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MONTE CARLO PATH LENGTH SELECTION ROUTINES BASED ON
SOME SPECIFIC FORMS OF THE IMPORTANCE FUNCTION

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ABSTRACT

One of the more fruitful techniques for importance sampling in Monte Carlo calculations is that of modifying the path length selection in the random walk. The simplest practical approach is usually referred to as the "exponential transform" and assumes that the value, or importance, function (which gives the value of a collision in the random walk to the answer of interest) is a simple exponential in space. In many cases of interest, more detailed information is available about the actual value function and a more complicated form of the importance function can be assumed. The formalisms and computer listings are given for some of these specialized importance functions which have been implemented in the path length selection routines of the O5R Monte Carlo code.

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I. Introduction

The most common usage of the exponential transform¹ assumes a simple exponential form of the importance function; i.e.:

$$I(z) = e^{cz},$$

where c may be taken to be a function of the particle energy, usually in broad groups, but is not a function of position or angle. This importance function is used to modify the spatial portion of the transport kernel. The modified kernel is then

$$\begin{aligned}\bar{K}(z_0 \rightarrow z) &= K(z_0 \rightarrow z) \frac{I(z)}{I(z_0)} \\ &= \Sigma e^{-\frac{\Sigma(z-z_0)}{\omega}} e^{c(z-z_0)} \\ &= \Sigma e^{-(1-v\omega) \frac{\Sigma(z-z_0)}{\omega}}\end{aligned}$$

where $c = v\Sigma$, and ω is the cosine of the angle between the neutron direction and the z -axis. After normalizing, $\bar{K}$ becomes

$$\bar{K}(z_0 \rightarrow z) = (1 - v\omega) \Sigma e^{-(1-v\omega) \frac{\Sigma(z-z_0)}{\omega}}.$$

Selection of a value of Σr [r , the actual path length, is $(z-z_0)/\omega$] from this distribution is accomplished by selecting a value η' from the distribution $e^{-\eta}$, then multiplying by $1/(1 - v\omega)$.

Many practical problems exist where this simple form of the importance function is clearly inadequate. In some of these it may be possible to assume the form to be some combination of exponentials, which will likely be more amenable to inclusion in existing Monte Carlo computer codes than some other analytical form. The routines described in this report are path selection subroutines for the O5R code,² which implement different forms

¹F. H. Clark, The Exponential Transform as an Importance-Sampling Device - A Review, ORNL RSIC-14 (1966).

²D. C. Irving et al., O5R, A General-Purpose Monte Carlo Transport Code, ORNL-3622 (1965).

of the importance function for the exponential transform. In the first of these, ETAREF, the importance function is assumed to be the sum of two exponentials when the collision point is greater than a given distance from the detector. When the collision point is closer to the detector, the importance function is assumed to be a continuous function which decreases exponentially, with a single slope, on either side of the detector. The second routine, ETAGAC, assumes a single exponential importance function far from the detector, and, when closer to the detector assumes a discontinuous importance function with decreasing exponentials, of different slopes, on either side of the detector. In each case the biasing parameter is given as a function of energy group. The last path length selection procedure, subroutines GETETA and EUCLID, combines the simple exponential transform³ with nonleakage.

II. Formalisms

THE REFLECTED EXPONENTIAL AND THE SUM OF TWO EXPONENTIALS (SUBROUTINES ETAREF AND GETNU)

The detector is assumed to be a plane located at $z = d$ and transport is considered on both sides of the detector. The system is divided into four spatial regions (see Fig. 1).

Fig. 1. Assumed Format Importance Function

³F. H. Clark and N. A. Betz, Importance Sampling Device for Selecting Track Lengths and Directions after Scatter in O5R, ORNL TM-1484 (1966).

Regions I and IV are far from the detector plane and the importance function $I(z)$ is represented by $I(z) = ae^{\lambda_1 z} + (1-a)e^{\lambda_2 z}$. In regions II and III the importance function is a continuous exponential reflected at the detector and having the form $I(z) = I_0 e^{\lambda_3 (z-d)}$ for region II and $I(z) = I_0 e^{-\lambda_3 (z-d)}$ for region III.

First a check is performed to determine which region the collision is in and then the appropriate importance function is used.

For regions I and IV the function is: $I(z) = ae^{\lambda_1 z} + (1-a)e^{\lambda_2 z}$. The unbiased kernel is $K = \Sigma e^{-\Sigma r}$ and the modified kernel is obtained by the product of $I(z)/I(z_0)$ and K , where z is the end point of the path and z_0 is the starting point of the path.

$$\frac{I(z)}{I(z_0)} = \frac{ae^{\lambda_1 z} + (1-a)e^{\lambda_2 z}}{ae^{\lambda_1 z_0} + (1-a)e^{\lambda_2 z_0}}.$$

Now $z = z_0 + rw$ where w is the direction cosine w.r.t. the z axis and r is the actual path length. Substituting in the above equation gives

$$\frac{I(z)}{I(z_0)} = \frac{ae^{\lambda_1 z_0} e^{\lambda_1 rw} + (1-a)e^{\lambda_2 z_0} e^{\lambda_2 rw}}{ae^{\lambda_1 z_0} + (1-a)e^{\lambda_2 z_0}}.$$

Dividing by $ae^{\lambda_1 z_0}$ gives

$$\frac{I(z)}{I(z_0)} = \frac{e^{\lambda_1 rw} + [(1-a)/a]e^{(\lambda_2 - \lambda_1)z_0} e^{\lambda_2 rw}}{1 + [(1-a)/a]e^{(\lambda_2 - \lambda_1)z_0}}.$$

Letting $A = [(1-a)/a]e^{(\lambda_2 - \lambda_1)z_0}$ results in

$$\frac{I(z)}{I(z_0)} = \frac{e^{\lambda_1 rw} + Ae^{\lambda_2 rw}}{1 + A}.$$

The modified kernel is then

$$\bar{K} = \frac{\Sigma e^{\lambda_1 rw - \Sigma r} + A \Sigma e^{\lambda_2 rw - \Sigma r}}{1 + A}.$$

Letting $\lambda_1 = v_1 \Sigma$ gives

$$\bar{K} = \frac{\Sigma e^{-(1-v_1 \omega)\Sigma r} + A \Sigma e^{-(1-v_2 \omega)\Sigma r}}{A + 1}.$$

Since $\alpha e^{-\alpha\eta}$ is a properly normalized probability density function,* (p.d.f.), it is desirable to put $\bar{K}$ into the following form:

$$\bar{K} = \frac{\Sigma(1-\nu_1\omega) e^{-(1-\nu_1\omega)\Sigma r}}{(1+A)(1-\nu_1\omega)} + \frac{A\Sigma(1-\nu_2\omega) e^{-(1-\nu_2\omega)\Sigma r}}{(1+A)(1-\nu_2\omega)}.$$

