

## QUALITY ASSURANCE IN HDR BRACHYTHERAPY - IN AIR AND IN WATER CALIBRATION OF Ir-192 HDR SOURCE.

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### INTRODUCTION

In August 1993 the first Ir-192 source for Nucletron-Oldelft microSelectron HDR afterloading unit was delivered to the Regional Oncology Centre in Bydgoszcz. The necessity of user's calibration was due to  $\pm 10\%$  uncertainty in the manufacturer's certificate, which is clinically unacceptable. Various calibration procedures have been developed to achieve better accuracy. However, because of financial limitations only in-air and in-water calibration methods based on self-made calibration phantoms have been employed and no well chambers had been used till the end of 1997. We started in-water calibration of the HDR source based on the Jones method. Since 1996 we have applied also an in-air calibration procedure. Until December 1997, 12 iridium sources have been calibrated.

In the autumn of 1996, seven HDR afterloading machines working in Polish hospitals were equipped with an iridium-192 source. Due to the relatively short half-life time of approximately 74 days, iridium sources have to be exchanged every 3 to 4 months. This makes the source calibration a routine procedure. Most of the users perform their own source calibration. To compare and verify different calibration methods comparative measurements were performed at the Regional Oncology Centre in Bydgoszcz. Physicists from six oncology centres performed measurements of the same iridium source using their own calibration phantoms and dosimeters. The paper presents the results of these measurements and discusses the errors arising during in-air and in-water calibration and the applicability of these methods.

### MATERIALS AND METHODS

Although the details can differ from centre to centre, the general concept of in-air and in-water calibration of an Ir-192 HDR source is always the same. The reference air kerma rate

(RAKR) can be derived using the following expression:

$$RAKR = \left( M \cdot \prod_i CF_i \right) \cdot \frac{1}{t} \quad [1]$$

where  $M$  is dosimeter reading,  $t$  is measurement time and  $CF$  is correction factor. The set of correction factors depends on the method used but the calibration factor of the chamber and a radial function is always necessary.

#### 1. In-water calibration.

Both a source and a detector (ionisation chamber) are placed in water. To protect the chamber from the water and to keep fixed geometry a special calibration phantom is necessary.

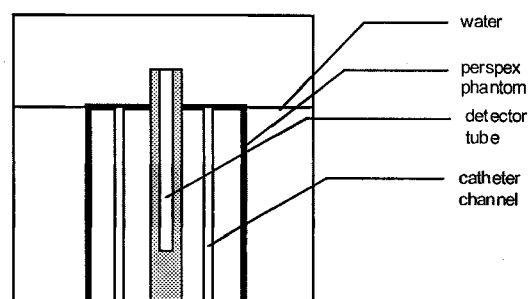


Figure 1. Phantom for in-water calibration.

Figure 1 shows the calibration phantom developed and used, at the Regional Oncology Centre in Bydgoszcz. It is based on the Jones concept (Jones, 1989) and is made of perspex and consists of a central tube for a Farmer type 0.6 ionisation chamber and four thin channels symmetrically located around the chamber tube to hold flexible plastic catheters for the HDR source. The channels are parallel to the chamber and the axis-to-axis distance is 50 mm. The distance is a compromise between the high dose gradient close to the source and the signal level falling with the distance.

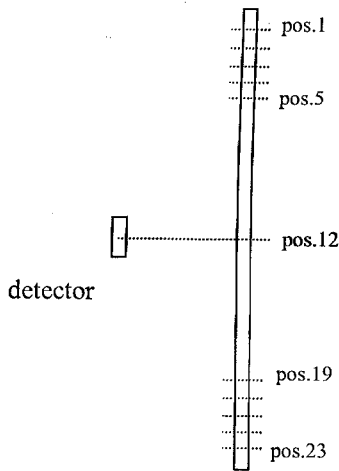


Figure 2. Dwell positions in a single catheter channel of the calibration phantom

Figure 2 presents the source dwell positions during measurements. Dwell positions within one channel are located symmetrically to the chamber centre. The symmetry of the measurement geometry and the number of measurement points assure the best performance of the set. In each dwell position a 30sec. measurement is performed, which gives 1200sec. of overall measurement time for 40 dwell positions in four channels.

