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RESPONSE DISTRIBUTIONS OF ^{6}LiF AND ^{7}LiF THERMOLUMINESCENCE DOSIMETERS IN LITHIUM BLANKET ASSEMBLIES

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Response Distributions of ^{6}LiF and ^{7}LiF Thermoluminescence Dosimeters in Lithium Blanket Assemblies

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Measurement of the radiation-heating rate distribution in the fusion blanket is as important as measurement of the fission-rate distribution in a fission reactor. To obtain the information of radiation heating, the response (integral glow value) distributions in pseudo-spherical lithium assemblies with and without a graphite reflector were measured with ^{6}LiF and ^{7}LiF TLD's. The measured responses are normalized to values per source neutron. Experimental error is about 35 %, and the error in positions of TLD's is about ± 3 mm. The experimental results are compared with those of calculation using RADHEAT code system and ENDF/B-III data file.

リチウムブランケット体系中での ^{6}LiF, ^{7}LiF 熱螢光線量計のレスポンス分布

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核融合炉ブランケット中の放射線発熱の情報を得るために，^{6}LiFと^{7}LiFの熱螢光線量計（TLD）を用いて，黒鉛反射体がある場合とない場合のリチウム球体系中のレスポンス（integral glow value）分布を測定した。測定値は源中性子1個当りに規格化されている。実験値の誤差は約35％で，TLDの位置の誤差は±3㎜である。実験結果はRADHEAT コードシステムとENDF／B-Ⅲのデータを用いた計算結果と直接比較した。

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I. INTRODUCTION

Fusion energy is converted to thermal energy in the blanket region surrounding the plasma of a fusion reactor. The measurement of radiation heating-rate distribution in the blanket is equally important as the measurement of fission-rate distribution in a fission reactor. According to the neutronics calculation(1), heating rate due to gamma-rays in a blanket is about a third of that due to neutrons. At present, there is no direct means for measuring the radiation heating-rate distribution. Some information on neutron heating can be obtained from our measurement of the fission-rate distribution in the blanket assemblies(2),(3). Gamma-ray heating-rate distribution in a fission reactor has been measured by G.G. Simons et al.(4) making use of the difference of response of ^{6}LiF and ^{7}LiF thermoluminescence dosimeters (TLD). In a fusion reactor blanket where the neutrons with high energy are present, it is impossible to measure gamma-ray heating selectively by ^{7}LiF TLD because ^{7}Li(n,n'α)T reaction contributes largely to the formation of thermoluminescence (TL).

The reaction of ^{6}Li(n,α)T and ^{7}Li(n,n'α)T are the two major reactions contributing to heat deposition in a blanket with lithium. When TLD's of ^{6}LiF and ^{7}LiF are employed, the major portion of radiation heating-rate in lithium may be measured. We have measured the responses* of ^{6}LiF and ^{7}LiF TLD's to the neutron and gamma-ray in pseudo-spherical lithium assemblies with and without a graphite reflector. The results of the measurements are compared with those of calculations. In order to calculate the total response of the TLD, the energy dependence of the TLD response to the neutrons and gamma-rays must be known respectively. The energy dependence of the response to gamma-ray are accurately known. As for the energy dependence to the neutrons, the responses of ^{6}LiF and ^{7}LiF TLD's to various monoenergetic neutrons are measured by Y. Furuta and S. Tanaka, and they were shown to be in good agreement with the calculated

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* The unit value is the equivalent ^{60}Co gamma-ray exposure in roentgens.

values[(5),(6)].

II. EXPERIMENTAL ASSEMBLIES AND PROCEDURES

1. PRINCIPLE OF MEASUREMENT

The response (integral glow value) of TLD in the unit of ^{60}Co equivalence* may be represented by the following equation from the values read from a TLD reader,

$$R(r) = \frac{\eta\, D(r)}{N} \tag{1}$$

Here, $R(r)$; The response of TLD at the position r, in the unit of ^{60}Co equivalence per unit source neutron (R/neutron).

η ; The factor for converting the value indicated in the reader to ^{60}Co equivalence.

$D(r)$; The dose of TLD at the position r as indicated by the reader.

N ; Total neutron yield during the measurement.

The conversion factor η may be obtained by irradiating the TLD's in the standard irradiation field of ^{60}Co gamma source prior to the experiment.

On the other hand, the response may be represented by the following equation using the calculated neutron and gamma-ray fluxes,

$$R(r) = \int_0^\infty R_n(E)\ \phi_n(r,E)dE + \int_0^\infty R_\gamma(E)\ \phi_\gamma(r,E)dE \tag{2}$$

where, R_n: the response-function for neutrons,

ϕ_n: neutron flux,

R_γ: the response-function for gamma-rays,

ϕ_γ: gamma-ray flux.

