PERSONAL DOSIMETRY INTERCOMPARISON ANALYSIS IN PUBLIC HEALTH INSTITUTE OF REPUBLIC OF SRPSKA

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Abstract:

Personal Dosimetry Laboratory of the Public Health Institute of Republic of Srpska (PHIRS) is estimating doses to approximately 1500 occupationally exposed workers to ionizing radiation on annual basis which represents 1/3 of occupationally exposed workers of Bosnia and Herzegovina. It is well known fact that the impact of ionizing radiation to human body and the risk of severe adverts effects are correlated with the magnitude of exposure. Therefore, delivering precise and accurate measurement result is essential in control of occupational exposure. Inter-comparison exercise plays an important role in testing laboratories to demonstrate technical competence. Participation in globally acknowledged and recognized EURADOS inter-comparison exercise for whole body dosemeters in photon fields is being conducted in 2 – years cycle by the laboratory. This paper is focused on the analysis of the EURADOS inter-comparison results. From 2014 to 2020, in total 4 inter-comparison exercises have been conducted, each requesting circa 30 dosemeters to be labelled and dispatched for irradiations. Entire number of the dosemeters is divided into groups for irradiations to a reference values with different irradiation qualities, dose ranges, angle of incidence and one group is kept to monitor the background. Statistical analysis of measured quantity $H_p(10)$ has been reported with response values (arithmetic mean, median, minimum, maximum and coefficient of variation). All response values are inside the trumpet curve defined in ISO 14146, ranging in mean response from 0.85 to 0.92. In addition, results are compared to $\boldsymbol{E_n}$ value and estimated uncertainty budget. This demonstrates that measured results are in compliance with recommendations on accuracy for radiation protection purposes.

Keywords: Personal dosimetry; inter-comparison; quality control; occupational exposure; ionizing radiation

1. INTRODUCTION

Radiation protection of occupationally exposed workers to ionizing radiation is the main purpose of personal dosimetry. Biological effects due to such exposure depend on dose received and therefore it is crucial to establish appropriate monitoring and dosimetry service competent to make evident compliance of individual doses to exposed workers with legal limits.

In order to be approved as dosimetry service and therefore having a license to assess the doses of occupationally exposed workers to ionizing radiation in Bosnia and Herzegovina, one of the regulatory requirements is participation in inter-comparisons at least once in three years [1]. Main objective for this is to evaluate performance of dosimetry system but also to assess precision and accuracy of delivered results.

PHIRS Dosimetry Laboratory is measuring doses to approximately 1500 occupationally exposed workers to ionizing radiation.

European Radiation Dosimetry Group (EURADOS) within working group 2 'Harmonization of individual monitoring' is organizing international inter-comparisons for individual monitoring services for whole body dosemeters in photon fields in 2-years cycle [2]. This is suitable for PHIRS Dosimetry Laboratory to fulfill regulatory requirement and verify quality of the service.

Since 2014 PHIRS is regularly taking part at EURADOS inter-comparisons and uses inter-comparison analysis results to compare with internal and international quality standards.

2. MATERIAL AND METHODS

Once inter-comparisons are announced by EURADOS, the laboratory is receiving the information on number of required dosemeters needed to be dispatched, but also the information on dose range, energy range and angle of incidence that will be used to enable participants to decide if inter-comparisons are suitable for their dosimetry systems. This scope differs to some extent from cycle to cycle and for the PHIRS participations is presented in the Table 1.

As it can be seen from the Table 1, the number of required dosemeters is always larger than irradiated because one group need to be kept to monitor the background, hence not irradiated.

Dosemeters were labelled according to beforehand given instructions by coordinator and dispatched for irradiations.

Table 1. Irradiation plans for $H_p(10)$

Inter-coparison cycle	Dosemters required/irradiated	Radiation categories
2014	30/20	S-Cs, S-Co, W-80 (0º,60º), W-150, RQR7
2016	30/22	S-Cs, S-Co, N-40(0º,60º), N-150 (0º,45º) S-Cs+90Sr
2018	34/22	S-Cs, S-Co, W-110, N-60(0º,60º), N-150 (60º) S-Cs+N-150
2020	30/20	S-Cs, S-Co, W-60 (0º,60º), N-150 (60º) S-Cs+W

2.1. Irradiation plan

Irradiations were carried out by selected metrology laboratories, at all times accredited according to EN ISO/IEC 17025 standard and in line with the irradiation plan developed by EURADOS organizing group [3].

Photon irradiation qualities were chosen from the ISO 4037 [4] including S-Co, S-Cs, N-quality series and since 2016 mixed irradiations fields were introduced.

In addition, special attention was taken to develop irradiation plan. Irradiation plan regarding the dose range was set up to include low, small, medium and high doses.