The radial function can be presented as (Meisberger et al., 1968):

$$F_{geo} = \sum_{i=1}^n \left[ r_i^2 \cdot S(r_i)^{-1} \right]^{n-1} \quad [2]$$

where  $n$  is the number of measurement points,  $r$  is the distance from the measurement point to the chamber centre and  $S(r)$  is the Meisberger polynomial. It converts the dose rate in the phantom to the dose rate free in air taking into account scatter and attenuation (Park and Almond, 1992). The polynomial is as follows:

$$\frac{D_w}{D_{air}} = A + B \cdot r + C \cdot r^2 + D \cdot r^3 \quad [3]$$

where:

$D_w$  is dose rate in water,

$D_{air}$  is dose rate in air,

$r$  is the distance from the source,

and:

$A=1.0128$ ;  $B=5.019 \cdot 10^{-3}$ ;  $C=-1.178 \cdot 10^{-3}$ ;  $D=-2.008$

### 2. In-air calibration.

Both the source and, the detector are in air. The source to chamber distance is usually 100 mm. Quadratic square law is assumed, so the radial function can be expressed as  $1/r^2$ . Figure 3 shows a phantom for in-air calibration used at the Regional Oncology Centre in Bydgoszcz. It

is possible to change the source to chamber distance, which is useful for room scatter measurements.

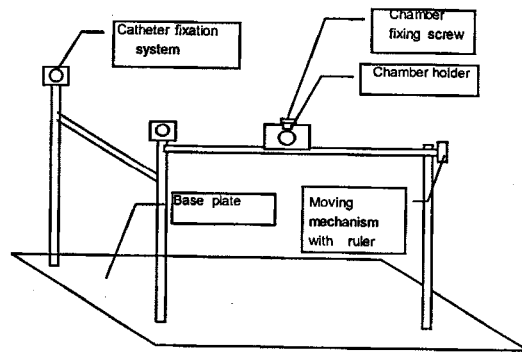


Figure 3. Phantom for in-air calibration

## RESULTS

Five teams from different oncology centres measured RAKR of the same Ir-192 source using their own methods and equipment.

Table I presents the results of comparative measurements. Large differences in the measured values of RAKR were obtained: the minimal value was 3.928 cGy<sup>2</sup>/h, the maximal was 4.308 cGy<sup>2</sup>/h. The value in the manufacturer's certificate is 3.976 cGy<sup>2</sup>/h. One value (4.308 cGy<sup>2</sup>/h) differs as much as +8.35% from the manufacturer's value and is completely unacceptable.

	RAKR [cGy *m <sup>2</sup> /h]	Measurement error [cGy *m <sup>2</sup> /h]	ΔX [%]
Manufacturer	3,976±5%	-	-
1	3,974	±0,021	-0,06
2	4,308	±0,026	+8,35
3	4,129	±0,023	+3,85
4	3,954	±0,079	-0,55
5	3,928	±0,055	-1,21

Table I. Results of the comparison measurements

The difference between the measured and manufacturer's value is given by:

$$\Delta X = \left( \frac{X_{meas}}{X_{man}} - 1 \right) \cdot 100\% \quad [4]$$

where:

$X_{meas}$  is the measured value,

$X_{man}$  is the manufacturer's value.

