Dosimetry for Ir-192 HDR Brachytherapy – Present Status and Future Direction TU-A-213AB

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Approaches for the determination and dissemination of absorbed dose to water in ^{192}Ir HDR brachytherapy

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- Canadian Institute of Health Research (CIHR)

NSERC CRSNG CIHR IRSC

Outline

- Rationale
- Review four techniques that have the potential to be primary absorbed dose standards
  - Water calorimetry
  - Graphite calorimetry
  - Ferrous sulphate-based
  - Ionization chamber-based
- For each technique a summary of principle, realization and uncertainties
- Conclusions

^{192}Ir Brachytherapy Dosimetry

$$\text{ADCL/NIST/NRCC} \rightarrow \text{Calibrated well-type chamber} \xrightarrow{\text{Chamber calibration}} S_K \xrightarrow{\text{TG-43}} \dot{D}_w(r)$$

See Lecture of Dewerd et al.

Rationale for absorbed dose calibrations of brachytherapy sources

$$\dot{D}(r,\theta) = \underbrace{S_K \cdot \Lambda}_{\dot{D}(r_0,\theta_0)} \cdot \frac{G_L(r,\theta)}{G_L(r_0,\theta_0)} \cdot g_L(r) \cdot F(r,\theta)$$

- Calibration in terms of the quantity needed in the first place
- Spectral effects that affect S_K affect much less $\dot{D}(r_0,\theta_0)$
- The dissemination of standards can proceed in virtually the same manner as now, but more robust
- Method can be applied to other BT radionuclides or even electronic sources

Water calorimetry as a standard for ^{192}Ir brachytherapy dosimetry

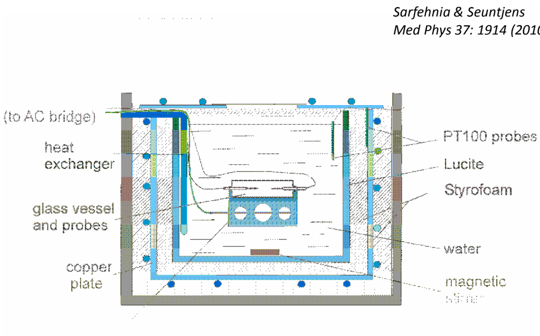
- In water calorimetry absorbed dose to water is determined by measuring temperature rise in water

$$D_w = c_w \Delta T \; \Pi k_i$$

- 0.23 mK per Gy absorbed dose!
- The devil is in the details:
  - Large source self-heating
  - Sharp dose gradient
  - Need for accurate positioning at small $d_{\text{src-det}}$
  - Small dose rate at large $d_{\text{src-det}}$

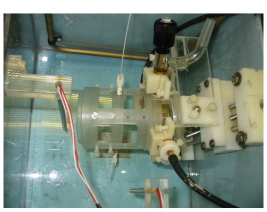
^{192}Ir BT water calorimeter (McGill)

Sarfehnia & Seuntjens
Med Phys 37: 1914 (2010)

