Original article

HDR and PDR ^{192}Ir source activity control procedures, as the part of the quality assurance system at Brachytherapy Department of Greater Poland Cancer Centre

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Abstract

Purpose: One of the main causes of treatment failures in brachytherapy is incorrect source strength specification in planning system or treatment delivery console. Source strength control is the only scheme to avoid such mistakes. The main aim of this work was to present results of three years of HDR and PDR sources activity control.

Material and methods: Study was based on data from 14 ^{192}Ir HDR and PDR sources exchanges. Sources were checked three times: at the exchange day and after one and two months. Measurements were performed twice with thimble chamber (PMMA phantom), and well chamber. The source strength were measured as air – kerma and recalculated to activity.

Results: Source activities measured using well chamber and thimble chamber, as well as activities provided by planning system, were presented for PDR and HDR, respectively. Differences between results obtained using each chamber and activities from planning system were presented graphically. The calculated and measured activities differed less than 5%. Wilcoxon test was performed as well, no statistically significant differences were observed among HDR or PDR activities.

Conclusions: Checking of source parameters is one of the most important parts of quality control system in brachytherapy facilities. Well chamber and thimble chamber based dosimetry systems are fast and reliable tools for ^{192}Ir source parameters checking in working brachytherapy department conditions.

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Key words: quality assurance, source activity check.

Purpose

Data published in IAEA report no 17 [1] showed that incorrect source strength specification in brachytherapy planning system or treatment delivery console of HDR or PDR afterloaders is the main reason of serious radiation accidents. Other human errors and incorrect usage of quantities and units could also induct errors relevant to patient safety and treatment results. For the quality assurance programme realised in brachytherapy department – calibration of the used sources is one of the most essential components [2, 3]. Main aim of this procedure is to ensure that the values provided by source vendor certificate agree with measured source strength within the predefined tolerance. Obtained values are used by the treatment planning systems and also by treatment console software to recalculate step times according to sources decay. Measurements performed between source exchanges are used to assuring that the source decay is properly represented in the software an its properly taken into account during the calculation of the steep time pattern. Proper calibration of the sources also assuring the traceability to international standards – for simple comparisons between national and international reports of the treatment results [4, 5].

The main aim of this study was to summarize and compare the results of the three years of HDR and PDR source activity control procedure realized by using two methods of measurements – according to recommended standards (redundancy and local).

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Material and methods

The measurements of the source activity were performed for HDR and PDR afterloaders. Every changed source was checked three times. First measurement was performed at the day of source exchange, second – after 30 days and third – after 60 days. All measurements was performed twice: first using redundancy standard equipment (thimble chamber, PMMA phantom) and afterwards with the local standard equipment (well-type chamber). For phantom measurements air kerma strength of the source (S_k) was recalculated to activity, using air kerma rate constant for ^{192}Ir (4.082 cGy cm^2/mCi h). For all measurements Unidos E electrometer was used.

Redundancy standard

Main reason for using redundancy standard is possibility to check the HDR and PDR with independent equipment. Measurements (of the doses) are done in solid media (PMMA) and thus this conditions are much closer to the clinical conditions, while by using the well type chamber the measured quantity is the kerma in gas (air). It's relevant that the redundancy standard cannot be used to determine reference values [6-8]. For the redundancy standard cylindrical PMMA phantom was used. The catheter was fixed inside custom made insert and placed in the central hole of the phantom. Measurements were performed using Farmer type chamber inserted inside one of the peripheral holes. Setup used for this type of measurements is shown on Fig. 1. For all the measurements PTW 30013 Farmer type chamber was used, and Unidos E electrometer.

The air kerma strength S_k [mGy/h m^2] can be determined from a dose measurement made by an ionization chamber calibrated in absorbed dose to water for Co-60 radiation:

$$S_k = \frac{1}{1-g_w}\,\frac{(\mu_{en}/\rho)_a}{(\mu_{en}/\rho)_w} \times k_{w-p} \times k_r \times k_{zp} \times k_\lambda \times N_w \times k_\tau \times K_D \times M \quad (1)$$

M: instrument reading [digit]
K_D: air density correction factor

$$K_D = \frac{273.15 + T}{293.15} \times \frac{1013}{p}$$

where T is the phantom temperature [°C] and p is the air pressure [hPa]
k_t: time correction factor (60/t), where t [min] is the measurement time

