CORRIGENDUM

W. M. STACEY, "Demo & Commercial Fusion Reactors Extrapolated from the ITER and Advanced Physics & Materials Data Bases," *Fusion Technol.*, **26**, 1119 (1994).

The original figures for this paper were inadvertently omitted. Thus, for the convenience of the reader, this paper and the figures are included here.

DEMO & COMMERCIAL FUSION REACTORS EXTRAPOLATED FROM THE ITER AND ADVANCED PHYSICS & MATERIALS DATA BASES

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ABSTRACT

The characteristics of demonstration (DEMO) reactors that could be conservatively extrapolated from the data base that will be provided by ITER and its supporting R&D and from a data base supplemented by advanced physics and advanced materials R&D programs are identified.

I. INTRODUCTION

Ten to fifteen years from now, decisions will be taken on the characteristics of a DEMO reactor to follow ITER, with the objective of demonstrating the engineering and economic feasibility of fusion power. If past experience is any guide, these decisions will be based on relatively conservative extrapolations of the existing physics and technology data base. Since ITER requirements can be expected to dominate the world fusion program over the intervening period, the major part of that data base will, perforce, be the data base developed in support of ITER and by the operation of ITER--the "ITER data base". Other advanced physics and technology R&D programs operating in parallel with the ITER program will provide a small, but crucial, supplementary "advanced data base". Identification of the characteristics of a DEMO reactor (and of a subsequent commercial reactor) that would extrapolate from the anticipated "ITER data base" and from various possible supplemented "advanced data bases" can thus provide useful programmatic guidance now, while there is still time to affect the specifics of both the ITER and advanced data bases. Such a pragmatic, "roll-forward" approach to the definition of likely DEMO characteristics complements the "roll backward" approach frequently taken. The purpose of this paper is to initiate this process of identification.

II. DATA BASES

For the purposes of this paper, we associate the "ITER data base" with the ITER design characteristics and objectives. In particular, we postulate 1) Nb_3Sn superconductor and 316LN stainless steel magnets that can produce about 13T at the conductor; 2) 316 stainless steel structural material cooled by H_2O; 3) dispersion-strengthened copper divertor structure cooled by H_2O and with a sacrificial coating; 4) energy confinement characterized by the ITER89-P scaling law with H = 2; and 5) plasma operating regimes characterized by ignition, $g_{Troyon} \leq 3.5$, $q_{95} \geq 2.8$, $\kappa = 1.5$, $\delta = .15$ and $\varepsilon\beta_p << 1$. We postulate Li_2O as the breeding material in this data base, since it has been commonly used in previous ITER, INTOR and national designs of ITER-class tokamaks.

For the "advanced data base", we postulate: 1) the V-4Ti-4Cr/Li system being developed as an advanced option in ITER for the structural/coolant-breeding system (including divertor); and 2) the advanced physics confinement (H = 4) and operating regimes (steady-state, g_{Troyon} = 4-5, κ = 2, δ = .45 and $\varepsilon\beta_p \equiv 1$) which will be explored by TPX.[1]

III. CALCULATIONAL MODEL

For reactors sized to achieve ignited operation, the minimum size was determined (iteratively) from the following constraints. The plasma radius was limited by $q_{95} \geq 2.8$ or by the peak heat flux (peaking factor 1.5) limit to the first wall calculated from thermal and fatigue stress limits in a tube-bank model (80% of the heat from the plasma was assumed to be incident on the first wall) with wall thickness set by coolant plus disruption pressure, whichever was most limiting. The structural thickness of the first wall was determined to withstand disruption forces. The blanket thickness was determined to achieve tritium breeding ≥ 1 and 95% nuclear heat removal. The vacuum vessel thickness was determined to withstand a 10 atm overpressure. The shield thickness was determine to limit peak nuclear heating (or neutron fluence) in the magnets to 1.1×10^3 W/cm^3 (or 1.9×10^{22} n/m^2). The central solenoid and toroidal field magnet thicknesses were determined to achieve primary stresses less than the ASME code quantity S_m, taking into account the reduction in load-carrying capability of the winding pack and the reduction of S_m to compensate crack growth. The bucking cylinder (support frame) thickness was determined to react the centering force from the toroidal field coils. The flux core radius was determined to induce and drive the plasma current for 10^4s, taking into account bootstrap current and 50% startup assist to overcome resistive losses. (The DEMO must be designed to accommodate about 10^4 'shakedown/fault' pulses, so a number of burn pulses on this order does not significantly further degrade fatigue/crack-growth related properties.) The major radius was determined by summing the constituent thicknesses and adding 10cm for gaps. The plasma current was then determined from the ITER89-P scaling law to yield an energy confinement time of 3.9s, which allows some small measure of confinement margin. Other relevant plasma parameters were Z_{eff} = 1.5 and n_{He}/n_e = 0.1. The various physics constraints and the materials properties are given in Refs.2 & 3 (Ref. 4 for V/Li), respectively.