The neutron and gamma-ray fluxes in the experimental assemblies are obtained from the blanket neutronics calculation procedures developed in JAERI for the design of fusion reactors [(1)]. The response-function for gamma-rays R_γ is calculated

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from the mass energy absorption coefficient of TLD. The response-function for neutrons R_n obtained by Y. Furuta and S. Tanaka[(5),(6)] is adopted.

2. EXPERIMENTAL ASSEMBLY

The vertical cross-section of the spherical lithium metal assembly with a graphite reflector (named Li-C Assembly) is shown in Fig. 1. It is constructed by loading stainless-steel canned lithium metal blocks and graphite blocks in drawers made of stainless-steel, which in turn were loaded on stainless-steel lattice matrix. The unit size of the block is about 2 inches cube. The 3 x 3 x 3 units in the center consist only of stainless-steel drawers and lattice and the region covered by these units are called Void region. The effective radius (meaning the radius of the equivolume sphere) of Void region is 10.0 cm. The effective outer radius of Li-region, where the lithium blocks are loaded, is 34.1 cm, and that of Graphite region with graphite blocks is 55.3 cm.

The spherical lithium assembly without a graphite reflector is called Li Assembly. The details of the experimental assemblies are given in the Refs. (2) and (3).

A Cockcroft-Walton type accelerator is used as the neutron generator. The D^+ beam of 300 keV is focused on a 10 Ci tritium metal target placed at the center of the experimental assemblies. The TLD response is measured in the direction perpendicular to the D^+ beam.

3. EXPERIMENTAL PROCEDURES

The hot-pressed type TLD-600 and TLD-700 supplied by Harshaw Chemical Co. are used for the measurement. They are rods 6 mm long with 1 mm square cross-section and their weight is about 15 mg.

Three TLD's (each ^{6}LiF (TLD-600) and ^{7}LiF (TLD-700)) are inserted in a small envelope of polyethylene and fixed by cellophane tape in the space for experimental hole in the stainless-steel drawers for each experiment point. The detector

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positions are in the direction perpendicular to the incident D^+ beam on the same holizontal plane as the target as shown in Fig. 1. An α-monitor is placed in the beam extension tube, at 179 degrees to the D^+ beam and about 107 cm from the target, to count the α-particles emitted by D-T reaction and to obtain the absolute neutron yield.

After irradiation, the TLD's were removed immediately from the assembly. They were left for 24 hours in room temperature, and the irradiation dose were measured by the TLD reader.

Prior to the irradiation, the TLD's are calibrated by ^{60}Co source with strength 7.2 mCi, in order to obtain exposure dose. The conversion factor η is calculated from the data. The TLD's having the dose within ± 3 % of the average were selected for use in the experiment.

III. CALCULATIONAL PROCEDURE

The neutronics calculations are based on RADHEAT(7), the code system for calculating radiation heating-rate. The 42 group neutron transport cross-sections of up to P_5 Legendre terms are obtained by SUPERTOG(8) from ENDF/B-III data file. The 21 group gamma-ray transport cross-sections are calculated by GAMLEG-JR(7). The energy structures of neutron and gamma-ray cross-sections are shown in Tables I and II, respectively. The gamma-ray production cross-sections are calculated by POPOP4 (9) from POPOP4 library(10).

The calculational models for Li and Li-C Assemblies are shown in Fig. 2. Neutron and gamma-ray fluxes are calculated by one-dimensional transport code ANISN employing P_5 - S_8 approximation. The group-wise responses of TLD's for neutrons and gamma-rays are calculated from the response-functions R_n and R_γ, respectively. The calculational response of TLD is the sum total of them. There is a little difference in the gamma-ray response functions for ^6LiF and ^7LiF TLD's, but the value for the natural lithium fluoride TLD is used in the present calculation.

IV. RESULTS AND DISCUSSIONS

The measured responses of ^{6}LiF and ^{7}LiF TLD's in Li and Li-C Assemblies are compared with calculated ones in Figs. 3 and 4, respectively. Since both measured and calculated values are normalized to values per one source neutron, direct comparison of absolute values are possible. Experimental error amounts to about 35 %, which is the sum of following errors;

the deviation of TLD elements	5 %,
the statistical reading error	10 %,
the total neutron yield error	5 %,
the measurement error of conversion factor	15 % .

The error in the position of TLD is about ± 3 mm.

Considering the experimental error and the accuracy of gamma-ray data using the calculation, the measured and calculated values in the Li Assembly are in fairly good agreement for both ^{6}LiF and ^{7}LiF for all except the first measured point (at 8.3 cm). But in Li-C Assemblies, while the measured and calculated values for ^{7}LiF are in fairly good agreement, a large difference between them is observed for ^{6}LiF.

