Fusion Energy Systems Studies:
1) Wrapping up the FNSF Study
2) Beginning the Liquid Metal PFC Study

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Fusion Energy Systems Studies

PPPL: C. Kessel, P. Titus, Y. Zhai, W. Blanchard, A. Khodak

INL: P. Humrickhouse, B. Merrill

Univ Wis: A. Davis, L. El-Guebaly, P. Wilson, J. Blanchard, E. Marriott

UCLA: S. Smolentsev, N. Morley, A. Ying,……….Y. Huang, N. Ghoniem

LLNL: T. Rognlien, M. Rensink

ORNL: A. Rowcliffe, L. Garrison, Y. Katoh

MIT: G. Wallace, S. Wukitch

UCSD: M. Tillack

Consultants: S. Malang, L. Waganer, K. Young

Others: P. Snyder (GA), P. Bonoli (MIT), C. Martin (UW), M. Harb (UW)……

FNSF Study

→ Better understand what a next step fusion nuclear facility (FNSF) is all about

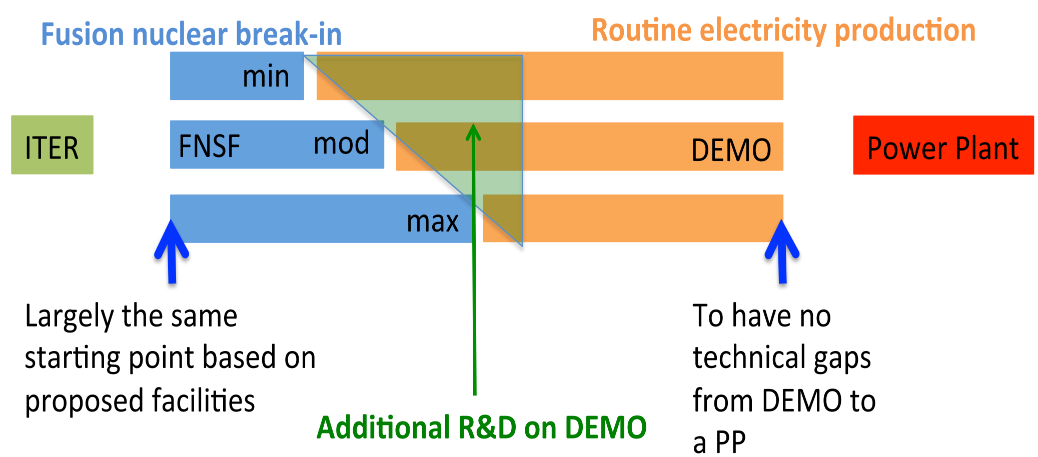
→ What does it need to do?

→ How does it accomplish its goals?

→ How is the progress toward a power plant measured?

→ What is pre-requisite R&D for the facility

→ How does the facility fit into a pathway from ITER to power plants



The FNSF Study is Over, and 13 Papers are Being Submitted to Fusion Engr & Design

Overview of the Fusion Nuclear Science Facility (FNSF), a Credible Break-in Step on the Path to Fusion Electricity Production - C. E. Kessel and FESS team

Core Plasma Physics and Its Impact on the Fusion Nuclear Science Facility - C. E. Kessel

Scrape-off Layer Plasma and Neutral Characteristics, and Their Interactions with the Wall for Fusion Nuclear Science Facility - M. E. Rensink and T. D. Rognlien

Neutronics Aspects of the Fusion Nuclear Science Facility - A. Davis, M. Harb, L. El-Guebaly, P. Wilson, E. Marriott

Multi-Physics Modeling of the First Wall and Blanket of the Fusion Nuclear Science Facility - Yue Huang, N. Ghoniem, M. S. Tillack

Tungsten Monoblock Concepts for the FNSF FW and Divertor - Yue. Huang, M. Tillack, N. Ghoniem

Effect of ELMs and Disruptions on FNSF Plasma Facing Components - J. P. Blanchard

MHD Thermal Hydraulic Analysis and Supporting R&D for the DCLL Blanket in the FNSF - S. Smolentsev

