Benchmark of EGS5 for ^{125}I brachytherapy in comparison to glass rod dosimeter and treatment planning system using AAPM-TR43U1 formalism

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Purpose

To develop a dose calculation method applicable to
- inter-seed attenuation (shielding by seeds already implanted)
- geometry lacking the equilibrium radiation scatter conditions
  (scattering margin below 5 cm, small organ such as tongue)

American Association of Physicists in Medicine
Task Group No 43 Updated Protocol (TG43U1) is N/A

Comparison
- Monte Carlo code EGS5 with a source geometry
- Glass Rod Dosimeter (GRD) (Data accumulation)
- TG43U1

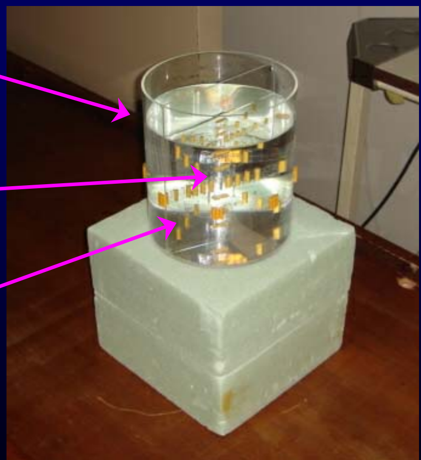
Methods (Exp.)

Irradiation for 1 day

Water phantom
(18cm diam. X 16cm)

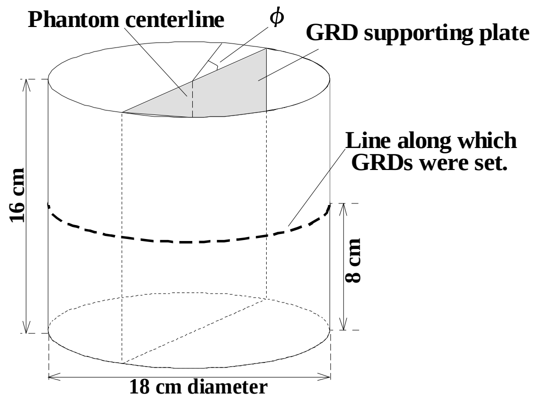
^{125}I seed: 0.414 U, 12.1 MBq
(Oncra Inc. Oncoseed 6711)

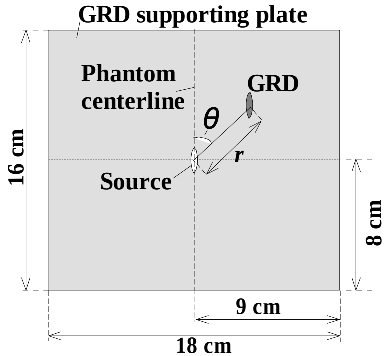
Radiophotoluminescent
glass rod dosimeter
(Asahi Techno Glass GD-302M)



Calibration:
6MV, 10cm into ToughWater, STD 100cm, 10.0MU (80mGy)

Methods (Exp. Cal.)





GRD position (r: 1 or 2 cm int., θ, ϕ : 45 deg. int.)

Some GRDs close to phantom surface :
Backscatter margin less than 5 cm (insufficient)

Methods (Exp. Correction)

Calibration at 6MV
to correct sensitivity difference among detectors

$$\varepsilon_{6MV} = \frac{D_{6MV}}{R_{6MV}}$$

Absorbed dose to water by ^{125}I

$$D_{^{125}I} = F \cdot R_{^{125}I} \cdot \varepsilon_{6MV} \cdot E$$

Normalization to TG43U1 at reference point (1cm, 90deg)
To compare relative distribution

Energy response correction

Reading of dosimeter

Methods (Exp. Correction)

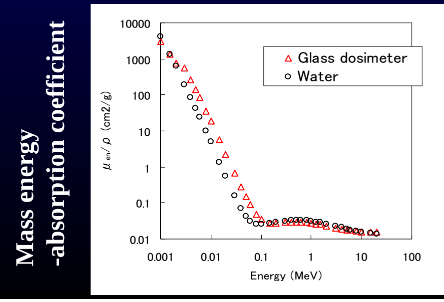
Absorbed dose to water by ^{125}I

$$D_{^{125}I} = F \cdot R_{^{125}I} \cdot \varepsilon_{6MV} \cdot E$$

$$D_{6MV} = E\phi \cdot (\mu_{en}/\rho)_{6MV,Glass} \cdot \frac{(\mu_{en}/\rho)_{6MV,Water}}{(\mu_{en}/\rho)_{6MV,Glass}} \alpha$$

R_{6MV} $\quad$ ε_{6MV}

Detector deviation etc.



