High dose rate $^{192}$Ir source calibration: A single institution experience

R Abdullah$^1$, N H Abdullah$^1$, M Mohamed$^{2,3}$, N R N Idris$^{2,3}$, A L Yusoff$^{2,3}$, S C Chen$^1$, and A Zakaria$^1$

$^1$School of Health Sciences, Health Campus USM, Universiti Sains Malaysia, Kelantan, Malaysia
$^2$Department of Nuclear Medicine, Radiotherapy and Oncology, School of Medical Sciences, Health Campus USM, Universiti Sains Malaysia, Kelantan, Malaysia
$^3$Department of Nuclear Medicine, Radiotherapy and Oncology, Hospital Universiti Sains Malaysia, Kelantan, Malaysia.

E-mail: reduan@usm.my

Abstract. Measurement of source strength of new high dose rate (HDR) $^{192}$Ir supplied by the manufacturer is part of quality assurance recommended by Radiation Safety Section, Ministry of Health of Malaysia. The source strength is determined in reference air kerma rate (RAKR). The purpose of this study was to evaluate RAKR measurement of $^{192}$Ir using well-type ionisation chamber with RAKR stated in the certificate provided by the manufacturer. A retrospective study on 19 MicroSelectron HDR $^{192}$Ir Classic from 2001 to 2009 and 12 MicroSelectron HDR $^{192}$Ir V2 sources from 2009 to 2016 supplied by manufacturer were compared. From the study, the agreement between measured RAKR and RAKR stated in the certificate by manufacturer for all 32 sources supplied were within $\pm$2.5%. As a conclusion, a threshold level of $\pm$2.5% can be used as suitable indicator to spot problems of the brachytherapy system in Department of Nuclear Medicine Radiotherapy and Oncology, Hospital USM.

1. Introduction

HDR brachytherapy is an adjuvant treatment to the external beam radiotherapy (EBRT) in treating many types of cancer such as cervical cancer, endometrial cancer, breast cancer, prostate cancer, and bone sarcoma. Nowadays, $^{192}$Ir source has become the most commonly used high dose rate (HDR) brachytherapy source. It has high specific activity; thus, a very small volume is needed to deliver a very high dose. Smaller volume of $^{192}$Ir source can easily travel through curvature anatomy of human body for example through intracavity, intraluminary, and interstitial. The only disadvantage of $^{192}$Ir is that it has a short half-life of 73.83 days, requiring relatively frequent source replacement after 4 to 5 months to maintain short treatment times [1]. Thus, Department of Nuclear Medicine, Radiotherapy and Oncology, Hospital USM needs to spend about USD 30,000 to USD 50,000 per year to purchase the $^{192}$Ir sources and this cost is increasing year by year.

Our department needs to get approval from the Radiation Safety Section of Ministry of Health to purchase the new source. After getting the approval, the department can make an order from a local vendor with a license to do sales operation to bring in the source from the manufacturer’s country. The license is endorsed by the Atomic Energy Licensing Board as local authorised agency that controls...
any activities involved with radiation. After the source arrived at the national airport, the local vendor must assign a transportation company with a license to conduct transportation operation relating to radioactive source to transport the source to the department. The same company will transport back the old source to the manufacturer’s country. At the department, the trained engineer from the local vendor company will carry out the exchange process by retracting the old source into the Dual Channel Transport Container (Nucletron, Mallinckrodt Medical B.V., Netherland) and transfer the new source from the container into the brachytherapy treatment unit. Each new \(^{192}\text{Ir}\) source delivered for exchange comes with a certificate which the manufacturer states its strength. The source strength is determined in reference air kerma rate (RAKR). All the procedures are supervised by our physicist based on a guideline prescribed by national authority, followed to ensure the safety of public, worker, and environment, and also security of radioactive material. Currently, there are 13 centres using the same brand of brachytherapy treatment unit manufactured by Mallinckrodt Medical (Netherlands) and \(^{192}\text{Ir}\) source in this country.