Table II shows the values which were and should be used for the calculations (wrong values are in italics and bold; in brackets below one will find correct values). Note that in three cases physicists were not quite sure what SSDL calibration factor they used (and this was

the cause of the largest error). A method to obtain an appropriate value of the SSDL a correction factor is described in (Goetsch at al., 1991). There were also doubts concerning source anisotropy (1 case), correction for scatter & attenuation in chamber walls and build-up cap

	1 in-water	2 in-water	3 in-water	4 in-air	5 in-air
SSDL calibration Factor	<i>Nx</i> (Co60)	<i>Nk</i> (?)	1.005*N (Co60)	<i>Nx</i> (?)	<i>Nx</i> (?)
Temperature & press $F_{pt}$	$1013/p \cdot (273.15+T)/293.15$	$1013/p \cdot (273.15+T)/293.15$	$1013/p \cdot (273.15+T)/293.15$	$1013/p \cdot (273.15+T)/293.15$	$1013/p \cdot (273.15+T)/293.15$
Source Anisotropy $F_{an}$	1.008	<b>1.008</b> (1)	1.008	1	1
Chamber walls Attenuation $A_w$	0.9916	0.9916	0.9916	<b>1.017</b> (0.9916)	<b>0.985</b> (0.9916)
Gradient Correction $P_r$	1.007	1.007	1.007	<b>1.004</b> (1.006)	<b>1</b> (1.003)
Source transport $F_{tr}$	-	-	-	-	-
Lack of Scattering $F_{pha}$	1	1	1	-	-
$F_{geo}$	$\frac{1}{n} \cdot \sum_i [d_i^2 \cdot s(d_i)^{-1}]$	<b><math>d^2 \cdot S(d)^{-1}</math></b>	$\frac{1}{n} \cdot \sum_i [d_i^2 \cdot s(d_i)^{-1}]$	$d^2$	$d^2$
CGy -> R $\frac{w \cdot 1}{e \cdot 1-g}$	<b>0.873</b> (0.877)	0.877	0.877	0.877	0.877
Room Scattering	-	-	-	<b>0.9975</b>	<b>1</b>
Other Corrections	1	1	1	1.005	1

Table II. Values which were and which should be used for RAKR calculations. Wrong values in bold and italic, ? means an uncertain quantity

(values for Co60 instead of that for Ir192 were used in 2 cases) and a replacement correction factor. In one case an, old value of Roentgen-to-rad conversion factor was used. The correct values were taken from the literature on the basis of a thorough description of the calibration procedure delivered by a certain team. Chamber and wall attenuation was taken from (Goetsch at al., 1991), gradient correction for in-water calibration from (Steggerda and Mijnheer, 1994), gradient correction for in-air calibration from (Kondo and Randolph, 1960), values of (W/e) and (1-g) from (IAEA, 1987). In the case of room scattering the values given by the teams cannot be correct, because the appropriate measurements were not performed.

Table III shows values of RAKR<sub>2</sub>, which would be obtained if correct values of CF<sub>i</sub> were used.

	RAKR <sub>1</sub> (reported) [cGy *m <sup>2</sup> /h]	Measurement error [cGy *m <sup>2</sup> /h]	RAKR <sub>2</sub> (corrected) [cGy *m <sup>2</sup> /h]	$\Delta R_{1,2}$ [%]	$\Delta X_2$ [%]
Mallinckrodt	3.976±5%	-	-	-	-
1	3.974	±0.021	3.992	+0.45	+0.40
2	4.308	±0.026	3.786	-12.12	-4.78
3	4.129	±0.023	4.129	0	+3.85
4	3.954	±0.079	3.863	-2.30	-2.84
5	3.928	±0.055	3.966	+0.97	-0.25

Table III. Corrected values of measured RAKR.

The difference between the corrected and manufacturer's value is given by:

$$\Delta X_2 = \left( \frac{X_{c.meas}}{X_{man}} - 1 \right) \cdot 100\% \quad [5]$$

where:

$X_{c.meas}$  is the corrected measured value and  
 $X_{man}$  is the manufacturer's value.

The difference between the measured value  $RAKR_1$  and corrected measured value  $RAKR_2$  is given by:

$$\Delta R_{1,2} = \left( \frac{RAKR_2}{RAKR_1} - 1 \right) \cdot 100\% \quad [6]$$

**DISCUSSION**

Taking into account all corrections mentioned above, we still have large differences in RAKR obtained by various teams. To find the reasons we analysed our own measurements we have performed for last 3 years with the use of the two methods. Figure 4 shows the results of in-water and figure 5 in-air calibration.

