Outgoing neutron spectrum from H_2O in a H_2O-uranium interface

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Abstract

The outgoing thermal neutron spectrum from H_2O in a H_2O-metal uranium (0.4 % U235 depleted) slab interface has been measured using standard time-of-flight techniques. The experimental flux was compared with calculations performed with a modified version of the DTF-IV code in S_8, P_0 and P_1 approximations. The ENDF/GASKET scattering kernel for H_2O was used in conjunction with the GGC-3 cross-section data for uranium. The P_0 approximation proved to be satisfactory for the spectra studied.

Zusammenfassung

Ausgang-Neutronenspektrum von leichtem Wasser in einer H_2O-Uran-Zwischenphase

Es wurde das thermale Neutronenspektrum von H_2O in der Grenzfläche zwischen H_2O und einer Uran-Metall-Schicht (0.4 % abgereichertes U-235) mit der Standard-Flugzeitmethode gemessen. Die Messung wurde mit Berechnungen verglichen, die mit dem Streumodell ENDF/GASKET für H_2O und mit GGC-3 für Uran zusammen mit einer modifizierten Version des DTF-IV in der S_8-, P_0- und P_1-Näherung durchgeführt wurden. Dabei zeigte sich, daß die P_0-Näherung für die untersuchten Spektren zufriedenstellend war.

INIS DESCRIPTORS

THERMAL NEUTRONS	URANIUM
NEUTRON SPECTRA	INTERFACES
WATER	TIME OF FLIGHT METHOD

Introduction

Spectrum investigation of materials used in a reactor, gives valuable information about the neutron energy distribution in the core. Without this information it is impossible to understand the reactor behaviour and design it succesfully. Certainly our knowledge of thermalization in H_2O is adequate for the design of power reactors. However, a careful review of the literature up to the present day reveal that the agreement between theory and observation is poor in interface regions over which large changes of spectral shape occur.

In previous papers [1; 2] results for the neutron thermalization in pure and borated H_2O in a quasi-infinite-medium, and the leakage spectrum from the H_2O in a H_2O/vacuum interface were reported. Also the procedures for measuring and analyzing neutron spectra were presented. The comparison with theoretical transport predictians were given with excellent agreement. In this paper, we present measurement and calculation of the outgoing neutron spectrum from H_2O in a H_2O/metal-uranium interface. It is an extension of the previous work in H_2O to include studies with large flux gradients, such as those existing at control or fuel-rod surfaces.

This research is part of a program of the Argentine »Comisión Nacional de Energía Atómica« (CNEA), to evaluate the various models, codes, and data sets used to calculate the spectra in water-moderated lattices and to anolyze the sensitivity of cell parameters to the scattering law.

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Description of the experiment

The experiment consisted basically of measuring the angular-neutron-spectrum outgoing from H_2O in an interface between H_2O and metal-uranium, using the time-of-flight technique. The Linac facility of the Centro Atómico Bariloche was used for this experiment. The facility is described in Ref. [3].

The experimental geometry, illustrated in Fig. 1, consisted of a 30×30×3.14 cm thick slab of depleted metal-uranium (0.4 % U-235) adjacent to a cubical tank, of side 30 cm containing H_2O. The geometry was lined with cadmium sheet and shielded with a boron mixture. The assembly was excited by a pulsed photo-neutron-source located externally to the assembly. The position-dependent angular neutron spectrum was extracted from the aluminium tank wall (0.5 mm thick), via a 12.7 mm diameter hole located at 7 cm from the edge through the uranium slab and the neutron shielding. A precollimator, 12 mm in diameter and a 17 metre flight path were used. The neutron background was obtained by placing a B-10 plug at the base of the reentrant hale. Neutrons were detected by means of a Li-6 glass scintillator and the neutron beam was monitored with two small U-235 fission detectors placed in different positions inside the vessel. Running time for the experiment was chosen to ensure good statistical accuracy. The mean temperature of H_2O for all the experiment was 23 °C.

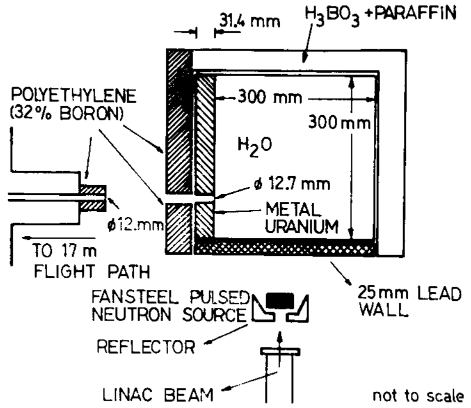

Fig. 1: Experimental set-up used to measure the outgoing spectrum from H_2O

The mean-emission-time at low energies was evaluated from the die-away experiments carried out with a small U-235 fissian chamber detector located in the spectrum measurement position. For the intermediate neutron energies, it was calculated with the CAGE [4] code and for the upper range of energies it was obtained from the slowing-down time.