Independent verification as well as exact measurement of source strength is quite significant to assure the quality of brachytherapy treatment [2]. As part of quality assurance programme for brachytherapy system in our department, the RAKR of a new source delivered by the vendor needs to be verified. Well-type ionisation chambers are preferred for routine calibration of HDR \(^{192}\text{Ir}\) source because of its ease, precision in use, fastness and reproducibility of source positioning [1-3]. The well-type ionisation chambers have been specifically designed for calibration of HDR sources. The advantages of using these chambers are that they can minimise uncertainties from wall scattering effect, room humidity, and transit dose effect. The source was programmed to enter the chamber and dwell at the maximum response dwell position of the chamber. This point was determined by varying in small steps of the source position in the central axis from the top to the bottom defining a small plateau and selecting most representative values [4].

Measured RAKR values were calculated and compared with values specified by manufacturer. The American Association of Physicists in Medicine (AAPM) report No. 40, gave an option of using either the manufacturer’s stated RAKR or the user’s measured activity if they were within a \(\pm 3\%\) agreement [5]. Nevertheless, the latest AAPM report No. 56 recommended that a calibration is performed by qualified medical physicist as a part of quality assurance programme and that the user calibration be used as the basis for treatment planning and prescription [5-6].

2. Material and methods

The retrospective study was carried out on 19 Microselectron HDR \(^{192}\text{Ir}\) Classic sources from 2001 to 2009 and 13 MicroSelectron HDR \(^{192}\text{Ir}\) V2 sources from 2009 to 2016. The study was conducted to assess the accuracy of HDR \(^{192}\text{Ir}\) supplied by manufacturer to our department.

2.1. *Reference Air Kerma Rate (RAKR) measurement of MicroSelectron HDR \(^{192}\text{Ir}\) Classic Source*

A MicroSelectron HDR Classic brachytherapy machine (Nucletron, Mallinckrodt Medical B.V., Netherland) was installed at our department on 3rd of August 1999. The first MicroSelectron \(^{192}\text{Ir}\) HDR Classic source (Nucletron, Mallinckrodt Medical B.V., Netherland) was installed into the machine on 5th May 1999. The source was encapsulated by stainless steel, AISI 316L. This miniature source has dimensions of 1.5 mm diameter and 5.0 mm length and source pellet dimensions of 0.6 mm diameter and 3.5 mm length. The first clinical case of cervical cancer patient was done on 22nd July 1999.

For the first five \(^{192}\text{Ir}\) sources, RAKR stated on the certificate were used to be entered into Plato treatment planning system (TPS) version 14.1 (Nucleteron, Netherlands) and into treatment console system (TCS). In July 2001, the department received the sixth MicroSelectron \(^{192}\text{Ir}\) HDR Classic source and our physicist performed RAKR measurement. The HDR 1000 Plus well-type ionisation chamber (Standard Imaging, USA), calibrated at the Accredited Dosimetry Calibration Laboratory of the University of Wisconsin (ADCL-UW) was used to measure RAKR. The well-type chamber was connected to the Max-4000 electrometer (Standard Imaging, USA) outside the treatment room through
a connection cable. Blunt side of the blue endobronchial catheter was inserted through the top of well-type ionisation chamber while open end of the catheter was connected through the gynaecological transferring tube which was then connected to the first indexer of treatment unit. The source was programmed to be at the most sensitive position of the well chamber. Production of ion pair (negative and positive charges) occurred when photon was interacted with argon gas molecule inside the well chamber. Next, the charges were collected and recorded. Temperature and pressure of the treatment room were recorded after the measurement procedure. RAKR value was calculated using Equation (1). After the measured RAKR was determined, the value needs to be compared using Equation (2)

\[
RAKR = A \times N_k \times K_{TP} \times A_{ion} \quad (1)
\]

\[
D (\%) = \left( \frac{(M - C)}{C} \right) \times 100\% \quad (2)
\]

