CONSIDERATION ON THE $H_p(10)$ AND $H^*(10)$ SECONDARY STANDARD CHAMBER CHARACTERISTICS

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Abstract. This work presents the operational parameters used for personal and radiation field monitoring: personal dose equivalent $H_p(10, R, \alpha)$ and ambient dose equivalent $H^*(10, R, \alpha)$ for powerful penetration radiation, the measurement method using both secondary standard ionization chambers from STARDOOR laboratory and the results of measurements made in the room adjacent to the irradiation hall where the 7 MeV liniar accelerator is located, also including the results of the measurements conducted at the Sr-90 - 20 MBq radioactive source for testing the ionizing chambers.

1. Introduction

As regards the external exposure to radiations, there are four operational parameters which show remarkable interest for radiation field characterization in radioprotection purposes. These ICRU parameters are: the personal dose equivalent, penetration, $H_p(d)$, personal dose equivalent, superficial, $H_S(d)$, ambient dose equivalent, $H^*(d)$ and directional dose equivalent, $H'(d)$, where 'd' is the depth under a specific point on the body, which is proper for the penetration powerful radiation. All these parameters are based on the absorbed dose equivalent concept in one point rather than on the equivalent dose concept.

In this paper, the descriptions of the concepts for the four operational parameters used for the radiation field characterization is followed by the presentation of some details on the standard chambers, on the measurement method and the dosimetric measured results made for the room adjacent to the irradiation hall where the 7 MeV linear accelerator is located and at the radioactive check device (Sr-90 - 20 MBq) used for ionization chamber testing.

2. Concepts of equivalent / effective dose

The equivalent dose proper for an organ or tissue 'T' is given by relation

$$H_T = \Sigma_R w_R \times D_{T,R}, \quad [Sv] \tag{1}$$

where w_R is the radiation weighted factor for R radiation and $D_{T,R}$ is the absorbed dose for a tissue or organ T, due to R radiation. Table 1 shows the values for different kinds of radiations.

Table 1.Values of w_R for some radiations

Radiation	w_R	$w_R = A + B \exp(-C/6)$
γ, $e^{\pm}$, $\mu^{\pm}$, for all energies	1	1
Neutrons, E < 1MeV	1-10	A = 2.5; B = 18.20; C = $(\ln(E))^2$
Neutrons, E = 1MeV - 50 MeV	5-20	A = 5.0; B = 17.00; C = $(\ln(2E))^2$
Neutrons, E > 50 MeV	5	A = 2.5; B = 3.50; C =
Protons, other than recoil one, E > 2 MeV	5	$(\ln(0.04E))^2$
Alpha particles, fission fragments, heavy nucleus	20	5
		20

The effective dose, E, recommended by ICRP 60, is defined like

$$E = \Sigma_T w_T \times H_T, \qquad [Sv] \qquad\qquad (2)$$

where w_T is the weighted factor for the tissue or the organ T, its values being shown in Table 2.

Table 2. Weighted factors for organs / tissue (w_T)

Organ or tissue	w_T	$\Sigma_T w_T$
Bone surface, skin	0.01	0.02
Bladder, breast, liver, esophagus, thyroid	0.05	0.25
Bone marrow(red), colon, lung, stomach	0.12	0.48
Gonads	0.20	0.20
Remainder Tissues (10 in total: Adrenals, Brain, trachea small intestine, muscle, Pancreas, Kidneys, spleen, thymus & uterus)	0.05	0.05
Total Body	1.00	1.00

The total effective dose collected by a person in a 'g' group age is determined with the relation:

$$\mathbf{E} = \mathbf{E}^{external} + \sum_j e(g)_{j,inh} \times A_{j,inh} + \sum_j e(g)_{j,ing} \times A_{j,ing} + \sum_k D_k(g) \times Q_k, \qquad [Sv] \qquad (3)$$

where $E^{external}$ represent the interest effective dose from the external exposure, [Sv], $e(g)_{j,inh}$ and $e(g)_{j,ing}$ are the effective doses engaged on the incorporation unit of one radionuclide j, [Sv/Bq], by inhalation, ingestion respectively, by one person from a 'g' group age, $A_{j,ing}$ and $A_{j,inh}$ represent the radionuclide incorporation j, [Bq], by ingestion, inhalation respectively, D_k [Gy] is calculated with relation (4):