Each response for neutrons and gamma-rays in the two assemblies is calculated for ^{6}LiF and ^{7}LiF TLD's. They are shown in Figs. 5 and 6. The calculated curves in Figs. 3 and 4 are the sum of neutron and gamma-ray responses in Figs. 5 and 6, respectively. The magnitude of the response to gamma-rays is of comparable order to that of the response to neutrons in the lithium region of Li-Assembly as shown in Fig. 5. It may also be observed from the figure that the response of ^{7}LiF TLD to neutrons cannot be neglected when 14 MeV neutrons are present. The response of ^{7}LiF TLD in Li-C Assembly is not much different from that in Li-Assembly. The response of ^{6}LiF TLD to neutrons is far greater than that to gamma-rays in the graphite region of Li-C Assembly. Therefore, the large difference observed between the calculations and experiment about the ^{6}LiF response in the graphite region may be attributed to the calculational error in low energy neutron flux, which contribute to $^6Li(n,\alpha)T$ reaction.

Similar results have been obtained from the absolute fission-rate distribution in Li-C Assembly[11], and the major cause of the discrepancy between measurement and calculation is identified as the inaccurate treatment of the anisotropy of nonelastic neutrons in processing multigroup cross-sections from nuclear data[12].

Large discrepancy observed near the center of the assembly are explained by treating the shape of neutron source as a small sphere in the calculation, by the fluctuation of the beam spot, and by the gamma-rays caused by the accelerated deuteron hitting the target which have been neglected in the calculation.

The following problems in the experimental procedures resulted in large errors:

(1) The error in the calibration of TLD elements, i.e. in the conversion factor , is large. There is 5 % error in the strength of ^{60}Co gamma-ray source itself and additional error is caused by the back-scattered gamma-rays from the floor and wall of the calibration room and also by the scattered gamma-rays from the structural materials for supporting the TLD elements and source.

(2) The reading error for low dose-rate by the TLD reader is large.

(3) Although TLD elements with least fluctuation is selected prior to the experiment, the fluctuation is still unacceptably large.

The following problems in the calculational procedures are pointed out:

(4) The calculated gamma-ray flux may have large error owing to the insufficient gamma-ray production data in the POPOP4 Library.

(5) The neutron cross-section processing code is inadequate for the analysis of fusion blanket neutronics because the anisotropy of nonelastic neutrons is not properly accounted for as already described in Ref. (12).

(6) One-dimensional sphere models used in the analysis does not reflect the details of the experimental assemblies.

(7) The stainless-steel structural materials near the target is accounted for in the calculations by including them into the homogenized atomic density of the region from 0.5 cm to 3.3 cm. Since the gamma-ray is produced mostly near the target, the search for the best model is required for the better description.

In spite of all the uncertainties accompanying the present experiment and analysis, the measurement of the distribution of ^{6}LiF and ^{7}LiF TLD response in the fusion blanket mock-up assemblies is very promising as an effective means for obtaining the information on radiation heating-rate distribution.

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Table I Neutron Energy Group Structure

Group	Energy Limits		Mid-Point Energy	
1	15.000 – 13.720	MeV	14.360	MeV
2	13.720 – 12.549		13.135	
3	12.549 – 11.478		12.014	
4	11.478 – 10.500		10.989	
5	10.500 – 9.314		9.907	
6	9.314 – 8.261		8.788	
7	8.261 – 7.328		7.795	
8	7.328 – 6.500		6.914	
9	6.500 – 5.757		6.129	
10	5.757 – 5.099		5.428	
11	5.099 – 4.516		4.808	
12	4.516 – 4.000		4.258	
13	4.000 – 3.162		3.581	
14	3.162 – 2.500		2.831	
15	2.500 – 1.871		2.186	
16	1.871 – 1.400		1.636	
17	1.400 – 1.058		1.229	
18	1.058 – 0.800		0.929	
19	0.800 – 0.566		0.683	
20	0.566 – 0.400		0.483	
21	0.400 – 0.283		0.342	
22	0.283 – 0.200		0.242	
23	0.200 – 0.141		0.171	
24	0.141 – 0.100		0.121	
25	100.0 – 46.5	KeV	73.25	KeV
26	46.5 – 21.5		34.0	
27	21.5 – 10.0		15.75	
28	10.0 – 4.65		7.325	
29	4.65 – 2.15		3.40	
30	2.15 – 1.00		1.575	
31	1.00 – 0.465		0.733	
32	0.465 – 0.215		0.340	
33	0.215 – 0.100		0.158	
34	100.0 – 46.5	eV	73.25	eV
35	46.5 – 21.5		34.0	
36	21.5 – 10.0		15.75	
37	10.0 – 4.65		7.325	
38	4.65 – 2.15		3.40	
39	2.15 – 1.00		1.58	
40	1.00 – 0.465		0.733	
41	0.465 – 0.215		0.340	
42	0.215 – 0.001		0.108	