RAKR is the reference air kerma or air kerma source strength of \(^{192}\text{Ir}\), \(\text{A}\) is the current, \(N_k\) is air kerma strength calibration factor of well-type ionisation chamber in mGy\(^{-1}\)h\(^{-1}\) at 1 m\(^2\), \(K_{TP}\) is temperature and pressure correction coefficient, \(A_{ion}\) is charge collection efficiency correction at the time of measurement, \(D\) is percentage deviation in \(\%\), \(M\) is measured RAKR in mGy\(\text{h}^{-1}\) at 1 m\(^2\) and \(C\) is certificate-stated RAKR in mGy\(\text{h}^{-1}\) at 1 m\(^2\) (the value needs to re-calculated to consider the decay or source strength from the time source manufactured to the time of measurement done)

2.2. Reference Air Kerma Rate (RAKR) measurement of MicroSelectron HDR \(^{192}\text{Ir} \ V2\ Source

In May 2009, a MicroSelectron HDR V3 brachytherapy machine (Nucletron, Mallinkrodt Medical B.V., Netherlands) was installed to replace the MicroSelectron HDR Classic treatment unit (Nucletron, Mallinkrodt Medical B.V., Netherlands). In the last 10 years of using the old treatment unit, 282 patients were treated.

For the new treatment unit, the new source needs to suit with the new machine. The first MicroSelectron \(^{192}\text{Ir} \ V2\ source (Nucletron, Mallinkrodt Medical B.V., Netherlands) was installed into the machine on 18th May 2009. Smaller source was encapsulated compared to the older source with dimensions of 0.9 mm diameter and 4.5 mm length and source pellet dimensions of 0.6 mm diameter and 3.5 mm length. The new treatment unit came with new set of quality assurance tools including a well-type ionisation chamber (HDR Chamber Type 3304) and an electrometer (Unidose E). These tools are manufactured by PTW, Germany. The procedures in measuring RAKR for the new source were slightly different compared to the older treatment unit. HDR Chamber Type 3304 is specially designed for brachytherapy calibration and measuring the RAKR of HDR sources. One end of the gynaecological transfer tube was connected to source holder that was kept inside the well of the chamber and the other end of the transfer tube connected to the first indexer of treatment unit. Unidose E electrometer was switched to the charge mode and high range was selected. From our experience with the system, the most sensitive dwell position was at position 22 with 138.8 cm, which was measured earlier using the source simulator ruler. The source was programmed to dwell in this position for 600 s. The charge was collected at a 60 s interval and two readings were taken each for + 400 V, - 400 V, + 200 V and - 200 V. At this maximum response of dwell position, the chamber charge is maximised and uncertain in the RAKR determination, due to minimised positional variations [1]. Temperature and pressure of the brachytherapy treatment room were recorded after measurement was done. The RAKR value stated on the certificate was corrected backwards for initial source decay and was compared with measured values. All these data were recorded and was entered into the Excel spreadsheet provided in the department based on Equations 1 and 2.

3. Results and Discussion

As part of quality assurance (QA) based on AAPM recommendations, the source calibration or RAKR measurements were carried out every time the HDR \(^{192}\text{Ir}\) source was exchanged. Based on this retrospective study, Table 1 shows that the percentage difference between measured RAKR and
RAKR stated in the certificate provided by manufacturer of MicroSelectron HDR $^{192}$Ir Classic source ranges from - 2.50% to 1.60%. Among 19 measured RAKR of the HDR source, it can be observed that 9 sources have a deviation more than 1% and all other 10 sources have a deviation within ±1%. Meanwhile for MicroSelectron HDR $^{192}$Ir V2 source as tabulated in Table 2, the percentage difference between measured RAKR and RAKR stated in the certificate provided by manufacturer’s values ranges from - 1.77% to 1.69%. Only 3 sources out of 12 sources that have been measured of RAKR have deviations more than 1%. From the study, all deviations were within the tolerance limits stated by national authority and international recommendations, which is ±3%.

