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SPENT-FUEL PHOTON AND NEUTRON SOURCE SPECTRA*

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Computational activities at Oak Ridge National Laboratory have been performed to develop appropriate data and techniques for computing the photon and neutron source spectra of spent fuel. The methods reviewed here include both the determination of spent-fuel composition and the radiation source spectra associated with these isotopic inventories.

The nuclide concentrations in spent fuel may be computed by either ORIGEN2[1] or ORIGEN-S,[2] two improved versions of the ORIGEN code,[3] or the SAS2 control module of the SCALE system.[2] These codes basically apply the same matrix-exponential-expansion model, but use different approaches in the preparation of cross-section constants. ORIGEN2 uses improved libraries of burnup-dependent cross-section constants that were derived from separate reactor analyses for specific types of reactors and fuel compositions.[4,5] ORIGEN-S uses burnup- and reactor-dependent libraries produced by SAS2 or the code may be used directly with basic libraries.[2,3,6,7] The primary function of SAS2 is to compute photon and neutron dose rates from shipping casks containing spent-fuel assemblies. The spent-fuel composition of these assemblies, specified by the unit-cell description and operating history input to the case, is computed in a depletion analysis performed by functional modules of SCALE.

In addition to functions discussed above, ORIGEN2, ORIGEN-S and SAS2 are relatively easy to apply in determining the photon source spectra of spent fuel at requested cooling times. The Master Photon Data Base,[8] containing energy-dependent photon-intensity data for more than 400 individual nuclides is utilized by the codes for computing the spectra. This data base, originally prepared for ORIGEN2, includes data from five different types of photon-production processes: (1) x-rays and γ-rays from delayed decay, (2) γ-rays produced from (α,n) reactions,[9,10] (3)

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prompt fission photons from spontaneous fission,[8,11] (4) delayed γ-rays from spontaneous fission,[8,12] and (5) bremsstrahlung produced from positron and negatron deceleration. The data for x-rays and γ-rays from the delayed decay of activation and fission products were taken from the Evaluated Nuclear Structure Data File (ENSDF).[13,14] The photon libraries used by the codes may include bremsstrahlung data developed[15] for either a uranium dioxide medium or a water medium. The photon source spectra computed by ORIGEN2 has an energy-group-structure that is frequently applied in shielding analyses. The energy-group-structure used in calculating the photon spectra in ORIGEN-S may be input by the user, whereas, SAS2 uses that of the photon cross-section library requested for the shielding analysis. The photon source spectrum of a 90-day-cooled PWR assembly, computed by SAS2, is shown in Fig. 1.

SAS2 can be applied to compute the neutron source spectra of spent fuel. The development of the method for computing a neutron source spectrum emitted within an oxide medium, i.e., for spent fuel from most types of reactors, required data of the following types: (1) α-decay half-lives and energies,[2,14] (2) neutron yields per fission[16] and half-lives[2,14,16] for spontaneous fission, (3) thick target neutron yields per (α,n) reaction in UO_2, as a function of α-energy, (4) neutron spectra from spontaneous fission, (5) neutron spectra from (α,n) reactions caused by α-decay from heavy nuclides and (6) the spent-fuel composition. The thick target (α,n) neutron yield data were produced by Bair and del Compo[17] by measuring thin target cross sections of $^{17}O(\alpha,n)$ and $^{18}O(\alpha,n)$ reactions and computing the thick target energy-dependent yields in UO_2. Since ^{242}Cm, ^{244}Cm and ^{238}Pu produce almost all of the neutron source in spent fuel, spectra from each of these isotopes (excluding spontaneous fission from ^{238}Pu) are applied first in deriving the neutron source spectrum. Then, the final spectrum is computed by simply normalizing this spectrum to the total neutron source strength. The spectra data[9,18-20] for these three isotopes were determined either by measurements or by calculations applying experimental data of other isotopes. An approximate uncertainty of the spectra data was derived[2] by comparing it with the total spectrum measured[21] for both ^{242}Cm and ^{252}Cf. Also, most of the neutron production data described above have been used with compositions computed by ORIGEN2 in evaluating[22] various shipping cask designs.

The method and data applied in computing photon source spectra described here, due to the contributions of numerous researchers, represent a notable achievement in the field of radiation science. Also, there is a significant improvement over previous methods of computing neutron source spectra. All three codes, including the data bases, are available from the Radiation Shielding Information Center (ORNL).

GAMMA SOURCE SPECTRUM FOR GAMMA LINES (SAS2)

90.00 DAY TIME OF THE REQUESTED NUCLIDES

ENERGY INTERVAL IN MEV			PHOTONS / SECOND	MEV / SECOND
1.0000E-02	TO	5.0000E-02	2.1970E+16	6.5911E+14
5.0000E-02	TO	1.0000E-01	6.8519E+15	5.1389E+14
1.0000E-01	TO	2.0000E-01	8.3370E+15	1.2505E+15
2.0000E-01	TO	3.0000E-01	1.6638E+15	4.1594E+14
3.0000E-01	TO	4.0000E-01	1.2949E+15	4.5323E+14
4.0000E-01	TO	6.0000E-01	1.0888E+16	5.4439E+15
6.0000E-01	TO	8.0000E-01	3.8119E+16	2.6684E+16
8.0000E-01	TO	1.0000E+00	1.7085E+15	1.5376E+15
1.0000E+00	TO	1.3300E+00	8.0689E+14	9.4002E+14
1.3300E+00	TO	1.6600E+00	5.4587E+14	8.1607E+14
1.6600E+00	TO	2.0000E+00	3.7805E+13	6.9184E+13
2.0000E+00	TO	2.5000E+00	1.6281E+14	3.6633E+14
2.5000E+00	TO	3.0000E+00	1.0535E+13	2.8972E+13
3.0000E+00	TO	4.0000E+00	2.9931E+11	1.0476E+12
4.0000E+00	TO	5.0000E+00	8.2902E+06	3.7306E+07
5.0000E+00	TO	6.5000E+00	3.3245E+06	1.9116E+07
6.5000E+00	TO	8.0000E+00	6.5171E+05	4.7249E+06
8.0000E+00	TO	1.0000E+01	1.3830E+05	1.2447E+06
TOTALS			9.2398D+16	3.9179D+16

TOTAL ENERGY FROM NUCLIDES WITH SPECTRUM DATA = 3.9175E+16

TOTAL ENERGY FROM NUCLIDES WITH NO SPECTRUM DATA = 4.3040E+12

Fig. 1. An example of a photon source spectrum produced by SAS2

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