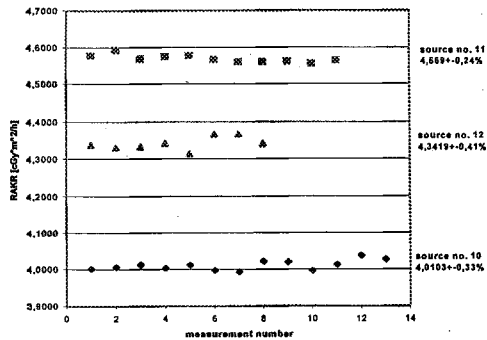


Figure 4. In-water calibration.

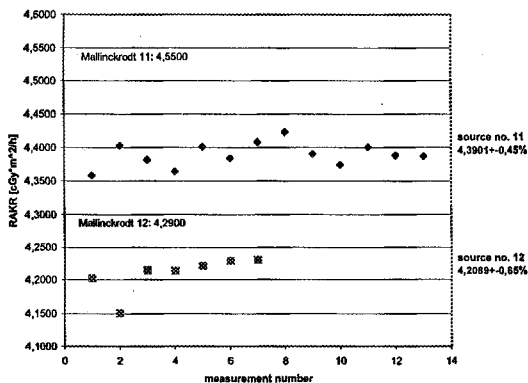


Figure 5. In-air calibration.

The results of in-water calibration are smoother (i.e. more repeatable) than those for in-air calibration. Also the difference between our

calibration and the manufacturer certificate is much smaller for in-water calibration (less than -0.5%) than for in-air calibration (-2.5% to -3.5%). The difference between the results obtained with the two methods is large. An average difference is defined as:

$$\left( \frac{RAKR_{inWater}}{RAKR_{inAir}} - 1 \right) \cdot 100\% , \text{ is } 3.6\% \text{ and}$$

shown in figure 6.

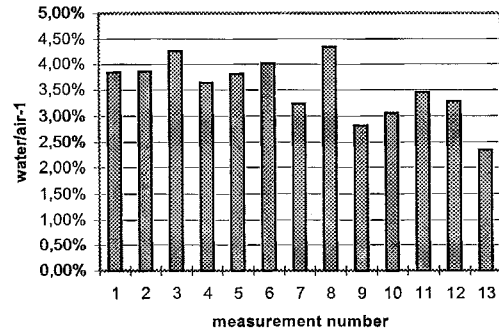


Figure 6. Difference between in-water and in-air calibration.

Note that the results obtained with the two methods should not differ at all, because the same source, as well as the same chamber and electrometer were used. To find the reason for the discrepancies we analysed some additional corrections in the methods.

1. A room scattering correction has to be taken into account in the case of in-air measurements. We found the correction factor using an interpolation method. The results of our measurements are presented in Figure 7. An average correction for room scatter is less than 0.9%, so that it does not explain the difference between in-air and in-water calibrations.
2. A medium correction is necessary in the case of in-water measurements. The replacement of water by a different type of medium (PMMA) around the chamber has to be taken into account. To find the correction value in our measurement geometry, we performed simple dose measurements in water, with different PMMA plates between the source and the chamber. Figure 8 presents the results of the measurements. The medium correction for our geometry is less than 0.6%, so it also cannot be the cause of the difference between in-air and in-water calibrations.

