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Measurements of Neutrons In A Mixed Gamma-Neutron Field Using Three Different Types of Detectors

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Abstract A linear electron accelerator for medical use is a device for the treatment of tumors by collimated beams of electrons and/or photons. These accelerators are devices that employ electromagnetic waves of high frequency, to accelerate electrons that are used directly in the treatment of superficial tumors, or, if they are made to hit them on an appropriate target, they can produce photons of high energy destined to the treatment of deeptumors.Depending on the energy of the electrons and photons and the materials that make up the head of the accelerator and the target, this equipment will produce in addition to the aforementioned radiation, neutron fields of regular intensity. It is necessary to estimate the equivalent dose due to the neutrons themselves, the doses due to the gamma field of neutron capture, produced by the capture of thermal neutrons in the concrete of the bunker, and the gamma doses due to phenomena of neutron activation of elements of the own accelerator.

It is therefore important to be able to measure (detect, quantify, dose, etc.) both photons and neutrons in these cases and others more. In this work we use three different detectors, namely a scintillator-photomultiplier system, a fast reading dosimeter and bubble detector. The idea is to measure the radiation separately and compare their results.

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The results obtained were the mixed gamma-neutron field spectrum, the dose due only to neutrons obtained by the bubble detectors, which is compared to the dose obtained by the second fast reading dosimeters (model 884), plus the dose obtained by the first dosimeters (model 609) and finally the dose obtained by the Victoreen dosimeter.

Keywords: Detectors, Gammas, Neutrons, Dosimeters, Dose

1. INTRODUCTION

Neutrons are indirectly ionizing radiation that causes, at the same absorbed dose, biological effects more important than those produced by photons. Therefore, they are particles that must be taken into account in the dosimetry of personnel exposed to radiation. One of the facilities where the most important neutron fields are located is the interior of the containment buildings of nuclear power plants and nuclear fuel treatment units. Also found are neutron fields in cosmic radiation and in the vicinity of particle accelerators, such as those used for medical applications.

While it is true that in installations such as nuclear power plants, thecontribution of neutrons to the personal dose is in most cases negligible,there are cases where there is a significant risk of neutron irradiation, such as an intervention in the containment area during reactor operation.

Another field where it is important to have very well determined the neutron field is in medicine, for example, machines like the LINAC. On the one hand, the radioprotection of the personnel working in the installation requires that the radiation fields, including the neutrons, present are perfectly characterized. In addition, the recommendations of the International Commission on Radiological Protection, published in its publication ICRP103 [1], take into account for the first time the radioprotection of patients undergoing treatments with ionizing radiation, and in particular that of patients submitted to radiotherapy treatments in linear electron accelerators (LINACs). Among the new recommendations is that of limiting the doses due to the radiation that can receive those healthy organs next to the treated tumor.

The neutron photo-production reactions that occur in the heavy materials (iron, lead, tungsten, ...) that constitute the gantry and collimators of the accelerator itself, give rise to a neutron field that occupies the entire irradiation room and which consequently contributes to the radiation dose to the tissues and organs of the patient outside the treated tumor. Most radiotherapy treatments are currently performed with energy potentialsranging from 15 to 18 MV, so this neutron dose must be taken into account. In addition, the survival of patients undergoing radiotherapy has increased in recent years and

it is not negligible that a treated patient will, in the long term, appear to have a new tumor in an organ other than that originally treated, which could be radio -induced.

Other particle accelerators for medical, industrial or research applications (cyclotrons for the production of radiopharmaceuticals used in nuclear medicine, synchrotrons used for the modification of structures of materials or for medical applications, high energy accelerators for researchcan also originate neutron fields by mechanisms similar to those of LINAC, so that in all this type of installations the dosimetric control of the neutron component of the radiation must be correctly carried out.

One of the problems associated with neutron dosimetry is that neutron fields are usually accompanied by other components of radiation, often much more intense than the neutron component although their contribution to the total dose may be of the same order of magnitude. The main problem with neutron dosimetry is that the neutron weighting factors, which allow the calculation of the equivalent dose from the absorbed dose, depend strongly on the energy of the neutrons, and therefore it is not advisable to carry out its dosimetry without knowing the energy spectrum of the neutron field to be detected, at least approximately. This leads to the fact that to perform the dosimetry correctly it is necessary to have spectrometric information. In addition, the detection of neutrons encounters the added problem that, in the case of neutral particles, they do not directly produce a measurable signal in the detectors, but the detection mechanisms are based on the secondary charged particles originated in the interaction of the same with the different components of the absorbents.

