MFE Technology Working Group Status Report

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Snowmass Fusion Summer Study

MFE Technology (T) Working Group

Chair: C. Baker, (UCSD)

SUBGROUP AREA	CONVENERS
T1 - Magnets	N. Martovetsky (LLNL) J. Minervini (MIT)
T2 - Plasma Facing Components	R. Mattas (ANL) M. Ulrickson (SNL)
T3 - Heating/Current Drive/ Fueling	D. Rasmussen (ORNL) R. Temkin (MIT)
T4 - Vacuum Vessel and Remote Handling	B. Nelson (ORNL) T. Burgess (ORNL)
T5 - Safety/Tritium/Materials	D. Petti/L.Cadwallader (INEEL) S. Willms (LANL) S. Zinkle/A.Rowcliffe (ORNL)
T6 - Costing	L. Waganer (Boeing)

Overall Assessment - Tentative

- There are no outstanding feasibility issues to prevent the successful design and fabrication of any of the three options.

  → ITER and IGNITOR have well-developed designs.
  → FIRE is at the preconceptual design level.
  →ITER has been supported by a comprehensive R&D program.

- The machine designs seem to be adequate to meet the different burning plasma missions of the three options.
- The costs for ITER and FIRE appear to be credible.
- ITER offers the most benefits in terms of demonstrating reactor-relevant technologies and integrated operating experience.
- There are numerous technical issues and concerns, particularly regarding operations. Key examples are:

→ surface erosion due to Type I ELM's.
→ tritium retention in carbon-based materials.

Magnet Technology - MFE. T1

- The magnets for all three burning plasma experiments should provide adequate capabilities for meeting all the requirements of the particular experiment.

- The magnet systems for all three machines do not represent feasibility problems, although the level of detail worked out in the design is different for these magnet systems: IGNITOR having the highest level of detail, FIRE the lowest.

- The identified and accomplished level of R&D was quite different; the superconducting magnet system for ITER had the highest effort.

- IGNITOR readiness is the highest; they essentially have completed their R&D, fabricated full-scale prototypes of critical elements and produced fabrication drawings developed in collaboration with industry.

- The IGNITOR construction schedule is 5 years. FIRE construction will take approximately 6 years. ITER construction schedule shows 9 years from the project start to first plasma.

- No systematic data available on the risk assessment on any of the machines, although some fault analyses have been performed.

- ITER has the highest overall relevance to a DEMO reactor; FIRE has high radiation effects relevance.

- Some key issues:
  - reliability and fault analysis (ALL)
  - provisions for fit-up of magnets (ALL)
  - additional magnet R&D (FIRE, ITER)
  - magnet insulator lifetime (FIRE)

Plasma Facing Components/Heat Removal - MFE.T2

- ITER is the most mature of the three designs. The design work for PFC's has been coupled with an extensive R&D program where PFC mock-ups have been tested to prototypic heat flux conditions.
- The ITER device is the most DEMO relevant with long burn times and highest neutron fluence of the three devices.
- There are a number of issues and concerns for ITER including:
  - tritium inventory and co-deposition. Carbon has been shown to retain high levels of tritium.
  - because of the potentially high frequency of ELM's during the plasma burn, the lifetime of PFC surfaces could be unacceptably short.
- Much of the work for the FIRE PFC's has been based upon the work done for ITER. Since FIRE does not use carbon, the tritium inventory and sputtering erosion issues are reduced.
- Issues and concerns for FIRE PFC's are:
  - material properties of plasma sprayed beryllium on the first wall.
  - erosion and tritium co-deposition performance of mixed beryllium/tungsten divertor surface.
  - surface erosion losses due to Type I ELM's.
- The first wall in IGNITOR is the plasma facing system. It does not have a divertor, although it is possible to configure the plasma to a double X-point configuration.
- Issues and concerns for IGNITOR PFC's are:

- ability to sustain a radiating mantle at the edge without hot spots.
- alignment of first wall tiles.

Heating, Current Drive and Fueling - MFE. T3

- For all three burning plasma experiments, heating and current drive capabilities should be achievable while meeting all safety and reliability goals. Fueling and pumping require pushing beyond the state of the art.

- ITER will employ negative-ion NBI at 1-MeV and development programs are underway (outside the U.S.) to provide steady-state systems to meet these requirements.

- ICRF technology is very highly developed and should be considered a relatively low risk for implementation on a burning plasma experiment. IGNITOR, FIRE and ITER would all contribute very significantly to the development and qualification of ICRF concepts for reactor application.

