Diagnostic systems in DEMO: engineering design issues

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The diagnostic systems of DEMO that are mounted on or near the torus, whether intended for the monitoring and control functions of the engineering aspects or the physics behaviour of the machine, will have to be designed to suit the hostile nuclear environment. This will be necessary not just for their survival and correct functioning but also to satisfy the pertinent regulatory bodies, especially where any of them relate to machine protection or the prevention or mitigation of accidents relevant to human safety. This presentation aims to indicate the more important of the design considerations that are likely to apply to diagnostics for DEMO, drawn from experience on JET, the provisions in hand for ITER and modelling results for the neutron effects in DEMO.

JET is presently the nearest machine to DEMO that is in operation, while ITER is of course a vital intermediate step. JET is not subject to nuclear regulatory scrutiny but nevertheless operates under a rigorously applied safety case following the same principles as those developed for the fission plant that the JET Operator (the UK Atomic Energy Authority) once operated. Accordingly diagnostic systems mounted on the machine have to satisfy over twenty criteria, described in a JET design approval check-list. These design constraints and approvals necessary to get diagnostic systems implemented on JET are necessarily more onerous than those applied to other (non-DT) operating tokamaks. It should be noted that DT operation in JET involved a site inventory of only 20g of tritium, totalled about $3x10^{20}$ neutrons and resulted in torus radiation fields two weeks after shut-down of around 10mGy/hr, while for ITER the figures are 4kg, $\sim 3x10^{27}$ neutrons and 500Gy/hr, and DEMO perhaps 6kg, $\sim 1.4x10^{29}$ neutrons (in ~3FPY) and about 10kGy/hr. The corresponding neutron damage, affecting components near the plasma, is in the region of $1.2x10^{-6}$, 2 and 60 displacements per atom respectively. It can immediately be seen that as onerous as the JET design criteria might be, those of ITER and one day DEMO will be far more so.

The following should be amongst the considerations in the design of DEMO diagnostics:

real-time radiation-induced effects
radiation damage (e.g. in mirrors and transparent optics)
remote handling compatibility (and fault-condition recovery)
useful life between component replacements (if possible)
neutron streaming (labyrinths, line of sight restrictions)
tritium and active dust confinement
use of reduced-activation materials and coolants
seismic and disruption acceleration forces
vibration and other operational cyclic loads
disruption-induced currents and voltages
installation and operational clearances
avoidance of halogens (tritium plant poisons)
impact on neutron fluxes elsewhere
earthing and signal paths
material transition welds
RAMI
EMI screening (source or recipient)
ICRH and ECRH immunity
vignetting of other systems (photon, particle)
thermal environment including cycling
UHV design principles
fast particle impacts

In this light, it becomes clear that if it is essential to operate DEMO with finely structured plasma profiles in order to achieve adequate stability or fusion gain, it will be especially challenging to meet all the necessary design and implementation criteria for the associated high resolution and sophisticated plasma diagnostics. Ultimately, though, the degree of sophistication desired in measurement and control should be a question of overall whole-life cost, or perhaps the amortised cost of each unit of electricity sold to the utilities. Accordingly, the presentation will focus on some of the more demanding engineering design requirements.

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