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Title: **Alpha-Like Calculations with MCNP**

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Alpha-Like Calculations With MCNP

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Introduction

Alpha (time-absorption eigenvalue) calculations are not an explicit calculational option in MCNP[1]. Nevertheless, it is possible to perform alpha calculations with MCNP. Such calculations are presently either very inefficient or require special coding or cross section library modifications. However, alpha-like calculations can easily be performed with MCNP using the KCODE option with neutron energy- or time-cutoffs. These approximate alpha-like calculations are described and tested below.

Alpha Calculations

The alpha eigenvalue is defined by the following equation,

$$\int \Omega \cdot \nabla\Phi \, dE dr d\Omega + \int (\Sigma_a + \frac{\alpha}{v}) \Phi dE dr = \int \nu \Sigma_f \Phi dE dr$$

where the constant α can be viewed as the concentration of a 1/v absorber required to balance the production of neutrons (the right-hand side) with the loss of neutrons (the left-hand side). At critical, $\alpha = 0.0$, the alpha solution and the more commonly used $k_{eff} = 1.0$ solution are identical. In supercritical situations, however, the α flux differs from the k_{eff} flux in both space and energy.

A direct calculation of α is possible in MCNP by starting neutrons in a supercritical system and allowing the neutrons to multiply until some predetermined problem time termination. (Without the termination, non-KCODE supercritical MCNP calculations would never end!) Tallies of the neutron population (flux divided by velocity) can be taken with respect to time and α determined by:

$$\alpha = \frac{\ln(N_2) - \ln(N_1)}{t_2 - t_1}$$

where N_1 and N_2 are the neutron populations at times t_1 and t_2. α can be evaluated only after asymptotic neutron population behavior has been established and this can require inordinate amounts of computer time.

An alternative approach[2,3], analogous to the alpha search algorithms in deterministic codes, is to add an everywhere-present 1/v absorber to a supercritical KCODE problem and calculate k_{eff}. The "concentration" (i.e., the multiplier α) of the 1/v absorber is then adjusted till the code calculates a modified $k_{eff} = 1.0$. This procedure is not available in MCNP. Neither is there a 1/v absorber available in the continuous energy cross section libraries.

A plausible workaround for thermal or epithermal systems is to use appropriately normalized concentrations of the 1/v absorbers He-3 or B-10, but this procedure fails in fast systems due to the non-1/v behavior of He-3 and B-10 at fission spectrum energies.

Alpha-Like Calculations

For approximate alpha-like calculations, the normal KCODE option of MCNP is used in conjunction with a time- or an energy-cutoff (see the cut:n card). An analogous procedure in space is to truncate the outermost regions of the reflector of a supercritical system. In all three cases (or in any combination of the three), additional neutron losses are being added to a supercritical system to force balance between production and losses. The time-cutoff adds something similar to absorption, while energy-cutoffs have the effect of an everywhere-present neutron absorber which is transparent above the cutoff, but black below the cutoff. Reflector truncation adds extra leakage - which is a localized effect (rather than everywhere-present) in an optically thick system.

Similar to deterministic α searches, the time- or energy-cutoffs or the reflector truncation are varied to force the modified k_{eff} to 1.0. In fact, only the time-cutoff procedure is unique to Monte Carlo methods.

There is physical motivation for all three possible cutoffs. In a rapid neutronic transient, any neutron which has too long a lifespan (time-cutoff) will be "left behind". Similarly, any neutron that drops to too low an energy (energy-cutoff) or wanders too far out in the reflector (reflector truncation) will also be left behind.

All three cutoff procedures can be viewed as substitutes for the everywhere-present α/v absorber. To the extent that they approximate the neutronic effects of that α/v absorber, the modified KCODE calculated flux distributions will approximate the true α flux distribution.

