RADOS TL-Dosimeter
Test Report

IEC 61066

RADOS
synOdys Group

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1. Introduction

The New Rados Technology TL-dosemeter was tested according to the IEC standard 61066. The test program included several sections regarding the radiation, environmental and mechanical performance. The tests were performed exclusively for the dosemeters. A test regarding the RE2000 TLD-reader was made separately.

2. Schedule

The tests were performed between the July and December of 2005 according to the IEC standard 61066.

3. The materials and accessories

The tests involved one Rados RE2000 TLD-reader, a Rados IR2000-irradiator and approximately 400 TL-dosemeters, each containing two to four TL-pellets. Two types of pellet materials were used: MCP-N (LiF:Mg,Cu,P) and MTS-N (LiF:Mg,Ti), and all the tests were performed separately for each material. In addition, MCP-Ns pellets were also tested when deemed necessary. All the TL-materials were manufactured by TLD Poland.

The radiation sources used in the tests were located at STUK (Radiation and Nuclear Safety Authority) in Helsinki. ^{137}Cs-, ^{60}Co-, ^{90}Sr/^{90}Y-, and ^{85}Kr-sources were used in addition with x-rays with different energies. The conventional values of the personal dose equivalents Hp(0.07;α) and Hp(10;α) were calculated from the air kerma using conversion coefficient determined at STUK. The air kerma values were determined using ionization chambers, the calibrations of which are traceable to the International Bureau on Weights and Measures (BIPM, France), the National Physical Laboratory (NPL, UK) and the Physikalisch-Technische Bundesanstalt (PTB, Germany).

Also, a ^{137}Cs-source in a calibrator of the Partnertech Co. was used, as well as the Rados technology IR2000-irradiator with a built-in ^{90}Sr-source.

The phantoms used in the tests varied between a 30*30*15 cm water-filled plastic-phantom, an equally sized solid plastic phantom, and a 20*20*8 cm PMMA-phantom. All the dosemeters were irradiated, unless otherwise noted, on the surface of the phantom in groups of 2-6 dosemeters.

All the pellets were annealed according to the manufacturer's recommendations, and the entire TLD-system was calibrated according to the standard RADOS procedures.

4. Radiation performance requirements and tests

4.1 Non-linear response

REQUIREMENTS: The variation of response due to a change of the dose equivalent shall not exceed –9 % to +11 % over the entire measuring range.

TEST METHOD: The test was performed for fifteen dose values, from 50 µSv to 10 Sv. At every dose, 5 dosemeters were irradiated with a ^{137}Cs-source. The used dose rates in the tests were the following: 3 mSv/h, 30 mSv/h, 100 mSv/h and 500 mSv/h.

RESULTS: The results of the linearity test are shown in tables 1-2 and in figures 1-2. Good linearity was found for both TL-materials throughout the entire measuring range. The dosemeters met the requirements of the test for both TL-materials.

Table 1 - Linearity of the MTS-N-dosemeters.

Dose (mSv)	Hp(0.07)			Hp(10)		
	Non-linearity (%)	v_1 (%)	v_2 (%)	Non-linearity (%)	v_1 (%)	v_2 (%)
0.05	+3.1 ± 5.8	1.11	1.58	- 4.0 ± 2.6	1.37	1.96
0.1	+5.9 ± 3.4	1.69	2.41	-2.7 ± 2.8	1.56	2.22
0.25	+4.1 ± 5.6	0.68	0.97	+0.3 ± 2.2	0.62	0.89
0.5	+3.9 ± 5.6	1.71	2.45	+1.1 ± 2.2	0.72	1.02
1.0	+4.4 ± 5.8	1.04	1.49	+2.1 ± 2.5	1.12	1.69
2.5	+3.7 ± 4.1	0.99	1.42	+2.1 ± 2.3	0.91	1.30
4.0	0.0 ± 7.3	2.30	3.29	0.0 ± 2.8	1.60	2.28
10	-3.6 ± 3.3	1.45	2.07	-4.1 ± 2.3	1.08	1.54
25	+2.6 ± 6.3	1.59	2.27	+2.7 ± 2.3	0.86	1.22
50	-2.2 ± 5.7	1.67	2.39	-3.7 ± 2.3	1.04	1.48
100	-3.5 ± 4.9	1.97	2.81	-5.5 ± 2.8	1.61	2.30
500	-1.3 ± 4.6	1.54	2.20	-0.7 ± 4.7	0.84	1.21
1000	-2.3 ± 3.3	2.64	3.77	-4.8 ± 3.8	3.94	5.62
4000	+2.6 ± 6.7	2.65	3.78	+3.4 ± 3.7	1.12	1.68
10000	+1.0 ± 9.2	7.50	10.71	+0.9 ± 5.8	2.68	3.90

