CULHAM LABORATORY
LIBRARY
19 SEP 1972

CULHAM LIBRARY
REFERENCE ONLY

CLM-R 121

CLM-R 121

UKAEA RESEARCH GROUP

Report

A DESIGN CONCEPT FOR A FUSION REACTOR BLANKET AND MAGNET SHIELD STRUCTURE

J T D MITCHELL
M W GEORGE

CULHAM LABORATORY
Abingdon Berkshire
1972

Available from H. M. Stationery Office

C.18

PRICE 50p

© - UNITED KINGDOM ATOMIC ENERGY AUTHORITY - 1972
Enquiries about copyright and reproduction should be addressed to the Librarian, UKAEA, Culham Laboratory, Abingdon, Berkshire, England

CLM-R 121

A DESIGN CONCEPT FOR A FUSION REACTOR BLANKET AND MAGNET SHIELD STRUCTURE

by

J T D Mitchell*
M W George**

ABSTRACT

This report lists the special requirements of and outlines an engineering design concept for a fusion reactor using magnetic confinement of the plasma. It proposes that the magnet should be structurally independent of the primary blanket and magnet shield, though allowing access between coils of the windings for connections to the inner structures. The magnet shield incorporates the necessary mechanical structure to withstand vacuum forces and the mass loads of itself and the inner blanket. The blanket is a flexible arrangement of close nested modules or cells containing the primary attenuator, e.g. lithium. The advantages of the design are discussed and some problems for further work outlined.

---

*A.P. & T. Division, Culham Laboratory, Abingdon, Berks
**Research Reactors Division A.E.R.E. Harwell, Berks.

UKAEA Research Group
Culham Laboratory
Abingdon
Berks

June 1972

SBN: 85311 009 3

CONTENTS

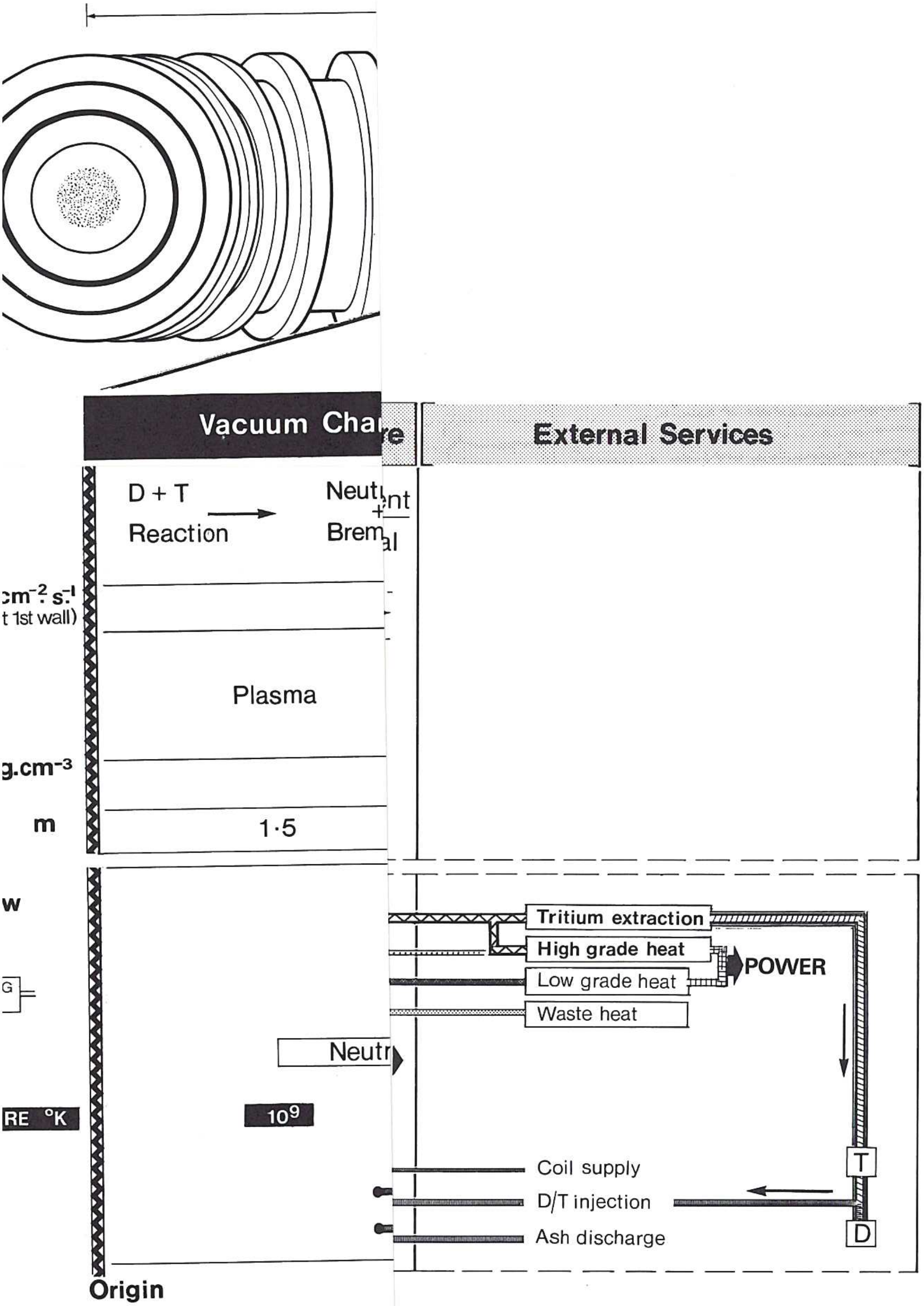

Vacuum Cha
re
External Services
D + T
Reaction
Neut
ent
+
Brem
al
cm^{-2} s^{-1}
t 1st wall)
Plasma
g.cm^{-3}
m
1·5
w
G
Tritium extraction
High grade heat
Low grade heat
Waste heat
POWER
Neutr
RE °K
10^{9}
T
Coil supply
D/T injection
Ash discharge
D
Origin

FIG.1 cture.

A DESIGN CONCEPT FOR A FUSION REACTOR BLANKET AND MAGNET SHIELD STRUCTURE

by

J T D Mitchell
M W George

INTRODUCTION

1. In recent years much thought has been given to the concept of a fusion power reactor(1-9). Simple models giving an impression of scale have been used for neutronics calculations, specification of functions and materials, and for economic studies(4,10,11) with allowances for fabrication costs. Calculations have also been made of tritium breeding and heating by the 14 MeV neutrons from the plasma. Such models are however inadequate for determining the engineering feasibility of fusion reactor structures and systems and so far rather less thought has been given to translating these ideas into conceptual engineering designs for the essential reactor components e.g. the blanket and magnet-shield structures(12-18).

