The HIFAR Oscillator

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A description is given of a pile oscillator which will enable thermal absorption cross-section measurements to be made on HIFAR. The apparatus is in course of construction. The principal design factors are discussed, with particular reference to the effects of scattering by the sample, and the extension of the range of cross-section measurements to include moderators such as graphite and beryllium.

INTRODUCTION

A pile oscillator for the measurement of thermal neutron absorption cross-sections on the HIFAR reactor is at present under construction. The apparatus is usable over a wide range of neutron flux, so that work can commence during the present low power operation of the reactor.

This apparatus is part of a general program to provide facilities for a range of material cross-section measurements. A later phase will probably include the construction of a high resolution time-of-flight spectrometer intended for partial cross section measurements over the energy range 1 eV to 10 keV. A time-of-flight machine of this type can be adapted to absorption cross section measurements at thermal energies; however, when the absorption cross-section, is much less than the potential scattering cross-section, errors in the measurement of σ_a will be fairly large. In addition, corrections may have to be made for Bragg scattering. The values of thermal obtained in this way are not sufficiently accurate for use in thermal reactor design.

Whereas a time-of-flight spectrometer is essentially a beam experiment, a pile oscillator is ideally operated in an isotropic neutron flux where the effects of scattering are greatly reduced. Under suitable conditions a very high discrimination of the order of 1,000 or more can be achieved, enabling measurements to be made on moderators and materials of importance in reactor construction. This discrimination against scattering is a fundametnal feature of the pile oscillator.

On completion, the HIFAR oscillator will be available for testing samples of local constructional materials intended for pile experiments, as well as samples of moderator-fuel mixtures which are to be irradiated as part of the high temperature gas-cooled reactor research program. The oscillator can also be used for work on radioactive samples, provided suitable sample changing facilities are provided.

The measurement of σ_a by the oscillator method is based on the early Danger Coefficient method (Anderson, Fermi, Wattenburg, Weil, and Zinn 1947), in which the sample under test is placed at the centre of a low power reactor and the change in reactivity is measured. The change is then calibrated using samples of known absorption. By placing the sample at the centre of the reactor core, considerable sensitivity can be obtained.

The accuracy of the Danger Coefficient method is limited by short-term changes in reactivity which occur in the course of the experiment. The effect of these fluctuations can be reduced and hence the overall sensitivity increased by a factor of about 20 by oscillating the sample in and out of the reactor. This method has been investigated by Weinberg and Schweinler (1948), and used by Langsdorf (1948). Conditions are arranged so that the pile period is long compared with the period of the longest delayed neutron group. The amplitude of oscillation of the reactor power is then directly proportional to the absorption area of the sample under test. An absolute value is again obtained by reference to a standard absorber. A well-known oscillator of this type is that on GLEEP. This machine plays an important part in testing reactor graphite.

An alternative oscillator was developed at Oak Ridge by Hoover et al. (1948) for measurements on small samples. A similar apparatus was that operating on BEPO (Small and Spurway 1954). The HIFAR oscillator will be of this general type. Here the material under test is oscillated with a comparatively small amplitude in a region removed from the core of the reactor, such as the thermal column, and the local flux depression produced by the sample is observed in a nearby counter or ion chamber.

If the flux depression is small, the oscillations observed will be directly proportional to the neutron absorption area of the sample. This method is about 10 times more sensitive than the Langsdorf oscillator. It has the additional advantage that it makes few demands on the reactor, and can be operated in conjunction with other experiments, provided the reactor power is fairly constant.

In a region removed from the core of the reactor the ratio of thermal to epi-thermal flux will in general be high, hence the thermal absorption will be measured with little interference from resonance absorption. In the earlier method the sample is oscillated through the centre of the core, thus large corrections for resonance absorption would often be required to obtain the thermal value.

DESCRIPTION OF THE APPARATUS

A section of the reactor showing the general arrangement of the oscillator is shown in Figure 1. It consists of two assemblies—the plug assembly, which is in the experimental hole, nd