Since this is the p.d.f. we wish to choose Σr from, it must be normalized so that:

$$\int_0^{\infty} C\bar{K} dr = 1$$

therefore

$$1 = C \int_0^{\infty} \left[\frac{\Sigma(1-\nu_1\omega) e^{-(1-\nu_1\omega)\Sigma r}}{(1+A)(1-\nu_1\omega)} dr + \frac{A\Sigma(1-\nu_2\omega) e^{-(1-\nu_2\omega)\Sigma r}}{(1+A)(1-\nu_2\omega)} dr \right]$$

$$1 = C \left[\frac{1}{(1-\nu_1\omega)(1+A)} + \frac{A}{(1-\nu_2\omega)(1+A)} \right]$$

$$C = \frac{(1+A)(1-\nu_1\omega)(1-\nu_2\omega)}{(1-\nu_2\omega) + A(1-\nu_1\omega)}.$$

Substituting in

$$\bar{K}_{\text{norm}} = \frac{\Sigma(1-\nu_1\omega)(1-\nu_2\omega) e^{-(1-\nu_1\omega)\Sigma r}}{(1-\nu_2\omega) + A(1-\nu_1\omega)} + \frac{A\Sigma(1-\nu_2\omega)(1-\nu_1\omega) e^{-(1-\nu_2\omega)\Sigma r}}{(1-\nu_2\omega) + A(1-\nu_1\omega)}.$$

Noting that $K(r) dr = K(\eta) d\eta$, where $\eta = \Sigma r$, $\bar{K}_{\text{norm}}(\eta)$ can be put in the form

$$\bar{K}_{\text{norm}} = \alpha(1-\nu_1\omega) e^{-(1-\nu_1\omega)\eta} + \beta(1-\nu_2\omega) e^{-(1-\nu_2\omega)\eta}$$

*Selection from the p.d.f. $\alpha e^{-\alpha\eta} d\eta$ is done by first selecting an η from $e^{-\eta} d\eta$ (function EXPRNF in O5R), then dividing by α .

where $\alpha = \frac{(1-v_2\omega)}{(1-v_2\omega) + A(1-v_1\omega)}$ and is the probability with which η is selected from $(1-v_1\omega) e^{-(1-v_1\omega)\eta}$, and $\beta = \frac{A(1-v_1\omega)}{(1-v_2\omega) + A(1-v_1\omega)}$ and is the probability with which η is selected from $(1-v_2\omega) e^{-(1-v_2\omega)\eta}$.

The weight of the particle is multiplied by the ratio of the original and modified kernels:

$$\begin{aligned} wt &= wt_o \frac{K}{\bar{K}} = wt_o \frac{e^{-\eta}}{(1-v\omega) e^{-(1-v\omega)\eta}} \\ &= wt_o \frac{e^{-v\omega\eta}}{1 - v\omega} \end{aligned} ,$$

using $v = v_1$ if selection was from $(1-v_1\omega) e^{-(1-v_1\omega)\eta}$ and $v = v_2$ otherwise.

In sections II and III the importance functions are:

$$\begin{aligned} I(z) &= I_o e^{\lambda_3(z-d)} & z < d & \text{ region II} \\ &= I_o e^{-\lambda_3(z-d)} & z > d & \text{ region III} \end{aligned}$$

where $\lambda_3 = Zv_3$.

The various cases that can be encountered in these two regions are:

1. $z_o < d$ $\omega < 0$
2. $z_o > d$ $\omega > 0$
3. $z_o < d$ $z < d$ $\omega > 0$
4. $z_o < d$ $z > d$ $\omega > 0$
5. $z_o > d$ $z > d$ $\omega < 0$
6. $z_o > d$ $z < d$ $\omega < 0$

where z_o = starting point of the path,

z = end point of the path, and

ω = direction cosine of the path w.r.t. z -axis.

For cases 1 and 2 the neutron is heading away from the detector plane and the importance function is assumed to have a constant slope for all path lengths. As before, the modified kernel is

$$\bar{K} = \frac{I(z)}{I(z_0)} \Sigma e^{-\Sigma r} .$$

For $z < d$ (case 1),

$$\begin{aligned} \bar{K} &= \frac{I_0 e^{\lambda_B(z-d)}}{I_0 e^{\lambda_B(z_0-d)}} \Sigma e^{-\Sigma r} \\ &= e^{\lambda_B(z-z_0)} \Sigma e^{-\Sigma r} . \end{aligned}$$

But $z = z_0 + \omega r$ and $\lambda_B = \nu_3 \Sigma$, so

$$\begin{aligned} \bar{K} &= \Sigma e^{\Sigma \nu_3 \omega r} e^{-\Sigma r} \\ &= \Sigma e^{-(1-\nu_3 \omega) \Sigma r} . \end{aligned}$$

Now $\bar{K}$ must be normalized so that $\int_0^\infty C \bar{K} dr = 1$:

$$1 = C \int_0^\infty \Sigma e^{-(1-\nu_3 \omega) \Sigma r} dr = \frac{C}{(1-\nu_3 \omega)} .$$

Therefore

$$C = (1-\nu_3 \omega) ,$$

and

$$\bar{K}_{\text{norm}} = \Sigma (1-\nu_3 \omega) e^{-(1-\nu_3 \omega) \Sigma r} .$$

Letting $\eta = \Sigma r$ and $\bar{K}(r) dr = \bar{K}(\eta) d\eta$, η is picked from the distribution $(1-\nu_3 \omega) e^{-(1-\nu_3 \omega) \eta}$ and the weight is corrected by:

$$\begin{aligned} \frac{wt}{wt_0} &= \frac{K}{\bar{K}_{\text{norm}}} = \frac{e^{-\eta}}{(1-\nu_3\omega) e^{-(1-\nu_3\omega)\eta}} \\ &= \frac{e^{-\nu_3\omega\eta}}{(1-\nu_3\omega)} \end{aligned}$$

Similarly, for case 2,

$$\bar{K} = \frac{I_0 e^{-\lambda_B(z-d)}}{I_0 e^{-\lambda_B(z_0-d)}} \Sigma e^{-\Sigma r} = \Sigma e^{-(1+\nu_3\omega)\Sigma r} ;$$

and η is chosen from the distribution

$$\bar{K} = (1+\nu_3\omega) e^{-(1+\nu_3\omega)\eta} ,$$

and the weight correction is

$$\frac{wt}{wt_0} = \frac{e^{\nu_3\omega\eta}}{1+\nu_3\omega} .$$

Note that for cases 1 and 2 the neutron is headed away from the detector and the paths are shortened.

For cases 3, 4, 5, and 6 there is a possibility that the end of the path may be in a region in which the importance function has a slope of opposite sign to that at the start of the path. The probability of this occurring must be taken into account in the path stretching procedure.

