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Retrospective Analysis of Treatment Time Calculation Agreement Between TPS And Manual Method and Source Strength Verification For 13 HDR Ir-192 Sources in Flexitron Brachytherapy Unit: A Single Institute Experience.

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Abstract

Introduction: Source strength measurement and verification during every source exchange in high dose rate (HDR) Brachytherapy ^{192}Ir is primary part of quality assurance program as recommended by national regulatory body Atomic Energy Regulatory Board, Mumbai, India. The purpose of this study was to evaluate RAKR (in-house measurement) of ^{192}Ir using re-entrant well-type ionization chamber with stated RAKR values as provided by the manufacturer in source certificate and to check the accuracy of the Oncentra treatment planning system calculation with manual method of computation at different intervals for 13 HDR Ir-192 sources.

Materials And Methods: We have retrospectively evaluate the in-house measured RAKR with the calibrated Standard Imaging HDR 1000 PLUS Well chamber /electrometer CDX 2000B for 13 HDR Ir^{192} sources with stated RAKR and the treatment time calculation accuracy of Oncentra TPS verified by manual method of computation using TG-43 formalism.

Results: The study shows, that the measured RAKR and stated RAKR were well within the tolerance limits set by the national and international recommendations i.e. ±3 % for 13 HDR Ir^{192} sources. The verification of TPS treatment time calculation with manual calculation for single source as well as for multi-source lies within ±2%.

Conclusions: There is good agreement between in-house measured and vendor quoted values of RAKR which shows that the chamber has been stable to better than ±3 % and manual calculations shows agreement with the TPS outcome within ±2% for 13 HDR Ir^{192} sources. The manual method of computation works reliably and reassures the TPS functioning.

Keywords: Brachytherapy,Documentation,Iridium-192.

Introduction

In the field of Radiation Oncology, Brachytherapy is rapidly growing modality to deliver radiotherapy with heterogeneous dose distribution to well-defined tumours of different accessible sites either alone or in conjunction with teletherapy. With rapid changes in the era of technology the brachytherapy planning has also evolved from the traditional model to modern three-dimensional (3D) treatment planning systems (TPSs) and better dose delivery **[1].** Small encapsulated radioactive sources or miniature x-ray sources used to deliver brachytherapy treatment are placed within or in the close proximity of the target **[2]**. The most commonly used radioactive source for brachytherapy is Ir-192 apart from other popular radioactive sources like Cs-137, Co-60 etc**. [3]**. The technological advancements focussed on precise radiation delivery, dose calculation and on recommendations for quality assurance **[2]** of radiation delivery equipment and planning systems. Various periodic quality assurance tests are designed to confirm the quality and performance of the whole treatment system is within the specified acceptable limits **[4]** and to ensure the Radiological fortification of the staff and health of the patient. Documentation of QA procedures play key role to achieve the error-free, consistent, and efficient treatment delivery. **[5]**. QA is a never ending process as it relates to quality of treatment. So, it is very important to maintain a QA programme for complete functional life span of the unit to reduce any consequential error in patient dose **[6]**. To specify the source strength, air-kerma strength (AKS) in the U.S. and reference air-kerma rate (RAKR) in Europe, are being used for the gamma emitting brachytherapy source**. [7]** The quantity air kerma strength is calculated at a distance where the source resembles a point source. An appropriate ionisation chamber with valid calibration traceable to NSDL is used to measure the RAKR and AKS**. [8,9]** American Association of Physicists in Medicine (AAPM) recommends the quantity air kerma strength S_k for specification of source strength. The definition of Air Kerma Strength (AKS) as provided by the AAPM is "the product of air kerma rate in free space and the square of the distance of the calibration point from the source centre along the perpendicular bisector." The unit recommended by AAPM for the source strength (AKS) is $\mu Gym^2/h$. The International Commission on Radiation Units (ICRU) Report 38, 58 (ICRU 1985,1997) defined the RAKR as an emission specification quantity. RAKR is the kerma rate to air, in air, at a reference distance of 1 meter, corrected for air attenuation and scattering. As per the Report of High Energy Brachytherapy Source Dosimetry Working Group the AKS or RAKR shall be used to measure source strength of high energy brachytherapy sources **[10].**

Both the recommended quantities i.e. AKS and RAKR are identical in their numerical values because the ref distance for measurement is 1m and differ only in the units in which the source strength is expressed, as these quantities are mutually related to each other by inverse square law to the reference distance.[11] In the modern era, Treatment Planning System (TPS) is the heart of the radiation therapy planning process, it consists of a computer, input and output devices, and software as the main component. The working and quality of any TPS is reliant on the type of algorithms used in the different steps of the planning process.