$$D_k = 1/\rho \; \Sigma_j \int_{Ek} E_k \int_{E\gamma} N_j \; \sigma_{kj}(E_\gamma) \; f_j(E_k,E_\gamma) \; \bar{\phi} \, (E_\gamma) \; dE_\gamma \; E_k, \qquad [Gy]$$
$$(4)$$

where: D_k represents the absorbed dose from the charged particle k resulted from nuclear reaction (γ,p), (γ,d), (γ,t), (γ, He^3), (γ,α) and (γ,n), in any organ or tissue T, with Q_k radiation quality factor; E_k – the charged particle energy k; N_j - atomic number density of the nucleus j in the phantom; $\sigma_{ij}(E_\gamma)$ – the efficiency section of the nucleus j to produce particle k in reaction to the energy of the phantom E_γ, $f_j(E_k,E_\gamma)$ – the energetic spectrum of particle k produced in the reaction between one photon with E_γ energy and j nucleus; $\bar{\phi}(E_\gamma)$ - the mean value of the photon spectrum in each organ or tissue, ρ – phantom tissue density.

3. Concepts of personal/ambient dose equivalent

For to define the parameters related to the effective dose equivalent and the skin dose equivalent the stipulation of some radiation fields derived from the radiation field is useful. In ICRU (ICRU, 1985) the "expanded" and "aligned" terms are given to characterize this derived radiation field. In the expanded field, the fluency and its angular and energy distribution have the same values everywhere in the interest volume like the real field in the reference point. In the aligned and expanded field, the fluency and its angular distribution are the same like in the expanded field, but the fluency is unidirectional.

For personal monitoring two concepts are introduced. The first one, the personal dose equivalent- penetration, Hp(d), is proper for an organ or tissue placed deep into the body and that can be irradiated with powerful penetration radiation. The second concept, the personal dose equivalent- superficial, Hs(d), is proper for superficial organs and tissue that are to be irradiated with powerful and soft penetration radiation. The personal dose equivalent penetration, Hp(d) is the dose equivalent in soft tissue, defined under a specific point on the body on 'd' depth, which is adequate for powerful penetration radiation.

As regards the monitoring of the area and the medium, two concepts which connect the external radiation field to the effective dose and equivalent dose in the skin, are introduced.

The first one, the ambient dose equivalent, H*(d), in one point in the radiation field, is the dose equivalent that can be produced by a properly aligned and expanded field, in ICRU sphere, to a 'd' depth, on the opposite direction ray of the aligned field. The measuring unit is [Sv]. The directional dose equivalent, H'(d), in one point of the radiation field is the dose equivalent that can be produced by the proper expanded field in ICRU sphere to a 'd' depth on a ray in one specified direction. Its measuring unit is [Sv].
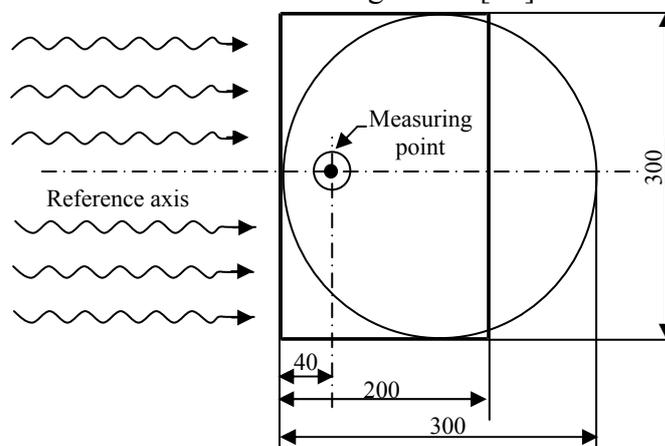

Fig. 1. The device model

4. Secondary standard chambers

Hp(10) secondary standard chamber 34035 type, was developed by Ankerhold et all at PTB. The device consists of one (30 x 30 x 15) cm ionization chamber made in a PMMA phantom used for personal dose equivalent measurement, Hp(10), namely, the radiation quantity which includes the radiation field and the phantom scattered radiation.

