Bremsstrahlung and Synchrotron Radiation Losses in Polywell Systems

By Robert W. Bussard and Katherine E. King, December 5, 1991, EMC2-1291-02

Power losses from Polywell systems due to bremsstrahlung and synchrotron radiation have been analyzed and compared with fusion power production. Results of these studies are given in two earlier technical reports.[1,2] The analyses reported here are supplementary to data given in these two studies.

Taking the ratios of fusion power to synchrotron radiation and bremsstrahlung as P_{fs} and P_{fb} from equations (10) and (13) of references (1) and (2), respectively, calculations have been made of these ratios as a function of system electron injection energy, over a range of virtual anode heights, for the four fusion fuel combinations previously considered. These were computed for optimum mixture ratios and for 50:50 mixtures. A key factor in the determination of bremsstrahlung losses is the functional term F_b (see equations 5, 8 of ref. 2) given as

$$F_b = \frac{F_3(Z) E_f k_e^{1.5} \sqrt{2 / m_p M_i}}{1.6x10^{-31}} \quad (1)$$

where E_f is fusion reaction energy in MeV, m_p is proton mass in gm, M_i is the "reduced" mass of the fusion reactive ions, normalized to one proton mass, and k_e = 1.6 x 10^{-12} ergs/eV is the Boltzmann constant. The functional term $F_3(Z)$ is

$$F_3(Z) = \frac{b_{ij}}{\left[1-(Z_2-1)f_2\right]\left[1+(Z_2^2-1)f_2\right]} \quad (2)$$

where f_2 is the fraction of fuel mixture taken up by the high-Z component, and b_{ij} is the (usual) fuel mixture weighting factor, given here by

$$b_{ij} = (1-f_2) f_2 \quad (3)$$

as used in references 1 and 2. The variation of F_b with mixture ratio factor f_2 is as shown in Figure (1) for the four fuels considered.

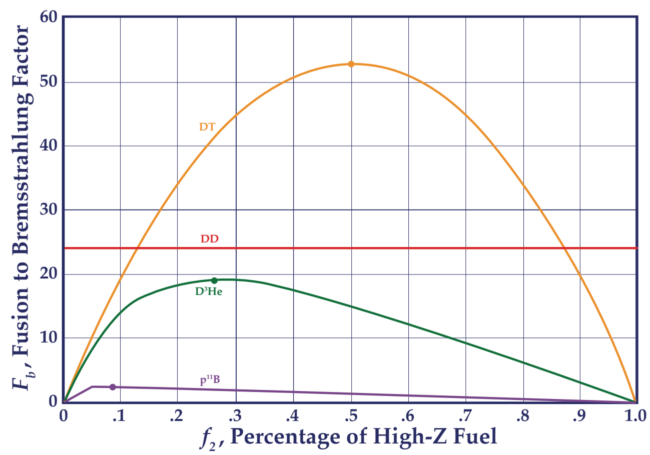

Figure 1 — Fusion to Bremsstrahlung power ration factor, F_b, for various fuels, as a function of fractional content of high-Z fuel

Note that F_b reaches a maximum as a function of f_2, for the higher-Z fuels. From the figure it is seen that this optimum operation (maximizing the ratio of fusion power to bremsstrahlung) occurs at fractional mixture content, f_2, smaller than 0.5. Optimum values are

Fuel	Optimum f_2
DT	0.50 (in range 5 keV < E_o < 50 keV)
DD	indeterminate
D^3He	0.261
$p^{11}B$	0.084

Note, also, that the variation of F_b with f_2 is very slow around these optimum values for D^3He and $p^{11}B$, so that higher values of f_2 may be used without strongly deleterious effects on the fusion-to-bremsstrahlung power ratios, especially in the case of $p^{11}B$.

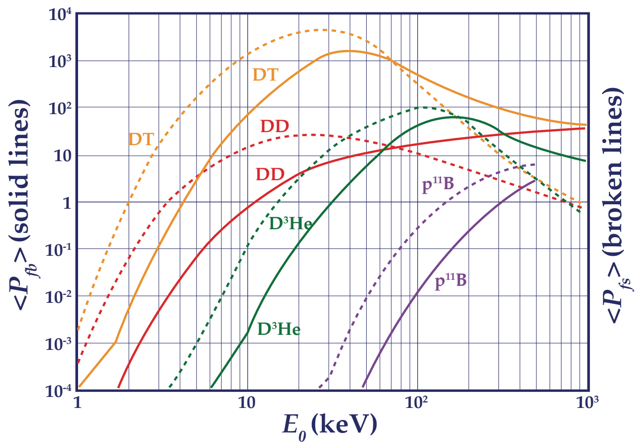

Figure 2a — Ratio of fusion power to bremsstrahlung (P_{fb}) and to synchrotron radiation power (P_{fs}), for various fuels, as a function of electron injection energy (E_0), for 50:50 (f_s = 0.5) fuel mixtures. Virtual anode height of (eta) = 0.01

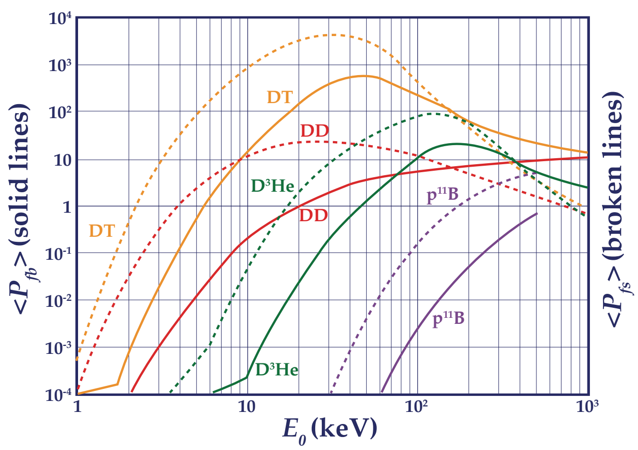

Figure 2b — Ratio of fusion power to bremsstrahlung (P_{fb}) and to synchrotron radiation power (P_{fs}), for various fuels, as a function of electron injection energy (E_0), for 50:50 (f_s = 0.5) fuel mixtures. Virtual anode height of (eta) = 0.1.