An algorithm is the formula for solving a problem based on sequence of specified instructions. During QA test of the TPS performance the treatment time calculation accuracy of the treatment planning system shall be checked by using an alternative method of computation such as manual method. **[6,12].** The dosimetric uncertainties linked to source calibration, time calculation and treatment delivery remains unchanged even after the technological advancements from 2-D HDR to 3-D HDR **[13].** QA of the TPS is the responsibility of the Medical Physicist of the department. **[6].** As per the recommendations of Technical Report Series (TRS) 430 **[6]** in this paper, we verified and compared the treatment time calculations of planning system with manual calculations using AAPM Task Group Report No.-43 (TG-43) formalism.

TG-43 Formalism: The dose calculation formalism named TG 43 was introduced by AAPM in 1995 **[14],** the dose rate from a point source can be presented as:

$\dot{D}(r, \theta) = S_k\, \Lambda\, [G(r, \theta)/ G(r_0, \theta_0)]\, g(r)\, F(r, \theta)$

where

S_k - Air Kerma Strength ($\mu Gy \cdot m^2 \cdot h^{-1}$)

Λ - Dose Rate Constant

$G(r, \theta)$ - Geometry Function

$g(r)$ - Radial dose function

$F(r, \theta)$ - Anisotropy Function

r, θ - Polar coordinates for the dose calculation point

r_0, θ_0 – Reference point co-ordinates along the transverse bisector of the source at a distance of 1 cm from brachytherapy source.

Calculation of Source Strength (RAKR):

RAKR (mGy/h at 1 m) = $MR \times N_{RAKR} \times K_{ion} \times K_{TP} \times K_{Pol}$

Where

MR : The average of Meter Reading in nA, corrected for the leakage current of the electrometer.

N_{RAKR} : The calibration factor of the ionization chamber provided by the NSDL, (expressed in $Gy.h^{-1}.A^{-1}$ at 1 m) at a reference temperature and pressure condition (20° C and 1013.2 mbar, respectively).

Kion: The correction factor for the ion recombination **[15]**

K_{TP}:Temperature and Pressure correction factor or air density, **[15]**

K_{pol} : the correction factor for polarization effect of the ionization chamber . **[15]**

Material and Methods

At our institute the HDR brachytherapy unit named Flexitron (Nucletron, Mallinckrodt Medical B.V., The Netherland originally from Isodose Control now known as Elekta Medical Systems) having a maximum source capacity of 12 Ci (442GBq) for Iridium-192 was installed/commissioned and was first used for patient treatment on 28.07.2011. Frequent source replacement after every 4–5 months requires for Ir-192 source due to its short half-life (73.84-74days) **[16-17].** In brachytherapy the accurate execution of planned dose depends upon several factors such as properly calibrated dose measuring equipment, measurement set up, agreement between TPS and manual treatment time calculation, the methodology adopted to measure the RAKR and correct entry of source specific data into TPS. Brachytherapy sources can be calibrated with number of methods **[11]** provided, they all have direct traceability to PSL. The calibration methods are; in-air measurement technique with ionisation chamber (e.g., 0.6 cc farmer type chamber) , well type (re-entrant type) ionisation chamber and use of dedicated solid phantom in which sources and ion chamber can be used in most suitable way to maintain the reproducible geometry **[11,18]**. Recommended and frequently used method for source strength measurement is a calibrated well type ionization chamber, which is also an easy, reliable and reproducible method **[11,19-20]**.

