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NEUTRON SKYSHINE CALCULATIONS

FOR THE PDX TOKAMAK

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The Poloidal Divertor Experiment (PDX) at Princeton will be the first operating tokamak to require a substantial radiation shield. The PDX shielding includes a water-filled roof shield over the machine to reduce air scattering skyshine dose in the PDX control room and at the site boundary. During the design[1] of this roof shield a unique method was developed to compute the neutron source emerging from the top of the roof shield for use in Monte Carlo skyshine calculations. The method is based on simple, one-dimensional calculations rather than multidimensional calculations, resulting in considerable savings in computer time and input preparation effort.

The PDX plasma position relative to its immediate surroundings is illustrated in Figure 1. Calculations for the magnitude and spatial distribution of the neutron current at the top of the roof shield can be done in three steps:

1) A one-dimensional, slab-geometry S_n calculation is first run to estimate the fraction, energy spectrum and average angular distribution of source neutrons escaping from the top surface of

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the roof. This calculation is based on a slab model that includes the concrete floor under the PDX torus, a vacuum region with an isotropic source of fusion neutrons and finally, the roof shield region. Vacuum boundary conditions are imposed at the top of the roof and the bottom of the floor. This procedure is nearly exact since the lateral extent of the roof is large compared to the plasma major radius and since, for a laterally infinite roof shield, the fraction of source neutrons transmitted is independent of the spatial distribution of the source, as long as the source lies in a vacuum. This idea can be extended to show that the simple slab model also correctly accounts for reflected source neutrons emerging from the concrete floor and subsequently passing through the roof.

2) The spatial distribution of the uncollided emerging neutron current at the top surface of the roof shield is then computed for a circular line source at the plasma location below the roof shield. This distribution is given by:

$$J(R) = \frac{2S}{8\pi^2} \int_0^{\pi} \frac{(\sin\alpha)e^{-\Sigma\ell}}{[\ell+r]^2} d\phi \qquad (1)$$

where all variables are defined in Figure 2.

3) Finally, the assumption is made that the spatial distribution of emerging collided current is also given by Equation (1) and thus Equation (1) can be normalized such that it's integral over the upper roof surface equals the total leakage (collided plus uncollided) obtained in Step 1. The spatial distribution of the collided current obtained in this manner is approximate due to the

presence of neutrons reflected from the floor and also because neutrons scattered in the roof shield will have had their directions altered. However, the integral of the distribution over the roof remains correct since the slab S_n calculation gives the correct leakage probability per neutron.

This simple model also provides the correct angular distribution of emerging neutrons averaged over the roof surface. The data obtained in steps 1-3 can subsequently be input as a planar neutron current source to a Monte Carlo problem that represents the external geometry, accurately treats air scatter and computes the neutron dose at desired occupancy positions with moderate computer cost.

The accuracy of the leakage probability computed with the one-dimensional S_n model was verified for one case by comparison with a Monte Carlo calculation in which the source geometry and machine-room structure were accurately modeled. The one-dimensional result was higher than the Monte Carlo result by 1.4 standard deviations which is a very acceptable comparison.

These ideas, in slightly different form, can also be extended to the computation of the capture-gamma leakage current at the top of the roof, and have provided an economical technique for use in shielding design.

1) R. A. Grimesey, et al., "Preliminary Studies for the PDX Tokamak Radiation Shield Design," TREE-1369, EG&G Idaho, Inc. (1979)

