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Environmental Conditions & Loads of ITER Diagnostic Equipment in the Port Plug Interspace & Port Cell

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Development of the port-based diagnostic and service system integration in the Tokamak has been a challenging task for ITER (Nuclear Facility INB-174) engineering. Port integration is demanding more work on ex-vessel to identify electromagnetic thermal and nuclear environment in interspace and port cell regions. Protecting the diagnostic equipment in the interspace & port cell regions poses considerable engineering constraints. This paper will focus on the normal and accidental environmental conditions such as seismic, magnetic field, radiation, pressure, temperature etc., with particular interest on US Domestic Agencies (USDA) based diagnostic systems.

Keywords: ITER Port Integration, Diagnostic Equipment, Interspace, Port Cell

1. Introduction

ITER diagnostic systems provide measurements to aid understanding of plasma behavior and optimize fusion performance. Port-based diagnostic integration is under way between the ITER Organization (IO) and the various Domestic Agencies (DAs). USDA will provide design, fabrication, assembly, and testing of port plugs, specifically the Upper Ports (U11, U14), Equatorial Ports (E3, E9. In addition, the USDA will support the integration into these port plugs of multiple diagnostics, including microwave, laser, x-ray, and optical systems.

Diagnostic systems extend from plasma to the various diagnostic areas, where they are controlled and acquired data is processed. Located in ex-vessel area, the interspace (IS) is the transition region between the port plug and port cell (PC), both mechanically and functionally, while the port cell is the adjacent room to the interspace regions, outside the bioshield. Fig. 1 & 2 illustrate the overviews of interspace and port cell support structure & components in the upper and equatorial port respectively.

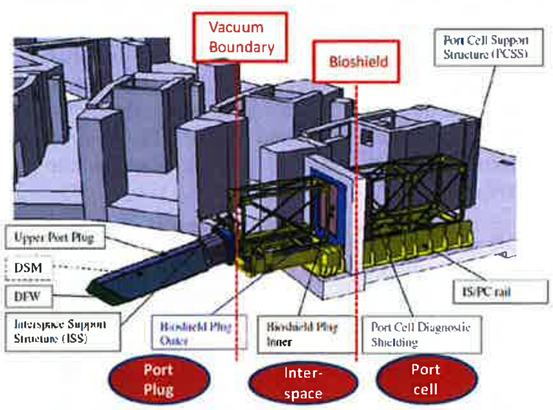

Fig. 1. Overview of interspace and port cell regions in a generic diagnostic upper port

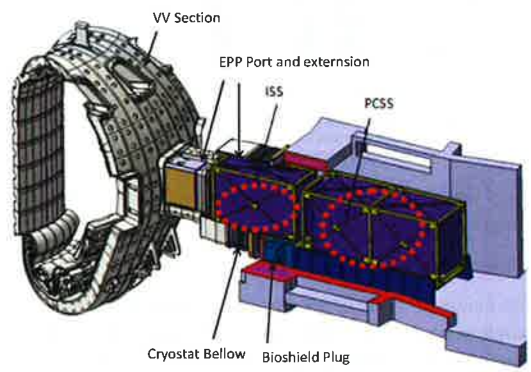

Fig. 2. Overview of interspace and port cell regions in a generic diagnostic equatorial port

Depending on the specific function/design of each diagnostics, interspace and port cell components have different level of safety requirement. Currently, those components are classified as safety related, Protection Important Activity is not being considered at this stage. Pressurized equipment is under ESPN exemption. With the progress of individual port integration, the safety related issue and its implications will be revealed.

2. Environmental Condition & loads

Diagnostic equipment requires adequate support in port interspaces in term of structural stability, acceptable temperature and maintainability. This paper depicts the normal and accidental environmental conditions such as seismic, magnetic field, radiation, pressure, thermal etc..

2.1 Seismic Events

Diagnostic equipment in the interspace and port cell region will be installed to resist seismic induced inertial loads. Most components placed in the interspace and port cell are supported by ISS or PCSS. Some are attached to the closure plate of port plug. ISS &PCSS are fastened to rail while port cell rail is anchored to the Tokamak building concrete. Seismic events will induce

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severe inertial loads on the diagnostic equipment. Under safe shutdown earthquake, the maximum vertical acceleration can be up to 198m/s^2 within equatorial interspace. The radial acceleration within upper port interspace is up to 197m/s^2 (Fig. 3) Particularly, for components supported by multiple supports the relative displacements at the connection points shall be taken into consideration because they can generate additional non negligible stresses (and support loads). Stresses and loads calculated from the relative displacement shall be added to the stress induced by the seismic acceleration. Relative displacement between support points, if significant, still need to be carefully considered.