Magnet Design Study for the Fusion Nuclear Science Facility - Y. Zhai, P. Titus,

Heating and Current Drive Actuators for the FNSF in the Ion Cyclotron and Lower Hybrid Range of Frequency - G. M. Wallace

Tritium Aspects of the Fusion Nuclear Science Facility - P. Humrickhouse and B. J Merrill

Examination of the **FNSF Maintenance Approach** - L. M. Waganer

Materials challenges for the Fusion Nuclear Science Facility - L. Garrison, A. F. Rowcliffe, Y. Katoh

Some Points & Observations

Examined the FNSF as the first in a two step pathway to commercial power plants in the US

Examined the conventional aspect ratio tokamak, and focused on moderate FNSF

- → A smaller step, warranted by the complexity of the combined nuclear and non-nuclear environment…motivated by multi-factor environment, and significant gradients in these features...AND fission experience
- → Power plant relevance is mandatory, fusion facilities are composed of many technologies, there are only two steps to optimize and make highly reliable/predictable
- → Blanket, divertor, RF launcher or other fusion core components require focusing (down-selecting)….carrying a program to address multiple component concepts is impractical
- → 10 missions and way too many metrics were identified, these help to understand how the FNSF moves us toward a power plant
- → A careful plasma strategy is required to provide the ultra-long duration plasmas at sufficient performance to meet the needs of the fusion nuclear mission
- → The databse systems analysis approach has helped us identify a robust operating SPACE, allowing us to recover from plasma or engineering parameters that don't go our way...and make sure the fusion nuclear mission can be met
- → Developing the program on the FNSF forces us to recognize the plasma physics needs in the DD phase, and the time-frames to reach the desired fusion nuclear goals
- → The Hot Cell will be a critical part of the facility to provide the handling and examination of fusion components...and in establishing the actual in-service materials/components database

Some Highlights

→ Nuclear analysis (**A. Davis, UW**) showed that with penetrations for H/CD, TBMs, MTM, diagnostics, FNSF could achieve TBR of 1.07 with 90% Li-6 enrichment, and 1.04 with 80% Li-6 enrichment

→ Disruption analysis (**J. Blanchard, UW**) showed significant currents are driven in the tungsten structures including FW coating, vertical stabilizer plates, and kink stabilizer shells

→ New FW high heat flux design (**Y. Huang, UCLA & M. Tillack UCSD**) has been explored to find maximum allowable heat flux, reaching up to ~ 5 MW/m^2 with NFA structure

→ TF coil stress analysis (**P. Titus, PPPL**) has shown how to accommodate the horizontal maintenance scheme in the FNSF, and bucking/wedging is shown to handle high CS currents

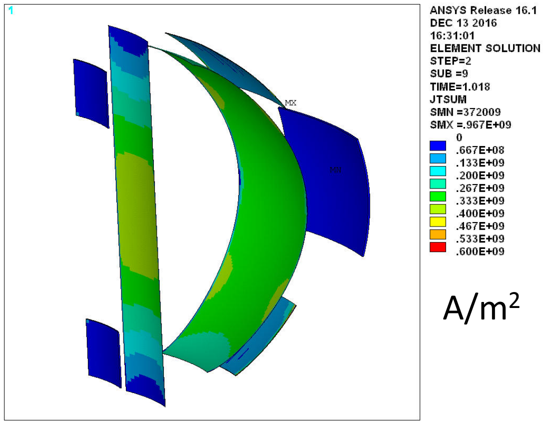
→ Low tritium losses (< 3 gm/year) are determined for the FNSF based on TMAP analysis (**P. Humrickhouse, INL**), without any additional enclosure, due to high LiPb flow rate, SiC FCI, efficient tritium extraction, and co-axial piping (hot leg inside cold annulus) with good and bad transport assumptions

→ High Field Side launch of Lower Hybrid waves was studied (**G. Wallace, MIT**) showing ~ 30% higher CD efficiency over LFS launch