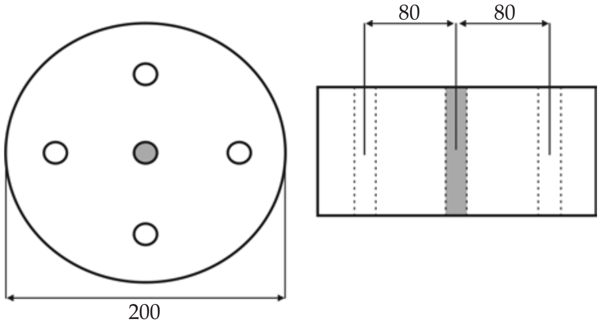

Fig. 1. PMMA phantom used for redundancy standard measurements

N_w: calibration factor for dose absorbed to water for Co-60 radiation [mGy/digit]
k_l: correction factor for Ir-192
This value was calculated from the instrument specifications. Assuming the instrument response is 1.00 for Co-60, the correction factor is equal to the interpolated response between Co-60 and the highest X-ray available assuming a mean Ir-192 energy of 380 keV.
k_{zp}: geometry correction factor for the cylindrical phantom used
This factor contains the volume correction for the used chamber 30013 (PTW) at distance 8 cm.
k_r: inverse square law correction factor ($k_r = (8/100)^2 = 0.0064$)
k_{w-p}: perturbation factor from water to PMMA environment ($k_{w-p} = 1$)
$(\mu_{en}/\rho)_w$ and $(\mu_{en}/\rho)_a$: mass energy absorption coefficients for air and water respectively, $(\mu_{en}/\rho)_w/(\mu_{en}/\rho)_a = 0.899$
g_w: relative energy lost by bremsstrahlung ($g_w = 0.001$)

Local standard

The local standard is established as well-type chamber. This chamber type is open to the atmosphere, pressurized chambers are not appropriate instrument due to some serious recombination problems due to high activity of HDR/PDR sources. The recommended calibration factor is the air kerma strength (cGy m^2 h^{-1}).

Measurements of the activity for PDR and HDR sources were done using PTW well chamber with vented sensitive volume of 200 cm^3. Dedicated adapter was used for assuring repeatable position of the source during measurements. Unidos E (PTW) was used as electrometer due to sensitivity and wide dynamic range. In the both checked sources (HDR and PDR) a source was driven into insert adapter to a reference depth of 61 mm above the chamber bottom.

The Source strength was calculated from the measurements reading with the following formula:

$$S_k = M \times N_i \times P_{ion} \times KD \quad (2).$$

S_i: source strength of the ^{192}Ir source

Depending on the selected calibration factor N_i, the output S_i can be calculated in:

- Air – Kerma Strength in cGy × m^2 × h^{-1}
- (Apparent) Activity in GBq or Ci
- "Exposure strength" in R × m^2 × h^{-1}

M: measurement reading in nA
N_i: calibration factor

- for Air – Kerma Strength, N_i is in cGy × m^2 ×h^{-1} × A^{-1}
- for (apparent) Activity N_i is in GBq × nA^{-1} or N_i is in Ci × nA^{-1}
- "Exposure strength" in R × m^2 × h^{-1} ×A^{-1}

P_{ion}: the reciprocal of Ion collection efficiency factor A_{ion}.

When chamber is employed with a collection potential of 300 V, A_{ion} is greater than 0.996 and in practice, for P_{ion} a value of 1 can be used.

When the source dosimetry system (chamber and electrometer) is employed with a different collecting potential, the ion collection efficiency factor A_{ion} is calculated as follows:

$$A_{ion} = \frac{4}{3} - \left(\frac{1}{3} \times \frac{Q_1}{Q_2}\right) \quad (3).$$

Q_1 and Q_2 are the charge (or current) reading at nominal (300 V) and half (150 V) potential, respectively.
K_D: environmental correction factor

The chamber is vented to the atmosphere, the currents are normalised to 20°C and 1013 hPa. Use of the chamber at other pressures and temperatures requires correction of the currents to these conditions. The multiplicative correction factor K_D is calculated from the following expression:

$$K_D = \frac{273.15 + T}{293.15} \times \frac{1013}{p} \quad (4).$$

T: room temperature in °C
p: atmospheric pressure in hPa.