2. The purpose of this report is to identify the essential features and requirements of a fusion reactor structure, and to present an outline design for further detailed study and development. The fusion reactor model used as the starting point is shown in Figure 1. It assumes a D-T fuelled, steady state toroidal system, aspect ratio, 6, rated at 10 MW m^{-2} of the first wall and total output of 10 GW(t). The D-T reaction parameter $(\sigma v)T^{-2}$ is greater at lower plasma temperatures than for any other fusion reaction and is a maximum with 50/50 D-T fuel for plasma temperatures around 20 keV. Thus in spite of the consequent necessity to breed tritium and therefore to have a lithium bearing blanket, a first generation fusion reactor is most likely to burn D-T fuel. However, the design is not specific to this model or wall loadings - and could be used with other plasma containment configurations, e.g. a deuterium fuelled mirror reactor with a sodium blanket. We are mainly concerned with the blanket and magnet-shield regions as will be seen later and for illustrative purposes we have assumed a simple toroidal magnetic field as produced by, say, 30 discrete magnet coils.

Basic Principles in the Design of a Fusion Power Reactor Structure

3. The essential requirements of a power-producing fusion reactor and their immediate consequences are easily stated but far-reaching. With the exception of the Blascon proposal for inertial confinement,(19) plasma containment can only be achieved under conditions of high vacuum and intense magnetic field. The latter can only be produced economically by a superconducting magnet, which must in turn be protected from radiation damage by neutrons from the fusion reaction.

e.g. $D + T \rightarrow (He^4 + 3.5\ \text{MeV}) + (n + 14.06\ \text{MeV})$.

The damaging effect of the neutrons on the copper or aluminium stabilizing component of the magnet conductor must be limited so that the conductivity can be maintained sufficiently high, and the need for replacement or frequent annealing of the stabilizing conductor is eliminated.

4. Conversion of the neutron and Bremsstrahlung energy produced by the D-T reaction into heat requires the plasma to be surrounded by a blanket of suitable absorbing material, and since tritium is scarce and must be produced for refuelling the system, the blanket must contain lithium, which is the only element from which a sufficient quantity of tritium can be produced by interaction with the neutrons.

5. Figure 1 summarises the basic engineering requirements for the blanket and magnet-shield of a fusion reactor. In considering a practical design some of these features are particularly important.

(i) Temperatures

The temperature of the lithium blanket must be at least 850 K for reasonable thermal efficiency of any heat engine to be driven from the absorbed energy. The temperature of the magnet-shield region should preferably not exceed 350 K and thus avoid boiling the water in it. The temperature of the magnet will be close to 4 K to maintain superconductivity in the windings.

Therefore the design will have to cater for a wide range of temperatures with attendant thermal expansion problems. Efficient thermal insulation will be required to conserve high temperature heat for power generation and to restrict heat input to the magnet because in removing heat from a region at 4 K the refrigeration efficiency is low.

(ii) Material densities

The average material density ranges from approximately 1 to as high as 6.4 g cm^{-3}.

(iii) Neutron flux

The neutron flux is attenuated by 10^{-2} in the blanket but the magnet shield must provide a further attentuation of 10^5.

(iv) Access for services

Coolant pipes and other services e.g. instrumentation, will be connected to the blanket and magnet-shield. There must be apertures in the magnet-shield and magnet to accommodate these services en-route to the external heat exchangers, controls, etc. Additional apertures will be required through the full depth of the plasma containment for fuel injectors and plasma diagnostic equipment.

(v) Magnet construction

For several practical reasons including ease of manufacture of the conductor, the magnet will consist of discrete axi-symmetric coils. This will allow access between the coils for services.

6. As a direct consequence of the need to restrict heat input to the cryogenic envelope of the magnet, physical contact between the magnet and the magnet-shield, sufficient to support the latter, will be impossible. All the magnetic forces and structure

will be contained within the cryogenic envelope with only the minimum of load bearing structure penetrating it to support the weight of the magnet system. Similarly the blanket and magnet-shield structure will be supported directly from the foundations between the separate magnet coils. Therefore the structural requirements of the blanket and magnet-shield should be considered separately from the magnet provided only that sufficient space is allowed for the magnet supports.

7. The economic studies of fusion reactor costs have forecast magnet costs many times the sum of the blanket and magnet-shield costs. Simple analysis shows the magnet costs to be proportional to surface area so that for a specific plasma confinement volume, reducing the blanket and shield thicknesses also reduces magnet costs. Therefore it must be a primary objective in the neutronic, thermal and structural design of the blanket and magnet-shield to achieve minimum overall thickness.

Blanket Design

8. The blanket has two functions, to thermalise, by collisions, the energy in the flux of neutrons leaving the plasma and to breed tritium for refuelling the reactor. Nuclear reactions producing tritium are:

$$Li^6 + n \rightarrow He^4 + T + 4.8\ \text{MeV}$$

$$Li^7 + n \rightarrow n' + He^4 + T$$

The first of these also accounts for a high proportion (70-80%) of the total energy deposition in the lithium. Another minor source of heat production is radiative capture. The heat must of course be transported away from the blanket for conversion to electrical energy and to limit the blanket temperature.

9. Typical breeding and heating rates are shown in Figure 2, and can be seen to vary with the magnitude and energy of the neutron flux. They are highest at the first wall or front of the blanket but the Li^6 breeding curve also shows an enhancement of the reaction rate near the graphite due to the thermal neutrons reflected from the latter. Radiation damage in the structure is similarly flux dependent. Therefore structure could with advantage be concentrated in the outer low flux regions. Also the dense material of the blanket - i.e. the graphite - is in the outer region and would require less structure for its support from the outer perimeter than from the wall near the plasma. In principle support for the blanket should therefore be derived from the outer perimeter of the system, i.e. near the magnet-shield.

10. The blanket assembly shown in Figure 3 assumes a cylindrical reactor structure around the axis of the plasma. Because of the severe radiation and thermal environment in the blanket region a cellular design is proposed, which provides for thermal expansion and radiation growth of individual cells in the spaces between them. These spaces must not however allow significant neutron leakage. The ideal shape of the lithium cell which satisfies all these conditions has yet to be established, it might for example have a hexagonal cross-section rather than the rectangular one shown in Figure 3; however no matter which cross-section is adopted the cells will be 'close-nested' and wedge-shaped to form an annular assembly.

11. To achieve maximum tritium breeding the cell structure should be designed to minimise parasitic neutron reactions. To satisfy this under the pressurised conditions of lithium circulation for cooling or tritium recovery requires the cell first wall (nose) to be so shaped e.g. hemispherical, that it will be stressed in simple tension, thus allowing the structural thickness to be a minimum. As mentioned earlier the structure can be concentrated in the low flux region, e.g. thickening the cell walls at the outer end of the lithium region but this may impair the efficiency of the graphite reflector behind it. In this event the cell structure could be extended behind the graphite, thus enclosing the reflector within the cell assembly behind a thin protective baffle. The greater thickness of the rear structural face of the cell would then be located behind the reflector. Individual cells could be anchored directly to the relatively massive and stable magnet-shield by supports which would also carry the weight of the graphite.