2. EXPERIMENTAL SETUP

In this work,we usethe electronical system mounted as in different laboratoriesto obtainthe neutron spectrum from the Am241/Be source[2, 3, and 4].The scintillator-photomultiplier system consists of a cylindrical Bicron© BC-400 scintillator coupled to Hamamatsu© R1250, No. RA2457 photomultiplier, powered by two C4840 and three HTV C762-01 Hamamatsu© power supplies, through Ortec© 269 photomultiplier bases. The scintillator has a 120mm diameter, and is 50mm high, and he is coupled to the photomultiplier by a silicon interface. The BC-400 plastic scintillator is known to produce a light output in the range of 400-500 nm, with a peak about 425 nm. The R1250 Hamamatsu© photomultipliers, on the other hand, they are sensitive between 300nm and 650nm, respectively, with peak sensitivity at 420nm, so they are an ideal match for the BC-400 series.

Figure 1: Geometrical arrangement of the BC-400 detector

The first step is to verify the scintillation spectrometer using an oscilloscope to check the type and form of the pulses. The system was mounted as can be seenin the Figure 1, where at the bottom the Visiflux contains the source in the middle of the water and in front it is shown the detector. For comparison two crystals are proposed, the BC-400 and the NE213 scintillator systems. The distance from source to detector were 100 cm collimating the beam and directed to the face of the detector, then between the source and the detectors will be used plates of lead and polyethylene to compare the signal. Due to the intensity of the source and the physics in the neutron behavior, the contribution of the neutron source in ambient background was present all the time in the laboratory.

The Bubble Detector Spectrometer (BDS) have six different energy thresholds ranging from 10 keV to 10 MeV [5, 6, 7, 8, and 9]. The number of bubbles obtained in each measurement is related to the dose (standardized response R) equivalent neutrons through sensitivity (b/μSv) and with the neutron flux (neutrons per unit area) through a relationship that is provided by the manufacturer. Bubble detectors were used with six different answers (0.11 b/ μSv, 0.14 b/μSv, 0.17 b/μSv, 0.093 b/μSv, 0.051 b/μSv) [6]. As can be seen in Figure 2, the detectors were placed inside the water container at 4 cm distance. We used several times to achieve low statistical error and to compare the response during the measurements. It was also measure the bare-naked beam from the source to analyze the contributions of thermal neutron. Following the equations1 and 2, it is possible to construct the spectra thru neutron fluence.

$$N_i = \frac{R_i - \sum_{j=i+1}^{6} \sigma_{ij} N_j}{\sigma_{ii}} \quad con\, N_7 = 0 \tag{1}$$

Figure 2: Visiflux with the holder and two kind of detectors.

$$R_i = \sum_{j=i}^{6} \sigma_{ij} N_j \tag{2}$$

Where Ni is the neutron fluence for each detector, R_i is the quotient of bubble's number and the sensitivity and σ_{ij} is the neutron cross section.

The arrangement is the same for both BDS and DLD, using different times depending on whether they are thermal or gamma ray detectors, the objective isto obtain the linear response, the reproducibility and the sensibility of the detectors. The distance to be used are in the range from 2 to 14 cm and times from 8 to 240 min. In every measure the charge was set to 0 to evaluate the response.

The direct reading dosimeter (DLD) is the size of a pocket pen, has a carbon fiber electroscope with an iron chamber for the detection and indication of integrated exposure to gamma radiation and neutrons. It has a thin wall that allows penetration and the detection of radiation. The dosimeters used are:Thermal neutron dosimeter, model 609, Equivalent dosimeter (gammas + rapid neutrons) model 884 and Gammas dosimeter model 5415 (Victoreen).
To obtain the sensitivity of the DLDs it is necessary to calculate the specific gamma constant for the radionuclides used in the experiment by equation 3

$$\Gamma = 19.38 \left[\sum_{i=1}^{n} K_i E_i \left(\frac{\mu_{en}}{A} \right)_{E_i, air} \right] \left[\frac{Rm^2}{Cih} \right] \tag{3}$$

Where Γ is the specific constant, K_i is the emission's probability, E_i is the photon´s energy, $\frac{\mu_{em}}{\rho}$ is the mass energy-absorption coefficient.

To obtain the calibration factor it is necessary to calculate the exposure rate at different distances by equation 4

$$\dot{X} = \frac{\Gamma A}{d^2} \tag{4}$$

where $\dot{X}$ the exposure rate is Γ is the specific constant and d is the source to detector distance.

In Table 1 are shown the DLDs used in the experiment, where two of them are for thermal neutrons and three for gamma rays. Time of measure needs to guarantee that the fiber in the DLDs are in the middle of the range, so the uncertainty in all the dosimeters is the same.