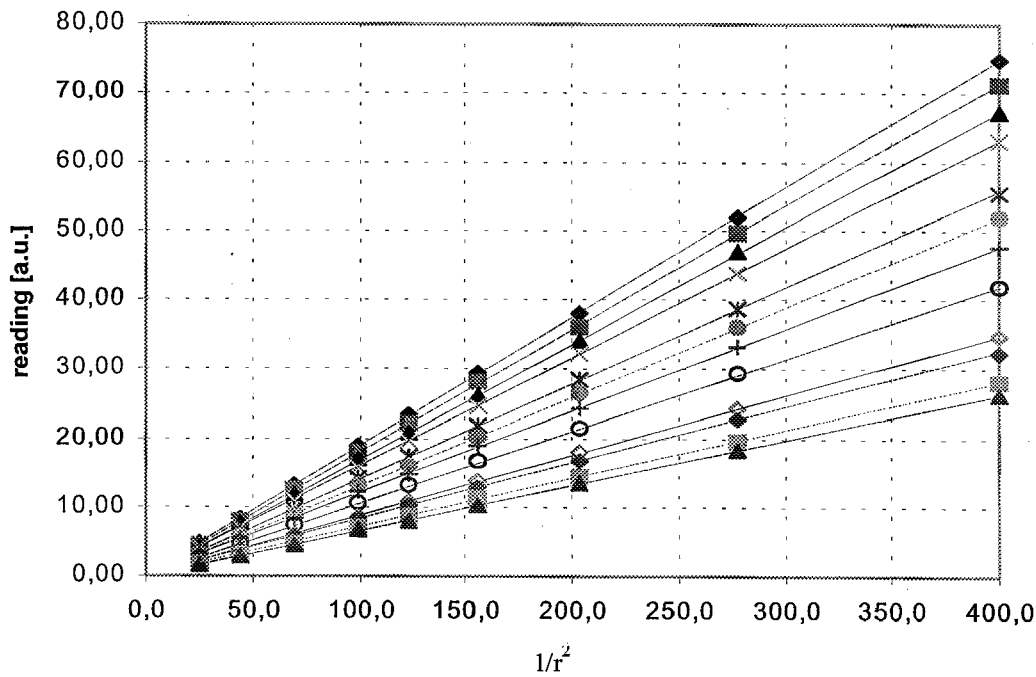


Figure 7. Room – scatter measurements.

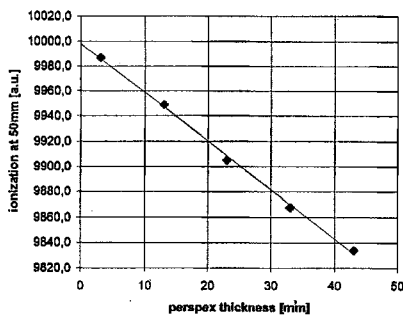


Figure 8. Ionization at 50 mm vs perspex thickness.

Another thing, which has to be considered, is the accuracy of calibration phantom geometry. In the case of water phantom, 0.1mm error in source-to-chamber distance was assumed on the basis of the manufacturer data. However, comparing average results of measurements in the different channels (figure 9) we see that the differences between the channels can be as large as 4%.

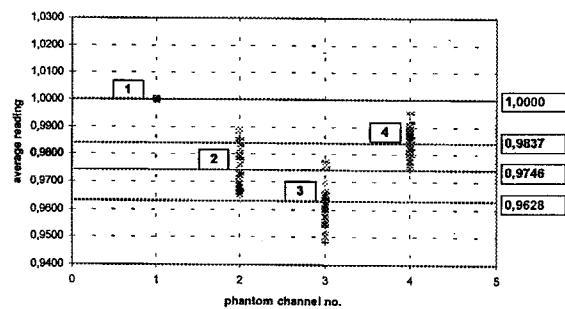


Figure 9. Average readings in phantom channels.

The only cause of these differences is the inaccuracy of the chamber-to-source distance. A 4% difference between the channel data results, on the basis of Meisberger polynomial, in about 1 mm difference in the real source-to-chamber distance. It means that in the case of our in-water calibration phantom the real source-to-chamber distance is  $50\text{mm} \pm 0.5\text{mm}$ . In the case of in-air measurements a 1.5mm in distance inaccuracy leads to a 3% difference in RAKR. This means that geometrical inaccuracy is the major origin of errors in the calibration methods discussed. It has to be emphasised that it is very difficult to avoid such uncertainties. In the case of a water phantom we have very thin, long catheter channel made of PMMA,

which can change its shape in water. In the air phantom the accuracy of the distance fixation between the chamber and flexible, thin catheter is about 1-2 mm. In the case of the water calibration method we could try to avoid the geometrical problem using a perspex solid phantom instead of water phantom. This would guarantee excellent geometry, however we know the radial function for water only. This means, that such a phantom is good only for relative measurements or the user has to perform at least one in-water calibration to obtain a correction factor. However, here we start with the same problem again.