Results

^{192}Ir source activity measurements (14 source exchanges) for HDR afterloader are presented in the Table 1. Every first and every third value represents the source activity at the day of the exchange. Values between them represents activity after 30 and 60 days from source exchange respectively. Measurements were performed using two methods $S_{HDR,WELL}$ value is for local standard, $S_{HDR,PMMA}$ value is for redundancy standard, $S_{HDR,SYS}$ is the activity calculated by treatment console, $S_{HDR,WELL}$ vs. $S_{HDR,SYS}$ and $S_{HDR,PMMA}$ vs. $S_{HDR,SYS}$ represents the percentage differences between measured and calculated values respectively. Graphical representation of obtained results is shown on Figs. 2 and 3.

^{192}Ir source activity measurements (14 source exchanges) for PDR afterloader are presented in the Table 2. Every first

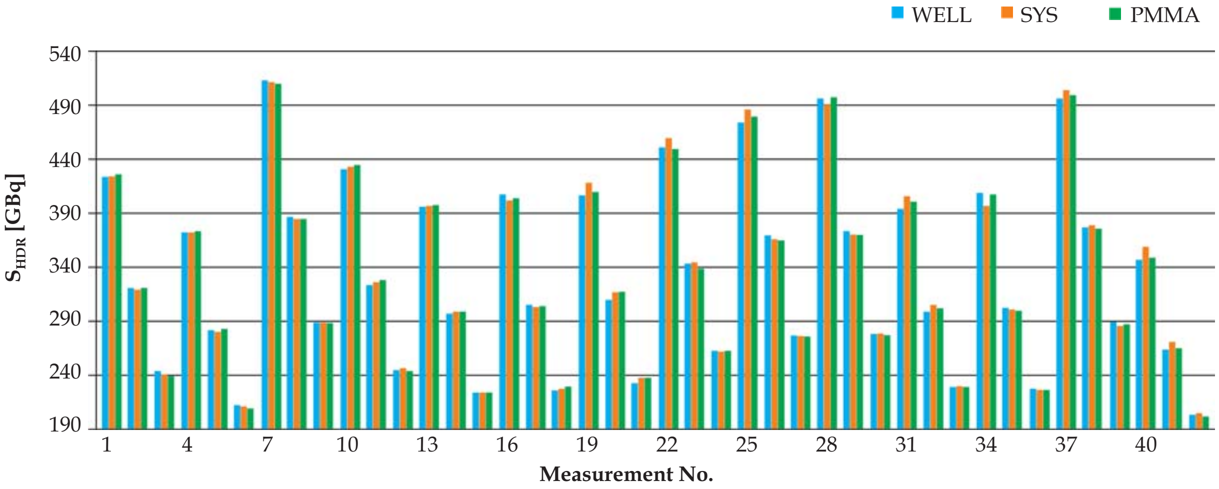

Fig. 2. Graphical representation of obtained activity values [GBq] (calculated and measured) for ^{192}Ir HDR source