$\bar{K}$ for case 3 will be the same as case 1 since z and z_0 are in the same region, i.e.:

$$\bar{K}_3 = \Sigma e^{-(1-\nu_3\omega)\Sigma r} .$$

For case 4

$$\begin{aligned}\bar{K}_4 &= \frac{I_0 e^{-\lambda_3(z-d)}}{I_0 e^{\lambda_3(z_0-d)}} \Sigma e^{-\Sigma r} \\ &= e^{-\lambda_3(z+z_0)+2\lambda_3 d} \Sigma e^{-\Sigma r}\end{aligned}$$

letting $\lambda_3 = \Sigma v_3$ and $z = z_0 + \omega r$ gives

$$\bar{K}_4 = \Sigma e^{-2\Sigma v_3(z_0-d)} e^{-(1+v_3\omega)\Sigma r}.$$

Let $r_d = \frac{d-z_0}{\omega}$ (the radial distance to the detector). So $\bar{K}_4$ becomes:

$$\bar{K}_4 = \Sigma e^{2\omega v_3 \Sigma r_d} e^{-(1+v_3\omega)\Sigma r},$$

and the complete kernel for cases 3 and 4 is

$$\begin{aligned}\bar{K} &= \Sigma e^{-(1-v_3\omega)\Sigma r} & ; & \quad z < d \\ &= \Sigma e^{2\omega v_3 \Sigma r_d} e^{-(1+v_3\omega)\Sigma r} & ; & \quad z > d.\end{aligned}$$

$\bar{K}$ must be normalized so that

$$\int_0^\infty C \bar{K} dr = 1.$$

$$C \left[\int_0^{r_d} \Sigma e^{-(1-v_3\omega)\Sigma r} dr + \int_{r_d}^\infty \Sigma e^{2\omega v_3 \Sigma r_d} e^{-(1+v_3\omega)\Sigma r} dr \right] = 1$$

$$C \left[\frac{1 - e^{-(1-v_3\omega)\Sigma r_d}}{(1-v_3\omega)} + \frac{e^{2\omega v_3 \Sigma r_d} e^{-(1+v_3\omega)\Sigma r_d}}{(1+v_3\omega)} \right] = 1$$

$$C \left[\frac{(1+v_3\omega) - (1-v_3\omega) e^{-(1-v_3\omega)\Sigma r_d} + e^{-(1-v_3\omega)\Sigma r_d} - v_3\omega e^{-(1-v_3\omega)\Sigma r_d}}{(1+v_3\omega)(1-v_3\omega)} \right] = 1$$

$$C \left[\frac{(1+\nu_3 \omega) e^{(1-\nu_3 \omega) \Sigma r_d} - 2\nu_3 \omega}{(1-\nu_3 \omega)(1+\nu_3 \omega) e^{(1-\nu_3 \omega) \Sigma r_d}} \right] = 1$$

$$C = \frac{(1-\nu_3 \omega)(1+\nu_3 \omega) e^{(1-\nu_3 \omega) \Sigma r_d}}{(1+\nu_3 \omega) e^{(1-\nu_3 \omega) \Sigma r_d} - 2\nu_3 \omega}$$

Therefore

$$\begin{aligned} \bar{K}_{\text{norm}} &= \frac{\Sigma(1-\nu_3 \omega)(1+\nu_3 \omega) e^{(1-\nu_3 \omega) \Sigma r_d} - (1-\nu_3 \omega) \Sigma r}{(1+\nu_3 \omega) e^{(1-\nu_3 \omega) \Sigma r_d} - 2\nu_3 \omega} ; r < r_d \\ &= \frac{\Sigma(1-\nu_3 \omega)(1+\nu_3 \omega) e^{(1-\nu_3 \omega) \Sigma r_d} - 2\nu_3 \omega \Sigma r_d - (1+\nu_3 \omega) \Sigma r}{(1+\nu_3 \omega) e^{(1-\nu_3 \omega) \Sigma r_d} - 2\nu_3 \omega} ; r > r_d \end{aligned}$$

Now the probability of r being greater than r_d is

$$\begin{aligned} P(r > r_d) &= \int_{r_d}^{\infty} \bar{K}_{\text{norm}} dr \\ &= \int_{r_d}^{\infty} \frac{\Sigma(1-\nu_3 \omega)(1+\nu_3 \omega) e^{(1-\nu_3 \omega) \Sigma r_d} - 2\nu_3 \omega \Sigma r_d - (1+\nu_3 \omega) \Sigma r}{(1+\nu_3 \omega) e^{(1-\nu_3 \omega) \Sigma r_d} - 2\nu_3 \omega} dr \\ &= \frac{e^{2\nu_3 \omega \Sigma r_d} - (1+\nu_3 \omega) \Sigma r_d}{(1+\nu_3 \omega) e^{(1-\nu_3 \omega) \Sigma r_d} - 2\nu_3 \omega} \frac{(1-\nu_3 \omega) \Sigma r_d}{(1-\nu_3 \omega) \Sigma r_d} (1-\nu_3 \omega) \\ &= \frac{(1-\nu_3 \omega)}{(1+\nu_3 \omega) e^{(1-\nu_3 \omega) \Sigma r_d} - 2\nu_3 \omega} \\ &= \frac{(1-\nu_3 \omega) e^{-\Sigma r_d}}{(1+\nu_3 \omega) e^{-\nu_3 \omega \Sigma r_d} - 2\nu_3 \omega e^{-\Sigma r_d}} \end{aligned}$$

Thus with probability $1 - P(r > r_d)$ η will be chosen from a distribution truncated at Σr_d . [That is, choose an η from $(1-\nu_3\omega) e^{-(1-\nu_3\omega)\eta} d\eta$ and replace η by the quantity Σr_d times the fractional part of $\eta/\Sigma r_d$.] The weight correction for $r < r_d$ becomes

$$\begin{aligned} \frac{K}{\bar{K}_{\text{norm}}} &= e^{-\eta} \bigg/ \frac{(1-\nu_3\omega)(1+\nu_3\omega) e^{(1-\nu_3\omega)\Sigma r_d} e^{-(1-\nu_3\omega)\eta}}{(1+\nu_3\omega) e^{(1-\nu_3\omega)\Sigma r_d} - 2\nu_3\omega} \\ &= \frac{[(1+\nu_3\omega) e^{-\nu_3\omega\Sigma r_d} - 2\nu_3\omega e^{-\Sigma r_d}] e^{-\nu_3\omega(\eta-\Sigma r_d)}}{(1-\nu_3\omega)(1+\nu_3\omega)} \end{aligned}$$

Similarly with probability $P(r > r_d)$, η will be chosen from the distribution $(1+\nu_3\omega) e^{-(1+\nu_3\omega)\eta}$ and replaced by $\eta + \Sigma r_d$. The corresponding weight correction is

$$\frac{K}{\bar{K}_{\text{norm}}} = \frac{[(1+\nu_3\omega) e^{-\nu_3\omega\Sigma r_d} - 2\nu_3\omega e^{-\Sigma r_d}] e^{\nu_3\omega(\eta-\Sigma r_d)}}{(1-\nu_3\omega)(1+\nu_3\omega)}.$$