The Hp(10) chamber response is presented in Figure 2. The chamber is connected to a reference dosimeter T10005-50406 model. Introducing the ionization chamber parameters in UNIDOS dosimeter memory and also its calibration factor, the absorbed dose equivalent, measured in Sv, at d = 10 mm depth under the marked point on the irradiated body, is obtain. The secondary standard chamber Hp(10) was calibrated at PTW regarding photon with 15 keV – 1400 keV energy measurement for quality radiation of narrow spectrum (N), corresponding to ISO 4037-1 with gamma radiation emitted by radionuclide S-Cs[137] (661.6 keV; $T_{1/2}$=11.500 days, 0.079 μSv m^2/h MBq) with 15,2 ± 3 % mSv/h rate. The calibration factor value for this secondary standard chamber is N_H = 3.17·10^6 Sv/C, and its relative expanded uncertainty is 3 %.

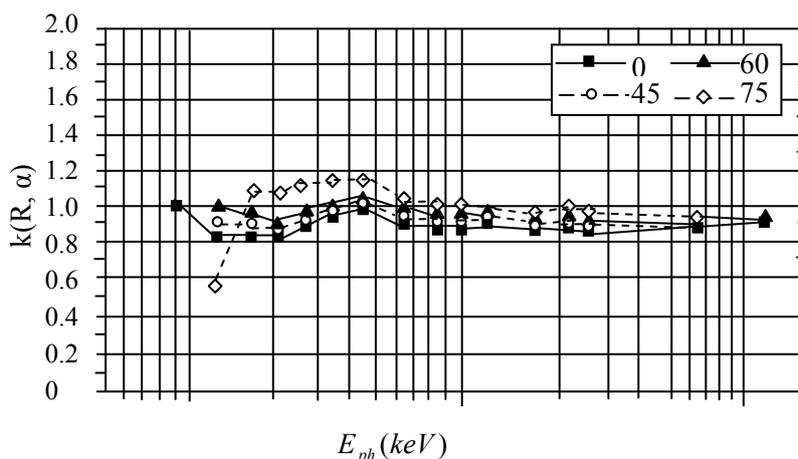**Fig. 2. Correction factors k(R, α) for radiation quality N-10 si N-300 and S-Cs ISO to incidence angles α, of 0°, 45°, 60°, 75° and for S-Co to angles α = 0° and 60°. $\overline{E}_{ph}$ is the photon mean energy given to N-10 and to N-120 by Ankerhold (Since Ankerhold (2000)) and for N-150 to N-300, S-Cs and S-Co with ISO/FDIS 4037-3.**

The spherical ionization chamber H*(10), TN 32002 type, was calibrated at PTW for to be used like a secondary standard chamber for ambient dose equivalent measurement, for photons between 25 keV – 50 MeV energy range. The radiation quality used for calibration was chosen in conformity with IEC60731 / ISO 4037-1 and the radiation was emitted by a Co^{60} source with ambient dose equivalent rate ranging 50 - 1000 mSv/h. The calibration factor value given in the calibration certificate delivered by PTW, is $N_H = 2{,}863 \cdot 10^4$ Sv/C, and its measurement uncertainty is equal with 2,5 %.
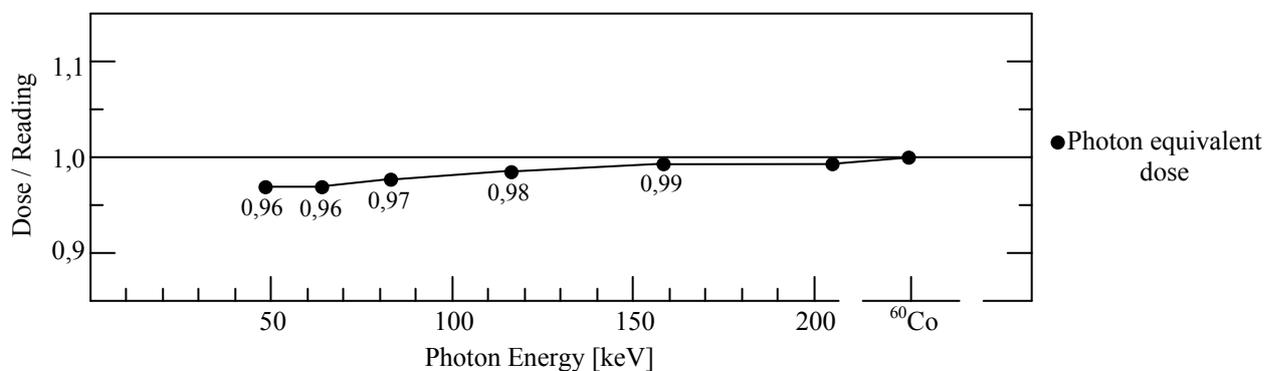

