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UCID-21815

AN ASDEX-TYPE DIVERTOR FOR ITER

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September 25, 1989

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Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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DE90 000903

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Abstract

An Asdex-type local divertor is proposed for ITER consisting of a copper poloidal field coil adjacent to the plasma. Estimates indicate that the power consumption is acceptable. Advantages would be a much reduced heat load not very sensitive to magnetic perturbations. A disadvantage is the finite lifetime under neutron bombardment that would require periodic replacement of the divertor coils in a reactor, but probably not in ITER because of its limited fluence. Another disadvantage would be poorer blanket coverage unless the divertor coil itself incorporates breeding material.

I. Introduction

The idea is sketched in Fig. 1, in which the proposed Asdex-type local divertor is overlaid on the current ITER baseline design. The expected magnetic flux structure is sketched in Fig. 2.

In contrast with the usual design that locates the divertor plate near an x-point, in the proposed design the divertor coil itself serves as the divertor plate. Because magnetic surfaces wrap around the coil, heat deposition spreads over the entire outer half of the coil surface, a much larger deposition surface than in the usual arrangement. Also, because the coil current exercises firm local control over these flux surfaces, one can take maximum geometric advantage of spreading out a thin scrape off layer over a large deposition surface.

2. Power Consumption

We approximate the area of deposition, A, as:

$$A = 2\pi R \bullet \pi r \tag{1}$$

where R is the plasma major radius and r is the minor radius of the divertor coil (approximated as circular, though optimal tailoring of the shape will be desirable). As is indicated in Fig. 2, the actual shape of the divertor armor would be eccen'ric to the conductor and optimized to spread out the impinging flux over an arc of dimensions approximated as πr above.

As can be seen from the following, the divertor coil power is independent of A. Since the divertor field must compete with the poloidal field due to the plasma current I, we scale the power in terms of I and require:

$$\frac{I_D}{5r} = \frac{I}{5aK} \tag{5}$$

where I_D is the divertor current, a is the plasma radius and K is the elongation. Then the divertor power per coil is

$$P_D = 10^6 \, I_D^2 \left(\frac{2\pi R\eta}{f\pi r}\right) = 10^6 \left(\frac{I}{aK}\right)^2 \frac{2R\eta}{f} \tag{3}$$

where I is in MA, P_D is in MW, $\eta = 1.7 \times 10^{-8}$ ohm-m is the resistivity of copper and f is the packing fraction. For ITER baseline parameters,

$$\begin{aligned}
I &= 22 \text{ MA} \\
R &= 6 \text{ m} \\
a &= 2.15 \text{ m} \\
K &= 1.95 \\
f &= 50\% \\
P_D &= 12 \text{ MW per coil}
\end{aligned} \tag{4}$$

Even if a realistic calculation doubles P_D, this is probably an acceptable power consumption, especially if this divertor design provides greater flexibility to increase T_e and decrease the current drive power. The divertor power might be even less for a reactor.

3. Heat Deposition

Since P_D is independent of A, a single-null divertor would be preferable from the point of view of consumed power, though other design characteristics might favor a double-null. For a single-null, the divertor heat load in ITER would be (for a fusion power of 1081 MW, R = 6 m):

$$\frac{\text{alpha plower}}{A} = \frac{0.2 \times 1081}{2\pi R \bullet \pi r} \cong \frac{2}{r}\ \mathrm{MW/m^2} \qquad (5)$$

For r = 0.5 m (roughly the scale in Fig. 1), this gives 4 $\mathrm{MW/m^2}$, in contrast with 26.4 $\mathrm{MW/m^2}$ for the current baseline in steady-state (Fig. 3).

Even though this approach relies heavily on grazing incidence to spread out the heat load, because divertor current provides strong local control of flux surfaces, this design should not be very sensitive to magnetic disturbances. Also, the scrapeoff layer thickness (D in Fig. 2) being uncertain, this approach should have an advantage in adjusting the field pattern to match the actual scrapeoff thickness by adjusting the divertor current I_D (of order (r/a)I ~ 4 MA in ITER). The deposition area would be held fixed (A in Eq. (2)) and I_D would be adjusted to spread the scrapeoff flux over A as fully as possible.

4. Impurity Control and Confinement

The proposed design does not appear to pose new problems following the present design philosophy for impurity control. The distance along a field line from the null to the armor surface, if order πr, is comparable to that in the new ITER baseline at the nominal value r = 0.5 m used above and there appears to be room to optimize r.

Since field lines strike the armor beyond line-of-sight contact with most of the plasma, it should also be possible to design baffles permitting high gas pressure in the divertor following alternative philosophies that use gas to convert heat to radiation.

5. Problems

Detailed calculations are required to verify the above claims.

Other issues requiring examination are the lifetime of the coil under neutron bombardment, and blanket coverage.

Neutron damage is possibly acceptable in ITER (total fluence/mW yr/m^2) but it needs attention for reactors.

The blanket coverage should be no worse than the present ITER baseline. In a reactor, it may be necessary to add breeding material to the divertor coil structure itself, for example, lithium oxide insulation.