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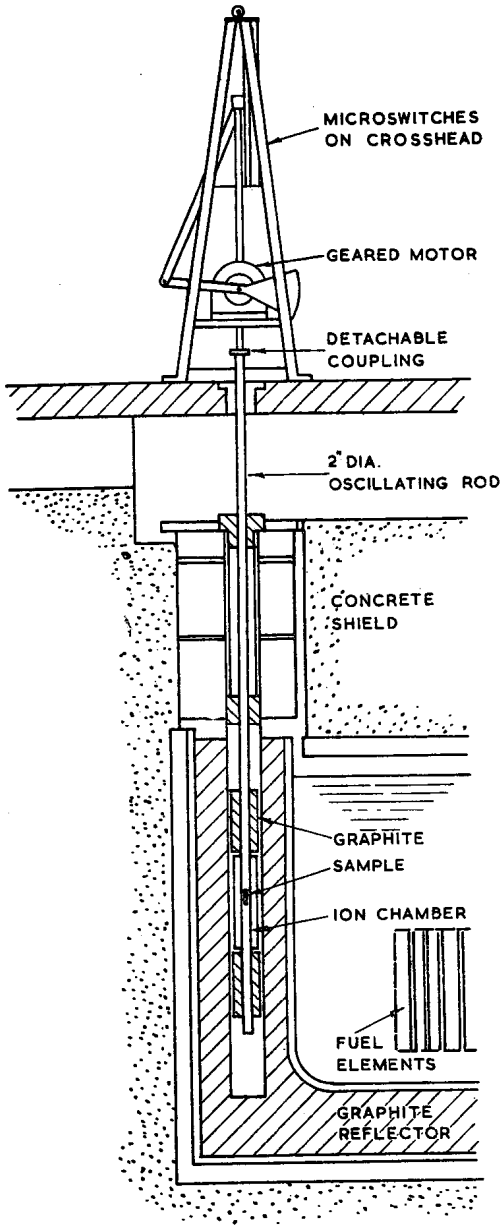

FIGURE 1: Section of oscillator, showing main items of equipment in 6VGR experimental role.

the drive unit, which is mounted on the reactor top plate.

The plug assembly consists of a modified shielding plug, which supports an annular boron coated ionization chamber on three aluminium rods. Passing through the centre of both plug and ion chamber is a 2in. diameter aluminium push-rod, which is guided by sets of rollers at opposite ends of the plug.

The sample to be tested is attached to a small cylindrical cage, which is inserted into the rod from outside the reactor and slid into position by means of a nylon thread. The push-rod complete with sample is oscillated so that the sample moves from the centre of the chamber to a point 20 to 30 inches above the chamber. The push-rod extends through the chamber at all times so that there will not be any appreciable output signal when the push-rod is in motion.

The ion chamber has an active length of 18in., and consists of four concentric thin-wall aluminium tubes. The inner and outer are 3in. and 5in. diameter, and are soldered to end plates, forming a demountable gas jacket sealed with neoprene rings. Two cylindrical electrodes are mounted in the container, the inner being coated on the outer surface with 2 mgm/sq. cm. of boron dag. The chamber is filled with carbon dioxide and maintained at a slight positive pressure via a polythene tube connected to a filling apparatus situated in the reactor gallery.

Annular graphite blocks are placed at both ends of the chamber to help in keeping the neutron flux as uniform as possible.

The push-rod is coupled to the drive rod with a solid screw type coupling placed so that it will be just clear of the reactor top plate at the bottom of the stroke. The driving unit is based on a ½ h.p. geared electric motor operating the vertical drive rod through a crank and connecting rod. The complete driving unit is mounted in a light metal frame, which is studded to the reactor top plate to permit easy removal when other work is in progress.

The main features of the recording equipment are shown in Figure 2. The output current from the ion chamber is fed to an electrometer head unit having a variable input resistance. The lowest flux for satisfactory operation is 10^5 $n/cm^{-2}/sec^{-1}$. Under these conditions, the ion chamber current will be 0.05 μ A and the input resistance will be about 10^8 ohms. By decreasing the input resistance the operating flux level can be increased up to a maximum of about 10^{10} n cm^{-2} sec^{-1}. The electrometer head unit has a voltage gain of 2, and a long term stability referred to the input of $\pm$ 2 mV. The output is A.C. coupled to a high gain D.C. amplifier, the gain of which is adjusted to produce an output signal of approximately 20 V peak to peak.

For the BEPO oscillator, the change in ion current produced by 0.5 sq. cm. of absorber is 0.15 per cent. (Small and Spurway, 1954). Assuming a similar figure for the HIFAR machine, an overall voltage gain of 10^4 (D.C. amplifier gain 5,000) should make it possible to measure 0.1 sq. cm of absorber and cover moderator materials such as beryllium and graphite.

The output waveform is fed to the integrator via microswitches, which are mounted on the drive unit and actuated by the cross head. The selected portion of the output is integrated over about 50 oscillations, the total output being shown on a 100 mV recorder.

The neutron flux of the reactor is monitored continuously by measuring the output of the electrometer head unit on another recorder. The electrometer in turn is checked for drift every 50 oscillations by removing the HT from the ion chamber.