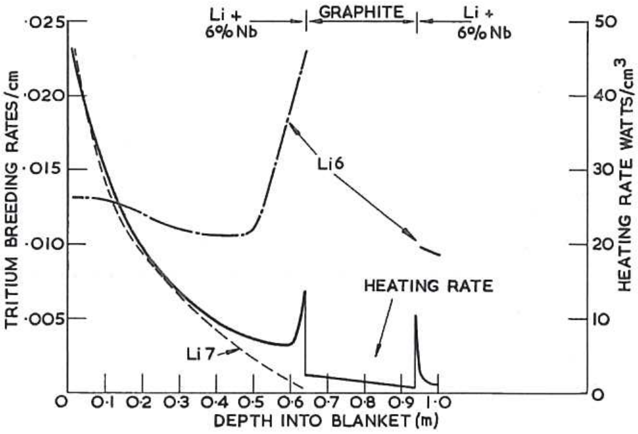


Fig. 2 Heating and tritium production rates in lithium for a typical blanket

12. Circulation of the lithium through the individual blanket cells requires the provision of both supply and return circuits. Thus penetrations will be required in the shielding for the lithium coolant circuits. In order to keep the number of these penetrations to a minimum and avoid complicating the shield structure it will be necessary to concentrate the circuits into a smaller number of pipes for their passage through the shield and magnet regions.

13. The supply pipe should extend into the cell and fan out near the cell nose to follow the nose profile, so that the relatively cold lithium can be distributed over the first wall for efficient cooling where the heating in lithium and structure is a maximum. As the lithium coolant flows back through the cell it will absorb more heat but with decreasing temperature difference with its surroundings because of the reduced heat generation rate (Figure 2). The maximum temperature of the coolant and probably also of the structure will occur at the point of coolant outlet from the blanket, on the side away from the plasma. While the temperature difference between the cell structure and the coolant may vary significantly through the cell, it may be possible to design for fairly constant temperature and low thermal stress in the structure.

14. Recent work using the blanket cell concept has shown that simple correlations exist between tritium breeding capability, coolant pumping power and the allowable access area for coolant pipes through the magnet region. These correlations are defined in Appendix I. An important advantage to be gained from their use is that the fractions of structure, lithium, graphite etc., in any given region can be correlated with other parameters e.g. tritium production (see also Lee(6)), power output and power lost in pumping coolant. Typically where s is the volumetric structure fraction in the lithium cell, P the fluid pressure and f the allowable stress in the pipe and cell walls then

$$P = \frac{f.s}{2}$$

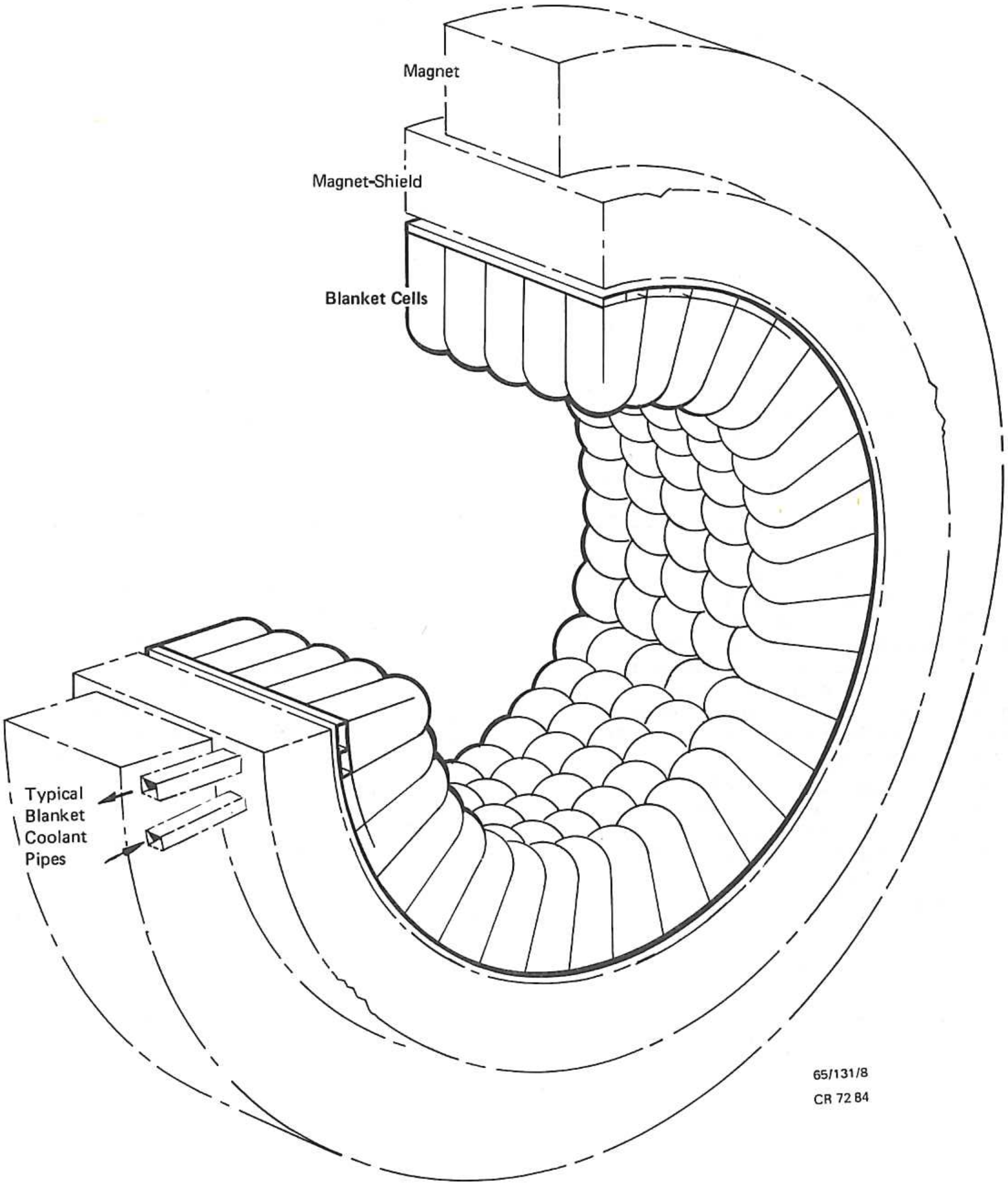


Fig. 3 Cellular blanket

Since the structure volume directly affects the tritium breeding, this is a correlation of breeding and heat removal capacity through the pumping power and thus the fluid pressure.