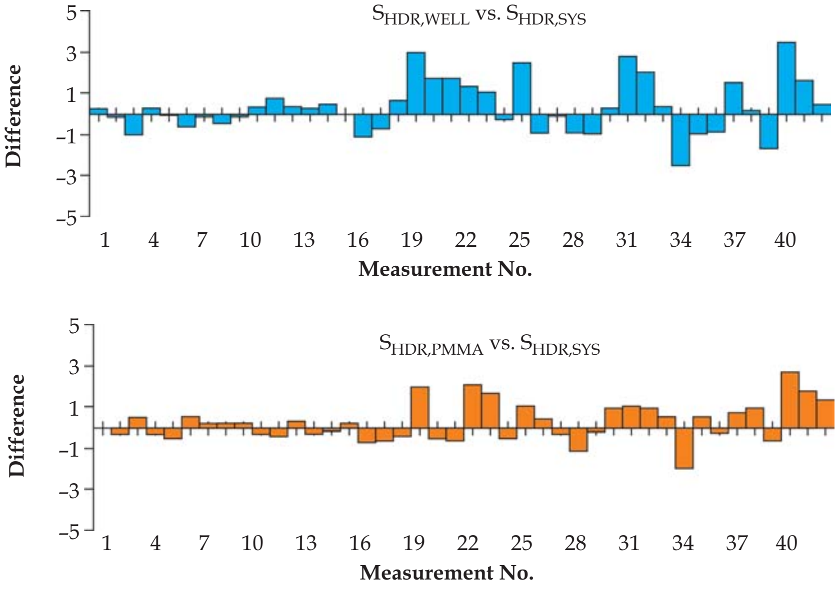

Fig. 3. Graphical representation of percentage differences between measured ($S_{HDR,WELL}$, $S_{HDR,PMMA}$) and calculated $S_{HDR,SYS}$ values of activity for ^{192}Ir HDR source

Table 1. Measured and calculated values of ^{192}Ir HDR source activity for 14 consecutive source exchanges

No	$S_{HDR,SYS}$ [GBq]	$S_{HDR,WELL}$ [GBq]	$S_{HDR,PMMA}$ [GBq]	$S_{HDR,WELL}$ vs. $S_{HDR,SYS}$ [%]	$S_{HDR,PMMA}$ vs. $S_{HDR,SYS}$ [%]
1	425.50	424.02	426.24	0.35	–0.17
2	321.05	321.53	322.27	–0.15	–0.38
3	242.24	244.57	240.87	–0.96	0.57
4	373.33	372.22	374.81	0.30	–0.40
5	281.69	281.94	283.42	–0.09	–0.62
6	212.54	213.86	211.27	–0.62	0.60
7	511.71	512.82	510.23	–0.22	0.29
8	386.10	387.76	384.98	–0.43	0.29
9	291.32	291.93	290.48	–0.21	0.29
10	434.38	432.53	435.86	0.43	–0.34
11	327.75	325.23	328.93	0.77	–0.36
12	247.30	246.42	246.42	0.35	0.35
13	397.01	395.90	398.49	0.28	–0.37
14	299.55	298.22	300.07	0.45	–0.17
15	226.02	226.07	225.33	–0.02	0.31
16	402.93	407.74	405.52	–1.19	–0.64
17	304.02	306.36	305.99	–0.77	–0.65
18	229.39	227.92	230.51	0.64	–0.49
19	419.95	407.37	411.44	3.00	2.03
20	316.86	311.17	318.57	1.80	–0.54
21	239.08	234.95	240.87	1.73	–0.75
22	459.54	453.25	449.55	1.37	2.17
23	346.74	342.99	340.77	1.08	1.72
24	261.62	262.33	263.07	–0.27	–0.55
25	486.18	473.97	480.63	2.51	1.14
26	366.84	370.37	365.19	–0.96	0.45
27	276.79	277.13	277.87	–0.12	–0.39
28	491.73	495.80	497.65	–0.83	–1.20
29	371.02	374.44	371.85	–0.92	–0.22
30	279.95	278.98	277.13	0.35	1.01
31	406.63	395.16	402.19	2.82	1.09
32	306.81	300.44	303.77	2.08	0.99
33	231.50	230.51	230.14	0.43	0.59
34	398.86	408.85	407.00	–2.50	–2.04
35	300.95	303.77	299.33	–0.94	0.54
36	227.08	229.03	227.55	–0.86	–0.21
37	503.94	496.17	499.87	1.54	0.81
38	380.24	379.25	376.66	0.26	0.94
39	286.90	291.93	288.97	–1.75	–0.72
40	360.01	347.43	350.02	3.49	2.77
41	271.64	267.14	266.77	1.66	1.79
42	204.96	203.87	202.02	0.53	1.43

Table 2. Measured and calculated values of ^{192}Ir PDR source activity for 14 consecutive source exchanges

