The Structure of a Collaborative Next Step Programme

NOTE BY THE JET DIRECTOR
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Introduction

1. This note is written at the request of the Fusion Review Board to elaborate and expand on the views of the JET Director on the way forward for the Euratom Fusion Programme in the possible framework of world collaboration (Note for the information of the CCFP, 5 February 1990).

Objectives

2. The fundamental objective of a European Fusion Programme is to establish the option to exploit Fusion as a source for power generation. To this end the strategy of the programme is directed ultimately towards the construction of demonstration Fusion Reactor(s) - "DEMO". Such a device is presently envisaged to be a power reactor of several gigawatts (3-5GW)with a fully hot breeding blanket. It will operate at ignition at least in a semi-continuous mode with superconducting coils.

3. The "Next Step" must provide the mechanism by which the Fusion Programme bridges the gap from the current position with existing devices - in Europe, JET and the medium sized tokamaks - to a position of being able to design and construct DEMO devices. In particular, each of the aspects of DEMO mentioned above has to be tackled. The main challenge now facing the Fusion community (and the raison d'etre of the ITER collaborative activity) is that of entering into the step after JET, TFTR and JT60. In the note for the CCFP, the JET Director concluded that the right direction was to move towards an ITER programme rather than a single ITER project.

Issues for the Next Step

4. Notwithstanding the progress that has been made and the results achieved or planned from the existing devices and technology programmes some significant issues must still be addressed and some conflicting demands resolved before starting the construction of Next Step devices.

5. In terms of plasma physics, the only major remaining area of uncertainty is the problem of impurity control and the related issues of fuelling, particle transport and exhaust. Intermediate to physics and technology are questions relating to the nature of first wall components and the control of the heat load so as to limit erosion and stress in the divertor plates. The objective of the proposed New Phase Programme at JET is to establish the effective control of plasma impurities in operating conditions

close to those of a Next Step. (This will also address the questions of transport and exhaust.) The aim is to provide the necessary information on these key features by the end of 1994. Once this has been done it will be possible to finalise the design of the core of a Next Step tokamak.

6. Before implementing a full programme, significant technological and physics developments are required for the following component items:-

- the technology of high and variable field superconductors in very large coils;
- development of tritium breeding blankets;
- resistance of highly sensitive materials, eg insulators, to high neutron fluences;
- development of the option, for a reactor, of an efficient method of non-inductive current drive for full steady state operation.

7. These issues are expected to come to maturity on varying timescales. The Next Step Programme needs to address them all, but attempting to cover all of them in a single device will limit the domain of investigation and lead to unacceptable risk of failure unless a large safety margin is allowed on each component. This will impact on both the start-time and construction time, with a consequential impact on costs. The whole development of fusion will also be over-concentrated at too early a stage (cf nuclear fission when, at a similar stage, there were many different reactor concepts being developed and it was not required to incorporate all the major technologies too early).

Specific components for the Next Step

8. In view of this, the JET Director concluded that it is more sensible to envisage a Next Step programme comprising several complementary components, each optimised with respect to specific clear objectives. There would be two Next Step Tokamaks, whose outline specifications are summarised in Table 1.

I A Fusion Furnace ("M1")

9. There is a case for considering, in the first instance, the use of conventional copper coils in a device which focuses on operating a plasma at reactor power levels and on testing plasma facing components. This would also allow testing of some prototype blanket modules for a reactor. The use of conventional copper coils would

reduce the complexity of the shielding requirements and relieve the constraints that these would impose on potential fusion performance.

10. The device, "M1", would thus be a thermonuclear furnace, featuring a full reactor plasma to allow exploration of a wide ignition domain. It would include systems for exhaust and fuelling, but exclude a tritium breeding blanket and superconducting coils and therefore will require relatively little shielding. It should demonstrate the potential of fusion as an energy source. Achieving the necessary plasma conditions will require a large device (R~7m) operating a long pulse (~1000s) and a high duty cycle (semi-continuous operation). The simplest possible technology should be used for systems outside the central core. The device would be used to test different elements of a DEMO blanket at a realistic level of power density (not provided in the present NET/ITER concepts). However, the operation of this device will not require breeding of tritium. In addition to the basic aim of learning how to operate the plasma of a power reactor the device would also address the technological aim of establishing industrially relevant solutions for the issues mentioned above. It would also allow tests of advanced fuels (eg low T, high D).