15. The discussion so far has been based on circulation of the lithium for heat transport, but the general concepts and construction are applicable to the use of a separate cooling fluid. In this case, the wall of the cell might be hollow, cold inlet coolant would be circulated inside the wall and then ducted through the bulk lithium to cool it. The lithium itself would however still have to be circulated, although very slowly, to recover the tritium being generated. The blanket wall structure fraction to contain the coolant would be derived from pressure and heat transfer considerations as with the pumped lithium, but the containment of the lithium itself might be thinner due to much reduced flow and therefore pumping pressure.

Magnet-Shield Design

16. We can now consider the magnet-shield functions and design in more detail. Figure 4 shows clearly that for practical values of tritium gain, the neutron flux leaving the blanket will be more than 1% of the incident flux from the plasma, though, owing to the moderating effect of the blanket the emergent neutron spectrum is the softer of the two. McCracken(20) has shown that the performance of a superconducting magnet will be seriously degraded by radiation damage for neutron doses exceeding 10^{17} n cm^{-2}. This is a more stringent constraint than the energy deposition (and consequent cryogenic refrigeration load). It is equivalent to a neutron flux of 1.7×10^{8} n cm^{-2} s^{-1} for 20 years. The emergent flux fron a 1 metre blanket(21) is 4×10^{13}n cm^{-2} s^{-1} and consequently the shield attenuation required is $> 10^{-5}$, necessitating a shield thickness $\sim$ 0.8 m to the composition given in Figure 1. About 1% of the energy leaving the plasma is deposited in the shield and this can be removed by circulating and cooling the liquid component.

17. The magnet-shield and blanket must be supported and within them there must be components with adequate strength to maintain the structural integrity. In our toroidal containment system and using the average densities given in Figure 1, a 1 metre thick blanket and 0.8 metre thick magnet-shield would weigh respectively 25 tonnes and 80 tonnes per metre length, in cylindrical form around a plasma region 4 metres diameter (see Figure 5). A strong structure is therefore essential.

18. Although the ideal blanket would consist only of lithium, there must be some structure to form the components of the blanket as a lithium container. A volumetric structure fraction of 6% is calculated to give adequate breeding after allowance for blanket displaced by injectors and other access requirements(6). This fraction,however, makes no allowance for stiffening, e.g. to take the vacuum load. By contrast the magnet-shield region, with a neutron flux below 10^{14} n cm^{-2}s^{-1} and thus low radiation damage, requires a high proportion of dense neutron-absorbing material, some of which can be used as structure.

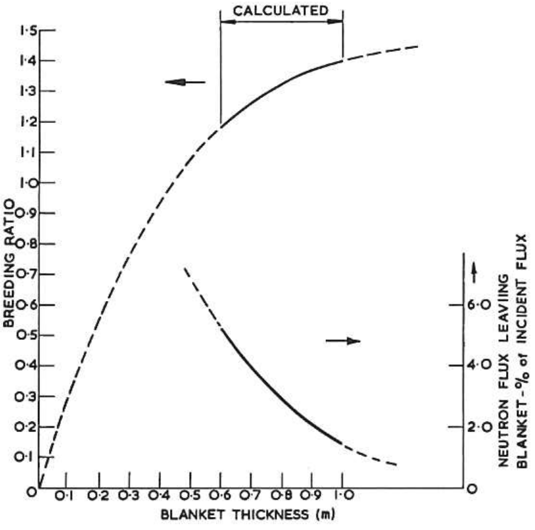


Fig. 4 Overall breeding ratio v. blanket thickness

19. The shield could therefore be composed of about 50% iron(21) but it must also be non-magnetic to avoid distorting the magnetic field within which it is situated. A suitable structure material containing enough iron to satisfy the shielding requirements would be a weldable non-magnetic stainless steel. At least one such steel, A.I.S.I. type 316, has been tested for use in fast breeder reactors and irradiation data is available. Since the shield is partly liquid (50% borated water) the structure is also preferably a closed vessel. Thus in cylindrical form it would suitably be an annular tank or tanks to contain the rest of the shielding materials.

20. The thickness of the magnet shield to give the required neutron attenuation is 0.8 metres. A concentric cylindrical structure roughly 8 metres diameter and 6 metres bore can be designed economically to support the combined mass loads of all the shielding and the internal blanket as well. It can be made of the familiar box construction analogous to a submarine hull and will have inherently high stiffness. Computerised methods of structural analysis are already available and we have adapted one(22) to this case and shown that metal thicknesses of $\sim$ 2 cm are all that is required in a structure similar to that shown in Figure 6, to carry the mass loads. The volumetric structure fraction is about 0.1.

21. Comparing this with the 0.5 volume fraction of iron specified from shielding calculations, it is obvious that there is a large surplus of structural capability in the shield region. This is available without any economic penalty because it can be achieved at constant shield thickness and with no increase in magnet costs. For example, structural capability is not a constraint against supporting the full plasma chamber vacuum from the shield structure (see para.25) similarly local reinforcement can be easily incorporated into the structure without increase in overall dimensions, e.g. for the attachment of supports (see Figure 6).

Temperature Effects and Thermal Insulation

22. In a practical reactor system the blanket region should operate at $\sim$ 900 K to achieve an overall thermal efficiency of about 45%. The magnet-shield on the other hand if it contains water, should operate below 373 K, to avoid boilding or the need for high pressure to suppress it. Direct attachment of the blanket to the shield without thermal insulation would thus give rise to an appreciable heat loss into the shield. Structural supports of low thermal conductivity and good thermal insulation are therefore required for a successful design.

23. Temperature changes and radiation damage both cause dimensional changes in metal structures which in turn generate high stresses. Thermal expansion or contraction due to temperature change is reversible but material growth due to neutron bombardment is irreversible. Radiation damage will occur mainly in the blanket region and growth allowances could be made in the attachment of supports and between the blanket cells. The effects of thermal expansion in the blanket and shield when the temperature is raised from ambient to the operating levels of 850 K and 350 K respectively, will of course depend on the arrangement of components and the properties of the materials from which they are made. For instance if the blanket structure is fabricated in a refractory metal and the support structure is stainless steel,