The Standard Imaging Dosimetry System consists of vented well-type ionization chamber, electrometer, co-axial cable, and source holder specially designed for calibration of the Iridium 192 source as shown in **figure 1**. Source calibration measurement was performed using calibrated HDR 1000 PLUS Well chamber (Ref No 90008) /electrometer CDX2000B (Ref No 90001) from Standard Imaging, USA. The chamber is specially designed for calibration of HDR Iridium brachytherapy sources and is meant for measuring the RAKR. The calibration factor of the dosimetry system is traceable to National Standard Dosimetry Laboratory (NSDL), Radiation Standards Section, BARC, Mumbai. The national regulation recommends calibration once in 3 years and the same is followed at our institute. Detailed specifications of the HDR Well Chamber are listed in **Table 1**. The calibration factor provided by NSDL has a standard uncertainty of ±3% at the confidence level of 95%. The manufacturer's certificate states the value of RAKR in mGy per hour at 1 m with an expanded uncertainty of ±5% at the confidence level of 99.7%.

The HDR Ir-192 Flexi Source is enclosed in a single layer of stainless steel supplied by Curium Netherlands. This miniature source has capsule dimensions of 0.86 mm diameter, 4.6 mm. The source specifications of Flexi Ir-192 HDR source are given in **Table 2**. The well-type ionization chamber and the dedicated source holder used for source positioning as shown in **figure 2**. The source holder is placed inside the chamber, it defines the path for source along the axis of cylindrical measuring volume for highly reproducible measurements. **[21]** The retrospective comparison of the specified and measured source strength of 13 Flexi Ir192 sources is covered under the first part of the study.

After every source replacement in the Flexitron HDR afterloading system, the estimation of RAKR as primary QA with the help of calibrated chamber that has been described by several authors. As recommended, we have used vented well type ionization chamber. **[14,22]** The HDR 1000 plus chamber was placed in the brachytherapy room one hour before the measurements for thermal equilibrium and electronic stabilization. The chamber was connected to electrometer, a bias voltage of +300 V was applied to the chamber as recommended by NSDL, and the dosimetry system was stabilized by warm-up time of 20 min. To nullify the scatter contribution in chamber current, the well chamber was placed on the treatment table and at a minimum distance of 1 m from the floor and 1.5 m from walls of the brachytherapy room. One end of the transfer tube was connected to the channel one of the Flexitron HDR unit and other end was connected to flexible catheter inserted into the source holder in the well type ion chamber, as shown in **figure 3** measuring set-up. Dosimeter was setup in current mode and high range. On execution of treatment, maximum response position (maximum current reading in one dwell position) of chamber was obtained. As per the dosimeter's manufacturer and our institutional experience the most sensitive spot of 1000 plus Chamber is between 50 and 53 mm from the bottom of the chamber and the dwell position can be easily estimated by knowing the length of flexible catheter used for measurement. The verification treatment was programmed and executed to dwell on maximum response position for 120 sec. The chamber sensitivity varies when the source is moved up or down from most sensitive spot. Three measurements were taken and tabulated for same setup. The average reading of the current in nA has been used to calculate the RAKR of HDR source with the help of equation as mentioned above. The Treatment Room temperature (T) and pressure (P) were recorded before and after measurement. The manufacturer's RAKR values were corrected with decay correction and were compared with measured values.

The second part of the study was to check the consistency in TPS treatment time calculations by comparing with independent method of calculation (manual). The point source consideration of a brachytherapy source is an easiest approach to calculate the dose from brachytherapy source. The source can considered as a point source if the distance of the point of measurement is at least two times of the active length of the source. HDR source Ir-192 is an extensively used source in brachytherapy with active length less than 5 mm, so minimum distance of 10 mm can considered for dose verification. **[23]**. For single source calculation, consider a single source in straight catheter as shown in **figure 4**. The dose rate, calculated at point of measurement i.e. at 1 cm from the centre of the source along the transverse axis, by using TG-43 formalism as stated above. Dose prescribed at the point of measurement was 1000 cGy and manually calculated treatment time was compared with treatment time calculated by Oncentra Brachytherapy treatment planning system for the same setup. Similarly for multiple source verification we considered a single straight catheter with three source positions as shown in **figure 5**. Distance between two consecutive sources is 1 cm and the point of measurement is 1 cm along the transverse axis of the central source. The prescribed dose is 1000 cGy. The dose rates from individual source contributed to the point of prescription were calculated separately, and then the total dose rate to the point of interest was calculated by summing up the individual dose rate. The treatment time calculated with TPS was compared with treatment time calculated manually. **Table 3** shows the calculation of the angle between longitudinal axis of the source and radius between source and prescription point.