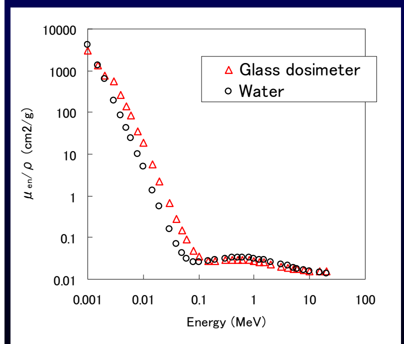
Reading: glass dose
Needed: water dose

J.H. Hubbell and S.M.Seltzer, NISTIR 5632 (Ver 1.4); 2004

Methods (Exp. Correction)

Absorbed dose to water by ^{125}I

$$D_{^{125}I} = F \cdot R_{^{125}I} \cdot \varepsilon_{6MV} \cdot E$$



E=0.291

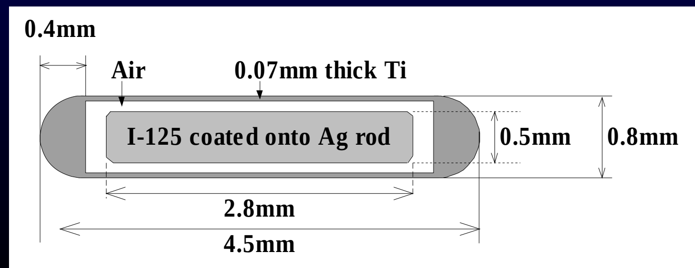
$$E = \frac{(\mu_{en}/\rho)_{^{125}I,Water/Glass}}{(\mu_{en}/\rho)_{6MV,Water/Glass}}$$

$$(\mu_{en}/\rho)_{x,Water/Glass} = \frac{(\mu_{en}/\rho)_{x,Water}}{(\mu_{en}/\rho)_{x,Glass}}$$

$$(\mu_{en}/\rho)_{^{125}I,m} = \frac{\sum_i (\mu_{en}/\rho)_{E_i,m} I_i}{\sum_i I_i}$$

Methods (Cal. for GRD measurement)

- **EGS5**
- **Geometry : phantom, GRD, seed, Styroforam stand (,Pb, wall)**
- **Seed: RM.Kennedy et al. Med. Phys. 33 (2010) 1681-1688**



Methods (Cal.)

^{125}I : NuDat2 (http://www.nndc.bnl.gov/nudat2/)

Energy E_i (keV)	Intensity I_i (%)
3.77	14.9
27.202	40.1
27.472	74
30.944	6.83
30.995	13.2
31.704	3.8
35.4922	6.68

Methods (Cal. Correction)

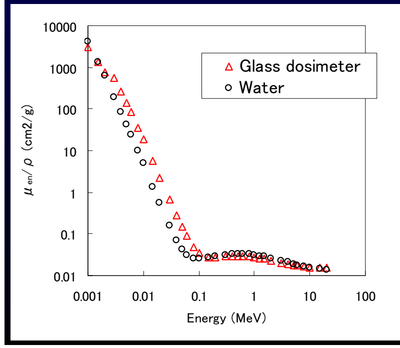
Absorbed dose to water by ^{125}I

$$D = F \cdot O_E \cdot \frac{(\mu_{en}/\rho)_{^{125}I,Water}}{(\mu_{en}/\rho)_{^{125}I,Glass}} \cdot N_D \cdot \sum_i I_i$$

EGS output (Glass dose)

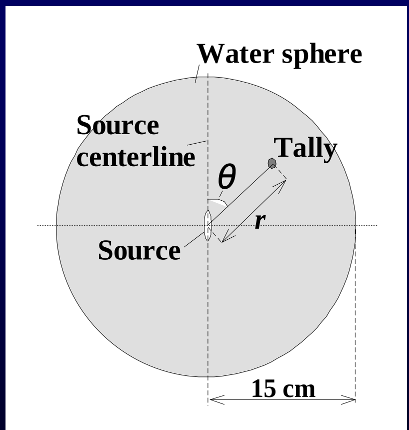
Energy correction (0.328)

Photon/integration



Amount of disintegration
complicated to include source air kerma
→ integration of apparent activity with time, and determined F for this N_D

Methods (Cal. for TG43U1 parameters)



- Radial dose function $g(r)$, 2D anisotropy function, $F(r,\theta)$
- EGS5
- Varied r and θ following TG43U1
- Tally radius : 4 % of r

Methods (TG43U1)

Dosimetry used for brachytherapy

Radial dose function (absorption and buildup dependent on r at 90 deg.

