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REFERENCE FIELDS SUPERPOSITION METHOD FOR DOSIMETRIC APPARATUS CALIBRATION TO OPERATE WITHIN THE NEUTRON RADIATION FIELDS

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Abstract

Britvich G.I., Chumakov A.A. Reference Fields Superposition Method for Dosimetric Apparatus Calibration to Operate Within the Neutron Radiation Fields: IHEP Preprint 93-66. – Protvino, 1993. – p. 15, figs. 11, tables 3, refs.: 18.

It has been proposed to calibrate some single neutron dosimetric detector in several reference fields with neutron spectra whose linear combination with some weighting coefficients approximates the spectrum in the real measurement place. The corresponding linear combination of the readings from this detector in these reference fields with the same weighting coefficients is used as the detector readings in a single reference field. The efficiency of this calibration method with real 8 reference fields has been investigated with the help of the computer simulation. It has been shown that this method allows one to calibrate some dosimetric detector more correctly than commonly used ones.

Аннотация

Бритвич Г.И., Чумаков А.А. Метод суперпозиции опорных полей при градуировке дозиметрической аппаратуры для работы в полях нейтронного излучения: Препринт ИФВЭ 93-66. – Протвино, 1993. – 15 с., 11 рис., 3 табл., библиогр.: 18.

Предложено градуировать каждый нейтронный дозиметрический детектор в нескольких опорных полях, таких, что линейная комбинация нейтронных спектров этих полей с некоторыми весовыми коэффициентами аппроксимирует спектр в реальном месте измерения. Соответствующая линейная комбинация показаний этого детектора в тех же полях с теми же весовыми коэффициентами рассматривается как показание детектора в одном опорном поле. Посредством компьютерного эксперимента исследована эффективность этого метода при использовании восьми реальных опорных полей. Показано, что такой метод позволяет градуировать дозиметрические детекторы более корректно, чем обычно используемые методы градуировки с помощью опорных полей.

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Г.И.Бритвич, А.А.Чумаков

Метод суперпозиции опорных полей при градуировке дозиметрической аппаратуры для работы в полях нейтронного излучения.

Редактор А.А.Антипова. Корректор Е.Н.Горина.

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Introduction

It is common knowledge that the reading of the neutron radiometers and dosimeters in the neutron radiation fields behind the biological shields of nuclear-physics and nuclear-energetic installations are spectra dependent. That is why it is necessary to interpret these reading correctly. To this end someone must know in detail a detector response function[1] or calibrate this detector with help of the reference neutron field provided that the neutron spectrum in the place of the measurement is known. The calculated detector response functions are used as a rule when the first approach is applied to the abovementioned interpretation. It connected with the fact that the detailed experimental determination of the real detector response function, as a rule, is a dufficult problem. Only the spectra measurements are required for the 2nd approach application. Such measurements are a more easy problem. It is required of the reference field that its neutron spectrum be similar enough to the spectrum in the real measurement place. The commonly used reference field of the direct neutrons from the ^{252}Cf radioactive source satisfies this condition not in all cases. That is why the direct calibration in the measurements place is used sometimes [1]. But such method is not always possible and convenient. The other method used is the calibration with single reference field with the spectrum which simulates the real measurement place field spectrum [2]. The spectra belonging even to a single installation can be significantly different [3,5]. It limits the application of this calibration method. However, the simple analysis of a great number of spectra behind the biological shields of different nuclear installations points to the fact that these spectra, as a rule, consist of a limited number of typical components. The main of them are the following:

[1] Hereafter we shall use the term "detector response function" meaning "energy dependence of the detector efficiency".

— the high energy leakage neutron component of the spectrum behind the biological shields of accelerators (it is dominant above 20 MeV);

— quasy-maxwell "evaporation" component of the spectrum with the effective temperature about 0.8 MeV (below 20 MeV);

— 1/E component of the spectrum from the air scattered neutrons (below 0.1 MeV);

— intermediate neutrons peak behind the thick iron shields which is related to the neutron-iron interaction cross-section minimum (in the vicinity of 20 keV);

— an additional contribution of the intermediate neutrons from the communication labyrinthes of the biological shields (below 1 keV).

