# MODIFICATION OF OPEN SOURCE MONTE CARLO CODE OPENMC TO INCLUDE TIME-DEPENDENCE IN A FISSILE SYSTEM INCLUDING INDIVIDUAL DELAYED NEUTRON PRECURSORS

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In the field of nuclear reactor physics, transient phenomena are usually studied using deterministic or hybrid methods. These methods require many approximations, such as: geometry, time and energy discretizations, material homogenization and assumption of diffusion conditions, among others [1]. In this context, Monte Carlo simulations are specially adequate to study these problems, since they do not resort to space or energy discretizations. Challenges presented when using Monte Carlo simulations in space-time kinetics in fissile systems are the immensely different time-scales involved in prompt and delayed neutron emission, which implies that results obtained have a large variance associated when an analog Monte Carlo simulation is utilized [2]. Furthermore, in both deterministic and Monte Carlo simulations delayed neutron precursors are grouped in a 6- or 8- group structure, but nowadays there is not a solid reason to keep this aggregation.

In this work, and for the first time, individual precursor data is implemented in a Monte Carlo simulation, explicitly including the time dependence related to the β-delayed neutron emission. This was accomplished by modifying the open source Monte Carlo code OpenMC [3]. In the modified code – Time Dependent OpenMC or OpenMC(TD) – time dependency related to delayed neutron emission originated from β-decay was addressed. This work was done in the context of the doctoral thesis of Mr. Jaime Romero-Barrientos, carried out at the Chilean Nuclear Energy Commission.

To include time-dependence in a Monte Carlo simulation, the first step was to add an individual timestamp to each particle, whose value is updated using the kinetic energy and the distance traveled by the neutron between fission events. Then, the simulation was divided in discrete time intervals, so variance reduction and population control techniques could be applied at the end of these intervals. Lastly, a time filter was implemented in OpenMC(TD), so the time evolution of any tally from the simulation could be monitored.

After the steps taken to explicitly include time in the simulation, the variance of the expected values of observables, such as neutron flux, associated to the different time scales between prompt and delayed neutrons was addressed. This was done by forcing the decay [4] of a new Monte Carlo particle-like included in OpenMC(TD), the *precursor*, within each time interval, intentionally increasing the number of delayed neutrons in the simulation. Since there is a continuous production of delayed neutrons, population control had to be enforced. This was accomplished by using the combing method [5] at the end of each time interval.

With respect to the β-delayed neutron emission from individual *precursors*, if a delayed fission is sampled and the delayed neutron emission from individual *precursors* is being simulated, instead of directly inserting a delayed neutron, a *precursor* is produced. Then this *precursor* decays, emitting a neutron with the appropriate time delay. The delayed neutron energy will be the average energy from the corresponding precursor delayed neutron spectrum.

Continuous energy neutron cross-sections data used comes from JEFF-3.1.1 library [6]. Individual *precursor* data was taken from JEFF-3.1.1 (cumulative yields) and ENDF-B/VIII.0 [7] (delayed neutron emission probabilities and delayed neutron energy spectra).

OpenMC(TD) was tested first in a monoenergetic system. Then an energy dependent unmoderated system where the precursors were taken individually or in a group structure was studied in supercritical and subcritical configurations.

Finally, and approaching a more realistic system, a light-water moderated energy dependent system was studied. Here, the following cases were discussed: (a) comparison between 6-group and 50 individual precursor structure in a critical configuration, (b) comparison between 6-group, 50 individual and 40 individual precursor structure in a critical configuration.

The OpenMC(TD) code developed in this work has the potential of becoming an open source Monte Carlo tool with the capability to explore the impact of *precursor* data from nuclear databases on results obtained for calculations in fissile systems. In that sense, OpenMC(TD) could become a reliable tool to prompt new experimental data on individual β-delayed neutron emitters.

**References**

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