Results

AAPM's report 41 recommends to verify the source strength every time the HDR 192Ir source is exchanged/replaced. AAPM Task Group 40 and Report 56 recommend that locally measured source strength should be used for clinical calculations and qualified Medical Physicist should measure the same. Most sensitive spot of the chamber was investigated every time and same corresponds with that given by the manufacturer. From our study the maximum sensitive position was 51 mm from the bottom of the chamber. **Table 4** demonstrates the percentage variation in RAKR of quoted and measured values. The variation in RAKR among 13 brachytherapy sources ranges between -1.66 % to +1.74 %. Deviations in source strength verification for 13 sources are within the stated acceptable limits by national regulatory body and also as per international recommendations. Variation in manual and TPS calculation verification for single source ranges between -0.73 % to +1.36 % as shown in **Table 5** similarly range for multi-source verification the variation is -1.08 % to +0.906 % as presented in **Table 6**. Deviations between manual and TPS for both single and multi- source treatment time calculation lies within ± 2 %.

Discussion

During Brachytherapy treatment planning and execution errors can appear and these may have different origin. In order to avoid serious errors and their consequences a QA/QC programs should be designed carefully to develop safety culture. The most common factors with real examples that cause radiation hazards to patient as well as to staff are well elaborated in IAEA's Safety Report Series No 17 "Lessons learned from accidental exposures in radiotherapy" and in the ICRP Publication 97 "Prevention of High-dose-rate Brachytherapy Accidents" . The lack of training of involved personnel and lack of double check procedures cause major accidents in radiotherapy **[24-25]**. Several methods have been recommended in the literature to verify a number of factors in a practical way to promote the safety culture in radiation oncology. Source strength verification as RAKR and periodic check of the time calculation accuracy of TPS with manual computation method by TG 43 formalism gives the confidence and accuracy in Brachytherapy Treatment system. R Abdullah et al , High retrospectively reviewed source calibration data of high dose rate 192Ir as a single institution Experience and found the percentage variation between sated and measured RAKR values are within ± 3 % and recommended to reduce the limit to ± 2.5 % **[26]**. Our study also shows the deviation between stated and measured RAKR values are well within prescribed limits by national regulatory agency. It is recommended to agree on nationally and internationally accepted common limits for source strength verification that describes all methods of calibration using the best available correction factors. Further the reproducibility of maximum sensitive spot in well chamber ensures the stability in set up as well as in measuring equipment. Kumar et al : dose verification for brachytherapy plans made code that independently verifies the dose calculation by TPS at selected points using TG-43 with deviation in the order of 2 % **[27]**. Similarly Vicente Carmona, Jose Perez-Calatayud, Françoise Lliso et al made a spreadsheet based program to independently verify the calculations of individual plans of brachytherapy treatment planning systems for low dose rate, high dose rate and pulsed dose rate techniques and the agreement between calculated and TPS outcome was within 2% **[28]**. Another author N A M Safian et al developed workbook based verification programme to verify point dose calculation in brachytherapy treatment planning system for 40 clinical cases and the results shows the agreement between TPS and independent calculation in the range of 2% **[29]**. The reported results shows that deviations between the TPS and the manual method of computation are within 2%. This manual method of time calculation does not require any additional computer system for calculation so; it is cost effective, could be carry out with minimal available resources and is free from bugs. The manual method relies on treatment system TG 43 data but it works reliably and reassure the TPS functioning.

Conclusion

Various national and international bodies strongly emphasize that the source strength of vendor supplied HDR Ir-192 Brachytherapy source must be verified prior its clinical use. The calibration of brachytherapy sources at the hospital is a crucial element of the QA program. This study shows good agreement between that measured and quoted source strength values of 13 Ir-192 Flexitron HDR Brachytherapy sources which lies within the limits (±3%) as given by competent authority of India (AERB, Mumbai) [8]. It is desirable to agree on an internationally accepted common protocol which describes all methods of calibration using the best available correction factors, and also giving recommendations for Ir-192 sources. Based on this study it is recommended that in house measured source strength should be used for clinical calculations if the measured source strength values are within 3% of the vendor's specified values [4]. The treatment time calculation accuracy of Treatment planning system compared with manual method and deviations for both single and multi-source calculations are less than ± 2%. In conclusion, the manual check for TPS calculation is must to reassure the TPS functioning. Therefore, this retrospective analysis helps not only to verify the source strength supplied by the manufacturer and time calculation accuracy of TPS but also ensures quality and self-reliance in brachytherapy treatment. This study serves as a part of Basic Safety Standards (BSS).

