Brachytherapy
Dosimetry in the
Clinic
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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”

Self-luminous paint stopped in 1950’s

Radium Girls - Occupational disease
Labour law
4 % of all new cancer cases receive brachytherapy (12% in USA)
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
Implantation Rules

- System of work for source implantation
- How best to cover defined volume
- How best to minimize dose to organs at risk
- What is practically achievable
- What AKR of source(s) available
Clinical Dosimetry Systems

- Intracavitary ……Historically Modified Manchester System, Point A: now volumetric
- Interstitial with Ir….Paris System
- Line sources…..prescription at distance from a plane
- Permanent seeds……volumetric isodose coverage (D90)
- Moulds………different Manchester System, treatment at a specified distance
Purpose of source 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
<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 1m from the source centre, <em>in vacuo</em>.</td>
<td>$\mu$Gyhr$^{-1}$ at 1m</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>$\mu$Gym$^2$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 method:
- source or calibrator has been calibrated at a national standards laboratory (NPL in the UK, NIST in the USA).

Secondary method:
- source is calibrated in comparison with a source of the same design and comparable strength, which has direct traceability.
Remote traceability: 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?)
Properties of Re-entrant Well Chambers

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

- Reproducibility better than 2%.
- Proven long-term stability (+-1%)
- 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
- Temperature stabilisation
- Method of constancy check
- Second, independent check of source calibration
HDR/PDR Afterloading Systems

Nucletron HDR
Micro Selectron
Ir192 (370Gbq)

Flexitron
Dual source
Ir192
(Co60/Yb169)

Ir192 (370GBq)
Co60 (74GBq)
source available

Varian / GammaMed
Single Ir192 source
Currents from HDR sources

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.
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.
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.
Constancy checks of well-chambers (long t1/2 source)

- 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 (2)

- 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
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
Ir-192 Source Calibration

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

Possibly some applicator checks (especially rings)
Quality Assurance
Remote Afterloading Systems

1. Source Integrity
   Sources inaccessible
   High activity
   Wipe source path or transfer cable at machine service
   Check catheters for activity

2. Source Position Check
   Following position calibration or after source change.
   Autoradiography
   Use reference jig viewed by in room camera
Quality Assurance
Remote Afterloading Systems

HDR source stepping checks during a single transfer: 10mm steps
1500mm-1470mm
Required Measurements for Calibration

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.
Ir-192 Source Calibration

How?

– Using a re-entrant chamber traceable to NPL
– Prior to measurement leave well chamber connected to electrometer in treatment room for at least half an hour.
Published 2010

Recommends use of a well chamber

Defines the factor $k_{sg}$ to account for different source types. No consensus so set to 1.

Comparison with source cert may be used as the second check if cert comes from a approved and registered calibration centre.

Well chamber stability check – ratio or check source

Electrometer calibration in terms of current.
Ir192 HDR Source Calibration in Clinic
The IPEM Code of Practice based on the NPL Air Kerma Standard

METHOD

Set up well chamber 1m from walls and floor on low scatter surface

Thermal equilibrium

Connect to calibrated electrometer

300V (collecting electrode is +ve wrt outer electrode)

Find position of max response

Measure stable current from at least 3 source transfers

Measure ion recombination using half voltage technique, typically around 1.001 for 370GBq source

Correct for temp/pressure, ion recombination, source decay
Ir-192 Source Calibration

- 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

\[ N_{\dot{K}_R} \]

- 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.
Position of maximum chamber response (Sweet Spot) of chamber

- 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
Positional Response of Nucletron SDS Well Chamber 25039 with HDR V2 Source
Source Number D36B 1458 7/2/2007

MicroSelectron Source Position in Channel 3
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.

The RAKR, $\dot{K}_R$, in terms of Gy s$^{-1}$ at 1 m, can be determined from

$$\dot{K}_R = M \cdot k_{\text{ion}} \cdot k_{\text{sg}} \cdot N_{K_R},$$
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.
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
Calibration Outcome

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><strong>Total</strong></td>
<td><strong>32</strong></td>
</tr>
</tbody>
</table>
When calculating dosimetry - it is important to consider:

- Method of dose calculation used and standardisation of input data.

**Methodology**

- **Monte Carlo**
- **Encapsulation**
- **Sievert Integral**
- **Apparent Activity**
- **Scatter and Attenuation**
- **TG 43**
How does a TPS calculate dose?

- If activity is used in the TPS or for “convenience” then dose rate is usually calculated via:

\[ D = \frac{A k}{r^2} \]

- 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

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

- 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

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

Air Kerma Strength

Dose rate constant: dose rate to water at 1 cm
Website for validated MC source data (TG-43)

- Currently accessible through Valencia University
- New data continuously validated by a BRAPHYQS/AAPM subgroup
- Easy access through ESTRO website:
  - www.estro.org
Good QA procedures
Second checks
Work instructions
Thorough familiarity with TPS
Communication between multi-disciplinary staff groups
MRI at time of Brachytherapy

AFTER: 45Gy EXT B 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
Standard loading pattern

Point A

45 Gy EBRT + 4 x BT: 85 Gy
60 Gy

10 mg

15 mg

20 mg

20 mg

85 Gy_{\alpha\beta_10}
60 Gy_{\alpha\beta_10}

Courtesy: Kirisits, Vienna
Standard loading pattern

Courtesy: Kirisits, Vienna
Patient Results

Before Treatment

40cc HR-CTV

Prior to any treatment

After Treatment

2mths after treatment

Courtesy S Aldridge and A Winship
Clinical dosimetry issues

- Problem; organ motion, brachy applicator motion
- Multiple imaging sequences and parameters (fusion)
- Varying dose rates (complex biologically equivalent doses)
- Application of more complex algorithms (TG 186) Acuros and ACE are two commercial planning systems that implement this now
Prostate Brachytherapy
HDR with u/s guided needles and remote afterloading or LDR Iodine seeds

HDR needles (Ir 192) I 125 seeds
Test the whole process

Phantom imaged

Digitised

Applicator and sources identified

Dose prescription

Isodoses

Plan analysis (DVH)
Aspects that need checking include:

- Input of patient and applicator data
- Source and applicator localization
- Dose calculation around sources
- Use of multi-modality imaging, evaluation and visualization of 3D dose distributions
- Optimization routines
- Output of patient plan and associated information
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

UK: Alanine audit and Gaf chromic Applicators and line sources
What can we expect from the future in brachytherapy?
Image fusion

Rigid fusion is a common technique
But non-rigid?

Patient study to evaluate dose summation of EBRT, ICBT, external beam nodal boost using CT data and deformable image registration software.

Mean dose left external iliac node:
Orig: 4.8Gy, deformably mapped: 4.6Gy

Mean right external iliac node:
Orig: 6.7Gy, deformably mapped 7.1Gy

Yu et al. Brachytherapy
Volume 10, Pages S34-S35 (May 2011)
DOI: 10.1016/j.brachy.2011.02.048
Real time luminescence dosimetry

- radiation absorption
- signal emission
- signal transmission
- signal collection
- dose rate measurement

Important requirements on *in-vivo* dosimeter:
• small size
• real-time signal
• dose linearity
• large dynamic range
• bendable

Courtesy Gustavo Kertzscher, DTU, Denmark
References


- www.e-lfh.org.uk
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.

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