Consequently, it is reasonable to suggest that some spectrum out of a great variety of the neutron spectra behind the biological shields can more often be approximated than not with sufficient validity by means of superpositions of a limited number reference field spectra.

We propose to calibrate each detector in several reference fields, alternatively. Then it is necessary to approximate the real measurement place field spectrum with a linear combination of these reference field spectra with some weighting coefficients. The corresponding linear combination of this detector reading at these fields with the same weighting coefficients is equivalent to this detector reading at the single reference field with a spectrum similar to the measurement place field one.

We have at hand 8 suitable neutron reference fields. 7 of them are based on the ^{252}Cf and Pu-alpha-Be radioactive sources [4] and the 8th one is the field of the high energy leakage neutrons behind the biological shield of the 70 GeV proton synchrotron [8] (spectra N 1333, see [5]). In this paper we investigate the proposed method efficiency with these 8 reference fields, and we compare it with the efficiencies of the calibrations made with direct neutrons from ^{252}Cf and single reference field. This investigation and comparison are carried out by means of computer calculation.

1. Testing of the detector calibration methods

To compare the efficiencies of different methods of the dosimetric detector calibrations we have simulated the maximum dose equivalent measurement processes by the computer calculation based on the data available in literature. In the case being considered it has been suggested that the measurements are carried out within the neutron fields with the known spectra with the help of the calibrated dosimeters. And no information about the response functions of

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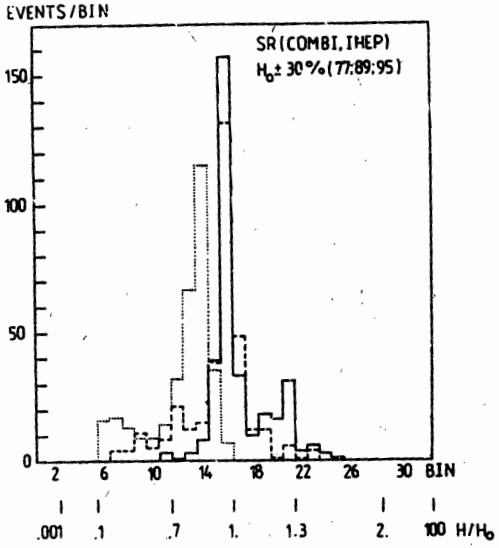

Figure 11. The same as in Fig.1 for SR(COMBI IHEP) dosimeter.

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these dosimeters has been used to interpret readings. Three calibration techniques have been simulated:

— "method A" consists in the calibration with direct neutrons from the ^{252}Cf radioactive source;

— "method B" consists in the calibration with a single reference field with the spectrum which simulates the "measurement" place field spectrum;

— "method C" is the proposed calibration technique with the help of the several reference fields.

The sample of 333 neutron spectra have been exploited to develope this comparative testing. This sample contains the cosmic rays spectra in small proportion and spectra behind the biological shields of the nuclear reactors, tokamaks, different accelerators, some health installations and a number of other nuclear installations spectra. All of them have been found in the published papers, but the reference list is not presented because of its great volume. Most of them have been chosen from [3] and [5]. The true maximum dose equivalents have been calculated for all of them:

$$H_0 = \int_{E_{min}}^{E_{max}} f(E)h(E)dE, \qquad (1)$$

where $f(E)$— literature spectrum; $h(E)$ — energy dependence of the neutron maximum dose equivalent [6]; E_{min} and E_{max} — the spectrum energy range bounds given in the literature. Then, 11 dosimeters have been chosen (see Table 1). They are: two albedo personnel dosimeters, five fast neutron dosimeters and four radiation monitoring ones. The readings of these 11 dosimeters at each of 333 spectra have been simulated as follows:

$$N = \int_{E_{min}}^{E_{min}} f(E)\Phi(E)dE. \qquad (2)$$

Here $\Phi(E)$ — the literature dosimeter response function (all the references are given in Table 1). The corresponding maximum dose equivalents are calculated on the basis of readings:

$$H = \frac{N}{N_c}H_c. \qquad (3)$$

Here N_c and H_c are the simulation of the dosimeter readings and the neutron maximum dose equivalents for the calibration measurements, respectively. The values of N_c and H_c have been calculated by means of the three different methods which correspond to three different calibration techniques A, B, C.