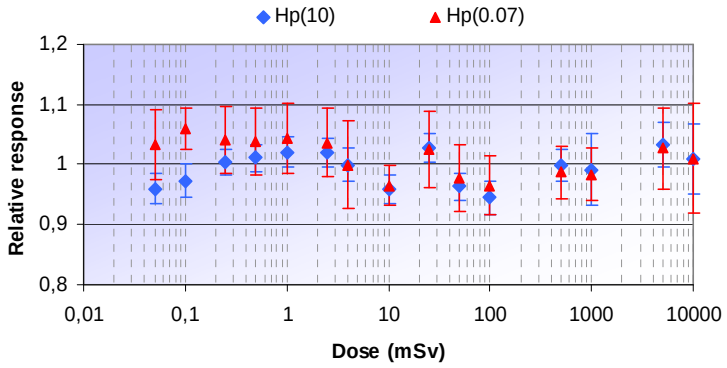


Figure 1. Linearity of the MTS-N-dosemeters

Table 2 - Linearity of the MCP-N-dosemeters.

Dose (mSv)	Hp(0.07)			Hp(10)		
	Non-linearity (%)	v_1 (%)	v_2 (%)	Non-linearity (%)	v_1 (%)	v_2 (%)
0.05	+3.0 ± 3.7	1.60	2.28	+1.2 ± 2.2	1.83	2.61
0.1	+0.7 ± 3.1	0.97	1.38	-2.4 ± 1.5	0.80	1.15
0.25	-2.7 ± 3.6	1.69	2.42	-4.6 ± 1.7	1.17	1.67
0.5	- 2.1 ± 3.5	1.52	2.16	-4.5 ± 1.6	1.09	1.55
1.0	+0.9 ± 3.5	1.37	1.96	+0.5 ± 1.7	1.17	1.67
2.5	-1.2 ± 3.9	1.79	2.55	-1.3 ± 1.8	1.37	1.95
4.0	0.0 ± 3.9	1.87	2.67	0.0 ± 1.9	1.42	2.03
10	-2.8 ± 3.0	0.89	1.27	-5.2 ± 1.4	0.81	1.16
25	-5.7 ± 3.2	1.54	2.19	-5.4 ± 1.7	1.31	1.87
50	-5.4 ± 3.2	1.39	1.95	-6.8 ± 1.7	1.26	1.80
100	- 4.1 ± 4.6	1.81	2.58	-5.3 ± 1.8	1.56	2.23
500	-2.7 ± 4.7	1.80	2.57	-6.8 ± 2.0	1.92	2.74
1000	-3.2 ± 2.8	0.93	1.33	-6.3 ± 2.3	1.05	1.49
4000	+1.0 ± 6.5	2.90	4.13	-4.7 ± 4.0	2.46	3.56
10000	-1.0 ± 4.2	1.35	1.92	-4.2 ± 3.5	1.34	1.94