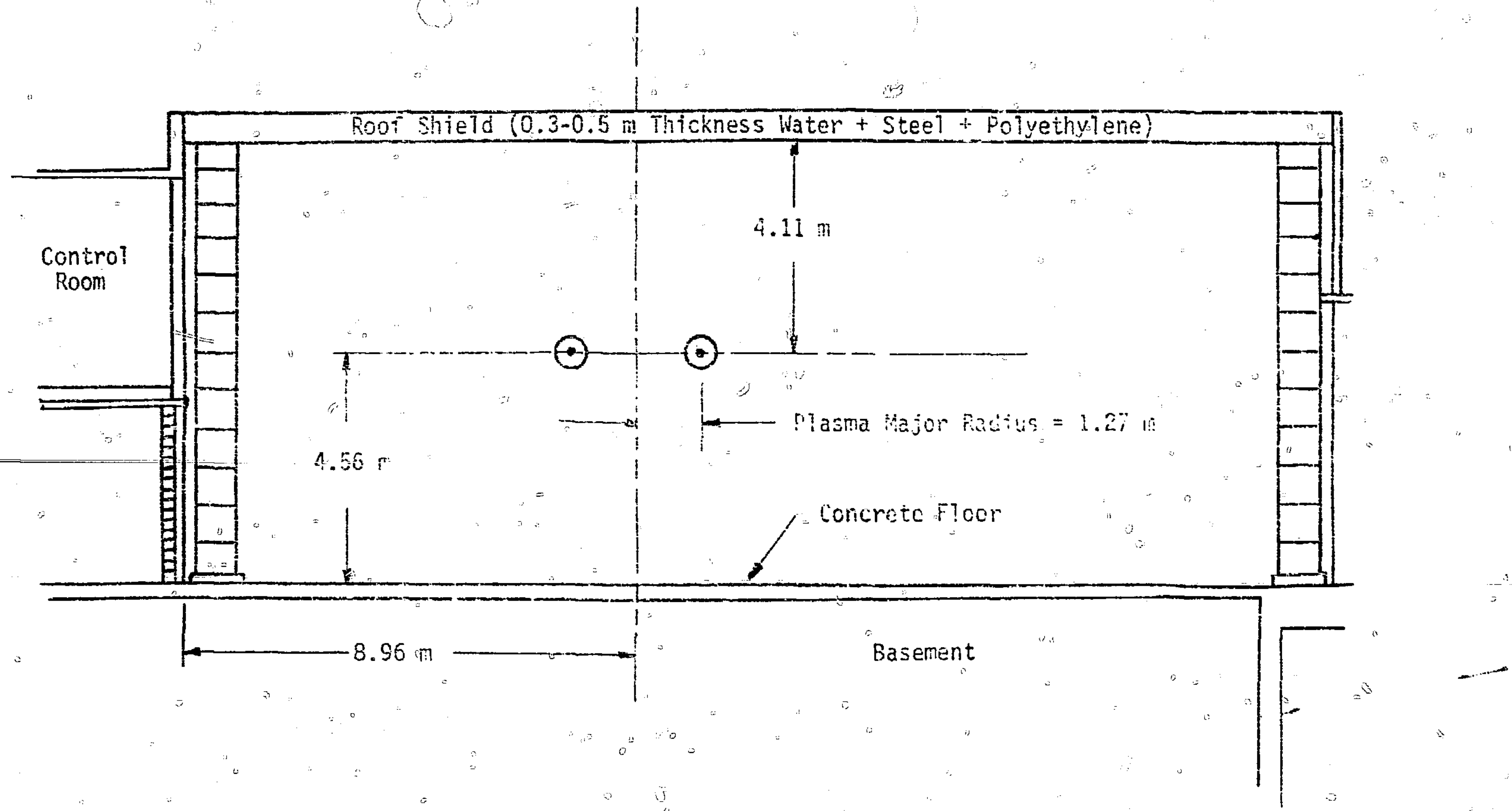
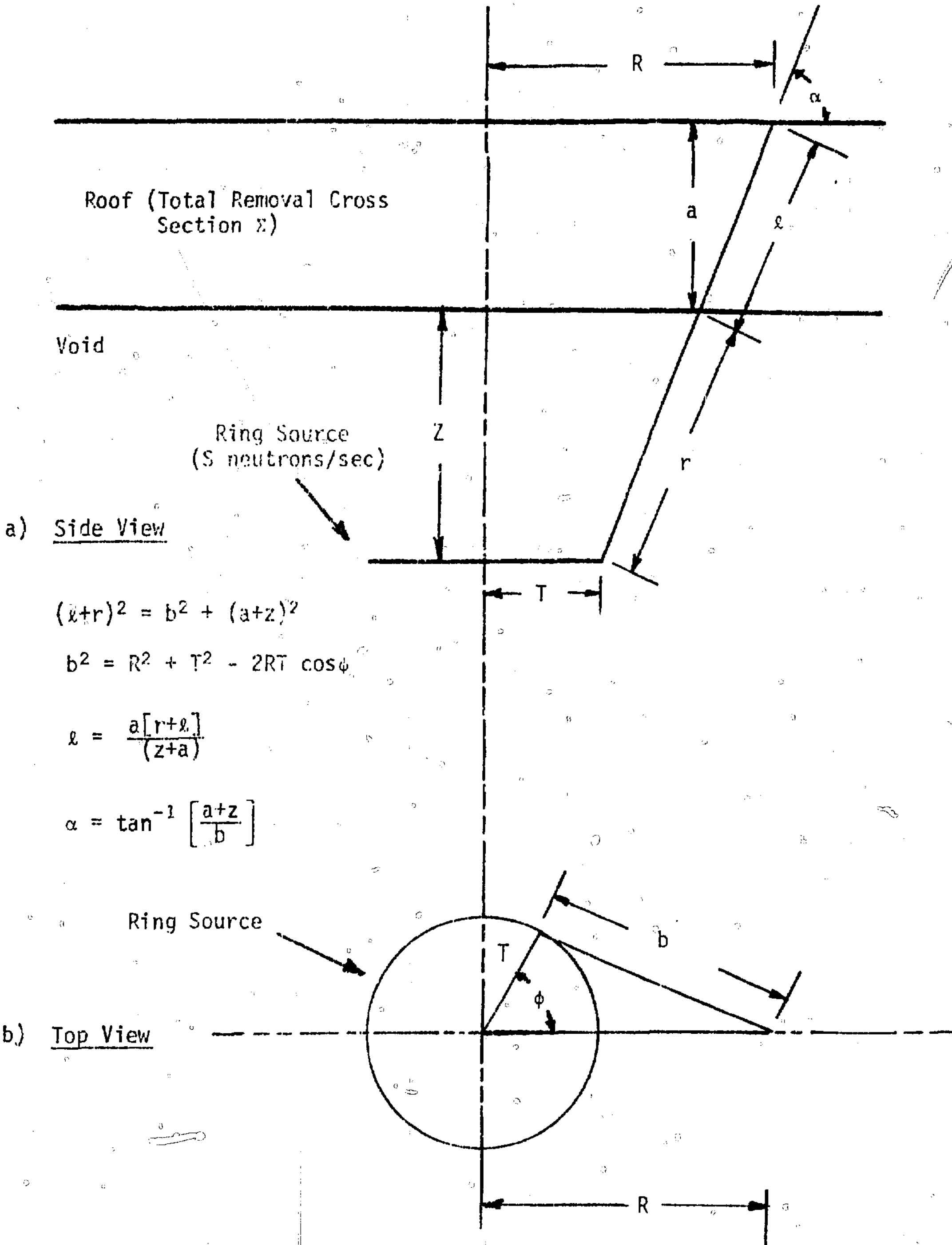


Figure 1. Cross Section of PDX Torus, Shielding Walls and Roof and Control Room



$$(\ell+r)^2 = b^2 + (a+z)^2$$

$$b^2 = R^2 + T^2 - 2RT\cos\phi$$

$$\ell = \frac{a[r+\ell]}{(z+a)}$$

$$\alpha = \tan^{-1}\left[\frac{a+z}{b}\right]$$

Figure 2. Geometry for the Ring Source Uncollided Flux and Current Calculations