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Neutron thermalization process in benzene[1]

Die Thermalisierung von Neutronen in Benzol

*By Maximo J. Abbate, José V. Lolich and H. Wio**

Introduction

The close relation between the molecular dynamics of the moderotors and the neutron thermalization process in them is widely known.
Since these processes have fundamental importance in the design of thermal nuclear power plants there is interest to obtain a precise description and knowledge about them.
The problem so explained is highly complex in a general point of view because firstly implies to formulate particular models for each molecular species that can be found in the reactor, and secondly the definition of these models is limited to semiempiricol procedures, that means the models ore not totally independent from the experimental information that they intend to reproduce with its results.
To consider different moderators we selected and studied primarily the H_2O and D_2O, and then we included too the benzene in order to onolize a foirly complex molecular structure but with symetrical properties sufficient to simplify the problem.
So, a new and general scheme for the description of the molecular dynomics was opplied to this material [1] and the availoble experimental information about neutron total cross section and diffusion parometers was completed [2]. At this point, three different models based in other known vibrational frequency spectra were used and the scattering laws obtained with them showed better agreement than earlier models.
In this paper we present an additional test on the cited colculotional scheme consistent with differentiol neutron spectra measurements in o cleon geometry and its comparison with results from the tronsport theory.

Description of the experiments

The experimental facilities and procedure used in this work were detoiled fully in Refs.[3] and [4].
The principal port of the experiment was the measurement of the angular neutron spectra as a function of the position in pure C_6H_6 ot 23°C using the time-of-flight technique. The experimental arrangement is shown in Fig. 1
A 30 × 30 × 50 cm³ assembly lined with a codmium sheet and shielded with a boron mixture wos used. The neutron beom was extracted via o 25 mm diameter reentrant hole.
Stotic measurements of the thermal and epithermol flux distributions were mode using indium foils in conjunction with the codmium difference method. From the epithermol flux distribution in the reentrant hole direction, the spatial form of the moderation source wos obtoined and from the distribution perpendicular to this,

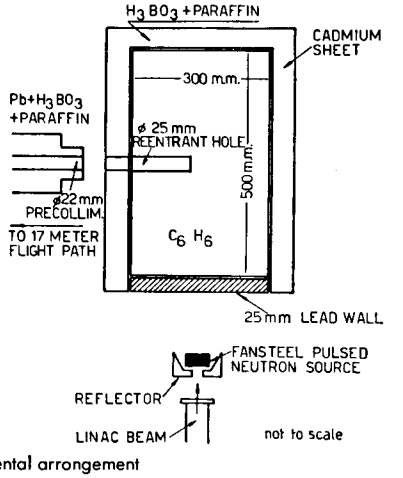

Fig. 1: Experimental arrongement

the inverse relaxation constant, γ, wos derived to get the local buckling, the results were:

$$\gamma = 0.181\,\text{cm}^{-1}\ (\pm 5\,\%)$$
$$\text{Total } B^2 = -0.0121\,\text{cm}^{-2}$$
$$\text{Transverse } B^2 = -0.0224\,\text{cm}^{-2}$$

and the thermal leakage term was:

$$DB^2 = -0.00454\,\text{cm}^{-1}$$

Through the meosurement of the thermal neutron decay constant ($\alpha = 4220 \pm 20\,\text{sec}^{-1}$) and an auxiliary calculation performed with the NYR261 Code [5] the mean emission time necessory for the experimental data correction was obtained.
A neutron spectrum was measured in the middle of the assembly, and the leokoge spectrum too, and to complete prior study performed in H_2O related to interfaces with vocuum [6]. The measured spectra are shown in Figs. 2 and 3.
In order to perform the correct background subtraction (using o B-10 filter) the neutron beam intensity was monitored with two U-235 miniature fission counters locoted inside the vessel. The responses of these detectors agreed within 1% during all measurements. In oll cases the standard deviotion due to statistics wos less than 4% over all the energy range. The correction derived from the time resolution function was less than 1%. The dota reduction wos made with the NYRTOF Code [7], the poorest energy resolution was 9%, and outside the energy range from 0.07 to 0.24 eV was better than 5%.

Theoretical calculations

Molecular Models

In order to obtain the group cross sections to be used in the transport calculations the first problem was to select the molecular model. Known models were considered [8–11], and can be reoched the conclusion that it wos convenient to develop o new theoretical scheme able to represent the complex molecular system dynomics [1].
This scheme gives o kind of global description of the dynomics of complex and polyatomic systems through adequote frequency spectrum and effective mosses and reduces the diversity and quontity of calculations necessory to obtoin the molecular scattering low from codes of the GASKET type [12].
The first results obtained with this scheme were described in [1], and mean that it is possible to reoch better agreement with the experimental scattering low for

