feasibility of the generation of electricity by pure D-T fusion Clearly the magnitude of the step is a matter of scientific and engineering judgement, to be reached after rather careful study of what has already been done, what new information will be available in the early 1980s, and what problem areas need to be tackled before construction (or even detailed design) can be started. We hope that the workshop will start on these problems in Vienna early in 1979.

If the technical progress we are currently experiencing continues, and in particular if those tokamaks now under construction can give information which we need on the behaviour of power-producing reactions in the high temperature plasma, then such an international initiative may prove to be the key to a demonstration of electricity generation by controlled nuclear fusion in the early 1990s It is essential, if the forward thrust of the work is to be maintained, that the design and development work for the next step is well advanced by the early 1980s.

CONCLUSION

In summary, then, the scientific research on controlled nuclear fusion is making rapid progress. High temperature plasma is now produced, controlled and thermally insulated in a wide variety of devices, of which the most advanced is the toroidal magnetic system known as the Tokamak. These systems are based on what have turned out to be comparatively simple physical principles. Consequently there are good prospects of reaching both the temperatures and thermal insulation together needed for power production. In devices now under construction and expected to be in operation in the early 1980s, thermal fusion power of the order of tens of megawatts in bursts of 10–20 seconds duration is predicted in some estimates International co-operation in fusion research and the role of the IAEA in this co-operation have been excellent, and a new IAEA workshop is to study the possible aims of an international tokamak experiment to follow the devices presently under construction

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