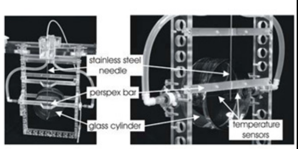


Possible setups

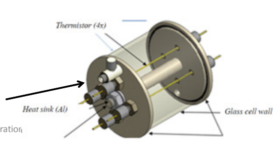
McGill University

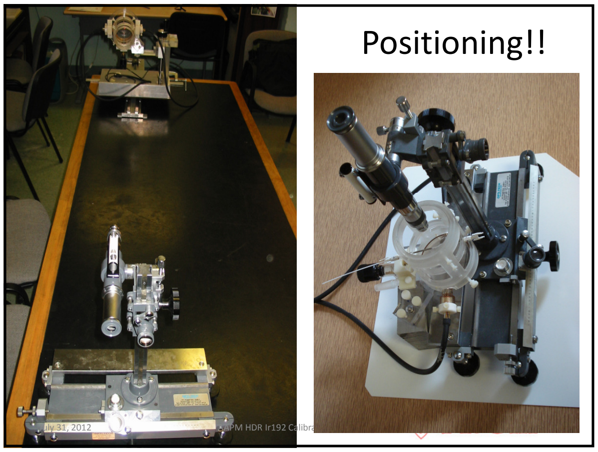


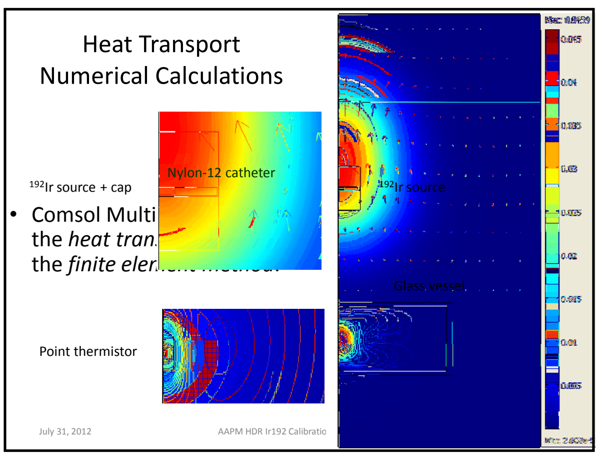
PTB (PSDL Germany)

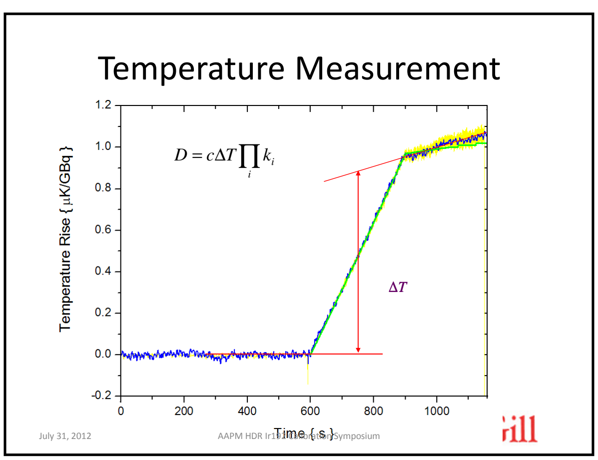


VSL (PSDL Holland)

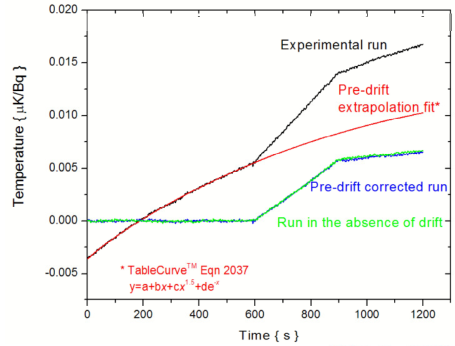



Positioning!!
July 31, 2012


Heat Transport
Numerical Calculations
^{192}Ir source + cap
Nylon-12 catheter
• Comsol Multi
the heat tran
the finite ele
Point thermistor
^{192}Ir source
Glass vessel
July 31, 2012
AAPM HDR Ir192 Calibratio


Temperature Measurement
$D = c\Delta T \prod_i k_i$
ΔT
Temperature Rise { µK/GBq }
Time { s }
July 31, 2012

Drift linearization



July 31, 2012 AAPM HDR Ir192 Calibration Symposium McGill

TABLE I. The uncertainty budget for ^{192}Ir water calorimetry.

Uncertainty	Type A (%)	Type B (%)
Std error on the mean (meas.)	0.43	
c_w		0.03
Absolute temperature		0.01
$(\Delta R/R)/\Delta V$ calibration		0.04
Thermistor calibration (β)		0.1
k_ρ		0.05
k_{hd}		0.3
k_p		0.1
k_{ht}		
Conv. model (physical data)		0.35
Simulation data		0.05
Interval extrapolation		0.01
Vessel dimension		0.02
k_{dd}		0.45
Source-vessel separation		0.85
Probe position wrt vessel		0.03
Dwell time		0.01
Dummy/real source position		0.00
Predrift linearization		1.5
Total uncertainty (1σ) (%)		**1.90**

