

Relative Dose Distribution in the Biological Irradiation Facility at TRIGA Mark-III Reactor

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Abstract

A result of measurement for the relative dose distribution of neutron gamma mixed radiation field in the biological irradiation facility installed at TRIGA Mark-III reactor is described.

The relative dose distributions of neutron-gamma mixed radiation field in the biological exposure room have been experimentally determined using a thermoluminescent dosimeter. Presented herein in graphical forms are the experimental results obtained. It was observed that the region commonly having the characteristics of rather homogeneous horizontal and lateral dose distributions is confined to the area bounded by the two planes horizontally parallel to the beam direction with heights of about 40 cm and 130 cm, respectively, at distances beyond 100 cm from the segmentary surface of the aluminum pool liner projected into the exposure room, while other areas show a steeper gradient in dosage, especially the places adjacent to the segment of the aluminum pool liner and near the inner portion of the concrete walls of the exposure room.

요 약

TRIGA Mark-III 원자로에 설치된 조사시설에서 중성자-감마 혼합 방사선장의 상대적 선량분포 특성을 중성자와 감마 방사선에 대한 감응함수가 다른 한쌍의 열형광 선량계를 사용하여 측정된 결과이다.

수평방향 및 수직방향의 거리에 따른 비교적 균일한 선량 분포를 공유한 지역은 조사실 바닥으로부터 약 40 cm 와 130 cm 의 높이에 있는 두 수평 평행판사이의 구역중 조사실쪽으로 반원통형으로 돌출된 알루미늄 저수조표면에서 수평방향으로 100 cm 이상의 거리에 있는 지역에 한정됨이 관찰되었다. 그 이외의 지역은 급격한 선량구배 특성을 갖고 있었고 특히 반원통형 알루미늄수조 표면근처와 조사실 콘크리트 차폐내벽 근처에서 더욱 구배가 컸다.

1. Introduction

Experiments making use of various facilities of TRIGA Mark-III reactor installed at

the Korea Atomic Energy Research Institute can be divided roughly into two categories. The first category includes such experiments as the study of radiation effect on the irradiated samples. In this case, the radiation

effect may be sought from different angles depending upon the degree of interests and fields of the investigators, i.e., from nuclear, physical, chemical or biological aspects. The second one covers experiments for the investigation of natural state of samples by means of radiation as a tool.

Description is made with regard to the property characteristics of neutron-gamma mixed radiation field in the exposure room for biological experiments from the viewpoint of the first category, with the emphasis on the uniformities of both vertical and horizontal dose distributions.

It is usually preferable especially when conducting biological irradiation experiments to have a source with constant neutron spectrum and gamma activity level giving reproducible dose rates. Some of obstacles to this requirement with thermal reactors are associated with the need for frequent refuelling, changes in fuel positions in the core and the duration of reactor operation prior to the experiments. Since achieving criticality in 1972, the reactor has been refuelled three times up to date, and it is desirable to know of the influence of refuelling on the stability of gamma exposure rate, neutron spectrum, neutron kerma and on the RBE, all of which are indispensable for the effective utilization of irradiation facility.

As a part of investigation of dose distribution characteristics, an attempt was made to measure the profiles of relative dose distribution the irradiation facility at the TRIGA Mark-III reactor. The profiles drawn up in this work must provide us with sufficient information for the utilization of the irradiation facility than ever.

Radiation dose rates at different positions along the vertical and horizontal axes of the

exposure room were measured under the steady state reactor operation at 10 KW thermal power by means of solid state dosimeters (thermoluminescent dosimeters) from Harshaw Chemical Co. It has become an accepted practice¹⁻⁶⁾ to make use of the two isotopic extruded ^6LiF and ^7LiF in neutron-gamma mixed radiation field on the assumption that ^7Li is not responsive to neutrons. The gamma response of the two fluorides was determined with ^{60}Co and radium gammas and it was found to nearly the same each other. Therefore, the ^7Li experimental values were subtracted from the ^6Li data.

2. Description of Biological Exposure Room

Some of facilities for experiments and irradiation associated with the TRIGA Mark-III reactor are situated at both ends of the pool, while some others are attached to the reactor core itself. Physical access to, and the observation of the core are possible at all times through the vertical water shield.

