Dose Characteristics of the IHEP Neutron Reference Fields

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INTRODUCTION

Interpretation of neutron detector readings in terms of dose equivalent is an important problem. Since response of a neutron detector has usually an energy dependence which is not adequately simulating the energy dependence of dose equivalent, its using as a dosimeter in real neutron fields of nuclear-physics device after a simple calibration in a neutron field of radionuclide source (such as ^{252}Cf) leads to considerable errors. There are some different approaches to solve this problem. One of them [1], [2] proposing the dosimeter's calibration in workplace fields is available for personnel and area dosimeters. Another method [3] is the calibration at neutron field having the spectrum simulating the real neutron field one. The method of superposition of calibration fields [4] to obtain weighted neutron response is a following step in this direction. All of these approaches one way or another are concerned with application of neutron reference fields for these goals.

THE IHEP NEUTRON REFERENCE FIELDS

Requirements to neutron field to be "reference" are the following. First of all it would have a neutron spectrum which is simulating typical workplace neutron spectra. Its main characteristics such as neutron spectrum, dose equivalent rate, angular distribution, etc. must be well established. It would be reproducible and enough intensive to provide possibility of quick calibration.

At the Institute for High Energy Physics (IHEP), the workplaces concerned with personnel irradiation are concentrated mostly at the experimental hall of IHEP 70-GeV proton synchrotron. The radiation fields behind the biological shielding of the accelerator have rather component composition where neutrons in a wide energy range from thermal energies up to primary proton beam's energy of 70 GeV are dominated. Numerous investigations of real radiation fields behind the accelerator's shielding [2] ,[5] ,[6] ,[7] , show that they can be separated into three main groups: 1) high energy fields behind the upper shielding (320--350 cm of concrete); 2) low energy neutron fields behind the side shielding (600 cm of concrete); 3) radiation fields with large contribution of charged particle nearby the charged particle transport beams. The IHEP neutron reference fields include the high energy reference field and four radionuclide reference neutron fields [10] formed by filtered and direct radiation of ^{252}Cf and ^{239}Pu-Be radionuclide sources: ^{239}Pu-Be in free air (PU), ^{252}Cf in free air (CF), ^{252}Cf at the centre of polyethylene sphere ⊗ 30 cm (CH) and ^{252}Cf at the centre of iron sphere ⊗30 cm (FE). The radionuclide reference neutron fields are reproduced at the middle of a special calibration room having dimensions of 5.4 m × 13 m and 4 m height. The distance between a radionuclide source creating the field and a reference point is the same for all the four fields (0.75 m) as well as the distance from a floor (1.65 m). The high energy reference field (HEF) is reproduced at 1 m height outside the upper shielding in the experimental hall of the IHEP 70-GeV proton accelerator. Inside a volume of $0.5 \times 0.6 \times 0.3$ m^3 with the centre at the reference point the intensity of radiation varies in the range less than 10%.

MEASUREMENT TECHNIQUES

The dosimeters and spectrometers being used in measurements are listed in the Table 1. The detailed description of measurement procedures may be found in the original the main spectral papers. Briefly, the tissue-equivalent proportional counter TEPC allow one to obtain dose equivalent and absorbed dose of radiation of any kind by simultaneous measuring the charge produced in a cavity and the event spectrum. The analog component remmeter ACR includes three high-pressure ionization chambers (IC): argon-filled IC with aluminium wall (γ and charged particles absorbed dose), tissue-equivalent IC (total absorbed dose) and ^{3}He-filled IC in a 10"-diameter polyethylene moderator (neutron dose equivalent). Other instruments are: multysphere spectrometer (MS) with ^{6}LiI(Eu) detector (the method of linear combination of six spheres readings), thermoluminescent proportional counter SLETCP with aluminum wall.

Table 1. The instruments used in dose equivalent measurements in the IHEP reference fields.

Instrument	Refs.	Measuring components.	Scopes, limitations.	Errors	Certification
TEPC	[8]	Photons and charged particles, neutrons.	E_n > 0.3 MeV	9%	VNIIFTRI, State Standard
ACB	[9]	Photons and charged particles, neutrons.	$H_n/H\gamma$ <100, $H_n/H\gamma$ >0.1	18%	VNIIFTRI, State Standard
MS	[10]	neutron	--	15%	VNIIM, State Standard
TLD	[11]	Photons and charged	--	15%	VNIIM, State Standard
SLETCP	---	Photons and charged	--	10 %	----

RESULTS AND DISCUSSION

The results of neutron and photon ambient dose equivalent measurements for the IHEP Radionuclide reference neutron fields are given in Table 2. They are relate to one neutron of a radionuclide source generating a field, for convenience of further applications. The results are the expert estimation of the values usually taken as an average between TEPC, ACR and MS results except the cases when the error obtained after treatment of an instrument readings exceeds the permissible level for the dosimeter here we use the data for IKS and SLETCP.