BT water calorimeter uncertainty budget

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Graphite calorimetry as a standard for ^{192}Ir brachytherapy dosimetry

- In graphite calorimetry absorbed dose to water is determined by measuring temperature rise in graphite

$$D_w = c_g \Delta T_g \, \Pi k_i$$

- 1.2 mK per Gy absorbed dose (vs. 0.23 mK/Gy in water calorimetry)!
- The devil is in the details:
  - A dose conversion graphite to water is built into the correction factors
  - Sharp dose gradients are less of a problem
  - Self heating of the source

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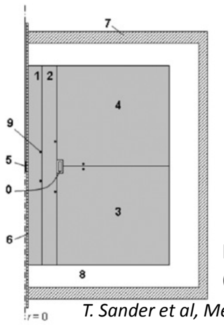
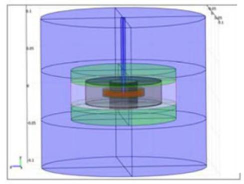
Practical designs



NPL
(PSDL, UK)



ENEA (PSDL Italy)
Guerra et al, 2009

T. Sander et al, Metrologia (in press, 2012)

Correction factors

$$\dot{D}_{w,1cm} = c_p \frac{dT_0}{dt} k_{\mathrm{ht,q-a}} k_{\mathrm{gr/w}} k_{\mathrm{volavg}} k_{\mathrm{imp}} k_{\mathrm{gap}} k_{\mathrm{inh}} k_{\mathrm{fullscat}}$$

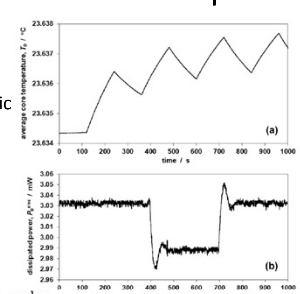
Table 1. MC calculated correction factors and statistical (type A) standard uncertainties.

	EGSnrc		FLUKA	
Symbol	Value	Standard uncertainty	Value	Standard uncertainty
$k_{\mathrm{gr/w}}$	6.90	0.02	6.92	0.03
k_{imp}	0.9997	0.0003	0.9999	0.0004
k_{volavg}	1.0024	0.0008	1.002	0.001
k_{gap}	0.9992	0.0004	0.9987	0.0006
k_{inh}	1.0008	0.0004	1.001	0.001
k_{fullscat}	1.0060	0.0005	1.006	0.001

T. Sander et al, Metrologia (in press, 2012)

Two modes of operation

Quasi adiabatic



Isothermal

T. Sander et al, Metrologia (in press, 2012)

$$\dot{D}_{w,1cm} = -\frac{\Delta P_0^{\mathrm{elec}}}{m_0} k_{\mathrm{ht,q-a}} k_{\mathrm{gr/w}} k_{\mathrm{volavg}} k_{\mathrm{imp}} k_{\mathrm{gap}} k_{\mathrm{inh}} k_{\mathrm{fullscat}}$$

Isothermal mode: uncertainties

Table 3. Uncertainty budget of the HDR brachytherapy calorimeter for quasi-isothermal absorbed dose rate measurements.

	Relative standard uncertainties	
Quantity	100 × Type A	100 × Type B
Repeatability of $\Delta P_0^{\mathrm{elec}}$ measurements	0.20	—
Stability of power supplies	—	0.05
Heat transfer correction factor, $k_{\mathrm{ht,q-i}}$	—	0.50
Mass of core, m_0	—	0.10
Radial source position	—	0.10
Vertical source position	—	0.10
MC calculated perturbation correction factors	0.10	0.10
Graphite-to-water conversion	—	0.35
Quadratic summation	0.22	0.64
Combined relative standard uncertainty in $\dot{D}_{\mathrm{w,1\,cm}}$	0.68	