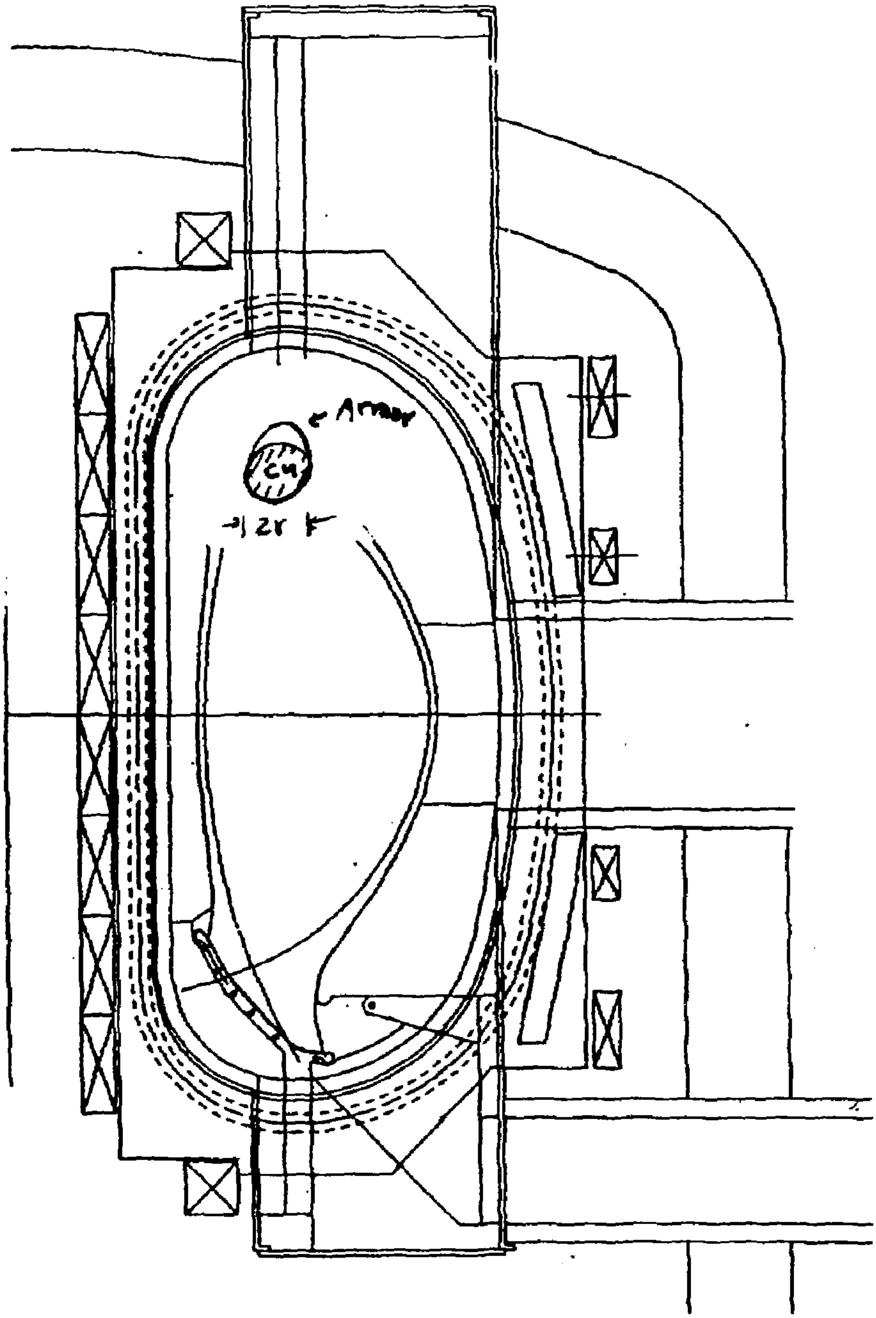

Fig. 1. Porposed local divertor superposed on ITER baseline. A single-null divertor is shown but a double-null divertor is also possible.

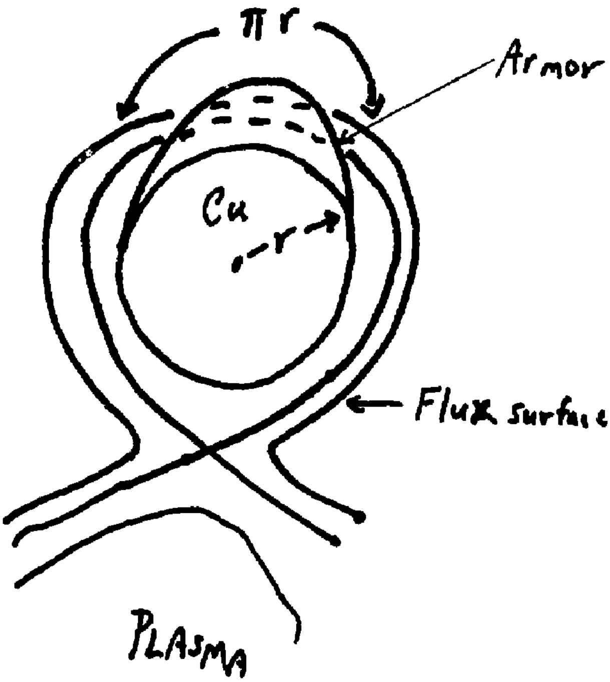

Fig. 2. Sketch of flux surfaces.

	Plasma Conditions n_e / T_e	Injection Power (MW)	Power to Divertor** (MW)	Divertor Plasma Temp (eV)	Divertor Peak Power Density (MW/m^2)
INDUCTIVE IGNITED OPERATION (τ_{burn} ~ 200 s)	1.17×10^{20} m^{-3} 10 keV	0	153 + 0 = 153	21	6.9
TYPICAL HYBRID OPERATION (τ_{burn} = 3000 s)	1.2×10^{20} m^{-3} 8 keV	138	148 + 138 = 286	81.4	18.4
TYPICAL STEADY STATE OPERATION ($\tau_{burn} = \infty$)	0.67×10^{20} m^{-3} 20.8 keV	145	171.2 +145 = 316	232	26.4

*For 1 MW/m^2 neutron wall load (i.e., 1080 MW fusion power)

**Sum of $P_\alpha - P_{rad}$ and P_{inj}, where $P_\alpha = 216$ MW

Figure 3. ITER divertor conditions* present baseline.