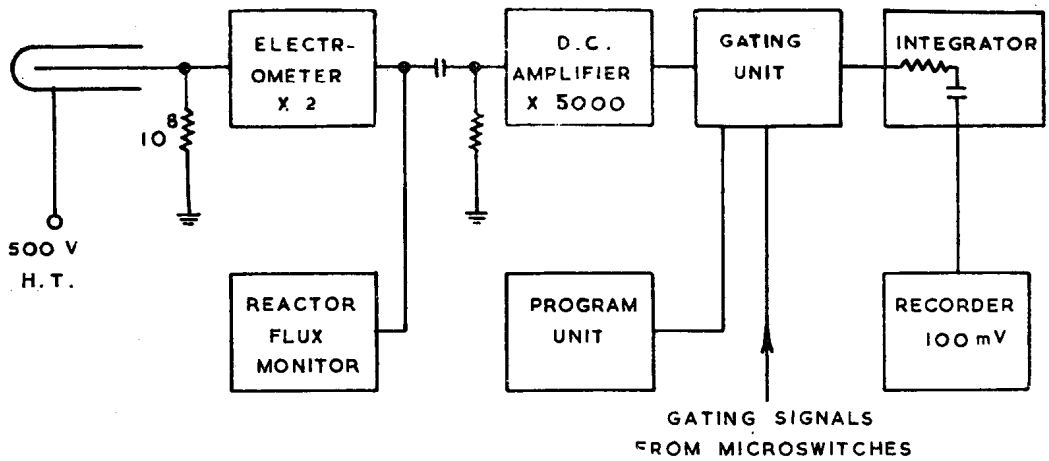

FIGURE 2: Oscillator recording apparatus.

The programming will be done automatically with a counter based on uniselectors. In practice, the apparatus will be left to operate over a period of ½ to 1 hour depending on the accuracy required. The exact accuracy to be expected is difficult to estimate as one of the main limiting factors is expected to be reactor fluctuations which will vary with operating conditions. Neglecting fluctuations, it should be possible to obtain a comparison accuracy of about 1 per cent. by oscillating for 1 hour.

CHOICE OF EXPERIMENTAL FACILITY

The following properties are desirable for the proper operation of the oscillator:

(i) The ratio of thermal to epi-thermal neutron flux must be as high as possible.

(ii) The thermal neutron flux in the hole must be as uniform as possible.

(iii) There must be sufficient depth to allow the push-rod to project through the chamber at all times.

The first condition is best satisfied in the thermal column. However, for the HIFAR reactor there is only 2ft. 10in. of graphite in which to work. In addition, there is a large flux gradient so that both the second and third conditions are not satisfied.

The best compromise is the use of a vertical graphite hole which is sufficiently long to accommodate the push-rod. The thermal neutron flux along the 6VGR—2 hole is given in Figure 3, which shows a region where the flux gradient is quite small. It is proposed to place the ion chamber as near as possible to this position.

The ratio of thermal to epi-thermal neutron flux is lower for a 6VGR hole than for the thermal column. It is estimated that this ratio is 136 when the reactor has a full core. However, it can be shown that this value is sufficiently high for accurate measurements. Let the integrated thermal flux be ϕ_1, and the epi-thermal flux in the range 0.3eV to 2 MeV be ϕ_2. It can then be shown that the cadmium ratio, R, of a $\frac{1}{v}$ absorber such as boron is given by:

$$R = 25\,\frac{\phi_1}{\phi_2}$$

The cadmium ratio for a $\frac{1}{v}$—absorber is thus 3,400. The cadmium ratios of a number of elements can then be estimated using the results of Harris, Muehlhause, and Thomas (1950). These are shown in Table 1.

It can be seen that for most materials the correction for resonance absorption will be negligible for measurements in a 6VGR hole. Even for the strong resonance absorbers such as In^{115} an Au^{197} the correction will be less than 1 per cent., which corresponds to the limit of accuracy offered by the method.

Recent measurements in 6VGR—2 show that the cadmium ratio for 0.12 cm Cd thickness is in the region of 10^5. This is for the minimum core size of 11 elements. Corrections to a complete core indicate that the figures are possibly a little higher than those given in Table 1.

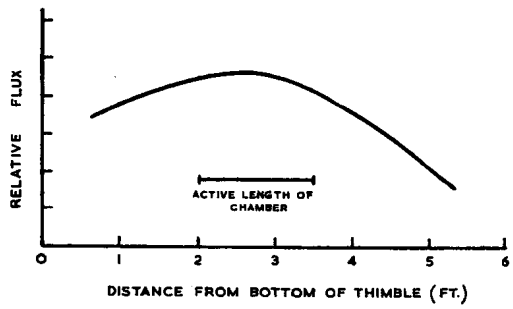

FIGURE 3: Relative thermal neutron flux in 6VGR-2 hole for minium core of 11 elements.