As one end of the pool structure is a borated-concrete-lined exposure room with dimension of 2.74 m high, 3.05m wide, and 3.66 m long, in which large specimens for engineering and biological experiments may be exposed to very high neutron and gamma flux. A segment of the aluminum pool liner is projected into the exposure room; the size of this segment permits the maximum leakage of radiation into the room and provides 180 degree access to the core perimeter for experiments. With the reactor core in the position, a nominal clearance of about 1.27 m is maintained between the core shroud and the inside surface of the tank segment so as to provide the core with about 2.54 cm

water barrier between the G-ring fuel elements and the shroud. The pool water provides sufficient shielding for personnel working in the exposure room when the core is operating at the thermal column and of the pool. Boron is used in the inner portion of the concrete walls of the exposure room to minimize the activation of the concrete.

When this experiment took place, a total U-235 inventory of 4,777 g was charged in the core, comprising of 101 regular fuel elements (20 w/o enriched), 6 FLIP fuels (70 w/o enriched) and 4 control rod-fuel followers (20 w/o enriched) thus making 111 fuels in total. The reactor is regularly put into operation for 35 hours per week.

3. Experimental Methods

In the experimental environment of the reactor as described above, radiation dose distribution in the exposure room was determined by a pair of thermoluminescent dosimeters (TLD), one being thermal neutron and gamma sensitive, and the other only gamma sensitive. TLD's employed as detectors consist of commercially available Harshaw TLD-600 which is enriched with ^6Li (95.62%) and TLD-700 which is predominantly ^7Li

(99.98%). LiF was selected as the detectors because it has become an accepted practice¹⁻⁶⁾ to utilize the two isotopic extruded ^6LiF and ^7LiF in neutron-gamma mixed radiation field in order to evaluate the gamma component of the irradiation field on the assumption that the ^7Li is not responsive to neutrons.

For exposing dosimeters to neutron-gamma mixed doses, TLD-700 and -600 enclosed in the separate thin polyethylene tubes with thickness of 0.03 mm were attached side by side on the polyethylene strip of which both ends were taped on the inner walls of the exposure room. Each pair of dosimeters mounted on the polyethylene support was placed at an interval of 20 cm apart to the vertical direction and of 40 cm to the horizontal direction. The locations of each pair of dosimeters correspond to the jointed positions of horizontal and vertical lines on the vertical plane going along the central axis in the exposure room. Thus the total number of measuring positions shown in Fig. 2 amounted to 112 points.

Following each irradiation at the steady state reactor operation at 10 KW power for 5 minutes, all the irradiated dosimeters were read on Harshaw-2000 integrating reader