After completed irradiations by the metrology labs, TLDs were sent back by coordinator to all participating laboratories including PHIRS for the measurement process and reporting of the results.

2.2. Dosimetry system

PHIRS is using semiautomatic RADOS RE-2000 thermoluminescent (TL) reader with compatible two element thermoluminiscent detectors (TLD) placed into dosemeter case. Detector type is LiF: Mg, Ti also known as MTS-N, 4.5 mm in diameter and thickness of 0.90 mm. In appropriate position - position 1, covered with aluminum filter, personal dose equivalent $H_p(10)$ is being measured and reported. The second detector, in position 4 is measuring $H_p(0.07)$ which is not subject of obligatory reporting, however it is giving valuable information.

Once laboratory receive dosemeters, additional precaution to a routine measurement needs to be performed. At this phase, an average value obtained from the reading of the background TLD group is used to correct values of irradiated dosemeters.

2.3. Basic statistics

Statistical analysis of measured quantity $H_p(10)$ is presented with response value (R) that was calculated for each dosemeter by equation (1)

$$R = \frac{H_{p,participant}}{H_{p,reference}} \quad (1)$$

where $H_{p,participant}$ is the $H_p(10)$ value measured and reported by participant (PHIRS) and $H_{p,reference}$ is reference dose given by the irradiation laboratory received from the coordinator.

To investigate reproducibility of the system, the coefficient of variation (CV) was calculated for all irradiation categories. Furthermore, central value of distribution of response values was given with arithmetic mean and median. Extremes are also noted for all irradiation categories with minimum and maximum values. Finally, the total performance over the whole range was given.

2.4. Acceptance criteria

As mentioned earlier, response value R has been calculated for each irradiated and measured TLD. These values were compared with criteria defined in ISO 14146 [5,6] commonly known as “trumpet curve”. The trumpet curve is defined by equation (2)

$$\frac{1}{F}\left(1 - \frac{2H_0}{H_0 + H_C}\right) \le R \le F\left(1 + \frac{H_0}{2H_0 + H_C}\right) \quad (2)$$

where F=1.5, H_C is the conventional true value and H_0 is the lower limit of dose range for which the system has been approved and it is assumed to be 0.085.

The ISO standard 14146 allows a maximum of 1/10 of irradiated dosemeters to exceed this criterion.

2.5. Internal quality checking

To measure how closely reported value agrees with reference value, laboratory made additional analysis by calculating E_n score taking into account uncertainty for reference value and reported value using equation (3):

$$E_n = \frac{(\chi - X)}{\sqrt{U_\chi^2 + U_X^2}} \quad (3)$$

where χ is reported result by laboratory, U_χ expanded uncertainty of reported result, X reference value and U_X expanded uncertainty of reference value.

The results of E_n score were interpreted as:
$|E_n| \le 1$ satisfactory and
$|E_n| \ge 1$ questionable.

3. RESULTS AND DISCUSSIONS

Summary of the results with mentioned statistics for inter-comparisons conducted in 2014, 2016, 2018 and 2020 respectively are presented in Tables 2-5.

Different radiation qualities mentioned in Table 1. stand for different origins of irradiations and numbers associated with the series is giving information about energy [4]. Where necessary, information of incident angle is presented. Series N and W describe X-ray irradiations, S-Cs and S-Co gamma irradiations and mixed fields used either beta and gamma or X-rays and gamma irradiations. For every irradiation category the number of dosemeters and consequently number of values used for statistics is stated.

Table 2. PHIRS inter-comparison statistics in 2014 for $H_p(10)$ quantity

Radiation quality	No of values	Mean *R*	Median *R*	Max *R*	Min *R*	CV *R*
RQR/0°	2	1.07	1.07	1.09	1.04	3%
W-80/0°	2	1.03	1.03	1.03	1.02	1%
W-80/60°	2	1.12	1.12	1.14	1.10	3%
W-150/0°	2	0.91	0.91	0.92	0.89	2%
S-Cs/0°	6	0.86	0.87	0.90	0.82	4%
S-Co/0°	6	0.82	0.81	0.90	0.75	7%
Total	20	0.92	0.89	1.14	0.75	13%

Table 3. PHIRS inter-comparison statistics in 2016 for $H_p(10)$ quantity

Radiation quality	No of values	Mean *R*	Median *R*	Max *R*	Min *R*	CV *R*
N-40/0°	2	1.11	1.11	1.13	1.09	2%
N-40/60°	2	1.15	1.15	1.22	1.09	8%
N-150/0°	2	0.79	0.79	0.81	0.80	3%
N-150/45°	2	0.82	0.82	0.83	0.80	2%
S-Cs	6	0.80	0.80	0.82	0.77	3%
S-Co	6	0.77	0.77	0.81	0.75	3%
S-Cs/Sr-90/0°	2	0.83	0.83	0.83	0.82	1%
Total	22	0.85	0.82	1.22	0.75	15%

