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OAK RIDGE TNS PROGRAM 1976/1977

INTEGRATION OF ENGINEERING REALITY BRINGS US CLOSER TO REALIZABLE REACTOR

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ABSTRACT

Both the techniques and results of bringing engineering reality into the exploration of the possible design choices for The Next Step (TNS) in the Tokamak Fusion Program after TFTR are discussed in this report. Each of the elements of our interrelated, three-part approach --plasma engineering, engineering design, and program planning -- is highlighted. The constraints developed from an engineering viewpoint are seen to stimulate creative improvements in each area. Plasma engineering activities that reduce technological requirements for reactor core performance are described. The engineering design study comparing quantitatively various technical options for TF coils is outlined with summarized findings leading to a clearer view of the essential problems -- namely the setting of objectives and making of decisions. The findings of the draft program planning exercise are also presented.

1. INTRODUCTORY SUMMARY

The objective of our TNS efforts is to provide a focus within the U.S. fusion program for the development of a reactor core experiment in the next decade. Our prior advanced systems studies started with point designs (F/BX I and II) (1), explored the design issues of the tokamak EPR (scoping studies) (2) and culminated in an evaluated reference design (3). With this basis, the TNS activities were directed at characterizing the design space between TFTR and EPR with a fundamental emphasis on higher beta plasma systems than previously projected, i.e., $\bar{\beta} \sim 5$-10% as compared to 1-3%. The orientation toward higher beta rather than larger systems at the lower beta has come from an engineering judgment that economical systems are necessary, not optional. The characterization of this design space has proceeded by plasma engineering investigations of the dynamics of the higher beta plasmas and the requirements on technology of heating and fueling (Section 2), by developing consistent, feasible engineering models of systems of different size and magnetic field strength (Section 3) and by program planning studies of the steps required to implement the designs (Section 4).

In the first area, namely plasma engineering, early indications were that very stringent requirements were to be placed on physics achievements ($\beta \sim 10$-15%), beam technology ($\sim$ 500 keV), and system size including a divertor (up to $\sim$ 1/3 more in linear dimension). Rather than pursue these difficult requirements with even more difficult technology development programs, high risk physics or high cost solutions, we reexamined the basis for the requirements. We found that as more realistic models of the higher beta plasma are used, specifically going from 0-D to 1-D models with spatial profiles, the lower the requirements on achievable beta, neutral beam energy and fueling technology become. Under the constraint of a fixed, no-divertor TF coil shape, an innovative design concept for a compact poloidal divertor was developed that can have significant impact on the options available to plasma engineers (4).

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In the second area, system modeling, the principal questions asked were, "What is the cost variation with size?", and, "How does cost depend upon the TF coil technology used?". Based upon fairly comprehensive engineering models as opposed to optimized point designs, curves of relative cost vs the principal geometric and operating characteristics have been produced. With the costing and sizing model (5), the cost sensitivity to any of the assumptions can be investigated and modifications made. With respect to the second question -- impact of TF coil type -- the result was that the principal differences between the use of superconducting and copper coils were those of objectives and risks and not cost alone; the relative costs for the Cu, Nb_3Sn, NbTi, and NbTi/Cu options were roughly 1:1.3:1.5:1.5. A closer examination of similar physical devices indicated that the balance of plant is the dominant factor and that the high technology questions are of great concern but have little economic impact.

In the third area, program planning, various elements of a preliminary program plan were initiated (6) that identified the central programmatic questions. In particular, an assessment of the R&D needs for TNS was made and recommendations for more emphasis on existing programs and for new initiatives were made and documented (7). Planning schedules for integration of the TNS project with the supporting R&D work and the subsequent reactor devices were developed (8) as well. From all this came the findings that plasma physics and decision-making are the true critical paths and that a route to engineering reliability must be laid out.

Based upon the findings in these three areas, the continued activities in the TNS program are being directed toward cost reduction and increased feasibility in the most critical areas, namely, divertor/poloidal magnetic design, mechanical assembly and maintenance and the interface with supporting R&D work (Section 5).

2. PLASMA ENGINEERING

The purpose of the plasma engineering studies within this program has been to establish credible ranges of physics parameters for an ignition test reactor as the next step (TNS) beyond TFTR. Our reactor concept is based on medium toroidal fields (9) (B_T = 4-7 Tesla), high plasma densities (10) ($\bar{n}$ = 0.6-2.5 x $10^{20}m^3$) and high tokamak betas ($\bar{\beta}$ = 5-10%).

Use of medium field strengths is compatible with the introduction of a large amount of neutral beam power which in turn is important to high density. With large neutral beam power, the plasma is expected to heat up in a time scale much shorter than the plasma skin time, resulting in a Flux Conserving Tokamak (FCT) (11). Calculations in D-shaped FCT (12) have produced equilibria at $\bar{\beta}$ above 20% with the safety factor up to 5. Although MHD instabilities may limit $\bar{\beta}$ to lower

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