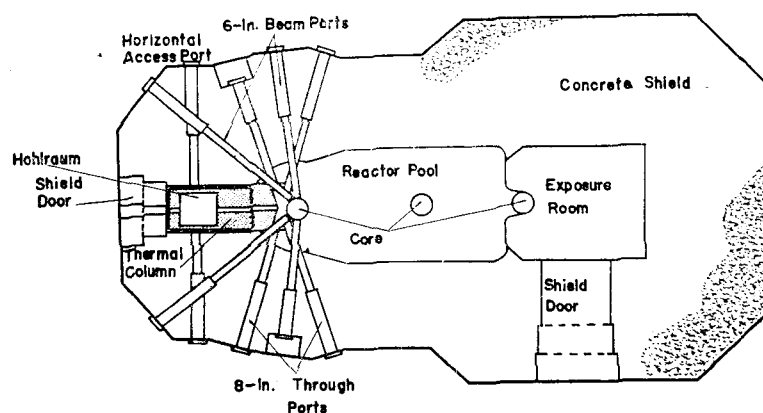


Fig. 1. Horizontal cross section of TRIGA Mark-III reactor

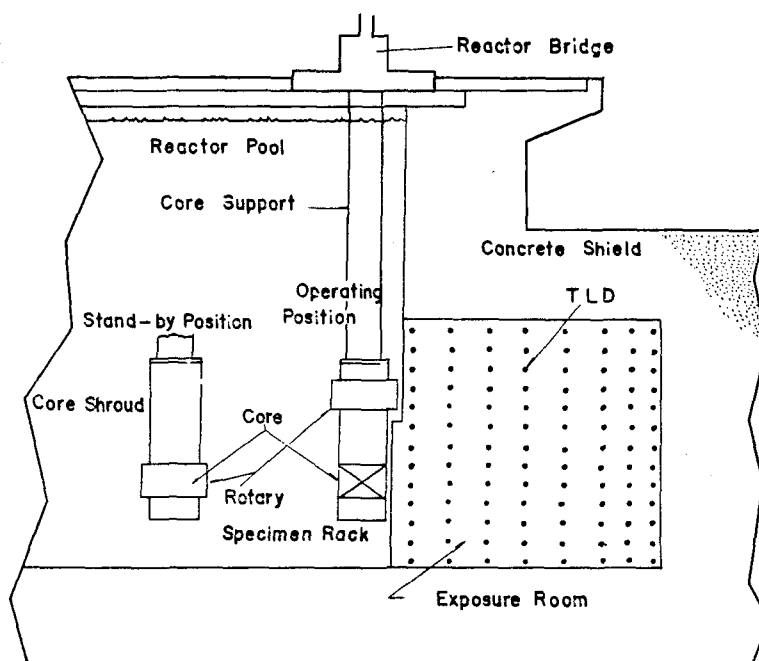


Fig. 2. Relative position of the reactor core, a detector array in the exposure room during irradiation

after having allowed 24 hour cooling time. The unit measures the integrated light output or area under the glow curve. A ^{14}C -powered reference light source provides a check of the stability of the photomultiplier-electrometer system. In each measurement the integrated light output in coulombs was used for calibration and dose measurements. A heating rate of approximately $5^\circ\text{C}/\text{sec}$ and a reading cycle of 30 sec has been used with the maximum temperature of 240°C throughout this work. The annealing procedures were carried out in two separate furnaces, one having maintained the temperature at 400°C as per requirement and the other at 80°C . The temperature was regulated to $\pm 2^\circ\text{C}$ by electronically controlled circuit. The temperature gradient inside the furnaces was very small. Special aluminum blocks having grooves to accommodate individual dosimeters were used to ensure uniform temperature to

every dosimeter in each group. The dosimeters used were annealed before use at 400°C for 90 minutes, then cooled down to the room temperature and finally heated up to 80°C for 24 hours.

4. Results

The experimental results obtained through the measurement on the relative dose distribution of vertical plane passing through the central axis of the biological exposure room are graphically presented in Fig. 3 through Fig. 6. The finding is such that the lateral relative dose distributions shown in Fig. 3 through Fig. 6 have three meaningful different characteristics in dose patterns.

The first one, shown in Fig. 3, appears in the region below the height of about 30 cm from the bottom floor. As shown in Fig. 4 dose rates depending upon distance from the core are upstream up to about 150 cm.

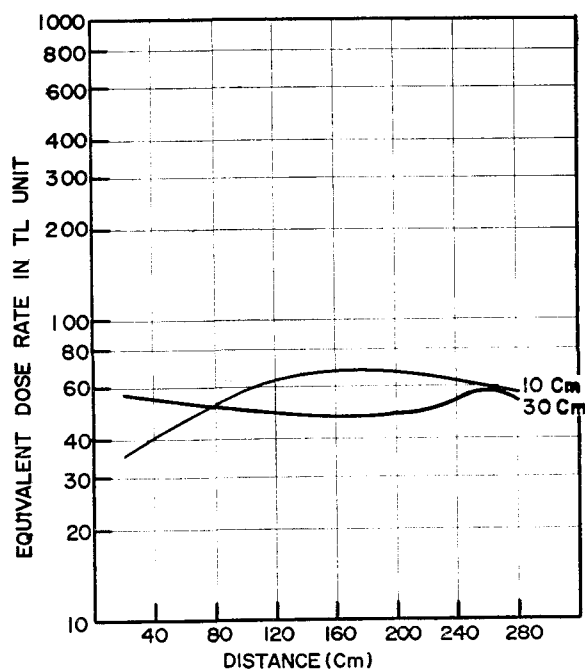


Fig. 3. Lateral dose distributions below the height of 30 cm from the bottom floor.

