LA-UR-97- 222

CONF-970607--14

Title:

Definition of Neutron Lifespan and Neutron Lifetime in MCNP4B

Author(s):

Robert D. Busch (UNM)
Gregory D. Spriggs (LANL)
John S. Hendricks (LANL)

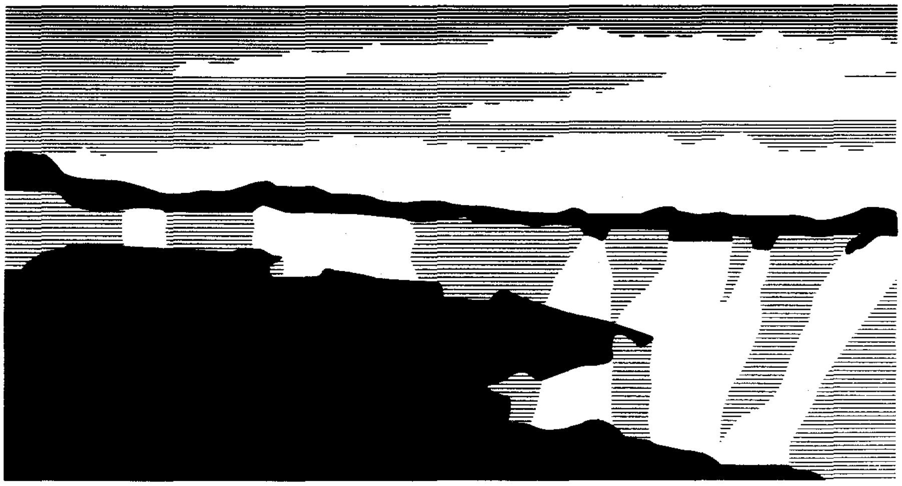
Submitted to:

American Nuclear Society Meeting
Orlando, FL
June 1-5, 1997

RECEIVED
APR 10 1997
OSTI

January 15, 1997

MASTER



Los Alamos
NATIONAL LABORATORY

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the University of California for the U.S. Department of Energy under contract W-7405-ENG-36. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Definition of Neutron Lifespan and Neutron Lifetime in MCNP4B

Robert D. Busch
University of New Mexico, Dept. of Chem. & Nucl. Eng., Albuquerque, NM 87131-1341

Gregory D. Spriggs and John S. Hendricks
Los Alamos National Laboratory, P. O. Box 1663, MS B226, Los Alamos, NM 87545-0001

Abstract

MCNP4B was released in early 1997. In this new version, several major changes were made to the underlying theory used to estimate the non-adjoint-weighted removal, fission, capture, and escape prompt-neutron lifetimes. These four lifetimes are now being calculated in accordance to the neutron-balance theory described by Spriggs et al.[1] in which the non-adjoint-weighted lifetime for a particular type of reaction (i.e., fission, capture, escape, removal, etc.) is defined as the total neutron population in the system divided by that reaction rate:

$$\tau_x = \frac{\int \frac{\phi}{v} dr dE d\Omega}{\int \Sigma_x \phi dr dE d\Omega} \quad , \tag{1}$$

where ϕ is the neutron flux, v is the neutron velocity, and Σ_x is the macroscopic cross section for the x^{th} type of neutron interaction. Furthermore, in MCNP4B, a new concept was introduced—a neutron *lifespan*—which was previously referred to as a neutron lifetime in earlier versions of MCNP.[2] In the context of the neutron-balance theory, a *neutron lifespan* is the mean time from birth-to-event, whereas, a *neutron lifetime* is the mean time from event-to-event. We attempt to clarify the meaning of these two lifetime definitions with the following example.