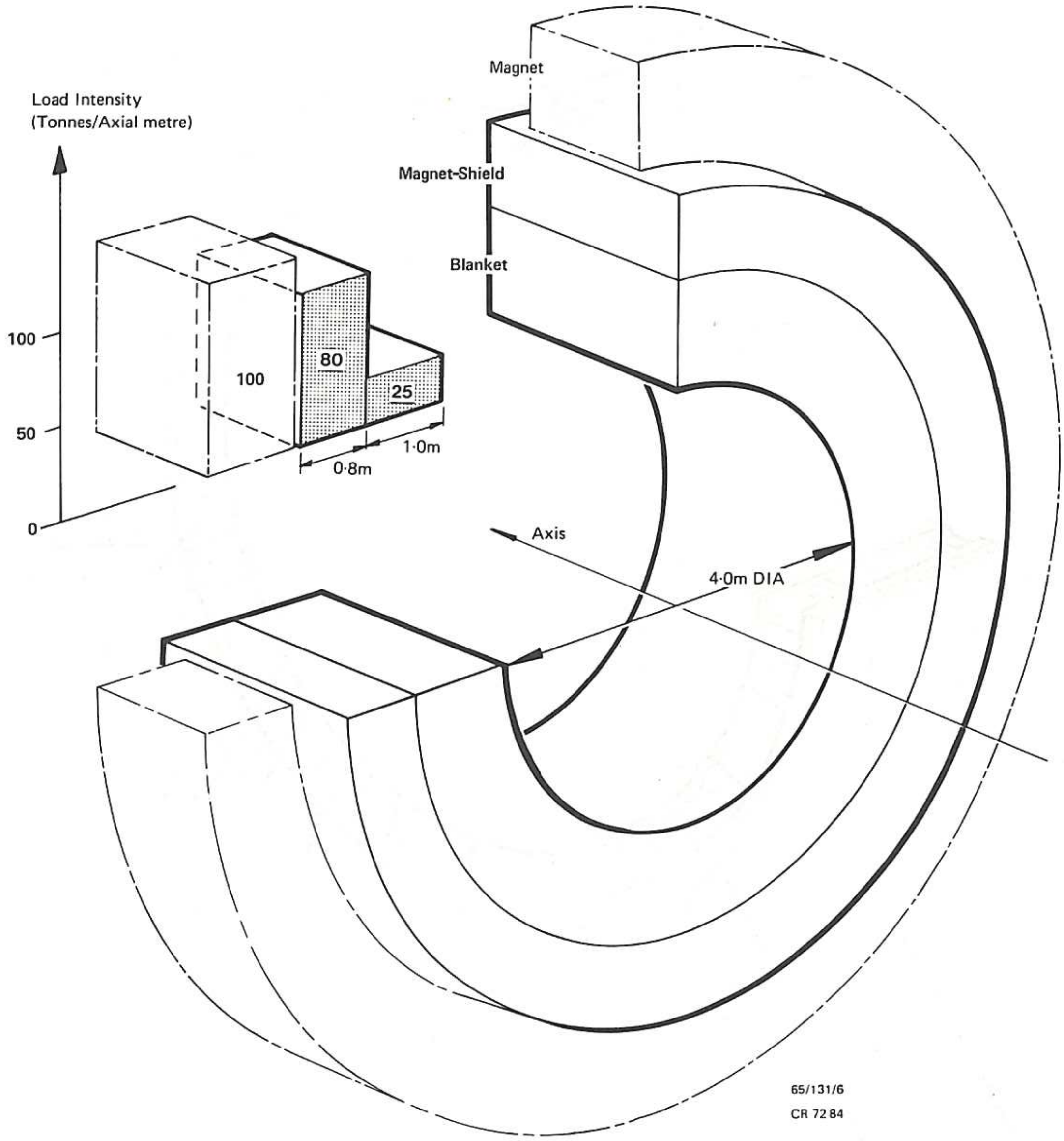


Fig. 5 Weight distribution

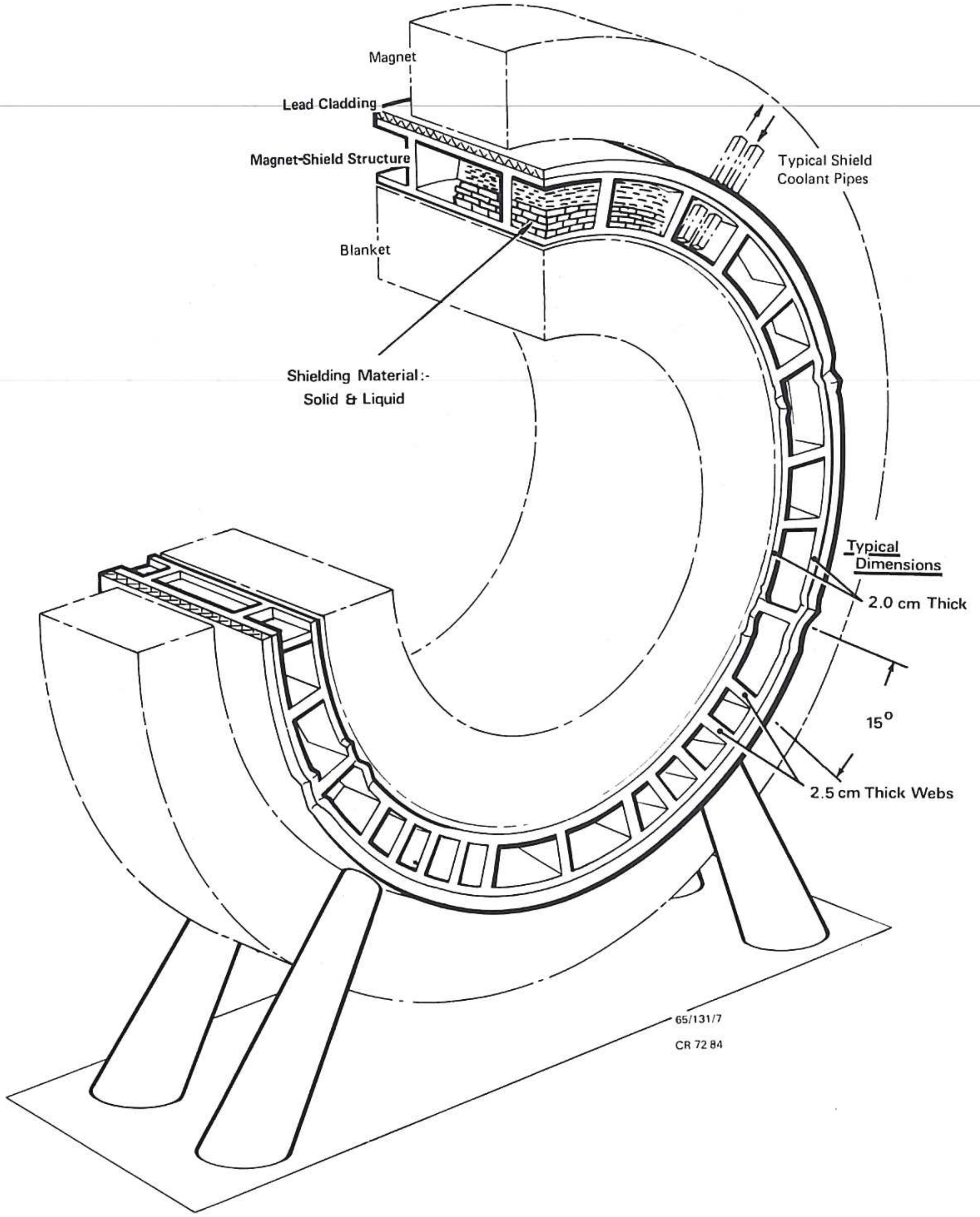


