Multi-Physics Coupled Predictive Modeling & Simulation of Technology of Fusion Energy Systems

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Oral Desired - Y andrew.davis@wisc.edu **Topic - D (Cross-cut B/C/F/G)**

Motivation

For whole machine modeling, in the Engineering sense, it is important to consider all physical effects that may affect the final modeling quality. For engineering analysis, the plasma is considered as a source of neutrons and ions and therefore, one of the first inputs into a large chain of calculations. However, it is the subsequent analysis of heating, radiation damage, tritium production, cooling rates, mechanical stresses and so on that drive and evolve the engineering design of the system. There is a complex interplay of different physical phenomena across different physical scale lengths that must be properly coupled in order to provide the best estimate of the quantity of interest.

Approach

Predictive engineering analysis of fusion energy systems is a multidisciplinary and complex task due to the number of inputs that must be considered. A modest list of analysis domains includes: neutron transport & activation, photon transport, thermo-mechanics, thermal-hydraulics, neutral particle transport, fast ion transport. A simplified representation of the flow of data is shown in Figure 1.

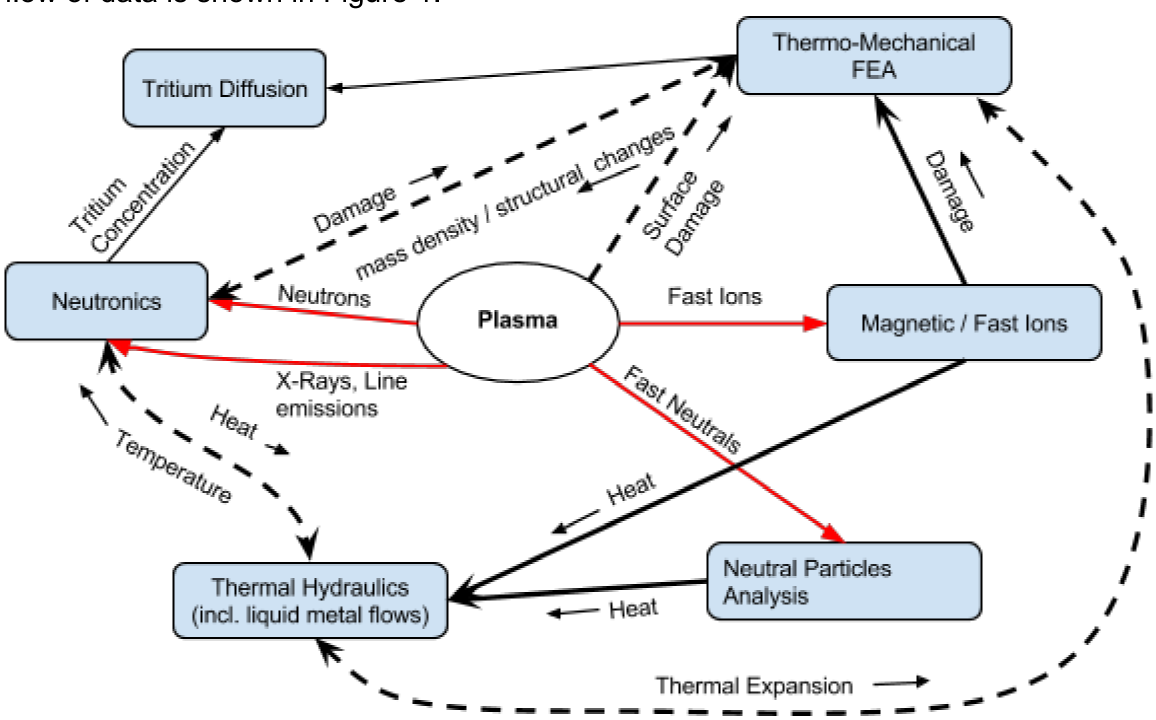
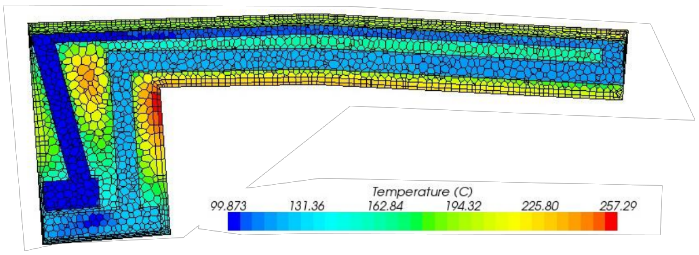


Figure 1. Flow of data to and from analysis descriptions and the main quantity of interest

Figure 1, shows the flow of data from simulation to simulation. For example, since the plasma emits neutrons, we must determine how and where those neutrons interact in the fusion device and the resultant energy deposition. This is then the heat source for the thermal hydraulics analysis to determine the coolant flow distribution around specific components, and consequent material temperatures and densities. These, in turn, feed back to the neutronics, since the density and temperature of materials impact energy lost by neutrons in scattering and the probability of certain reactions occurring.



There have been successful attempts to couple neutronics codes to thermal hydraulics codes, these specifically rely on analytic approximations and do not use full analysis software packages. For example, here at UW we have coupled the results of a DAG-MCNP5 calculation with STAR-CCM shown in Figure 2.

In fields outside of fusion technology, there are growing efforts to develop tools for coupled predictive analysis. In the domain of fission reactor design, efforts such as CASL, NEAMS, and MOOSE are well-funded examples from which some technology can be borrowed. At the UW-Madison, we have demonstrated a linkage between neutronics & mechanical FEA in which gross deformations of a space reactor were passed as input to a criticality calculation to confirm a safe operating envelope for a space reactor design. Multiphase flow simulation efforts are presently being pursued coupling the spectrum of structures in turbulence to heat transfer processes in flows relevant to cooling and energy applications.

To date, most (all?) examples of such coupling for multi-physics analysis in the fusion technology domain have been ad-hoc and required duplication of effort with each attempt. There is a growing need to address a fully coupled workflow to provide a systematic approach to coupling the many types of physics necessary for a comprehensive analysis of the engineering components of a fusion energy system. This work cross cuts through several of the present work areas, touching on areas partially in **B** and **C** and has large contributions to **D**,**F** and **G**. Development will include:

1. Finalizing the full range of analysis domains to be included
2. Identifying promising software tools for analysis in each domain
3. Defining the enabling technology development that will be required to enable a systematic coupling of these tools
4. Apply the results of this a design effort like FNSF

Impact

Successful realization of this work would allow a more comprehensive approach to be taken to designing fusion energy systems, allow a better understanding of the strength of the correlations between phenomena and allow a more complete engineering analysis.