T. Sander et al, Metrologia (in press, 2012)

$$\dot{D}_{w,1cm} = -\frac{\Delta P_0^{\mathrm{elec}}}{m_0} k_{\mathrm{ht,q-a}} k_{\mathrm{gr/w}} k_{\mathrm{volavg}} k_{\mathrm{imp}} k_{\mathrm{gap}} k_{\mathrm{inh}} k_{\mathrm{fullscat}}$$

Dose rate constants for microSelectron v-1 Classic HDR source

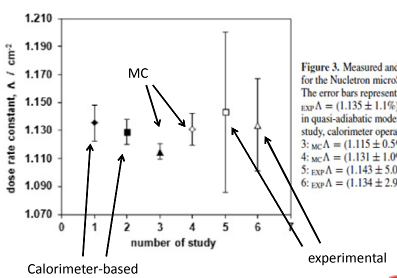


Figure 3. Measured and MC calculated dose rate constants for the Nucletron microSelectron-v1 Classic HDR ^{192}Ir source. The error bars represent the standard uncertainty. 1: $_{\mathrm{EXP}}\Lambda = (1.135 \pm 1.1\%)\,\mathrm{cm}^{-2}$, this study, calorimeter operated in quasi-adiabatic mode; 2: $_{\mathrm{EXP}}\Lambda = (1.129 \pm 0.8\%)\,\mathrm{cm}^{-2}$, this study, calorimeter operated in quasi-isothermal mode;
3: $_{\mathrm{MC}}\Lambda = (1.115 \pm 0.5\%)\,\mathrm{cm}^{-2}$ [20];
4: $_{\mathrm{MC}}\Lambda = (1.131 \pm 1.0\%)\,\mathrm{cm}^{-2}$ [21];
5: $_{\mathrm{EXP}}\Lambda = (1.143 \pm 5.0\%)\,\mathrm{cm}^{-2}$ [22];
6: $_{\mathrm{EXP}}\Lambda = (1.134 \pm 2.9\%)\,\mathrm{cm}^{-2}$ [23].

T. Sander et al, Metrologia (in press, 2012)

Ferrous sulphate as a standard for ^{192}Ir brachytherapy dosimetry

- Based on the conversion of Fe^{2+} to Fe^{3+} ions in a aqueous solution under irradiation

$$D(r_0, \theta_0) = \frac{\Delta OD}{\epsilon G(\mathrm{Fe}^{3+}) d\rho}$$

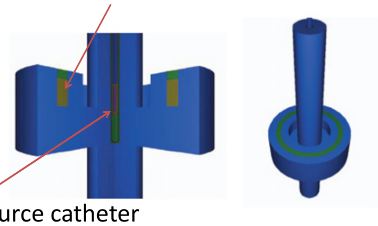
Radiation chemical yield of the solution – system calibration

… and a large number of correction factors

Implementation by Austerlitz *et al*

Med. Phys. 35: 5360 (2008)

Ferrous sulphate solution



^{192}Ir source catheter

TABLE III. Uncertainty budget in the determination of $D(r_0, \theta_0)$ using the Fricke device.

Main components of uncertainty	Type A (%)	Type B (%)	Remarks
1. Relative to the PMMA			
MC correction for PMMA ring not equivalent to water	0.50	0.50	Discussed in text
Mechanical tolerances of the PMMA ring		0.40	Assuming machine tolerance of ±0.001 cm at 1 cm and inverse square law
PMMA may react with Fricke		0.10	Discussed in text
PMMA holder and base (scatter ^{192}Ir)		0.30	Based on the asymmetry of Fig. 3
Volume averaging		0.23	Evaluated by MC using ring cross section 0.1 mm × 0.1 mm
2. Fricke solution and reader			
Temperature of irradiation and reading		0.47	Assuming 1 °C variation
Reproducibility of the reader (electronics)	1.70		Estimated using five readings of the same sample
Extinction coefficient	0.74		Estimated from ICRU 35 data
G value	1.00		Based on ICRU 14 and 17 data
3. Irradiation			
Source positioning longitudinal		2.50	Discussed in text
Volume of the solution		0.10	Assuming drift of 0.01 cm height of the Frick solution
Water phantom too small (not full scatter)		0.01	Based on Ref. 13
Reproducibility of irradiation time	0.05		QA data
Transit time and decay	0.05		QA data
Square root of the quadratic sum	2.17	2.65	
Combined standard uncertainty	3.43		
Expanded uncertainty (k=2)			