Table II Gamma-Ray Energy Group Structure

Group	Energy Limits (MeV)	Mid-Point Energy (MeV)
1	14.0 – 12.0	13.0
2	12.0 – 10.0	11.0
3	10.0 – 8.0	9.0
4	8.0 – 7.5	7.75
5	7.5 – 7.0	7.25
6	7.0 – 6.5	6.75
7	6.5 – 6.0	6.25
8	6.0 – 5.5	5.75
9	5.5 – 5.0	5.25
10	5.0 – 4.5	4.75
11	4.5 – 4.0	4.25
12	4.0 – 3.5	3.75
13	3.5 – 3.0	3.25
14	3.0 – 2.5	2.75
15	2.5 – 2.0	2.25
16	2.0 – 1.5	1.75
17	1.5 – 1.0	1.15
18	1.0 – 0.4	0.7
19	0.4 – 0.2	0.3
20	0.2 – 0.1	0.15
21	0.1 – 0.01	0.055

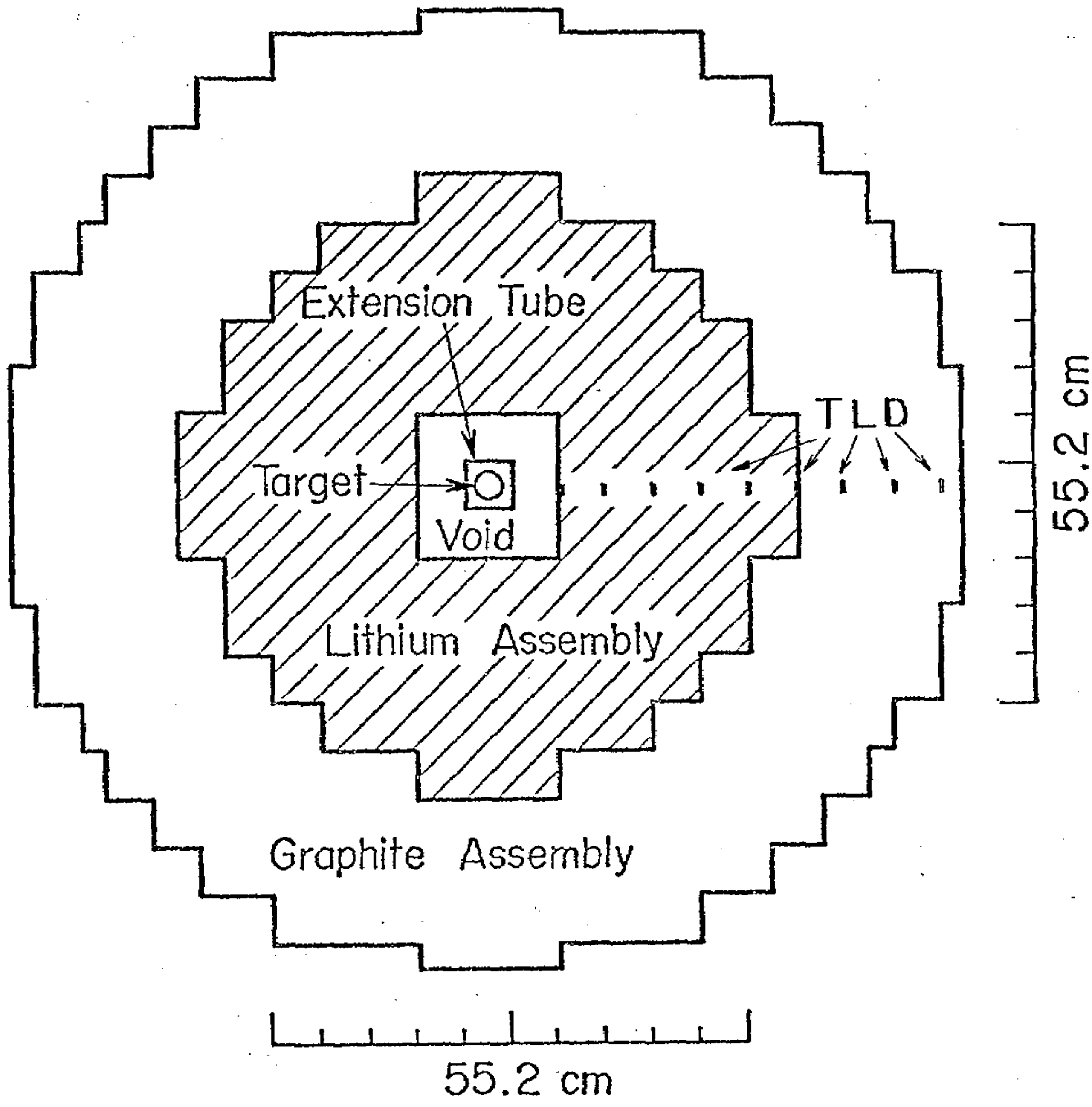

Fig. 1 Vertical Cross Section of the Spherical Lithium Metal Assembly with a Graphite Reflector