Fig. 6 Support structure

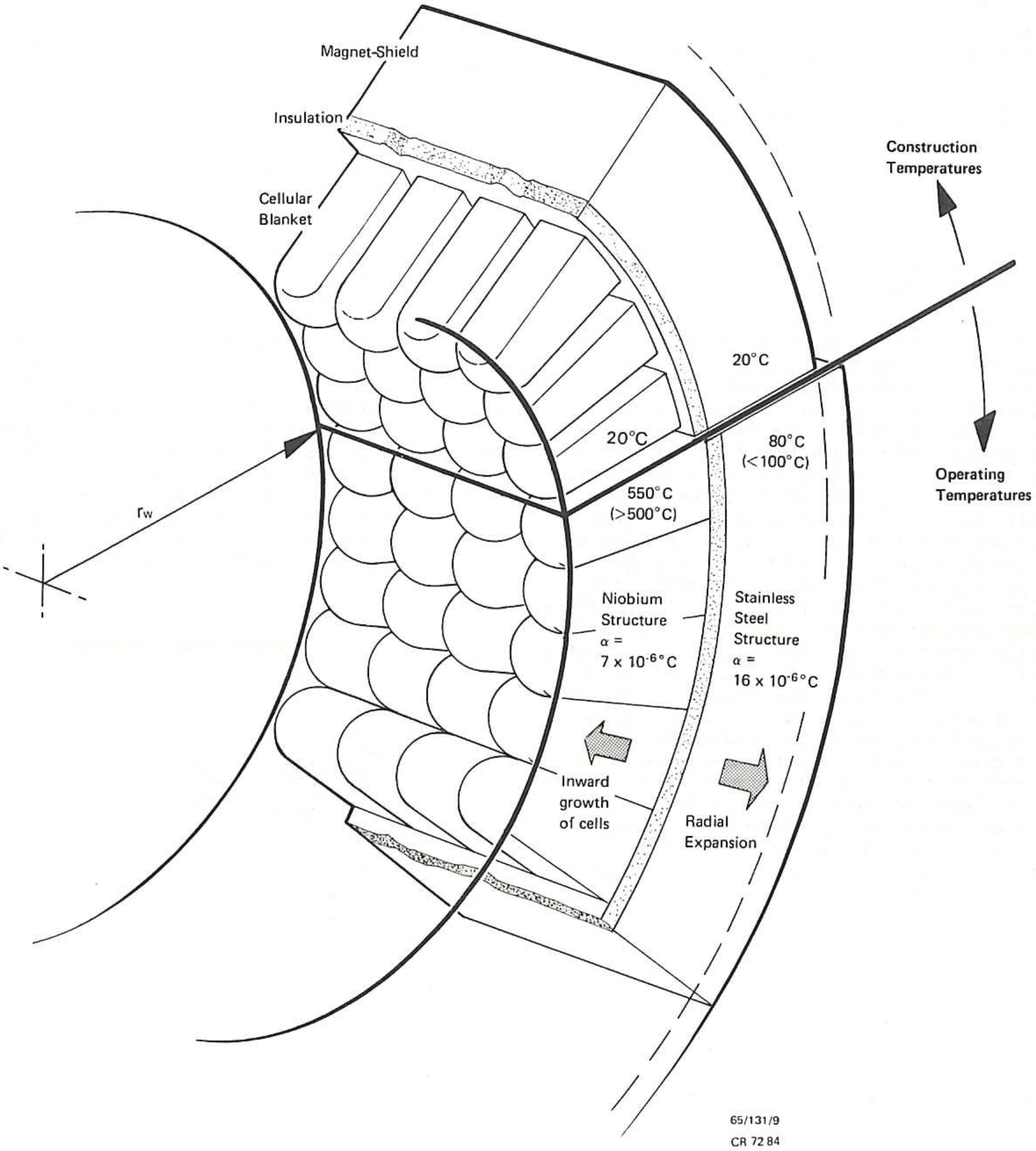
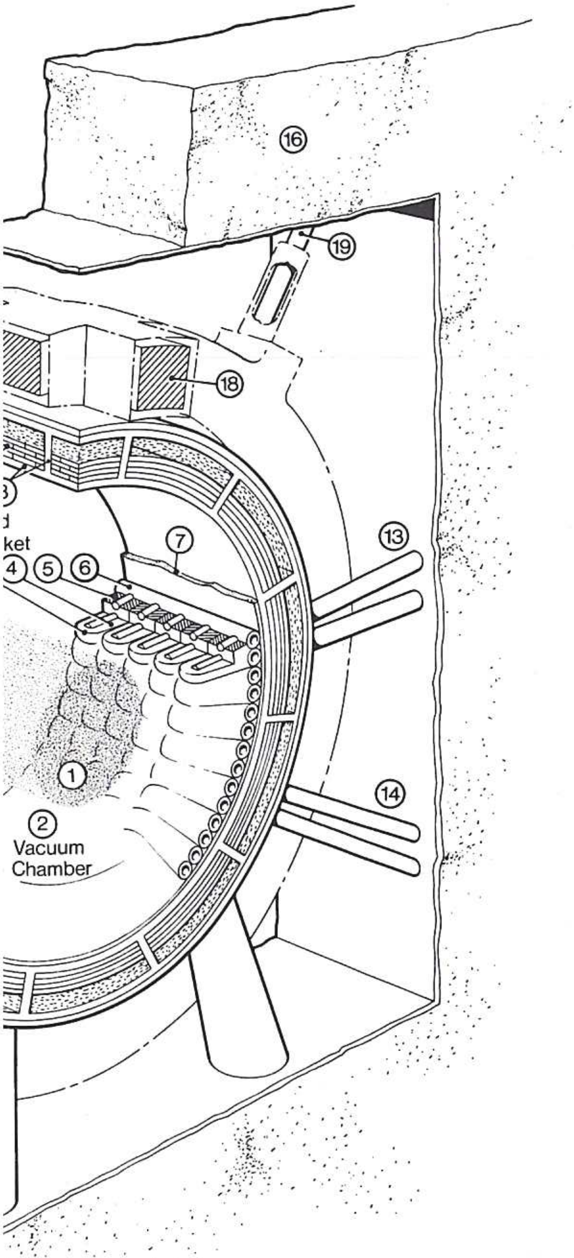


