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Seven Surrogate Precursors for Modeling Delayed Neutron Decay and Predicting Reactivity

by

David J. Loaiza and F. Eric Haskin

1. Introduction

Delayed neutron activity has traditionally been represented by six delayed neutron groups, whose yields and decay constants are obtained from nonlinear least-squares fits to out-of-pile measurements.[1] The six-group delayed neutron decay constants obtained in this manner are empirical fits to the data. They cannot be matched with decay constants of specific delayed neutron precursors. The traditional six-group delayed neutron decay constants are, therefore, different for each fissionable nuclide. In addition, the traditional group decay constants for any particular fissionable nuclide changes with the neutron energy spectrum.

The use of a different set of group decay constants for each fissionable nuclide complicates analysis of the dynamic behavior of fast reactors. A fast reactor containing six principal fissioning nuclides of uranium and plutonium must, in effect, be described by 36 delayed neutron groups.[2] Additionally, the use of group decay constants that depend on the neutron energy spectrum makes it difficult to select values that describe the dynamic response of epithermal systems because virtually all delayed neutron activity measurements have been performed for fast or thermal-neutron-induced fission.

Clearly, it would be desirable to have a single set of group decay constants that could be applied to all fissionable nuclides. A set of seven fixed decay constants is proposed herein. Each of the proposed decay constants is associated with a specific, dominant delayed neutron precursor. In effect, each group is represented by a single surrogate precursor. Using recently measured delayed neutron activities for U-235 and Np-237,[3] the proposed set of decay constants actually improved the goodness of fit to the data. For other fissionable nuclides lacking experimental data, a method has been devised to obtain yields consistent with the proposed set of decay constants from the traditional six-group parameters. This transformation is accomplished without altering the traditional inferred reactivity scale.

2. Identification of Dominant Precursors

In order to identify a set of decay constants that are independent of the fissioning nuclide and the neutron energy spectrum, precursors that are dominate contributors to the delayed neutron activity were first identified. From the data prepared by England and Rider precursor yields and probability of neutron emission, P_n, values were extracted for the 271 known delayed neutron precursors.[4] The effective delayed neutron yield for each precursor was obtained by multiplying the P_n value by the precursor yield. Based on these effective yields 13 precursors were consistently found to be the dominant contributors to delayed neutron activity for 32 fissioning systems. A sensitivity analysis was performed to identify a set of seven dominant surrogate precursors that provide excellent agreement with the traditional reactivity scale based on Keepin's six-group formulations. Table I summarizes the seven surrogate precursors that were selected and their half-lives. Note that two of the surrogate precursors, I-137 and Br-88, come from traditional group 2. It is suggested that the traditional group 2 should be split into two new groups. This recommendation is supported by performing a regression analyses in the experimental data of U-235. From this regression analysis, the half-lives of the three longest lived precursors were identified. A six-group formulation with fixed decay constants can also be obtained by using the geometric average of the I-137 and Br-88 half-lives. Results from the seven-group formulations are discussed herein.

Table I. Seven-group Surrogate Delayed Neutron Precursors

Group Numbers	Dominant Precursor	Half-life (sec)
1	Br-87	55.9
2	I-137	24.5
3	Br-88	16.4
4	Rb-93	5.85
5	I-139	2.30
6	Br-91	0.54
7	Rb-96	0.199

3. Results

When the dominant-precursor decay constants from Table I are used to fit experimental data with a linear least squares method, the goodness of fit actually improves over that obtained using a nonlinear least square fit in which both group yields and decay constants are determined. Table II shows the goodness of fit to experimental data from U-235 and Np-237. Using standard least-squares algorithms, linear least squares fits are slightly better than the corresponding nonlinear fits in which both group yields and decay constants are determined. Although the six-group nonlinear fit is better than the seven-group nonlinear fit, the linear fit seven groups is marginally better than that for six-groups. The fact that a nonlinear fit using eight groups did not converge supports the selection of seven surrogate precursors.

Table II. Goodness of Fit Test to Experimental Data

Number of Groups	Fissionable Nuclide	Type of Least Squares Fit	Reduced Chi-square
6	U-235	Nonlinear	1.032
6	U-235	Linear	1.006
6	Np-237	Nonlinear	1.057
6	Np-237	Linear	1.011
7	U-235	Nonlinear	1.135
7	U-235	Linear	1.003
7	Np-237	Nonlinear	1.141
7	Np-237	Linear	1.008
8	U-235/Np-237	Nonlinear	Did Not Converge

Previous work showed that traditional six-group formulations can be transformed to equivalent fixed-decay-constant, seven-group formulations without introducing significant differences in reactivity predictions.[5] The transformation preserves the integral characteristics of delayed neutrons such as the total delayed neutron yield per fission, the average decay time, and the mean decay time. The maximum relative deviation observed from the traditional inhour reactivity prediction for periods from delayed critical to prompt critical is 10^{-4} to 10^{-5} for the fixed-decay-constant seven surrogate precursor formulation (see Table III) and roughly and order of magnitude (10^{-3} to 10^{-4}) larger using six fixed decay constants.

Table III presents the abundances obtained for nine important fissioning systems for the seven-group surrogate-precursor formulations. The last column in table III shows the maximum relative error obtained when comparing delayed reactivity based on the fixed-decay-constant representation to that based on the traditional six-group parameters of Keepin and ENDF/B-V.

Table III. Abundances for Seven-Group Surrogate Precursors

Dominant Surrogate Precursors and Half-lives								
Half-lives (sec)	Br-87 55.9	I-137 24.5	Br-88 16.4	Rb-93 5.85	I-139 2.3	Br-91 0.54	Rb-96 0.199	Max Relative Error[a]
Abundances based on Seven-Group Fixed Decay Constants								
U-235F	0.0339	0.1458	0.0847	0.1665	0.4069	0.1278	0.0344	2.3E-5
U-235T	0.0321	0.1616	0.0752	0.1815	0.3969	0.1257	0.0270	8.2E-5
U-238F	0.0168	0.0239	0.1488	0.0254	0.4650	0.2222	0.0979	4.3E-4
U-233F	0.0788	0.1666	0.1153	0.1985	0.3522	0.0633	0.0253	7.3E-5
U-233T	0.0787	0.1723	0.1355	0.1884	0.3435	0.0605	0.0211	6.5E-5
Pu-239F	0.0312	0.2215	0.0670	0.1643	0.3703	0.1183	0.0274	8.9E-5
Pu-239T	0.0301	0.2522	0.0578	0.1728	0.3514	0.1153	0.0204	1.6E-4
Pu-240F	0.0224	0.2056	0.0777	0.1350	0.3914	0.1327	0.0352	2.5E-4
Pu-241F	0.0090	0.1780	0.0658	0.1094	0.4001	0.2004	0.0353	2.8E-4
Pu-242F	0.0023	0.1336	0.0722	0.1145	0.4361	0.2273	0.0140	1.8E-5
Th-232F	0.0346	0.0561	0.1159	0.0930	0.4830	0.1849	0.0325	4.3E-4
Np-237F	0.0350	0.1983	0.0741	0.1428	0.3822	0.1490	0.0186	2.3E-4

[a] Taking correct delayed reactivity to be that based on Keepin's six-group parameters.

4. Conclusions

The proposed seven-group surrogate-precursor representation improves the fit to experimental data, reproduces the reactivity scale associated with traditional six-group representations for all fissionable nuclides analyzed, and offers significant simplifications in the analysis of fast and epithermal reactors with multiple fissioning nuclides.

5. References

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