Consider a multiplying system with an effective multiplication factor of k_{eff}=0.9 that is in source equilibrium with an external/intrinsic neutron source. Neutrons will disappear from this system in one of two ways—absorption or leakage. Let us assume that 36% of the neutrons in this system are absorbed in fission reactions, 20% are absorbed in parasitic capture reactions [i.e., $(n,0n)$ reactions], and the remaining 44% of the neutrons leak from the system. Furthermore, let us assume that the average time from birth-to-fission of those neutrons that are destined to be absorbed in a fission reaction corresponds to 100 μs, the average time from birth-to-capture of those neutrons that are destined to be absorbed in a capture reaction corresponds to 90 μs, and the average time from birth-to-leakage of those neutrons destined to leak from the system corre-

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

sponds to 50 μs. On an average, a neutron in this hypothetical system will live for

$$\tau_r = 0.36 \times 100 + 0.20 \times 90 + 0.44 \times 50 = 76 \ \mu s \quad .$$

We define the quantity, τ_r, as the *non-adjoint-weighted removal lifetime* since it represents the mean time between removal events due to either an absorption event or a leakage event. And, per our previously stated definition of a neutron lifespan, the *fission lifespan* for this example corresponds to 100 μs, the *capture lifespan* corresponds to 90 μs, and the *escape lifespan* corresponds to 50 μs. The non-adjoint-weighted removal lifetime is merely the fission, capture, and escape lifespans weighted by their respective probability of occurrence, P_x. That is,

$$\tau_r = P_f \bar{t}_f + P_c \bar{t}_c + P_e \bar{t}_e \quad , \tag{2}$$

where the subscripts *f*, *c* and *e* refer to fission, capture, and escape, respectively. When calculated in this fashion, the removal lifetime, τ_r, is an unweighted quantity since each neutron is assumed to have equal importance in the multiplication process. (The definition of an importance-weighted removal lifetime is discussed fully in Ref. 1. Unfortunately, MCNP4B does not have the capability to estimate importance-weighted lifetimes at this time.)

It is very important to note that the neutron lifespan corresponding to a particular type of event differs from the mean time between events of that particular type. We demonstrate this difference as follows. Let us assume that the external/intrinsic source strength in our hypothetical system produces an equilibrium neutron population of 1.0 for this particular value of k_{eff}; that is to say, if a snapshot in time were taken at any point in time, the total number of neutrons that could be found in this system would be, on an average, 1.0. To maintain this equilibrium neutron population, one neutron must be lost from the system once every 76 μs. This equilibrium neutron population and average removal lifetime corresponds to an average loss rate of 13,158 n/s—of which 4,737 n/s (i.e., 36%) are being absorbed in fission reactions, 2,632 n/s (i.e., 20%) are being parasitically captured, and 5,789 n/s (i.e., 44%) are leaking.

Because the system is in source equilibrium at a k_{eff}=0.9, neutrons must be appearing in the system at a rate of 13,158 n/s —of which $Sk_{eff}/(1 - k_{eff})$ neutrons per second are being produced by fission reactions. Hence, 11,842 n/s are being produced by fissions and the remaining 1,316 n/s are being injected by the source. If we further assume that the average number of neutrons produced per fission is $\bar{\nu} = 2.5$, then it follows that the fission rate in this system corresponds to 4,737 fissions/s (i.e., 11,842/2.5).

From this example, we can readily identify several other neutron lifetimes that are of interest in reactor physics. For example, the mean time between fission events—*the non-adjoint-*

weighted fission lifetime—corresponds to 211.1 μs (i.e., 1/4,737), the mean time between parasitic captures—*the non-adjoint-weighted capture lifetime*—corresponds to 380 μs (i.e., 1/2,632), and the mean time between leakage events—*the non-adjoint-weighted escape lifetime*—corresponds to 173 μs (i.e.,1/5,789). In general, the non-adjoint-weighted lifetime corresponding to a particular type of event can be calculated by dividing the non-adjoint-weighted removal lifetime by the probability of occurrence:

$$\tau_x = \frac{\tau_r}{P_x} \quad . \tag{3}$$

A complete summary of these lifetimes and their relationship to other systems parameters is shown in Table 1.

