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SUBJECT: Preliminary Study of Intermediate-Energy Research Reactors

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FROM: J. P. Sanders

SUMMARY

A limited investigation was made of possible reactor configurations which would contain a region having a high intermediate-energy (1 to 10^3 ev) flux relative to the fast and thermal flux. All calculations were performed with a multigroup, multiregion reactor program (GNU-II). Consideration of a single-region, unreflected sphere indicated that the desired flux distribution could not be generated in a region containing fuel because of its resonance absorption.

A "flux trap" configuration was investigated with a cylindrical iron core surrounded by a fuel annulus. Calculations indicated that the fast flux would not be depressed significantly in the central region unless the dimensions were large.

Consideration was then given to an iron reflector for an infinite slab reactor. Good agreement was obtained between reported experimental and calculated relaxation lengths for the flux at different energies. It was found that the desired flux-energy distribution was approached at a point some 20 to 30 centimeters into the iron slab from the fuel; however, the magnitude of the flux relative to that in the fuel region was low.

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A PRELIMINARY INVESTIGATION OF FLUX-ENERGY DISTRIBUTIONS IN AN INTERMEDIATE-ENERGY RESEARCH REACTOR

J. P. Sanders

Introduction

The purpose of this study was to determine the configuration for a research reactor which would produce a relatively-high neutron flux in the intermediate energy range (1.0 to 1000 ev) compared to the flux in the fast and thermal ranges. Such a research reactor would be valuable in determining the resonance integrals of various elements at relatively-low power operation, and for furnishing beams of neutrons having intermediate energies.

Within the limited time available for this study, it was proposed to consider as many configurations and choices of materials as possible. In addition, it was hoped that some indication would be obtained as to how these choices could be varied in order to shift the energy spectrum of the flux.

Development

Three different configurations were considered. The first was a single-region, unreflected sphere containing only uranium-235 and moderator. The second considered the "flux-trap" principle in which an annular fuel section was employed to generate a flux in a central core. In the third configuration, various arrangements of reflectors around an infinite slab fuel section were investigated.

Spherical Reactors

It was first hoped that by decreasing the moderating ratio in an unreflected sphere, a reactor could be obtained with a flux predominately in the intermediate range. Critical concentrations for these reactors were estimated from plots in papers (2,3) by G. M. Safonov. Three cases for a bare spherical reactor which was 16 centimeters in radius and which contained mixtures of uranium-235 and H_2O were calculated using the GNU-II program on the IBM-704 located at K-25. The concentration of uranium-235 in the three cases was approximately 630, 1220, and 2290 grams per liter. It was noted that the calculated k_{eff} for the three cases was in the range of 0.8 to 0.85.

The result of decreasing the moderating ratio did decrease the thermal flux in the reactor; however, because of resonance absorptions in the uranium, the intermediate flux was also depressed. The relative fast flux remained substantially the same over this range of concentration.

It was concluded, therefore, that it is impossible to generate a flux-energy distribution which peaks in the intermediate range in a bare reactor containing fuel having a high resonance-absorption integral.

Cylindrical Reactors

Because of the success of "flux-trap" reactors in generating a high thermal flux in the central core of an annular fuel section, this principle was investigated for the generation of a high intermediate flux. In this case an annular fuel region 11 centimeters thick containing uranium-235 and H_2O was considered. A beryllium reflector 30 cm thick surrounded the fuel region, while iron was assumed in the flux-trap region which was 14 cm in diameter. Iron was selected as the material for the center region because of reported results¹ indicating that in iron the fast and thermal flux were attenuated more rapidly than the intermediate flux. It was also believed that the iron would be advantageous because of its relatively-high inelastic-scattering cross section and its relatively-low threshold energy of 0.85 Mev.

The cross section tapes for the GNU-II program have been recently altered to correct some cross sections which were in error on the original program tapes and to change the energy spacings of the various groups. Unfortunately, the cross section tapes for inelastic scattering have not been altered to correspond to the new energy-group structure. Therefore, the contribution of inelastic scattering was neglected in the calculation of the cylindrical case.

A plot of the flux-energy relationship at various points in the iron core indicated that while the thermal flux was depressed near the center and the intermediate flux was sustained, the fast flux was also undiminished. This did not agree with the experimental results of Nilsson and Braun (1) who reported a relaxation length, λ , of 6.2 centimeters for the fast flux in an iron plug. Nilsson and Braun also state that after 10 centimeters in an iron plug, the epithermal flux was entirely predominant.

Slab Reactors

In order to compare the calculations with the experiment of Nilsson and Braun, a slab reactor (which better approximates their case) was investigated. The fuel section contained uranium-235 and H_2O and was 15 centimeters thick; the fuel region was reflected on one side by a 20-centimeter slab of beryllium and on the other by a 60-centimeter slab of iron.

Two different cases were considered. In the first, the calculation was made using the energy group structure and cross section tapes originally provided with the GNU-II program; this permitted inelastic scattering to be considered. In the second calculation the revised group structure and cross-section tapes were used and inelastic scattering in iron was neglected.

A plot of the relative flux as a function of energy for points 20, 30, 40, and 50 centimeters into the iron slab are shown in Fig. 1. The results obtained when inelastic scattering was neglected (for point 20 centimeters into the iron slab) shifted the peak-flux energy to about 1 Mev (from about 0.3 Mev).

