Need for $^{16}O(n, \alpha)$ Measurement and Evaluation in the Range 2.5 to 10 MeV

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Abstract

This document summarizes the request for the measurement of $^{16}O(n, \alpha)$ cross section from 2.5 to 10 MeV. A brief status of the available measurements and evaluations is given. The benefit of a new measurement and evaluation is illustrated by several examples of application in the field of reactor physics and neutron cross-section metrology.

1 Introduction

The High Priority Request List (HPRL) is maintained by the Nuclear Energy Agency (NEA) and a new website *http://www.nea.fr/html/dbdata/hprl/index.html* is now open to submit requests for new evaluations and measurements. This working document suggests the measurement and the evaluation of $^{16}O(n, \alpha)$ cross section to improve the k_{eff} predictions of thermal and fast reactors as well as the calculation of Helium production in reactor. $^{16}O(n, \alpha)$ is also important for the measurement of neutron source strength.

This document attempts to summarize discussions and exchanges of e-mails between several people including: D. Bernard (CEA), O. Bouland (CEA), A. Carlson (NIST), A. Courcelle (CEA), S. Dewey (NIST), G. Hale (LANL), R. Jacqmin (CEA), C. Lubitz (KAPL), P. Page (LANL), A. Santamarina (CEA), R. Sayer (ORNL), and J. Tommasi (CEA).

2 Brief survey of measurements and evaluations

The threshold of $^{16}O(n, \alpha)$ reaction is 2.36 MeV. By use of reciprocity theorem, $^{16}O(n, \alpha)$ cross section can be deduced from $^{13}C(\alpha, n)$ reaction. Table 2 presents the measurements of $^{16}O(n, \alpha)$ and $^{13}C(\alpha, n)$ available in experimental databases and open publications below 10 MeV (neutron energy).

Numerous measurements of angular distribution of $^{13}C(\alpha, n)$ reaction are also reported [1]. Other experimental data exist at higher energies for fusion application and are not discussed here. Despite large number of experiments, most of them were performed with a rather poor energy (neutron or α) resolution.

ENDF/B-VI.8 and JEFF3.1 share the same evaluation based on the work of G. Hale et al. [15] at LANL using the R-matrix EDA code. In the range 3-8 Mev, large differences between $^{16}O(n, \alpha)$ cross-section level (10% to 50%) are noticed as shown in Figure 1: JENDL3.3 being significantly lower than in ENDF/B-VI.8.

Reference
$^{16}O(n,\alpha)$ measurement.
Seitz et al. - 1955 [2]
Walton et al. - 1957 [3]
Lister et al. - 1967 [4]
Dandy et al. - 1968 [5]
$^{13}C(\alpha,n)$ measurement.
Bonner et al. - 1956 [6]
Walton et al. - 1957 [3]
Sekharan et al. - 1967 [7]
Davids et al. - 1968 [8]
Bair et al. - 1973 [10]
S.E.Kellogg et al. - 1989 [11]
Drotleff et al. - 1993 [12]
Heil et al. - 2002 [13]

Table 1: Overview of measurements of $^{16}O(n,\alpha)$ and $^{13}C(\alpha,n)$ cross sections in the range 2.5 to 10 MeV. Other older measurements are not quoted.

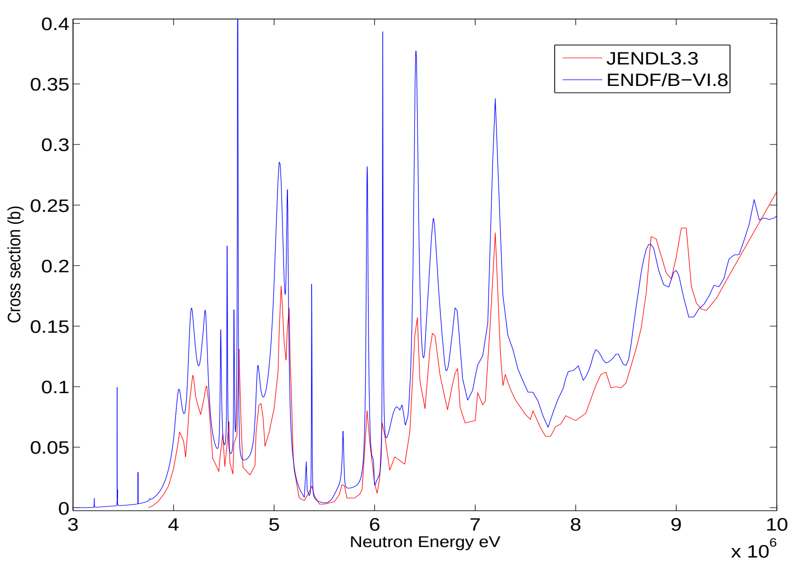

Figure 1: $^{16}O(n,\alpha)$ cross section in ENDF/B-VI.8 and JENDL3.2

Recent R-matrix analysis of (n, α) was also performed at ORNL with the SAMMY code by R. Sayer et al. [1]. $^{16}O(n, \alpha)$ values from ORNL and LANL evaluations are mainly based on the measurements of Drotleff et al. [12] and Bair et al.[10], which are considered to be the best data available. For the Bair data, the publication [10] suggests, in a note added in proof, to renormalize upward the original data. Whether the Bair data are renormalized (as in the LANL evaluation) or not, it is still significantly higher than the Drotleff data by about 10-20% and than older data such as Sekharan et al. [7] or Walton et al.[3] by 50%. According to the comment file, the JENDL3.3 $^{16}O(n, \alpha)$ evaluation is based on older experimental data of Nordborg et al. [14] (that actually measured (n,$\alpha\gamma$) reaction), Davis et al. and Bair et al. This rough analysis suggests that a high uncertainty should be assigned to the present $^{16}O(n, \alpha)$ cross-section evaluation.