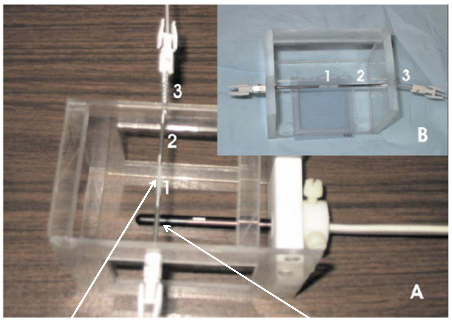
7%! (k=2)

Ionization chamber as a standard for ^{192}Ir brachytherapy dosimetry

- Use of a ^{60}Co absorbed dose to water calibrated ionization chamber
- Using detailed MC methods to extract the chamber calibration coefficient for ^{192}Ir in the experimental setup used

$$N_{D,w}^{^{192}\mathrm{Ir}} = N_{D,w}^{^{60}\mathrm{Co}} \left[\frac{(D_w/D_{\mathrm{cav}})_{^{192}\mathrm{Ir}}}{(D_w/D_{\mathrm{cav}})_{^{60}\mathrm{Co}}} \right]_{\mathrm{MC}}$$

Sarfehnia, Kawrakow & Seuntjens (2010) Med Phys 37, 1924



Source catheter

Exradin A1SL

-Positioning
-Detailed modeling

Sarfehnia, Kawrakow & Seuntjens (2010) Med Phys 37, 1924

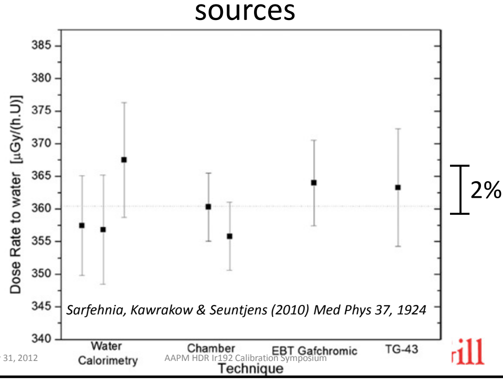
Uncertainties – ionization chamber

TABLE I. Uncertainty budget analysis for the A1SL Exradin mini-Shonka farmer chamber measurements made in water in ^{192}Ir brachytherapy beam.

Uncertainty description	Type A	Type B
$N_{D,w}(^{60}\mathrm{Co})$ calibration		0.7
$[D_{gas}/D_w]_{MC}^{60\mathrm{Co}}$	0.1	
$[D_w/D_{gas}]_{MC}^{192\mathrm{Ir}}$	0.09	
$P_{ion}P_{pol}P_{elec}P_{TP}$		0.17
Measurement reproducibility	0.31	
$d_{src\text{-}det}$		1.2
Dummy/real source		0.00
$d_{src\text{-}det}$ renormalization to 55 mm depth		0.25
Overall uncertainty on Dose (1-sigma)	**1.46**	

Sarfehnia, Kawrakow & Seuntjens (2010) Med Phys 37, 1924

Comparison of methods for one of the sources



Sarfehnia, Kawrakow & Seuntjens (2010) Med Phys 37, 1924

Conclusions

- Direct absorbed dose rate calibration of ^{192}Ir sources brings more simplicity and robustness to HDR brachytherapy reference dosimetry
- Standards laboratories and research centres are actively developing standards
- Uncertainties of typically 2% (k=1) are achievable
- The dissemination of these standards can be based on vitually the same technology as currently available at standards laboratory

Conclusions

- A move from air kerma rate calibrations to absorbed dose rate calibrations is necessary and logical
  - Fits within TG43 concept
  - Can be disseminated using current-day practices
  - Reduces uncertainties at early steps of calibration chain
  - Ultimately improves clinical brachytherapy dosimetry