

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

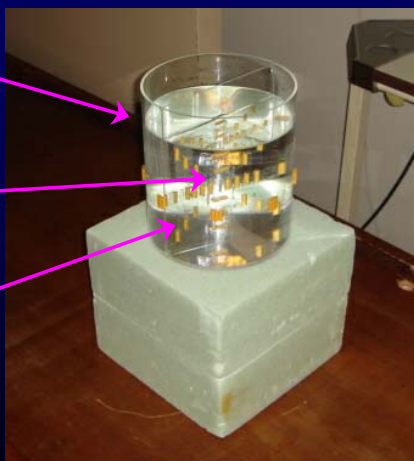
Methods (Exp.)

Irradiation for 1 day

Water phantom
(18cm diam. X 16cm)

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

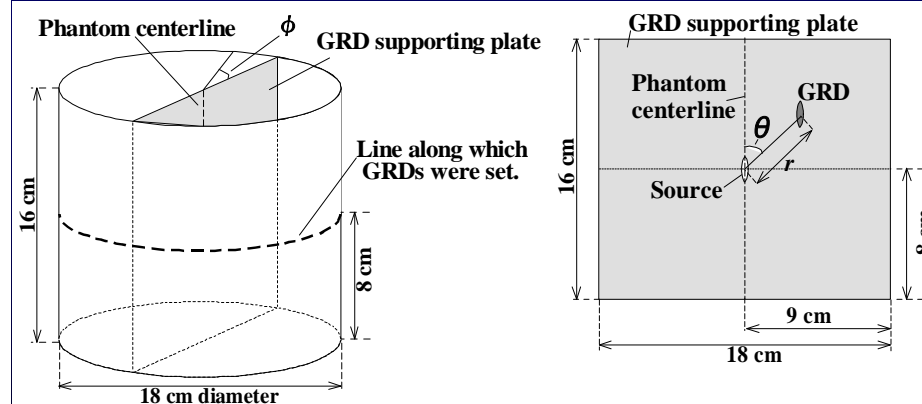
Radiophotoluminescent
glass rod dosimeter
(Asahi Techno Glass GD-302M)



Calibration:

6MV, 10cm into Tough Water, 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)

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Calibration at 6MV
to correct sensitivity
difference among detectors

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

Absorbed dose
to water by ^{125}I

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

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

Energy response
correction

Reading of dosimeter

Methods (Exp. Correction)

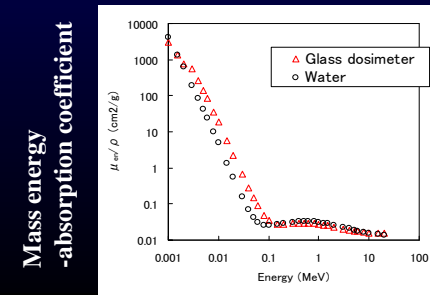
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Absorbed dose
to water by ^{125}I

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

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

R_{6MV} ϵ_{6MV} Detector deviation etc.



Reading: glass dose
Needed: water dose

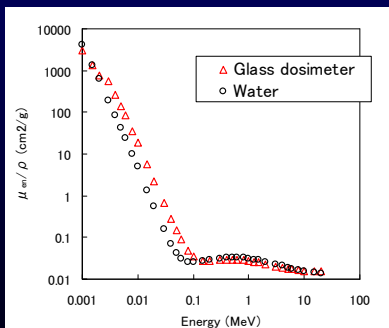
J.H. Hubbell and S.M.Seltzer,
NISTIR 5632 (Ver 1.4); 2004

Methods (Exp. Correction)

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Absorbed dose
to water by ^{125}I