In the above example, we defined the non-adjoint-weighted removal, fission, capture, and escape lifetimes. All four of these lifetimes are associated with events in which a neutron disappears from the system. We can also define another lifetime that is associated with the production of neutrons. We refer to this production lifetime as a neutron *generation time* and define it as the mean time between the appearance of fission production neutrons. In accordance with this definition, the neutron generation time for this example corresponds to 84.5 μs (i.e., 1/11,842). Note that the generation time is a factor of $\overline{\nu}$ smaller than the fission lifetime, 211.1 μs. Also note that the ratio of the removal lifetime to the neutron generation time is identically equal to k_{eff}—as it should be. When $k_{eff} < 1.0$, neutrons are being removed faster than they are being produced by fission; hence, the removal lifetime must be smaller than the generation time.

MCNP4B is programmed to calculate the non-adjoint-weighted removal lifetime from estimates of the capture, fission, and escape lifespans in accordance with Eq. (2). A new lifetime table is contained in the output file which gives values for the removal, fission, capture, and escape lifetimes as well as for the lifespans for fission, capture, and escape. Furthermore, a new tally multiplier allows other non-adjoint-weighted lifetimes, corresponding to other types of reactions, to be determined via a track-length tally.[3] This option is particularly useful when estimating die-away time constants for (n,γ) reactions in non-multiplying systems which are widely used in nuclear well-logging applications.

In summary, a neutron lifespan is the average time from birth-to-event, whereas, a neutron lifetime is the mean time from event-to-event. A neutron lifetime is associated with the loss of a neutron from the system, whereas, a neutron generation time is the mean time between the appearance of neutrons produced by fission reactions. As we have shown, albeit somewhat informally, the neutron removal lifetime is a function of several neutron lifespans. The neutron generation time, however, is strictly a function of the fission reaction rate and, as such, is not related to the neutron lifetime per se. However, the neutron lifetime and the neutron generation time can be related to each other by the effective multiplication factor.

Table 1: Summary of Neutron Balance

Quantity		Time Constant
k_{eff}	0.9	
Equilibrium Neutron Population	1.0	
Fission lifespan (birth-to-fission)	36%	100 μs
Capture lifespan (birth-to-capture)	20%	90 μs
Escape lifespan (birth-to-escape)	44%	50 μs
Absorbed in Fission Reactions	4,737 n/s	—
Absorbed in Capture Reactions	2,632 n/s	—
Leakage Rate	5,789 n/s	—
Total Loss Rate =	13,158 n/s	—
Source Injection Rate	1,316 n/s	—
Fission Neutron Production Rate	11,842 n/s	—
Total Appearance Rate =	13,158 n/s	—
Unweighted Removal Lifetime (mean time between removal events)	[see Eq. (2)]	76 μs
Unweighted Fission Lifetime (mean time between fission events)	76 μs/0.36	211.1 μs
Unweighted Capture Lifetime (mean time between capture events)	76 μs/0.20	380 μs
Unweighted Escape Lifetime (mean time between leakage events)	76 μs/0.44	173 μs
Source Lifetime (mean time between source neutrons)	1/1,316	760 μs
Unweighted Generation Time (mean time between fission neutrons)	1/11,842	84.5 μs

REFERENCES

1. G. D. SPRIGGS, R. D. BUSCH, K. J. ADAMS, D. K. PARSONS, L. PETRIE, and J. S. HENDRICKS, "On the Definition of Neutron Lifetimes in Multiplying and Non-Multiplying Systems," Los Alamos National Laboratory report, to be published (1997).

2. J. F. BREIMEISTER, "MCNP-A General Monte Carlo Code for Neutron and Photon Transport," Los Alamos National Laboratory report LA-7396-M, Rev. (Sept. 1986).

3. J. S. HENDRICKS, and G. D. SPRIGGS, "Lifetime Patch Documentation," Los Alamos National Laboratory memo XTM:JSH-96-427 (U) (Dec. 19, 1996).