For the last part, we used a single channel analyzer (Berthold Nuclear Spectrometer LB 2040) with a BF3 tube (Berthold LB6400) and a pre-amplifier (Charge sensitive LB 2008) to measure the spectra of thermal neutrons [10, 11]. Figure 3 shows the BF3 detector and the polyethylene moderator. The measures were done at 1 m, in three conditions bare-

Figure 3: BF3 tube and moderator.

Table 1: Characteristics of the five DLD.

Label	D1	D2	D3	D4	D5
Serial number	A040262	1515017	166843	110225	A060618
Range	0 to 200 mR	0 to 200 mR	0 to 200 mR	0 a 120 mrem	0 a 120 mrem
Field	gamma	gamma	gamma	Thermal neutrons	Thermal neutrons

naked detector, detector with polyethylene moderator and a measure with the source in its shield.

RESULTS

From the modules used, no defective signals were observed on the oscilloscope and cables and connectors were checked to avoid false contacts. Figure 4 and 5 shows the spectra obtained with the two detectors, BC-400 and NE-213, in the case where the detectors were placed in front of the source in the collimated beam and without attenuators the spectra are similar, the first peak corresponds to the signal of the photons and from there the neutron spectrum is shown. To verify the behavior of the spectra two plates, one of lead and another of borated polyethylene, were placed between the source and the detector. The decrease due to neutron attenuation and moderation by the plates in the contribution of both gamma rays and neutrons is observed.

For the bubble detectors, we used 18 tubes and count the bubbles manually, for each set of thresholds the equations 1 and 2were used.In Figure 6 we present the BDS before and after the irradiation with neutrons from the Am-241/Be source, the color in the background helped us to count the bubbles using a two-dimension photographic image, some tubes did not present bubbles at all.

The neutron spectra measured at 4 and 26 cm from the source are shown in figure 7. As expected the spectra as a function of water thickness changes not only in altitude but in shapebecause the neutron fluence change due to moderation and absorption inside the water. One parameter that cannot be controlled was the temperature in the laboratory, the manual specified that

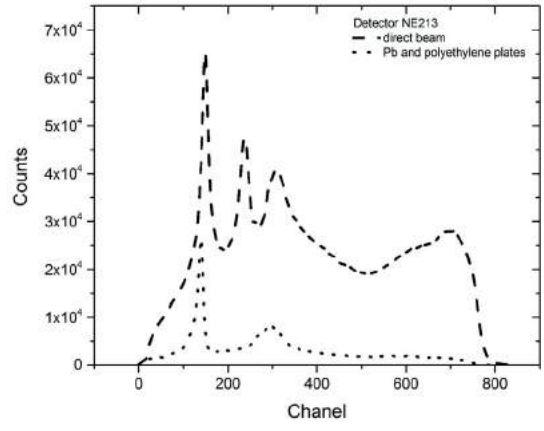

Figure 4: Neutron spectra measured with NE-213.

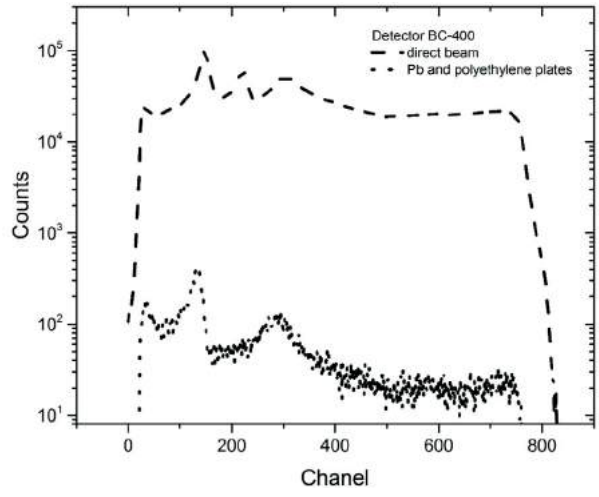

Figure 5: Neutron spectra measured with BC-400.

Figure 6: BDS before and after irradiation with neutrons

all the measures had to be done at 20°C, the spectra at 26 cm was obtained at 25°C. This could lead to a change in the response of bubbles detectors.

With the sensitivity of the BDS, we obtained the dose equivalent Hnear the source, then by dividing H per time we get the dose equivalent rate, which can be extrapolated to a different distance. Table 2 shows the data with which H was calculated, the number of bubbles is the average of three measurements performed under identical conditions, it should be noted that the measurements were made 4 cm apart from the source for a time of 45 minutes. According to current Mexican regulations [12], the limit of the dose equivalent for public is set at 5 mSv per year.