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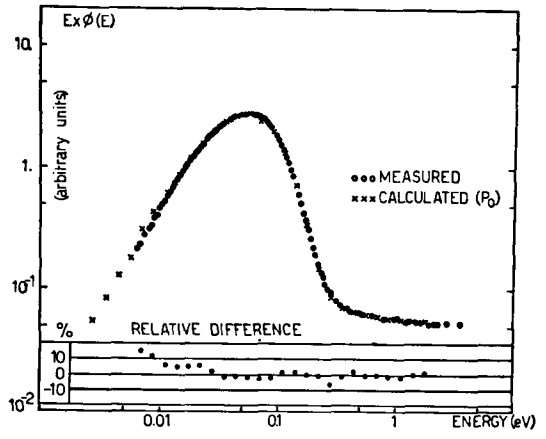

Fig. 2: Measured central neutron spectrum in C_6H_6 compared to calculation using P_0 opproximation

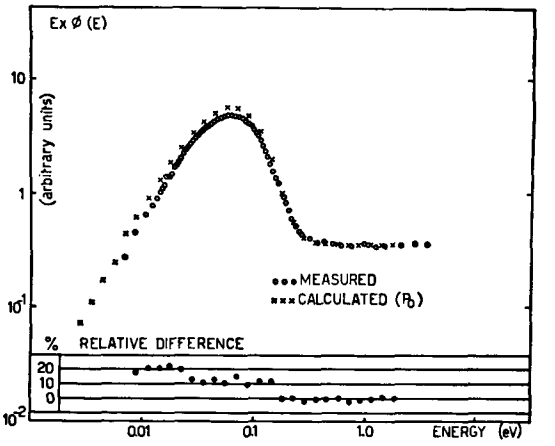

Fig. 3: Measured neutron spectrum in C_6H_6 compared to calculation using P_0 opproximation

benzene from *Gläser* [13], specially using a frequency spectrum obtoined from *Marsden* and *McMurry* data [10].
For the neutron totol cross section the ogreement was also better than the previous results, for the case of the modified Sprevak's frequency spectrum [8]. For this work it was necessary to remeasure this cross section [2] due to the evidence that the accuracy of known data [14–17] was not suitable for a definitive comparison.
From these results was selected for this work a model based on the vibrotionol frequency spectrum from Sprevok, a rotational spectrum adjusted to reproduce the Gläser dota and diffusion motion, instead of free tronslotion, for the whole molecule.

Calculations

The distributed moderation source in one dimension was calculated by the NYR232 code [18], using the measured transverse distribution of epithermal neutrons. Group cross sections for 30 energy groups were obtoined with GASKET, NYR190 [19] and NYR081 [20] codes. The transport theory calculations were performed by the NYR230 [21] code in 30 spotial intervals and S_8 and P_0 opproximations. The results of the colculated spectro are shown in Figs. 2 and 3 together with the experimental doto.

Discussion of results

About the central spectrum, Fig. 2, the transport calculation agrees with the measured spectrum within −3 and +6%, thus it is satisfactory; but is possible to see that for energies of 0.009 and 0.0072 eV shows deviations to +15%.
With respect to the leakage spectrum, Fig. 3, normolizing both theoreticol and experimental values at epithermal region, the first ore 12% more thermolized, and for energies lower than 0.0225 eV the discrepancies are in the order of 20% or more. Also in this cose appeor anomalies ot 0.009 and 0.0072 eV.

Conclusion

Taken into account that the experimental results were confirmed through new measurements, it is possible to conclude that calculations using group constonts derived from the cited theoreticol scheme in conjunction with a model based on the vibrotional frequency spectrum from Sprevak, reproduce quite well o quosi-infinite-medium neutron spectra in benzene. But there are deviations not function on the position, at lower energies, that mean a selfscottering overestimated effect thot must be studied.
From the leakage neutron spectrum results we conclude that anisotropic scottering must be used in the calculations and that more experimental information will be necessary in the region near the boundory for a better understonding of the discrepancies olready shown. These works ore at present under woy.

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To the space dependence of reactivity noise in pressurized water reactors

Zur Raumabhängigkeit des Reaktivitäts-rauschens in Druckwasserreaktoren

*By D. Ziegenbein**

1. Introduction

Investigations of space-dependent effects on reactor dynamic perturbation measurements at pressurized water reactor (PWR) ore reported in Ref. [1], the results ore of interest for the space dependence of neutron noise, too. In [1] a determined reactivity perturbation is given on the reactor and the system response is measured. If the used outcore detector is arranged in different core heights then the measured signal is dependent on the detector position. This effect can be explained only by deviations of neutron flux from the behaviour according to the one-point model.

By using the odiabatic approximation it is possible to describe the measured effect by only one parameter [2] that can be estimated both by means of theoretical investigations [3] and experimentally [4]. In this way quontitative assertions on the space dependence of the global effect of neutran noise [5] are possible.