Fig. 3. Energy dependence for spherical ionization chamber type 32002.

The H*(10) chamber response given in Fig. 3, shows the dependence of the photon energy in the domain between 50 keV and Co-60 energy and the photon dose equivalent.

5. Measurement and calculation method

The **personal dose equivalent** determination, Hp(10, R, α), for X and γ rays, of R quality, at α incidence angle between the beam and the normal to the phantom surface, is given by the relation:

$$H_p(10, r, \alpha) = N_H k(R, \alpha) Q, \qquad (5)$$

were N_H is the calibration factor for the reference radiation quality N-60 and the reference angle of radiation incidence $\alpha = 0°$; $k(R, \alpha)$ correction factor for the radiation quality R and the angle of radiation incidence α and Q is charge measured by the chamber.

The calibration factor N_H with respect to the personal dose equivalent Hp(10), is determined with the radiation quality S-Cs^{137} and the incidence angle $\alpha = 0°$. It is given by the expression:

$$N_H = h_{pk}(10; S - Cs, 0°)\frac{K_a}{Q},$$ (6)

where K_a is conventional true value of the air kerma free in air; $h_{pk}(10)$ is conversion coefficient from K_a to Hp(10) and S-Cs^{137} shows that the measurements were made for a PMMA phantom to a reference radiation S-Cs and incidence angle $\alpha = 0°$.

The correction factor $k(R,\alpha)$ for the radiation quality R = S-Cs^{137} ($\overline{E}_{pk} = 662 keV$) at α incidence angle is given by formula:

$$k(R,\alpha) = (h_{pk}(10; R, \alpha)\frac{K_a}{Q})\frac{1}{N_H},$$ (7)

where $h_{pk}(10, R, \alpha)$, Q, K_a and N_H as given above.

The **ambient dose equivalent** determination in radiation field of R quality is made with the relation

$$H^*(10) = N_{60}\, k(R)\, Q,$$ (8)

where N_{60} is the calibration factor at the reference radiation quality N-60; k(R)- is the correction factor at the radiation quality R and Q is the charge measured by the chamber.

$$N_{60} = k_K^*(10, N - 60)\frac{K_a}{Q},$$ (9)

where K_a- the conventionally true value of the air kerma free-in-air for the reference quality N-60; $k_R^*(10, N-60)$ is the conversion coefficient from K_a to $H^*(10)$ for the quality N-60.

For the determination of the calibration factor N_{60} and the correction factors k(R), the measurements were carried out for energies ranging 9 - 1250 keV using the radiation qualities of the ISO, narrow-spectrum series ($N_{10} - N_{300}$) and the ISO gamma qualities S-Cs and S-Co.