Appendix

Tables

Table 1 HDR 1000 PLUS Well Chamber

Manufacturer	Standard Imaging
Type of product	Vented Well Chamber
Measuring Quantity	Air kerma strength; reference air kerma rate
Bias Voltage used for Measurement	+ 300 volts
Active Volume	245 cc
Height Of Chamber	15.6 cm
Base Diameter	10.2 cm
Insert Diameter	3.5 cm
Insert Height	12.1 cm
Most sensitive spot	50- 53 mm from the bottom of the chamber
Calibration Laboratory	National Standard Dosimetry Laboratory, RSS, BARC, Mumbai

Table 2 Technical Specifications of Radioactive Source

Source Type : Flexisource Ir-192 (Cylindrical Source)	
Active Diameter	0.6 mm
Active Length	3.5 mm
Capsule Dimensions	Diameter – 0.86 mm Length – 4.6 mm
Encapsulation	Single encapsulation of Stainless Steel
Manufacturer	Curium Netherlands

Table 3 Calculation of Angle

Theta 1 (Θ_1)	**Theta 2 (Θ_2)**	**Theta 3 (Θ_3)**
$\tan(180-\Theta_1) = 1$ $180-\Theta_1 = \tan^{-1}(1)$ $180-\Theta_1 = 45$ $\Theta_1 = 135^0$	$\Theta_2 = 90^0$	$\tan\Theta_3 = 1$ $\Theta_3 = \tan^{-1}(1)$ $\Theta_3 = 45^0$

Table 4 Source Strength Verification

Source No.	**Quoted Source Strength (mGy/h at 1 m)**	**Measured Source Strength (mGy/h at 1 m)**	**% Variation**
1	33. 2	33.11	0.27
2	37.86	38.5	-1.66
3	34.81	34.713	0.28
4	35	35.2	-0.57
5	36.319	36.08	0.66
6	34.049	33.897	0.45
7	34.09	33.68	1.22
8	40.78	40.34	1.09

9	39.84	39.16	1.74
10	38.8	38.16	1.68
11	38.65	38.8	-0.39
12	38	38.1	-0.26
13	38.94	39.3	-0.92

Table 5 Manual and TPS calculation Verification (Single Source verification)

Single Source verification (At different intervals of different sources life time)		
TPS TT (Sec)	**Manual calculated TT (Sec)**	**% Deviation**
123.14	122.86	0.227
224.61	225.95	-0.59
157.74	158.90	-0.73
514.98	506.345	1.705
145.28	146.19	-0.62
293.45	294.0238	-0.195
88.92	88.24	0.77
135.80	135.46	0.25
180.04	179.60	0.244
90.40	90.18	0.25
161.49	162.110	0.38
112.25	110.38	1.70
296.16	296.91	-0.25

Table 6 Manual and TPS calculation Verification (Multi Source verification)

Multi Source verification (At different intervals of different sources life time)		
TPS TT (Sec)	**Manual calculated TT (Sec)**	**% Deviation**
469.28	470.88	-0.339
114.70	115.1697	-0.4078
257.01	258.0804	-0.414
45.50	45.686	-0.407
73.97	74.916	-1.2627
80.86	80.974	-0.14
148.51	149.832	-0.88
56.89	57.78	-1.54
68.65	69.042	-0.56
45.70	45.76	-0.14
91.00	91.51	-0.557
82.08	82.31	-0.279
151.32	150.87	-0.297