With A approach they are calculated as follows:

$$N_c = \int_0^\infty f_c(E)\Phi(E)dE, \tag{4}$$

$$H_c = \int_0^\infty f_c(E)h(E)dE, \tag{5}$$

where $f_c(E)$ is the well-known spectrum of the direct neutrons from the ^{252}Cf radioactive source [7].

With B approach they are calculated as follows:

$$N_c = \int_{E_{cmin}}^{E_{cmax}} f_c(E)\Phi(E)dE, \tag{6}$$

$$H_c = \int_{E_{cmin}}^{E_{cmax}} f_c(E)h(E)dE, \tag{7}$$

where $f_c(E)$ is one of the 30 spectra of reference fields which have previously been reported [3-5, 7-12]. This set of spectra contains the above-mentioned spectra: the direct neutrons from the ^{252}Cf spectrum and the spectra of cur 8 reference fields. Each out of 333 literature spectra has its own reference field spectrum $f_c(E)$ chosen out of 30 in such a way as to minimize the following functional:

$$S = \sum_{j=1}^{j_{max}} [K(X_j) * X_j * W_j * Q(E_j) * h(E_j)]^2, \tag{8}$$

where $X_j = f(E_j) - f_c(E_j)$, (9)

$$K(X_j) = \begin{cases} 1, & if \quad X_j < 0, \\ 1, & if \quad X_j = 0, \\ 10, & if \quad X_j > 0, \end{cases} \tag{10}$$

$$W_j = \begin{cases} E_{j+1} - E_j, & if \quad j = 1, \\ E_{j+1} - E_{j-1}, & if \quad 1 < j < j_{max}, \\ E_j - E_{j-1}, & if \quad j = j_{max}, \end{cases} \tag{11}$$

$$Q(E_j) = 1. \tag{12}$$

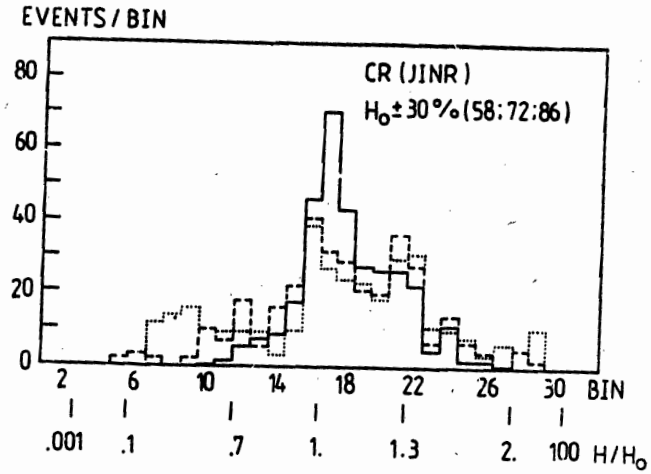

Figure 9. The same as in Fig.1 for CR(JINR) dosimeter.

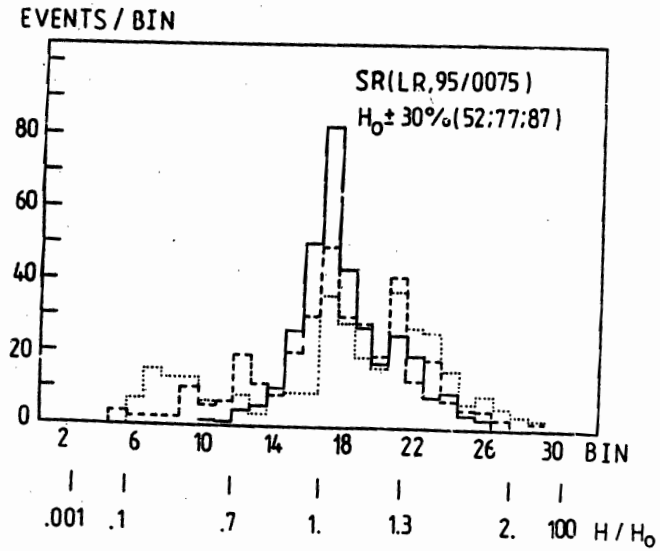

Figure 10. The same as in Fig.1 for SR(LR, 95/0075) dosimeter.