For reactors sized to achieve steady-state operation, the plasma radius was increased to achieve high $\varepsilon\beta_p$ and high bootstrap current (limited to ≤ 80%) needed to obtain Q ≥ 20 with η = .45 (NBI). The noninductive current drive power was included in the power term in the ITER89-P scaling law and also reduced the required confinement time relative to the ignition value. Otherwise, the determination of size proceeded as described for ignition sizing.

IV. DEMO & COMMERCIAL REACTOR CHARACTERISTICS

The characteristics of reactors which would extrapolate from the "ITER data base" and from the supplemented "advanced data base", as defined above, are depicted in Figs. 1-8. Two cases are depicted for each data base: reactors sized for ignition and $\Delta t_{burn} = 10^4$s; and reactors sized for steady-state with Q ≥ 20. All cases are sized to achieve 20 years of operation at 40% plant factor, although the results are relatively insensitive to this specification.

The "ITER data base" extrapolates to rather large (R ≅ 8-10 m) tokamaks with rather large plasma currents (≅ 20-30 MA). The ignited devices would operate within the plasma regimes explored by ITER, but the steady-state devices would have to operate well above the values of q_{95} and $\varepsilon\beta_p$ (and somewhat above the values of g_{Troyon}) that will be explored in ITER. The ignited devices would operate at the limiting peak first wall heat flux for 316SS (≅ 0.5 MW/m^2), with a correspondingly modest average neutron wall load (≅ 1.5 MW/m^2), only at $P_{fus} \geq 3000$ MW. In order to achieve high $\varepsilon\beta_p$ and high bootstrap current to obtain steady-state operation with Q ≥ 20, the minor radius must be increased substantially above the heat-flux or q_{95} limited value. Thus, the "ITER data base" should suffice to support an ignited $SS/H_2O/Li_2O$ DEMO, but the TPX data base would also be needed to support a steady-state DEMO.

The "advanced data base" extrapolates to smaller (R ≅ 5-7 m) reactors with smaller plasma currents (≅ 10-20 MA). The plasma operating regimes of the ignited reactors could possibly be explored by ITER, but the steady-state reactors would have to operate with values of g_{Troyon} (≅4-5) and $\varepsilon\beta_p$ (≅.7-.8) well above those explored in ITER but within the range that will be explored in TPX, albeit not in DT. The greater heat flux capability of vanadium allows operation at neutron wall loads up to 3.0-3.5 MW/m^2 for $P_{fus} \geq 3000$ MW.

The characteristics of DEMOs based on either an advanced physics or an advanced materials data base alone were examined. The first wall heat flux limitation of stainless steel made it difficult to find design points with $\varepsilon\beta_p$ ≤ 1 except at low P_{fus}, thus preventing utilization of the advanced physics regimes to achieve a more attractive design with stainless steel. The q_{95} constraint on minor radius prevented taking advantage of the higher heat flux limit of vanadium to reduce the plasma size when ITER physics constraints were imposed.

REFERENCES

1. G. H. Neilson, et al., Mission and Design of the Tokamak Physics Experiment, these Proceedings.
2. ITER Physics, ITER Doc. Series 21, IAEA, Vienna, 1991.
3. ITER Material Data Base, ITER Doc. Series 29, IAEA, Vienna, 1991.
4. D. L. Smith, private communication, 1994.