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



$E=0.291$

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

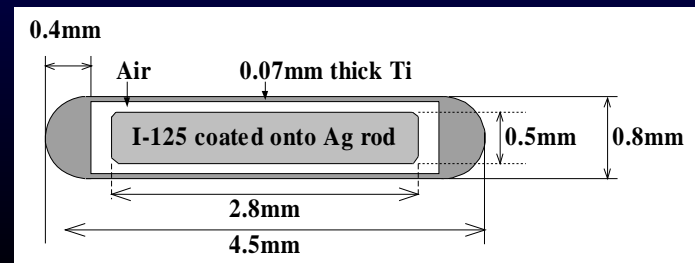
$$(\mu_{en}/\rho)_{x, \text{Water}/\text{Glass}} = \frac{(\mu_{en}/\rho)_{x, \text{Water}}}{(\mu_{en}/\rho)_{x, \text{Glass}}}$$

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

Methods (Cal. for GRD measurement)

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



Methods (Cal.)

¹²⁵I : 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)

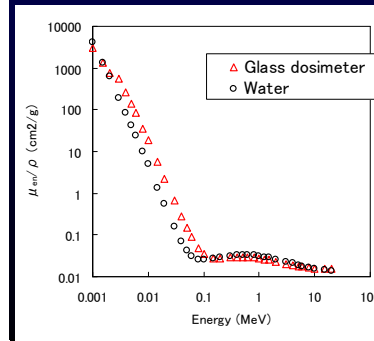
Absorbed dose to water by ¹²⁵I

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

EGS output
(Glass dose)

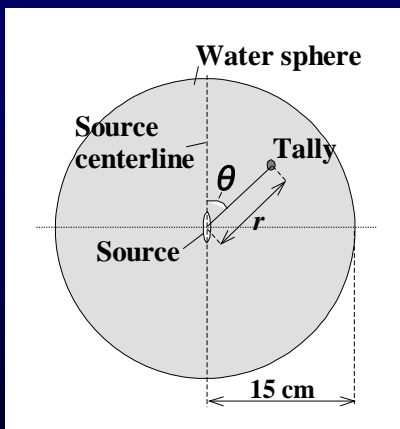
Energy correction (0.328)

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

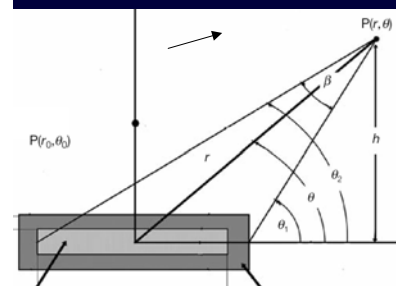
Air kerma strength

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

Dose rate constant
(to water dose)

Geometry function
 $1/r^2$

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



Result (Normalization factor F)

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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)

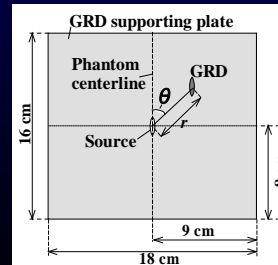
Agrees within 3 % : validity of GRD

$F = 0.97$

TG43U1 (0.095 Gy)

EGS5 (0.053 Gy)

$F = 1.8$



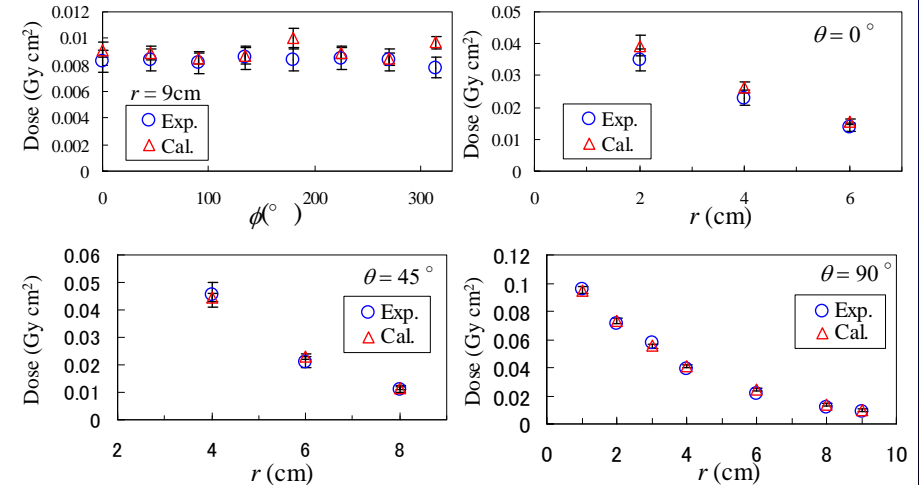
Low value is reasonable because we used
integration of apparent activity with time as
amount of disintegration