Careful static measurement of the thermal and epithermal flux distribution were done. From them, the spatial form of the neutron source and the inverse relaxation constant ($\gamma^2 = 0.0284$ cm^{-2}), were obtained. A detailed description of the procedure is given in Refs. [1] and [2].

The reduction and treatment of data applied to the experimental results in order to obtain the angular-neutron-flux were as described in Ref. [1]. The aluminium H_2O-tank woll was included in the reduction of the experimental data together with the flight tube aluminium windows. Counts per channel were grouped in order to obtain an energy resolution of 5 % in all the energy range, together with a statistical fractional error of 3 % from 0 to 0.002 eV, 1 % from 0.002 to 0.1 eV, and 2 % from 0.1 to 10 eV. Ninety-one energy points were obtained experimentally from 0.0065 to 10 eV.

Calculational method

The scattering kernel for H_2O, was generated by means of the GASKET code [5], according to the description given in Ref. [1]. For metal uranium (0.4 % U-235 depleted), a diagonal scattering kernel was generated from the GGC-3 [6] thermal data for U-238 and U-235. Using this scattering kernel and the codes NYR190 and NYR081, the thermal cross-section groups P_0, were obtained for 30 energy groups. In view of the relatively small U-235 concentration in the uranium slab and in order to accelerate convergence in the transport calculations fission was treated as a pure removal reaction.

Using the measured transverse distribution of epithermal neutrons as data, a one-dimensional isotropic-distributed-source was calculated in both material regions by means of the NYR232 code [7], using the "free-gas-model" for H_2O and the "moderation-model" for metal uranium, for computing the energy distribution of the slowing-down neutrons.

The transport theory calculation to obtain the angular neutron spectra was done with the NYR230 code [8] (a modified version of the one-dimensional DTF-IV code). This code solves the neutron transport equation by the method of discrete ordinates (S_N approximation). In the code, an external source is treated as an isotropic volume source. Anisotropic scattering is taken into account by the usual transport approximation. Calculations were carried out in 16 spatial intervals, using 30 energy groups, S_8 approximation and the computed isotropic volume external source. The flight-path axis was the direction accounted for the one-dimensional calculation. Both P_0 and P_1 scattering kernel approximation for H_2O were considered. As our transport code accepts only an isotropic distributed external source, it was not possible to use a P_1 external source in conjunction with the P_1 approximation. The axial mesh interval sizes were obtained from

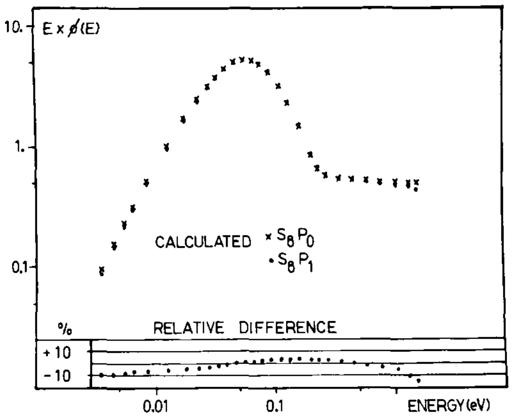

Fig. 2: Outgoing spectrum from H_2O computed in P_0 and P_1 approximation

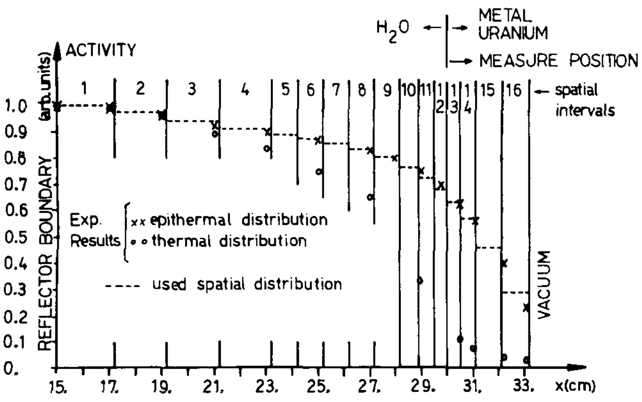

Fig. 3: Spatial distribution of indium resonance flux and used spatial source distribution

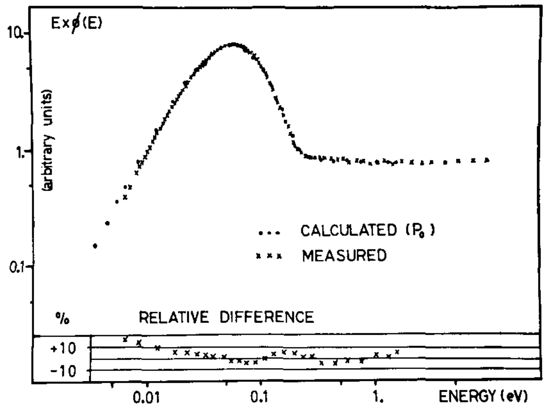

Fig. 4: Outgoing measured neutron spectrum from H_2O compared to calculation using P_0 approximation

Table 1: Angular neutron spectrum outgoing from H_2O (23 °C)