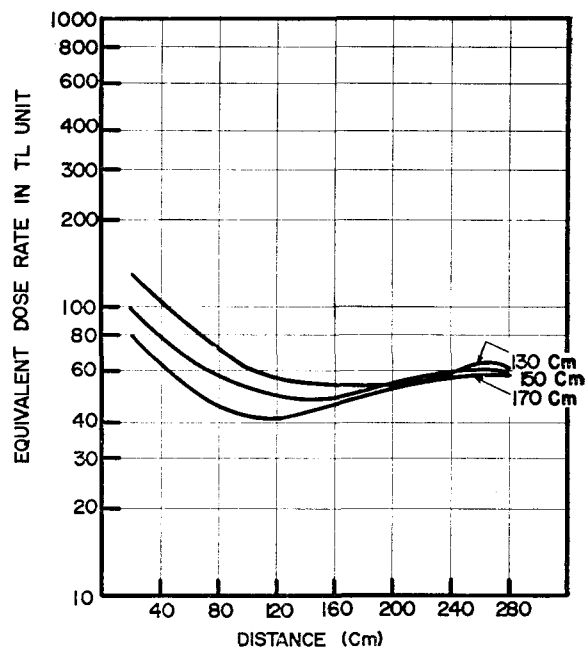


Fig. 5. Lateral dose distributions between the height of 130 cm and 170 cm

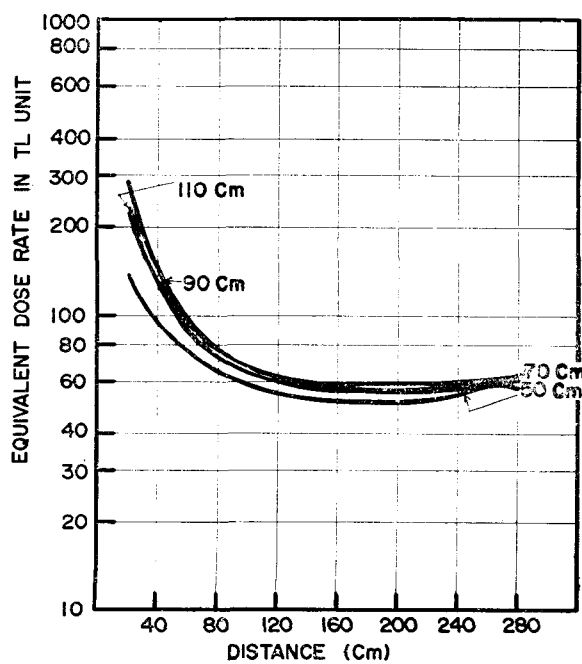


Fig. 4. Lateral dose distributions between the height of 50 cm and 110 cm.

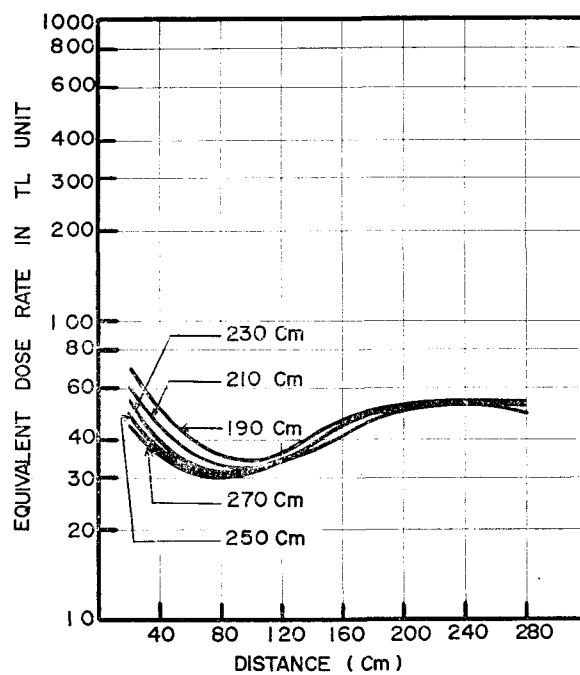


Fig. 6. Lateral dose distributions at various elevations near the ceiling

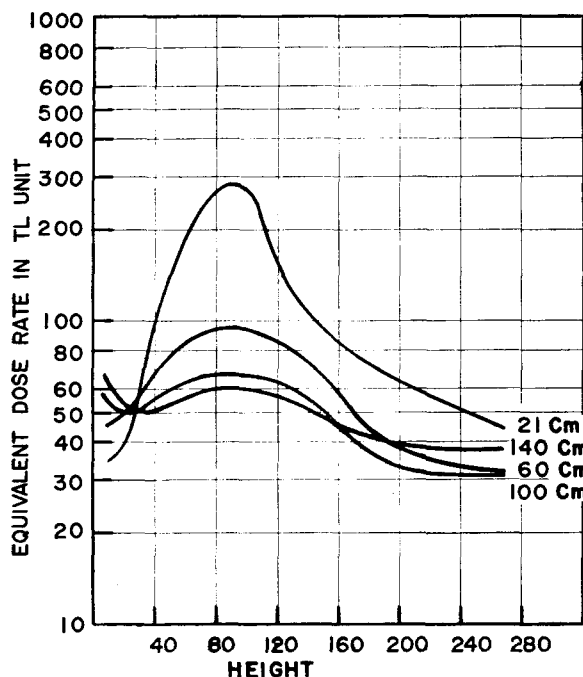


Fig. 7. Vertical dose distributions at various distances from the reactor core.

