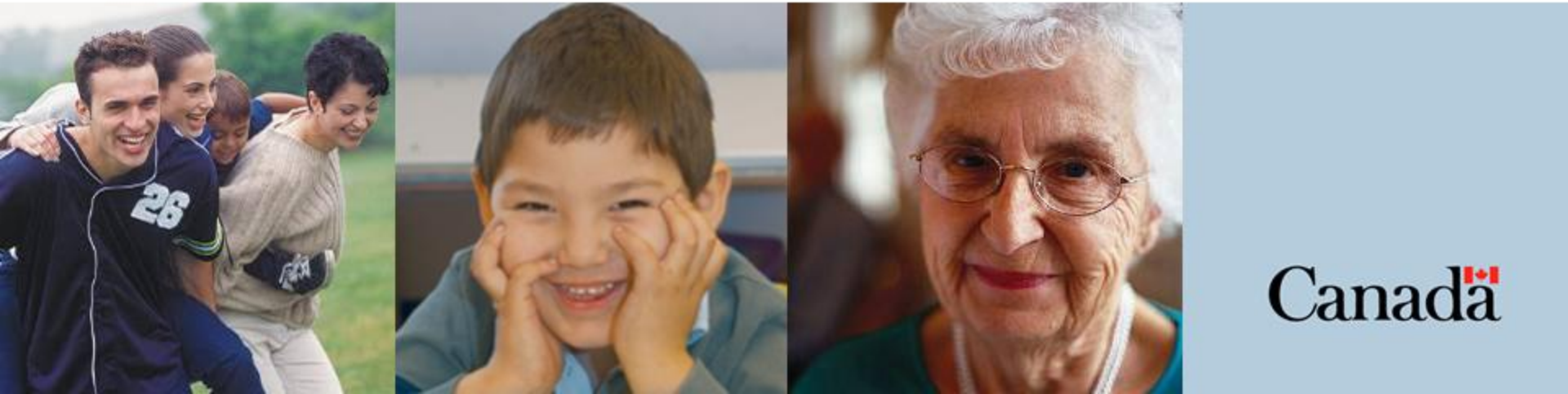
A Microdosimetric Study on Radiation Quality of Tritium

Jing Chen

Radiation Protection Bureau, Health Canada

57th Annual Meeting of the Health Physics Society
July 24th 2012, Sacramento



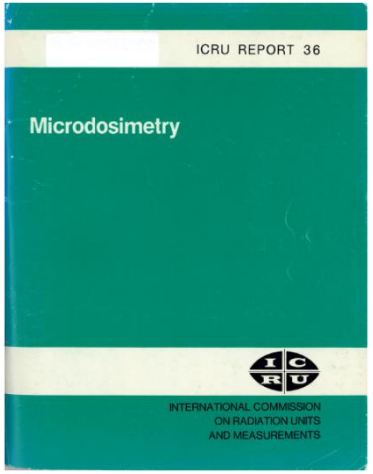
Contents

- Basics of microdosimetry
- Track structure of HTO and OBT
- Radiation quality of HTO and OBT



Basics of Microdosimetry

- Ionizing radiation deposits energy in discrete packages non-uniformly throughout the irradiated volume.
- Radiations which differ in the number, size and distribution of energy deposits may cause different biological effects for the same absorbed dose.
- These differences between radiations begin with spatial patterns of the initial energy deposits, although chemical and biological environment play an important role.
- To improve our understanding of radiation effects through concept development and systematic analysis of microscopic distribution of energy deposition in irradiated matter.
- Microdosimetric quantities describe energy deposition events in microscopic structures.





Basics of Microdosimetry

Basic quantities - *stochastic*

The energy deposit, ε_i, the energy deposited in a single interaction, i.

The energy imparted, ε, the sum of all energy deposits in a volume

$$\varepsilon = \sum_i \varepsilon_i$$

The specific energy, z, the energy imparted divided by the mass of the volume:

$$z = \varepsilon / m$$

The lineal energy, y, the energy imparted divided by the mean chord length in that volume:

$$y = \varepsilon / \bar{\ell}$$

To determine radiation quality, it is useful to consider the probability distribution of z or y: $f(z)$ or $f(y)$



Basics of Microdosimetry

The concept of *Single Event*s

An energy deposition event is an independent particle track, initiated from a primary particle.