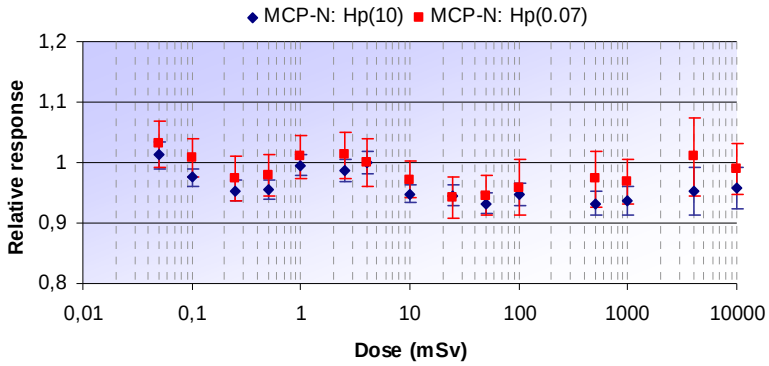


Figure 2. Linearity of the MCP-N-dosemeters.

4.2 Overload characteristics, after-effects and reusability

REQUIREMENTS: The requirements of the test are divided into 3 parts:

- When the dosemeters are irradiated with a dose of 10 times the upper limit of the measuring range (max.10 Sv), the indicated value shall not be less than H_{up}.
- A dosemeter irradiated with high dose values shall not produce any after-effects on any subsequent measurements.
- The fact that the dosemeter cannot be reused indefinitely, or that the usability depends on the history of the dosemeter shall be stated by the manufacturer.

TEST METHOD: Four groups of dosemeters were irradiated with ^{137}Cs-source using the following doses:

- Group 1: 4 mSv (10 dosemeters);
- Group 2: 10 Sv (1 dosemeter);
- Group 3: 100 µSv (10 dosemeters);
- Group 4: 500 mSv + 100 µSv (10 dosemeters).

The dosemeters were read out in that order. For the groups 1, 3 and 4, the variation of the response shall not exceed -9 % to +11%.

RESULTS: The evaluated value of a dosemeter, irradiated with a dose of 10 Sv, was 11.2 Sv and 10.3 Sv for the MTS-N- and MCP-N-dosemeters, respectively. These results fulfill the requirements of the standard. After a dose of 10 Sv, the performance of the TLD-reader remains stable. It was discovered that the MTS-N pellets remains reusable up to a dose of 500 mSv. For MCP-N pellets the limit is slightly lower: 200 mSv.

4.3 Radiation energy and angle of incidence for $H_p(10)$- or H*(10)-dosemeters

4.3.1 Photon radiation

REQUIREMENTS: The variation of the relative response due to a change of the radiation energy and the angle of incidence within the rated range shall not exceed –29% to +67%.

TEST METHOD: The dosemeters were irradiated in groups of 3-6 dosemeter, with radiation qualities specified in ISO 4037:

N-20 (16 keV),	N-30 (24 keV),	N-40 (33 keV),	N-60 (48 keV),
N-80 (65 keV),	N-100 (83 keV),	N-150 (118 keV),	N-300 (250 keV),
S-Cs (^{137}Cs),	S-Co (^{60}Co).		

From the reference direction (α = 0°), dosemeters were irradiated with the whole energy range. In addition, the three lowest energies were irradiated with an angle of incidence ±60°.

RESULTS: The results of the test are illustrated in figures 3 and 4. All the responses are within the required limits in the energy range of 16 keV – 1.3 MeV.

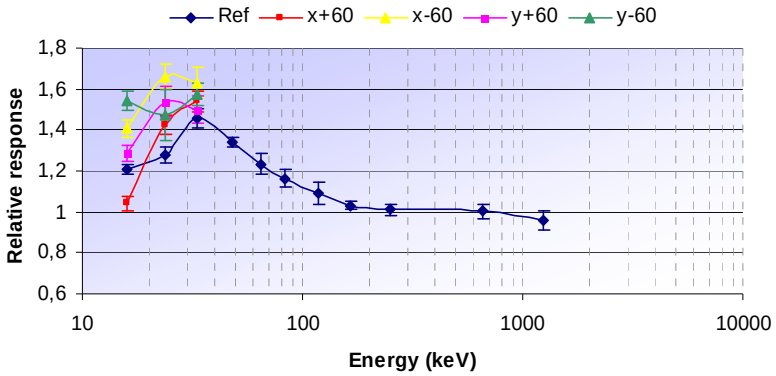


Figure 3. The radiation energy and the angle of incidence for the MTS-N-dosemeters.