If we add the contributions of each energy threshold and then sum the average dose equivalent of the complete spectrum, we obtained a value of2.16mSv/h. Whereas for a distance of 26 cm that corresponds to the outer

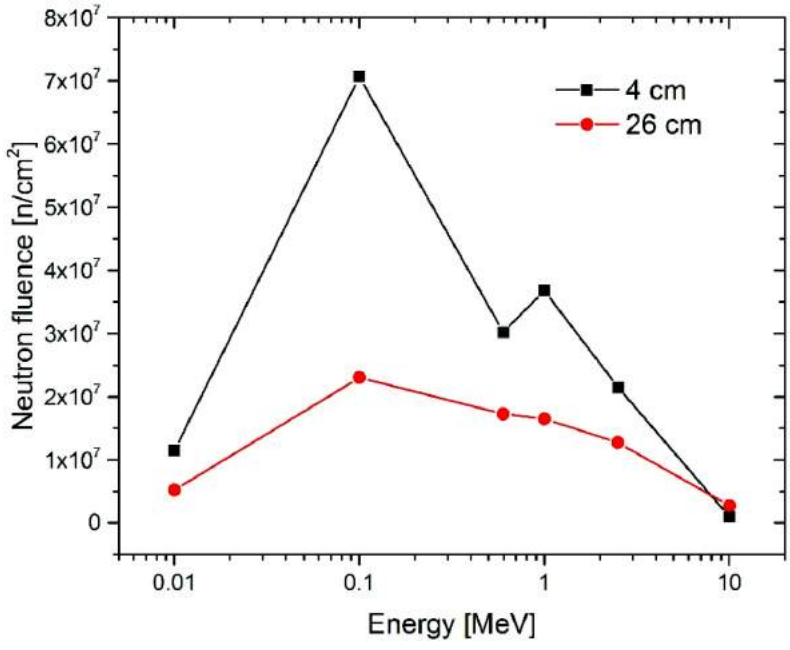

Figure 7: Spectra from the Am-241/Be source measured with bubbles detectors.

part of the shield, the dose equivalent rate of the complete spectrum is 61μSv/h. Using a Bonner sphere detector we get a reading of 70 μSv/h value similar of that obtained by the bubble detectors. Table 3 shows the values obtained for the distance of 26 cm and 17 h of irradiation.

The gamma exposure rates measured as a function of distance with DLDs are presented in figure 8, as well as a theoretical calculation with eq. 4, as can be seen, the exposure decreases rapidly as function of thickness. The exposure rate measured compared with the calculation has a maximum difference of about 9% for detector D1, detector D2 has a difference of 16% at 2 cm and around 9% for distances greater than 2 cm for detector D2 and between 15 and 28% for detector D3.Figure 9 shows the behavior of DLD4 and DLD5 for thermal neutrons, for comparison we fit an exponential decay equation, showing that no points match the attenuation.

In the case of thermal neutrons, the laboratory background was measured with the source inside its shield but without a polyethylene cover, then the collimated beam was left directly on the naked detector and finally a polyethylene cover was placed on the detector, all measurements were made one meter from the source. Figure 10 shows that both background and bare

Table 2: Dose equivalent at 4 cm from the source.

Energy [keV]	Bubbles	Sensitivity bub/μSv	H [μSv]	[μSv]
10	0	0.1	0	6.5
10	1	0.11	9.1	
10	2	0.19	10.5	
100	4	0.093	43.0	26.8
100	6	0.16	37.5	
100	0	0.19	0	
600	1	0.14	7.1	4.8
600	0	0.14	0	
600	1	0.14	7.1	
1000	89	0.15	593.3	375.5
1000	10	0.16	62.5	
1000	80	0.17	470.6	
2500	1	0.12	8.3	504.3
2500	110	0.14	785.7	
2500	115	0.16	718.8	
10000	3	0.042	71.4	119.5
10000	4	0.044	91.0	
10000	10	0.051	196.1	
			μSv/h	**61**

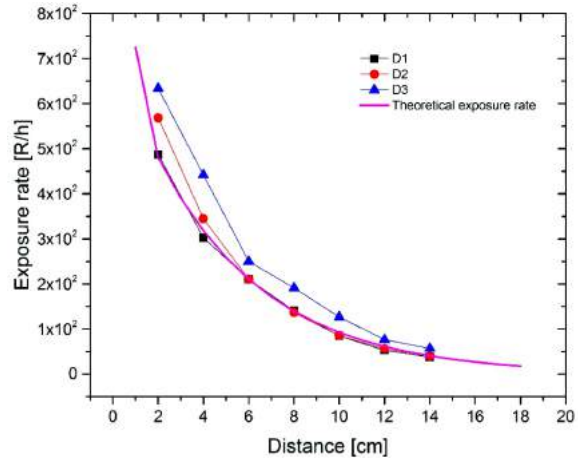

Figure 8: Exposure rate as a function of distance measured for photons using DLDs. Also shown a theoretical calculation using eq. 4.