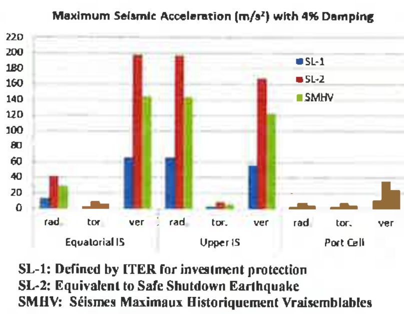

Fig. 3. Maximum Seismic Acceleration Values with 4% damping

2.2 Magnetic Field

The magnetic field is present during operation and short maintenance. The load cases are defined in ITER documentation "DINA disruption cases". In order to obtain the worst scenarios for the IS/PC structures and components at upper and equatorial port level, the scanning of the DINA simulations should be performed at various IS/PC locations when there are loops, i.e. components are connected to the surface of vacuum vessel (VV) or closure plate. When the diagnostic components are insulated from the surface of the VV, easy calculations could be done assuming the variations of the fields in IS/PC areas. Magnetic stray field map will be further refined by PPPL and IO. The maximum of stray field and of its time derivative outside the bio-shield has been identified corresponding to four scenarios (*Ref. 2*). The maximum |B| reached 179 mT during a full plasma scenario, while the maximum d|B|/dt reached 37.5 T/s

2.3 Nuclear Environment

Nuclear loads in the IS/PC come from three main sources. During experimental operations prompt neutron and gamma radiation is escaping or leaking from the port plug into the interspace. Also during experimental operations gamma photons will be emitted from water pipes running through the IS/PC due to activated water. The third source of radiation is gamma photons emitted from neutron activated steel structures during the shutdown. The two operational loads mainly effect the equipment while the activated steel gamma load affects worker safety and maintenance planning.

In the interspace and port cell nuclear volumetric heating, helium production and material damage (DPA) are generally not an issue. Instead, the nuclear loads affect the useful life or survivability of diagnostic components such as electronics or glass optics. The nuclear load from activated steel has a major impact on diagnostic maintenance scenarios which are a critical part of the diagnostic system design.

A series of neutronics analyses for the USDA equatorial and upper port diagnostic system has been done. Each analysis focuses on assessing the interspace shutdown dose rate for the diagnostic using ITER 20° B-Lite model. Fig. 4&5 illustrate the nuclear loading results on upper port 14 based on conceptual upper port 14 with wide angle viewing visible-IR system. The average neutron flux is 5E x 10^8 n/cm^2/s (Fig. 3), while the Shut Down Dose Rate (SDDR) is 100 µSv/hr (Fig. 4), which is calculated at an approach of 1-meter from the port plug closure plate.

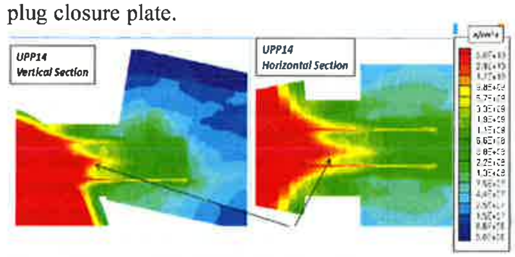

Fig. 4. Neutron Flux of Upper Port 14

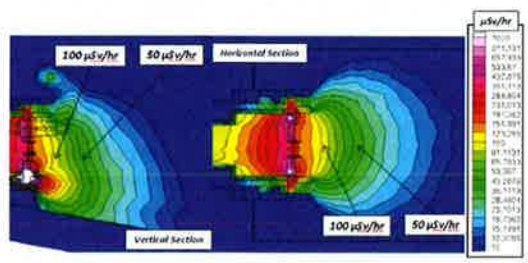

Fig. 5. Shut Down Rate Contour of Upper Port 14

PPPL has further developed Attila-based ITER 40° C-Lite model for neutronics analysis. Fig. 6 shows the C-Lite model (*Ref. 4*) and resulting neutron flux contour. It is assumed that the diagnostic systems contribute to the interspace dose rate by leaking neutrons through to the port plug closure plate and flange. These structures become activated and emit gamma photons into the interspace.