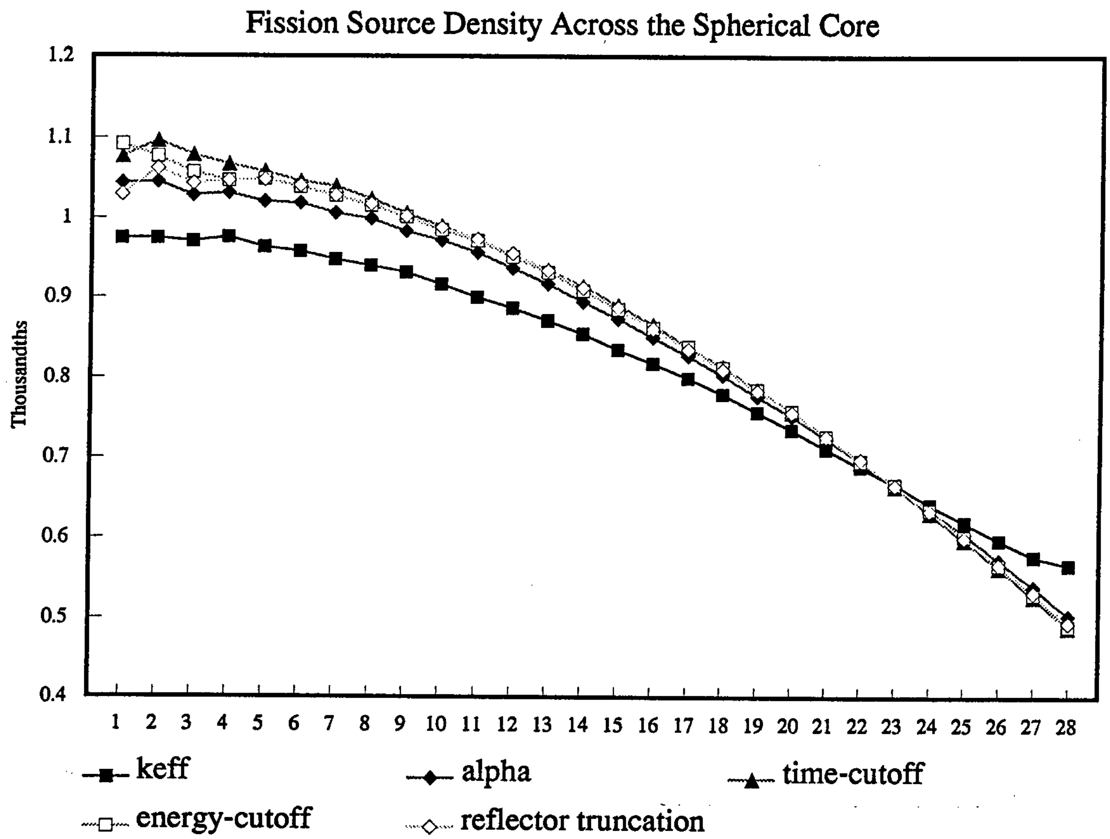
Sample Results

Sample problem 11 of a set of problems originally defined for neutron lifetime calculations[4] was chosen as a calculational exercise. It is a simplistic problem with a 7 cm sphere of highly enriched uranium metal surrounded by 10 cm of graphite.

MCNP4B results for sample problem 11 for each of the three cutoff methods are presented on the table below as well as the figure of merit (on the combined estimate of k_{eff}) and the average energy of the α/v (or equivalent cutoff) absorptions.

Type of Calculation	Result	Figure of Merit	Avg. Energy of 1/v Absorption
k_{eff}	1.062 ± 0.001	4112	-
α	0.043 sh^{-1}	4701	430 keV
time-cutoff	6.55 sh	5370	63 keV
energy-cutoff	51 keV	5358	~51 keV
reflector truncation	5.65 cm	6894	~1345 keV

Fission source distributions for each of the 5 cases are plotted on the figure. The similarity of the approximate alpha-like fission source distributions to the α distribution is readily apparent, as well as the significant difference from the k_{eff} distribution.



Conclusions

MCNP KCODE calculations with time- or energy-cutoffs, or with reflector truncation are similar to α calculations. These alpha-like calculations give spatial flux distributions which resemble true α distributions. Unfortunately, the equivalence is not exact due to the failure of the various cut-off mechanisms to match exactly the 1/v energy dependance of the α/v absorber.

References

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