Evaluated Neutron Capture Cross Section for Samarium and Xenon Fission Products

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ABSTRACT

The neutron-capture cross-sections of the fission products are extremely important in the design of reactors, as well as in nuclear reactor operation. A special consideration is usually given to the Xe-135 and Sm-149 which are considered as a highly poisoning material in the operation of nuclear reactors. The evaluated neutron-capture cross-sections based on the credible experimental data are essential in order to increase the safety factors of reactor designs; we evaluate the cross sections of some of the Xenon and Samarium isotopes published by the major international nuclear institutions and determine the discrepancies among libraries.

INTRODUCTION

Neutron Cross section data play a major role in the design of nuclear reactors, as well as in reactor safety analysis. The evaluated data libraries currently being used for many applications, such as burn-up, calculation for spent fuel transportation, criticality calculation and design analysis are the base of any reactor activity. A number of improved neutron capture cross section are elaborated by some national institution and accepted by the international agency of nuclear energy are available for researchers of reactor designers.

Some of fission products created as a result of the fission in the reactor has a large neutron capture cross sections both in thermal and epithermal energy range. The neutrons absorbed by these fission products represent a significant portion of the total loss of neutron in reactors.

Fission fragments generated at the time of fission decay can produce a variety of fission products. These fission products are of concern in reactors primarily because they become parasitic absorbers of neutrons and result as long term sources of heat. Although several fission products have significant neutron absorption cross sections, Especially Xenon-135 and Samarium-149 which have the most substantial impact on reactor design and operation. They have a high
neutron absorption capacity, such as Xenon-135 (2,000,000 barns) and Samarium-149 (74,500 barns). As these two fission product poisons remove neutrons from the reactor, they will have an impact on the thermal utilization factor and the effective multiplication factor and reactor reactivity. The poisoning of a reactor core by these fission products may become so serious that the chain reaction comes to a standstill [1].

Xenon-135 in particular has a tremendous impact on the operation of a nuclear reactor. The inability of a reactor to be restarted due to the effects of Xenon-135 is sometimes referred to as Xenon precluded startup. The period of time in which the reactor is unable to override the effects of Xenon-135 is called the Xenon dead time or poison outage. During periods of steady state operation, at a constant neutron flux level, the Xenon-135 concentration builds up to its equilibrium value for that reactor power in about 40 to 50 hours. When the reactor power is increased, Xenon-135 concentration initially decreases because the burn up is increased at the new higher power level. Because 95% of the xenon-135 production is from the decay of Iodine-135, which has a 6.57 hour half-life, the production of Xenon-135 via decay of Iodine-135 will continue since the half life of Iodine-135 is shorter than the half life of Xenon-135[2].

Samarium is a widely used rare earth element in nuclear reactors as a neutron absorber because of high thermal and epithermal neutron cross sections of some of its isotopes, they has also a great importance in nuclear medicine for therapeutic purposes because of the suitable decay and dose parameters of some radioisotopes to be delivered to the patient. a stable isotope, Sm-152 is used as control material in nuclear reactors, it’s produced radioactive isotope, and Sm-153 is used as one of the negative beta emitters therapeutic radioisotope in nuclear medicine for tumor therapy and bone pain palliation due to its high local beta dose per disintegration and suitable half-life (46.5 h).The radioactive isotopes Sm-153 decay with a half life of (46.384h) to the stable Eu-153 and emit strong radiation of 69.67 keV and 103.18 keV[3].

The accurate knowledge of the $^{151}\text{Sm} (\text{n, } \gamma)$ cross section has an important implications for nuclear technology developments as well as in fundamental nuclear physics. The $^{151}\text{Sm} (\text{n, } \gamma)$ reaction rate has a great relevance in nuclear astrophysics as this isotope is an important branching-point isotope in the slow process (s process) path; the s-process flow has the possibility of undergoing neutron capture or, alternatively, $\beta$-decay. Since the relative probability of the two processes depends on the stellar thermodynamic conditions, in particular on the temperature as well as on the capture rate [4].
Because Samarium-149 is not radioactive and is not removed by decay, it presents problems somewhat different from those encountered with Xenon-135. The equilibrium concentration and (thus the poisoning effect) builds to an equilibrium value during reactor operation in about 500 hours (about three weeks), and since Samarium-149 is stable, the concentration remains essentially constant during reactor operation [3].

A number of different national and international comities have been engaged in considerable theoretical and experimental efforts to build their nuclear data libraries. The most recent evaluated neutron nuclear data libraries concerning the fission products are actually JENDL-4 from Japan[5,6]EXFOR from IAEA[7],ENDF/B-V1 release 8 from United States[8],JEFF-3.0 and JEF-2.2 from Europe [9], BROND-2 from Russia [10], and CENDL-3.0 from China [11]. These libraries are considered now as containing the most up-to-date nuclear data of evaluated (recommended) cross sections, spectra, angular distributions, fission product yields, thermal neutron scattering, photo-atomic reactions, and other data which are important in neutron-induced reactions relevant principally to reactor calculations [12,13]. They contain too cross sections of numbers of fission products nuclides according to their yields, half-lives, capture, elastic, inelastic and absorption cross sections, for example the Chinese library contain 138 fission product nuclides which are evaluated in the energy range from 1.e-5 eV to 20. MeV, while the Japanese, European, Russian and American libraries they contains 209, 203, 36 and 199 respectively mostly in the same energy range.