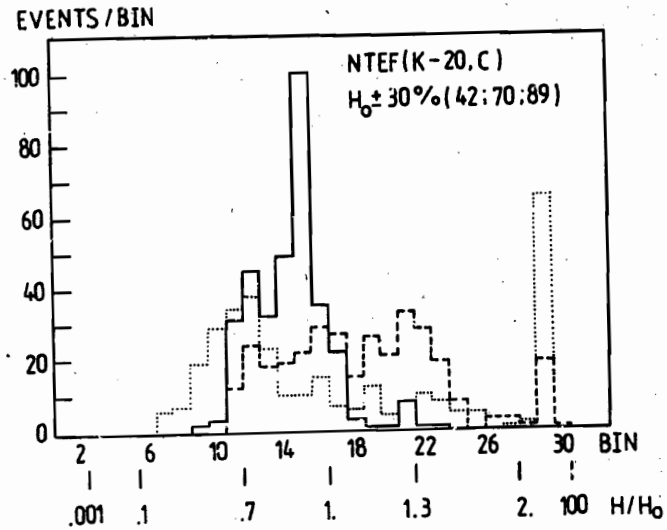

Figure 7. The same as in Fig.1 for NTEF(K-20 C) dosimeter.

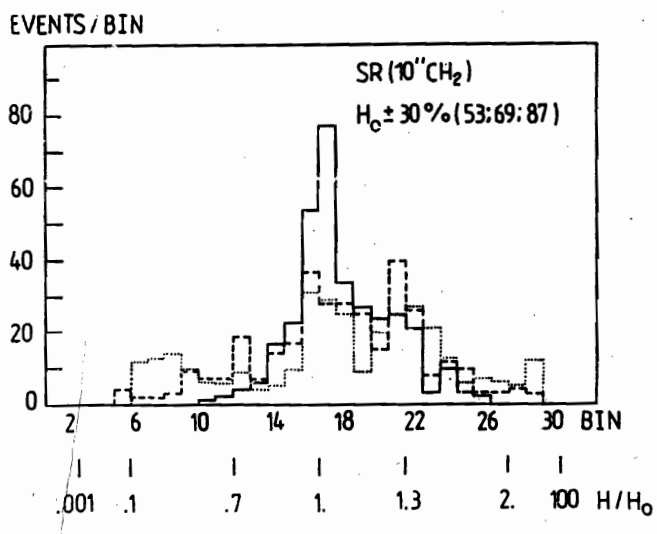

Figure 8. The same as in Fig.1 for SR(10" CH_2) dosimeter.

Here E_j, $j = 1, ..., j_{max}$ — the set of the energy points in which the literature spectrum $f(E)$ is given; $K(X_j)$ — the function to prefer the exceeding of H above H_0, rather than vice versa; W_j — the weighting function to minimize the contribution of jth term to the error of H; $Q(E_j)$ — the weighting function to apply the information about the dosimeter response function. $Q(E_j) \equiv 1$ when no information is used.

With C approach:

$$N_c = \sum_{i=1}^{8} A_i \int_{E_{imin}}^{E_{imax}} f_i(E)\Phi(E)dE, \tag{13}$$

$$H_c = \sum_{i=1}^{8} A_i \int_{E_{imin}}^{E_{imax}} f_i(E)\,h(E)dE, \tag{14}$$

where $f_i(E)$, $i = 1, ..., 8$ are the spectra of our 8 reference fields; Ai, $i = 1, ..., 8$ are the fitting weighting coefficients which minimize functional (8) with the substitution of

$$X_j = f(E_j) - \sum_{i=1}^{8} A_i f_i(E_j) \tag{15}$$

for (9).

Then we have built the distribution of the H/H_0 ratios by 34 nonuniform groups. The bounds of these groups are given in Table 3. This distributions are plotted in Figs.1-11 for all 11 chosen dosimeters. The results obtained with the methods A, B and C are plotted by points, dotted line and solid line, respectively.