For cases 5 and 6 the same procedure is used and the equations obtained are

$$\begin{aligned} \bar{K}_{\text{norm}} &= C \Sigma e^{-2\nu_3\omega\Sigma r_d} e^{-(1-\nu_3\omega)\Sigma r} & r > r_d \quad (\text{i.e., } z < d) \\ &= C \Sigma e^{-(1+\nu_3\omega)\Sigma r} & r < r_d \quad (\text{i.e., } z > d) \end{aligned}$$

where

$$1/C = \left\{ \frac{(1-\nu_3\omega) e^{(1+\nu_3\omega)\Sigma r_d} + 2\nu_3\omega}{(1-\nu_3\omega)(1+\nu_3\omega)} \right\} e^{-(1+\nu_3\omega)\Sigma r_d}$$

and the probabilities and weight corrections derived for $r < r_d$ and $r > r_d$

for cases 3 and 4 apply to cases 5 and 6 respectively if $-\omega$ is substituted for ω .

For purposes of computation the equations for all these cases may be combined as follows: First, if $r_d = (d-z_0)/\omega$ is negative, case 1 or 2 applies. The procedure is to select η from

$$\bar{K}_{\text{norm}} = (1+v_3 |\omega|) e^{-(1+v_3 |\omega|)\eta}$$

and apply the weight correction

$$\frac{K}{\bar{K}_{\text{norm}}} = \frac{e^{v_3 |\omega| \eta}}{1+v_3 |\omega|} .$$

If r_d is positive, one of cases 3, 4, 5, or 6 applies and $P(r > r_d)$ must be calculated. This is

$$P(r > r_d) = \frac{(1-v_3 |\omega|) e^{-\Sigma r_d}}{(1+v_3 |\omega|) e^{-\Sigma v_3 |\omega| r_d} - 2v_3 |\omega| e^{-\Sigma r_d}} .$$

With probability $P(r > r_d)$, η is selected from

$$\bar{K}_{\text{norm}} = (1+v_3 |\omega|) e^{-(1+v_3 |\omega|)\eta}$$

and replaced by $\eta + \Sigma r_d$. With probability $1 - P(r > r_d)$, η is selected from

$$\begin{aligned} \bar{K}_{\text{norm}} &= (1-v_3 |\omega|) e^{-(1-v_3 |\omega|)\eta} ; & \eta < \Sigma r_d \\ &= 0 & ; \quad \eta > \Sigma r_d . \end{aligned}$$

The weight correction for either of the above selections (corresponding to cases 3, 4, 5, or 6) is

$$\frac{K}{\bar{K}_{\text{norm}}} = \frac{[(1+v_3|\omega|) e^{-v_3|\omega|\Sigma r_d} - 2v_3|\omega| e^{-\Sigma r_d}] e^{v_3|\omega||\eta-\Sigma r_d|}}{(1-v_3|\omega|)(1+v_3|\omega|)}$$

THE DISCONTINUOUS EXPONENTIAL (SUBROUTINE ETAGAC)

Again, as shown in Fig. 1, the system is divided into four spatial regions, two of which are on either side of the detector plane at $z = d$.

The assumed importance function is

$$\begin{aligned} I &= I_1 e^{\lambda_1(z-d)}; & z < d \\ &= I_2 e^{-\lambda_2(z-d)}; & z > d \end{aligned}$$

This complete form will be used in regions II and III but only the single exponential will be used in regions I and IV.

For region I, similar to procedures used previously,

$$\begin{aligned} \bar{K} &= \Sigma e^{-\Sigma r} \frac{I_1 e^{\lambda_1(z-d)}}{I_1 e^{\lambda_1(z_0-d)}} \\ &= \Sigma e^{-(1-v_1\omega)\Sigma(z-z_0)/\omega} \end{aligned}$$

where $v_1 = \lambda_1/\Sigma$, and $z = z_0 + r\omega$. Then selection in region I is from

$$\bar{K}_{\text{norm}} = \Sigma(1-v_1\omega) e^{-(1-v_1\omega)\Sigma r}$$

and the weight adjustment is

$$\frac{K}{\bar{K}_{\text{norm}}} = \frac{e^{-v_1\omega\eta}}{1-v_1\omega}$$

Similarly in region IV, the modified kernel is

$$\begin{aligned}\bar{K} &= \sum e^{-\Sigma r} \frac{I_2 e^{-\lambda_2(z-d)}}{I_2 e^{-\lambda_2(z_0-d)}} \\ &= \sum e^{-(1+\nu_2\omega)\Sigma r}.\end{aligned}$$

Selection is then from

$$\bar{K}_{\text{norm}} = \sum (1+\nu_2\omega) e^{-(1+\nu_2\omega)\Sigma r},$$

with weight correction

$$\frac{K}{\bar{K}_{\text{norm}}} = \frac{e^{\nu_2\omega\eta}}{1+\nu_2\omega}.$$

Note that the formulas for region I apply in region IV with the substitution of $-\omega$ for ω and with the appropriate ν value.

In regions II and III, six cases must be considered:

1. $z_0 < d$ $\omega < 0$
2. $z_0 > d$ $\omega > 0$
3. $z_0 < d$ $z < d$ $\omega > 0$
4. $z_0 < d$ $z > d$ $\omega > 0$
5. $z_0 > d$ $z > d$ $\omega < 0$
6. $z_0 > d$ $z < d$ $\omega < 0$

Cases 1 and 2 are treated as though they were in regions I and IV respectively.

Consider cases 3 and 4. The modified kernel for case 3 is:

$$\begin{aligned}\bar{K} &= \sum e^{-\Sigma(z-z_0)/\omega} \frac{I_1 e^{\lambda_1(z-d)}}{I_1 e^{\lambda_1(z_0-d)}} \\ &= \sum e^{-(1-\nu_1\omega)\Sigma r},\end{aligned}$$

holding for $r < r_d$, where $r_d \equiv (d-z_0)/\omega$. For $r > r_d$ (case 4),

$$\bar{K} = \Sigma e^{-\Sigma(z-z_0)/\omega} \frac{I_2 e^{-\lambda_e(z-d)}}{I_1 e^{\lambda_1(z_0-d)}}$$

$$\Sigma \frac{I_2}{I_1} e^{(\nu_2+\nu_1)\omega\Sigma r_d} e^{-(1+\nu_2\omega)\Sigma r}$$