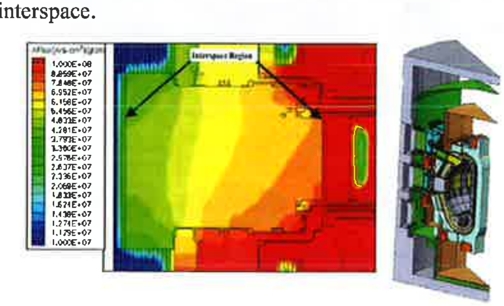

Fig. 5. Neutron flux in the port interspace of the upper and equatorial port using C-lite model

Overall the neutron flux within the interspace can range significantly depended on the port labyrinths and shielding schemes. In this paper, the general model was used to produce an overall basic neutron flux result. Within the equatorial port interspace the neutron flux will be in the range of around $3e^7$ [n/s/cm^2] to $1e^8$ [n/s-cm^2], shown in Fig. 5. This value will be higher if shielding is removed from the lower port plug level in order to make accommodations for diagnostics. However, current shielding configurations have minimized neutron streaming within the equatorial port, leaving most interspace neutrons within the thermal range. This will allow thermal neutron absorption materials to be extremely effective in shielding interspace components.

Activation of cooling water in IS/PC regions will result in the increasing gamma dose rate from ^{16}N and neutron dose rate and neutron flux from ^{17}N activated water during 500MW fusion power plasma discharges. Tokamak Cooling Water System (TCWS) is being redesigned to reduce radiation dose due to activated water "Project Change Request: PCR662 Revise TCWS Design and Shielding to Mitigate Gamma Radiation and Fast Neutron Dose Rates". Much radiation analysis is on-going associated with PCR-662. Some initial analysis has shown promising results (Fig. 6)

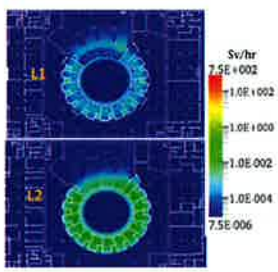

Fig. 6: Shut dose rate contour plots at Tokamak Building Level L1 & L2

2.3 Thermal Loads

Thermal loads acting on the IS/PC structures and components can be listed as:

- •Thermal loads during the full plasma operation of ITER
- •Thermal loads associated with vacuum baking
- •Thermal loads during maintenance
- •Increase of temperature of the PC atmosphere during Ex-Vessel Loss of Coolant Accident
- •Increase of temperature in VV during In-Vessel ICE
- •Increase of temperature in PC during fire event

Table 1 summarizes the heat load in IS/PC for four USDA ports abstracted from the report. However, there is no detailed instruction of heat loads and their influence areas. Proper thermal boundaries are still needed in order to apply correct heat loads on IS/PC separately. It may be assumed that in-vessel component's baking will cause higher heat load into IS/PC areas.

Table 1: Head loads Summary (*Ref. 3*)

	Operation	Maintenance	Baking
	kW	kW	kW
E03	18.4	4.2	26.2
E09	18.4	4.2	26.2
U11	17.7	8.2	25.2
U14	20.2	6.2	25.2

The interspace is confined by port plug closure plate, port extension, cryostat bellows and Tokamak building at the bioshield. Fig. 7 illustrates the generic port plug interspace region, starting from the closure plate to the bioshield interfaces (black dotted line).

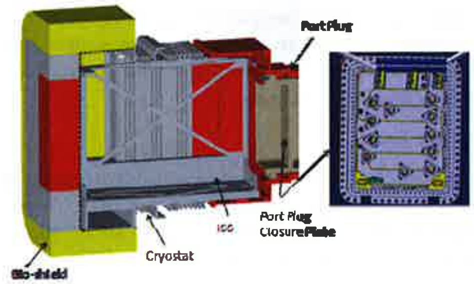

Fig. 7. Geometry Overview of Equatorial Interspace Thermal Boundary

The atmosphere of the interspace is shared with the Port Cell. Port cell is cooled by local air coolers and must be sufficient for normal operation temperature of the IS ≤ 50°C. In terms of temperature issue, the components located interspace region may suffer from higher temperature during vacuum baking and fire events.

Some thermal studies have performed to identify the thermal environment of equatorial interspace, such as the effects of interspace thermal isolation conditions, natural air convection effects, effects of insulation thickness. Fig. 8 summarizes the results of corresponding thermal studies. Table 2 summarizes the maximum values of temperature in interspace area under various conditions with the value exceeding the 50°C, (*Ref. 5*) which suggests the need for thermal protection scheme.