To characterize the efficiency of the A, B and C methods the fraction of spectra when the maximum dose equivalent estimations H differ from the true one H_0 by less than 30% of H_0 have been given on a percentage basis for all these distributions. This 30% interval corresponds to H/H_0 ratio values from 0.7 to 1.3. These proportions are given in each of Figs.1-11 for the A, B and C methods consistently and are summarized in Table 2.

2. Short discussion

As can be seen from Table 2 and from Fig.1-11 the proposed method C is more efficient for the dosimeter calibrations than A and B. It should be noted that the sample of 30 reference fields used for the method B testing has included

8 reference fields used for the method C. It is interesting that with the method B in none of 333 cases the spectrum of the direct neutrons from ^{252}Cf source has been chosen as a reference field spectrum most similar to the measurement place spectrum. It can be seen the worse the dosimeter response function duplicates the energy dependence of the maximum dose equivalent the more superior is the method C over A and B. It is essential, e.g., for such convenient on routine operation dosimeters as albedo personnel ones. It is obvious that the proposed method is applicable not only to the maximum dose equivalent measurements but to any integral values (e.g., flux density, kerma etc.) measurements as well. It is simple to apply the information about the dosimeter response function with the help of the weighting function Q (see formula (8)). And it is simple to make changes in the measurement results using this calibration method when the energy dependence of the measurement value is modified.

Conclusions

The method of the reference fields superposition has been proposed for the dosimetric apparatus calibration to operate within the neutron fields behind the biological shields of different nuclear installations. The main point of this method is the calibration of a single detector in several reference fields, alternatively. Then it is necessary to approximate the spectrum in the real measurement place by means of the linear combination of these reference field spectra with some weighting coefficients. The corresponding linear combination of the detector evidences at these reference fields with the same weighting coefficients is used as a detector evidence at the single reference field. This method efficiency with utilization of our real 8 reference fields has been investigated with the help of the computer simulation. It has been shown that this method allows us to calibrate some dosimetric detector more correctly than two commonly used ones: the calibration with the direct neutrons from ^{252}Cf radioactive source and the calibration with the help of a single reference field with the neutron spectrum similar to the real measurement place one. It can be seen the worse the detector response function duplicates the energy dependence of the value under measurement the more superior is the proposed method efficiency over those commonly used. It is essential for some convenient for the routine operation detectors.

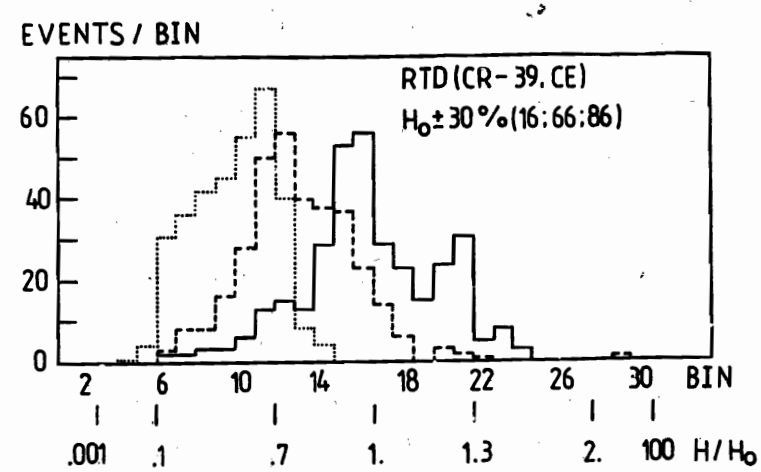

Figure 5. The same as in Fig.1 for RTD(CR-39 CE) dosimeter.