No	$S_{PDR,SYS}$ [GBq]	$S_{PDR,WELL}$ [GBq]	$S_{PDR,PMMA}$ [GBq]	$S_{PDR,WELL}$ vs. $S_{PDR,SYS}$ [%]	$S_{PDR,PMMA}$ vs. $S_{PDR,SYS}$ [%]
1	40.70	41.44	40.33	–1.82	0.91
2	30.71	31.45	29.60	–2.41	3.61
3	23.17	22.94	23.68	1.00	–2.20
4	43.66	42.55	42.18	2.54	3.39
5	32.94	33.67	32.19	–2.21	2.28
6	24.86	24.05	25.16	3.24	–1.22
7	44.03	43.45	42.92	1.32	2.52
8	33.22	33.67	32.19	–1.35	3.11
9	25.07	25.40	24.97	–1.35	0.39
10	40.33	38.85	39.59	3.67	1.83
11	30.43	29.31	29.97	3.68	1.51
12	22.96	22.41	22.12	2.40	3.66
13	41.81	41.07	41.07	1.77	1.77
14	31.55	32.19	31.03	–2.04	1.64
15	23.80	23.31	22.94	2.07	3.63
16	39.59	39.22	38.85	0.93	1.87
17	29.87	29.97	29.97	–0.33	–0.33
18	22.54	22.11	21.83	1.90	3.15
19	44.40	43.66	44.77	1.67	–0.83
20	33.50	33.67	34.04	–0.50	–1.61
21	25.28	25.40	26.27	–0.50	–3.93
22	44.40	44.03	43.29	0.83	2.50
23	33.50	34.04	32.93	–1.61	1.70
24	25.28	24.79	25.78	1.93	–1.99
25	42.55	41.81	41.07	1.74	3.48
26	32.11	31.45	32.19	2.04	–0.26
27	24.22	24.05	23.31	0.72	3.77
28	40.33	41.12	40.89	–1.96	–1.39
29	30.43	31.45	30.12	–3.35	1.02
30	22.96	22.57	22.57	1.70	1.70
31	45.14	43.31	43.96	4.05	2.61
32	34.06	34.12	32.93	–0.18	3.32
33	25.70	26.27	26.27	–2.22	–2.22
34	42.92	42.19	44.40	1.70	–3.45
35	32.38	32.93	33.30	–1.69	–2.83
36	24.43	24.05	24.49	1.57	–0.23
37	44.77	43.98	44.95	1.76	–0.40
38	33.78	32.93	33.98	2.52	–0.59
39	25.49	25.53	24.97	–0.16	2.03
40	41.44	40.70	40.33	1.79	2.68
41	31.27	31.45	32.19	–0.58	–2.95
42	23.59	22.94	24.05	2.76	–1.94

and every third value represents the source activity at the day of the exchange. Values between them represents activity after 30 and 60 days from source exchange respectively. Measurements were performed using two methods $S_{PDR,WELL}$ value is for local standard, $S_{PDR,PMMA}$ value is for redundancy standard, $S_{PDR,SYS}$ is the activity calculated by treatment console, $S_{PDR,WELL}$ vs. $S_{PDR,SYS}$ and $S_{PDR,PMMA}$ vs. $S_{PDR,SYS}$ represents the percentage differences between measured and calculated values respectively. Graphical representation of obtained results is shown on Figs. 4 and 5.

Wilcoxon test was used for statistical evaluation of obtained results – there were no statistically significant differences observed between activity values measured using two dosimetry standards and values calculated by treatment console for both (HDR and PDR) sources (Table 3).

Discussion

For absolute calibration of the ^{192}Ir sources the recommended method is using the primary standard. This is realised by measuring the air kerma rate at relatively large to the source dimensions distances (it's defined at 1 m) [9]. In this conditions when small charges or currents are measured chamber positioning errors can induct large uncertainties. For the best results it's needed to interpolate