**Calculation Method and Results**

One of the main important utilization of the fission product cross sections is illustrated in the time-dependent behavior of neutron absorption in fission products which is considered as a major problem concerning the reactor depletion calculation. The degree of complexity required for adequate treatments of fission products build up depends on several factors, such as, energy spectrum, fuel isotope composition and burn up rate, neutron capture and total cross sections, isotopic yields productions... etc.

An exact calculation of full fission products build up is not feasible since there are several hundreds of fission products nuclides, and some number of lattice group constants for core calculation which have to be generated at numerous points. The calculations are done using a modular program system composed of number of codes capable to do cross section preparation, flux calculations and evaluations, burn-up and depletion calculation in terms of time and reactor power.
Such models, even the most sophisticated, which must take into account the half-life, yield and nuclear transformation as show in fig (1) due to the decay to other nuclides during the reactor operation, cannot give in spite of the very important and substantial progress in this area a definite cross section values due to the complexity of the problem originated practically by the complicated process of fission.

From the large number of fission products and excluding all of those having half-lives in seconds or minutes, we present some representative fission products having the following characteristics:

Four of them are stable or (very long half life), and these are:

Samarium-149, Samarium-150, Samarium-152, Xenon-134

One of them (Samarium-151) has medium-lived fission product and acts as a neutron poison in the nuclear fuel cycle, the half-life of Samarium-151 is (90y)

One of them has a large cumulative yield, which is:

Xenon-135(6.54%),

One of the selected fission products has acceptable half-life for measurement purpose which is Samarium-153(46.284 h)

In order to obtain an average value($Y$) for the different libraries data we applied the following weighted mean formula [14],

$$Y = \frac{\sum w_i y_i}{\sum w_i}$$

Where: $w_i = 1/\sigma_i^2$

$\sigma_i$ = standard deviation of sample i

$y_i$ = cross section value of sample i

Some libraries declare the uncertainty of calculation which we considered; otherwise we used 10% for the unmentioned error as usually recommended by the IAEA.

Using the above formula, different sets of programs are built in Matlab language depending on the number of data used (From 3 to 7 sets of cross section data), and has an energy interval considered is from 0.00001 to 20 MeV.

Results of 7 fission products (from different libraries and evaluated data) are presented in graphs as shown in figures (2-8).

**CONCLUSION**

The evaluated capture cross sections of seven fission products are based on the main international data libraries presented in figures (2-8). The average weighted values indicate clearly the necessity to adopt such calculations which are very important for some problems such as neutron dosimetry, fuel burn-up and determination of isotope production.
A complete dependency on individual or even collective experimental results are not recommended due to experimental deviations and errors and the impossibility of measurement for all the detailed interval of energy. This may be one of the important reasons to explain the observed deviations in some energy intervals of the international libraries. Thus using the weighted average one can obtain an accurate, complete and deviation less results in some energy intervals of the international libraries.

Fig -1: Schematic decay representation of some fission products [15].

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\begin{align*}
^{140}\text{Ba} & \rightarrow ^{149}\text{La} \rightarrow ^{149}\text{Ce} \rightarrow ^{149}\text{Pr} \rightarrow ^{149}\text{Nd} \rightarrow ^{149}\text{Pm} \rightarrow ^{149}\text{Sm}(\text{stable}) & 93.1\text{ d} \\
^{150}\text{Pm} & \rightarrow ^{150}\text{Sm}(\text{stable}) \\
^{151}\text{La} & \rightarrow ^{151}\text{Ce} \rightarrow ^{151}\text{Pr} \rightarrow ^{151}\text{Nd} \rightarrow ^{151}\text{Pm} \rightarrow ^{151}\text{Sm} \rightarrow ^{151}\text{Eu} & 151\text{ Gd} \\
^{152}\text{Ba} & \rightarrow ^{152}\text{La} \rightarrow ^{152}\text{Ce} \rightarrow ^{152}\text{Pr} \rightarrow ^{152}\text{Nd} \rightarrow ^{152}\text{Pm} \rightarrow ^{152}\text{Sm}(\text{stable}) \\
^{153}\text{La} & \rightarrow ^{153}\text{Ce} \rightarrow ^{153}\text{Pr} \rightarrow ^{153}\text{Nd} \rightarrow ^{153}\text{Pm} \rightarrow ^{153}\text{Sm} \rightarrow ^{153}\text{Eu}(\text{stable}) \\
^{134}\text{In} & \rightarrow ^{134}\text{Sm} \rightarrow ^{134}\text{Te} \rightarrow ^{134}\text{Xe} \rightarrow ^{135}\text{Cs} \rightarrow ^{134}\text{Ba} & 19.5\text{ h} \\
^{135}\text{Sn} & \rightarrow ^{135}\text{Sb} \rightarrow ^{135}\text{Te} \rightarrow ^{135}\text{Xe} \rightarrow ^{135}\text{Cs} \rightarrow ^{135}\text{Ba}(\text{stable}) & 135\text{ La} \rightarrow ^{135}\text{Ce} \rightarrow ^{135}\text{La}
\end{align*}
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Fig. 2: capture cross section of Sm-149

Fig. 3: capture cross section of Sm-150

Fig. 4: capture cross section of Sm-151
Fig. 5: capture cross section of Sm-152

Fig. 6: capture cross section of Sm-153
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Fig. 7: Capture Cross Section of Xe-134

Fig. 8: Capture Cross Section of Xe-135
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