$\bar{K}$ must be normalized such that $\int_0^\infty C \bar{K} dr = 1$. Therefore:

$$\begin{aligned} C \int_0^\infty \bar{K} dr &= C \left[\int_0^{r_d} \Sigma e^{-(1-\nu_1\omega)\Sigma r} dr \right. \\ &\quad \left. + \int_{r_d}^\infty \frac{\Sigma I_2}{I_1} e^{(\nu_2+\nu_1)\omega\Sigma r_d} e^{-(1+\nu_2\omega)\Sigma r} dr \right] \\ &= C \left[\frac{1-e^{-(1-\nu_1\omega)\Sigma r_d}}{(1-\nu_1\omega)} + \frac{I_2 e^{-(1-\nu_1\omega)\Sigma r_d}}{I_1 (1+\nu_2\omega)} \right], \end{aligned}$$

and

$$C = \frac{(1-\nu_1\omega)(1+\nu_2\omega) I_1}{I_1(1+\nu_2\omega)(1-e^{-(1-\nu_1\omega)\Sigma r_d}) + I_2(1-\nu_1\omega) e^{-(1-\nu_1\omega)\Sigma r_d}}.$$

The probability of choosing an $r > r_d$ is

$$\begin{aligned} P(r > r_d) &= \frac{I_2 e^{-(1-\nu_1\omega)\Sigma r_d} (1-\nu_1\omega)}{I_1(1+\nu_2\omega)(1-e^{-(1-\nu_1\omega)\Sigma r_d}) + I_2(1-\nu_1\omega) e^{-(1-\nu_1\omega)\Sigma r_d}} \\ &= \frac{1}{\frac{I_1(1+\nu_2\omega)}{I_2(1-\nu_1\omega)} (e^{(1-\nu_1\omega)\Sigma r_d} - 1) + 1}. \end{aligned}$$

The weight correction for $r < r_d$ (case 3) is:

$$\begin{aligned} \frac{K}{\bar{K}_{\text{norm}}} &= \frac{\Sigma e^{-\eta}}{C \Sigma e^{-\eta} e^{\nu_1 \omega \eta}} = \\ &= \frac{e^{-\nu_1 \omega (\eta - \Sigma r_d)}}{e^{\Sigma r_d}} \left\{ \frac{I_1 (1 + \nu_2 \omega) [e^{(1 - \nu_1 \omega) \Sigma r_d} - 1] + I_2 (1 - \nu_1 \omega)}{I_1 (1 - \nu_1 \omega) (1 + \nu_2 \omega)} \right\} . \end{aligned}$$

For $r > r_d$ (case 4), the weight correction is:

$$\begin{aligned} \frac{K}{\bar{K}_{\text{norm}}} &= \frac{\Sigma e^{-\eta} I_1 e^{\eta} e^{\nu_2 \omega \eta}}{C \Sigma I_2 e^{\nu_2 \omega \Sigma r_d} e^{\nu_1 \omega \Sigma r_d}} = \\ &= \frac{I_1 e^{\nu_2 \omega (\eta - \Sigma r_d)}}{I_2 e^{\Sigma r_d}} \left\{ \frac{I_1 (1 + \nu_2 \omega) [e^{(1 - \nu_1 \omega) \Sigma r_d} - 1] + I_2 (1 - \nu_1 \omega)}{I_1 (1 - \nu_1 \omega) (1 + \nu_2 \omega)} \right\} \end{aligned}$$

Cases 5 and 6 are similar. For case 5,

$$\begin{aligned} \bar{K} &= \Sigma e^{-\Sigma (z - z_0) / \omega} \frac{I_2 e^{-\lambda_2 (z - d)}}{I_2 e^{-\lambda_2 (z_0 - d)}} \\ &= \Sigma e^{-(1 + \nu_2 \omega) \Sigma r} . \end{aligned}$$

For case 6,

$$\begin{aligned} K &= \Sigma e^{-\Sigma (z - z_0) / \omega} \frac{I_1 e^{\lambda_1 (z - d)}}{I_2 e^{-\lambda_2 (z_0 - d)}} \\ &= \Sigma \frac{I_1}{I_2} e^{-(\nu_1 + \nu_2) \omega \Sigma r_d} e^{-(1 - \nu_1 \omega) \Sigma r} . \end{aligned}$$

The normalization condition is that $\int_0^\infty C \bar{K} dr = 1$, so that

$$C \left[\int_0^{r_d} \Sigma e^{-(1+v_2\omega)\Sigma r} dr + \int_{r_d}^{\infty} \Sigma \frac{I_1}{I_2} e^{-(v_1+v_2)\omega\Sigma r_d} e^{-(1-v_1\omega)\Sigma r} dr \right] =$$

$$= C \left[\frac{1-e^{-(1+v_2\omega)\Sigma r_d}}{(1+v_2\omega)} + \frac{I_1 e^{-(1+v_2\omega)\Sigma r_d}}{I_2 (1-v_1\omega)} \right],$$

and

$$C = \frac{I_2 (1+v_2\omega) (1-v_1\omega)}{I_2 (1-v_1\omega) [1-e^{-(1+v_2\omega)\Sigma r_d}] + I_1 (1+v_2\omega) e^{-(1+v_2\omega)\Sigma r_d}}.$$

The probability of choosing $r > r_d$ is

$$P(r > r_d) = \frac{I_1 e^{-(1+v_2\omega)\Sigma r_d} (1+v_2\omega)}{I_2 (1-v_1\omega) [1-e^{-(1+v_2\omega)\Sigma r_d}] + I_1 (1+v_2\omega) e^{-(1+v_2\omega)\Sigma r_d}}$$

$$= \frac{1}{\frac{I_2 (1-v_1\omega)}{I_1 (1+v_2\omega)} [e^{(1+v_2\omega)\Sigma r_d} - 1] + 1}$$

The weight correction for $r < r_d$ (case 5) is:

$$\frac{K}{\bar{K}_{\text{norm}}} = \frac{\Sigma e^{-\eta}}{C \Sigma e^{-\eta} e^{-v_2\omega\eta}} = \frac{e^{v_2\omega\eta}}{C} =$$

$$= \frac{e^{v_2\omega(\eta-\Sigma r_d)}}{e^{\Sigma r_d}} \left[\frac{I_2 (1-v_1\omega) [e^{(1+v_2\omega)\Sigma r_d} - 1] + I_1 (1+v_2\omega)}{I_2 (1-v_1\omega) (1+v_2\omega)} \right]$$

Similarly, for $r > r_d$ (case 6), the weight correction is:

$$\frac{K}{\bar{K}_{\text{norm}}} = \frac{\Sigma e^{-\eta} I_2 e^{(1-\nu_1 \omega) \eta}}{C \Sigma I_1 e^{-(\nu_1 + \nu_2) \omega \Sigma r_d}}$$

$$= \frac{I_2 e^{-\nu_1 \omega (\eta - \Sigma r_d)}}{I_1 e^{\Sigma r_d}} \left[\frac{I_2 (1 - \nu_1 \omega) [e^{(1 + \nu_2 \omega) \Sigma r_d} - 1] + I_1 (1 + \nu_2 \omega)}{I_2 (1 - \nu_1 \omega) (1 + \nu_2 \omega)} \right] .$$

NON-LEAKAGE (SUBROUTINES GETETA AND EUCLID)

As stated before, the unbiased path length kernel is

$$K = \sum e^{-\Sigma r} .$$

If an external boundary lies τ mean free paths from the starting point along the track, then the probability of escape in this flight is $e^{-\tau}$. The non-leakage procedure requires that no particles escape so the selection is made from the truncated distribution

$$\begin{aligned} \bar{K} &= \frac{\sum e^{-\Sigma r}}{1 - e^{-\tau}} & 0 \leq \Sigma r \leq \tau , \\ &= 0 & \Sigma r > \tau . \end{aligned}$$

The weight correction is, of course,

$$K/\bar{K} = 1 - e^{-\tau} .$$

It should be noted that the above procedure for nonleakage can be combined with the other path modification techniques. It is merely necessary to use one of the other $\bar{K}$'s for K above, and apply separately the two weight corrections.