Fig. 7 Thermal expansion effects



ıtainment — general arrangement

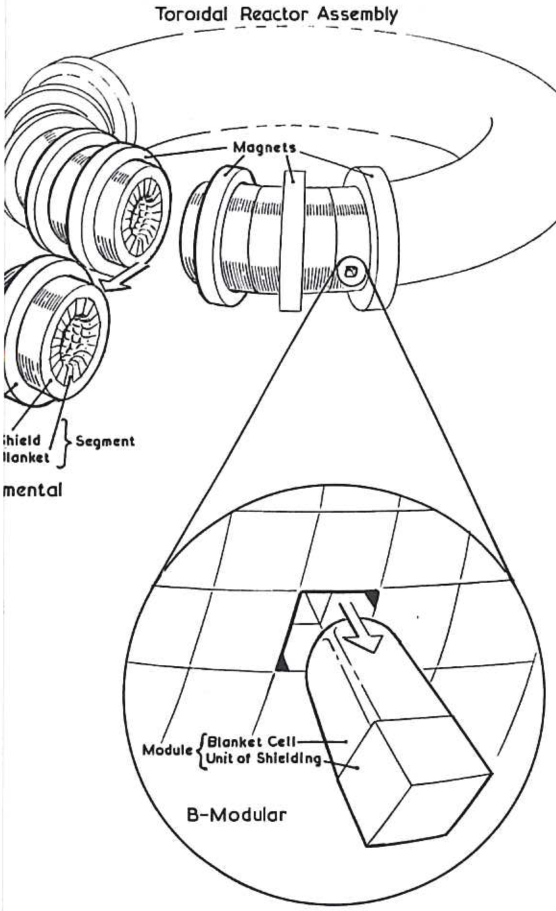
ties but in all cases access to the blanket
is a necessity.

may conveniently define three methods of
renewal.

) Total renewal - a complete reactor shut-
uld be required for replacement of the whole
structure after an interval of time based
edicted material life.

) Segmental renewal (see Fig.8) - a periodic
ment of segments of the blanket based on a
ed material life. By replacing segments in
e disturbance to the rest of the reactor could
small and the reactor shut-down times need
excessive. We have already suggested in para-
that the magnets should be supported separately
e blanket and magnet-shield structure. This
ral concept can be extended to a segmented
. Each segment, associated with one or more
, would be self-contained and removable to
ccess to the blanket region within it.

) Modular renewal (see Fig.8) - a continuous
ment as required by reason of radiation damage
ure in service, of small sections of the blan-
obably individual cells. This process is of
ee the most comparable to fission reactor fuel
changing. It is worth investigating whether
thod might be developed for on-load renewal
ost to require only a brief shut-down of
ctor. It has the advantage that of the three
, it is the only one that might be carried
hout significant disturbance to the reactor
ng conditions of vacuum and temperature. Re-
shment of the normal operating conditions of
wo parameters could well be the most **time**
ng element of a reactor shut-down.



g. 8 Methods of blanket structure renewal currents which would otherwise inhibit the penetration of pulsed magnetic fields into the plasma chamber.

Conclusion

35. Having established the general feasibility of the structural concept and indicated its potential for use in a practical fusion reactor there remain many unsolved problems on which further work is required, e.g.

(i) Detailed shielding between and outside the magnet coils.
(ii) Shield joints and possibilities of segmenting the blanket shield structure, or development of the modular demountable cell.
(iii) Thermal insulation techniques and structures especially for the blanket shield region.
(iv) Extended and detailed study of the limitations of and comparisons between blanket cooling systems, e.g. pumped lithium, helium etc.

Acknowledgements

36. The authors gratefully acknowledge the assistance they have received in preparing this report from colleagues at Culham and Harwell including the Culham Fusion Technology Study Group and the value of discussions with workers from other laboratories.

References

1. IMPINK, A.J. Nuetron economy in fusion reactor blanket assemblies. M.I.T. TR 434, 1965.

2. HOMEYER, W.G. Thermal and chemical aspects of the thermonuclear blanket problem. M.I.T. TR 435, 1965.

3. MILLS, R.G. Some engineering problems of thermonuclear reactors. Nuclear Fusion, vol.7,1967, p.223.

4. STEINER, D. Neutronics calculations and cost estimates for fusion-reactor blanket assemblies. ORNL-TM 2360, 1968.

5. ROSE, D.J. Engineering feasibility of controlled fusion. Nuclear Fusion, vol.9, 1969, p.183.

6. LEE, D. Tritium breeding and energy generation in liquid lithium blankets. BNES Nuclear Fusion Reactors Conf., 1969, British Nuclear Energy Society, paper 5.3. Proceedings, p.471.

7. BLOW, et al. Neutronics calculations for blanket assemblies of a fusion reactor. BNES Conf. 1969, paper 5.5. Proceedings, p.492.

8. BLOW, S. Transmutation activity and after-heat in a fusion-reactor blanket. AERE-R 6581, 1971.

9. ROSE, D.J. Controlled nuclear fusion: status and outlook. Science, vol.172, 21 May 1971, p.797.

10. CARRUTHERS, R. et al. The economic generation of power from thermonuclear fusion. CLM-R 85, 1967.

11. SEARBY, P.J. and BROOKES, L.G. The economic factors affecting research into fusion power. BNES Conf., 1969, invited paper. Proceedings, p.20.

12. FRAAS, A.P. Conceptual design of a fusion power plant to meet the total energy requirements of an urban complex. BNES Conf. 1969, invited paper. Proceedings, p.1.

13. HOPKINS, G.R. and MELESE-d'HOSPITAL, G. Direct helium cooling cycle for a fusion reactor. BNES Conf. 1969, paper 6.1. Proceedings, p.522.

14. WERNER, R.W. Module approach to blanket design. BNES Conf. 1969, paper 6.2, Proceedings, p.536.

15 MOHR, P.B. Fusion reactor power conversion studies. BNES Conf. 1969, paper 6.3 Proceedings, p.558.

16. POST, R.F. Fusion power: direct conversion and the reduction of waste heat. TID-25414, 1970.

17. FRAAS, A.P. Comparison of two tritium removal systems (for thermonuclear power plants. ORNL-TM-2932, 1970.

18. POSTMA, H. Engineering and environmental aspects of fusion power reactors. Nuclear News, April 1971.

19. LUBIN, M.J. and FRAAS, A.P. Fusion by laser. Scientific American, vol.224, June 1971, p.21.

20. McCRACKEN, and BLOW, S. The shielding of superconducting magnets in fusion reactors. Culham Report, CLM-R 120, 1972.

21. BLOW, S. Private Communication.

22. Naval Construction Research Establishment, Dunfermline, Scotland. PEGASUS computer specifications, plane frame analysis. NCRE/R.484, 1963. (and later revisions).

23. British Patent Specification, 1,243,338.

24. LUBELL, M.S. et al. Engineering design studies on the superconducting magnet system of a Tokamak fusion reactor. IAEA Conference, Madison, Wisconsin, 1971, Paper CN-28/K-10. Proceedings, vol.III, p.433.

25. FRAAS, A.P., POSTMA, H.P. Preliminary appraisal of the hazards problems of a D-T reactor power plant. ORNL-TM-2822, revised, May 1970.

APPENDIX I

CORRELATIONS FOR USE IN BLANKET DESIGN

37. A conceptual reactor design must relate the requirements of engineering and nucleonics so that they become mutual constraints. Estimates of nucleonic performance based on an ideal system of continuous blanket and reflector regions must be modified if they are to be made realistic, either by introducing estimated amounts for structure and voidage into the calculations or by establishing correlations between them and the nucleonic performance parameters, e.g. tritium breeding. This appendix presents some useful correlations which can be used in this way.