Available : kerma strength – apparent activity.

Purpose : relative distribution,
absolute to be normalized

Result (normalized, distribution in/on phantom)

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

Method (Uncertainty estimation)

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Formalism

Partial derivative

Y: value required

g: parameters with uncertainty

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

Standard deviation

(rectangular probability distribution)

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

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

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

Method (factors to make uncertainty)

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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 ($0-3^\circ$) 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)

Uncertainty for EGS5 calculated dose using GRD experimental setup.

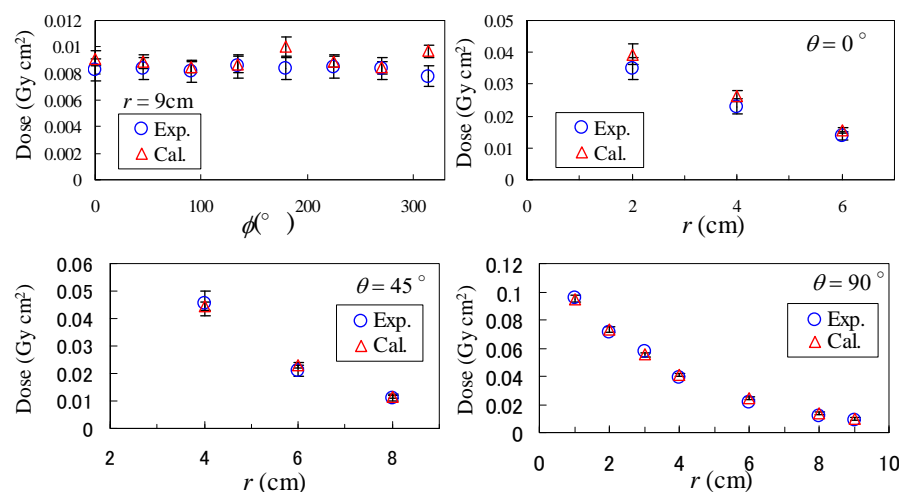
Geometry parameter	Uncertainty at (r, θ)				
	(1 cm, 90°)	(3 cm, 270°)	(6 cm, 45°)	(2 cm, 0°)	(9 cm, 90°)
Type A					
MC statistic	0.1%	0.5%	1.5%	0.4%	2.0%
Type B (Geometry)					
Rod shift (transversal)	0.5%	0.4%	1.1%	3.2%	1.0%
Rod shift (longitudinal)	< 0.1%	0.3%	1.1%	4.6%	0.1%
Rod tilt angle	0.2%	0.1%	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)