II A Steady-state Tokamak ("M2")

11. The technology of reactor scale steady state operation would then be the focus of a complementary tokamak, M2. This machine would address the basic question of superconducting magnets and non-inductive current drive and their integration in a tokamak of reactor scale. It would operate with an equivalent $Q_{DT} \sim 2$ but would not need ~~to be~~ designed for Tritium operation and could therefore be a smaller machine (M ~ 4m). A machine of this kind would need more time for superconductor and current drive development but, by avoiding the shielding requirements and other provisions for tritium operation (notably a breeding blanket which would, of necessity, not be reactor relevant), it would need a shorter design and construction period and would clearly cost less than M1. Because it would not be a Tritium device, M2 could also serve as a testbed for diagnostics or advanced tokamak concepts.

III Materials Test Facility ("M3")

12. As well as the advances in tokamaks, there is an inescapable need for some kind of test facility for first wall and blanket materials to allow the extensive study of the effects of a high fluence of 14MeV neutrons on material properties, especially strength, weld integrity and corrosion. Such a facility would be required before DEMO regardless of the number of tokamaks in the Next Step and, of itself, establishes the need for a coherent programme.

13. A Next Step programme of the kind proposed above would demonstrate the feasibility and reliability of all the elements that need to be brought together in a DEMO device. M1 would concentrate on operating a reactor plasma with a wide domain of sustained ignition, including plasma engineering and blanket module tests; M2 would concentrate on proving the integrated technology for superconducting coils and steady state operation; and M3 would be devoted to the testing of internal reactor materials.

DEMOnstration Reactors

14. The information from the programme would be integrated to provide the basis from which to proceed to DEMO-type devices. Again there are different concepts and these should be pursued in more than one such device. The study for DEMO reactors could start by 2000 with the aim of starting a first DEMO ("D1") around 2005. This would be a pulsed machine (semi-continous based on a quasi-stationary mode of operation, with current reversed every hour with a duty cycle >90%). The breeding blanket design would be finalised in the light of experimental experience of blanket module tests in M1.

15. A second DEMO ("D2") could be started some years later and could be a steady-state machine using current drive if the physics and technological results of M2 warrant this. The blanket design for D2 would be based on the range of module tests and actual experience which would have been gathered by then. The design of superconducting coils could exploit any significant developments by that time in advanced superconducting technology.

Timescales

16 A broad indication of the possible sequence of the suggested programme is shown in Figure 1. For M1 the key information missing at present is the data on impurity control, fuelling and exhaust. The relative simplicity of M1 means that, allowing the build-up of a construction team over a few years, it would be possible to start on the infrastructure and initial construction from early in 1995 (taking account of JET results on impurities from 1993 and continuous further input through to 1995/1996). The construction period would be 7-8 years. The first plasma would thus occur some 5-6 years after the proposed closure date of JET. Breeding blanket element tests could be carried out from 2005.

17. M2 would require further time for development of superconducting coils and current drive (negative ion beams) but, because it is smaller and would not be a tritium machine, it would need shorter planning and construction periods, possibly being complete in 6 years.

18. The study for M3 should start urgently with a view to starting a 5-6 year construction period from 1995.

19. On this basis it would be appropriate to initiate the study for a first DEMO device by 2000, with a view to starting construction around 2005, allowing for final definition of the breeder blanket by about 2008. A target date for the start of design for D2 would be 5 years later.

Cost Estimates for the Next Step

20. A broad estimate for the cost of the M1 device can be derived either by comparison with the preliminary costings of JIT (a similsr concept to M1) or by analysis of the cost data given in the ITER interim report, adjusting for the provisions in that estimate which relate to superconductivity and current drive. Both approaches suggest that an estimate of about 3 BioECU for the full construction cost of M1 is reasonable.

