In-vessel Engineering Instrumentation for Future Fusion Devices

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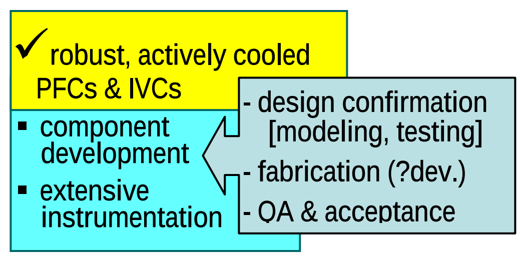
Where we have significant investments in equipment, diagnostics warn us when their operation goes outside prescribed ranges. Then we make adjustment or do maintenance to avoid damage.

This is true of the cars we drive and our power plants.

We need diagnostics, called "engineering instrumentation" here, to monitor the performance of in-vessel components as well as auxiliary systems in fusion devices, including upgrades to existing confinement devices to add robust and reliable plasma facing components (PFCs) and in-vessel components (IVCs), such as guard limiters, RF launcher, mirrors and probes, as well as for the first wall and shield module in ITER, and the integrated first wall and blanket module in a CTF or DEMO. Particularly for in-vessel components, this monitoring presents significant challenges, and to date this area has been largely discounted in ITER and is the type of detail not pursued in design studies for DEMO or other future facilities. Two exceptions are systems needed in ITER, one for leak detection and the other for measuring the accumulation of dust, and neither of these currently has a proven solution.

The link between the need for engineering instrumentation of PFCs and IVCs arises from the need to operate these components reliably to support the physics missions of the confinement devices plus the useful complementary benefit of learning about their performance. This is covered in another white paper by Nygren titled "Future Plasma Facing Components (PFCs) & In-vessel Components (IVCs): Strengthened Sustained and Integrated Approach for Modeling and Testing HHFCs."



For fusion systems, we can identify the conditions of interest and assign diagnostics based on common sense and some insight from the instrumentation used on other technologies. The information desired from such engineering diagnostics would likely include at minimum some confirmation that the blanket and first wall systems were functioning safely, i.e., in a manner that did not suggest short term failure from malfunctions such as insufficient coolant flow and distortion and cracking due to overheating of some section of the first wall or blanket. For example, in ITER the first wall may be visible to the view of an IR camera, but the same is not true for the blankets and mounting structure. In an actively-cooled guard for an RF launcher or and actively-cooled mirror, overheating might be due to deficiencies in the coolant flow or local conditions of the plasma, and it will be useful to distinguish between these causes to both learn about and improve future performance.

The following examples of current use in of instrumentation used in harsh environments for fission power plants, MHD power generators and fission fuel reprocessing systems give some insights into diagnostic functions for fusion in-vessel components that would provide useful information in evaluating whether these components were operating within their prescribed operating. Fission reactors typically use an array of thermocouples in the core to measure core temperature and to identify hot channels where the coolant flow may be lower than desired and also to monitor the inlet and outlet temperature of the core coolant. In the steam generator of PWRs, there are measurements of the inlet and outlet coolant temperatures, pressure, water level and water chemistry. There are also acoustic measurements for monitoring of mechanical noise that might arise from such conditions as vibration of tubes in the tube bank or a steam generator, action of the check valve in the return flow channel from a PWR steam generator or rattling of loose hardware. Liquid metal systems typically have purification systems and diagnostics to monitor chemistry and oxygen levels and for MHD generators there are probes used to make measurements of electrical potential in the walls and in the flowing metal. More extensive examples with references are still being developed (see end notes.)

An important area that needs to also be addressed in a future paper (see end notes) as well as in future development are the challenges in developing and deploying instrumentation for in-vessel components. Among the threats for such instrumentation are potential electrical shorts and ground loops (which are not wholly unique for fusion but are exacerbated by the extensive need for electrical isolation of components) and unreliable or distorted signals due to the severe environment of high and electrical magnetic fields and neutron radiation.

This white paper does not provide references or many specific examples. The intention is to develop further examples and references and to incorporate these into another white paper, perhaps one aimed at the thrust of Greenwald Initiative I-6, which is covered in part in another white paper by Nygren titled "Future Plasma Facing Components (PFCs) & In-vessel Components (IVCs): Strengthened Sustained and Integrated Approach for Modeling and Testing HHFCs" or one in the area of safety and reliability.