Perturbation Theory for Neutron and Photon Transport Calculations in Controlled Fusion Blankets and Shields

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PERTURBATION THEORY FOR NEUTRON AND PHOTON TRANSPORT CALCULATIONS IN CONTROLLED FUSION BLANKETS AND SHIELDS

Until about four years ago, research in the area of controlled thermonuclear fusion was concentrated almost entirely on plasma physics problems. Whereas these efforts have not diminished (nor should they be), there has recently been a reasonable expansion in efforts to uncover and examine the technological problems associated with other areas of a controlled thermonuclear reactor (CTR). This paper will deal with the study of CTR blankets and shields and, in particular, will consider the use of perturbation theory and variational methods in this field. An overview of the total system, as it has evolved in some recent studies[1,2], will be included so that the blanket and shield problems may be seen in their appropriate context.

It is most likely that the first CTR power system will be fueled with deuterium and tritium. In a D-T fusion reaction, 17.6 MeV of energy is released in the form of a 14.1MeV neutron and a 3.5 MeV alpha particle. In a system utilizing magnetic confinement, the alpha particle will be trapped by the magnetic field but the neutrons will freely escape the plasma zone. These neutrons must therefore be slowed down in a region, now called the blanket region, which surrounds the plasma. Figure 1a is a schematic drawing which indicates the main segments of a CTR reactor of the magnetic confinement type. Typically, the blanket and shield thickness is between 1.5 and 2.5 meters.

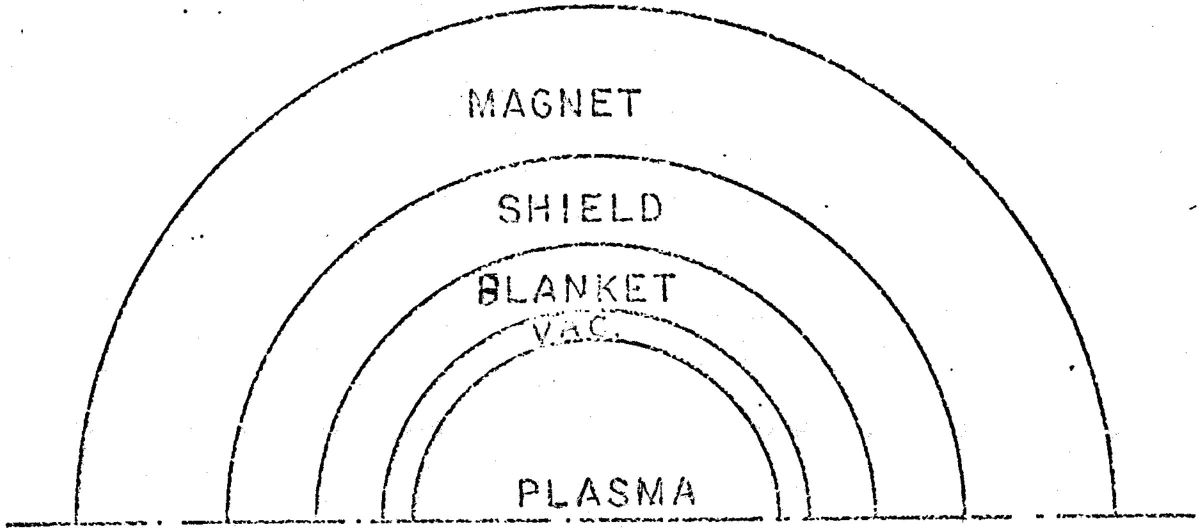
The blanket region must be designed to fulfill two primary functions: (1) to breed tritium and (2) to take up the energy deposited by neutrons and by gammas from neutron-induced reactions.

The shield behind the blanket zone protects the magnets from excessive radiation damage and heat deposition. In CTR systems based on the Tokamak or Mirror concepts, these coils will be superconducting. Typically, a flux attenuation through the blanket and shield zone of at least 10^{-6} is required.