outward and thereafter slowly decrease. On the contrary, most curves of dose distribution decrease, in general, with increasing distance. The build-up of dosage is most probably attributed to the unique configuration of the reactor core itself. This implies that it is reasonable to consider the reactor core as a finite semicylindrical source with mono-directional beam rather than an isotropic point source. Thus the contribution of the reactor radiation is progressively significant as increasing the distance from the core, reaching at the maxima referred to as a transition point. The second one, shown in Figs. 4 and 5, is characterized by both the left part of the curves having steeper dose gradient, and the rest one with no significant variation in dosage depending on the distance. It can be taken for granted in interpreting the curves that the former results from predominant contribution of direct

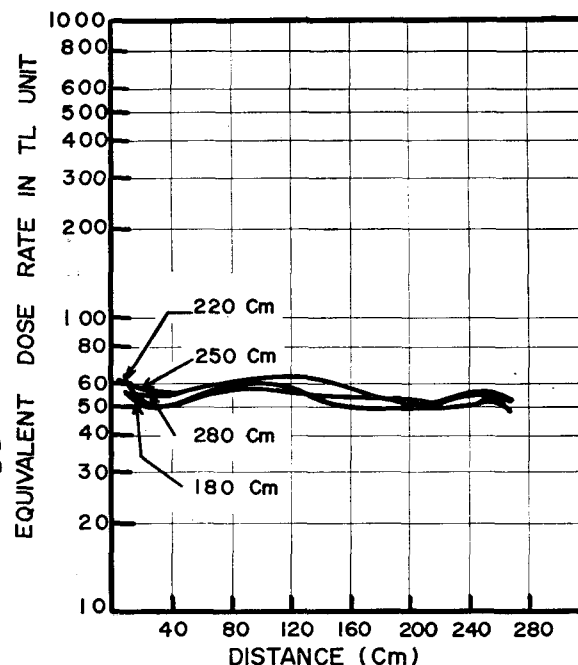


Fig. 8. Vertical dose distribution at various distances near the wall facing the reactor core

radiation from the core, while the latter is due to compensation of the decrements of dose attenuated with increasing distance by the scattered radiation from the surrounding concrete shield walls. These curves are observed in the region bounded by the two parallel planes with heights of 40 cm and 130 cm, respectively, except for the places near the wall. The result of relative dose distribution with the last one is shown in Fig. 6, all being appeared above the height of 150 cm. These curves, at first, fall down approximately following the inverse square law up to reaching at the minimum points and have the increasing tendency at farther distances from the core after passing the transition points. The transition points of these curves are progressively displaced to the core with increasing height because of the prevailing contribution of the direct radiation.

In contrast with lateral dose distribution, vertical relative dose distribution on the midlines of the planes perpendicular to the direct beam direction has fairly different characteristics, in which the difference between the maximum and the minimum dose rates slowly decreases with increasing distance from the core, approaching approximately to a constant value near the wall facing the reactor core. This means that the variation in dosage is nearly independent of height especially near the wall, namely, the uniformity of the vertical dose distribution. The results are shown in Fig. 7 and Fig. 8.

5. Conclusion

The radiation intensity and its spectrum in the biological exposure room are usually function of position of the reactor core within the exposure niche as well as the location of the samples to be irradiated. The experiments results in the fact that the homogeneous characteristics of dose distribution are appeared only in a limited region of horizontal and vertical directions.

Such region is restricted to the area bounded by the two planes horizontally parallel to the beam direction with heights of about 40 cm and 130 cm, respectively, at distances beyond 100 cm from the segmentary surface of the aluminum pool liner projected into the exposure room. On the other hand, other positions show a steeper gradient in dosage.

As a conclusion of this experimental work by and large, recommendation is made on the importance of the placement of sample to be irradiated for biological, physical or engineering experiments in the exposure room of TRIGA Mark-III reactor, especially

for the case of sample having a large volume, and at the same time meeting the requirement for homogeneity of the irradiation field as well. The results obtained in this work provide the information necessary for obtaining the maximum uniform dosage. For a small sample, however, the dependence of dose uniformity in dose on a changing location gives no serious problem within the required limits if a sample is placed within the bounded region between the height of 50 cm and 130 cm above the bottom floor. In the meanwhile, irradiation experiment with a sample of large volume should be carried out beyond the distance of 100 cm from the reactor core within the same region as that for the small sample.

Details of other important properties in the exposure room such as neutron spectra, neutron to gamma ratio and inhomogeneity of the irradiation field during irradiation will be treated in a later report.

Acknowledgment

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