Energy imparted to a target volume may be due to one or more energy deposition events.

To determine radiation quality, it's important to measure or calculate energy imparted to a target volume due to single events:

$f_1(z)$ *or* $f_1(y)$; $\overline{z_D}$ or $\overline{y_D}$

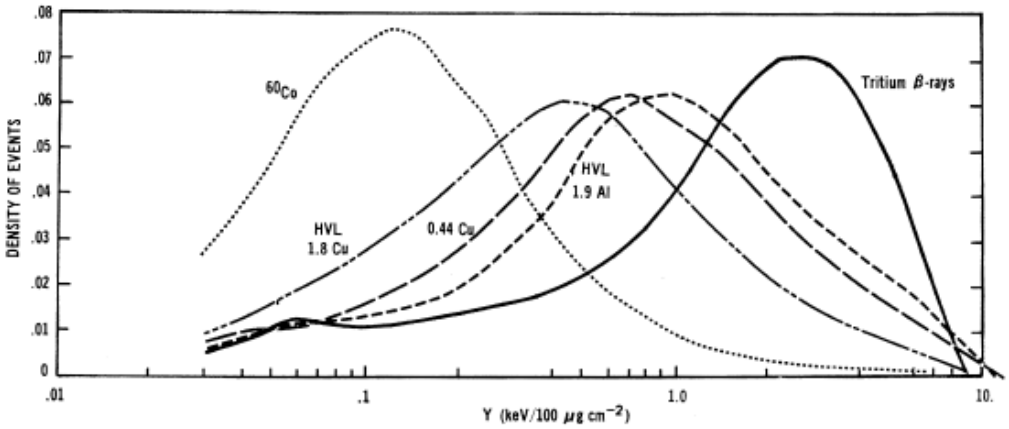
At 6th Symposium on Microdosimetry in 1978, Harald H. Rossi proposed "For purposes of radiation protection, the quality factor should be based on *y* rather than *LET*."



Microdosimetry of Tritium

Measurement of event spectra from 250kVp x-rays, ^{60}Co gamma rays and tritium beta rays using a grid-walled proportional counter

William H. Ellett and Leslie A. Braby at the 3rd Symposium of Microdosimetry, 1971



Probability density of single events occurring in spheres of 92µg/cm^2 in diameter.

Estimated RBE based on dose average of specific energy imparted by single events in spherical sites

Site diameter (100 μg cm^{-2})	^{60}Co	250 kVp HVL 1.8 mm Cu	Tritium
0.6	0.5	1	1.6
1	0.4	1	1.5
2	0.4	1	1.3
3	0.4	1	1.1
5	0.4	1	1

