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Princeton Plasma Physics Laboratory
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The Status of USITER Diagnostic Port Plug Neutronics Analysis Using Attila

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INTRODUCTION

USITER is one of seven partner domestic agencies (DA) contributing components to the ITER project. Four diagnostic port plug packages (two equatorial ports and two upper ports) will be engineered and fabricated by Princeton Plasma Physics Lab (PPPL). Diagnostic port plugs as illustrated in Fig. 1 are large primarily stainless steel structures that serve several roles on ITER. The port plugs are the primary vacuum seal and tritium confinement barriers for the vessel. The port plugs also house several plasma diagnostic systems and other machine service equipment. Finally, each port plug must shield high energy neutrons and gamma photons from escaping and creating radiological problems in maintenance areas behind the port plugs. The optimization of the balance between adequate shielding and the need for high performance, high throughput diagnostics systems is the focus of this paper. Neutronics calculations are also needed for assessing nuclear heating and nuclear damage in the port plug and diagnostic components. Attila, the commercially available discrete-ordinates software package, is used for all diagnostic port plug neutronics analysis studies at PPPL.

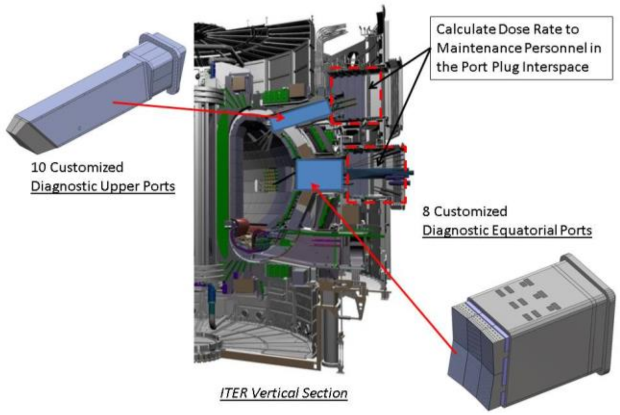

Fig. 1. This vertical section through the ITER Vacuum Vessel and Cryostat highlights the location of the Upper and Equatorial diagnostic port plugs.

ITER PORT PLUG NUCLEAR SHIELDING REQUIREMENTS

Nuclear shielding design in the diagnostic port plugs is primarily driven by the specification for the shut-down dose rate in the port plug interspace. The interspace is the room behind the ports where maintenance personnel can enter to work on the back of the ports. The ITER requirement for interspace dose is 100 µSv/hr 10 seconds after shut-down. The term "shut-down" refers to the end of ITER life after all planned 500 MW and even some 700 MW experiments. This is very conservative but also provides a built-in safety margin for the neutronics calculations.

Dose is calculated using ICRP-74 flux-to-dose conversion factors. Ultimately acceptable levels of Occupational Radiation Exposure (ORE) will need to be demonstrated based on some realistic maintenance scenarios. At this time most interspace equipment design is too conceptual to accurately predict ORE.

THE ATTILA ANALYSIS PROCESS

All calculations documented in this report were performed using Attila-8.0.0 furnished by Transpire, Inc. of Gig Harbor, Washington (www.transpireince.com). The USITER port plug engineering team runs Attila-Severian (the parallel-processing version) on the "Jassby" scientific computing cluster at Princeton Plasma Physics Lab. Jassby uses a total of 96 2.6 GHz processing cores with a total of 768 GB of shared memory. This allows for rapid neutron and photon transport calculations.

Neutron and photon transport calculations in Attila use FENDL-2.1 processed for discrete-ordinates transport to contain 175 neutron groups and 46 gamma energy groups. Currently to help expedite the transport calculations a "few group" FENDL library has been prepared with 46 neutron groups and 21 gamma photon groups. Activation and depletion calculations in Attila use FENDL-2.1 as well as a module called FORNAX. The FORNAX module of Attila uses the neutron transport flux solution to calculate the build-up and decay of radioisotopes in the model structures.

SIMPLIFIED APPROACH TO EQUATORIAL PORT PLUG NEUTRONICS

The ITER organization provides a global neutronics model to unify calculations across the DAs. In order to expedite parametric port plug shielding calculations a simplified approach is taken as shown in Fig. 2.

