Experimental report

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Proposal: 1-04-105 **Council:** 4/2016

Title: Measurement of the double-differential neutron cross section of U in UO2 from room temperature to Hot Full Power conditions

Research area: Nuclear and Particle Physics

This proposal is a new proposal

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Samples: UO2

Instrument	Requested days	Allocated days	From	To
IN5	5	0		
IN4	5	5	18/11/2016	23/11/2016
IN6	0	7	23/11/2016	30/11/2016

Abstract:

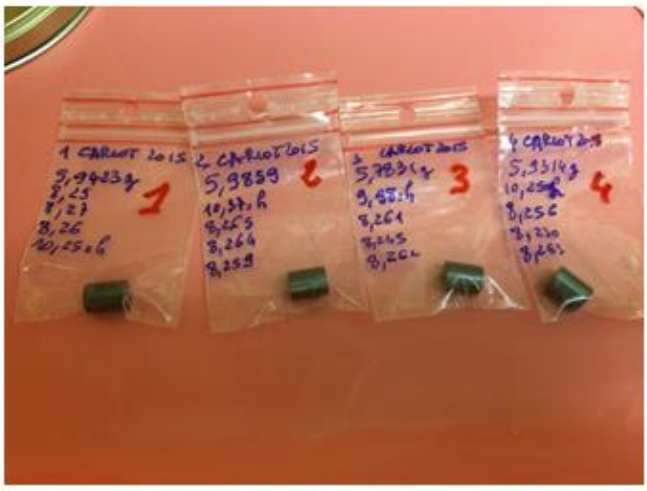
The motivation for the proposed experimental program is the recent interest throughout the world on revisiting and revising the existing thermal neutron scattering data in the cross section libraries such as ENDF/B (US), JEFF (OCDE/NEA), JENDL (Japan), CINDL (China) and BROND (Russia). Many questions emerge from the Working Party on International Nuclear Data Evaluation Co-operation (WPEC) of the NEA data bank related to the impact of the thermal scattering data on criticality benchmarks. Investigation and production of covariance matrices are also key issues for light and heavy water reactors.
This proposal is part of a multi-year program plan on actinides. First, we wish to extract S(alpha,beta) tables from the double-differential neutron cross sections of UO2 as a function of the temperature. The temperatures of interest range from room temperature to Hot Full Power conditions (T=1000 K). Final S(alpha,beta) tables will be introduced in evaluated nuclear data libraries and tested on critical benchmarks carried out in the zero-power reactor EOLE located at the CEA of Cadarache and on Power reactor benchmarks.

Measurement of the double-differential neutron cross section of U in UO2 from room temperature to Hot Full Power conditions

The present document provides a short description of the experiments performed on a UO2 sample at the IN4 and IN6 facilities of ILL in November/December 2016. The double-differential neutron cross section was studied at three temperatures (T=300 K, 600 K and 900 K) and three incident neutron energies (3 meV, 66 meV and 112 meV).

Sample characteristics

The UO2 sample used for this experiment was prepared at ILL by using four depleted UO2 pellet provided by CEA Cadarache. Characteristics of the UO2 pellets are given in Fig 1. The final UO2 sample has a cylindrical shape. It is composed of a stack of four UO2 pellets, sealed under vacuum in a glass tube.



	Pastille 1	Pastille 2	Pastille 3	Pastille 4
Masse (g)	5,9423	5,9859	5,7831	5,9314
Hauteur (mm)	10,25	10,37	9,98	10,25
diamètre (mm)	8,25	8,265	8,261	8,256

[1]unites g/100gU
234 U = 0.002+-.001

235 U = 0.300+-.008

236 U = 0.006+-.001

238 U = 99.692+-.010

[4]unites g/100gUO2
U = 87.87+-0.04
at/at
O/U = 2.04+-0.01

[7]unites g/100gUO2
H2O = 0.08+-0.02

Fig. 1. Characteristics of the four UO2 pellets

Experimental program

The experiment were performed on the IN4 (λ=0.86 Å and 1.11 Å) and IN6 (λ=5.12 Å) spectrometers. Three incident neutron energies were investigated (3 meV, 66 meV and 112 meV) at three temperatures (300 K, 600K and 900 K). A description of the experimental program is listed in Tables 1 and 2 for IN4 and IN6, respectively. It mainly consisted in measuring sequentially UO2, vanadium and dummy samples. UO2 sample was measured two times (before and after heating) in order to verify the consistency of the results and the possible effect or the heating on the UO2 sample (oxidation …). Preliminary results indicate that time-of-flight data measured before and after heating at the same incident neutron energy are consistent. Raw data provided by the acquisition system were treated with the LAMP package developed at ILL. Fig. 2 (left hand plot) shows the experimental double differential neutron cross sections measured at four angles with the IN6 spectrometer.