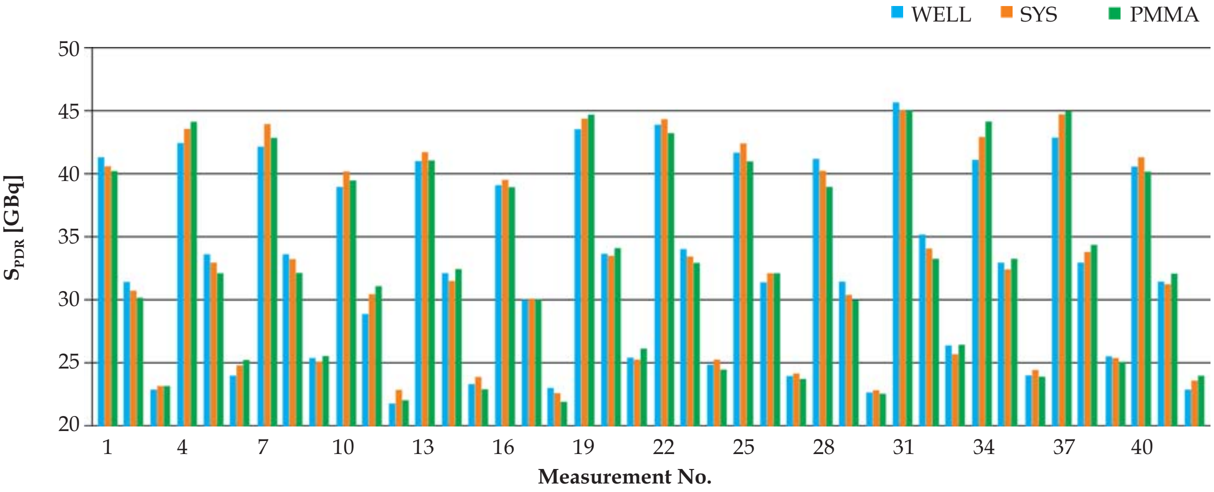

Fig. 4. Graphical representation of obtained activity values [GBq] (calculated and measured) for ^{192}Ir PDR source

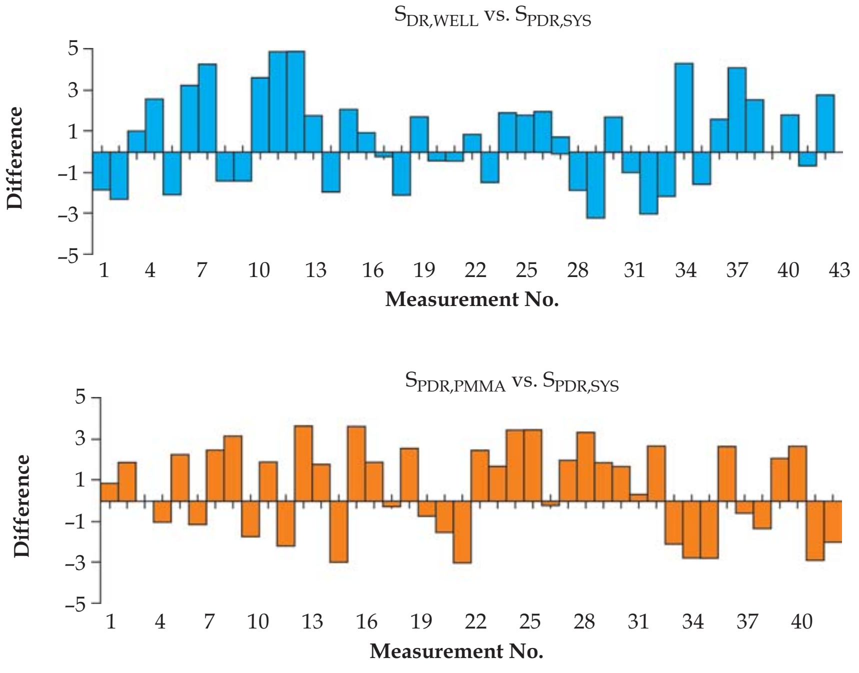

Fig. 5. Graphical representation of percentage differences between measured ($S_{PDR,WELL}$, $S_{PDR,PMMA}$) and calculated $S_{PDR,SYS}$ values of activity for ^{192}Ir PDR source

Table 3. Statistical evaluation of obtained results – activity values from the measurements ($S_{HDR,WELL}$, $S_{HDR,PMMA}$, $S_{PDR,WELL}$, $S_{PDR,PMMA}$) compared to calculated by treatment console ($S_{HDR,SYS}$, $S_{PDR,SYS}$) for both checked sources

p Wilcoxon		
HDR	$S_{HDR,WELL}$ vs. $S_{HDR,SYS}$	0.1768
	$S_{HDR,PMMA}$ vs. $S_{HDR,SYS}$	0.8774
PDR	$S_{PDR,WELL}$ vs. $S_{PDR\ SYS}$	0.1210
	$S_{PDR,PMMA}$ vs. $S_{PDR\ SYS}$	0.0557

the values by measuring kerma at several different distances [10, 11]. Increasing of the measuring distance decreases positioning inaccuracies but also reduces the signal to noise ratio and increasing scatter contribution. Chamber size effects, and current leaks also contribute to the overall uncertainties when in-air calibration is going to be performed. Proper realisation of calibration using primary standard could be time consuming and difficult to realise in hospital conditions. In practice – calibration and quality control actions for the sources used in brachytherapy could be done in well chambers or solid phantoms. Setup for measurements is repeatable and whole procedure is not time consuming.