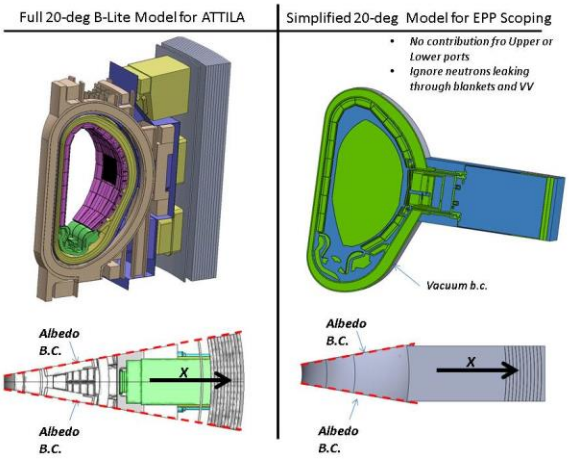

Fig. 2. A simplified modeling approach for equatorial port plug neutronics was used to expedite parametric shielding studies.

For equatorial port plug studies, the Upper and Lower Diverter ports are ignored as are the external magnetic field coils. All of the detail of components inside the vacuum chamber are included in order to get the correct first-wall loading on the port plug. Albedo or “White” boundary conditions are used on the 20-degree model wedge faces while all other neutrons escaping the model are ignored at vacuum boundary conditions.

Other simplifying assumptions were also used to help expedite calculations. The most important is the structures selected for the activation/depletion calculation. In Attila one can pick and choose which structures should be included in calculating a dose rate. For the diagnostic equatorial port plug dose rate analysis only the port plug vacuum closure plate and flange are “activated”. The interspace dose due to neutrons leaking through the diagnostics is primarily from gamma photons transported off of the closure plate and flange. There are other sources of dose but these can be ignored in order to focus on optimizing the port plug.

EQUATORIAL AND UPPER PORT PLUG NEUTRON TRANSPORT AND DOSE RATE RESULTS

This section provides a sample of Equatorial and Upper Port plug neutron transport results and the subsequent interspace shut down dose rate. There are many other examples that will be provided in the full paper.

Equatorial Port 9 Neutron Transport Results

Equatorial Port 9 is a USITER diagnostic port plug containing three primary systems. There is a Wide Angle Viewing Visible-IR (WAV-VIR) camera system provided by the EU. The USDA is providing an Electron Cyclotron Emission (ECE) diagnostic and the Toroidal Interferometer and Polarimeter (TIP) system. An Attila analysis of EPP9 with TIP and ECE was performed in order to optimize the two US systems. The EUDA WAV-VIR system will be added in a subsequent analysis. Fig. 3 and 4 show the EPP9 neutron flux contours.

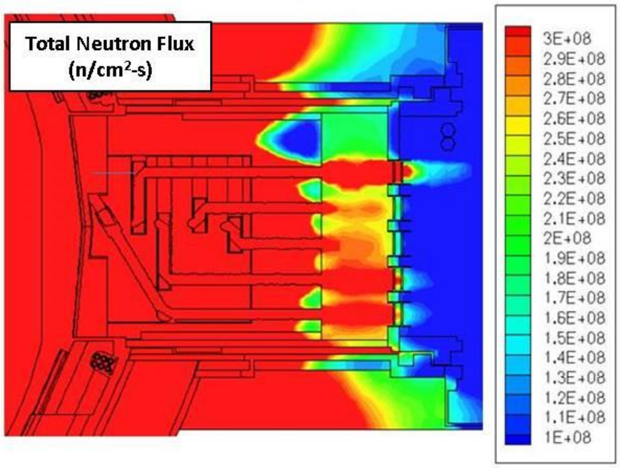

Fig. 3. This vertical section through the TIP shield module in EPP9 shows total neutron flux contours (n/cm^2-s). There are five optical paths through the module. The vacuum closure plate is on the far right.

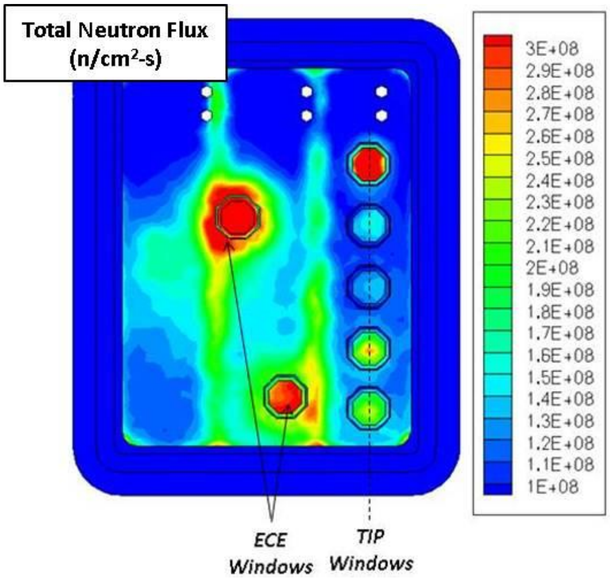

Fig. 4. This is a view of total neutron flux contours (n/cm^2-s) at the EPP9 closure plate when standing behind the port plug. There are five TIP windows and two ECE windows.

