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ITER Neutronic Challenges for Upper Port 14

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ITER Neutronic Challenges for Upper Port 14

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INTRODUCTION

The future of magnetically confined nuclear fusion facilities is extremely promising, yet there are extensive challenges that still have to be addressed. These challenges range significantly, but one of the more difficult challenges is nuclear shielding and nuclear safety. The challenge of adequately shielding neutrons is especially prevalent at ITER. Throughout the lifetime of ITER there will be large quantities of high energy (14.1-MeV) neutrons generated, with the expected neutron lifetime fluence to be around 0.3 $\frac{MW \cdot a}{m^2}$ [1].

For such a large neutron fluence, shielding is a very important factor for the operation of ITER. Not only the shielding of the people that will be supporting the facility, but also to the components that surround the plasma. Without the many diagnostics that are planned for ITER operation, ITER would not be able to function. But with the inclusion of the diagnostics and the many apertures required, an interesting neutronics environment is created. This environment is like nothing we have seen or are currently able to create on the earth. Due to this unknown, significant time and effort is being placed on the research, design, and analysis of the ITER neutronics environment.

A neutron has an interesting life after birth within the plasma on ITER. There are many different paths and reactions that can take place; so many, that trying to simplify the problem has brought significant unknowns into the analysis. Due to unique material compositions, neutron streaming paths, and neutronics requirements, the simplest of ITER neutronics calculations have to be thought out in great detail. Placing a new hole for a diagnostic creates a new streaming path; internal components must survive a high fast neutron flux, while external components face a completely different neutron energy spectrum of a high flux; material activation within human accessible areas must be maintained to an allowable level. As the complexity of the ITER device grows, so does the complexity of the neutronics challenges.

DESCRIPTION OF WORK

To solve the extensive neutronics challenges on ITER, computational solutions are obtained. These solutions need to be of high detail that approximate the appropriate geometries while minimizing the computational time. In order to focus the work that is being done on ITER, multiple ports and diagnostics have been split over multiple Domestic Agencies (DAs). The US-DA has been tasked with the analysis and integration of the ITER Upper Port 14 (UP14). This work covers the neutronics calculations, results, and shielding methods that have been done by the US-DA to reach the required nuclear loads for ITER.

UP14 houses three systems; Glow Discharge Cleaning (GDC), Visible Infrared viewing (VisIR), and Disruption Mitigation System (DMS) [2]. Each of these diagnostics must survive the high neutron fluence of ITER while operating at peak performance. Plus, each of the diagnostics require initial shielding material to be removed to accommodate the components. Key interest is the overall affect that the diagnostics have on the neutron environment. To do this we used the Attila neutronics code. Attila is a commercially available radiation transport code distributed by Varex Imaging [3].

Attila solves for the linear Boltzmann equation with discretization in space, energy, and angle. To split the problem spatially, a tetrahedral mesh is created of UP14 and a UP baseline model that does not include any of the diagnostics. This is done to create a comparative analysis that will allow for the affects that the diagnostics have on the environment to be explicitly shown. The baseline model mesh count is 5.4 million, with the diagnostic model mesh count at 8.7 million. Energy is split into 46 neutron and 21 gamma groups, covering a neutron energy range of 14.19 MeV to 1.0e-11 MeV and a gamma energy range of 14 MeV to 1.0e-3 MeV. The angle quadrature that is used is a port directional biased quadrature with 1040 ordinates.

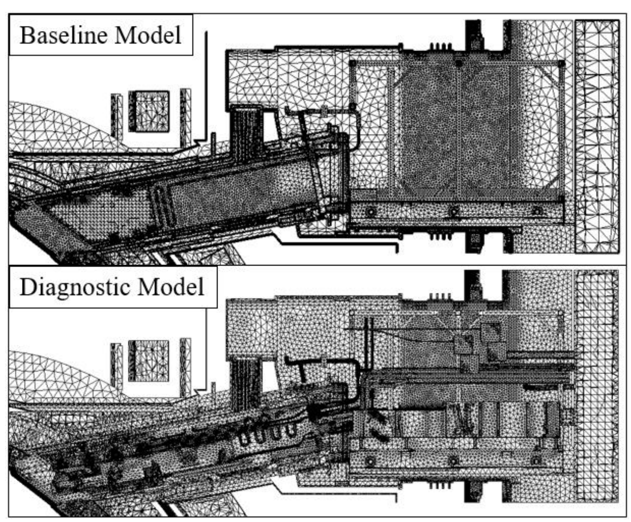

Fig. 1. The model mesh that is used for both the baseline case and diagnostic case of UP14.

