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Observations Regarding Fixed Decay Constants on the Reactivity Prediction for the Fast Fission of U-235

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Introduction

Delayed neutron precursors have traditionally been represented by six-groups. The group yields and decay constants (a_i and λ_i, respectively, for $1 \leq i \leq 6$) are obtained from nonlinear fits to delayed neutron emission rates obtained experimentally. Each fit to the data produces a different set of group decay constants based on the statistical precision of the instruments used and on the time domain used. As a result, standard data libraries contain different sets of group decay constants for each fissionable nuclide based on the nonlinear least-squares fit. The group decay constants for thermal and fast fission of the same fissile nuclide are also different. The advantages of using a single set of decay constants for all isotopes facilitate the analysis to cores that have different types of fissionable materials. This and other advantages have been discussed by several authors.[1,2,3] Cahalan and Ott developed six-group formulations with fixed decay constants for fast fission of eight different nuclides.[2] A simpler transformation is used in this work to demonstrate that fixed-decay-constant formulations can easily be developed and differences in reactivity introduced by the transformation are very small. The seven decay constants used for this demonstration are not optimal or recommended in any sense. The selection of a fixed set of decay constants that could be used for all fissionable nuclides and neutron energies appears feasible and is under study, but it is well beyond the scope of this abstract.

Description

Group yields and decay constants appear in the inhour equation in a sum of terms $a_i/(\omega+\lambda_i)$, where ω is the inverse reactor period. Row 1 of Table I compares reactivity predictions from the Godiva assembly based on Keepin's original[4] six-group parameters for the fast fission of U-235. Rows 2 and 3 present six-group and seven-group parameters obtained by Loaiza[5] in measurements performed at Los Alamos Critical Experiments Facility using Godiva IV for the fast fission of U-235. The time-dependent six-group representation from the Loaiza experiments predict reactivities within 5% or less for periods smaller than 50 seconds when compared to the traditional six-group Keepin representation. The greatest difference is 6% for larger periods. This difference is attributed to the enrichment of the sample used, which was 93% compared to Keepin's 99.9%. Therefore, there will be a contribution of about 7% from the U-238 delayed neutrons to the reactivity scale.

Rows 4-6 in Table I are alternative formulations that correspond to rows 1-3, but which use a fixed set of seven-group decay constants (0.01247, 0.02829, 0.04332, 0.115, 0.311, 1.4, and 3.87). The first three of these decay constants are those for the dominant long-lived precursors Br-87, I-137 and Br-88. The decay constants for groups 4-7 are Keepin's group 3-6 values, which match very well the decay constants of the Loaiza experiment. The alternative formulations in Table I are obtained by forcing the sum of $a_i/(\omega+\lambda_i)$ to be equal at seven periods, spaced to provide equal delayed reactivity increments. Each of the fixed-decay-constant formulations in rows 4-6 agrees to within 0.01% with its counter part from rows 1-3. Similar agreement has been obtained with established six-group formulations for thermal and fast fission of other nuclides.

Row 7 of Table I results from direct linear least-squares fit to Loaiza's data using the aforementioned decay constants. The χ^2 value for this linear least-squares fit is slightly better than that obtained for the six- and seven-group nonlinear least-square fits (Rows 2 and 3). These results indicate that a fixed-decay-constant formulation can provide an adequate fit to the experimental data without affecting the reactivity scale.