It is evident in these views that improvement is needed in the labyrinth design for the two ECE channels and the upper TIP channel.

Equatorial Port 9 Dose Rate Results

As stated earlier, only the plug closure plate and flange are included in the activation/depletion calculation. Figure 5 shows the in-air dose from gamma photons transported off of the EPP9 closure plate and flange. The port interspace where people will need to perform maintenance tasks is on the right side of the horizontal section. Depending on where one stands the peak dose could range anywhere from 200 to down below 50 µSv/hr.

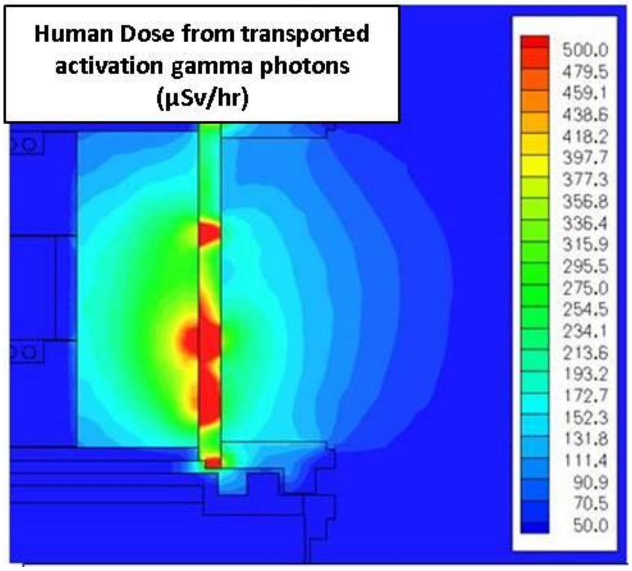

Fig. 5. Horizontal section through EPP9 showing contours of human dose (µSv/hr) from transported gamma photons. The dose to personnel is of course strongly dependent on where one stands in the interspace.

Upper Port 14 Neutron Transport Results

In a similar fashion the USITER diagnostic upper port plugs are evaluated for interspace shut down dose. Upper Port 14 contains an upper port WAV-VIR camera system as well as a Glow Discharge Electrode and other equipment. As can be seen in Fig. 6 the upper port neutronics are currently dominated by streaming through gaps around the port. It is actually very difficult to measure the added flux from diagnostics because the results are inundated by this streaming problem. A major effort is underway at ITER to fix this by forming a better labyrinth at the front of the upper port plugs.

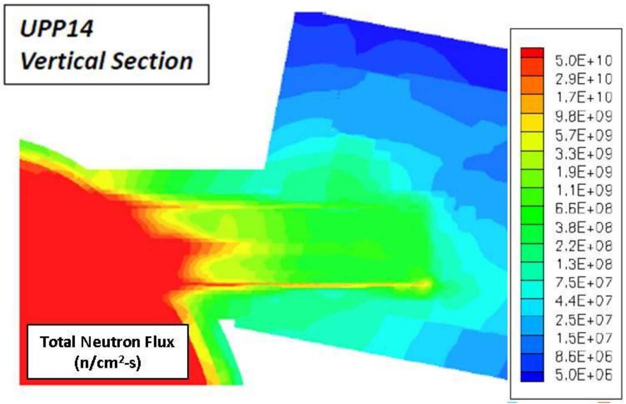

Fig. 6. This vertical section through the middle of UPP14 shows total neutron flux (n/cm^2-s). Neutrons streaming underneath the port plug can be clearly seen.

Upper Port 14 Dose Rate Results

The upper port plug interspace dose presented here in Fig. 7 is also only due to activation of the port closure plate. The upper port closure plate is much smaller than the equatorial port plate. There is less volume of activated steel and the dose rates are lower. The UPP14 dose is also lower because the UPP WAV-VIR diagnostic has a small aperture and relatively small optics labyrinth. Notice the high dose at the bottom of the flange due to the neutron streaming underneath the port plug.

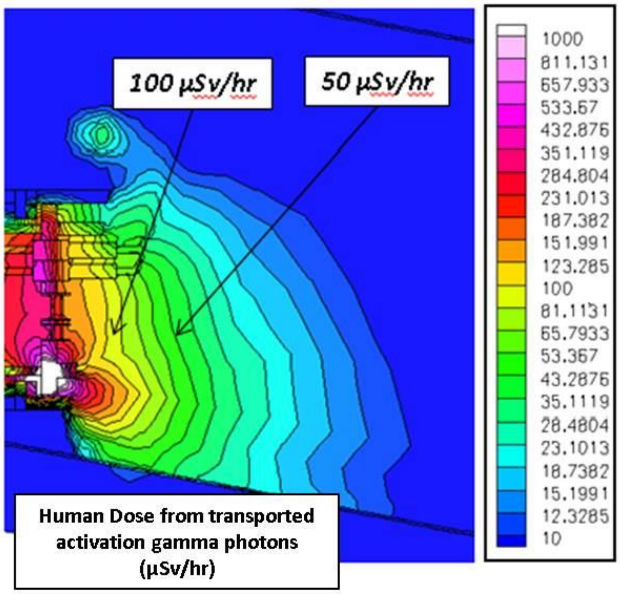

Fig. 7. This vertical section through the middle of UPP14 shows the shut-down interspace dose rate (µSv/hr). Gamma photons from activated steel are emitted by the closure plate and flange in to the interspace.