## CONCLUSIONS

At present, the iridium source manufacturers determine the source strength with an uncertainty of  $\pm 5\%$ . It is recommended to have an in-house calibration performed by the user to improve the accuracy. However it is very difficult to improve it by in-air or in-water calibration because of geometrical inaccuracy. We cannot avoid the problems by performing very precise, time-consuming measurements, because the routine calibration method should be rather simple and fast in clinical practice. The method should also assure that such comparative measurements as described above would not result in larger differences than  $\pm 1\%$ . It seems that only a well chamber fulfills these conditions.

In summary we conclude that:

1. The geometrical uncertainties of self-made calibration phantoms do not make it possible to improve the manufacturer's certificate accuracy
2. Well chambers ought to be used for site calibration, because they assure excellent reproducibility, are easy and quick in use.
3. A national protocol for HDR Ir-192 source calibration is needed.

## ACKNOWLEDGEMENTS

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## REFERENCES

- AAPM, „Remote Afterloading Technology”, Report No. 41 (1993)
- British Institute of Radiology „Recommendations for brachytherapy Dosimetry”, (1992).
- Dove D B. Effect of Dosemeter Size on Measurements Close To a Radioactive Source. *Brit.J.Radiol.* 32 (375) 202-204.
- Ezzel G. Evaluation of Calibration Techniques for the microSelectron HDR System. *Brachytherapy.* 2 (1989) 61-70.
- Goetsch S J, Attix F H, Pearson D W, Thomadsen B R. Calibration of  $^{92}\text{Ir}$  high-dose-rate afterloading systems. *Med.Phys.* 18 (1991) 462-467
- IAEA, Absorbed dose determination in Photon and Electron Beams. TSR no.277, (1987)
- ICRU, Radiation Quantities and Units, Report 33 (1980)
- Jones C H. Calibration of the microSelectron HDR System. *Brachytherapy* 2 (1989) 75-83
- Kondo S, Randolph M L. Effect of Finite Size of Ionization Chambers on Measurements of Small Photon Sources. *Radiation Research.* 13 (1960) 37-60.
- Melsberger L L, Keller R J, Shalek R J. The Effective Attenuation in Water of the Gamma Rays of Gold 198, Iridium 192, Cesium 137, Radium 226, and Cobalt 60. *Radiology* 90 (1968) 953-957.
- Park H C, Almond P R. Evaluation of the buildup effect of an  $^{92}\text{Ir}$  high dose-rate brachytherapy source. *Med.Phys.* 19 (1992) 1293-1297.
- Spiers F W. Invers square law errors in gamma-ray dose measurements. *Brit.J.Radiol.* 14 (1941) 147-156.
- Steggerda M J, Mijnheer B J. Replacement corrections of a Farmer-type ionization chamber for the calibration of  $^{37}\text{Cs}$  and  $^{92}\text{Ir}$  sources in a solid phantom. *Radiother. and Oncol.* 31 (1994) 76-84.
- Thomason C, Mackie T R, Lindstrom M J. Effect of source encapsulation on energy spectra of  $^{92}\text{Ir}$  and  $^{37}\text{Cs}$  gamma-rays. *Phys.Med.Biol.* 4 (1991) 495-505.
- Van Kleffens H J, Star W M. Application of stereo-X-ray photogrammetry (SRM) in the determination of absorbed dose values during intracavitary radiation therapy. *Int.J.Radiation Oncol. Biol. Phys.* 5 (1979) 557-563.
- Venselaar J L M, Brouwer W F M, van Straaten B H M., Aalbers A H L. Intercomparison of calibration procedures for Ir-192 HDR sources in The Netherlands and Belgium. *Radiother. and Oncol.* 30 (1994) 155-161.