In this introduction we give examples from the present literature on
the requirements on solid breeder materials arising from the design of the
blanket system, and even more generally from the concept of the reactor.

Our aim is not to limit the discussion to the internal behaviour of
the blanket, with respect to necessary values of the Tritium breeding ratio
(T.B.R.), for instance, or in connexion with given properties or character­
istics of the solid.

However it will not be possible to build a table of blanket system designs
versus precise solid breeders requirements because such relations have
seldom been worked out quantitatively in the original papers.

STATUS

The most extensive review is probably the 1979 Fusion Reactor blanket
shield design study made at Argonne followed by the Argonne Starfire
Project (1980). Since then most notable is the international Intor Projects
has led to three propositions in Phase I (American - Japanese - European)

However other designs are described at almost every meeting on fusion
technologie.
1° Heat and Tritium must be extracted from the blanket. In most concepts use is made for those two purposes of separate circuits in which two fluids—may be, but not necessarily—of the same nature—circulate at different temperatures, pressures and flow rates.

2° However studies have been published differing from this general scheme by the following:

2-1 : Extraction of Tritium by the main Helium flow (described by Dr A. BOND at the Erice workshop on fusion blanket technology, June 6-10 1983)

2-2 : Using a breeding ball concept (consisting of a mixture of Li-ceramic breeder spheres with lead spheres) presented by the Kernforschungszentrum Karlsruhe at the same workshop. This decouples Tritium extraction from Tritium production.

2-3 : The use of a fluidized bed design. This has been proposed—in the context of solid blankets—by a Westinghouse Electric Corporation Group.

Obviously the general concept and the three proposals quoted imply different requirements on the mechanical properties initial and under irradiation, chemical stability, compatibility, temperatures of extraction of Tritium, and each leads to its own specifications.

For instance extracting simultaneously heat and Tritium requires that the lower limit of the “temperature window” is below the operating temperature of the fluid. If pellets are used and T₂ is to be efficiently extracted outside the reactor it has to be above, or else a suitable cladding should be provided.

A concerted effort from neutronic and mechanical engineers to outline specification such as Lithium 6 and Lithium 7 content, hardness, Young’s and Poisson’s modulus, Brittleness, Shock resistance is necessary to provide the data necessary to develop a suitable breeding material.

3° Even requirements of more conventional solutions, as in 1° differ greatly if the solid breeder can be replaced with a frequency comparable to that of a fuel element in a fission reactor (3 years) or must stay in place over the whole lifetime of the machine (20 years ?)
II - CHOICE OF COOLANT

Temperature windows and safety problems

Next to the choice of a physical form and of an in reactor residence time, that of the coolant is capital. The temperature window of the breeder has to be compatible with the coolant.

In the case of water the maximum temperature of the fluid is about 320°C. It may be necessary to insulate the blanket on the cooling side to raise its temperature to the required value for tritium extraction. This makes the difference in temperature dependant on the integrity of the thermal barrier.

In the case of Helium there is a large difference between entrance and exit flows. The temperature window of the blanket must consequently be wide enough, depending on the arrangement of the circulation of this gas.

Other proposed coolants are: Molten salts now in disfavor. Liquid Lithium is in a similar position. Gases like CO₂, such liquids as organic coolants proved, or tried, in fission reactors are not considered today in the fusion context.

Water, as coolant raises safety problems. It reacts with Li⁺ Pb₂⁻, Li₂O inter alia. The problem exists of whether blankets should even be considered, where water and reactive breeding materials, i.e. rapidly tritiated when in use, can come in contact, in case of a pipe rupture. One has to consider tubing not only from the cooling system of the blanket itself but of limiters, multipliers etc., as well.

III - STRUCTURAL MATERIALS - NEUTRON MULTIPLIERS

They may raise compatibility problems that can vary in acuteness during the life of the blanket either because of evolution in chemical stoichiometry or in the nature of the tritiated species produced.

Also capture of neutrons by those materials produces excess energy but limits the T.B.R. One defines a multiplying factor $M$. An optimum chemical isotopic composition of a blanket may have to be found to balance both effects. Neutron multipliers may be in a separate region of the machine or dispersed or even in solid solution in the breeder.

(N) along with the intensity of the thermal flux
(NN) respective to the energy evolved
IV - MECHANICAL AND THERMAL REQUIREMENTS

Breeder materials must obey strict specifications: limited dimensional changes under irradiation, ability to resist mechanical and thermal shocks induced by breakdowns of the magnetic field etc...

V - INFLUENCE OF SYSTEM PARAMETERS ON TRITIUM BREEDING RATIOS (T.B.R.)

Identifiable parameters whose choice affects the selection of breeder materials because they affect T.B.R. are:

1° Structural material thickness - (reflecting cooling fluid pressure)
Capture of neutrons by structures lowers T.B.R.

2° Maximum dimensions of magnets
They may limit the volume available to the blanket and indirectly the choice of materials.

3° Geometrical factors
Let $g$ be the effective fraction of the plasma neutrons entering a blanket. T.B.R. is proportional to $g$. It may be affected by the following characteristics of the system.

In a torus access for maintenance may forbid to put in an inboard blanket aperture or holes for pumping pipes, etc... introduce losses of neutrons lowering $g$. The effect may be much larger than accounted for by pure geometrical considerations, as neutrons losses due to diffusion mechanisms, specially by heavy nuclei, may amount to several times those due to a straight escape of the particles.