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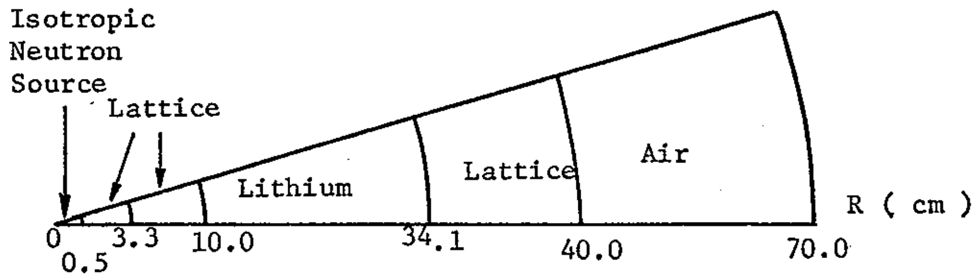
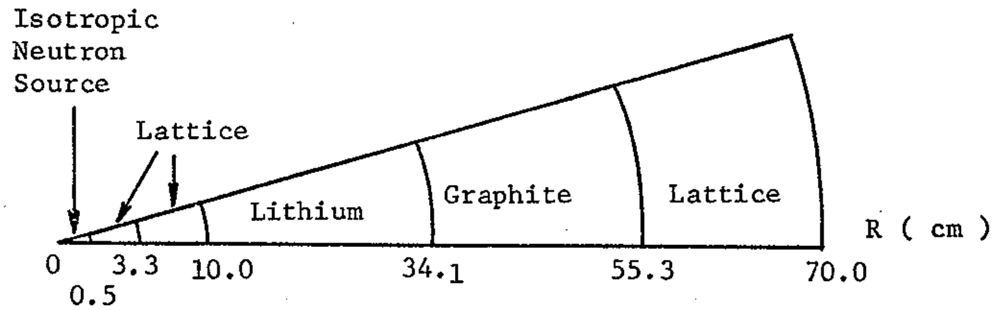