COMPUTER LISTINGS

Following are computer listings corresponding to the formalisms derived previously. All are given as they were used in the Monte Carlo system 05R.

```

SUBROUTINE ETAREF
CHANGES HERE MADE 8/2/767
C   RIAS TOWARD SHELL AT RBIAS
C   IF CHLUSIFN IS WITHIN +/- RCU(1) OF RBIAS CALL GETNU
C   OTHERWISE PICK FROM SUM OF TWO EXPONENTIALS WITH THE IMPORTANCE
C   FUNCTION GIVEN BY  $1-AB1 \cdot \exp(RB1 \cdot SIGT \cdot R) + (1-AB1) \cdot \exp(BB2 \cdot SIGT \cdot R)$ 
C   AB1 MUST BE GREATER THAN .5
COMMON/SINGLES/BLZON,EBOT,ECUT,EGROUP,EINC,ENONO,ESOUR,
1ETAPF,ETA,FTATH,ETAUSD,ETOP,FONE,FTOTL,FWATE,ITERS,ITSTR,
2LELEN,LF,MARK,MXGP,MEDIA,MGPREG,MP1STP,MXREG,N,NCOLPR,
3NWPOL,NCONT1,NCONT2,NCONT3,NEWNM,NFISH,NFONE,NFPT,NGEOM,
4NGROUP,NGWT,NHISX,NHISTH,NINC,NFINC,NPING,NITS,NKILL,
5NLAST,NGLAST,NSIGL,NPLAST,NLEFT,NMEM,NMOST,NREL,NPCOF,
6NPTAPE,NQUIT,NRODM,NSOUR,NPLT,NSTAPE,NSTRT,NTHRM,NTHHML,
7NTYPE,OLDWT,PSIE,SPOLD,THETH,TNUC,UINP,UOLD,VINP,VOLD,
8WATEF,WINP,WOLD,WTAVR,WTWR,WFLOF,WTRED,WTSTRT,XOLD,XSTRT,
9YOLD,YSTRT,ZOLD,ZSTRT,UNUSED(10)
COMMON/NEUTRON/NAME,NAMEX,SPDSQ,U,V,W,X,Y,Z,WATE,NMED,NREG,BLZNT
COMMON/BIAS/IBE,IRBE,ISE,RBIAS,AB1(15,20),BB1(15,20),BB2(15,20),
1ELB(20),RCU(20)
COMMON/SIG/SIGT,R
C   BB1 AND BB2 ARE XNU VALUES
C   BB1 MUST BE DOMINANT XNU
J2=NREG
S2=SPDSQ
RESORTF(X**2+Y**2+Z**2)
IF(R=1.)3,4,4
3 DIR=1.
GO TO 8
4 D=BIAS-R
DIR= ((J*X+V*Y+W*Z)/(R*SQRTF(S2)))
IF(ABS(DIR)=.01)7,8,8
7 ETA=EXPRAF(F)
RETURN
8 DO 1 K=1,IBE
IF(S2=ELB(K))1,2,2
1 CONTINUE
K=IBE
2 J=K
XNU=BB1(J2,J)
B1=XNU*SIGT
B2=BB2(J2,J)*SIGT
IF(R=(RBIAS-RCU(J))0,60,61
61 IF(R=(RBIAS-RCU(J))0,62,63
62 CALL GETNU(ETA,WATE,RBIAS,R,SIGT,XNU,DIR)
RETURN
63 R=2.*RBIAS-R
IF(R)31,60,60
31 R=0.
60 AZ= (1.-AB1(J2,J))*EXP((B2-B1)*R)/AB1(J2,J)
DIR=DIR*ABS(D)/D
XN1=1.+XNU*DIR
IF(XN1)22,22,13
13 IF(XN1=1.9)12,12,23
22 CALL ERROR
23 XN1=1.9
12 XN2=1.-BB2(J2,J)*DIR
IF(XN2)22,22,15
15 IF(XN2=1.9)14,14,25

```

```

25 XN2= 1.9
14 C1=XN2/(XN2+X2*XN1)
   R1= FLTRNF(F)
   IF(R1=C1)16,17,17
16 ETA= EXPRNF(F)/XN1
   WATE= (WATE/XN1)*EXPF((XN1-1.)*ETA)
   RETURN
17 ETA= EXPRNF(F)/XN2
   WATE= (WATE/XN2)*EXPF((XN2-1.)*ETA)
   RETURN
   END

SUBROUTINE GETNU(ETA,WT,D,R,SIGT,XNU,DIR)
C THE FOLLOWING PROCEDURE SELECTS A TRACK LENGTH MODIFIED
C BY AN IMPORTANCE FUNCTION WHICH DECREASES EXPONENTIALLY ON
C EACH SIDE OF A DETECTOR PLANE
C D IS DEFINED AS DISTANCE FROM ORIGIN TO DETECTOR
C AND COORDINATE AXIS, DIR SUPPLIED BY DIRECT
C DIR IS COSINE OF ANGLE BETWEEN NEUTRON DIRECTION
C R IS DISTANCE FROM ORIGIN TO PARTICLE LOCATION
C SIGT IS TOTAL X-SECTION
C XNU DEFINED BY XNU=SIGT AS INVERSE SLOPE OF IMPORTANCE
C
   T4=XNU*ABSF(DIR)
   SUMT= 1.+T4
   RNOR=(D-R)/DIR
   IF(RNOR)1,1,2
1 IF(T4=.66)6,6,7
7 T4=.66
   SUMT= T4+1.
   XNU=T4/ABSF(DIR)
6 ETA=EXPRNF(ETA)/SUMT
   WT=WT*EXPF(T4*ETA)/SUMT
   RETURN
2 CONTINUE
   S1RN=SIGT*RNOR
   T1=SIGT*XNU*ABSF(D-R)
   T2=EXPF(-S1RN)
   T3=EXPF(-T1)
   T5=SUMT *T3-2.*T4*T2
   FRLT(1,0T4)*T2/T5
   RAN=FLTRNF(RAN)
   IF(RAN=FRL)3,3,4
3 ETA=EXPRNF(ETA)
   ETABETA/SUMT +S1RN
   T2=ETA
   GO TO 5
4 ETA= MODF(EXPRNF(ETA)/(1.-T4),S1RN)
   T2=ETA
5 WT=WT*T5/(1.-T4)/SUMT *EXPF(T4*ABSF(T2-S1RN))
   RETURN
   END

