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Title: Impact of Delayed Neutron Precursor Mobility in Fissile Solution System

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Impact of Delayed Neutron Precursor Mobility in Fissile Solution System

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Abstract

A research version of the Monte Carlo software package MCNP6 is modified to incorporate advection and diffusion of delayed neutron precursors, resulting in the emission of delayed neutrons at locations different from the original fission sites. Results of two test problems, a pipe carrying flowing fissile solution and a sphere of fissile solution with precursor diffusion, show that the fission product mobility tends to perturb the fundamental mode, has a negative reactivity effect, and causes a decrease in the effective delayed neutron fraction.

Introduction

- Motivation
- Equations & Solution Technique
- Test Problems

Motivation

- Coupling radiation transport to fluid dynamics packages now practical
 - Example: MCNP6 supports ABAQUS, a Finite Element package, geometry
- Applications:
 - Chemical processing may involve flowing solution of fission material
 - Molten Salt Reactors (MSRs) may have fuel dissolved in solution

Equations

Neutron Transport Equation:

$$\frac{1}{v} \frac{\partial \psi}{\partial t} + H\psi(\mathbf{r}, \hat{\Omega}, E, t) = P\psi(\mathbf{r}, \hat{\Omega}, E, t) + \sum_{i=1}^M \sum_{j=1}^N \frac{\chi_i^j(E)}{4\pi} \lambda_i^j C_i^j(\mathbf{r}, t),$$

Neutron Precursor Balance:

$$\frac{\partial C_i^j}{\partial t} + \nabla \cdot [\mathbf{u}(\mathbf{r}) C_i^j(\mathbf{r}, t) - D_i^j(\mathbf{r}) \nabla C_i^j(\mathbf{r}, t)] = B_i^j \psi(\mathbf{r}, \hat{\Omega}, E, t) - \lambda_i^j C_i^j(\mathbf{r}, t).$$

Advection and Diffusion

Precursors are swept with fluid movement (advection):

$$\nabla \cdot \mathbf{u}(\mathbf{r}) C_i^j(\mathbf{r}, t)$$

Precursors experience random motion from atomic collisions (diffusion):

$$- \nabla \cdot D_i^j(\mathbf{r}) \nabla C_i^j(\mathbf{r}, t)$$

Precursor Boundary Conditions

- Continuity
Precursor concentration across boundary preserved.
- Sink
Precursor concentration at boundary is zero, precursor lost.
- Wall
Precursor concentration gradient at boundary is zero.
- Capture
Precursor becomes non-mobile at boundary.

Monte Carlo Strategy

- Normal power iteration scheme except when delayed neutron sampled.
 - Typical behavior: Create precursor at fission site.
 - New behavior: Create precursor and simulate until decay, make neutron as before, but at new location.

Precursor Simulation

Start precursor at $\mathbf{r} = \mathbf{r}_0$ and $t = 0$,

Advance precursor distance $\Delta\mathbf{r}$ over a time step Δt :

$$\Delta\mathbf{r}_n = \mathbf{u}(\mathbf{r}_n)\Delta t_n + \mathbf{W}(\mathbf{r}_n),$$

\mathbf{W} is a random vector (Weiner process):

$$\mathbf{W}(\mathbf{r}_n) \leftarrow \mathcal{N}(0, 2D_i^j(\mathbf{r}_n)\Delta t),$$

Repeat until sink or capture boundary condition or $t = \tau$ where:

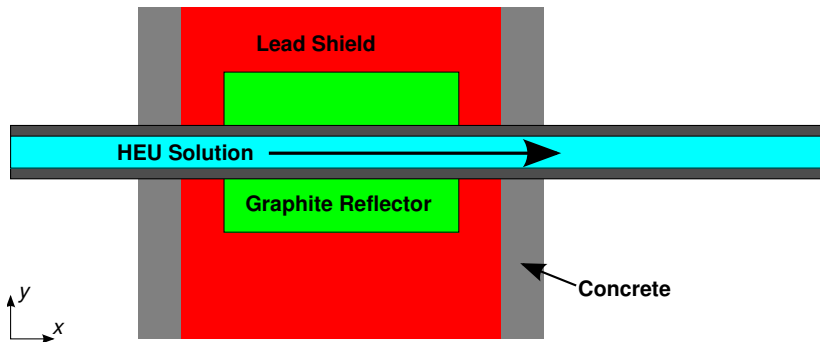
$$\tau \leftarrow \mathbf{Exp}(-\lambda_i^j),$$

Bank delayed neutron at final \mathbf{r} , continue neutron transport.

Test Problems

1. Fissile solution flowing through a pipe (advection).
2. Fissile solution in a tank with diffusion.

Advection Test



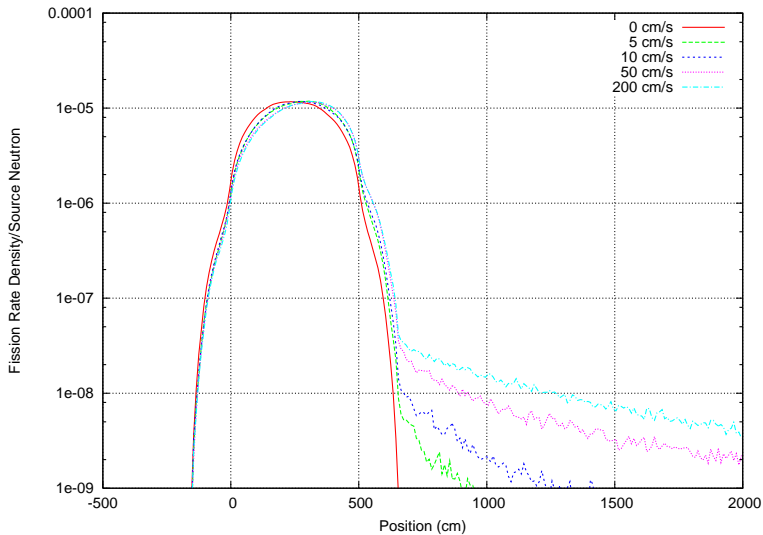
Advection Test

- Laminar flow profile:

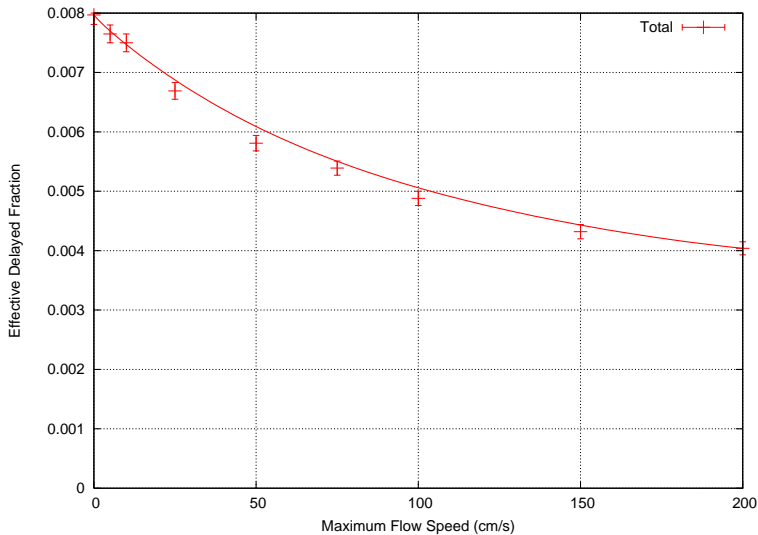
$$u_x(r) = u_{\max} \left[1 - \left(\frac{r}{R} \right)^2 \right].$$

- Compute k , fission rate density, β (effective delayed fraction)

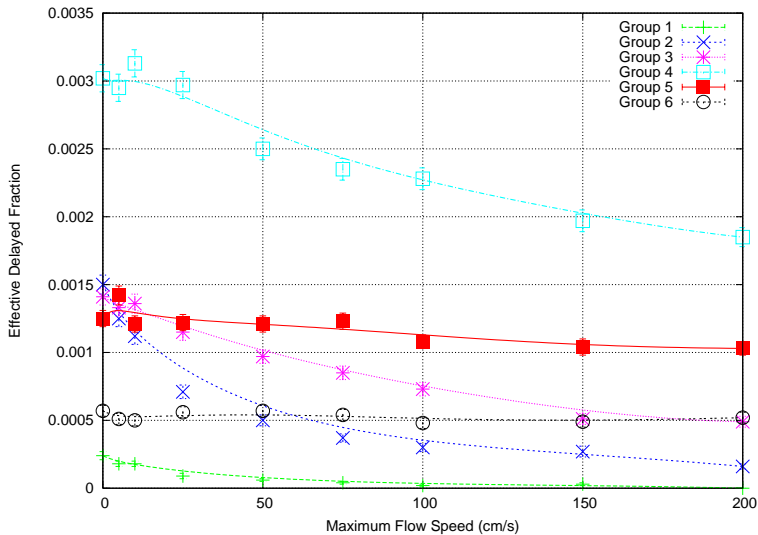
Advection Test Results



Advection Test Results



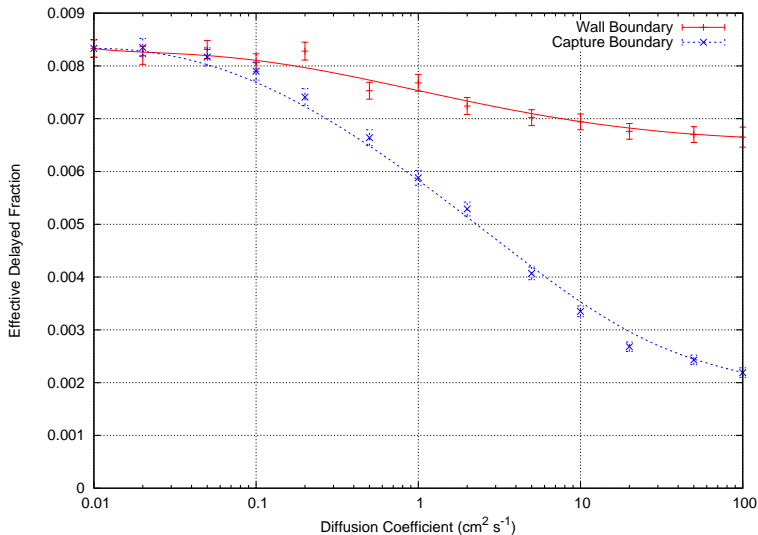
Advection Test Results



Diffusion Test

- Problem Description:
 - HEU solution in spherical tank ($R_{in} = 9$ cm).
 - Tank composition: 316 stainless steel ($R_{out} = 9.2$ cm).
 - Vary diffusion coefficient of solution.
 - Consider wall and capture boundary conditions.

Diffusion Test Results



Impacts

- Advection causes shift in fundamental mode.
 - Affects cooling and shielding needs.
- Both advection and diffusion can decrease effective delayed fraction.
 - Delayed neutrons often emitted in less important regions.
 - Implication in Molten Salt Reactor safety margins.
- Advection much stronger effect than diffusion.

Questions?