38. The blanket structure is assumed to be a cylindrical system with its axis perpendicular to the paper, through the origin O (see Fig.10). The inner end or first wall of each cell in the assembly is at r_W from the origin. The length or thickness of the lithium filled cell region is ℓ_1, with the graphite reflector ℓ_2 and the magnet shield ℓ_3 radially beyond. As has been mentioned the individual cells might be of hexagonal cross section: for the purpose of simplifying the stress analysis and since $r_W > \ell_1$ these can be represented by cylinders of diameter d_1 and wall thickness t_1. The lithium feed pipes have diameter d_2 and wall thickness t_2.

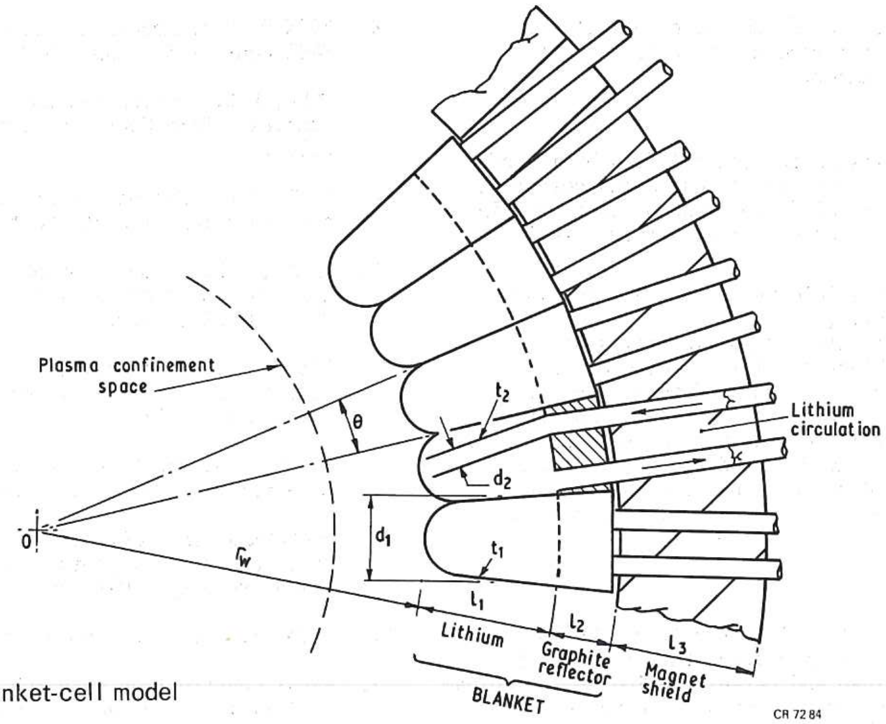


Fig. 10 Blanket-cell model

39. Correlation of Breeding and Pumping Power

Let the design pressure for the lithium circulating system be P. Now to cater for the possibility of a blockage, the whole system must be capable of withstanding this pressure. Therefore the allowable hoop stress (f) will be the same in both the body of the cell and the feed pipes. Therefore

$$f_1 = f_2 = f$$

and
$$f = \frac{Pd_1}{2t_1} = \frac{Pd_2}{2t_2} \qquad (1)$$

Assuming a cylindrical cell and neglecting the cell ends - the volumetric fraction of the structure in the cell is given by

$$s = \frac{\pi d_1 t_1 + \pi d_2 t_2}{\frac{\pi}{4} d_1^2}$$

Now
$$d_1 t_1 \gg d_2 t_2 \quad \text{and} \qquad (2)$$

therefore
$$s \simeq \frac{4t_1}{d_1}$$

Combining (1) and (2)

$$f = \frac{2P}{s} \quad \text{or} \quad P = \frac{f.s}{2} \qquad (3)$$

Thus we have a simple correlation between tritium breeding gain on the one hand and on the other, pumping pressure, and ultimately pumping power and the ability to remove heat from the blanket.

40. Definition of the Access Fraction ψ

In our present concept of the plasma containment the fluid pipes serving the blanket and magnet-shield, penetrate the latter region between the separate magnet coils. The total access area for pipework is therefore limited to the area left between the magnet coils, less the area required for shield supports, injectors etc.

If the total external area of the magnet-shield is A_T and the access area between the magnet coils is A then the total access fraction

$$\psi = \frac{A}{A_T}$$

If we further define the cross section area of lithium pipes entering the magnet shield radially through its outer surface as A_L we have an access fraction for lithium pipes only of

$$\psi_L = \frac{A_L}{A_T}$$

As reactor designs are developed the limitation ψ_L will become more apparent, but present estimates suggest that it can hardly exceed 0.2 and may have to be no greater than 0.1.

41. Use of the Access and Materials Fractions

With values of ℓ_1, ℓ_2 and ℓ_3 and r_w initially defined by reactor size and blanket breeding calculations based on models such as Fig.1, it is possible to make more refined calculations using the structure and materials fractions which can be specified geometrically throughout the blanket.

For example, assuming a cylindrical blanket, the volume fraction (V) of lithium in, say, the graphite reflector can be defined as follows:

$$V = \frac{\text{total area required for lithium supply and return pipes to the blanket}}{\text{cylindrical surface area of the reflector region at its mean radius}}$$

For an incompressible fluid, e.g. lithium, and assuming constant velocity flow, the flow area will be constant throughout the system of supply and return pipes. This is an adequate approximation for conceptual design even though a practical system may deviate from it.

Thus the area of radial lithium pipe work at all points through the reflector and magnet-shield will be A_L.

Therefore the fractional area will vary inversely with radius from the origin O of the system.

Thus if r_o is the radius of the magnet-shield outer surface

(where $r_o = r_w + \ell_1 + \ell_2 + \ell_3$)

and if r_m is the mean radius of the reflector

(where $r_m = r_w + \ell_1 + \frac{1}{2}\ell_2$)

then
$$V = \frac{A_L}{\dfrac{A_T r_m}{r_o}} \equiv \psi_L \frac{r_o}{r_m}$$

This relationship applies also with reasonable accuracy to a toroidal system with an aspect ratio not less than 5.

ψ and s form an essential link between the engineering and nucleonic requirements of a reactor and provide the means of determining an optimum relationship between the two.

HER MAJESTY'S STATIONERY OFFICE
Government Bookshops

49 High Holborn, London WC1V 6HB
13a Castle Street, Edinburgh EH2 3AR
109 St Mary Street, Cardiff CF1 1JW
Brazennose Street, Manchester M60 8AS
50 Fairfax Street, Bristol BS1 3DE
258 Broad Street, Birmingham B1 2HE
80 Chichester Street, Belfast BT1 4JY

Government publications are also available
through booksellers