Brachytherapy Dosimetry in the Clinic

Margaret Bidmead
Royal Marsden NHS Trust
Two Curies

Bequerel
Brachytherapy

What is it?

“Sealed radioactive source(s) placed directly into, or immediately adjacent to the volume to be treated.”

Treatment of melanoma, 1910, Sydney, Australia
Uses for Radium

“Guaranteed to Contain Real Refined Radium And to be Perfectly Harmless”

1904
Types of Brachytherapy

Intracavitary
  Cervix
  vagina
  oesophagus/bronchus
Why do we use it?

- localised treatment, i.e. high dose to the target volume, whilst sparing adjacent normal tissue, and minimal whole body dose
Types of Brachytherapy

Interstitial

- Prostate
- Head and neck
- Breast
- Rectum
Types of Brachytherapy

Surface Moulds

- Angiosarcoma
- Melanoma
- Basal Cell carcinoma
- Recurrent disease
2010 Brachytherapy Statistics:

3.7% of all new cancer cases receive brachytherapy (12% in USA)
Distribution of cases per centre
Clinical Dosimetry Systems

- Intracavitary .... Manchester System
- Interstitial with Ir.... Paris System
- Line sources..... prescription at distance
- Permanent seeds...... volumetric isodose coverage (D90)
- Moulds....... different Manchester System
Purpose of calibration and dosimetry?

- To verify source strength independently and improve precision.
- To achieve national and international agreement
- (DOH requirement: check measured source strength against manufacturer’s certificate)

Source specification:
AKR in air @ 1m - RAKR
## Brachytherapy Source Specification

<table>
<thead>
<tr>
<th>Reference</th>
<th>Quantity</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAPM TG 43 Update: <em>Med. Phys. 31 (3), March 2004</em></td>
<td>Reference Air Kerma Rate (RAKR)</td>
<td>Air kerma rate due to photons of energy greater than ( \delta ), at a point located at a distance of 1 m from the source centre, <em>in vacuo</em>.</td>
<td>( \mu \text{Gyhr}^{-1} ) at 1 m</td>
</tr>
<tr>
<td></td>
<td>Air-kerma strength ( S_k )</td>
<td>The air kerma rate, <em>in vacuo</em>, and due to photons of energy greater than ( \delta ), at distance ( d ), multiplied by the square of the distance.</td>
<td>( \mu \text{Gym}^2\text{hr}^{-1} ) (U)</td>
</tr>
</tbody>
</table>
Source Strength

Past:
- Activity
- Effective Activity
- mg Ra equivalent

Present:
- Air Kerma Rate
  Under standard conditions

NB: Link to algorithm in TPS or MC model of each source

Uncertainties in conversion factors
Direct calibration: source or calibrator has been calibrated at a national standards laboratory (NPL in the UK, NIST in the USA).

Secondary: source is calibrated in comparison with a source of the same design and comparable strength, which has direct traceability.
Remote: if the user relies on the manufacturer’s calibration as the only standard. (not recommended)
Calibration Methods

- Ion chamber in air: AKR at known distance from the source
- Calibrated re-entrant well chamber
- Ion chamber and source inside a solid phantom. (2nd check?)
Re-entrant Chamber

- Linear response with source strength.
- Accurately measured energy response.
- Response dependent on geometric configuration (size, shape, orientation and position), filtration and encapsulation of source.

PTW and Standard Imaging well chambers
Re-entrant well chamber

- Reproducibility better than 2%.
- Signal-to-noise ratio > 100:1.
- Collection efficiency better than 99%.
- Easy to set up and use
Issues With Well Chambers

- Effect of source type used for standard calibration
- Sweet spot of chamber
- Saturation effects of well chambers at high currents
- Method of constancy check
- Temperature stabilisation
- Second, independent check of source calibration
Reference air kerma rate (RAKR) comparison between a Standard Imaging 1000 Plus well chamber calibrated using the new COP, and a Farmer chamber, calibrated at 280 kVp according to the old 1992 BIR/IPSM recommendations.

Data collected by Chris Lee
RAKR PTW 22004 Well chamber, calibrated according to the new COP, and an NE 2571 Farmer Chamber, calibrated according to the IPEM 1992 Recommendations, manufacturer’s source certificate for a Nucletron microSelectron-v1 (classic) HDR 192Ir source.
The BS EN 60731:1997 standard sets a "maximum input current" for a secondary standard dosemeter at 5 nanoamp currents of 10-30nA per Ci therefore possibly 500nA from a very hot HDR source
HDR/PDR Afterloading Systems

- **Nucletron HDR**
  - Micro Selectron
  - Ir192 (370Gbq)

- **Flexitron**
  - Dual source
  - Ir192
  - Ir192 (370GBq)

- **Varian / GammaMed**
  - Single Ir192 source
  - Co60 (74GBq)
  - source available

- **Ir192 (370GBq)**
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  - Single Ir192 source
Objective:

Determine reference AKR of an HDR source to ensure that the agreement with the RAKR stated on the source certificate agrees within +/- 5%.