Dose rate

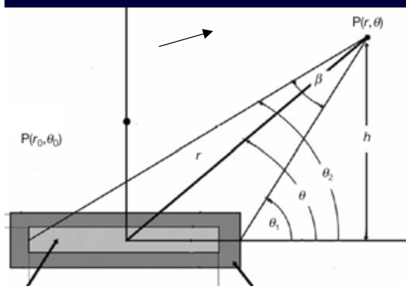
Air kerma strength

$$\dot{D}(r,\theta) = S_K \Lambda \frac{G(r,\theta)}{G(r_0,\theta_0)} g(r) F(r,\theta)$$

Dose rate constant (to water dose)

Geometry function 1/r^2

Anisotropy function (absorption and buildup dependent on theta at r)



Result (Normalization factor F)

Normalization at reference point of TG43U1 (1cm, 90 deg)

especially reliable : abundant data for composing formalism

GRD (0.097 Gy at 90 deg, 0.098 Gy at 270 deg)

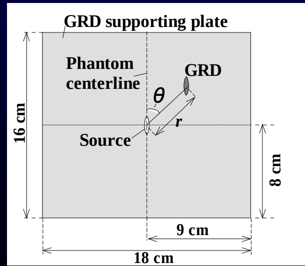
Agrees within 3 % : validity of GRD

***F* = 0.97**

TG43U1 (0.095 Gy)

***F* = 1.8**

EGS5 (0.053 Gy)

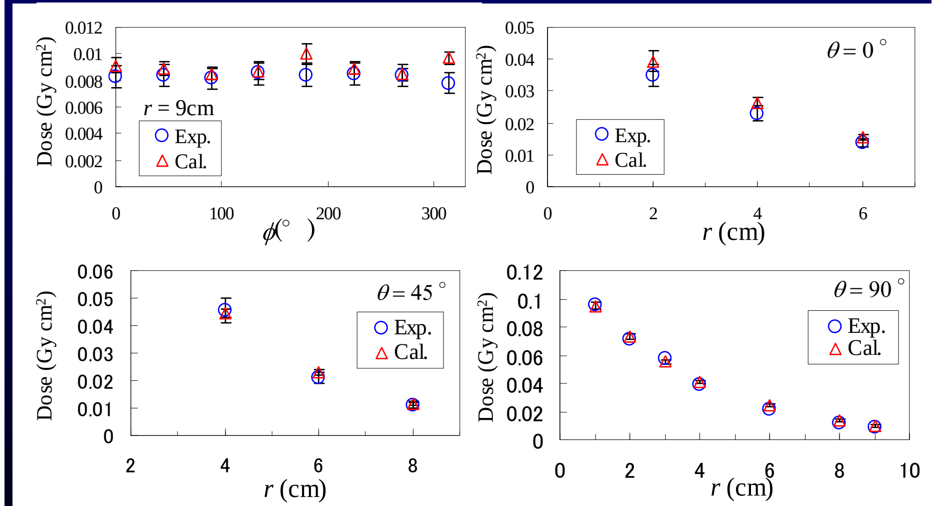


Low value is reasonable because we used integration of apparent activity with time as amount of disintegration

Available : kerma strength – apparent activity.

Purpose : relative distribution, absolute to be normalized

Result (normalized, distribution in/on phantom)



EGS5 reproduces dose distributions by GRDs to **within 25%** in geometry lacking equilibrium radiation scatter conditions.

Method (Uncertainty estimation)

Formalism

Partial derivative
Y:value required
g: parameters with uncertainty

$$\frac{\partial Y}{\partial g_i} = \frac{\left|Y(g_{\max}) - Y(g_{\min})\right|}{g_{\max} - g_{\min}}$$

Standard deviation
(rectangular probability distribution)

$$\sigma_{g_i} = \frac{\left|g_{\max} - g_{\min}\right|}{2\sqrt{3}}$$

Combined standard uncertainty with coverage factor 1 : *CSU(k=1)*

$$\sigma^2(Y\,|\,Geo) = \sum_{g_i} \left(\frac{\partial Y}{\partial g_i}\right)^2 \left(\sigma_{g_i}\right)^2$$