Table 4. PHIRS inter-comparison statistics in 2018 for $H_p(10)$ quantity

Radiation quality	No of values	Mean *R*	Median *R*	Max *R*	Min *R*	CV *R*
N-60/0°	2	1.11	1.11	1.13	1.08	3%
N-60/60°	2	1.17	1.17	1.17	1.17	0%
W-110/0°	2	0.94	0.94	0.96	0.91	4%
N-150/60°	2	0.97	0.97	1.00	0.93	5%
S-Cs/0°	6	0.80	0.81	0.83	0.77	3%
S-Co/0°	6	0.78	0.77	0.88	0.70	9%
N-150/Cs-137	2	0.80	0.80	0.82	0.77	4%
Total	22	0.88	0.83	1.17	0.70	16%

Table 5. PHIRS inter-comparison statistics in 2020 for $H_p(10)$ quantity

Radiation quality	No of values	Mean *R*	Median *R*	Max *R*	Min *R*	CV *R*
W-60/0°	2	0.99	0.99	1.02	0.95	5%
W-60/60°	2	1.07	1.07	1.09	1.05	2%
N-150/60°	2	0.90	0.90	0.92	0.88	3%
S-Cs/0°	6	0.83	0.83	0.86	0.81	2%
S-Co/0°	6	0.86	0.80	1.05	0.73	16%
S-Cs/W-80/0°	2	0.93	0.93	0.95	0.91	3%
Total	20	0.90	0.87	1.09	0.73	12%

It can be noted over the years of participating that the system shows good stability as CV varies between 0% and 8% for different radiation qualities and angles and in total range from 12% to 18%. It is, however, interesting to observe that in 2020 CV for S-Co has been significantly increased.

When receiving inter-comparisons dosemeters and dosemeters from field in general, one cannot distinguish if it is irradiated with small, medium or high dose. During the measuring process the reader provided an error that channel count limit is being exceeded. After completed measurement of the first detector, the system automatically stopped the reading process as one of the quality control measures. At this point, it was clear that the dosemeter had a high dose so the assumption was that saturation took place in the reader.

Immediate action by the responsible personnel was to check for type testing of the system and dose responses of high doses in the analysis from the previous inter-comparisons. The in-house type testing was conducted up to 50 mSv dose because of limitations in local SSDL, and assumed dose that was measured from the first detector was around 170 mSv. Consequently, as there were no in-house type test results for this dose range, mean response of S-Co high doses for $H_p(10)$ from previous inter-comparisons was checked and calculated to be 0.80.

Therefore, the measured dose was corrected by factor of 20%.

The estimation of the value was good, but it reflected inadequately on statistics and gave impression that linearity of the system is affected. If reported value for high doses was measured value without corrections, all results within tested dose range would show adequate linear response.

3.1. Trumpet curve

Figure 1. illustrates PHIRS response values as a function of reference doses for four consecutive participations. Although requirement is that 90% of irradiated TLD must be within the trumpet curve, it is noticeable that in period of 2014-2020 fraction of outliers is 0%.

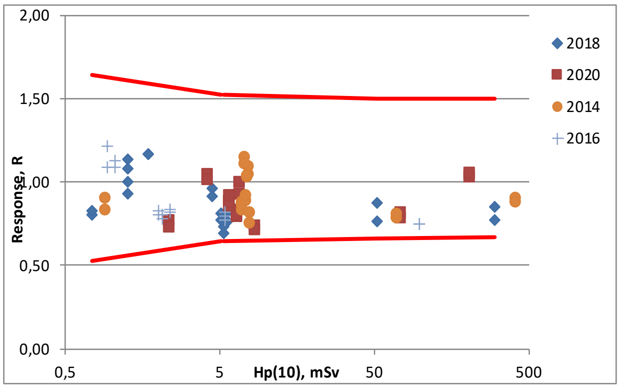

Figure 1. Results of PHIRS dosemeters results for period 2014-2020.

Analysis shows that mean response ranges between 0.85 and 0.92 among all irradiation categories. This is very well in compliance with recommended uncertainty [7] for personal dosimetry systems. Yet, a systematic under exposure in gamma fields is observed. Further testing showed that underestimation in gamma fields is due to characteristic of TL material called fading which represents gradual loss of the signal over time. The time between sending and measuring TLDs for the inter-comparisons is approximately 6 months whereas maximum time between sending and receiving TLDs in laboratory routine is four months.

3.2. E_n scores

All values were checked for the E_n scores. Figures 3-6 are presenting E_n values for examined radiation qualities over averaged dose ranges and signs L, S, M and H stand for low, small, medium and high doses respectively for different years of participation in IC. It was identified that only S-Co category in the range of small doses and in a single year exceeded E_n score. Average E_n value for S-Co in range of small doses was 1.39.