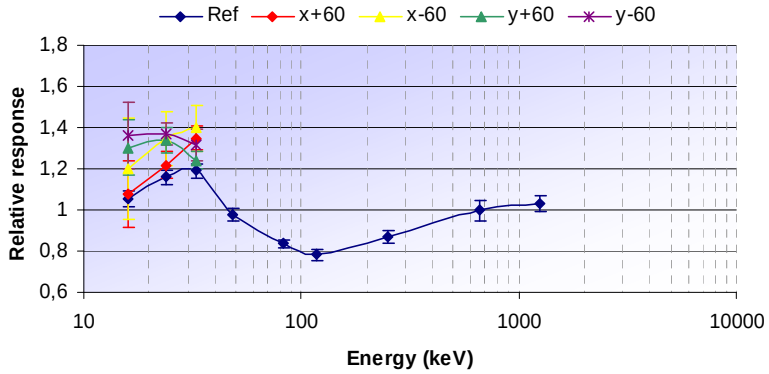


Figure 4. The radiation energy and the angle of incidence for the MCP-N-dosemeters

4.3.2 Beta radiation

REQUIREMENTS: The indicated value due to beta radiation with energies up to the energy equivalent of $^{90}Sr/^{90}Y$, shall be less than 0.1*Hp(0.07)

TEST METHOD: A group of eight dosemeters was irradiated with a dose of 100 mSv (Hp(0.07)), using a $^{90}Sr/^{90}Y$-source

RESULTS: With beta radiation, the evaluated values were 2.68 ± 0.12 % and 5.17 ± 0.37 % from the Hp(0.07) dose equivalent *C* for the MTS-N- and MCP-N-dosemeters, respectively. Both values are within the required limits of the test.

4.4 Radiation energy and angle of incidence for $H_p(0.07)$-dosemeters

4.4.1 Photon radiation

REQUIREMENTS: The variation of the relative response due to a change of the radiation energy and the angle of incidence within the rated range shall not exceed –29% to +67%.

TEST METHOD: The dosemeters were irradiated in groups of 3-6 dosemeter, with radiation qualities specified in ISO 4037:

N-20 (16 keV),	N-30 (24 keV),	N-40 (33 keV),	N-60 (48 keV),
N-80 (65 keV),	N-100 (83 keV),	N-150 (118 keV),	N-300 (250 keV).

From the reference direction (α = 0°), dosemeters were irradiated with the whole energy range. In addition, the three lowest energies were irradiated with an angle of incidence ±60°.

RESULTS: The test results for the Hp(0.07)-dosemeters are illustrated in figures 5-6. The responses of the MTS-N-dosemeters are within the required limits over the energy range of 16 keV to 250 keV. The rated energy range for the MCP-N dosemeters is 24 keV to 250 keV

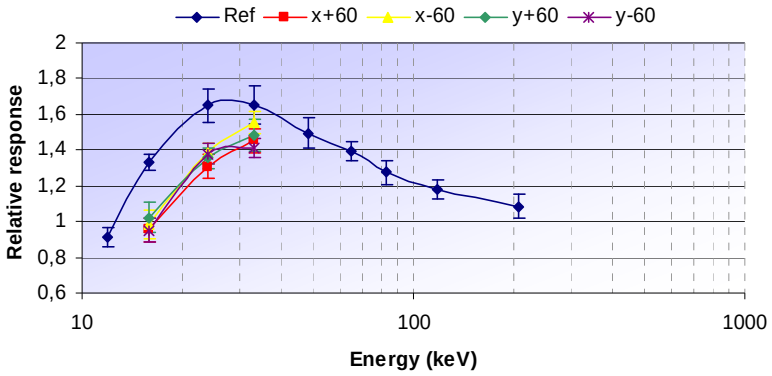


Figure 5. The radiation energy and the angle of incidence for the MTS-N-dosemeters.