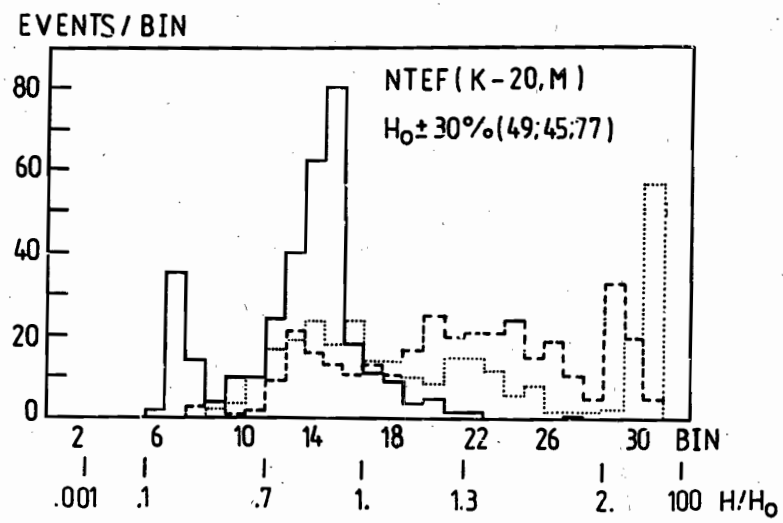

Figure 6. The same as in Fig.1 for NTEF(K-20 M) dosimeter.

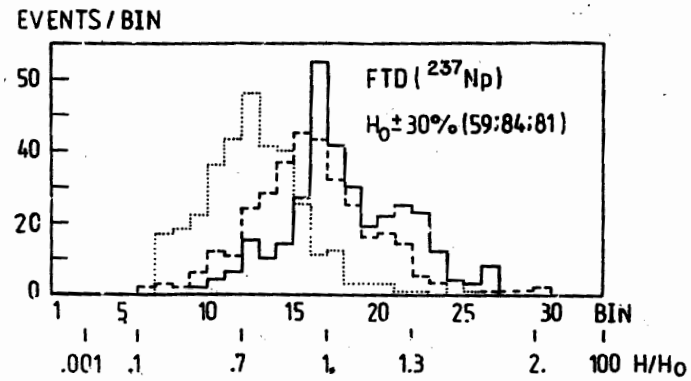

Figure 3. The same as in Fig.1 for $FTD(^{237}Np)$ dosimeter.

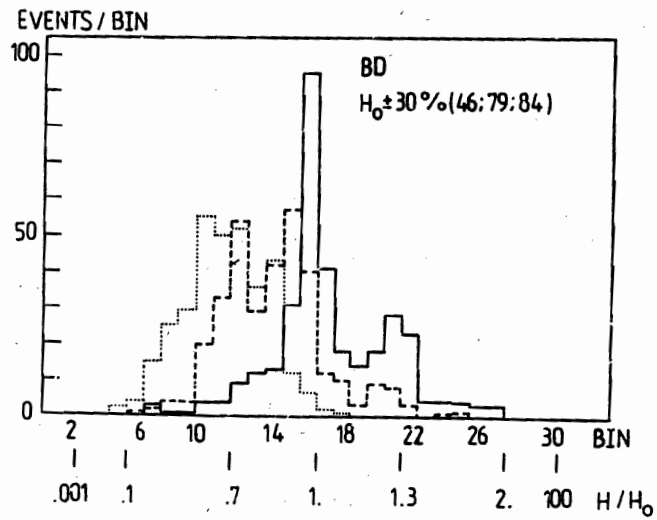

Figure 4. The same as in Fig.1 for BD dosimeter.

Table 1. The neutron dosimeters used

Dosimeter short description	Symbols for designation	Calculated or measured	References
Albedo personnel dosimeters:			
^6LiF within cadmium-plated polyethylene moderator.	$AD(^6LiF)$	M	[13]
^{235}U with cadmium-plated track detector.	$AD(^{235}U)$	M	[13]
Fast neutron dosimeters:			
Fission track detector ^{237}Np	$FTD(^{237}Np)$	C, M	[3]
Bubble detector with superheated disperse working substance.	BD	M	[14]
Recoil track detector CR-39, chemically etched.	RTD(CR-39 CE)	C, M	[3]
Nuclear track emulsion film, type K-20.	NTEF(K-20 M)	M	[13]
Nuclear track emulsion film, type K-20.	NTEF(K-20 C)	C	[15]
Radiation monitoring dosimeters:			
^6LiI detector within cadium-plated 10" diam. polyethylene moderator.	SR(10" CH_2)	C	[16]
Cylindrical remmeter with BF_3 counter.	CR(JINR)	M	[17]
Leake remmeter, 95/0075	SR(LR, 95/0075)	M	[3]
6 cadmium-platted polyethylene spheres 2"+3"+5"+8"+10"+12" combination dosimeter	SR(COMBI IHEP)	C, M	[4]