Table 1. Details of the experimental program (IN4 spectrometer)

Sample	Neutron energie	Temperature	Time	Run
UO2	111,9 meV (0,855 A)	290,15 K (17°C)	12h	88121-88144
	111,9 meV (0,855 A)	591,15 K (318°C)	12h31min	88146-88171
	111,9 meV (0,855 A)	901,8 K (628,65°C)	12h	88174-88197
	66.4 meV (1,11 A)	902,15 K (629°C)	7h46min	88198-88213
	111,9 meV (0,855 A)	296,15 K (23°C)	3h57min	88257-88264
	66.4 meV (1,11 A)	296,15 K (23°C)	2h46min	88265-88270
Vanadium	66.4 meV (1,11 A)	288,18K (15°C)	1h30min	88396-88398
	111,9 meV (0,855 A)	287,15K (14°C)	4h02min	88399-88407
Dummy	111,9 meV (0,855 A)	290,15K (17°C)	6h	88468-88479
	111,9 meV (0,855 A)	598,15K (326°C)	6h	88482-88493
	111,9 meV (0,855 A)	905,15K (632°C)	6h	88496-88507
	66.4 meV (1,11 A)	905,15K (632°C)	3h	88508-88513
	66.4 meV (1,11 A)	306,15K→297,15K 33°C→24°C	4h58min	88542-88551

Table 2. Details of the experimental program (IN6 spectrometer)

Sample	Neutron energie	Temperature	Time	Run
UO2	3 meV (5,12 A)	336,15K→324,15K (63°C→51°C)	20h	189008 - 189048
	3 meV (5,12 A)	584,15K (311°C)	7h	189049-189062
	3 meV (5,12 A)	888,15K (615°C)	6h	189064-189075
	3 meV (5,12 A)	306,15K→302,15K (33°C→29°C)	12h30min	189233-189257
	3 meV (5,12 A)	587,15K 314°C	6h30min	189259-189271
	3 meV (5,12 A)	890,15K (614°C)	12h30min	189272-189296
Vanadium	3 meV (5,12 A)	304,55K (31,4°C)	2h30min	189094-189098
Dummy	3 meV (5,12 A)	302,68K (29,53°C)	18h	189101-189136
	3 meV (5,12 A)	594,15K (321°C)	15h	189138-189167
	3 meV (5,12 A)	598K (324,85°C)	18h	189169-189204

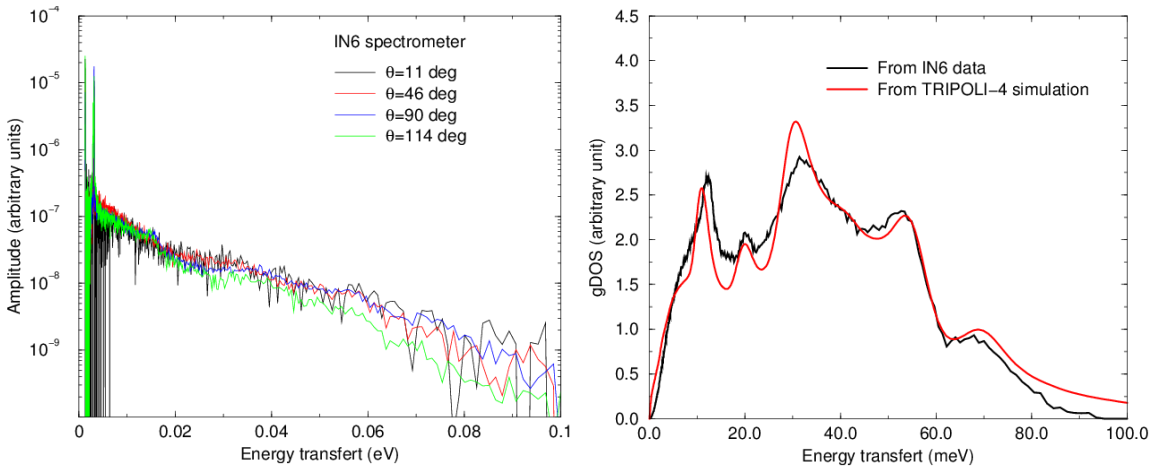


Fig. 2. The left hand plot shows the double-differential neutron cross sections measured at T=300 (IN6 spectrometer) at four different angles. The right hand plot compares the experimental density of states, obtained with the MUPHOCOR procedure of the LAMP package, with results provided by Monte-Carlo simulations.

Preliminary results

A precise experimental validation of the Thermal Scattering Laws of UO2, available in the international neutron libraries dedicated for reactor applications, was never reported in the literature. Therefore, the analysis and interpretation of the data measured with the IN4 and IN6 spectrometers will first consist in comparing the experimental results with Monte-Carlo simulations. Fig. 2 (right hand plot) compares the generalized density of states obtained with the IN6 data and with the Monte-Carlo code TRIPOLI-4. The simulation was performed by using densities of states of U in UO2 and O in UO2 calculated with the VASP code at the North Caroline State University (see the US library ENDF/B-VIII). The simulation takes into account the energy dependent resolution function of the IN6 spectrometers established from the vanadium peak. The rather good agreement between the theoretical and experimental density of states confirms the peak positions of the acoustic and optical modes calculated for Uranium and Oxygen atoms. More work is still needed for a better understanding of the observed differences at low energy transfer (resolution function, incorrect background subtraction …).

Improved results will be presented at the 5th International Workshop On Nuclear Data Evaluation for Reactor applications (WONDER) in Aix en Provence (October 2018).