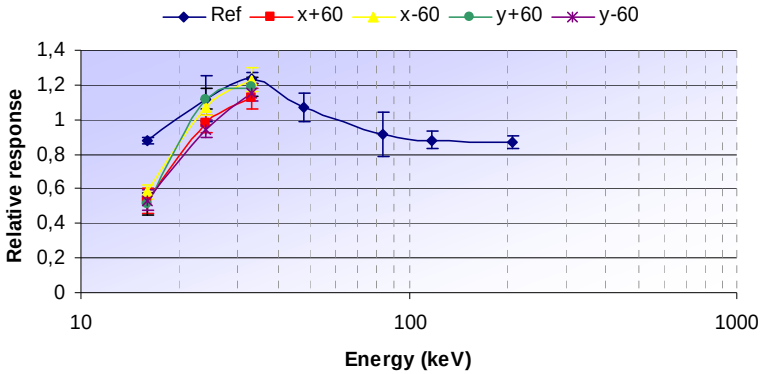


Figure 6. The radiation energy and the angle of incidence for the MCP-N-dosemeters.

4.4.2 Beta radiation

REQUIREMENTS: The variation of the relative response due to a change of the radiation energy and the angle of incidence within the rated range shall not exceed –29% to +67%.

TEST METHOD: Instead of the normal MCP-N pellets, MCP-Ns pellets were used in order to achieve a more constant energy response. The dosemeters were irradiated using the following radiation qualities:

- ^{85}Kr;
- ^{90}Sr/^{90}Y.

All the dosemeters were irradiated from a reference direction. In addition, the MCP-Ns dosemeters were irradiated with an angle of incidence ± 45°.

RESULTS: The test results are shown in figure 7. As illustrated, the angular responses with the low energy beta-radiation (^{85}Kr) are not within the required limits. The responses with the ^{90}Sr/^{90}Y-source are well within the required limits.

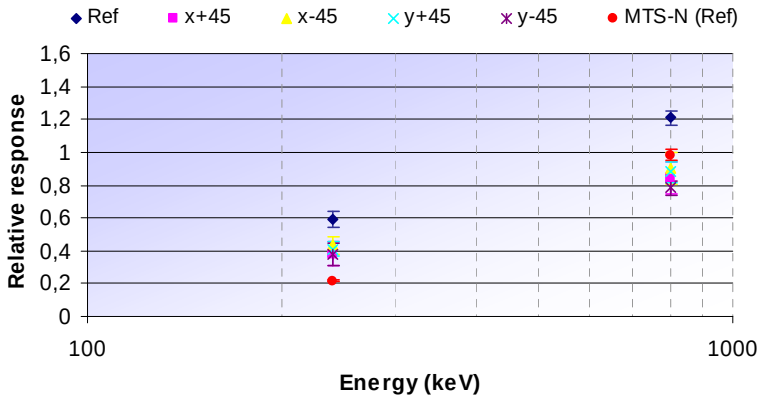


Figure 7. The beta-energy response using the MCP-Ns- and MTS-N-materials.

4.5 The Radiation incidence from the side of an $H_p(10)$- or an $H_p(0.07)$-dosemeters

REQUIREMENTS: If the dosemeter is irradiated from the side, the indicated value shall not exceed 1.2 times the indicated value resulting from an irradiation with the same radiation quality from the front.

TEST METHOD: The test was performed with the MTS-N material only, using radiation energies 16 keV and 33 keV.

RESULTS: The indicated value irradiated from the side of the dosemeter was > 28 % smaller than the indicated value irradiated from the front. This fulfills the requirements of the test.