After three years of using both methods of HDR and PDR source activity checking there were no statistically significant differences observed between values measured using well-chamber and thimble chamber and solid PMMA phantom. For reducing equipment inducted errors exact the same electrometer (Unidos E) was used for both measurements conditions. The most important question in this part of quality control procedures it's "reaction level" and "reaction type". The reaction level was set (and newer reached) at 5% for both machines, according to recommendation and previous experiences [12, 13].

In realised measurements the maximum observed percentage differences between values from the system and measured activity were 3.49% for HDR source and 4.05% for PDR. As in other aspects of quality control reaching of reaction level should result in appropriate and previously planned actions. In general the irradiation equipment should not be used clinically if the levels are exceeded and always carefully taken into consideration by responsible medical physicist.

Conclusions

1. Checking of source parameters is one of the most important parts of quality control system in brachytherapy facilities. Elaborated procedure is essential to assure patient safety and reliable clinical results.
2. Well-chamber and thimble chamber based dosimetry systems both are fast and reliable tools for ^{192}Ir source parameters checking in working brachytherapy department conditions.

References

1. Ballester F, Puchades V, Lluch JL et al. Technical Note: Monte-Carlo dosimetry of the HDR 12i and Plus 192 Ir sources. *Med Phys* 2001; 28: 2586-2591.
2. Briot E. Quality assurance programme in high dose rate brachytherapy with Iridium-192 source. Recommendations of the French Medical Physicists Society. *Radioth Oncol* 1996; 39: 20-27.
3. Butler W, Merric G. Clinical Practice and Quality Assurance Challenges in Modern Brachytherapy Sources and Dosimetry. *Int J Radiat Oncol Biol Phys* 2008; 71 (1 Suppl): 142-146.
4. DeWerd LA, Huq MS, Das IJ et al. Procedures for establishing and maintaining consistent air-kerma strength standards for low-energy, photon-emitting brachytherapy sources: Recommendations of the Calibration Laboratory Accreditation Subcommittee of the American Association of Physicists in Medicine. *Med Phys* 2004; 33: 675-681.
5. Goetsch SJ, Attix FH, Pearson DW et al. Calibration of 192 Ir high-dose-rate afterloading systems. *Med Phys* 1991; 18: 462-467.
6. Kindlein J, Hovestadt L. Quality assurance for brachytherapy using a dose measuring system. *Phys Med Biol* 2007; 52: 387-391.
7. Kohr P, Siebert FA. Quality assurance of brachytherapy afterloaders using a multi-slit phantom. *Phys Med Biol* 2007; 17: 387-391.
8. Kubo HD, Glasgow GP, Pethel TD et al. High dose-rate brachytherapy treatment delivery: report of the AAPM Radiation Therapy Committee Task Group No. 59. *Med Phys* 1998; 25: 375-403.
9. Lliso F, Pérez-Calatayud J, Carmona V et al. Fitted dosimetric parameters of high dose-rate 192 Ir sources according to the AAPM TG43 formalism. *Med Phys* 2001; 28: 654-660.
10. Nath R, Anderson LL, Luxton G et al. Dosimetry of interstitial brachytherapy sources: Recommendations of the AAPM Radiation Therapy Committee Task Group No. 43. *Med Phys* 1995; 22: 209-234.
11. Nath R, Anderson LL, Meli JA et al. Code of practice for brachytherapy physics: report of the AAPM Radiation Therapy Committee Task Group No. 56. American Association of Physicists in Medicine. *Med Phys* 1997; 24: 1557-1598.
12. Tolli H, Johansson KA. Quality assurance in brachytherapy. Principles for ionization chamber measurement of absorbed dose close to brachytherapy sources. *Phys Med Biol* 1999; 38: 1475-1483.
13. Zuofeng L, Thomas PM, Jatinder RP et al. Quality assurance test tool for high dose-rate remote afterloading brachytherapy Units. *Med Phys* 1998; 25: 232-235.