Nuclear Instruments and Methods in Physics Research A 629 (2011) 288–295

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Interpretation of pile-oscillation measurements by the integral data assimilation technique

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A R T I C L E I N F O

Article history:
Received 14 September 2010
Received in revised form
27 October 2010
Accepted 4 November 2010
Available online 21 November 2010

Keywords:
Pile-oscillation measurements
Neutron resonance shape analysis
CONRAD
PIMS
MINERVE reactor

A B S T R A C T

The Integral Data Assimilation (IDA) was designed to deduce values of infinite dilute neutron cross-sections from specific integral measurements. Performances of the IDA procedure are demonstrated with pile-oscillation measurements carried out on ^{155}Gd in the pool type reactor MINERVE (CEA Cadarache, France). At low neutron energies, the Integral Data Assimilation is based on the Neutron Resonance Shape Analysis technique routinely used in neutron spectroscopy measurements. As a result of the IDA analysis, a value of (61 900 $\pm$ 1500) b has been obtained for the ^{155}Gd thermal capture cross-section at (E_{th}=25.3 meV).

1. Introduction

Pile-oscillation techniques were developed in the early years of the integral measurements to characterize the neutron absorption properties of a given isotope [1]. For non-fissile isotopes, the absorption process in a thermal flux reduces to the capture of the incident neutron by the nucleus. The probability of such a reaction taking place is stated as a "neutron capture cross-section" expressed in barns (1 b$=10^{-24}$ cm^2). In this work, we have used cross-section values compiled in the latest European neutron library JEFF-3.1.1 [2] and capture cross-section data measured at the Linac facility of the Renssealer Polytechnic Institute (RPI) by the time-of-flight technique [3]. Fig. 1 shows the complex behavior of the ^{155}Gd(n,γ) cross-section as a function of the incident neutron energy. Each observed structure is a resonance level λ defined by its resonance energy E_λ and partial widths ($\Gamma_{\lambda\gamma}$ and $\Gamma_{\lambda n}$) corresponding to the decay possibilities of the excited nuclear system ^{155}Gd+n. In JEFF-3.1.1, the upper energy limit of the so-called resolved resonance range is 180 eV.

Oscillation techniques of interest for this work consist in moving periodically in a well-characterized neutron flux a sample containing the isotope under consideration. The challenging task is to convert the periodic variation of the neutron population, measured during the oscillations, into an accurate neutron cross-section value. A two-step approach is often applied to extract an "effective" neutron cross-section averaged over the neutron energy spectrum and to deduce an infinite dilute cross-section independent of the neutron flux. Reliable results can be obtained using some approximations and phenomenological corrections valid for clean thermal neutron beams impinging on small samples.

The Integral Data Assimilation technique (IDA) presented in this work allows the estimation of thermal neutron cross-sections from integral trends measured in various neutron energy spectra. The methodology was developed in the frame of the Burn-Up Credit experimental program carried out in the MINERVE facility (CEA Cadarache, France) [4]. The method uses the capabilities of the nuclear data code CONRAD [5] and of the neutronic interface tool PIMS [6]. CONRAD was designed to adjust resonance parameters involved in the theoretical description of the cross-sections. PIMS was developed to simulate integral experiments performed in MINERVE.

Performances of our data reduction procedure are illustrated with pile-oscillation measurements performed on a ^{155}Gd sample. The experimental conditions and the PIMS analysis are shortly described in this paper. More detailed explanations are given on the IDA principle and on the main data analysis problems caused by the existence of a strong ^{155}Gd s-wave resonance close to the thermal energy E_{th}=25.3 meV. Analytic and Monte-Carlo solutions are proposed to establish prior resonance parameter covariance matrix, to perform sensitivity studies and to propagate in integral calculations of the large energy uncertainty of the first resonance. The ^{155}Gd thermal capture cross-section obtained with our IDA technique is compared with results reported in the literature.

2. Experimental conditions

The Burn-Up Credit experiment started at the beginning of the 1990s to investigate separated fission product samples, spent fuel

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doi:10.1016/j.nima.2010.11.034

samples and natural fission product in UO_2 and Al_2O_3 matrix by means of the oscillation technique. The Burn-Up Credit samples are regularly measured in different core configurations. The focus of the present work is the analysis of oscillation measurements carried out in 1993 on a ^{155}Gd sample in the so-called R1-UO2 configuration (PWR spectrum).