+/- 3% should be possible
When to Calibrate?

Field chamber should be cross calibrated with secondary standard chamber immediately after return from NPL

At machine Commissioning.
Following major repair or modification.
Following Source Replacement.
Associated QC

Timer checks, source position and room safety checks should also be done following service, source replacement.

Possibly some applicator checks (especially rings)
Required Measurements

2 independent measurements: A and B
Measure AKR to derive activity.
Uses measured AKR to deliver a set dose.

2 physicists.

2 dosimeter / chamber combinations in ideal situation.
Present HDR Systems

Nucletron MicroSelectron HDR - *Traditional AKR or TG43*

- 5.0mm
- 3.5mm
- 1.1mm
- 0.6mm

Gammamed HDR - *Traditional AKR*

- 1mm
- 10mm
- 0.59mm
- 0.34mm

VariSource HDR Source - *Traditional AKR or TG43*
Ir-192 Source Calibration

How?

– Using a re-entrant chamber traceable to NPL
Part A: Measure Reference Air Kerma Rate (RAKR) of new source using the NPL calibrated secondary standard well chamber and electrometer, using chamber calibration coefficient $N_{KR}$.

Connect to the HDR unit using the same transfer tube for sake of consistency.

Minimize scatter conditions.
If the water equivalent thickness of the tabletop (at least 1 m above floor level) is between 2.5 mm and 15 mm, the scatter contribution to the measured ionisation current is within ±0.1% of the scatter contribution during calibration of the well chamber at the NPL.
Each centre must find its own sweet spot for a particular transfer tube

NPL will also test for sweet spot location

“Peak” is broad (15-20mm) so any positional error (<+-1mm) in source is not significant

Min and Max measurement positions should be at least +-10mm from expected SS position

Range in position should be within +- 2.5mm of previously determined value
Part A

• Send the source to the position of maximum chamber response where the NPL calibration is valid.
• Take at least 3 current readings, each from separate source transfers and correct for background. There should be no significant trend in the readings.
• Calculate mean corrected current and its standard deviation (SD< 0.1%)
Ion Recombination

- Recommend Attix two voltage method for determination of recombination factor within the COP for users to determine their own factor. Therefore Part A readings repeated with chamber voltage at 150V.
- Factor $\sim 1.001$ for 300GBq source but does depend on AKR.

Part B

- Use RAKR measured in Part A to calculate the time required to deliver a specified air kerma at 1m. Set time on HDR unit and measure the delivered air kerma with an independent chamber and electrometer.
- The time set must be corrected for the additional air kerma recorded during source transit.
Constancy checks of well-chambers

- Cs 137 source, available but custom made jig for well chamber required.
- Activity and associated current to be selected

Error bars give estimates of the 95% confidence intervals based on the uncertainties of the temperature, pressure and fluctuations of the measured charge.
Constancy checks of well-chambers

- Calculate ratio for the two measured currents and compare with the original reference value. Ratio should agree with reference to within 2%.

- If difference greater than 2% should be investigated

- Problem may lie with either chamber
Second “independent” check

- Is the AKR from the source certificate a second check?

- Yes in Austria, the Netherlands, Belgium and Norway! (unless the measurement is >5% different from the certificate)

- AAPM TG-56 (Nath et al 1997) for a confirmatory check of source strength
Phantom end-to-end check

- Small phantom drilled to take a tertiary instrument (e.g. Farmer chamber) at a fixed distance of 1cm-5cm from a drilled channel which carries the source catheter would be suitable for a “second check”

- (3-5cm probably best for HDR)

- This would allow “end-to-end” check
Source accepted if:

- the activity calculated by AKR measurement is within +/-5% of that stated on the source certificate.

- dose delivery measurement calculated from the RAKR measurement is also within +/-3%.

If source is from a nationally accredited lab then we can use the source certificate supplied by the manufacturer as a “second check”.
However it is suggested that the AKR measured at the Hospital is used in the treatment planning system, rather than the AKR from the source certificate.

Generally do not know the measurement conditions/parameters of source certifying institute.
### TABLE XVII. TYPE AND FREQUENCY FOR ACCIDENTS REPORTED IN BRACHYTHERAPY TREATMENTS

<table>
<thead>
<tr>
<th>Accident caused by</th>
<th>Number of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose calculation error</td>
<td>6</td>
</tr>
<tr>
<td>Error in quantities and units</td>
<td>2</td>
</tr>
<tr>
<td>Incorrect source strength</td>
<td>7</td>
</tr>
<tr>
<td>Equipment failure</td>
<td>4</td>
</tr>
<tr>
<td>Other</td>
<td>13</td>
</tr>
<tr>
<td>Total</td>
<td>32</td>
</tr>
</tbody>
</table>
Reportable medical events involving treatment delivery errors caused by confusion of units for the specification of brachytherapy sources

Specifically confusion of air-kerma strength with apparent activity in terms of mCi.