During the writing of this document, it was discovered that a recent measurement have been performed at Stuttgart by Heil et al [13]. These unpublished data have never been included in any evaluation and might provide a valuable information on the $^{16}O(n, \alpha)$ level.

3 Justification for measurements and evaluations with improved accuracy

This section presents some results from quick sensitivity studies to assess the impact of the current uncertainties of $^{16}O(n, \alpha)$ in practical applications. Because of the spread of experimental data, we assume that $^{16}O(n, \alpha)$ is known with an accuracy of 30% (1σ) from threshold to 8 MeV.

3.1 k_{eff} prediction in thermal and fast reactor

In Light-Water Reactors, fuel elements are usually made of uranium oxide (UO_2) or mixed oxide ($UO_2 - PuO_2$) and water (H_2O) plays the role moderator and coolant. For typical Leu-Comp-Therm benchmark (ICSBEP classification), the sensitivity coefficient $\frac{dk}{k}/\frac{d\sigma}{\sigma}$ to k_{eff} to $^{16}O(n, \alpha)$ is roughly -3.5 pcm/% integrated (E > 3 MeV), leading to an uncertainty of about 100 pcm. For instance, the use of JENDL3.2 O16 evaluation instead of JEFF3.1 (same as ENDF/B-VI.8) increases the k_{eff} of typical Leu-Comp-Therm of 85 pcm. In fast Reactor, such as Phenix located in France, sensitivity coefficients in several energy ranges are presented in table 1.

Energy range MeV	Sensitivity Coefficient pcm / %
19.6 - 10.0	-0.17
10.0 - 6.07	-1.09
6.07 - 3.68	-2.12
3.68 - 2.23	-0.03

Table 2: Sensitivity coefficients to k_{eff} to the capture cross section of ^{16}O for the Phenix core.

Roughly, $^{16}O(n, \alpha)$ produces a total uncertainty of $\approx$ 100 pcm .

3.2 Helium production in reactor

The knowledge of helium production during irradiation is of primary importance to assess the performance of fuel pins and clads. Besides α decay of actinides and ternary fission, (n,α) reaction on light elements can be a significant source of helium production. For instance, in a typical reactor fuelled with mixed-oxide, $O(n,\alpha)$ contribute for 25% of the total helium production at 50 GWd/t (65% from actinides decay and 10% from ternary fission). Thus, the uncertainty of helium production, due to $^{16}O(n,\alpha)$ is about 7%. Note that the contributions of α production on oxygen from $O17(n,\alpha)$ and $O18(n,\alpha)$ are very small in reactor applications.

3.3 Measurement of neutron-source strength

To measure the neutron strength source such as AmBe or ^{252}Cf, a technique used at NIST consists of using a bath filled with $MnSO_4$ and H_2O. The neutron-source strength is directly deduced from the gamma-ray counting rate produced by the absorption of neutrons in ^{55}Mn. However, experimental corrections are needed to account for the absorption of neutrons in the oxygen and sulfur of $MnSO_4$ and, in the hydrogen and oxygen in water. The major source of uncertainty in this correction comes from the $^{16}O(n,\alpha)$ cross section in the range 2.5 - 20 MeV. A note provided by Scott Dewey [16] at NIST estimates that the contribution of $^{16}O(n,\alpha)$ uncertainty is about 0.5% on the final uncertainty of the neutron-source strength. Since an accuracy below 1% is requested by users of neutron source, improvement of $^{16}O(n,\alpha)$ is of importance to achieve this goal.

4 Conclusions

- Above threshold (2.4 MeV), measurements and evaluations of $^{16}O(n,\alpha)$ are discrepant. The current uncertainty of $^{16}O(n,\alpha)$ is large ($> 30\%$).
- These uncertainties have a significant impact on several applications:
  - $\approx$ 100 pcm in the k_{eff} of thermal and fast reactors.
  - $\approx$ 7% in the prediction of helium production in reactors.
  - $\approx$ 0.5% in the calibration of reference neutron-source strength.
- To improve the situation, new measurement and evaluation are requested in the range 2.5 - 10 MeV. The target accuracy for $^{16}O(n,\alpha)$ is 5% especially below 6 MeV.

As said before, a new unpublished measurements of $C(\alpha,n)$ by Heil et al. was found during the writing of this document. These new data could give further information on $O(\alpha,n)$ and possibly improve the knowledge of the cross section. Nevertheless, an evaluation work will be still needed.

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