```

```

SUBROUTINE ETAGAC
COMMON/STNGLES/BLZON,EBOT,ECUT,EGR50,EINC,E40N0,ESOUR,
1ETAPE,ETA,ETATH,ETAUSD,ETOP,FONE,FTOTL,FWATE,ITERS,ITSTH,
2LELEH,LF,HARK,HXGP,MEDIA,HGPREG,HFISTP,HXREG,N,NCOLPR,
3NWPCL,NCONT1,NCONT2,NCONTP,NEWMH,NFISH,NFNE,NFPT,NGEOM,
4NGR50P,NBWT,NHISX,NHISTR,NINC,NFINC,NPINC,NITS,NKILL,
5NLAST,NGLAST,NS13L,NPLAST,NLEFT,NMEM,NMST,NDEL,NPCOF,
6NPYAP,NOUTT,NR5JR,NSOUR,NSPLT,NSTAPE,NSTRT,NTHERM,NTHHNL,
7NTYPE,OLONT,P3IE,SPOLD,THETH,TNUC,UINP,UOLD,VINP,VOLD,
8WATEF,WINP,WMLD,WTAVR,WTIR,WTOR,WTRED,WYSTRT,XOLD,XSTRT,
9YOLD,YSTRT,ZOLD,ZSTRT,UNUSED(10)
COMMON/NEUTRON/NAME,NAMEX,SPDSQ,U,V,W,X,Y,Z,WATE,NMED,NHEU,ULZNT
COMMON/BIAS/IBE,ISE,RBIAS,ABI(20),ABI(20),B9(20),B9(20),ELB(20)
DATA(ZMIN,49),(CONM,1,9)
J2=NREG
S2=SPDSQ
Z0=SQRTF(X*X+Y*Y+Z*Z)
DO 50 I=1,IBE
IF(S2.GT,ELB(I))60,50
50 CONTINUE
I=IBE
60 J=I
XNU1=BB1(J)
XNU2=BB2(J)
EI1=ABI(J)
EI2=ABI(J)
IF(Z0.LT,ZMIN)10,20
10 DIR=1,
GO TO 90
20 DIR=(U*X+Y*V+Z*W)/(Z0*SQRTF(S2))
IF(ABSF(DIR),LT,0.02)30,40
30 ETA=EXPRNF(XXX)
RETURN
40 SIGT=GTSECT(S2,NMED)
RCUJ=4./SIGT
IF(DIR)70,70,80
70 IF(Z0.LT,RBIAS)90,100
90 CON1=1.+XNU1*DIR
IF(ABSF(CON1),GT,CONM)120,110
110 IF(CON1)130,130,140
130 CALL ERROR
120 CON1=CONM
140 ETA=EXPRNF(XXX)/CON1
WATE=(WATE/CON1)*EXPF((CON1-1.)*ETA)
RETURN
80 IF(Z0.GT,RBIAS)150,200
150 CON2=1.+XNU2*DIR
IF(ABSF(CON2),GT,CONM)170,160
160 IF(CON2)180,180,190
180 CALL ERROR
170 CON1=CONM
190 ETA=EXPRNF(XXX)/CON2
WATE=(WATE/CON2)*EXPF((CON2-1.)*ETA)
RETURN
100 IF(Z0.GT,RBIAS+RCUJ)150,210
200 IF(Z0.LT,RBIAS-RCUJ)190,210
210 CON1=1.-XNU1*DIR
IF(ABSF(CON1),LT,CONM)220,230
220 IF(CON1)240,240,250

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```

240 CALL ERROR
250 CON1=CONM
250 CON2=1.+XNL2*DIR
    IF (ARSF(CON2),LT,CONM) 260,270
260 IF (CON2) 280,280,290
280 CALL ERROR
270 CON2=CONM
290 RAN=FLTRNF(XXX)
    IF (DIR) 320,320,330
320 TEMP=CON1
    CON1=CON2
    CON2=TEMP
    TEMP=E11
    E11=E12
    E12=TEMP
330 SGRD=SIGT*(RB1AS*Z)/DIR
    FRAC=E11*CON2/(E12*CON1)
    PRGB=1./(FRAC*EXPF(CON1*SGRD)+FRAC*1)
    AMESS=(E11*CON2*EXPF(CON1*SGRD)+E11*CON2+E12*CON1)/(CON1*CON2*
    EXPF(SGRD))
    IF (RAN,LT,PRGB) 310,300
300 ETA=HONF(EXPRNF(XXX)/CON1,SGRD)
    WATE=WATE*EXPF((CON1-1.)*(ETA-SGRD))*AMESS/E11
    RETURN
310 ETA=EXPRNF(XXX)/CON2*SGRD
    WATE=WATE*EXPF((CON2-1.)*(ETA-SGRD))*AMESS/E12
    RETURN
END

```



```

SUBROUTINE GETETA
COMMON/SINGLES/BLZON,EBOT,ECUT,EGROUP,EINC,EMONO,ESOUR,ETAPE,ETA,E
TATH,ETAUSD,ETCP,FONE,FTOTL,FWATE,ITERS,ITSTR,
2LELEM,LF,MARK,MAXGP,MEDIA,MGPREG,MFISTP,MXREG,N,NCOLPR,
3NWPCL,NCOAT,1,NCNT2,NCONTP,NEWMN,NFISH,NFANE,NFPT,NQEOH,
4NGROUP,NGWT,NHISMX,NHISTR,NINC,NFINC,NPINC,NITS,NKILL,
5NLAST,NGLAST,NSIGL,NPLAST,NLEFT,NMEM,NMOST,NDEL,NPCOF,
6NPTAPE,NQUIT,NROOH,NROUR,NPLT,NSTAPE,YSTRT,NTHERM,NTHRML,
7NTYPE,OLDWT,PSIE,SPOLD,THETH,TNUC,UINP,UOLD,VINP,VOLD,
8WATEF,WINP,WOLD,WTAVH,WTMR,WTOR,WTRED,WTSTRT,XOLD,XSTRT,
9YOLD,YSTRT,ZOLD,ZSTRT,UNUSED(10)
COMMON/NEUTRON/NAME,NAMEX,SPDSQ,U,V,W,X,Y,Z,WATE,NMED,NREG,BLZNT
COMMON/GETETA/XNJ(20,10),EAD(20)
COMMON/GECH/MARKG,XTWOG,YTWOG,ZTWOG,XONEG,YONEG,ZONEG,NMEDG,NREGG
1,ETAG,ETAUSD,BLZNG
DATA(ZTRUNC = -150.), (RADIUS = 912.)
IF(NMED=999)1,2,1
2 ETA=0.
RETURN
1 DOST=1,19
IEA=1
IF(SPDSQ=EAD(1))4,4,3
3 CONTINUE
IEA=20
4 IEA=IEA+1
IF(IEA)5,5,6
5 IEA=1
6 BIAS=1./((1.-XNU(IEA,NREG)*DIRECT(DUM))
IF(Z.GT. ZTRUNC .AND. W.GT. 0.)8,10
8 S = SQRTF(SPDSQ)
X2 = RADIUS * U/S + X
Y2 = RADIUS * V/S + Y
Z2 = RADIUS * W/S + Z
MARKG = 1
CALL EUCLID(X,Y,Z,X2,Y2,Z2,RADIUS,SPDSQ,ARG,0)
IF (ARG + 1,E=0) 9,11,11
11 ETA = 100.0
RETURN
9 ARG = -ARG
ETA=MODF(EXPRNF(X)*BIAS,ARG)