21. Taking account of the smaller size of M2 and of the fact that it does not need to accomodate tritium, the costs can be broadly estimated at 2 BioECU.

22. Thus in broad terms, M1 and M2 together appear likely to cost no more than the currently estimated overall cost of a single ITER Device.

23. The concept of the Materials Test Facility, M3, is not yet advanced but its costs may be expected to fall in the range 1-2 BioECU.

Benefits in the collaborative framework

24. The note to the CCFP highlighted a number of managerial issues for Next Step activities that have to be addressed in the frame of a collaborative programme, namely: the setting of technical objectives; the definition of clear funding/management responsibility for projects; and the siting issue. Proceeding by means of a coordinated Next Step programme of the kind suggested above offers a more robust and practicable way of realising the benefits of global collaboration than would the concentration into a single device. In particular:-

Overall the pace of development will be faster and better balanced between the partners and with respect to the needs of the different technologies involved;

All the elements of DEMO power plant devices will be systematically tested in realistic and relevant conditions up to the full power of a reactor;

Technical risks on any one machine will be reduced to acceptable levels, thereby giving an assurance of sustained operations of machines significant for DEMO;

An element of competition in research will be provided;

A range of options will be held open and explored. This will allow design decisions for DEMO on the basis of comparative tests;

Each project could have a practical direct management structure within a coordinated global programme;

Siting and project leadership could be determined in light of the relative strength and states of readiness of the different ITER partners and thus utilise resources and skills to best effect; on this basis M1 would be best placed for an early start in Europe, M2 probably in Japan and M3 in USA ;

The combined costs of the two tokamak devices proposed would be similar to that of a single ITER device.

Conclusions

Collaboration should not be used as a means of reducing the overall world programme but rather to increase speed and reduce risk.

1. For technical and managerial reasons, the Next Step in a collaborative Fusion Programme would proceed more effectively and efficiently by means of two complementary tokamak projects in a coordinated programme. In addition a Materials Testing Facility will be required.

2. Within this approach the design of the first machine, M1, with the objective of operating a reactor plasma with a wide domain of sustained ignition, could be completed once the results on impurity control, fuelling and exhaust expected from the New Phase JET programme are available. Thus the project could start early in 1994.

3. A second smaller tokamak device, M2, could integrate at a relevant scale the technologies of superconducting coils and non-inductive current drive needed for steady state operation without the added complexity of tritium operation. Construction of the device would start some two years later than M1.

4. Results from these two tokamaks, together with the information from a Materials Testing facility, M3, would provide a satisfactory base for the first DEMO-type reactor which could be started from 2005.

5. A single ITER project, as currently conceived, has higher physics, technical and management risks and does not provide such a comprehensive information base, mainly in the domains of ignition, reactor performance and blanket testing.

6. The combined cost of M1 (~3 BioECU) and M2 (~2 BioECU) would not exceed the current estimated cost of a single ITER device. The Materials Test Facility, M3, will be required in any event. The combined cost of such a global programme would stay below 1 BioECU/year.

7. Europe is best placed to construct M1 and should offer to do so in the frame of a collaborative programme with minority participation from other ITER partners.

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Table1: TOKAMAK COMPONENTS OF THE NEXT STEP

FUSION FURNACE (M1)	STEADY STATE TOKAMAK (M2)
Long Pulse Operation (Pulse length > 1000 sec)	Continuous Operation
Copper Coils	Superconducting Coils
ICRH Heating (50 MW)	Non-inductive Current Drive (~ 100 MW -ve ion Beams)
D-T Operation	D Operation
Major Radius, R~ 7m	Major Radius, R~ 4m
Minor Radius, $\sqrt{ab}\sim 4$m	Minor Radius, $\sqrt{ab}\sim 2$m
Plasma Current 25-30 MA	Plasma Current 10-12 MA
Magnetic Field 4T	Magnetic Field 5T
Full Ignition, 3 GW Thermal Output	Equivalent QDT = 2
Impurity Control by Swept Divertor and Imposed Plasma Flow	

Fig I: Structure of a Collaborative Next Step Programme
(Indicative Timescale)