5. Environmental performance requirements and tests

5.1 General

The geometrical sum of the variation of the response due to all environmental disturbances shall not exceed 20 %.

5.2 Ambient temperature and relative humidity (dosemeter)

REQUIREMENTS: The relative response due to a change of the ambient temperature and relative humidity within their rated ranges shall be within the interval from 0.83 to 1.25.

TEST METHOD: Five groups of dosemeters (10 dosemeters / group) were irradiated with a dose of 700 µSv. The treatment of the groups after the irradiation was:

- Group 1: The dosemeters were exposed to a temperature of -20°C;
- Group 2: The dosemeters were exposed to a temperature of +40°C and a relative humidity of 60 %;
- Group 3: The dosemeters were exposed to a temperature of +5°C ;
- Group 4: The dosemeters were exposed to a temperature of +50°C and a relative humidity of 90 %;
- Group 5: The reference group. The temperature and the relative humidity are according to the standard test conditions.

The duration of the exposure was 80 h.

RESULTS: All the responses are within the required limits of the test. Results of the test are shown in table 3.

Table 3 - Ambient temperature and relative humidity

Group Nr	Conditions	Change in response (%) MTS-N	MCP-N
1	-20°C	+0.9 ± 0.9	-0.3 ± 1.8
2	+40°C, 60%	-4.2 ± 0.9	-4.0 ± 2.1
3	+5°C	-1.7 ± 2.1	+0.8 ± 1.9
4	+50°C, 90%	-10.1 ± 1.0	-4.3 ± 2.5
5	Standard	0.0 ± 0.9	0.0 ± 2.1

5.3 Light exposure (dosemeter)

REQUIREMENTS: The variation of the response due to a change of the light exposure within its rated range shall not exceed -9 % to +11 %.

TEST METHOD: Two groups of 10 dosemeters were irradiated with a dose of 0.7 mSv. After the irradiation, the dosemeters of the 1st group were exposed to the extreme value of the light exposure within the rated range. The duration of the exposure was 80 h. The dosemeters of the 2nd group were stored at reference conditions.

RESULTS: The results of the light exposure test are shown in table 4. All the dosemeters met the requirements of the test. It is highly advisable to use a non-transparent beta-window when using the MCP-N material

Table 4 - Light exposure

	MTS-N		MCP-N	
	Hp(0.07)	Hp(10)	Hp(0.07)	Hp(10)
Group 1 (mSv)	0.675 ± 0.01	0.673 ± 0.01	0.716 ± 0.02	0.703 ± 0.03
Group 2 (mSv)	0.675 ± 0.01	0.672 ± 0.01	0.682 ± 0.02	0.711 ± 0.02
Variation of response (%)	0.0 ± 1.8	+0.2 ± 1.5	-4.8 ± 3.0	+1.5 ± 3.5

5.4 Dose build-up, fading, self-irradiation, and response to natural radiation

REQUIREMENTS: The variation of the response due to dose build-up and fading shall not exceed –9% to +11%. The coefficient of variation (COV) shall be less than 15% at the dose smaller than the lower limit of the measuring range. For a dose higher than 11 times the lower limit, the COV shall be less than 5%, and in between those dose levels the COV should be less than (16-(H/0.1mSv))%. The indicated values due to self-irradiation and natural radiation shall not differ by more than the lower limit of the measuring range during the maximal rated measurement time.

TEST METHOD: The dosemeters were divided into five groups. The groups 1-3 were exposed to a reference source (4mSv), group 4 was exposed to the lower limit of the measuring range (0.1mSv), and group 5 was not exposed. Group 4' was formed by subtracting the mean value of group 5 from the indicated values of the dosemeters in group 4.

The 1st group was read 1 hour after the exposure, the 2nd group 1 week after, and the rest of the groups 3 months after the exposure.

RESULTS: Table 5 shows the test results for the MTS-N- and MCP-N-materials, respectively. All the values are within the requirements of the test.