- LHCD is very attractive for current drive and could be critical to advanced tokamak operation scenarios. Although none of the three machines has selected LHCD as a necessary component of its heating and current drive system, any of them could be used to test an LHCD system.

- ECH/ECCD systems are very attractive for burning plasma experiments because they take up a small port space and can be implemented with a very small impact on the nuclear environment. ECH/ECCD is in the baseline design for ITER.

- The ITER fueling and pumping system designs are very well advanced. The fueling system design, in particular the pellet

injection system, is beyond the current state of the art and will require further technology development effort.

- The FIRE fueling system requirements are well developed and seem reasonable to meet the performance objectives of the machine.

- The IGNITOR fueling and pumping system are not as well defined as those for ITER and FIRE.

Vacuum Vessel and Remote Handling - MFE T.4

- The vacuum vessel configurations for the three options are somewhat different, although all provide the necessary plasma vacuum and safety barrier functions.
- The ITER vessel could be considered prototypical of a DEMO device, while the FIRE and IGNITOR designs have much less direct relevance.
- The remote maintenance approach of ITER, IGNITOR and FIRE is similar although the details of the handling equipment, machine components and the level of design maturity varies considerably.
- ITER is by far the most advanced in terms of design and has completed some major remote maintenance R&D projects.
- ITER is the most representative of the remote handling requirements of DEMO, with activation levels, and component designs and sizes more typical of a power reactor.

- Some key issues:
  - analysis of disruption loads (FIRE)
  - vacuum vessel design for disruption loads (IGNITOR)
  - access for in-vessel remote handling (IGNITOR)

Safety/Tritium/Materials - MFE. T5

- The primary safety issue is the ability to obtain regulatory approval, and an ancillary issue is the ability of the design to highlight the safety and environmental (S&E) potential of fusion power plants.

- IGNITOR and FIRE have modest inventories of tritium and small to moderate size energy sources. These machines can easily gain regulatory approval, but would provide little demonstration of the S&E potential of fusion.

- ITER is projected to have power plant relevant hazards, including large inventories of tritium and activated dust, and large energy sources that could mobilize those inventories.

- ITER has developed a high degree of safety integration in the design, and good depth and rigor of the safety analysis.

- Regulatory approval of the ITER safety approach, concurrence and validation of the safety analysis, and safe operation of the facility would in large part demonstrate the S&E potential of fusion power plants.

- The tritium systems for IGNITOR and FIRE are relatively straightforward and will have a high probability of success, but are only of marginal value for DEMO.

- ITER tritium systems will be much more challenging to design, construct and operate; but they will have considerable value as very similar systems will be needed for DEMO.

- For ITER, the projected neutron fluences are such that radiation effects on materials behavior must be accounted for; accumulated neutron fluences are one and two orders of

magnitude lower in FIRE and IGNITOR, respectively, and radiation effects are relatively minor.