Table 2. Measured ambient dose equivalents (expert estimation) and some important integral characteristics of the IHEP reference fields.

Reference.	$H^*(10)$, fSv/neutr., neutrons.	$H^*(10)$, fSv/neutr., γ + ch.part.	$h^*(10)$, pSv.cm^2	E_n, MeV.	$N_{10''}/N_{5''}$ rel.units.
PU	4.88±9%	0.183±20%	322.	3.32	1.32
CF	4.47±12%	0.220±15%	284.	1.83	1.01
CH	0.631±10%	0.250±10%	193.	1.36	0.73
FE	3.38±9%	0.023±15%	216.	0.76	0.61
HEF	4.0±13%, μ Sv/cycle	0.8±15%, μ Sv/cycle	282.	49.	0.86

The neutron spectra of the IHEP reference fields have been measured in[10] by the IHEP multisphere spectrometer [4]. Cadmium-covered polyethylene spheres of 2",3",5",8",10" and 12" diameter with ^{6}LiI(Eu) ⊗ 10× 10mm^3 thermal detector have been used in measurements. For spectrum measurements in high energy neutron fields a 18"-diameter sphere and activation carbon-based scintillation detector $^{12}C(x,xn)^{11}C$ were used. The neutron spectra of radionuclide reference neutron fields are shown at Fig.2 in comparison with accelerator low energy spectra outside the side shield. It could be noticed that the radionuclide fields do not closely simulate the real ones, but nevertheless have more spread neutron spectrum like real ones and rather similar shape of a separate part of a real spectrum which could be interesting from a point of view of a detector response. Then, in Table 3 the components of a neutron spectrum as well as the main spectral characteristics are given for the reference fields in comparison with the same values for the real neutron fields behind the IHEP accelerator shielding, measured in [5] and [7]. The real neutron spectra are divided on several groups according to spectrum hardness. As it is seen from the Table, the range of ambient dose equivalent conversion factors (193--322 pSv. cm^2) and the mean neutron energies in spectrum (0.76--3.32 MeV) as well as the ratio between a separate parts of neutron spectra cover a most part of a real neutron spectra behind the side shielding of the IHEP accelerator . The main advantage of the radionuclide neutron reference fields is a constant spectrum and component composition, good reproducibility and intensity (30--200 nSv/s) which we cannot reach in real fields behind the accelerator shielding.

The neutron spectrum at the high energy reference field is measured by the IHEP multisphere spectrometer with using apriori information. Comparison of neutron spectrum at the IHEP high energy reference field with theoretical spectrum behind shielding calculated by FLUKA [13] and ROZ6H [14] computer codes presence of two peaks - in evaporation region and near 100 MeV is confirmed by all authors. Such behavior of high-energy neutron spectrum appears also in the cosmic neutron spectrum measured in [15].

Table 3. Comparison of the main characteristics of neutron spectra of the reference and real workplace fields.

Type	Spectra	Part of F_n, rel. unit., intermed.	Part of F_n, rel. unit., fast	Part of F_n, rel. unit.,>20 MeV	$h^*(10)$, pSv.cm^2	E_n, MeV
Reference Fields						
	PU	0.11	0.89	0.	322.	3.32
	CF	0.13	0.87	0.	284.	1.82
	CH	0.41	0.59	0.	193.	1.36
	FE	0.20	0.80	0.	216.	0.76
	HEF	0.20	0.36	0.44	282.	49.1
Measured workplace neutron fields						
Soft, iron	MS[5]	0.79- 0.84	0.16- 0.21	0.	41.-52.	0.11-0.141
	PDSN[7]	0.51- 0.73	0.24 -0.49	0. -- 0.0014	75. 137.	0.6 -5.9
Side shieldig	MS[5]	0.45 -0.67	0.28- 0.47	0.013- 0.04	106-157	0.7 -3.5
	PDSN[7]	0/37- 0.60	0.37- 0.57	0.054- 0.16	156-222	5.7- 47
Top shielding	MS[5]	0.20	0.36	0.44	282.	49.
	ROZ6H[4]	0.22	0.39	0.38	253.	71.

CONCLUSION

Investigations of dosimetric characteristics of the IHEP reference neutron fields have been fulfilled by different dosimeters specially developing for measurements in mixed radiation fields. The ambient dose equivalent data obtained with an accuracy of 10-20%. It is shown that the main spectral characteristics of this set of reference fields are cover a most part of a real neutron spectra behind the side and the upper shielding of the IHEP accelerator. It allows one to using these reference fields for routine dosimeter calibration purposes, dosimeter intercomparisons and other applications as cosmic spectrum simulations.

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