The constants a_1, a_2, and a_3 for cases 4-7 may be interpreted as the fractional delayed neutron yields of Br-87, I-137, and Br-88. The results shown are generally consistent with published precursor yields and delayed neutron emission probabilities; however, the quality of the estimates may be affected by the nonphysical decay constants assumed for groups 4-7 or the use of the least-squares method. On the other hand, Gudkov et al used an incremental deconvolution method to estimate yields for eight precursors (Br-87, I-137, Br-88, I-138, Rb-93, Br-89, Rb-84, and I-139) for eleven fissionable nuclides.[6]

Results

Fixed decay constant formulation are readily obtained, predict reactivities adequately, and offer several advantages. First, the determination of kinetics response for mixtures of fissionable nuclides is simplified. The effective group yields become concentration-weighted averages of the precursor yields of the individual fissionable nuclides. Second, the yields of the longest-lived groups can be associated with dominant long-lived precursors. This assures a consistent physical interpretation of asymptotic and near asymptotic negative periods, and also permits comparison between experimentally measured and theoretically computed precursor yields. Finally, experimental error analysis is facilitated. The linear least-squares method provides a direct estimate of group yield errors, and error estimates associated with individual delayed-critical and burst irradiations can be combined in a straightforward manner.

Table I. Impact of alternative group parameters on computed Godiva reactivity

Case	**Maximum Difference in Computed Reactivities (Alternate-Base)/Base**	
1. Nonlinear least-squares, Six-group Keepin Data **#** **(a_i/a)** **λ (sec^{-1})** 1. 0.038±0.003 0.0127±0.0002 2. 0.213±0.005 0.0317±0.0008 3. 0.188±0.016 0.115±0.003 4. 0.407±0.007 0.311±0.008 5. 0.128±0.008 1.40±0.081 6. 0.026±0.003 3.87±0.369	Base	-6.6%
2. Nonlinear least-squares, Six-group Loaiza Data **#** **(a_i/a)** **λ (sec^{-1})** **χ^2 = 1.012** 1. 0.039±0.001 0.0127±0.0001 2. 0.235±0.005 0.0315±0.0004 3. 0.207±0.008 0.117±0.006 4. 0.381±0.011 0.314±0.010 5. 0.114±0.005 1.37±0.051 6. 0.024±0.001 3.83±0.114	7.0%	Base
3. Nonlinear least-squares, Seven-group Loaiza Data **#** **(a_i/a)** **λ (sec^{-1})** **χ^2 = 1.13** 1. 0.027±0.005 0.0127±0.0009 2. 0.135±0.008 0.0287±0.003 3. 0.130±0.009 0.035±0.005 4. 0.275±0.023 0.157±0.032 5. 0.306±0.045 0.322±0.014 6. 0.092±0.006 1.41±0.06 7. 0.035±0.004 3.82±0.26	6.0%	-2.6%
4. Fixed λ Seven-group fit to case 1 (Keepin six-group formulation) **#** **a_i/a** **λ (sec^{-1})** 1. 0.034 0.01247 2. 0.155 0.02829 3. 0.069 0.04332 4. 0.178 0.115 5. 0.410 0.311 6. 0.127 1.40	0.011%	-6.6%

7. 0.026 3.87		
5. Fixed λ Seven-group fit to case 2 (Loaiza six-group formulation) # a_i/a λ (sec^{-1}) 1. 0.035 0.01247 2. 0.174 0.02829 3. 0.072 0.04332 4. 0.191 0.115 5. 0.391 0.311 6. 0.114 1.40 7. 0.022 3.87	7.0%	0.011%
6. Fixed λ seven-group fit to case 3 (seven-group Keepin formulation) # a_i/a λ (sec^{-1}) 1. 0.021 0.01247 2. 0.223 0.02829 3. 0.018 0.04332 4. 0.220 0.115 5. 0.400 0.311 6. 0.076 1.40 7. 0.041 3.87	6.0%	-2.6%
7. Linear least-squares, seven-group fit to Loaiza Data # (a_i/a) λ (sec^{-1}) χ^2 = 1.007 1. 0.038±0.0015 0.01247 2. 0.151±0.0063 0.02829 3. 0.086±0.0062 0.04332 4. 0.179±0.0041 0.115 5. 0.414±0.0026 0.311 6. 0.111±0.0025 1.40 7. 0.021±0.0021 3.87	4.7%	-2.4%

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