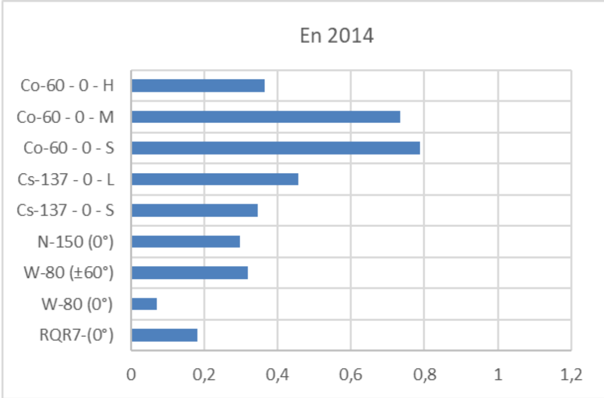

Figure 3. E_n scores grouped by the radiation quality and dose values for the inter-comparisons in 2014.

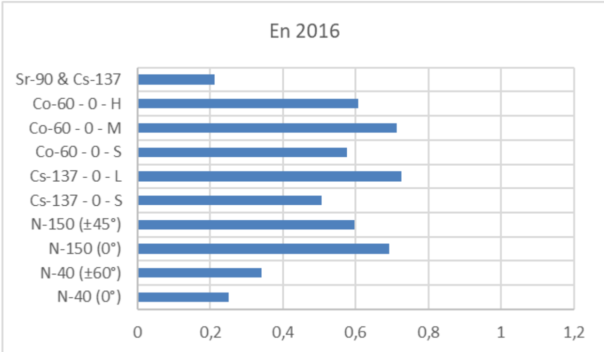

Figure 4. E_n scores grouped by the radiation quality and dose values for the inter-comparisons in 2016.

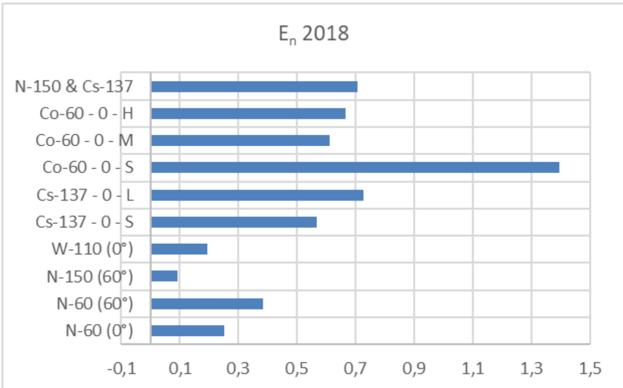

Figure 5. E_n scores grouped by the radiation quality and dose values for the inter-comparisons in 2018.

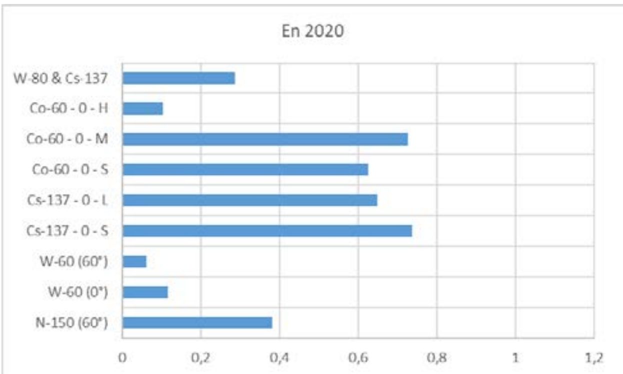

Figure 6. E_n scores grouped by the radiation quality and dose values for the inter-comparisons in 2020.

This was not expected, therefore, this value was compared with uncertainty budget of the laboratory.

PHIRS uncertainty budget is taking into account the dose levels based on test results performed on laboratory's own dosimetry system. For smaller doses, the uncertainty is greater and expanded uncertainty of reported result in range of small doses was 35.5%. Average dose response in range of the questionable result is 0.71 which is 29% offset of the reference value. This shows that questionable result was within the uncertainty limits and therefore considered as valid.

4. SUMMARY

Measured doses of workers occupationally exposed to ionizing radiation conducted by PHIRS are accurate, precise and reliable over wide dose range and in accordance with the general recommendations of the ICRP on the accuracy of the dosimetry system for the purpose of radiation protection. This can be confirmed by consistent inter-comparisons participation and extensive result analysis.

5. AKNOWLEDGEMENTS

Authors would like to express their gratitude to EURADOS Working Group 2, more specifically inter-comparison (IC) Organizing Group for continuous organization of self-sustained IC where IMS have the possibility to demonstrate validity of their results for the purposes of authorization, accreditation or other.

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