```

```

WATE=WATE*(1.-EXP(-ARG/BIAS))
00 Y0 12
ETA=BIAS*EXP(-X)
10 WATE=WATE*BIAS*EXP(-ETA*(1.-1./BIAS))
12 RETURN
END

SUBROUTINE EUCLID(X1,Y1,Z1,X2,Y2,Z2,P1,P2,V2,ARG,NT)
C THIS VERSION OF EUCLID IS INTENDED FOR USE IN OSR AND NOT IN
C ANALYSIS. IT ASSUMES THAT INTERNAL VOIDS ARE LABELLED AS MEDIUM
C 1000, NOT 500 AS IS USED IN ANALYSIS. IT REQUIRES A SPECIAL
C SUBROUTINE GTXSECT FOR USE IN THE OSR FRAMEWORK.
C
C SET MARK=1 WHENEVER STARTING FROM A NEW COLLISION POINT
C NT=0 PROGRAM RETURNS WITH TOTAL MFP FROM SOURCE TO DETECTOR
C NT=1 PROGRAM RETURNS WITH INTERSECTION PTS. AND MFP BETWEEN
C INTERSECTION POINTS
COMMON/GEOM/MARK,XTH0,YTH0,ZTH0,XONE,YONE,ZONE,NMED,NREG,ETA,ETAUSD
10,BLZON
DATA (MARK=1), (NINTV=0)
IF(MARK)5,1,5
5 MARK=1
ARG=0.
CALL LOOKZ(X1,Y1,Z1)
XONE=X1
YONE=Y1
ZONE=Z1
ETA=P1/P2
1 IF(NMED=1000) 3,2,3
2 SIGT=0.
NINTV=1
XTH0=X2-Y1
YTH0=Y2-Y1
ZTH0=Z2-Z1
GO TO 4004
3 SIGT=GTXSECT(V2,NMED)
4 XTH0=X2
YTH0=Y2
ZTH0=Z2
4004 CALL GEOM
IF (NINTV) 25,23,21
21 ETAUSD = SQRT((XTH0-XONE)**2+(YTH0-YONE)**2+(ZTH0-ZONE)**2)
NINTV=0
25 IF (MARK) 6,5,7
6 IF(MARK)7,8,9
5 ARG=ARG+SIGT*ETAUSD
ETA=ETA+ETAUSD
XONE=XTH0
YONE=YTH0
ZONE=ZTH0
IF(NT)13,1,13
13 X1=XONE
Y1=YONE
Z1=ZONE
19 RETURN

```

```

7 ARG=ARG+SIGT*ETA
  XONE=XTWO
  YONE=YTWO
  ZONE=ZTWO
  IF(NT)13,19,13
8 ARG=ARG+SIGT*ETAUSD
  XONE=XTWO
  YONE=YTWO
  ZONE=ZTWO
  IF(NT)17,19,17
17 NT=0
  GO TO 13
9 CALL ERROP
END

```

```

FUNCTION GTXSECT (V2,NM)
C THIS ROUTINE OBTAINS MACROSCOPIC CROSS SECTIONS FOR USE IN O5R. IT
C IS CALLED BY EUCLID WHEN EUCLID IS USED IN 45R. IT CANNOT REPLACE
C THE GTXSECT USED IN ANALYSIS. IF USED IN ANALYSIS, YOU WILL GO
C DIRECTLY TO JAIL, NOT PASS GO AND NOT COLLECT 200 DOLLARS.
COMMON STORAG(1)
COMMON/SINGLES/BLZON,EBOT,ECUT,EGROUP,EINC,EMONO,ESOUR,
ETAPE,ETA,FTATH,ETAUSD,ETOP,FONE,FTOTL,FWATE,ITERS,ITSTR,
ZLELEN,LF,HARK,MAXGP,MEDIA,HGPREG,HFISTP,HXREG,N,NCOLPR,
JNWPCL,NCONT1,NCONT2,NCONT3,NEWMH,NFISH,NFONE,NFPT,NGEOM,
NGROUP,NGWT,WHISX,NHISTR,NINC,NPINC,NPINC,NITS,NKILL,
NLAST,NGLAST,NSI3L,NPLAST,NLEFT,NMEM,NMOST,NDEL,NPCOF,
NP1APE,NQUIT,NRO3H,N3OUR,N3PLE,N3TAP,N3STR,N3THER,N3THRL,
NTYPE,OLDWT,PSIE,SPOLD,THETH,TNUC,UINP,UOLD,VINP,VOLD,
WATEF,WINP,WOLD,WTAVR,WTWIR,WTLOC,WTRED,WTSTAT,XOLD,XSTR,
YOLD,YSTR,ZOLD,ZSTR,UNUSED(10)
COMMON/MEDIA/NTHETA(16),NPSI(16),NP(16),NFISHNT(16),LMAX(16),NPTS(16),
SLOTH(16),SLOPS(16),SLOFS(16),PTS(16),FWLOW(20)
EINC = V2*EGROUP
NINC = NPTS(NM)-XFIXF(PTS(NM)*EINC/EGROUP)
IF(NINC)4,5,6
4 CALL ERROP
6 IF(NINC=NPTS(NM))3,3,4
5 NINC = 1
3 NI = NINC + NTHETA(NM) = 1
GTXSECT = 1./STORAG(N1)/SQRTF(V2)
RETURN
END

```

```

FUNCTION DIRECT(DUM)
COMMON/NEUTRON/NA,NX,S,U,V,W,X,Y,Z,WT,VM,NR,BL
GO TO (2,2,5,5,5,5,2,2,2,2) NR
2 DIRECT=W/SQRTF(5)
RETURN
3 RAD=SQRTF((X**2+Y**2+Z**2)*5)
DIRECT=(X*U+Y*V+Z*W)/RAD
RETURN
END

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