Cause: human error
When calculating dosimetry - it is important to consider:

- Method of dose calculation used and standardisation of input data.
If activity is used in the TPS or for “convenience” then dose rate is usually calculated via:

\[ D = \frac{Ak}{r^2} \]

Where \( k \) is a specific gamma ray constant or an air kerma rate constant.

If \( A \) is determined from the RAKR, then \( k \) is a dummy variable which must be identical to that in the TPS.
Update of AAPM Task Group No.43 Report: A revised AAPM protocol for brachytherapy dose calculations

  2004 Med. Phys. 31 633-74
\[ D(r, \theta) = S_k \Lambda \left[ \frac{G(r, \theta)}{G(r_0, \theta_0)} \right] g(r) F(r, \theta) \]

- the dose rate constant \((\lambda)\)
- radial dose function \(g(r, \theta)\) (absorption and scattering)
- geometry factors or source data (spatial resolution of radioactivity within source) \(G(r, \Theta)\)
- anisotropy function & factors \(F(r, \Theta)\)
Schematic diagram illustrating the geometry considered by the Task Group 43 dose calculation formalism for a linear radioactive source (adapted from AAPM 1995).

**TG43: Medical Physics 22 (2) 209-235 Feb 1995**
Cylindrically symmetric source

\[ D(r, \theta) = S_k \Lambda \left[ G(r, \theta) / G(r_0, \theta_0) \right] g(r) F(r, \theta) \]

Air Kerma Strength

Dose rate constant: dose rate to water at 1cm
Currently accessible through Valencia University

New data continuously validated by a BRAPHYQS/AAPM subgroup

Easy access through ESTRO website:

www.estro.org
“Insurance”

- Good QA procedures
- Second checks
- Work instructions
- Thorough familiarity with TPS
- Communication between multi-disciplinary staff groups
MRI at time of Brachytherapy

AFTER:
45Gy EXTB and 200mg/m2 cis-platin

GTV measured 2cm w, 3cmt, 3cmh
6 cm tube + medium ovoid

HDR

But R < 65Gy or < 60% dose to A
High Dose Rate

- HDR (Iridium 192) (300 cGy/min)
- Dose reduction 55-70% of classical dose-rate (53cGy/hr)
- Fraction size 5.5-10 Gy 1-3 times per week (Combined with external beam)

Joslin, 1972, Sharma et al 1991
Patient Results

Before Treatment

Prior to any treatment

40cc HR-CTV

After Treatment

2mths after treatment

?  

Courtesy S Aldridge and A Winship
Clinical dosimetry issues

- How to move on from Point A?
- Prospective dose volume data collection correlated to point A
- Problem; organ motion, brachy applicator motion motion Multiple imaging parameters (fusion)
- Varying dose rates (complex biologically equivalent doses)
Prostate Brachytherapy
HDR with u/s guided needles and remote afterloading or LDR Iodine seeds

HDR needles (Ir 192)  
I 125 seeds
Useful references

IAEA-TECDOC-1274

Calibration of photon and beta ray sources used in brachytherapy

Guidelines on standardized procedures at Secondary Standards Dosimetry Laboratories (SSDLs) and hospitals

Use of phantoms and external audit

Reconstruction

Dosimetry

Source

TLD

5 cm

ESTRO ESQUIRE PROJECT
Education, Science and Quality Assurance for Radiotherapy
Brachytherapy Physics Quality assurance System
References


- The IPEM code of practice for determination of the reference air kerma rate for HDR (192)Ir brachytherapy sources based on the NPL air kerma standard. (2010)

- www.e-lfh.org.uk

Luc Beaulieu, Åsa Carlsson Tedgren, Jean-François Carrier, Stephen D. Davis, Firas Mourtada, Mark J. Rivard, Rowan M. Thomson, Frank Verhaegen, Todd A. Wareing, Jeffrey F. Williamson
References

- **TG43:**
  Medical Physics 22 (2) 209-235 Feb 1995

- **Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy dose calculations.**
  Rivard MJ, Coursey BM, DeWerd LA, Hanson WF, Huq MS, Ibbott GS, Mitch MG, Nath R, Williamson JF.

- **Supplement to the 2004 update of the AAPM Task Group No. 43 Report.**
  American Association of Physicists in Medicine.
Dose calculation for photon-emitting brachytherapy sources with average energy higher than 50 keV: Report of the AAPM and ESTRO