9. OVERALL SUMMARY AND PROGRAM DIRECTIONS

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9.1. OVERALL SUMMARY

During the Scoping Phase, the TITAN team has succeeded in its interim objectives: to define the parameter space for a high mass power density (MPD) RFP reactor; to explore a variety of approaches to the design of major subsystems; to narrow to two major design approaches consistent with high MPD; and to reach an intermediate stage which includes preliminary engineering design and integration. The program retains a balance in its approach to investigating high MPD systems. On the one hand, parametric investigations of both subsystems and overall system performance are performed. On the other hand, more detailed analysis and engineering design and integration are performed, appropriate to determining the technical feasibility of the high MPD approach to RFP fusion reactors. Furthermore, a strong coupling and feedback between the engineering design effort and the parametric systems activity have been established. Because of this balance, we have come to refer to the TITAN effort as a "parapoint" study.

Detailed technical conclusions are given in individual sections. The physics issues for compact RFP reactors are discussed separately in Sec. 4.8. Major technical results at this interim stage can be summarized as follows:

1. Parametric system studies continue to suggest that a shallow minimum in cost of electricity (COE) versus neutron wall loading exists, extending from about 10 MW/m^2 to 20 MW/m^2 with the minimum COE at 18 MW/m^2. Reversed-field pinch reactors with this range of neutron wall loading have MPD values well in excess of 100 kWe/tonne. The TITAN reference design at a neutron wall loading of 18 MW/m^2 has a MPD of 640 kWe/tonne and a COE of 35 mills/kWeh (constant 1986 dollars).

2. Reversed-field pinch systems with high MPD at 15-20 MW/m^2 neutron wall loading are physically compact systems. The cost of the fusion power core (FPC) is a small fraction of plant cost (about 7% of the direct cost), which means that small units can be used to minimize the cost of a development program as well as allowing shortfall in FPC performance goals without seriously impacting COE.

3. Single-piece maintenance of the entire reactor torus (first wall, blanket, divertor sections, with or without the shield) is feasible for high MPD systems. At 18 MW/m^2 neutron wall loading, the entire reactor torus of TITAN, drained of coolant, can be vertically lifted with a crane and replaced with a complete and pre-tested unit with a minimum amount of down time and start-up time. The full impact of single-piece maintenance and the ability to pre-test the entire reactor torus as a unit on reliability and availability is not yet determined. The shallow minimum in COE is largely a result of the assumption that the availability is not a strong function of the maintenance concept, at least at the level of single-piece versus modular approach to design and testing.

4. Reversed-field pinch experiments appear to operate well even when the dominant core plasma loss mechanism is radiation rather than conductive energy transport. This is particularly advantageous for high wall loading systems, as it distributes the plasma energy loss uniformly on the walls. For TITAN, this approach has been adopted, along with four toroidal field divertors as the particle removal system.

5. The dominance of poloidal field and weak toroidal field external to the plasma makes the RFP particularly well suited to liquid-metal cooling. One design approach being pursued uses liquid lithium as coolant and breeder and vanadium alloy (V-3Ti-1Si) as the structural material. The first wall, blanket, shield, and divertor cooling are all accomplished using lithium in this design; no other coolant is needed. This simplifies system integration and design. AT 18 MW/m^2 neutron wall loading, the fluid pressure in the first wall tubes is estimated to be about 100 atm (about 10 MPa): this level is reasonable, since the stresses and pumping power requirements associated with this high pressure are modest. The coolant pressure in the blanket is much lower at about two MPa.

6. The integrated blanket-coil concept (IBC) is significantly better suited to the RFP than to the tokamak concept because of the lower value of the magnetic field that the coil must produce. The IBC is especially advantageous, perhaps uniquely so, for use as the main divertor field coil in an RFP. It can also be used to generate the toroidal field. In TITAN, the IBC has been adopted for both divertor and TF coils. When applied to

the divertor, the IBC truly improves the RFP as a reactor, whereas the advantages over a copper TF coil system are less clear. Since the copper TF coil approach appears certain to work, the TITAN team chose to vigorously pursue the TF-coil IBC approach. It is not, however, required for achieving high wall loading.

7. The aqueous "loop-in-pool" blanket has emerged as an alternative design approach for high-MPD RFP systems. This design incorporates a water-cooled copper first wall and steel structural material for blanket and shield. The cooling is achieved with a loop design. The fusion power core (FPC) as a whole is submerged, however, in a low pressure water pool to achieve level 2 passive safety. Tritium breeding is achieved using a lithium salt dissolved in the water while controlling the pH of the solution to minimize corrosion. Work on this design is less advanced within the study.

9.2. PROGRAM DIRECTIONS

During the scoping phase of the TITAN study a large number of design concepts and options were considered. Of particular importance are the four blanket concepts, reported in Sec. 8. It was decided to narrow to two the number of FPC designs to be pursued during the design phase. The decision was a necessary because of inadequate resources to pursue all four designs. The decision on which of the two concepts to pursue was difficult to make. All four concepts have attractive features. The lithium-loop design promises excellent thermal performance and is one of the main concepts being developed by the blanket technology program. The water design promises excellent safety features and use of more developed technologies. The helium-cooled ceramic design offers true inherent safety and excellent thermal performance. The molten-salt pool design is the only low-pressure blanket and promises passive safety. The lithium loop concept and the aqueous "loop-in-pool" concept were chosen for detailed conceptual design and evaluation in the design phase of the TITAN program. The choice was made primarily on the capability to operate at high neutron wall load and high surface heat flux. The choice not to pursue the helium-ceramic and molten-salt designs should in no way denigrate these concepts. Both concepts offer high performance and attractive features when used at lower wall loads; these concepts should be pursued in other design studies.

In the design phase, the TITAN program will emphasize engineering design and complete technical evaluation of the high-MPD approaches based first on the Li/V loop system and then on the aqueous "loop-in-pool" concept. About half of the duration of the design phase will be devoted to complete the Li/V design, with essentially allocating the full resources of the program during this period. Major efforts will be made to provide the technical material needed to establish engineering feasibility and the design integration. In addition, safety and environmental tasks will receive special attention; work on the plasma modeling, first-wall design, and divertor system will continue. The area of high-heat-flux components is the most difficult physics-engineering interface and will receive major attention.

Once the Li/V design has been brought to completion, the TITAN team will concentrate on establishing the feasibility and examining key issues of the aqueous blanket design. All of the major subsystem design and analysis will be addressed along with the assessment of safety and environmental impact. The technical feasibility and key issues for high-MPD RFP reactors will be established; having more than one design approach strengthens this case.

Finally, parametric studies will continue in concert and iteration with the engineering design so that a better understanding of the changes in system design in going to lower wall loadings (e.g., about 10 to 12 MW/m^2), and in using high-MPD RFP systems in a development program will emerge.