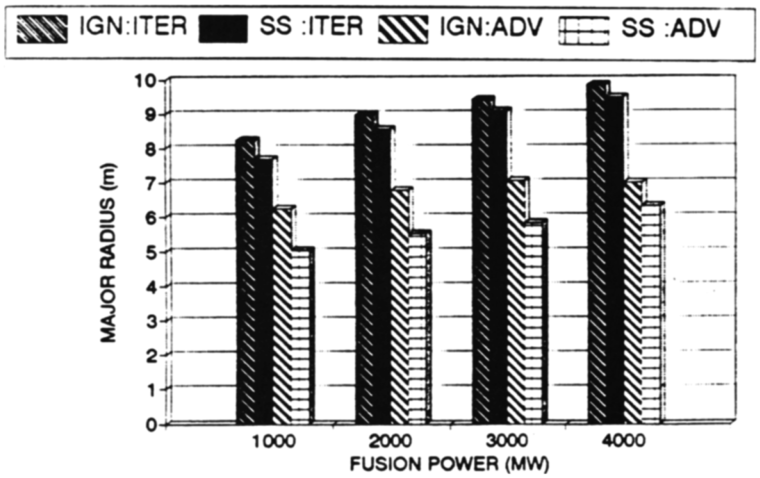

Fig. 1. Major Radius

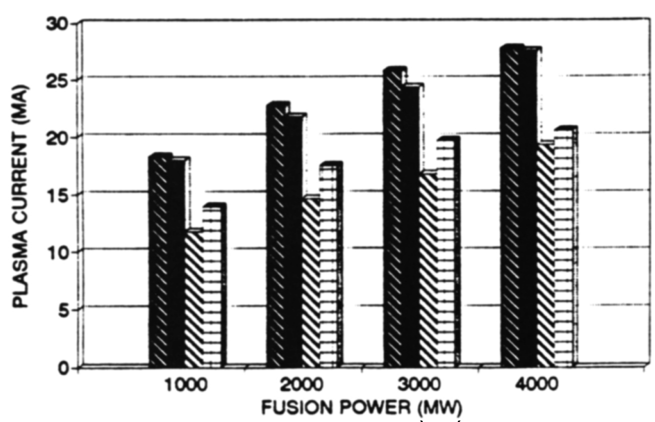

Fig. 2. Plasma Current

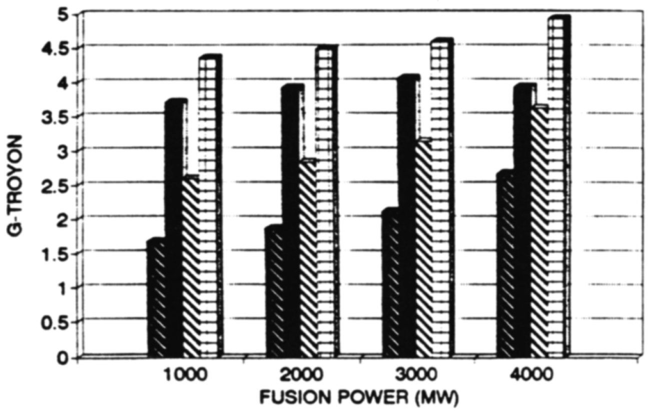

Fig. 3. Plasma Stability

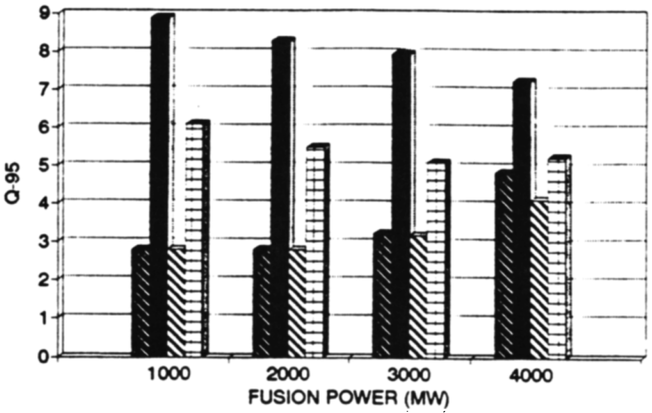

Fig. 4. Kink Mode Stability