Table 1. Measured RAKR, RAKR stated in the certificate, and respective percentage differences of MicroSelectron HDR $^{192}$Ir Classic source.

| No. | Source no. | Measurement date | Stated RAKR (corrected for decay) $\text{mGy m}^{-2} \text{h}^{-1}$ | Measured RAKR using well type ionisation chamber $\text{mGy m}^{-2} \text{h}^{-1}$ | Percentage difference (%) |
|-----|------------|------------------|-------------------------------------------------|-------------------------------------------------|--------------------------|
| 1   | D35Q-568   | *                | *                                               | *                                               | *                        |
| 2   | D35S-154   | *                | *                                               | *                                               | *                        |
| 3   | D35S-772   | *                | *                                               | *                                               | *                        |
| 4   | D35T-446   | *                | *                                               | *                                               | *                        |
| 5   | D35U-365   | *                | *                                               | *                                               | *                        |
| 6   | D35V-003   | 7/19/2001        | 43.352                                          | 43.786                                          | 1.00                     |
| 7   | D35V-736   | 11/27/2001       | 43.030                                          | 42.518                                          | - 1.19                  |
| 8   | D35W-992   | 7/17/2001        | 46.043                                          | 45.440                                          | - 1.31                  |
| 9   | D35Y-270   | 2/24/2003        | 40.210                                          | 39.981                                          | - 0.57                  |
| 10  | D35Z-024   | 6/28/2003        | 38.620                                          | 39.238                                          | 1.60                     |
| 11  | D35Z-307   | 9/7/2003         | 43.779                                          | 43.061                                          | - 1.64                  |
| 12  | D35A0149   | 6/30/2004        | 45.497                                          | 44.360                                          | - 2.50                  |
| 13  | D35A1495   | 3/3/2004         | 40.211                                          | 39.660                                          | - 1.37                  |
| 14  | D35A1720   | 9/26/2004        | 42.937                                          | 42.559                                          | - 0.88                  |
| 15  | D35A1951   | 1/10/2005        | 36.722                                          | 37.053                                          | 0.90                     |
| 16  | D35A2995   | 6/28/2005        | 44.477                                          | 43.350                                          | - 2.31                  |
| 17  | D35A3585   | 12/28/2005       | 38.580                                          | 38.900                                          | 0.83                     |
| 18  | D35A4298   | 7/31/2006        | 43.532                                          | 43.793                                          | 0.60                     |
| 19  | D35A4853   | 12/26/2006       | 40.340                                          | 40.090                                          | - 0.62                  |
| 20  | D35A5510   | 8/28/2007        | 30.663                                          | 30.326                                          | - 1.10                  |
| 21  | D35A5680   | 1/1/2008         | 39.110                                          | 39.094                                          | - 0.04                  |
| 22  | D35A6231   | 6/10/2008        | 44.797                                          | 44.389                                          | - 0.91                  |
| 23  | D35A6823   | 11/30/2008       | 46.366                                          | 45.930                                          | - 0.94                  |
| 24  | D35A7141   | 3/22/2009        | 36.215                                          | 36.070                                          | - 0.40                  |

*RAKR was not measured; RAKR stated on certificate was used.

The associated uncertainty with a source certificate calibration is ±5% for $^{192}$Ir source based on measurement done for initial RAKR and the uncertainty in well-type chamber calibration recommended by national and international bodies is ±3%. The well-type chamber uncertainty may be smaller than the source certificate but if an error were to occur with the departmental ionisation chamber calibration, the extent of the error would be far greater than error on an individual source calibration. This is due to the length of time that an ionisation chamber is used in a departmental before re-calibration, with ionisation chamber calibrations to be performed every 2 years [7]. In Malaysia, only the Nuclear Agency provides the service, or another option is to send it to other calibration centres in Europe to re-calibrate the chamber, which will be very costly.
Table 2. Measured RAKR, RAKR stated in the certificate, and respective percentage differences of MicroSelectron HDR $^{192}$Ir V2 source.