NUCLEAR HEATING IN THE PORT PLUG DIAGNOSTIC FIRST WALL BLOCKS

Attila is very useful in evaluating nuclear heating for components close to the plasma neutron source. Detailed CAD models with complex aperture geometry can be easily meshed and evaluated. The nuclear heating results are then used in ANSYS or other FEA codes as an input to thermal/hydraulic and structural analysis.

The front plasma facing components of the upper and equatorial diagnostic ports are called the Diagnostic First Wall (DFW) blocks. The DFW blocks are large stainless steel structures filled with water passages to remove the nuclear heating and the high .35 MW/m^2 plasma radiant heating.

Equatorial Port 3 DFW Nuclear Heating

The apertures in the EPP3 are very complex. This is due to the steep edge viewing optics for the Russian Charge Exchange system and the USDA MSE diagnostic. It would be difficult to find EPP3 nuclear heating as shown in Fig. 8 without the ability to import CAD geometry in to Attila.

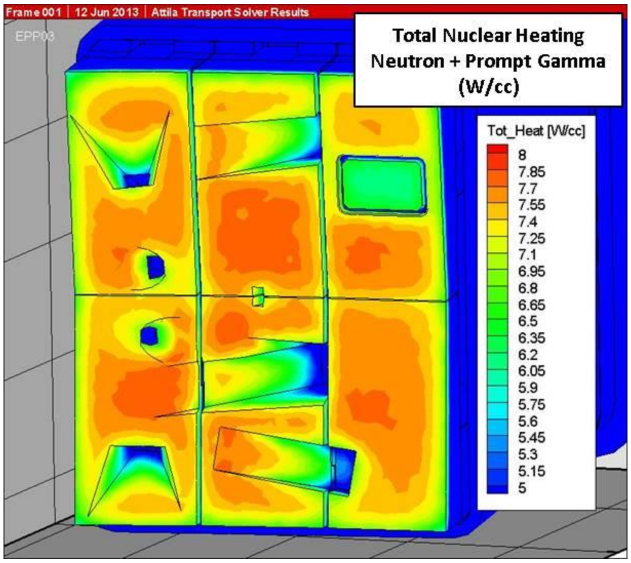

Fig. 8. Peak nuclear heating at the front of the EPP3 DFW is close to 8 W/cc.

Upper Port 14 DFW Nuclear Heating

Nuclear heating in the upper port DFW peaks at about 6 W/cc. Fig. 9 shows the UPP14 DFW model results.

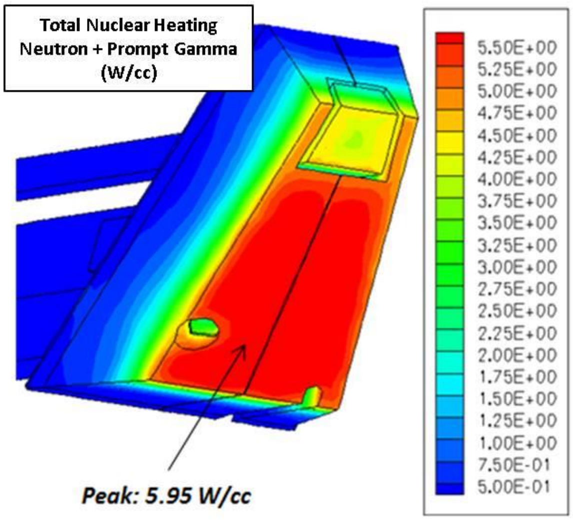

Fig. 9. Peak nuclear heating at the front of the UPP14 DFW is close to 6 W/cc. Most nuclear heating is from prompt gamma photon heating in the stainless steel.

CONCLUSION

A small sample of USITER diagnostic port plug neutronics calculations using Attila are shown in this summary paper. In the full paper a broader survey of port plug interspace dose rate performance will be provided along with ITER strategies for mitigating the shielding and streaming issues. The full paper will also present more detail on the first wall nuclear heating and how Attila is linked to ANSYS for the thermal/hydraulic calculations.

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