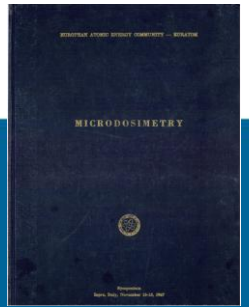




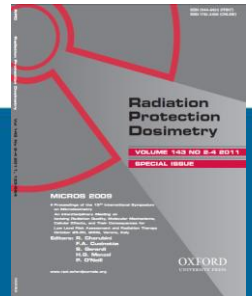




1st 1967



=> 15th 2009



Microdosimetry of Tritium

- Example of experimental studies

Compared to ^{60}Co gamma rays,

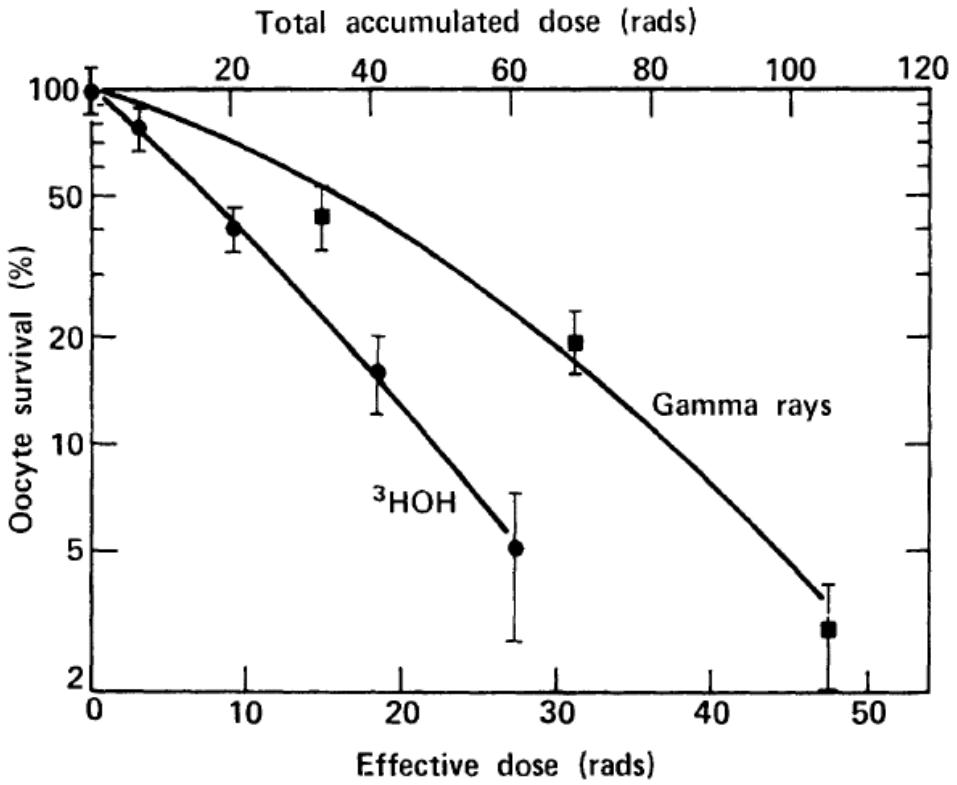
the RBE of tritium is great than 1,

it is not constant and increases at low dose.

At low dose and low dose rate,

for size < 1μm, the RBE of ^{3}H

estimated in range 2.9 to 4.2.



Dobson and Kwan,
Radiat. Res. 66, 615-625 (1976)



Microdosimetry of Tritium

- In addition to dose rate and target size,
  low-dose RBE depends also on biological endpoints and cellular environment.

Radiat Environ Biophys
DOI 10.1007/s00411-012-0424-y

ORIGINAL PAPER

Estimated yield of double-strand breaks from internal exposure to tritium

Jing Chen

The average DSB yields of 2.7, 0.93, 2.4 and 1.6 DSBs/Gy/Da x10^{-11} could be reasonable estimates for tritium in plasmid DNAs, yeast cells, Chinese hamster V79 cells and human fibroblasts, respectively. If a biological system is not specified, the DSB yield from tritium exposure can be estimated as (2.3 0.7) x 10^{-11} DSBs Gy^{-1} Da^{-1}, which is a simple average over experimentally determined yields of DSBs for low energy electrons in various biological systems without considerations of variations caused by different techniques used and obvious differences among different biological systems where the DSB yield was measured.

Compared to ^{60}Co gamma rays:

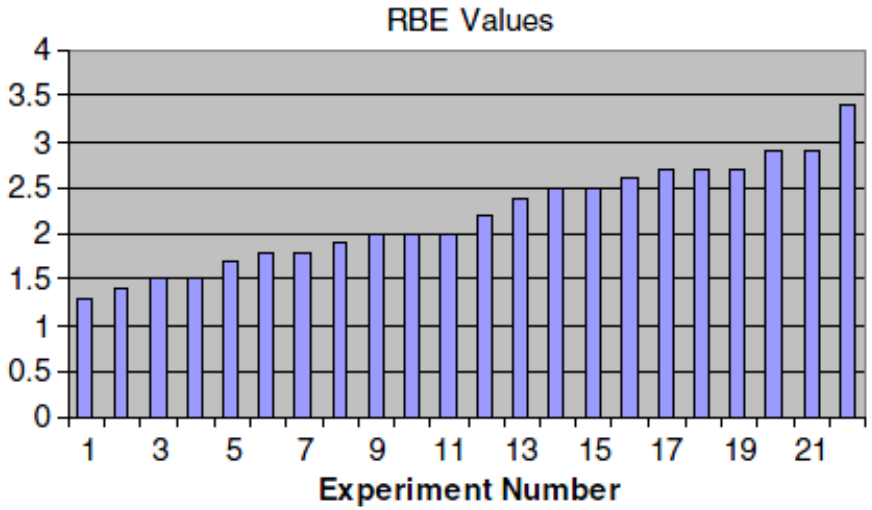
$RBE|_{DSB} = 2.7/1.6 = 1.7$ for plasmid DNAs
$RBE|_{DSB} = 0.93/0.42 = 2.2$ for yeast cells
$RBE|_{DSB} = 2.4/1.15 = 2.1$ for V79 cells
$RBE|_{DSB} = 1.6/0.84 = 1.9$ for HF cells



Radiation Quality of HTO

- A summary paper by I. Fairlie, J. Radiol. Prot. 27, 157-168 (2007)

RBE values for HTO/gamma



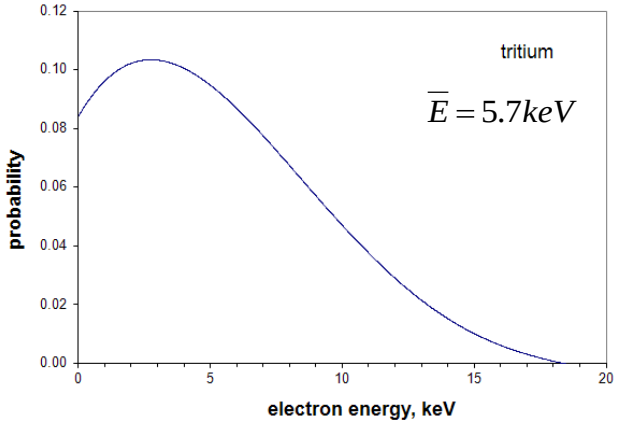
A simple average gives

RBE = 2.2

Experiment Number	Observed RBE value	Reference
1	1.3	Ueno *et al* 1989
2	1.4	Carr and Nolan 1979
3	1.49	Morimoto *et al* 1989
4	1.5	Carsten and Commerford 1976
5	1.7	Yamada *et al* 1982
6	1.8	Matsuda *et al* 1985
7	1.8	Matsuda *et al* 1985
8	1.9	Suyama and Etoh 1985
9	2	Hyodo-Taguchi, Hyodo 1985
10	2.0	Ueno *et al* 1982
11	2	UNSCEAR 1982
12	2.2	Etoh and Hyodo-Taguchi 1982
13	2.4	Nakamura *et al* 1985
14	2.5	Searle 1974
15	2.5	Xiang-yan *et al* 1986
16	2.6	Satow *et al* 1989
17	2.7	Kashima *et al* 1985
18	2.7	Byrne and Lee 1989
19	2.7	Nomura and Yamamoto 1989
20	2.9	Ueno *et al* 1989
21	2.9	Dobson and Kwan 1976
22	3.4	Prosser *et al* 1983 and Lloyd *et al* 1988



