Summary of FNST Survey : Thoughts of the Community on progress, concerns, and next steps in FNST

Some Key Leaders of the world fusion community were asked to provide their response to the following questions:

1. **What are the most important accomplishment(s) in FNST in the past 5 years?**
2. **What are the most important technical results in FNST in the past 5 years that had negative consequences?**
3. **What are the most critical next steps (large or small) that we are not doing now, which we should be starting soon?**

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It's Unanimous, ITER is a major step forward – it is a strong driver and forces confrontation of the FNST issues of fusion

- ITER has pushed the design, development, and fabrication of PFCs, plasma heating and fueling systems, vacuum vessel, superconducting magnets, large scale tritium processing, detritiation of water & air, etc.
- ITER has pushed the development and increased the understanding of the need for neutron transport and accident simulations, safety, reliability, QA/QC, licensing for nuclear fusion systems
- Official inclusion of TBM Program in the ITER Baseline. Many national programs efforts to build, qualify and field TBMs are confronting many of the FNST issues for reactor relevant blanket and first wall systems, including RAF/M steel fabrication, helium and liquid metal flow and purity control, tritium breeding and recovery, etc.

Concerns:

- The long schedule delays, long predicted maintenance/replacement times for in-vessel components in ITER
- Must avoid sole focus on ITER project at the expense of other critical research areas for DEMO

Physics Accomplishments and Concerns

- Good progress on plasma turbulence simulation and agreement with experimental observations – possibility of first principles simulations
- Confirmation of Neoclassical Tearing Mode stabilization electron cyclotron current drive
- Identification of potentially attractive plasma operational modes (hybrid, super-X divertors, lithium wall effects)
- Significantly greater understanding of ELMs and methods for control or suppression (pellet pacing, RMP, lithium walls)

Concerns:

- Impact of ELMs on PFCs and the difficulty to incorporate the related suppression systems
- Large uncertainty on the first wall heat flux requiring high local heat removal capability from the first wall and impact on blanket designs
- Possible impacts on confinement due to the usage of magnetic ferritic steels (local TBM in ITER or large port openings in power reactors)

Use of Reduced Activation Ferritic/Martensitic Steels

- EU and JA initiated serious efforts to develop various welding, hipping, drilling techniques for RAF/M fabrication – already large mockups of blanket and first wall structures have been built and tested
- International efforts have amassed large database irradiation effects, even to relatively high dose (~80 dpa)

Concerns:

- The long time frame needed to qualify a material for DEMO
- Growing worries that even moderate amount of helium generation may make current generation RAF/M steels unusable for DEMO
- ODS/NCF alloys with increased helium tolerance may not be fabricable by current methods
- Effects such as corrosion with PbLi may severely limit operating temperature
- Field ripple effects
- No other options!

Development of more integrated modeling and integrated testing capabilities

- The integration of CAD based solid modeling and various simulation capabilities such as MCNP, thermofluids, electromagnetics, etc. has accelerated the ITER design cycle and helped improve the design
- Tritium processing and fuel cycle models have helped design and improve ITER tritium system and increased understanding of tritium self-sufficiency requirements
- ITER-TBM and various mockup test facilities under development in the international program

What else is needed?

- More integration of physics, technology, and materials knowledge and simulation capabilities is needed to address the very difficult issues of diverter and first wall heat flux; ELM, disruption, VDE mitigation and survivability
- Validation is needed at all levels, there is an absence especially of multiple effect to fully integrated component level technology test facilities

Plasma Facing Components – Divertor and First Wall

- Several high temperature, helium cooled, W-Armor divertor concepts have been developed and tested to varying degrees. Capability to reach ~10 MW/m2 demonstrated.
- Proposal of magnetic schemes that reduce and better control divertor heat flux (e.g. Super-X divertor)
- Minimal measured penetration of lithium into core plasma and improvements in confinement/ELMs in tests of lithium PFC surfaces

Concerns:

- First wall heat flux uncertainty will require development of improved helium cooled ferritic steel first walls
- Temperature window of ductile W may be incompatible with available structural materials (requires ~ above 700C capability).
- W viability in the divertor: radiation effects, lifetime, fuzz, cracking.
- Liquid surface vaporization and MHD interaction with the plasma and magnetic field

Next Steps

- Resolve uncertainty about tritium solubility, transport, and removal from PbLi alloy and Beryllium
- Continuous improvement, validation and integration of FNST predictive capabilities
- Undertake the remaining tasks to code qualify one or more RAF/M steel alloys for fusion nuclear applications
- Non-Fusion Facilities for partially integrated FNST mockup and component testing, especially PFCs and Blanket performance and remote maintenance

Big Steps

- DT Plasma Facility (FNSF/CTF/VNS) for fully integrated FNST component testing and reliability growth IN PARALLEL with ITER
- Intense neutron source for material science testing
- Serious, coordinated, international DEMO design and R&D effort

Paradigm Shifts in Fusion Energy Development

- Resolution of the most difficult fusion issues will require strong:
  -- Physics / Technology Partnerships, and
  -- Materials / Engineering Partnerships
  -- Integrated efforts among the many elements of FNST (Blanket, PFC, Materials, Tritium Processing, Safety, RAMI)

- To reduce the time, cost, and risk of fusion energy development will take a concerted international effort
  -- International Green Fusion Energy Partnership