# Fuel Cycle Research Thrust Using a Full Fusion Nuclear Environment

Brad Patton, Grady Yoder, Martin Peng and Kofi Korsah
Oak Ridge National Laboratory

## 1. Mission and Scope Summary

The FESAC report [1] identified as a finding under Theme C. Harnessing fusion power related to the Fusion Fuel Cycle:

> *Learn and test how to manage the flow of tritium throughout the entire plant, including breeding and recovery.*

The report further identified the following major gap in the fuel cycle area which is likely to remain assuming world-wide research is completed as planned and ITER is successful:

> *Understanding the elements of the complete fuel cycle, particularly efficient tritium breeding, retention, recovery and separation in vessel components.*

The report also identified specific scientific and technical gaps in the solid breeders, liquid breeders, tritium recovery and tritium processing steps in the fuel cycle to be addressed before proceeding to the Demo. This white paper identifies the role of the proposed Fusion Nuclear Science Facility (FNSF) [2] in addressing the gaps in the fuel cycle area before proceeding to Demo.

The Fusion Nuclear Science Facility will enable the community to address many of the gaps by providing a full fusion nuclear environment to allow the complex interdependent phenomena associated with the fuel cycle to be studied to provide the scientific and technical data and knowledge needed for engineering design, performance estimates, and safety basis of Demo.

## 2. Closing a Research Gap to fusion Demo

The FNSF will provide the full fusion nuclear environment to test the solid breeder and liquid breeder concepts in a Demo relevant neutron flux, heat flux, temperature and tritium concentration conditions in a quasi-steady state operational mode. The FNSF also provides relevant tritium streams to demonstrate tritium recovery and tritium processing. The fuel cycle by its nature is an integration of the tritium processes including burning, production and recovery. The FNSF provides a highly instrumented platform to test the interactive phenomena at interfaces essential to the success of Demo.

Specific gaps identified by the FESAC report and examples of the underlying issues are as follows:

*a. Solid breeders (including irradiation sintering, operating temperature, tritium* *permeation to sweep gas, tritium permeation to coolant and from sweep gas piping, neutron multiplier material and structure, breeding material and structure, TBR control)*

Issue: What is the tritium distribution in solid breeder and surrounding systems?

What is the tritium concentration in the breeder as function of operation conditions and operating duration? How is the concentration measured/predicted for operational control?

What is the permeation rate and distribution of tritium in the breeder containment system?

What is the tritium transport rate through the containment to the coolant?

*b. Liquid breeders (including material compatibility and corrosion, MHD effects, thermal insulators, tritium permeation through pipes of heat exchanger, structural material choice, TBR control)*

Issue: What is the tritium distribution in liquid breeder and its containment systems?

What is the tritium concentration in the breeder as function of operation conditions and operating duration? How is the concentration measured/predicted for operational control?

What is the permeation rate and distribution of tritium in the breeder containment system?

What is the tritium transport rate through the containment to the coolant?

*c. Recovery (including separation of T from He gas or liquid metal, recovery of low concentration T from permeation protection, operational test experiment)*

Issue: Do surrogate tritium streams used in testing recovery processes outside a full fusion environment represent the streams in the Demo environment?

What are the impurities introduced in a full fusion environment that may impact the recover systems performance?

Are there radiation enhanced properties that may impact recovery system performance in a full fusion nuclear environment?

*d. Tritium processing (including isotope separation and impurity removal, steady state control of processing at high throughput (~10X ITER), accountability to about +/- 2 gm, chemical plant handling kilogram quantities of T, systems integration)*

Issues: What is needed to adequately perform tritium accountability and nuclear facility operations for Demo

What are the transient and steady state inventories of tritium in the plasma facing components, breeder blanket and containment material?

How is the inventory of tritium held up in materials affected by the operating neutron flux, the temperature and its gradient, the defects, and the tritium gradients? Are there synergistic effects among these parameters?

Is it necessary to have on-line tritium hold-up detection or can predictive modeling techniques based on integrated parametric experiments provide adequate accountability?

Can tritium detection technology be developed to measure tritium "on-line" in the full fusion environment?

### 3. Required FNS R&D Capabilities of a Full Fusion Nuclear Environment

An environment aimed at testing and discovering the underlying physical fuel cycle processes of interest to Demo must possess the following capabilities [3]:

- Fusion neutron fluxes ranging from ~0.01 – 2 $MW/m^2$, depending on the physical processes of interest, which include such as the threshold to in-situ tritium monitoring at minimal level of tritium production, and the tritium permeation rates in ferritic steel as a function of weak to strong fusion neutron fluxes.
- Continuous operational durations that can be increased from $10^3$ s progressively toward $10^6$ s, to observe and measure a broad range of physical mechanisms with increasing time constants of interest to the Demo knowledge base.
- Safe remote handling of test components (blankets, divertors, heating, current drive, fueling, measurement, and control systems) for removal to "hot cell laboratories" and replacement by new or improved components.
- Instrumentation of these components to measure in-situ physical properties of interest to Fuel Cycle.

### 4. Enabled R&D

Detection techniques to measure and manage tritium under the high temperatures, high neutron flux, and high gamma field in a full fusion environment do not exist and may not be practical to develop. Understanding the tritium consumption, production, material interactions, and permeation mechanisms in the full fusion environment and modeling these mechanisms are essential to managing the flow of tritium in Demo in the absence of direct measurement. These models, once developed can provide real time prediction of tritium flow for controlling the inventory and for preliminary tritium accountability. Although these tritium reaction and transport models can be initially developed in a laboratory and engineering environment, the validation of the models in a Demo relevant environment is essential to the success of these models to control and account for tritium during operations of Demo. FNFS will provide the highly instrumented test environment to validate these essential fusion fuel cycle models. Data developed in the FNFS will be essential to designing the Demo facility and to provide the knowledge base needed to build a defendable safety basis for the facility.

Although a number techniques exist for measurement of tritium in grab sample and bulk storage geometries [4,5], real-time tritium measurements are expected to be very challenging in the full fusion environment. Real-time tritium concentration in gas and liquid streams and tritium profiles in solid material would be invaluable in evaluating operational control, tritium accountability, and material radiation degradation effects. Successful R&D in the tritium monitoring area would provide significant contribution to success of Demo.

Advances in tritium monitoring are essential to understanding the fuel cycle phenomena on the path to Demo and also to address the sensitivities of the public to tritium accountability and releases (e.g., closure of the High Flux Beam Fission Reactor at Brookhaven). It is recommended an aggressive R&D effort be directed at measurement of tritium in a full fusion environment.

**References**

[1] http://www.ofes.fusion.doe.gov/FESAC/Oct-2007/FESAC_Planning_Report.pdf

[2] Y. K. M. Peng et al., "Extensive Remote Handling and Conservative Plasma Conditions to Enable Fusion Nuclear Science R&D using a Component Testing Facility", FT/P3–14.

[3] Y. K. M. Peng et al., white paper on "Fusion Nuclear Science Research Thrust and the Required Full Fusion Nuclear Environment," submitted to ReNeW (February 2009).

[4] R. Lasser et al., "Analytic of Tritium-Containing Gaseous Species at the Tritium Laboratory Karlsruhe", *Fusion Engineering and Design* **58–59**, 411–415 (2001).

[5] J. E. Klein, "In-Bed Accountability Development for a Passively Cooled, Electrically Heated Hydride (PACE) Bed", *Fusion Science and Technology*, **48**, (July/August 2005).