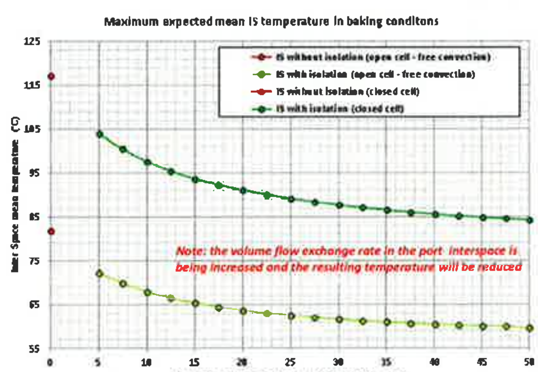

Fig. 8. Interspace Temperature Estimation during Baking

Table 2: Summary of Interspace Temperature Estimation

		No Insulation)	50 mm Insulation Blanket
Operating Condition	Closed cell limits	51 51°C	49.21°C
	Open cell limits	45.54°C	39.89°C
Baking Condition	Closed cell limits	117.27°C	84.24°C
	Open cell limits	81.75°C	59.57°C

The components placed in the Diagnostics Port Cell will be loaded by high temperatures during a fire event. The maximum temperature will be extremely high near the fire origin in the order of 1000°C based on the preliminary fire load assessment (*Ref. 6*). Specific calculations shall be performed for each Port Cell with validated codes for maximum fire conditions. Safety Importance Class (SIC) Components are protected from the consequences of fire so that their safety function is maintained. Fire passive protections with appropriate material may be a better scheme.

2.3 Interface Loads

Diagnostic systems are composed of sensors/detectors in the port area (port-plug, interspace and port cell). Some components inside assembled Ports may be anchored the supporting structures (PP structure, DSMs, DFWs, ISS and PCSS) through several supports. In these cases, apart from the maximum inertial loads seen by the component, additional stresses may be induced by the relative displacements between supports. These relative displacements could be arising from seismic events, electromagnetic VDE events and thermal operation.

4. Protection from Various Loading

Diagnostics equipment in IS/PC region is still working harsh environment. For instance, Radiation can damage or destroy electronic components or sensors, corrupt signals in analogue or digital circuits, corrupt data in memories, etc. In ITER, these effects can appear progressively, due to accumulated ionization or accumulated atomic displacements, or instantaneously, due to a single highly ionizing particle. Table 3 summarizes the effects of main loads.

Table 3: Summary of the effects of main loads

	Effects on Diagnostic Equipment
Inertial loads	Those components attached to port closure plate will suffer from VDE. Those components Attached to ISS/PCSS will suffer from gravity/seismic events
Electro-magnetic loads	Electronic components will suffer from non-negligible stray field. These fields may affect those components with moving parts.
Nuclear loads	Absorbed radiation doses in electronic and diagnostic equipment can damage or destroy electronic components or sensors, corrupt signals in analogue or digital circuits, corrupt data in memories, etc.
Thermal loads	Some components will suffer from high temperature, especially those components attached or near to the closure plate during the machine bake.
Interface loads	Component performance degradation due to misalignment (vibration & shock, thermal)
Accident loads	All components placed in IS/PC regions (fire sectors) will suffer from high heat flux from potential fire consequences, lead to severe damage of equipment

Diagnostic equipment requires adequate support in port interspaces in term of structural stability, acceptable temperature and maintainability. There are a few engineering concerns addressed in this paper. On one hand, the multiple thermal interface nature of interspace imposes much complexity in defining thermal loads on interspace diagnostics equipment. On the other hand, the port closure plate presents an interface crowded with windows, mechanical and electrical feedthroughs etc.. and may prove difficult to insulate effectively. Fig. 8 illustrates the Crowd diagnostic components near the closure plate of equatorial Port 9. Moreover, forced air convection may not be available for interspace regions. Therefore, thermal protection may differ for different diagnostics systems. Some equipment may need to be relocated to the Port Cell if the diagnostics performance is not adversely influenced. By doing so, improved air

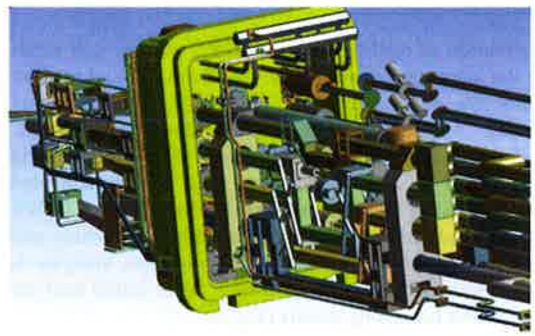

Fig. 8 Crowd diagnostic components near the closure plate of equatorial port 9

circulation in the port interspace may help convective heat exchange. However, it must be mentioned that thermal protection in port cell regions is still a long term activity, such as locating the acceptable insulation material, various mitigation especially protection fire.

5. Summary

Various diagnostics equipment in interspace & port cell will experience different loading arising from seismic & electromagnetic events, neutronic and thermal environments, as well as fire hazard. An overview of applicable loads is given in this paper. Some potential issues and solutions are highlighted.

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