Table 2. The proportions of spectra for which the maximum dose equivalent estimations H differ from true ones H_0 less than 30%

Dosimeters	A %	B %	C %
Albedo personnel dosimeters:			
$AD(^6LiF)$	7	21	68
$AD(^{235}U)$	6	22	68
Fast neutron dosimeters:			
$FTD(^{237}Np)$	59	84	81
BD	46	79	84
RTD(CR-39 CE)	16	66	86
NTEF(K-20 M)	49	45	77
NTEF(K-20 C)	42	70	89
Radiation monitoring dosimeters:			
$SR(10"CH_2)$	53	69	87
CR(JINR)	58	72	86
SR(LR, 95/0075)	52	77	87
SR(COMBI IHEP)	77	89	95

Table 3. The bounds of the groups for the building of distributions

Groups	1	2	3	4	5	6
bounds	1.00E-4	1.00E-3	1.00E-2	1.00E-1	2.00E-1	
Groups	6	7	8	9	10	11
bounds	3.00E-1	4.00E-1	5.00E-1	6.00E-1	7.00E-1	
Groups	11	12	13	14	15	16
bounds	8.00E-1	8.50E-1	9.00E-1	9.50E-1	1.00E-0	
Groups	16	17	18	19	20	21
bounds	1.05E-0	1.10E-0	1.15E-0	1.20E-0	1.30E-0	
Groups	21	22	23	24	25	26
bounds	1.40E-0	1.50E-0	1.60E-0	1.70E-0	1.80E-0	
Groups	26	27	28	29	30	31
bounds	1.90E-0	2.00E-0	5.00E-0	1.00E+1	5.00E + 1	
Groups	31	32	33	34		
bounds	1.00E+2	1.00E+3	1.00E+4			

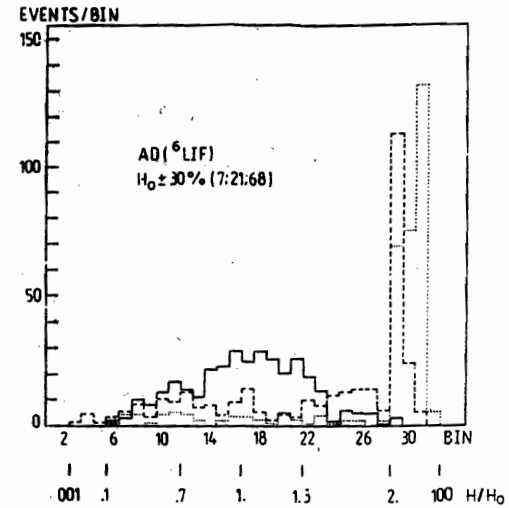

Figure 1. The distributions of the H/H_0 ratios, obtained with A (points), B (dotted line) and C (solid line) callibration methods for $AD(^6LiF)$ dosimeter.

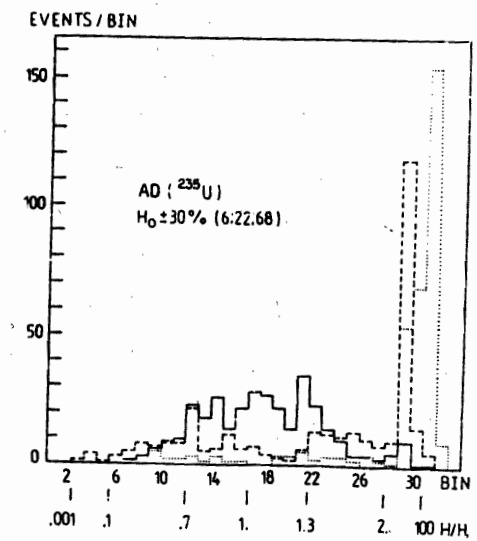

Figure 2. The same as in Fig.1 for $AD(^{235}U)$ dosimeter.