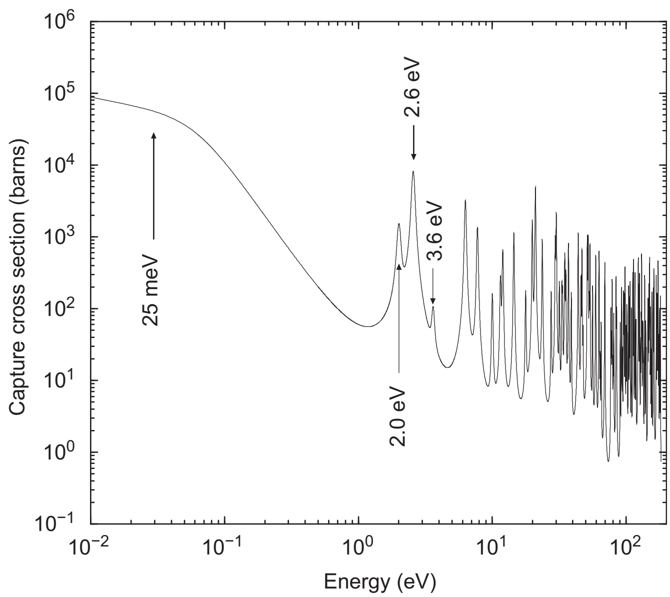

Fig. 1. Resolved resonance range of the ^{155}Gd capture cross-section reconstructed with parameters reported in Ref. [3].

2.1. Experimental set-up

MINERVE is a pool type reactor operating at a maximum power of 100 W. The core is submerged under 3 m of water. Various experimental lattices composed of UO_2 or MO_x cladded fuel pins can be loaded in a central square cavity of 70 cm length. In the present work, we have analyzed data measured in a uniform PWR-type lattice made of 800 3%-enriched UO_2 rods (Fig. 2).

The experimental set-up is composed of an oscillation rod, of a $\gamma-$compensated ionization boron chamber and of a so-called pilot rod. The studied and reference samples placed into the oscillation rod are moved periodically inside and outside the experimental zone. The boron chamber measures the variation of the neutron population during the oscillations. The criticality of the reactor is automatically maintained by the electronic set-up which drives the position of the pilot rod. The latter was designed to compensate small reactivity worth of 10 pcm via a neutronic shadow effect between a rotor and a stator made of small cadmium sectors.

Raw data recorded by the acquisition system corresponds to the angle between the rotor and the stator measured with an arbitrary unit called "Pilot Unit". The linear relationship between the raw data (in "Pilot Unit") and the reactivity worth (in pcm unit) is measured with ^{235}U and ^{10}B calibration samples. Typical accuracy of the normalization factor is lower than 2% [6]. In order to get a statistical uncertainty below 1%, each sample was measured at least three times. A measurement corresponds to 30 oscillations of 60 s.

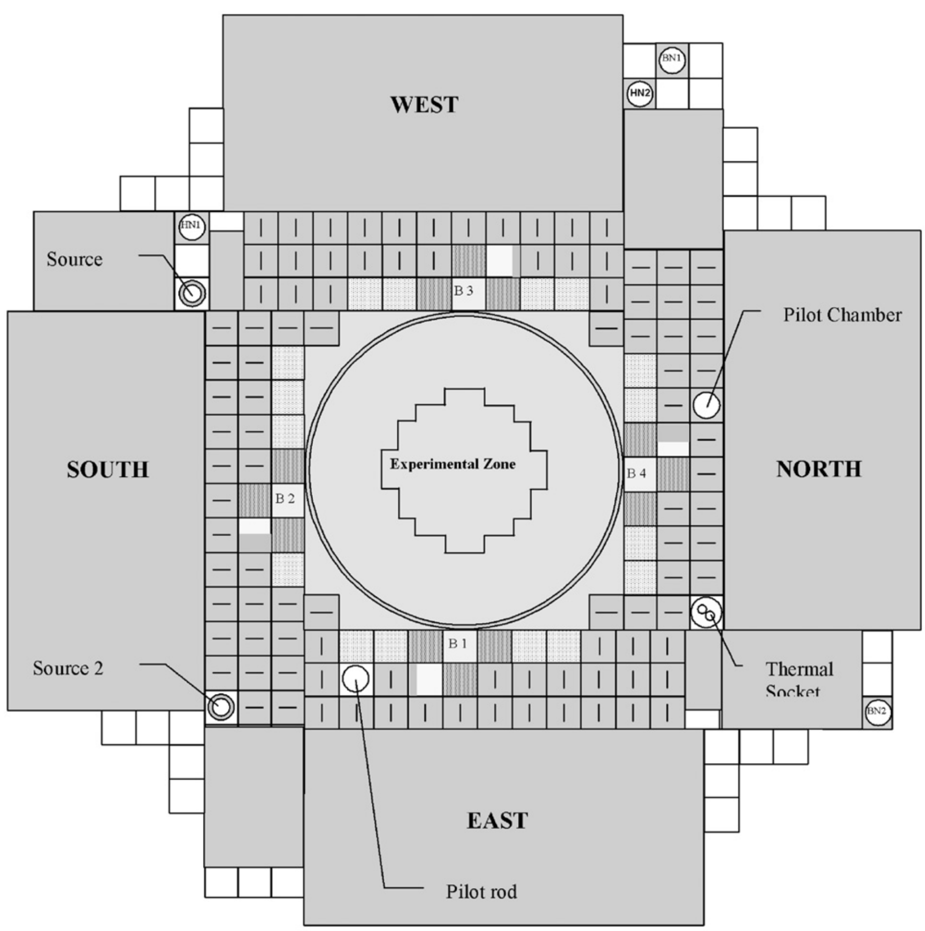

Fig. 2. Top view of the MINERVE reactor.