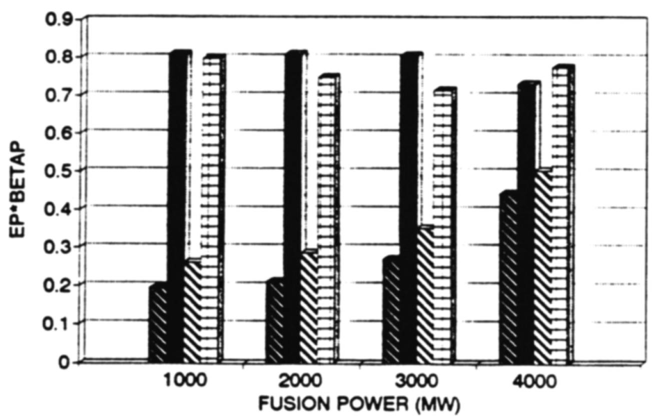

Fig. 5. Ballooning Stability

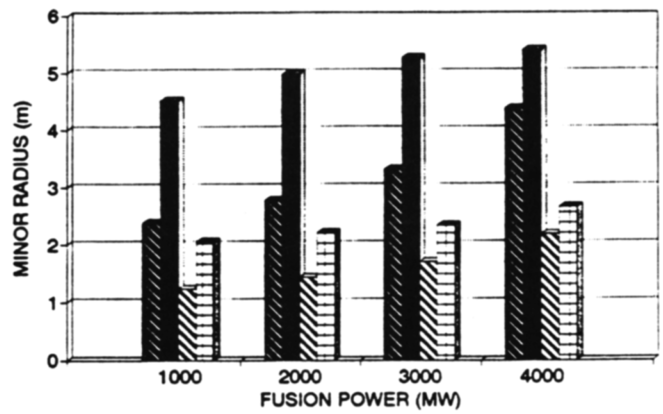

Fig. 6. Minor Radius

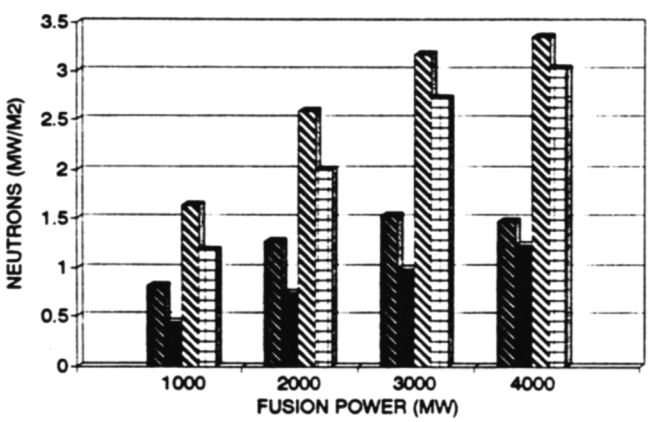

Fig. 7. Average Neutron Wall Load

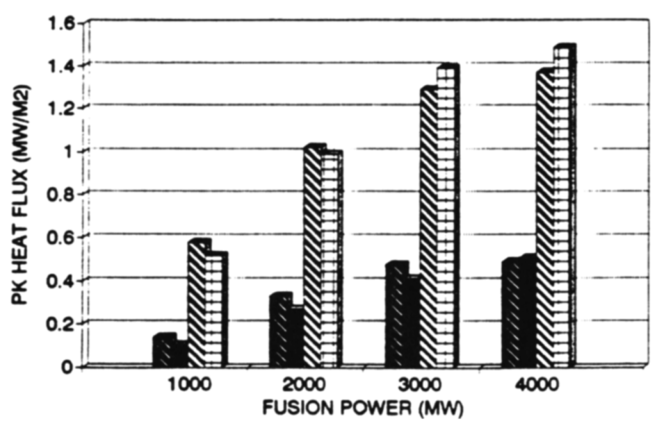

Fig. 8. Peak FW Heat Flux