RESULTS

Multiple areas of interest are found when looking at the neutronics results for UP14. Major focus is done on the diagnostic components close to the plasma, along with interest in how the components affect the interspace regions where manned access is to be.

The overall neutron transportation within the UP shows significant neutronics challenges. One key situation that is found is the neutron streaming around the gaps of the port plug. This will cause significant problems with activation of the port closure plate – where hands on operations are to be allowed. A neutron flux of 3.0e+8 $\frac{n}{s \cdot cm^2}$ has been shown to be the limit required to meet the interspace dose requirement of 100 $\frac{\mu Sv}{hr}$.

Another key area of focus is the plasma facing diagnostic components. These components must survive for the lifetime of ITER without significant degradation to the data that is acquired. The DMS will mitigate the disruptions as well as suppress runaway electrons. There is worry of significant heating within the front end of the system. These results show the key locations requiring cooling channel focus.

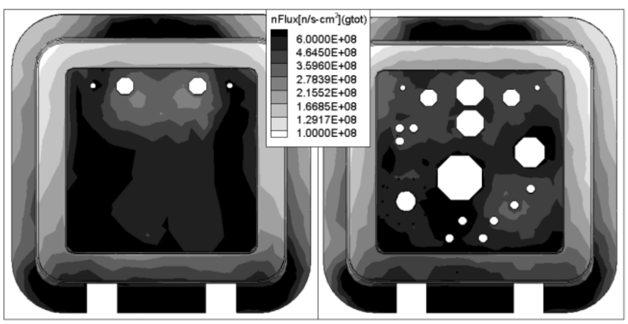

Fig. 2. The flux profile on the closure plate. Currently there is difficulty meeting the 3e8-$\frac{n}{s \cdot cm^2}$ neutron flux level.

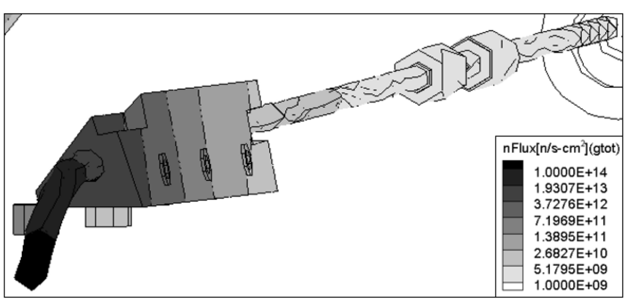

Fig. 3. The DMS and high total neutron flux levels on the plasma facing components.

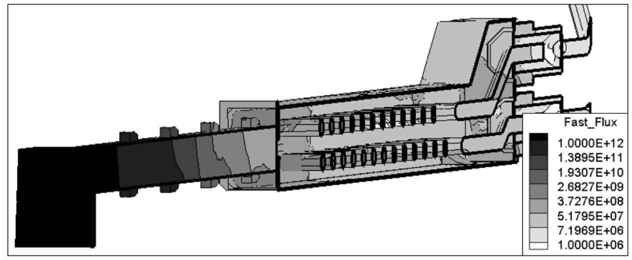

Fig. 4. Slice along center axis of GDC showing the water channels and the neutron streaming paths for the fast neutrons.

The GDC helps condition the plasma facing components before operations. This is a key component, that causes neutronics difficulties due to the large straight cutout required for the diagnostic.

As can be seen in Fig. 4, the hollowed tube of the GDC allows for neutron streaming through the shielding module.