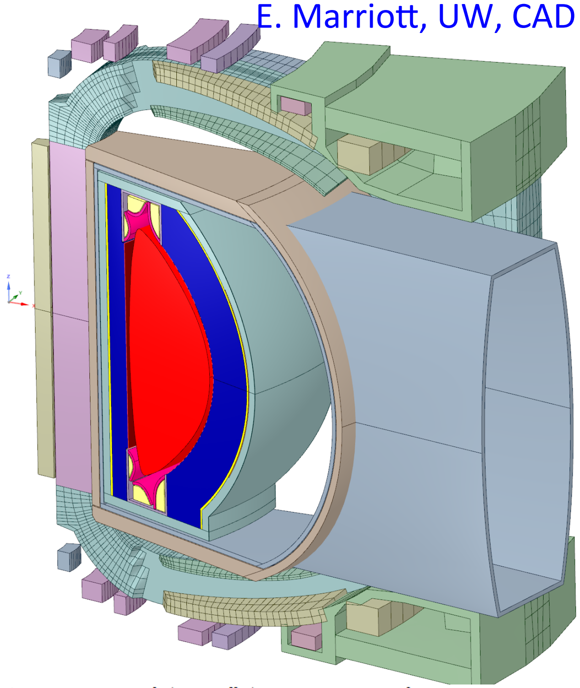
→ Both ITER-like and a fully detached divertor solutions are found (**M. Rensink & T. Rognlien, LLNL**) for the FNSF, with 6 MW/m^2 peak heat flux and < 3 MW/m^2, respectively

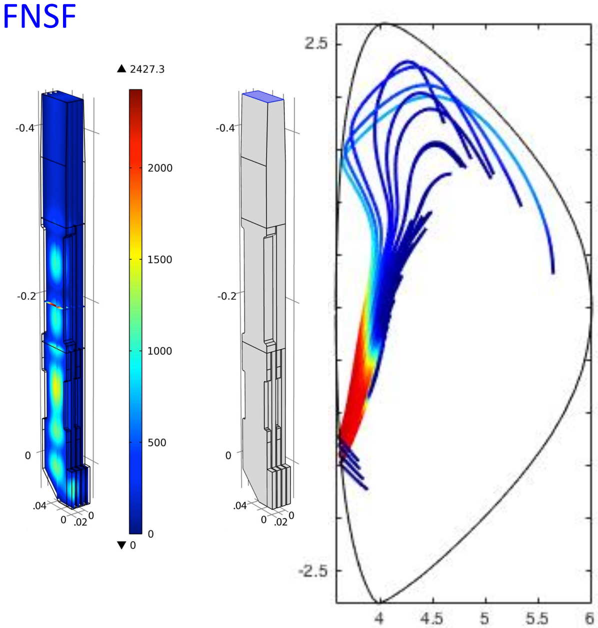
→ Liquid metal LiPb breeder MHD thermo-fluids analysis (**S. Smolentsev, UCLA**) shows that the full poloidal DCLL blanket has acceptable pressure drops with SiC FCI in the FNSF, and new correlations for 3D pressure drops were developed