Using the above in the calculation of P_{fb} and P_{fs} gives the curves shown in Figures (2a, b) and (3a, b). Figures (2a, b) are for fusion fuels operating with a mixture fraction of f_b = 0.5, while Figures (3a, b) are for f_b values that are optimum with respect to bremsstrahlung, production, as tabulated above. The (a) figures apply to the case of a small central virtual anode height (eta = 0.01) with correspondingly small central electron "temperature," while the (b) figures are for a considerably higher central anode (eta = 0.1), with much higher electron temperature.

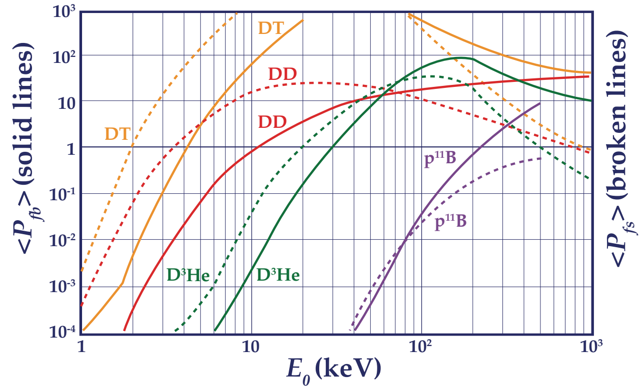

Figure 3a — Ratio of fusion power to bremsstrahlung (P_{fb}) and to synchrotron radiation power (P_{fs}), for various fuels, as a function of electron injection energy (E_0), for bremsstrahlung-optimum f_a fuel mixtures. Virtual anode height (eta) - 0.01

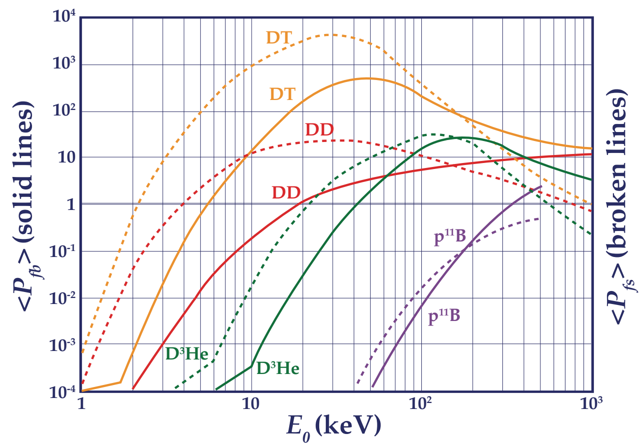

Figure 3b — Ratio of fusion power to bremsstrahlung (P_{fb}) and to synchrotron radiation power (P_{fs}), for various fuels, as a function of electron injection energy (E_0), for bremsstrahlung-optimum f_a fuel mixtures. Virtual anode height (eta) = 0.1.

Note that all of the systems can be made to operate with P_{fb} ratios greater than unity except for $p^{11}B$ at non-optimum mixture (f_b = 0.5) and large central anode conditions. If central anode height can be kept small, and operation be constrained to near-optimum mixtures, then $p^{11}B$ will yield net power gain if deep wells (e.g. E_o > 500 keV) can be provided for ion trapping.

However, the true overall power balance must also include losses associated with the provision of magnetic fields required for electrostatic well formation in the Polywell scheme. Two types of field systems can be considered; normal and superconducting magnets. The former will show losses proportional to B^2, while fusion power output varies as B^4. Thus, any normal magnet system can be made to approach the zero-magnet-power systems reported here and in references (1, 2) by operation at sufficiently large fields.

In a somewhat similar vein, superconducting magnets can be made to operate with arbitrarily small power consumption, by design reduction of thermal loads on the magnet coil systems, that set the level of the required cryogenic cooling power (and thus of the lost cryo-refrigeration drive power). Either approach can then be driven (by design) towards the asymptotic power ratios discussed above and shown here in Figures (2, 3). However, it is important to note that superconducting magnets must either be restricted to use with aneutronic fusion fuel systems, or well-shielded to prevent excessive unavoidable neutron heating of the conductor material, with concommitant excessive cryogenic refrigeration power requirements.

These heating, refrigeration, insulation and other magnet power balance issues are addressed in another EMC2 Technical Note (forthcoming), over a range of system sizes and *B* fields.

References

[1] Robert W. Bussard; "Edge Region Distributions and Synchrotron Radiation," Energy/Matter Conversion Corporation Technical Report, EMC2-0991-04

[2] Robert W. Bussard and Katherine E. King; "Bremsstrahlung Radiation Losses in Polywell Systems," Energy/Matter Conversion Corporation Technical Report, EMC2-0891-04