| No. | Source no. | Measurement date | Stated RAKR (corrected for decay) mGy m$^{-1}$h$^{-1}$ | Measured RAKR using well type ionisation chamber mGy m$^{-1}$h$^{-1}$ | Percentage difference (%) |
|-----|------------|------------------|------------------------------------------------------|---------------------------------------------------------------|----------------------------|
| 1   | D36B9249   | 7/20/2009        | 25.78                                                | 25.92                                                         | 0.55                       |
| 2   | D36C2132   | 2/4/2010         | 38.46                                                | 38.20                                                         | - 0.68                     |
| 3   | D36C4659   |                  | *                                                    | *                                                             | *                          |
| 4   | D36C6751   | 2/14/2011        | 48.68                                                | 48.35                                                         | - 0.68                     |
| 5   | D36C9646   | 10/10/2011       | 42.61                                                | 42.40                                                         | - 0.50                     |
| 6   | D36E1350   | 3/22/2012        | 42.40                                                | 42.40                                                         | 0.01                       |
| 7   | D36E4036   | 10/15/2012       | 37.73                                                | 37.65                                                         | - 0.22                     |
| 8   | D36E7071   | 5/8/2013         | 41.44                                                | 41.62                                                         | 0.43                       |
| 9   | D36F0151   | 1/28/2014        | 37.30                                                | 37.93                                                         | 1.69                       |
| 10  | D36P1156   | 6/18/2014        | 42.65                                                | 42.44                                                         | - 0.50                     |
| 11  | D36F4122   | 1/7/2015         | 42.77                                                | 42.40                                                         | - 0.86                     |
| 12  | D36F6233   | 4/26/2016        | 3.510                                                | 3.448                                                         | - 1.77                     |
| 13  | D36G0541   | 7/14/2016        | 39.65                                                | 39.16                                                         | - 1.23                     |

*RAKR was not measured; RAKR stated on certificate was used

Measuring the RAKR using well-type ionisation chamber is easier, faster and straightforward. If an institution determines the ratio of RAKR with manufacturer’s values and it differs more than 3%, that institution should review the data for calculations and measurements [8]. Nevertheless, the consideration due to positional uncertainty and source transit effect requires attention during the measurement. In order to minimise the positional uncertainty, the chamber should be placed at the same position for every exchange source procedures. Moreover, based on the contribution of scattered radiation from room’s wall, the chamber should be placed at the centre between two walls and above the floor (at least 1 m away or height from any wall or floor). Moreover, the chamber should be kept energised at the corner of the treatment room and should maintain overnight a day before the measurement was carried to attain thermal equilibrium and electronic stabilisation. Besides that, instead of using charge mode, the current mode was recommended to avoid extraneous current generated in chamber during source transit [9].

4. Conclusion

Radiation Safety Section under Ministry of Health as national authority stated that RAKR measurement should be carried out every time the source exchanges. The tolerance deviation between measured RAKR and RAKR stated in the certificate is ±3% [10]. From this retrospective study, the percentage difference between measured and stated RAKR values of 32 sources of brachytherapy $^{192}$Ir sources is within limit ±3%. As a conclusion, the percentage difference of RAKR ≤2.5% can be achieved between measured and certificate stated values. The ±2.5% of deviation is suitable to be a threshold level practiced as department standard procedure, as an indicator to spot any problems in calibrating HDR $^{192}$Ir source. It has been a standard operation procedure in our department to evaluate the HDR $^{192}$Ir source calibration supplied by the vendor prior to clinical use. Based on department experiences, either manufacturer’s stated RAKR or measured RAKR may be used in our TPS and TCS since the deviations are less than ±3%. In order to improve the brachytherapy treatment accuracy, it is strongly recommended that physicists should carry out RAKR measurement at the time of source replacement.
5. References

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