SAFETY RESEARCH THRUST USING A FULL FUSION NUCLEAR ENVIRONMENT

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1. MISSION AND SCOPE SUMMARY

Analyzing the gaps and opportunities to identify the path towards Demo, the Greenwald report[1]summarized the top-level goals in the Safety and Environmental Impact area as (1) ability to not require an evacuation plan; (2) generate only low-level waste; (3) ability to not disturb the public's day-to-day activities; (4) ability to not expose workers to a higher risk than other power plants; and (5) demonstrate a closed tritium fuel cycle.

The Greenwald report also identified broad safety scientific and technical issues that must be addressed before a Demo project can be committed. These broad issues include the knowledge base sufficient to guarantee safety over the fusion plant lifecycle, including licensing and commissioning, normal operation, off-normal events and decommissioning/disposal. This white paper addresses some of the safety-significant issues that will require a full fusion nuclear environment.

2. CLOSING THE SAFETY RESEARCH GAP BETWEEN ITER AND DEMO

We identify several safety related gaps in the knowledge base needed to monitor and measure radioactive materials in a Demo. To limit to 2-3 pages, this white paper identifies these gaps, before briefly discussing the research thrust needed to close the first gap described below.

2.1 Issue: Tritium Monitoring in Fusion Core (Fueling, Breeding, Extraction Systems)

It is well understood that due to the lack of commercial tritium sources, a closed tritium fuel cycle must be demonstrated before a commercial fusion power plant will be possible. This will require the development of blankets suitable for breeding tritium. The Fusion Nuclear Science (FNS)[2] mission will require the testing of different blanket designs contained in well controlled and monitored modules. There is a need to measure the distributed concentration of tritium held up in the fusion core within the vacuum boundary, which contains numerous locations for accumulated tritium (material surfaces, dusts, blankets, etc.) Such measurement systems are required to resolve issues of safety related to tritium inventory, migration and accountability.

Using the technology readiness levels (TRL) adopted by the Department of Defense (DoD) as a best practice to evaluate the readiness levels of new technologies, Tillack et. al. have identified TRLs for several issues related to tritium control and confinement.[3] Based on this study, several significant issues were identified including the need for (1) data on the solubility, permeation and transport of tritium in materials; (2) models that can be successfully benchmarked against radiological release data, and measured against environmental release limits; (3) conduction of large scale tests to validate tritium confinement predictions; and (4) demonstration of successful tritium confinement at the required fusion scale size. Resolution of these issues will require the ability to measure and monitor tritium distribution in a full fusion core.

2.2 Issue: Dust Characterization and Monitoring

In fusion systems, dust is produced by energetic plasma-surface interactions. Dust can pose potential safety concerns under accident conditions because the dust may contain tritium, may be radioactive from activation products, and may be chemically reactive and/or toxic.[4] For the path towards Demo, R&D is needed to develop a diagnostics system for dust in a harsh environment for operational control in Demo. Measurement of key divertor operations include vibration, temperature, flow rate, current, stress and strain, and tritium concentration. Research in dust characterization has been geared towards simulating geometry, flow conditions, and structural components (e.g., divertor and first wall (FW) grooves), that affect mobilization of dust with different characteristics.[3] Requirements towards Demo should include methods to remove dust as it builds up, which can adversely affect fusion plant operation. These also imply dust monitoring and removal in such a way as to satisfy safety requirements.

2.3 Issue: Measurement of Activated and Corrosion Products in Piping and Balance of Plant

There is a need for R&D to determine if higher (or other) activated corrosion products will be produced in cooling water, or other coolants, for machines operating at higher fluences than ITER. Other research needs in this area include transport, deposition, and dose of activated and corrosion products in heat exchangers, pumps, and piping of fusion systems. The FNS facility will be designed to facilitate studies in these areas.

2.4 Managing Radwaste for Fusion Systems

Radwaste management presents a key challenge in fission systems, and “taming” radwaste for fusion systems may lead to significant advantages for fusion energy. Significant issues need to be addressed in waste reduction, recycling, and clearance strategies for power plant-relevant materials. El-Guebaly and Cadwallader have pointed out[5] that while the majority of earlier fusion power plant designs focused on disposal of active materials in repositories, adopting fission radwaste management approach preferred in the 1970s, the new strategies for fusion are to (1) avoid geological disposal, if at all possible; (2) minimize volume of radwaste by clever designs and promote recycling and clearance strategies. In essence, we need to promote fusion as an energy source with minimal environmental impact. This approach requires addressing several issues prior to Demo. These issues include, but not limited to, further development of advanced, radiation-resistant remote handling (RH) equipment that can recycle highly irradiated materials, progress in the separation of various materials from complex components, and establishment of fusion-specific clearance limits.

3. ENABLED R&D

The ability to monitor tritium distribution in a full fusion core (i.e., fueling, breeding, and extraction systems), as identified in Section 2.1, is a significant R&D area in bridging the gap between ITER and Demo. The challenging problem is monitoring for tritium activity (betas) in real time or near-real-time, in a high radiation (neutron and gamma) and temperature (~ 400°F) environment. The current state of tritium monitoring is related to monitoring in a more benign environment (e.g., tritium plant). In addition, the focus is tritium accountability rather than on plant performance, where knowledge of tritium distribution in the fusion core is important. The various existing tritium measurement techniques, typically geared towards batch processing, are not suitable for real time tritium measurement required to address control, performance, and safety (e.g., tritium build-up in unwanted areas) in the harsh fusion environment. Progress in real time monitoring is essential in the path towards Demo. The FNS facility will provide the environment to test various real time tritium monitoring concepts prior to Demo. It will also provide the environment (e.g., instrumented ports) to fully characterize various test blanket modules (TBMs).

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1 *Priorities, Gaps and Opportunities: Towards a Long-Range Strategic Plan for Magnetic Fusion Energy*, A Report to the Fusion Energy Sciences Advisory Committee, October 2007.

2 Y.K.M. Peng et. al., “Fusion Nuclear Science Research Thrust and the Required Full Fusion Nuclear Environment,” White Paper for Renew Workshop, March 2009.

3 M.S. Tillack et. al., “Issues and R&D Needs for Commercial Fusion Energy,” An Interim Report of the ARIES Technical Working Group, UCSD-CER-08-01, July 2008

4 David A. Petti et. al., “Recent Accomplishments and Future Directions in the US Fusion Safety and Environmental Programs,” IAEA Technical Meeting, INL/CON-06-11493, July 2006.

5 L. El-Guebaly and L. Cadwallader, “Future Trend Toward the Goal of Radwaste-Free Fusion: US Strategy and Regulations,” ANS 18th TOFE, San Francisco, CA, Sept 29 – Oct 2, 2008.