Li Assembly



Li-C Assembly

Fig.2 Calculational Model of the Spherical Lithium Metal Assembly

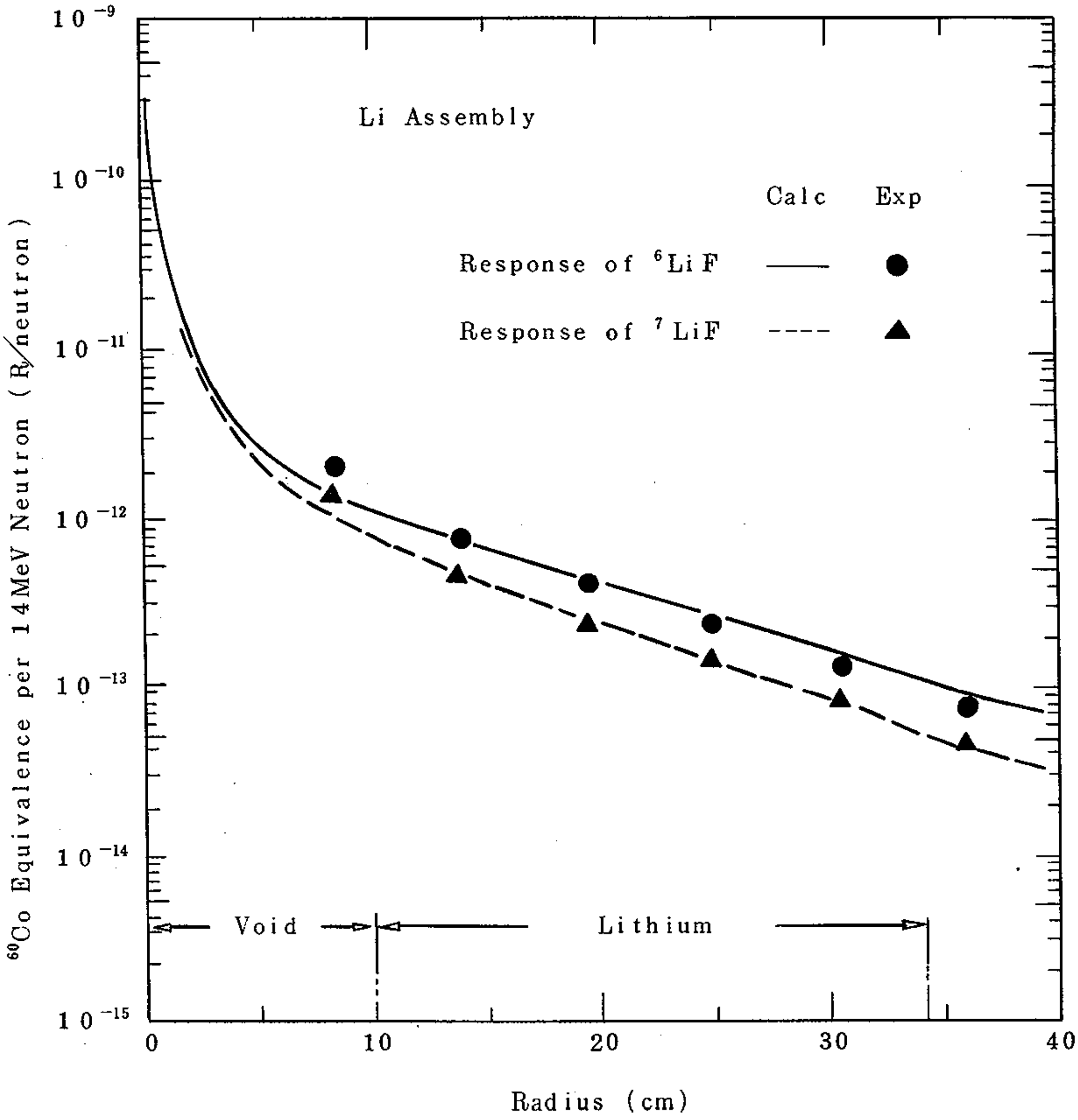


Fig. 3 Response Distributions of ^{6}LiF and ^{7}LiF TLD's in Li Assembly