Method (factors to make uncertainty)

Parameters g for EGS5

(1) the position of the silver rod in the Ti shell (±0.4 mm in longitudinal direction and ±0.08 mm in transversal direction with respect to the source centerline)
(2) the angle (0–3°) between the rod and Ti shell axes
(3) end weld thickness variations (±0.15 mm)
(4) radioactive layer thickness (1.0–2.5 mm)
(5) Ti capsule thickness variations (±0.01 mm)
(6) rod end face diameter (60%–80% of the maximum rod diameter)
(7) GRD position variations (±0.15 mm in transversal direction with respect to the GRD centerline) only for GRD setup

Parameters g for GRD

(1) Photon energy from ^{125}I (3.77 to 35.4922 keV)

Result (Uncertainty estimation)

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Uncertainty for EGS5 calculated dose using GRD experimental setup.

Geometry parameter	Uncertainty at (*r*, *θ*) (1 cm, 90°)	(3 cm, 270°)	(6 cm, 45°)	(2 cm, 0°)	(9 cm, 90°)
Type A					
MC statistic	0.1%	0.5%	1.5%	0.4%	2.0%
Type B (Geometry)					
Rod shift (transversal)	0.5%	0.4%	1.1%	3.2%	1.0%
Rod shift (longitudinal)	< 0.1%	0.3%	1.1%	4.6%	0.1%
Rod tilt angle	0.2%	0.1%	1.2%	0.2%	2.4%
End weld thickness	< 0.1%	<0.1%	0.4%	4.4%	2.0%
Halide layer thickness	0.9%	0.9%	2.1%	2.9%	1.4%
Ti wall thickness	2.1%	2.0%	2.6%	2.6%	3.5%
End face radius	0.1%	<0.1%	< 0.1%	< 0.1%	0.5%
GRD position	1.7%	0.8%	0.4%	0.8%	0.1%
Quadrature sum	2.9%	2.4%	3.9%	8.2%	5.0%
Combined standard MC uncertainty ($k = 1$)	2.9%	2.4%	4.2%	8.2%	5.4%

Result (Uncertainty estimation)

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Uncertainty for GRD measurement

Component	GRD uncertainties Type A	Type B
Repeated GRD measurements	2.0%	
Uniformity of dose at GRD calibration		2.0%
GRD sensitivity	2.4%	3.0%
GRD position		0.1-1.7%
Energy response		8.4%
Source strength	2.0%	2.0%
Quadrature sum	3.7%	9.4-9.6%
Combined standard uncertainty ($k = 1$)	10.1-10.2%	

Result (Distribution in/on phantom)

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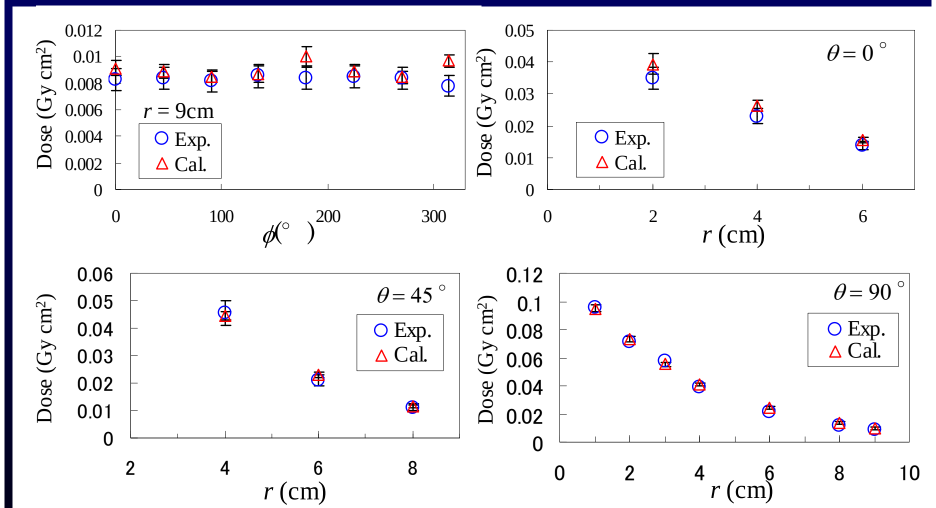

EGS5 reproduces dose distributions by GRDs to within 25%
in geometry lacking equilibrium radiation scatter conditions.

the combined standard uncertainty with the coverage factor of 2 to 3.