E(eV)	Ø (E) P_1 Approx.	Ø (E) P_0 Approx.	Ø (E) Measured Spectrum
0.0035	0.00873	0.00962	-
0.0045	0.0143	0.0157	-
0.0055	0.0210	0.0229	-
0.0065	0.0288	0.0313	0.0264
0.0085	0.0472	0.0509	0.0446
0.0125	0.0922	0.0986	0.0895
0.0175	0.1577	0.1676	0.1583
0.0225	0.2272	0.2389	0.2245
0.0275	0.2938	0.3054	0.2953
0.0325	0.3536	0.3645	0.3553
0.0385	0.4120	0.4207	0.4203
0.0460	0.4650	0.4686	0.4728
0.0550	0.4959	0.4956	0.5127
0.0650	0.4965	0.4918	0.5088
0.0750	0.4711	0.4628	0.4858
0.0900	0.4079	0.3953	0.4135
0.1100	0.3157	0.3061	0.3085
0.1300	0.2313	0.2249	0.2188
0.1600	0.1459	0.1410	0.1312
0.2000	0.0853	0.0826	0.0780
0.2300	0.0657	0.0639	0.0639
0.2700	0.0567	0.0555	0.0554
0.3500	0.0518	0.0513	0.0545
0.4500	0.0506	0.0509	0.0537
0.5900	0.0496	0.0507	0.0516
0.7800	0.0475	0.0497	0.0509
1.0400	0.0455	0.0491	0.0472
1.3600	0.0437	0.0488	0.0488
1.5800	0.0418	0.0480	0.0457

the related criterio given in the ANISN code [10]. To account for the transverse leakage, a correction energy-dependent term ($D(E)B^2$) was added to the absorption cross section in both materials. In the direction of the neutron source the local buckling was obtained from the measured inverse relaxation constant. For the transverse direction a cosine distribution was assumed.

A comparison of the transport theory calculation in P_0 and P_1 approximations is shown in Fig. 2. From it, a deviation of the P_1 approximation at epithermal energies is observed. Similar deviations were also observed in a previous study carried out in our laboratory [9], in an interface between H_2O and D_2O. It is attributed to the lack of a P_1 external source in the calculation.

In Fig. 3, the spatial mesh interval used and the spatial source distribution used in calculations are shown also the experimental spatial thermal and epithermal neutron distribution in the direction of measurement are plotted.

Discussion of results

As shown in Fig. 4, the agreement between theory and experiment is satisfactory. The transport calculation (P_0 approximation) *agrees with the measured spectrum within 13 % to −7 %*. Both, the experimental and computed spectrum were normalized to equal area between 0.0065 eV and 1.38 eV.

Neglecting P_1 scattering makes a difference in the low energy range. Normalizing to equal area between 0.0065 to 0.13 eV (*thermal region*), the P_0 approximation agrees with the measured spectrum within 11 % to −7 %, while the P_1 approximation agrees within 3 % to −6 %.

In view of the illogical shape of the computed neutron spectrum in P_1 approximation in the epithermal energy region and the consequent large disagreement with the measured spectrum (10 % to −12 %), it can be seen that the NYR230 code should be improved in order to accept P_1 external neutron source.

In Table 1, the results obtained for the angular neutron flux outgoing from H_2O to uranium are listed, all were normalized to equal area between 0.0065 eV to 1.38 eV. The listed data for the measured spectrum was interpoloted from the 91 experimental energy points. A systematic deviation between theory and experiment is observed in the energy range around 0.2 eV which cannot be attributed to statistical uncertainties or to resolution errors. The same effect was observed in our previous studies in H_2O [1; 2]. It could be attributed only to the model used to generate the scattering kernel for H_2O (ENDF/GASKET model [3]).

Conclusions

A quantity of great importance in the design and operation of light water moderated thermal reactors, is the thermal neutron scattering kernel employed for H_2O. The results obtained in this paper, together with the studies reported in previous papers, support that the scattering by H_2O is adequately described by the ENDF/GASKET model, and that a transport theory calculation in P_0 approximation is suitable for small H_2O ossembly in which large discontinuities are present such as at vacuum-surfaces, control-rod-surface or at fuel-cell-edges.

With the paper reported here, a total of three assemblies containing H_2O were investigated. The first study involved measuring and calculation of the thermal neutron spectra in pure and borated H_2O in a quasi-infinite medium. The second study consisted basically of measuring the leakage neutron spectra in pure H_2O. The third, which is reported in the present paper, consisted of measuring the angulor-spectrum-outgoing from H_2O to Uranium, in a H_2O/Metal Uranium slob interface. The studies have shown that time-of-flight-technique is suitable for making detailed observation of the neutron flux in heterogeneous systems in which large discontinuities are present. In addition little indication of reentrant hole perturbation has been found.

Measurements agree closely with the theoretical predictions not only due to the improvement in the experimental methods, but also because the calculation system, scattering models and cross sections were improved.

From the computed results, it is clear that higher-order in the slowing-down scattering moments of the external source should be investigated later in order to improve the agreement.

Future studies in assemblies containing fuel and moderator will be carried out and reported.

(Received on Jan. 11, 1979)

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