Uncertainty for GRD measurement

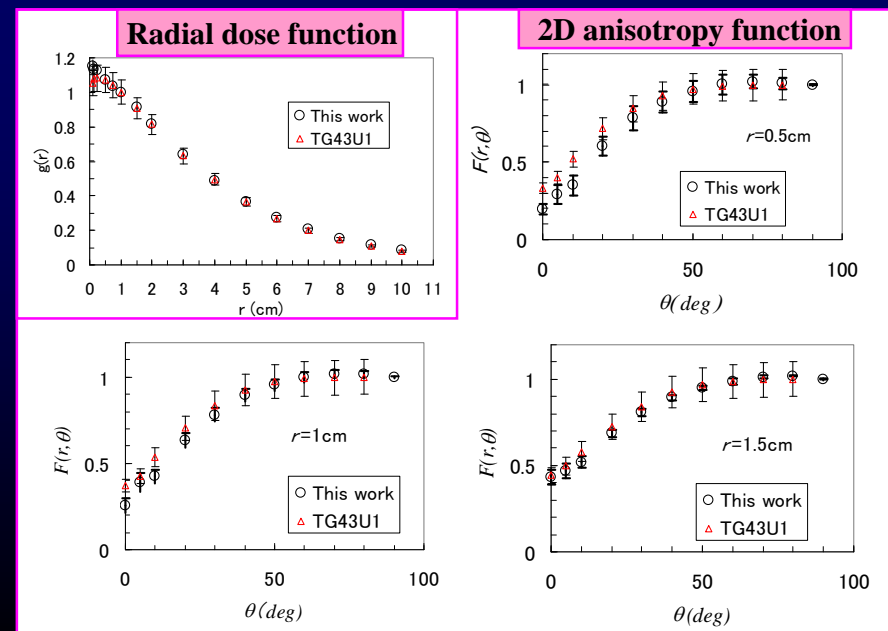
Component	GRD uncertainties	
	Type A	Type B
Repeated GRD measurements	2.0%	
Uniformity of dose at GRD calibration		2.0%
GRD sensitivity	2.4%	3.0%
GRD position		0.1-1.7%
Energy response		8.4%
Source strength	2.0%	2.0%
Quadrature sum	3.7%	9.4-9.6%
Combined standard uncertainty ($k = 1$)	10.1-10.2%	

Result (Distribution in/on phantom)

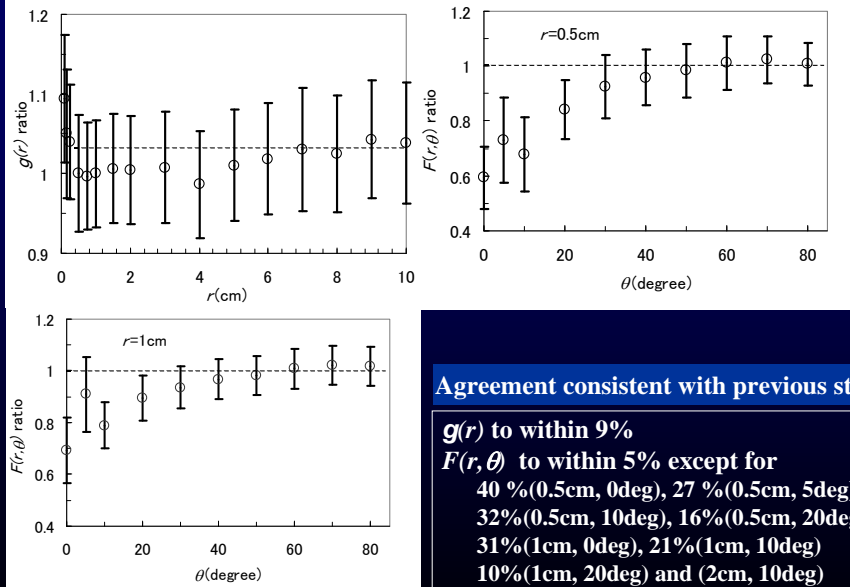


EGS5 reproduces dose distributions by GRDs to **within 25%** in geometry lacking equilibrium radiation scatter conditions. the combined standard uncertainty with the coverage factor of 2 to 3.

Result (EGS 5 ---- TG43U1 parameter)



Result (Ratio EGS5 / TG43U1)



Agreement consistent with previous study

$g(r)$ to within 9%
 $F(r, \theta)$ 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 inter-seed attenuation and geometry lacking equilibrium radiation scatter.
- **GRD** can also be used in brachytherapy dosimetry.

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

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