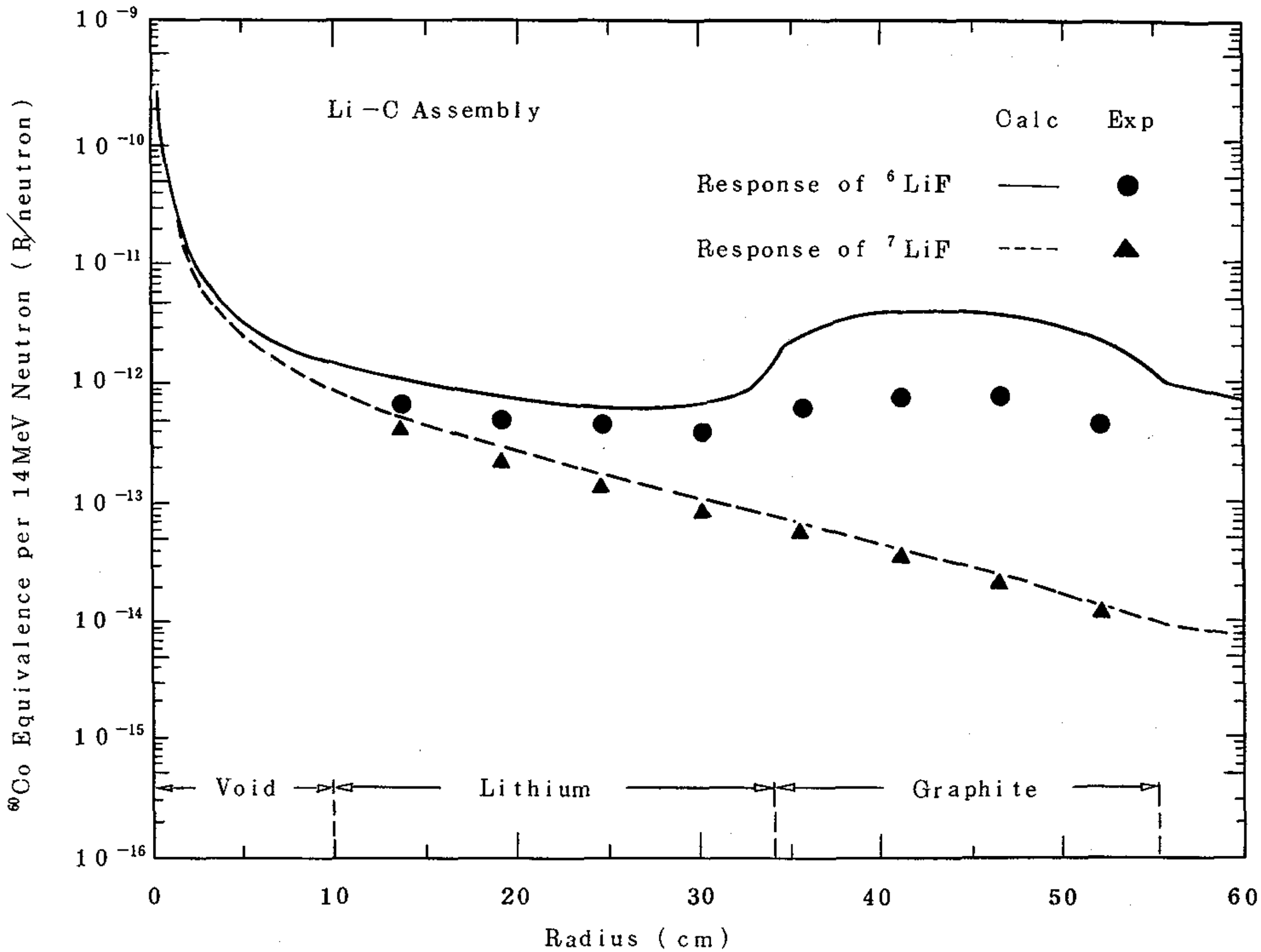


Fig. 4 Response Distributions of ^{6}LiF and ^{7}LiF TLD's in Li-C Assembly

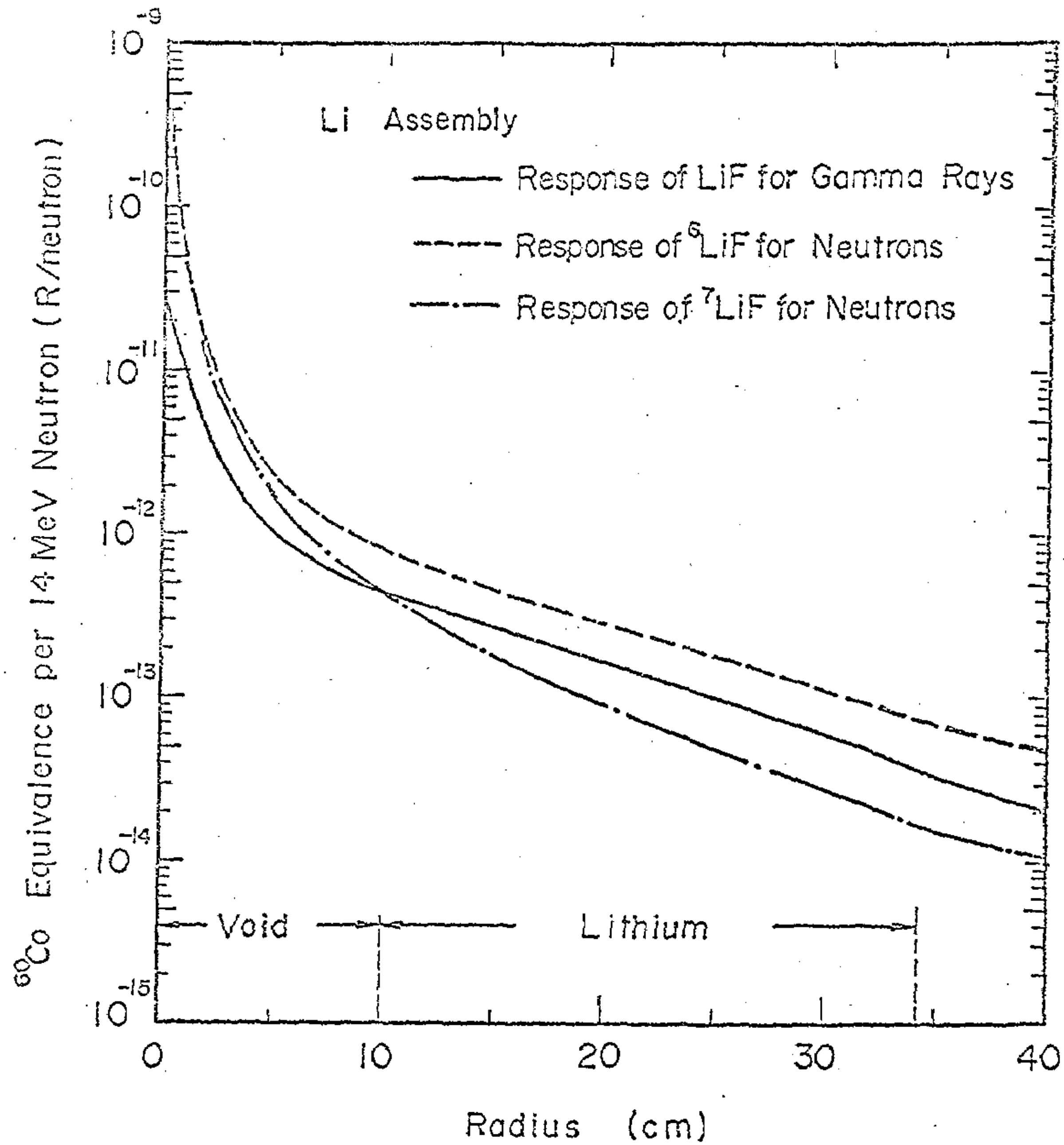