Blanchard, UW, disruption currents in W

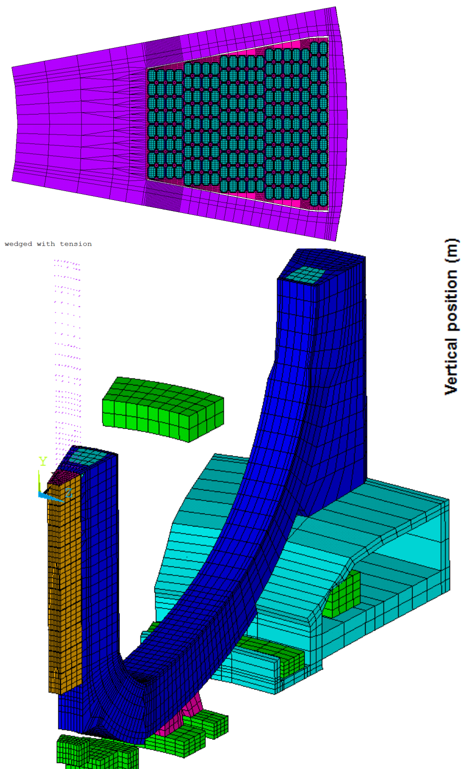


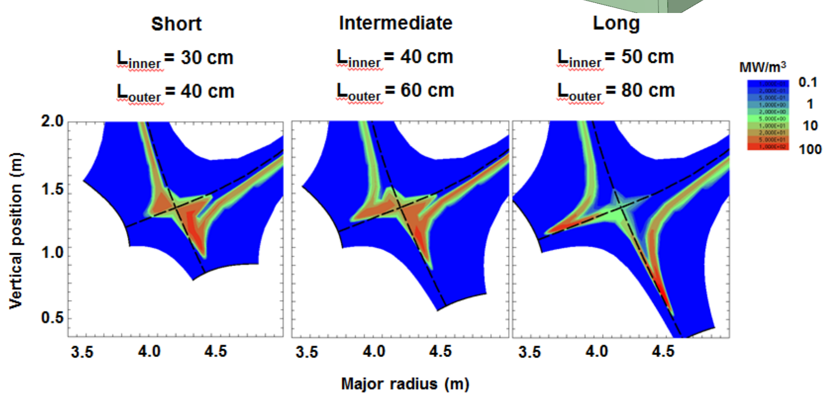
E. Marriott, UW, CAD of FNSF





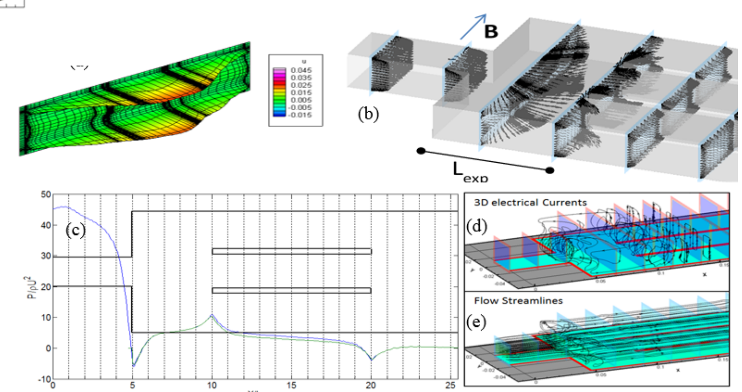
Wallace, MIT, ray-tracing HFS launch





Renskink & Rognlien, LLNL, detached divertor solutions

Smolentsev, UCLA, 3D MHD



P. Titus, Y. Zhai, PPPL, TF structure and winding pack

Master Topics for pre-FNSF R&D

Neutron irradiation of individual materials in 1) fusion relevant neutron source, 2) fission reactor and doping, 3) ion bombardment

Plasma facing components/plasma material interactions in 1) tokamaks, 2) linear plasma devices, 3) offline (e.g. HHF, liquid metal) → integrated PFC testing

Tritium science

(LiPb) Liquid metal science

Prototypical parameters & integration → Integrated blanket component testing & ITER TBM progress (weak nuclear)

Enabling technologies

Magnets
Helium cooling
Diagnostics
Fueling/exhaust
Heat exchanger
Tritium processing
Heating & current drive
……