6. Results and discussions

All measurements were made by the ionization chamber Hp(10) vertically positioned to 140 cm distance from the wall of the hall in which the accelerator is located. In sets 1 and 2, the accelerator was turned-off, and in other sets (3 and 4) the accelerator was operational in the electron and bremstrahlung modes (5 and 6). Tables show the preliminary results for personal dose equivalent, measured in the room adjacent to the hall the accelerator is located. The results led to the conclusion that, when the accelerator is turned-off, Hp(10) of 74.16 value and 73.11 respectively, the equivalent dose of 303 µSv/h is not exceeded, and when the accelerator is operational, Hp(10) of 91.98 value and 85.92 respectively, the equivalent dose of 303 µSv/h is not exceeded. Analyzing the values in the table, it results that only the population allowable equivalent dose of 5.7 µSv/h is exceeded in both accelerator conditions. For checking, a Sr-90 radiation source with 20 MBq activity (Figure 4) delivered by PTW, with test certificate, was used and a < 1 µSv/h dose at 10 cm distance was predicted. Table 4 includes the dosimetric measurement results made with the source placed to 10 cm distance from the secondary standard chambers oriented on a measurement direction of the secondary standard chamber detector.

Table 3. The results of measurements

Set 1 (Without radiation beam)		Set 3 (Electron operation)		Set 5 (Bremsstrahlung operation)	
Hp(10) [μSv/min]	1.236	Hp(10) [μSv/min]	1.533	Hp(10) [μSv/min]	1.637
Hp(10) [μSv/10 min]	12.36	Hp(10) [μSv/10 min]	15.33	Hp(10) [μSv/10 min]	16.34
Personal Dose Equivalent,Hp(10)	74.16	Hp(10) [μSv/h]	91.98	Hp(10) [μSv/h]	98.24
Tissue Equivalent Dose for public / training / occupational exposure, $H_T = \Sigma_R w_R \times D_{T,R}$				500 /150 /50 mSv/an	
Effective Dose for public / training / occupational exposure, $E = \Sigma_T w_T \times H_T$, (ICRP 60)				20 / 6 / 1 mSv/an	

Set 2 (Without radiation beam)		Set 4 (Electron operation)		Set 6 (Bremsstrahlung operation)	
Hp(10) [μSv/min]	1.21	Hp(10) [μSv/min]	1.43	Hp(10) [μSv/min]	**1.660**
Hp(10) [μSv/10 min]	12.18	Hp(10) [μSv/10 min]	14.32	Hp(10) [μSv/10 min]	16.60
Personal Dose Equivalent,Hp(10)	73.11	Hp(10) [μSv/h]	85.92	Hp(10) [μSv/h]	99.65
Tissue Equivalent Dose for public/ training / occupational exposure, $H_T = \Sigma_R w_R \times D_{T,R}$				500/150/50 mSv/an	
Effective Dose for public / training / occupational exposure, $E = \Sigma_T w_T \times H_T$, (ICRP 60)				20 / 6 / 1 mSv/an	

The measurement was made with the container housing the source, open, closed and the last measurement was recorded in absence of the source. It was noticed that when the source was absent, the obtained value was smaller than the case in which the container was closed but both values were smaller than in case in which the container was open.

Table 4. Obtained values for personal / ambient dose equivalent, using Sr-90 of 20 MBq.

Measure mode	Personal dose equivalent, Hp(10)	Measure mode	Ambient dose equivalent H*(10)
Without source	1.05 [μSv/min] = 63.0 [μSv/h]	Without source	0.70 [μSv/h]
Close container	1.41 [μSv/min] = 84,6 [μSv/h]	Open container	3.2 [μSv/h] ; SSD = 0 cm
Open container	1.44 [μSv/min] = 86,4 [μSv/h]	Open container	1.7/ **0.5** [μSv/h] ; SSD = 10/100 cm

7. Conclusions

The paper presents the method to measure the ambient/personal dose equivalent and the dosimetric results, the measurements being conducted by the use of a secondary standard chamber Hp(10) 34035 type. After conducting the measurements in the room of the hall in which the 7 MeV linear electron accelerators is located, in INFLPR, it was found that the obtained values corresponding to the equivalent dose for occupational exposed individuals,

show small values which fall-in CNCAN allowable limits. As an average, the obtained values are 3.76 times lower than the allowable equivalent dose limit for occupational exposure and 14.26 times higher than the allowable equivalent dose limit for population exposure. The obtained values, after the ambient dose equivalent measure, decrease with the distance between source and H*(10) secondary standard ionization chamber detector. For the measurements made with closed container, is realized the CNCAN condition about the ambient dose equivalent that must be smaller than 1 μSv/h at 0,1 m distance.

References

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