Table 3: Dose equivalent at 26 cm from the source.

Energy [keV]	Bubbles	Sensitivity bub/μSv	H H [μSv]	[μSv]
10	1	0.1	10	19.4
10	3	0.11	27.3	
10	4	0.19	21.1	
100	6	0.093	64.5	38.2
100	8	0.16	50.0	
100	0	0.19	0	
600	1	0.14	7.1	19.0
600	3	0.14	21.4	
600	4	0.14	28.6	
1000	193	0.15	1286.7	842.1
1000	12	0.16	75.0	
1000	198	0.17	1164.7	
2500	2	0.12	16.7	652.9
2500	173	0.14	1235.7	
2500	113	0.16	706.3	
10000	1	0.042	23.8	54.7
10000	1	0.044	22.7	
10000	6	0.051	117.6	
			mSv/h	**2.16**

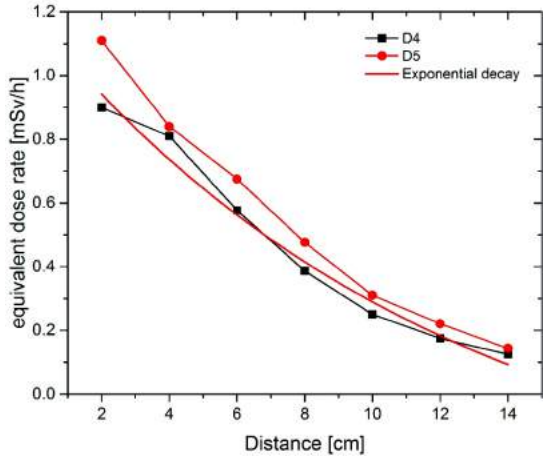

Figure 9: Exposure rate as a function of distance measured for neutrons using DLDs.

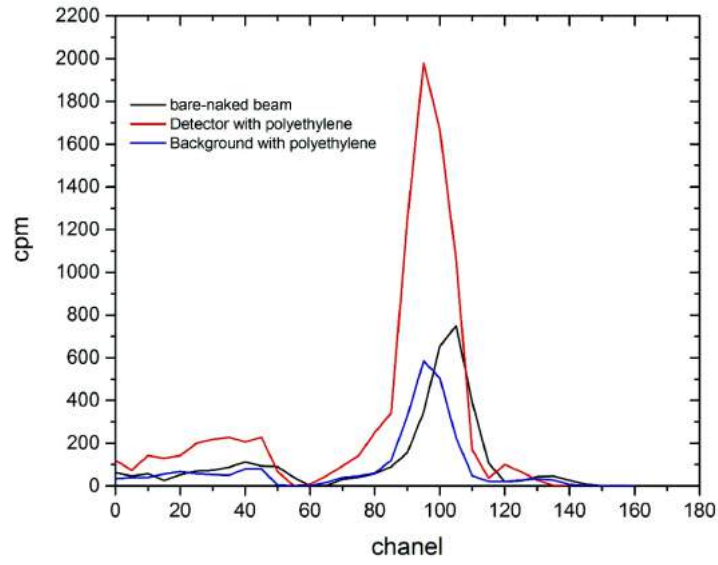

Figure 10: Spectral shape from thermal neutrons acquired with a BF3 detector.

detector readings coincide, since fast neutrons are thermalized and increase after the polyethylene shielding, for the case of the detector with polyethylene the values are higher because the cover that surrounds the detector moderates more neutrons.

CONCLUSIONS

In the case of the neutron spectrometry system, it has the disadvantage of not being calibrated with another neutron source; in addition, the background of a 5 Ci source is intense, obscuring the signal of interest. DLDs provide fast information, but in the case of thermal neutron detectors cannot be compared with some analytical calculation. The mono channel system will be useful when the counts can be compared with some dosimetric magnitude. The system that provided most information was the bubble detectors, in addition to obtaining a neutron spectrum, the dose equivalent was determined near the source and outside its shield. It was found that it is safe to use the Am241/Be9 source if it is in the water container.

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