Table 1 gives the relaxation lengths, λ , for the various energy groups as obtained from the calculation in which inelastic scattering was considered. The values obtained agree fairly well with the values for λ reported by Nilsson and Braun. These investigators determined the fast flux in an iron plug by irradiating packets of phosphorous. The (n,p) reaction has a threshold of about 2 Mev. Thus the λ of 6.2 centimeters reported from experiment should agree with the λ for energy groups 1, 2, and 3. Actually the relaxation length from the calculated flux distribution is slightly lower than this, but if group 4 is included (group 4 partially includes this range of energies) the calculated λ agrees with the experimental value.

Nilsson and Braun also determined the thermal and epithermal flux by irradiating Cu, Au, and Mn foils with and without cadmium covers. The relaxation length for the thermal group, that is, below the cadmium cut-off energy, was reported as 1.51 ± 0.02 centimeters (this value was based on the copper-foil measurements). Other values determined for λ were

1.43 ± 0.10 centimeters from Fe activation

1.33 ± 0.20 centimeters from Au activation

1.54 ± 0.04 centimeters from Mn activation

Their reported relaxation length of the epithermal flux (which was in effect the epicadmium flux) was 16 centimeters. This was at a position inside the iron plug. Again this was the value determined from copper-foil measurements; other λ values were

14.5 centimeters from Au activation

15.4 centimeters for Mn activation (the value was

7.3 centimeters at a position near the fuel surface).

The reported and calculated relaxation lengths agree quite well in the thermal range when it is considered that relaxation length as determined by the foils is "weighted" over the various energy groups according to the relative cross section of the foil in that energy range. The cadmium cut-off for these foils with 40-mil cadmium cover is in the range of 0.4 to 0.5 ev.⁴ The relaxation lengths for the epithermal range also agree reasonably well with the values from the calculated flux if again the values are weighted according to the cross section of the foils and it is remembered that Mn and Au have resonances at different energies in this range.

Discussion

From this very limited investigation, it appears that it is impossible to devise a single region reactor which has a neutron energy flux which peaks in the intermediate energy range (1 to 1,000 ev).

Table 1. Flux Relaxation Lengths in Iron as a Function of Energy

GNU II Group Number	Lowest Neutron Energy (ev)	Relaxation Length (cm)	λ From Experiment* (cm)
1	6.06×10^8	4.27	6.2
2	3.68×10^8	4.42	
3	2.23×10^8	4.58	
4	1.35×10^8	6.40	
5	8.52×10^5	10.50	16
6	4.98×10^5	14.44	
7	3.02×10^5	19.95	
8	1.8×10^5	24.4	
9	9,120	25.7	
10	420	20.9	
11	112	13.02	
12	33.7	11.88	
13	15.15	11.24	1.51
14	10.16	10.95	
15	4.56	10.78	
16	1.375	9.76	
17	0.921	8.26	
18	0.617	7.35	
19	0.414	6.66	
20	0.277	5.89	
21	0.227	6.64	1.51
22	0.186	4.95	
23	0.152	4.61	
24	0.125	4.25	
25	0.102	3.88	
26	0.084	3.55	
27	0.068	3.25	
28	0.056	2.97	
29	0.046	2.045	1.51
30	0.038	1.914	
31	0.031	1.780	
32	0.025	1.677	
132	Thermal	1.46	

*See Reference 1.

It also appears that a region containing iron has good possibilities of generating a flux-energy distribution which has its maximum in the intermediate range. This effect does not become pronounced for some 10 to 20 centimeters in a solid iron body; an annular fuel region would therefore have a large inner radius.

From an examination of the calculated relaxation lengths for the slab reactors, it appears that at progressive points into the reflector the flux will tend to become maximum around that energy level having the longest relaxation length. For the cases considered this energy was around 10,000 ev. It should also be pointed out that at long distances into the iron slab, the flux is low relative to that in the fuel region, in fact, it appears that the intermediate flux in this region is never higher than the intermediate flux in the fuel region.

The best possibilities at present for generating the desired flux appear to be to generate a fast spectrum, moderate it sufficiently to shift the maximum to the intermediate range, and then let it diffuse through a region containing iron. The development of the desired spectrum might be enhanced by including a thermal absorber with the iron, although iron appears to have a sufficiently large thermal cross section to accomplish this without an additional absorber. Any other materials selected for this region should not have a high cross section in the energy range of interest.

Conclusion and Recommendations

From the foregoing discussion, it is concluded that

1. It is not possible to generate an intermediate flux in a region containing fuel.
2. It appears that the region in which the high intermediate flux is generated will have to be external to the fuel section.
3. It appears that a region containing iron will generate a flux spectrum which peaks in the intermediate range.
4. In a region containing iron, the maximum flux will be obtained at an energy around 10^4 ev, although the maximum will be fairly broad through the intermediate range.

It is recommended that further studies investigate the possibilities of attenuating the fast flux by placing a moderating region between the fuel region and the iron region.

Fig. 1. Relative Flux-Lethargy Distribution in Iron Slab

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REFERENCES

1. R. Nilsson and J. Braun, "Absorption and Flux Density Measurements in an Iron Plug in R1," AE-13, Akebolaget Atomenergi, Stockholm, August 1958.
2. G. M. Safonov, "A Study of Homogeneous H₂O, D₂O, U²³⁵ Reactors with a note on Optimum Moderating Mixtures for a Minimum U²³⁵ Requirements," RM-842, The RAND Corporation, Santa Monica, California, May 1, 1952.
3. G. Safonov, "A Systematic Study of U²³⁵, U²³⁸, C Reactors," RM-639, The RAND Corporation, Santa Monica, California, June 20, 1951.
4. R. W. Stoughton, J. Halperin, and M. P. Lietzke, "Effective Cadmium Cutoff Energies," ORNL, (To be published in the Journal of Nuclear Science and Engineering).

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