The VisIR is the most difficult neutronics diagnostic for UP14. This is due to the fact that mirrors are required very close to the plasma, along with a labyrinth cutout to transport the light back into the interspace. The labyrinth help mitigates the high energy neutron streaming, but still the removal of the material allows for neutrons to transport into the interspace region.

Finally looking at the neutron results within the interspace localized hot spots can be observed. Due to the streaming around the port plug, significant neutron flux occurs directly behind the closure plate. While the diagnostic components help shield the neutron spectrum, there is still a large quantity of fast and thermal neutrons that make it to the interspace; leading to a difficult problem of both thermalizing and capturing the neutrons.

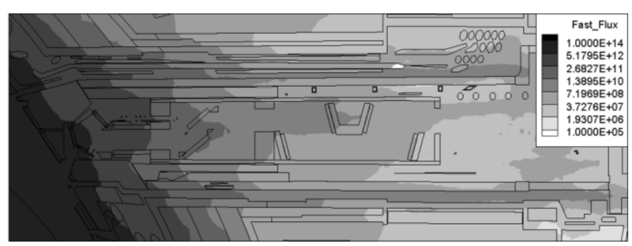

Fig. 5. VisIR labyrinth showing the neutron pathways available. There is a high fast neutron flux that is shown escaping out of the back end of the diagnostic.

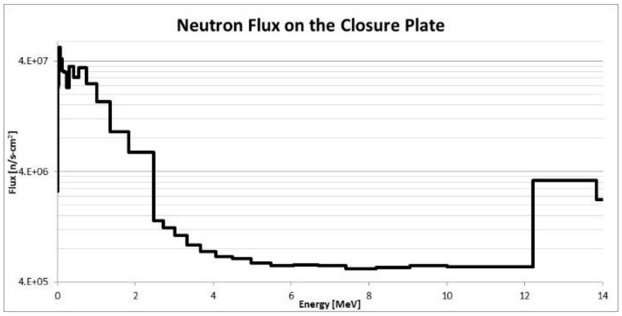

Fig. 6. The neutron spectrum along the closure plate.

FUTURE WORK

The basic approach to minimizing the activation of material within the interspace is to thermalize the fast neutrons, then capture them within a neutron absorbing material such as Boron. The material choices on ITER are limited due to the materials either needing to be ultra-high vacuum compatible or high temperature resistant. But due to the difficulty of thermalizing neutrons with high Z materials, focus is placed on low Z containing materials - such as water. When using water as a neutron moderator, there is activation of the water that takes place that then in itself creates a neutronics problem that must be dealt with. The problem that is being solved is multifaceted and the solutions are difficult to quantify.

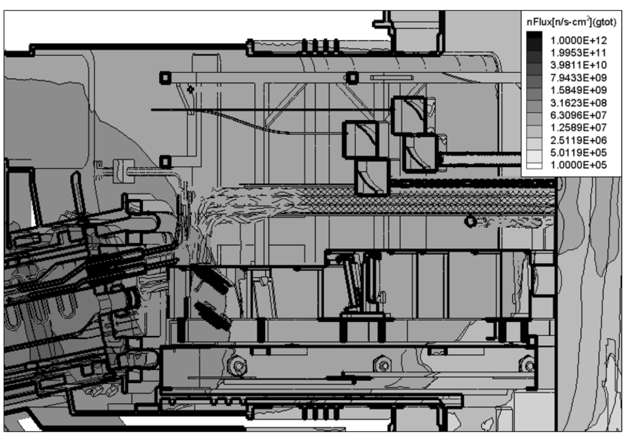

Fig. 7. The interspace region, showing the unique neutron environment that is being addressed.

There has been significant research on the best practices to address the ITER neutronics challenges, but there is still much work that must be completed. The ITER neutronics environment is one of significant complexity, and requires unique solutions to unique problems.

Analysis will begin shortly on equatorial port 9 and 3. Once this work is completed, focus will move outward from the plasma onto the interspace. The interspace work will focus on component survivability and activation optimization using ALARA. From there work will continue on the port cell region, where the nuclear loads will be minimal comparative on ITER, but will still be significant enough that components might have operational difficulties due to the radiation environment.

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