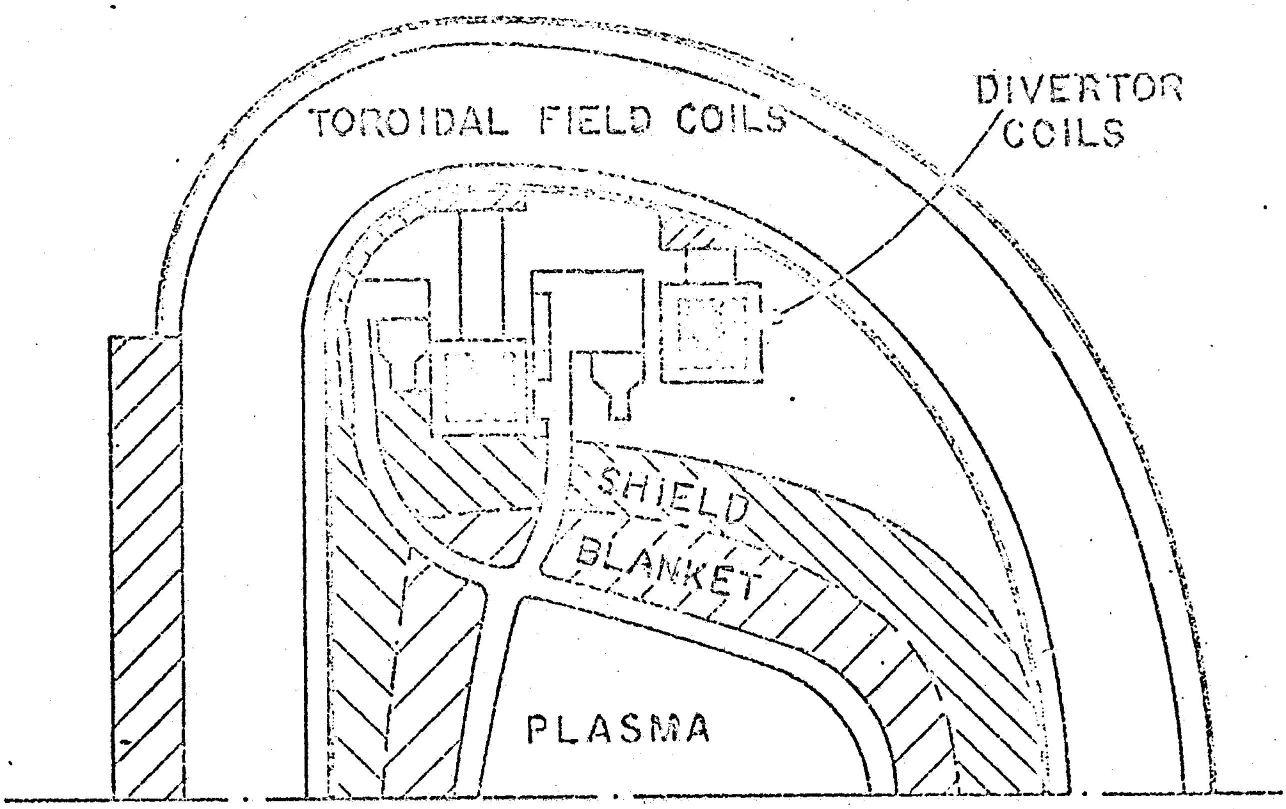
The parameters of interest in CTR blanket studies are reaction rate, in particular, the tritium production rate (by neutron reactions with ^{6}Li and ^{7}Li), the neutron and gamma heating rates, and the dose rates in the superconducting magnets. Additionally, quantities such as displacement rates, transmutation rates, and hydrogen and helium production rates, are important to the materials scientist, while transmutation rates and afterheat production are important for hazards and safety analysis.

For CTR systems, reaction rates both near the source and far away are important. Further, one is encouraged to design the thinnest blanket and shield compatible with their functions since this will place the magnets closer to the plasma zone and thereby minimize their costs.

It is clear therefore that CTR system studies require neutron and photon transport calculations generally very similar to those carried out by the shielding analyst. In both these areas, one is often interested in performing survey calculations and sensitivity studies. A procedure which allows one to assess the effects of alterations in either material composition or design, or in nuclear data, on the reaction rates of interest, without necessitating a new transport calculation following each alteration, can be formulated for CTR blanket and shield studies based on variational principles[3,4]. The functionals employed are the bilinear and fractional forms of the Schwinger variational principle.[5] The flux perturbations caused by such alterations will, on the whole, be such that variational methods will adequately predict the effects. For example, the substitution of one structural material or alloy for another can be accurately assessed with the variational method. Further, the use of such procedures will be especially advantageous on multi-dimensional problems. Figure 1b is the cross section of a Tokamak-like CTR system based on the feasibility study now underway at the University of Wisconsin.[1] The asymmetries caused by the divertor slots and the fueling and heating injection ports are the reasons multi-dimensional effects are important. Thus, in addition, methods such as the adjoint difference method[6], developed for shielding problems, will be helpful in CTR work. Typical results of calculations on CTR blankets and shields using the variational method will be presented.



I.a SIMPLIFIED FUSION REACTOR CROSS SECTION



I.b UNIV. OF WISC. TOROIDAL FUSION REACTOR CROSS SECTION

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2. R. G. Mills, "Princeton Reactor Studies Program," ibid.

3. Robert Conn and W.M. Stacey, Jr., "Variational Methods for Controlled Thermonuclear Reactor Blanket Studies," Nuclear Fusion (to be published).

4. For an overview of variational methods in shielding, see the remaining papers in this session; also, see D.E. Bartine, E. Oblow, and F.R. Mynatt, "Neutron Cross-Section Sensitivity Analysis: A General Approach Illustrated for a Na-Fe System," ORNL-TM-3944 (Oak Ridge National Laboratory, Dec., 1972).

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