Result (EGS 5 ---- TG43U1 parameter)

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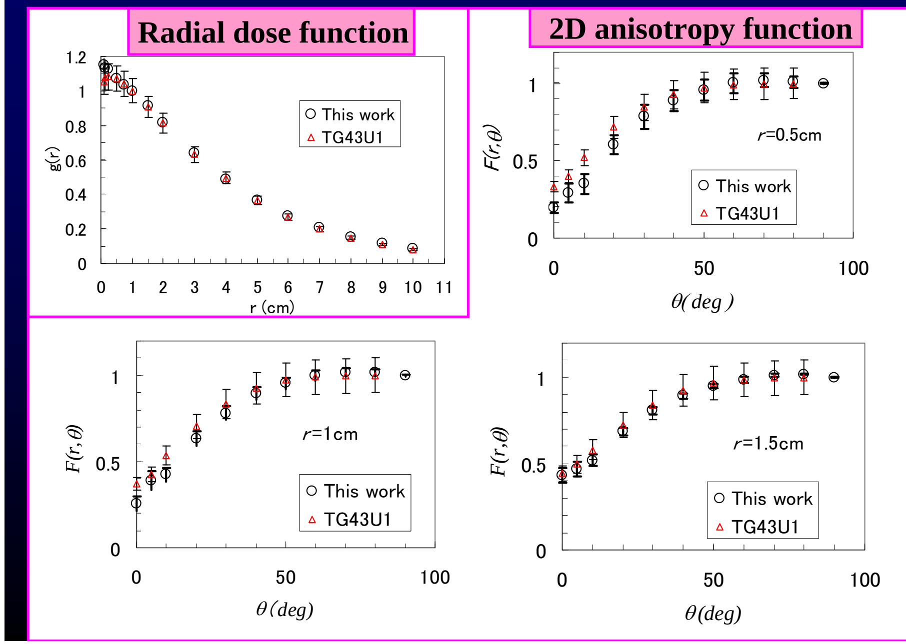
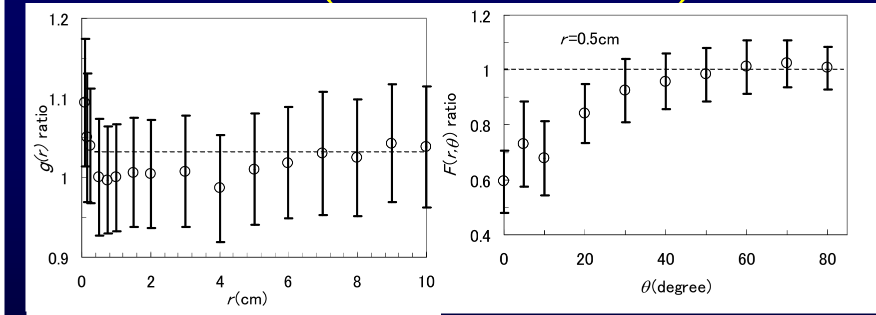
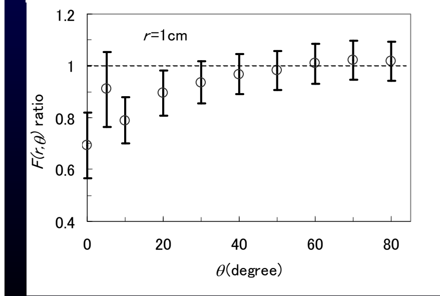


Result (Ratio EGS5 / TG43U1)





Agreement consistent with previous study

g(r) **to within 9%**
F(r,θ) **to within 5% except for**
40 %(0.5cm, 0deg), 27 %(0.5cm, 5deg), 32%(0.5cm, 10deg), 16%(0.5cm, 20deg), 31%(1cm, 0deg), 21%(1cm, 10deg) 10%(1cm, 20deg) and (2cm, 10deg)

Summary

Agreements between EGS5 with Kennedy's source , GRD, TG43U1

- **EGS5 agreed GRD in 25%.**
- **Absolute value of GRD agreed with TG43U1 in 3%.**
- ***F(r,q)*** **and** ***g(r)*** **by EGS5 agreed with TG43U1.**

➡ **Supports validity of EGS5, GRD, TG43U1**

- **EGS5 calculation is a potential option for treatment planning applicable to <u>inter-seed attenuation</u> and <u>geometry lacking equilibrium radiation scatter</u>.**
- **GRD can also be used in brachytherapy dosimetry.**

Detailes in : K.Tanaka et al. Med. Phys. 38 (2011) 3069-3076.

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