Table 5 - Build-up, fading, self-irradiation & response to natural radiation

Group No:	Time stored	MTS-N			MCP-N		
		$\underline{E}_i \pm$ sd (mSv)	Max. variation (%)	COV	$\underline{E}_i \pm$ sd (mSv)	Max. variation (%)	COV
1	1 h	4.03 ± 0.16	-4.92 ± 3.68	3.1 %	4.01 ± 0.20	+3.0 ± 3.2	3.9
2	1 w	4.24 ± 0.13	0.0 ± 3.74	2.5	3.89 ± 0.17	0.0 ± 2.9	3.6
3	3 m	3.90 ± 0.12	-7.4 ± 2.0	2.5	3.63 ± 0.13	-6.7 ± 2.5	2.9
4	3 m	0.33 ± 0.01	--	--	0.34 ± 0.01	--	--
5	3 m	0.25 ± 0.01	--	--	0.25 ± 0.01	--	--
4'	3 m	0.08 ± 0.01	--	12.3	0.08 ± 0.01	--	13.9

6. Mechanical performance requirements and tests

6.1 Drop (dosemeter)

REQUIREMENTS: A dosemeter should be able to withstand drops from a height of 1.0 meter onto a flat and hard surface made of concrete or steel, without the additional indication exceeding ± 0.7 * H_{low} after the drop. The dosemeters shall not be damaged, neither on the outside, nor on the inside.

TEST METHOD: The dosemeters were dropped once on each side of the dosemeter, so altogether 6 drops / dosemeter were made

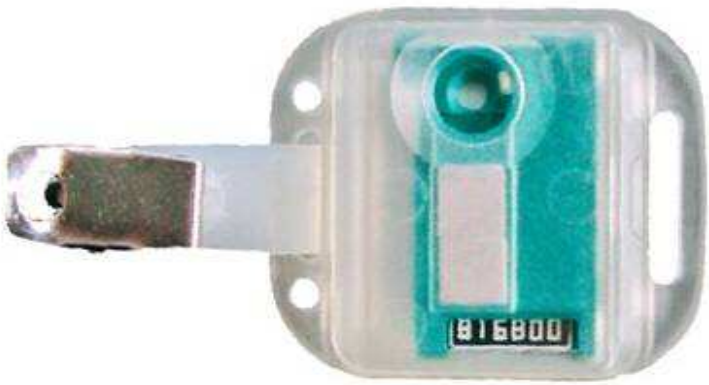
RESULTS: As a result of the drops, the additional indication due to a drop of the dosemeters was –1.1 ± 7 µSv for the MTS-N-dosemeters, and 13.7 ± 11 µSv for the MCP-N-dosemeters, respectively. Both values are inside the required limits of the test. None of the dosemeters were damaged as a result of the drops.

7. Conclusions

The Hp(10)-dosemeters fulfill all the requirements of the standard with both TL-materials, MTS-N and MCP-N. The Hp(0.07)-dosemeters also meet the requirements of the standard in all cases except for the beta-response test.

CHARACTERISATION OF A DOSIMETRY SYSTEM:

- Measuring range: 0.05 mSv - 10 Sv;
- Energy and angle of incidence (photon radiation):
  - MTS-N: Hp(0.07): 48 keV – 1.3 MeV, 0° – 60°;
    Hp(10): 16 keV – 1.3 MeV, 0° – 60°;
  - MCP-N: Hp(0.07): 24 keV – 1.3 MeV, 0° – 60°;
    Hp(10): 16 keV – 1.3 MeV, 0° – 60°;
- Energy and angle of incidence (beta radiation) (Hp(0.07)):
  - MTS-N > 500 keV, 0° - 45°;
  - MCP-Ns 500 keV – 1 MeV, 0° – 45°;
- Ambient temperature: -20°C - +50°C;
- Relative humidity: ≤ 90 %;
- Light exposure: ≤ 1000 W/m^2.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