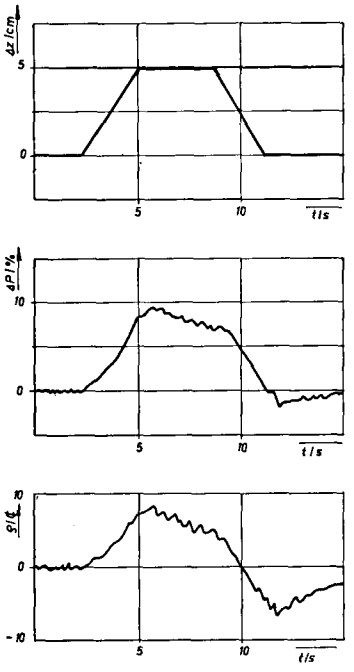

Fig. 1: Time dependence of control-rod position Δ z, power Δ *P* ond reactivity ϱ

2. Space dependence of reactivity measurements

In the derivation of the one-point model of neutron kinetic the equotion

$$\psi(\underline{r}, t) = N(t)\,\phi^{(0)}(\underline{r}) \qquad (1)$$

is supposed. $\psi(r, t)$ describes the neutron flux density, $N(t)$ its time-dependent amplitude, $\varphi^{(0)}(r)$ the stationary flux shape.

The investigations discussed in [1] show that in power reactors of WWER-440 type the neutron flux behaviour deviates from Eq. (1) olso in the case of smoll reactivity perturbations.

If the reactor is disturbed by o reactivity perturbation according to Fig. 1, which is produced by the motion of o control rod bank then the measured normalized alternation of the detector signol would have to be independent on the detector position. The measurements do not show such o behaviour. It can be seen a distinct change of the measured signol if the ionization chomber is situated in different core heights.

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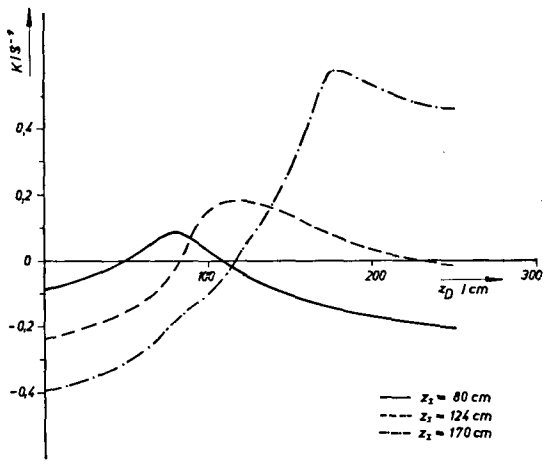

Fig. 2: Dependence of *K* on the detector z_D and perturbation positions z_I (zero power)

According to [3] the measured deviations from the one-point model behaviour can be described for the reactor without feedback (zero power) in good accuracy by the odiabatic approximation. In this case one obtains

$$\psi(\underline{r}, t) = N(t)\,\phi^{(0)}(r)\,(1 + K(\underline{r}; \underline{r}_p)\,\Delta\varrho(t)) \qquad (2)$$

The additional term in Eq. (2) describes the flux shape alternation with the perturbation reactivity. In the ploteou of the tropezoidal control rod motion on other flux shape exists than in the initial respectively final state. The flux shape alternotion is described in the frame of the odiabatic approximation by Eq. (2). The factor *K* is space-dependent and also a function of the perturbation position r_p.

With the optimization procedure described in [3] it is possible to estimate *K* for the investiegoted perturbation from the obtained measured values. In [3] this wos made with simulated values optoined by means of calculations with an one dimensional reoctordynomic code. The calculations are bosed on on axial geometry because the motion of o control bank obove all produces a perturbation in the axial flux shape. The geometric data and the cross sections used in the code are typical for a PWR of WWER-440 type. In Fig. 2 the values of *K* are shown for different perturbation and detector positions. The maximum of *K* that is placed on the perturbation position or nearly to the reflector is in the order of 0.5. It strongly depends on the perturbation position; for positions for from the shape maximum $K = >1$.

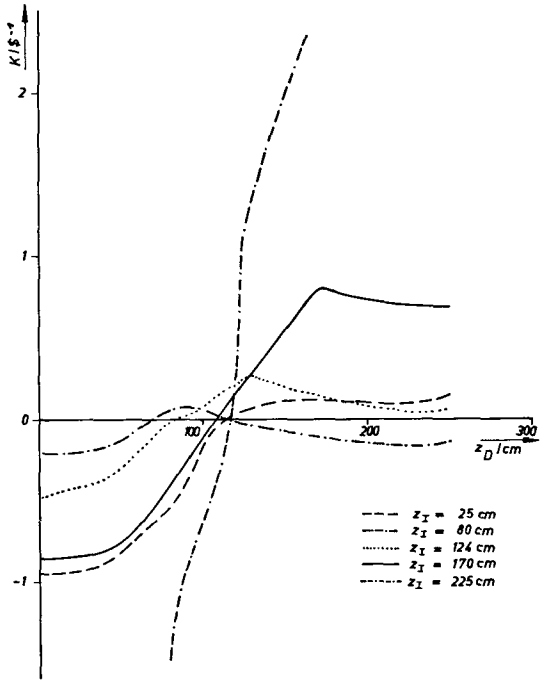

Fig. 3: Dependence of *K* on the detector z_D and perturbation positions z_I (full power)