TABLE 1:—ESTIMATED CADMIUM RATIOS IN 6VGR HOLE.

Element	R	Type of Absorber
B^{10}	3,400	pure $\frac{1}{v}$
Na^{23}	3,300	approx. $\frac{1}{v}$
Al^{27}	2,050	resonance absorbers
Mn^{55}	1,670	
Co^{60}	1,140	
Ag^{107}	620	
Ag^{109}	153	strong resonance absorbers
In^{115}	155	
Au^{197}	137	

DISCRIMINATION AGAINST SCATTERING

One of the most important properties of the pile oscillator is its ability to discriminate against the scattering component of the total cross section. If the neutron flux were perfectly isotropic, one would expect negligible effect from scattering. However, for the Oak Ridge type oscillator, where the measurements are taken remote from the core, there is a flux gradient across the chamber which causes an asymmetry in the distribution of scattered neutrons. The net effect is that of a very small absorption. When the sample is just outside the chamber, neutrons will be scattered back, resulting in a small increase in the chamber current and giving a change of sign for the signal due to scattering alone. An idealised version of the scattering and absorption signals expected is shown in Figure 4. By adjusting the gating interval shown, it should be possible to obtain almost complete cancellation of the scattering signal over an interval in which the absorption signal is large. A scattering discrimination of about 2,000 is desired for the HIFAR machine so that measurements can be made on moderators.

A series of experiments, using an almost pure scatterer such as D_2O, in which the position of the ion chamber in the hole, the centre, and amplitude of oscillation, and the gating interval are varied, will be necessary to find the optimum conditions for cancellation of the scattering signal.

METHODS OF COMPARISON AND INTERPRETATION OF RESULTS

In accordance with previous work, gold has been chosen as a standard to obtain absolute $\frac{1}{v}$ absorption areas. Gold is an almost pure $\frac{1}{v}$ absorber in the thermal region, and its absorption cross section is very accurately known. In practice, two gold foils with absorption areas slightly less and slightly greater than the sample would be required for an accurate measurement.

The effects of self-shielding can be partially overcome by the use of a sub-standard such as boron, which has similar geometry to the sample. This technique is particularly effective with liquids.

It is important to consider the exact nature of the comparison performed by the oscillator so that the results may be interpreted correctly. The apparatus is placed in a thermal neutron spectrum which has a Maxwellian distribution of velocities at the temperature of the graphite reflector. Now this spectrum will be slightly hardened by the boron in the ion chamber and the constructional materials, so that the comparison of sample and standard absorbers is made in a spectrum of higher average energy.

Fortunately, no correction is necessary for this effect if the sample has a $\frac{1}{v}$ absorption cross section, as both sample and standard absorption cross-sections will have the same variation with energy. If the 2,200 m/sec cross-section is used for the standard, then the comparison will yield the 2,200 m/sec cross-section for the sample. However, if the sample is not a $\frac{1}{v}$ absorber a knowledge of the cross-section variation with neutron energy is required to cor-

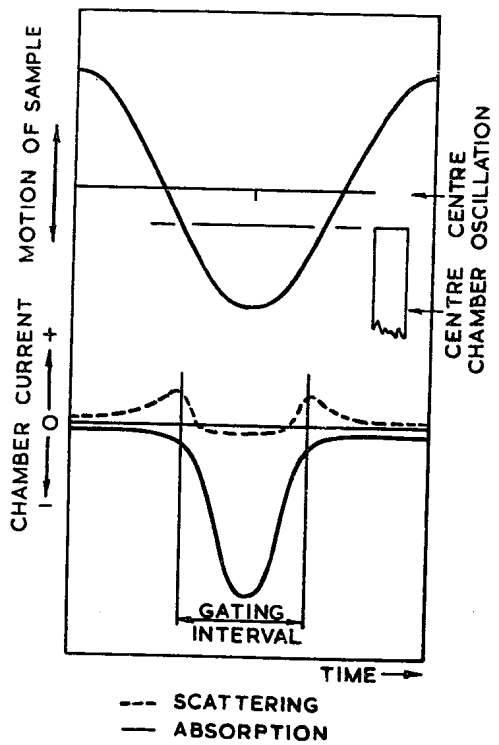

FIGURE 4: Idealised form of scattering and absorption signals from ion chamber over one complete oscillation of the sample.

rect the results back to 2,200 m/sec. This is not a great disadvantage in practice as the thermal absorption of most materials is very nearly 1/v.

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