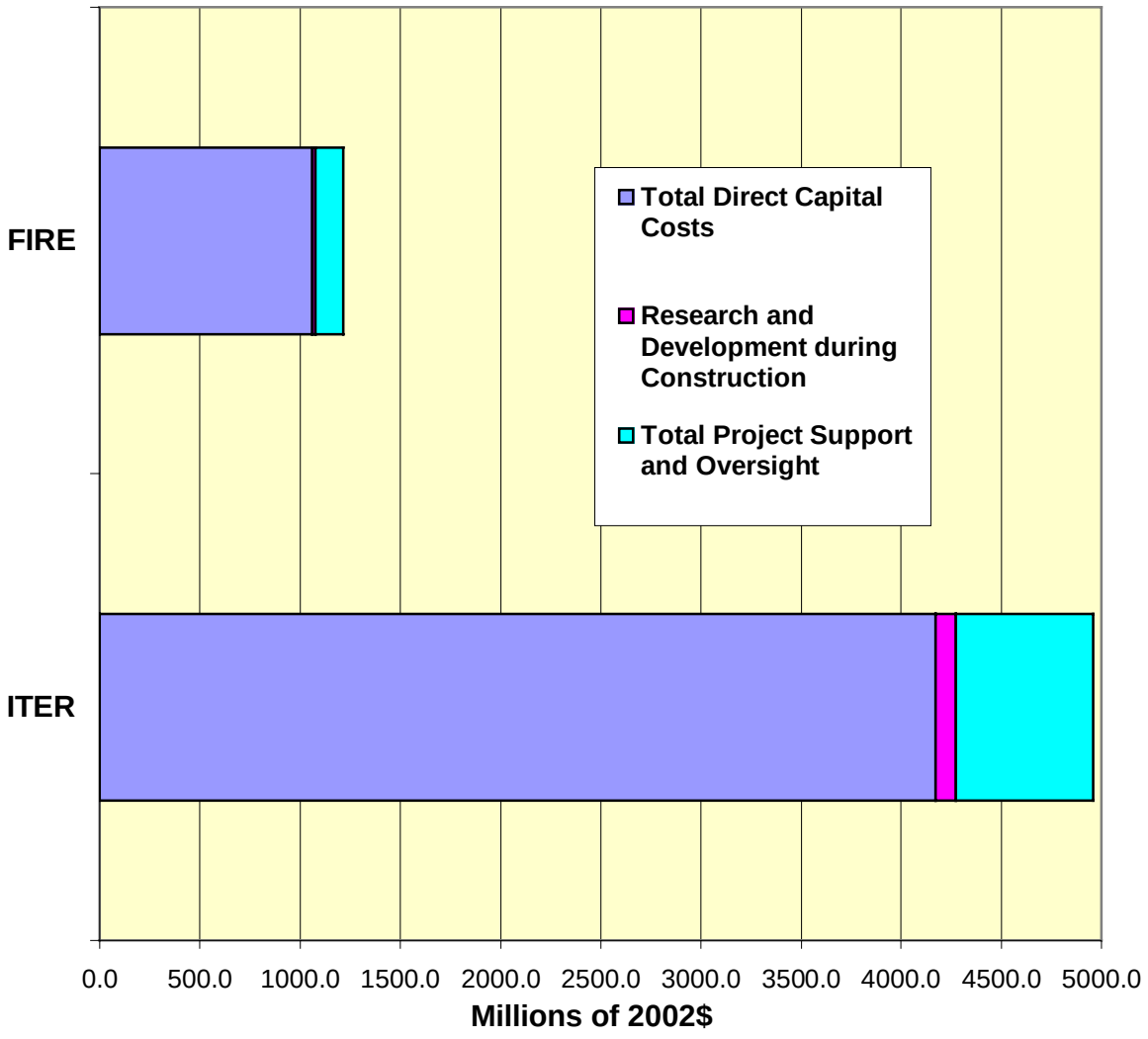
Cost Assessment - MFE.T6

- The Cost Assessment concluded the overall project costs for ITER and FIRE are reasonable for their respective development and design basis.

- The relative total cost of ITER and FIRE seem appropriate for their size, capability, and extent of operations.

- FIRE added contingencies to cover unknown adverse cost consequences. ITER considers its estimates are sufficiently conservative and requires no explicit contingency.

Comparison of ITER and FIRE Total Capital Costs



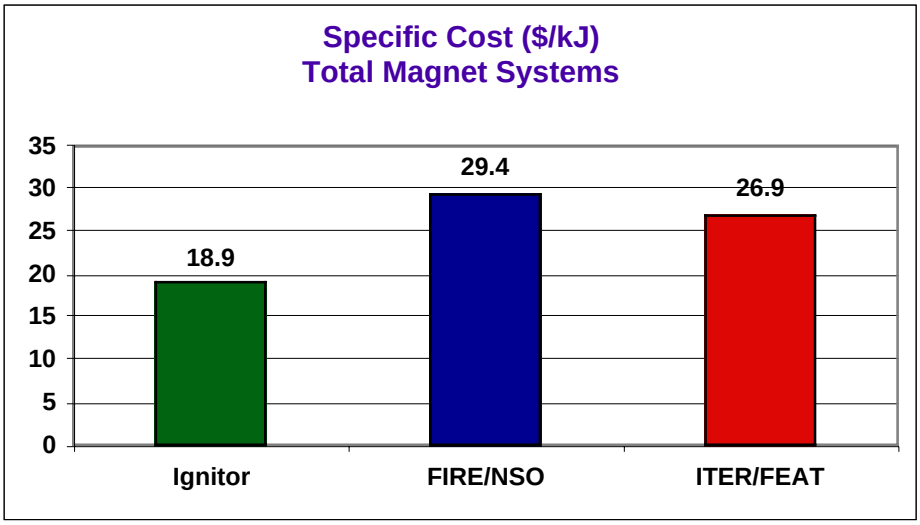


Figure 3: Specific Cost ($/kJ) for Total Magnet Systems of IGNITOR, FIRE/NSO, and ITER-FEAT