4° Limiters
The introduction of limiters -others design parameters- remaining identical, is accompanied by a decrease in T.B.R. that can be of several %.

5° Tritium handling system inventory and Tritium losses
Tritium hold-ups are a very important factor affecting the minimum T.B.R. required from a blanket. One must consider both Tritium inventory in the blanket (favouring the materials with a low $T$ solubility) and hold-ups of all external circuits in which it is processed before and after combustion. Large Tritium quantities stored in apparatus and equipment such as distillation columns and also large losses (for instance by dissolution in, and diffusion through, structural materials) would have to be compensated by achieving impossibly large T.B.R.
6° Last in this list, but not least, the burn up ratio in the machine that controls the amount of Tritium handled in the plasma exhaust processing unit.

Remark

I- The role of \( g \) and various parameters may be qualitatively described by an equation given in annex. This equation helps demonstrate, on an example, how optimum system parameters and even safety considerations may be modified by changing the composition and structure of the blanket. When investigating Li - Al alloys it is found that the reported temperature window may not be large, or well centered, enough to enable the use of Helium as coolant.

Water is reactive with alloys that are not in the phase, stable only at very low Li content. T.B.R. greater than one can only be achieved by the use of a multiplier.

Lead, contemplated first for the necessary multiplier, absorbs energy and makes Pf very small. Therefore one can try to improve safety by removing \( ^7 \text{Li} \), i.e., using pure \( ^6 \text{Li} \), and hope that Pth will remain constant. It is not so. The thickness of the blanket, necessary to keep T.B.R. 1, is found to increase inacceptably, because \( ^7 \text{Li} \) has also a slowing down function. To restore a high Ps and reasonable dimensions, introduction of graphite as moderator is then tried successfully. Finally turning from lead to Beryllium as multiplier, in a given geometry, improves m and Pm.

Thus a number of poor characteristics of LiAl alloys with regard to systems requirement could be alleviated (X).

II- Generalises remark :

A blanket might consist of several regions differing in nature, Li content or \( ^6 \text{Li} \) enrichment etc...

III- Tritium extraction circuit introduces also constraints on the blanket.

(X) Mr GERVAISE is responsible for many suggestions in the solution of this problem and for carrying out the detailed calculations of T.B.R.'s.
Goals

The assignment to the group is:

a) Prioritize importance of design issues and associated properties.

b) Identify mechanisms for systematic comparison and reassessment of solid breeder design requirements and associated properties in the future.

c) Rank the individual mechanisms for feasibility and productivity.

A - It is not easy to prioritize the importance of design issues because, as the preceding paragraph shows, a breeder material may be modified to some extend to compensate short comings in the blanket performance.

However we suggest that:

a) safety (interaction of breeder and coolants, or structural materials), and

b) Tritium losses, (due to permeation through structural materials, and Tritium inventories) are always of prime importance to the definition of systems, and that:

c) Other parameters be chosen so as to be compatible with a range of breeder materials characteristics. This is because requirements of exact values may prove either impossible to meet in preparation, or be achieved only by materials at the beginning of their lives.

B - Comparison of breeder design requirements can be made by tabulating the values of the parameters that have been considered here in a systematic fashion, i.e. : working temperatures, temperature windows required of the material, Tritium inventories, and resulting necessary T.B.R. values, volumes available to the blanket, expected multiplying factors, $\beta$ values, etc...
The number of constraints listed shows that it is probably prudent not to design Fusion Reactors making use of solid breeder materials under conditions where they would be subjected to stresses, or physicochemical conditions close to limits of tolerance.

It should, on the contrary, be aimed at that in the first operational units conditions be as mild as practicable.
A ROUGH GUIDE TO PREDICT THE INFLUENCE OF BLANKET COMPOSITION AND GEOMETRY ON TRITIUM BREEDING RATIOS:

\[ T.B.R. = g \left[ P_F + \left[ 1 + (M - 1) P_M \right] P_s P_{th} \right] \]

**T.B.R.** = TRITIUM BREEDING RATIO.

\( g \) = GEOMETRICAL FACTOR, i.e. PROBABILITY THAT A NEUTRON IS CAPTURED IN THE BLANKET.

\( P_F \) = PROBABILITY THAT A NEUTRON REACTS ACCORDING TO

\[ ^7_{\text{Li}} + N \rightarrow ^4_{\text{He}} + T + N' \quad Q = -2.5 \text{ MeV.} \]

\( P_M \) = PROBABILITY THAT A NEUTRON IS CAPTURED BY A MULTIPLIER.

\( M \) = MULTIPLICATION FACTOR OF THE MULTIPLIER.

\( P_s \) = PROBABILITY OF NEUTRONS BEING SLOWED DOWN WITHOUT BEING CAPTURED BY STRUCTURAL MATERIALS (DEPENDS ON THE ENERGY OF NEUTRONS).

\( P_{th} \) = PROBABILITY FOR A THERMALISED NEUTRON TO INDUCE REACTION

\[ ^6_{\text{Li}} + N \rightarrow ^4_{\text{He}} + T \quad Q = +4.8 \text{ MeV}. \]
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