FIGURES

Figure1 CDX2000B Electrometer & HDR 1000 PLUS Well Type Ionization Chamber

Figure 2 Well Type Ionization Chamber & Source Holder

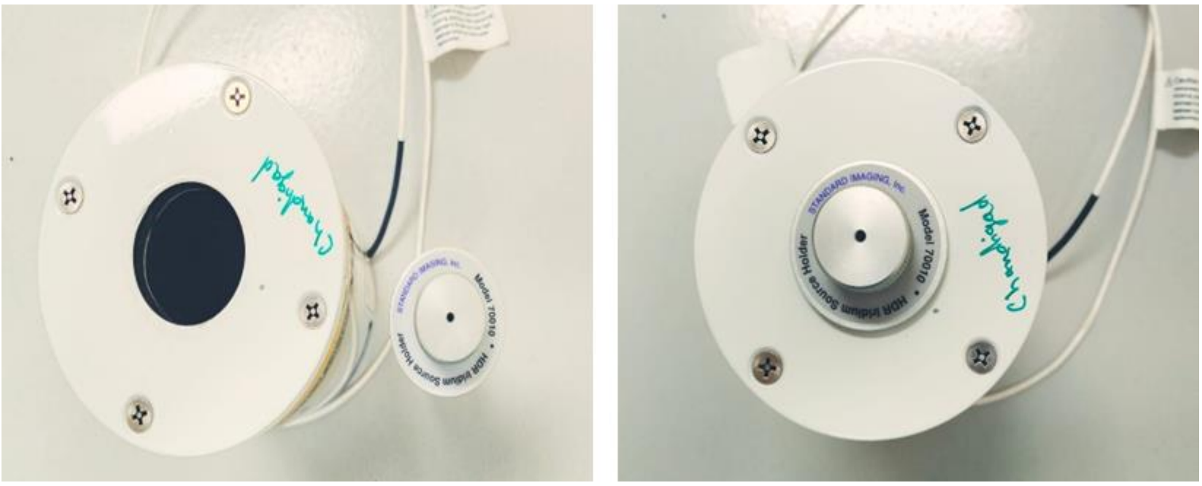


Figure 3 Measurement Set-up

Figure 4 Single Source Calculation

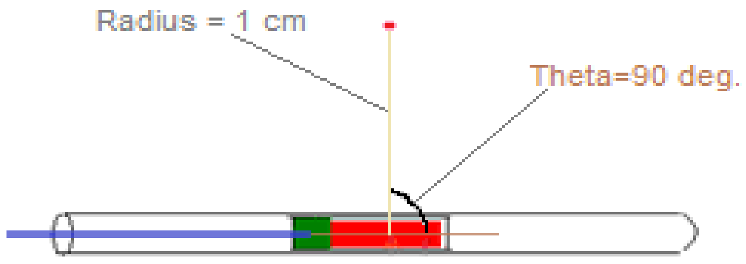
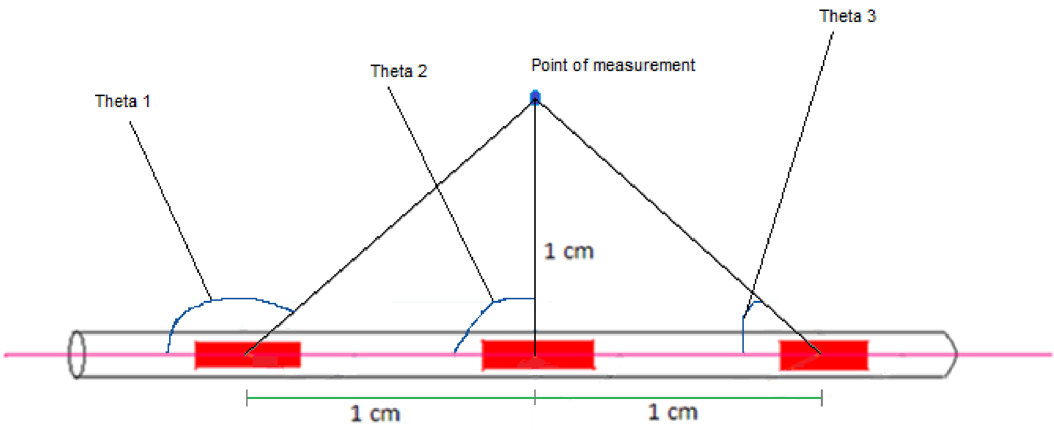


Figure 5 Multi Source Calculations



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