Integrated diagnostic testing

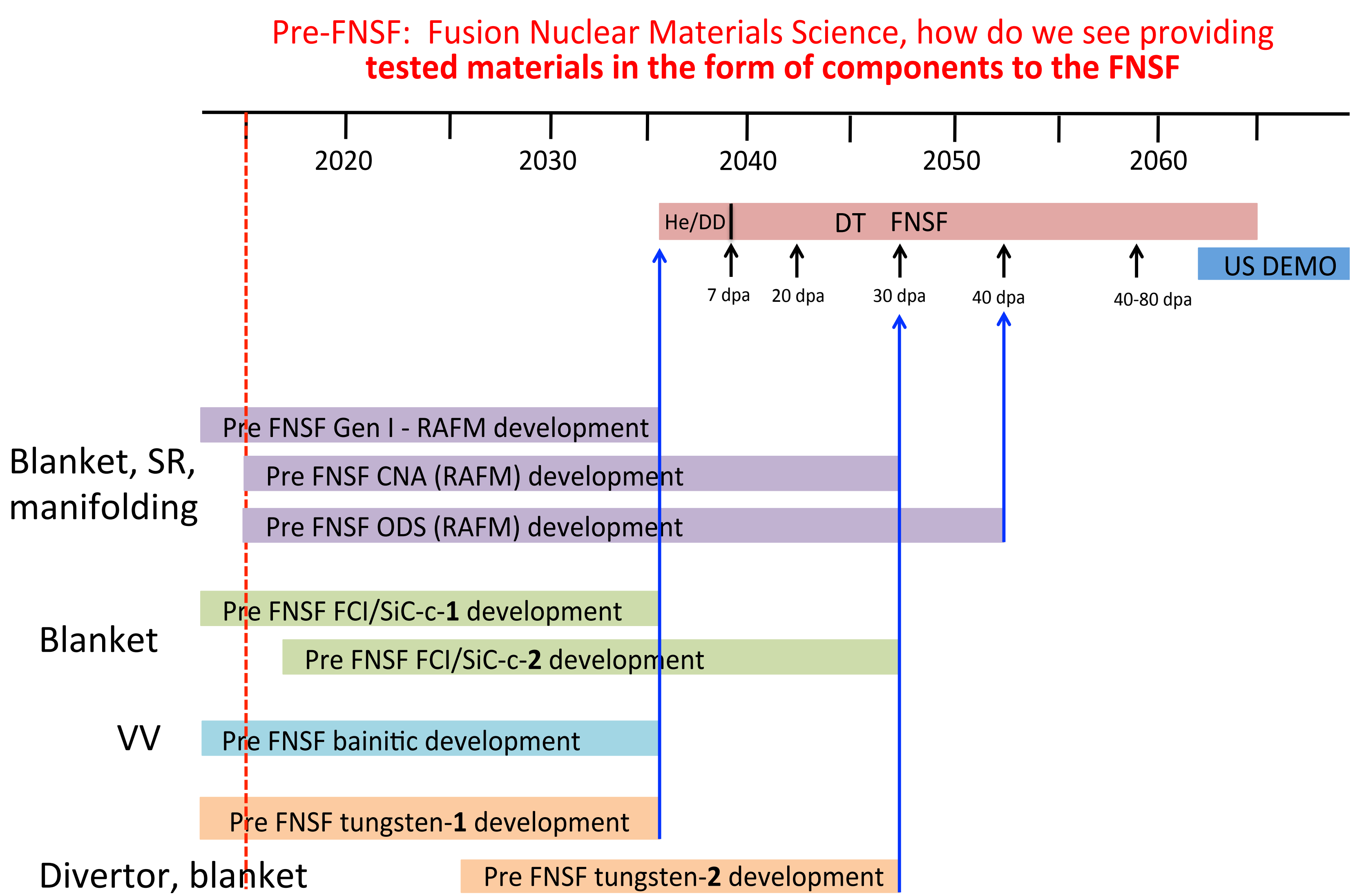
Integrated launcher/guide testing

Non-nuclear

Plasma development in 1) short pulse DD tokamaks, 2) long pulse DD tokamaks (EAST, KSTAR, JT-60SA), 3) ITER burning plasmas

Predictive simulation development

Example for DCLL blanket and W divertor, How the FNSF sets timelines



FESS, Next Project….Examine Liquid Metal Plasma Facing Components

Examine LM PFCs in an Integrated Tokamak Facility (like the FNSF), to understand impacts and help to identify where focused R&D can pay off

In response to the PMI/PFC Workshop Priority Research Directions, and more detailed text

Kick-off meeting Feb 14-16, at DOE Headquarters, Germantown

- Review of ALPS/APEX
- Liquid metal candidates
- Solid support material candidates
- Loading environment
- Safety and tritium
- FNSF configuration
- Examples of LM PFC design concepts
- Review of LM free-surface models/simulation tools
- Impacts on integrated facility
- Workscopes for participants

FESS LM PFC study, cont’d

~2 year duration

Main phases

1) Use existing design, such as FNSF, and examine the incorporation of LM PFCs into this facility….working through LM choices, LM properties, LM flow and other behavior inside a tokamak, PFC designs and integration, etc.

2) Establish a LM-FNSF (or power plant) design using knowledge established in first phase, taking advantage of the LM concepts and their impacts

Participants: FESS team and LM experts
PPPL, Univ Wis, UCLA, ORNL, LLNL, INL, MIT, SRNL, LANL, GA, consultants