Fig. 5 Calculated Response Curves of LiF TLD for Neutrons and Gamma-rays in Li Assembly

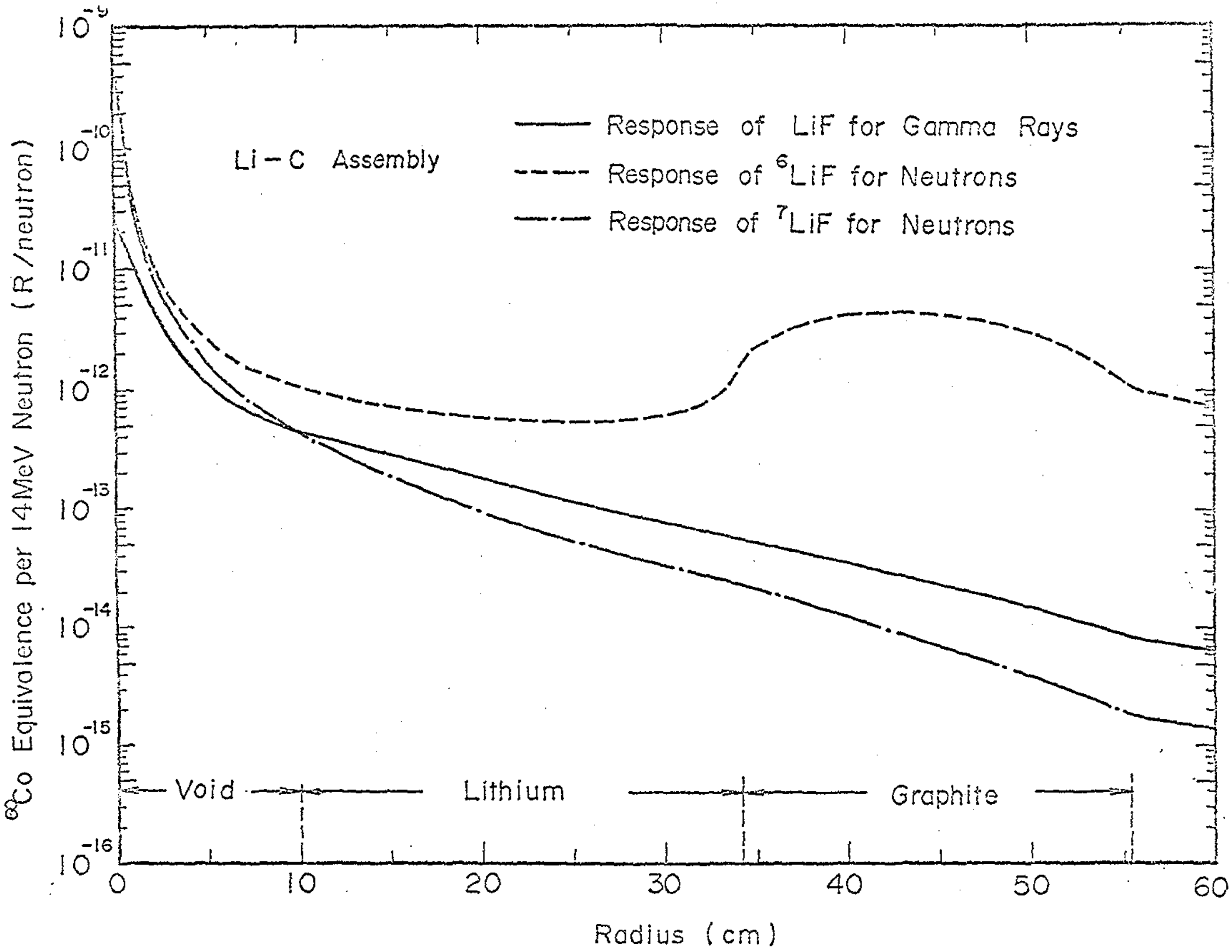


Fig. 6 Calculated Response Curves of LiF TLD for Neutrons and Gamma-rays in Li-C Assembly