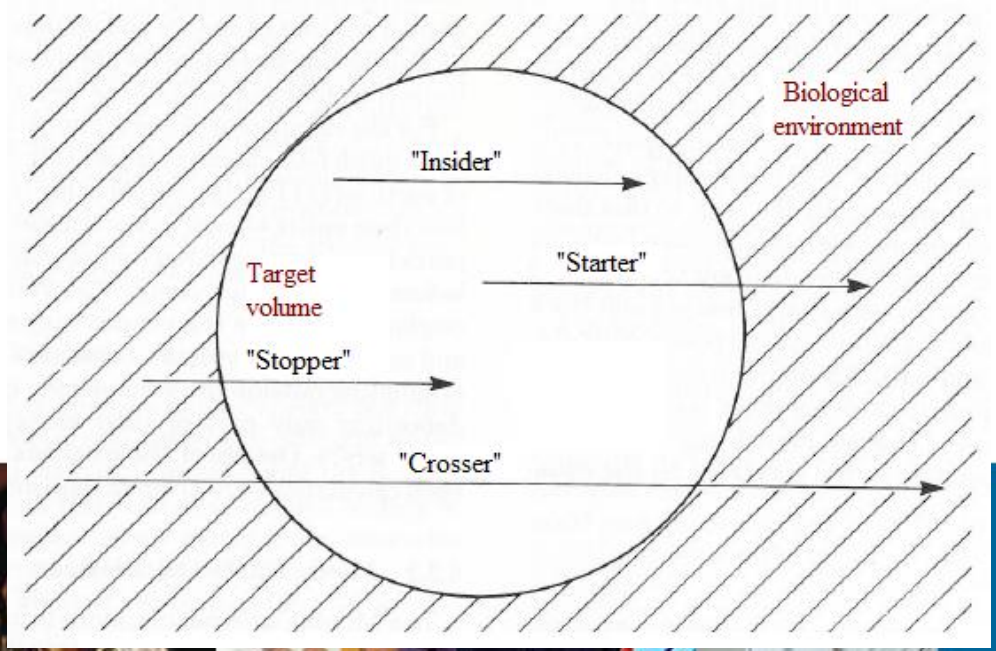
Why RBE of OBT can differ from HTO ?

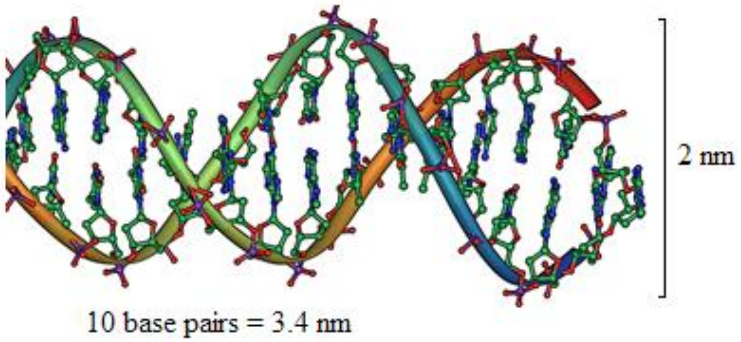


Electrons in water

Energy	Range	LET_{tot} keV/µm
20 eV	0.8 nm	13
50 eV	2.9 nm	23
100 eV	4.5 nm	30
500 eV	22 nm	20
1 keV	53 nm	13
5 keV	0.77 µm	3.9
10 keV	2.5 µm	2.3
50 keV	42 µm	0.68

Four classes of tracks





Radiation Quality of OBT

- The energy imparted in cells, cell nuclei or DNA structures depends on the spatial distribution of the emitters and the range of the emitted particles.
- At the 6th Symposium on Microdosimetry

MICRODOSIMETRY OF RADIOACTIVE NUCLEI INCORPORATED INTO THE DNA OF MAMMALIAN CELLS

D.E.Charlton, J.Booz, J.Fidorra, Th.Smit, L.E.Feinendegen
Institut für Medizin, Kernforschungsanlage Jülich, D-5170 Jülich

Dose distribution factor (DDF) was defined as the absorbed dose in the cell nucleus per unit radioactivity for heterogeneous distribution of activity (incorporated into the DNA), divided by the dose from a uniform distribution of the same amount of activity.

For a mean human cell with a cell diameter of 11.5 µm and a nucleus of 8.0 µm ($V_{cell}/V_{nucleus} = 3$),

DDF=2.8 for tritium



Radiation Quality of OBT

At the 14th Symposium on Microdosimetry

RADIATION QUALITY OF TRITIUM

Jing Chen*

Radiation Protection Dosimetry (2006), Vol. 122, No. 1–4, pp. 546–548

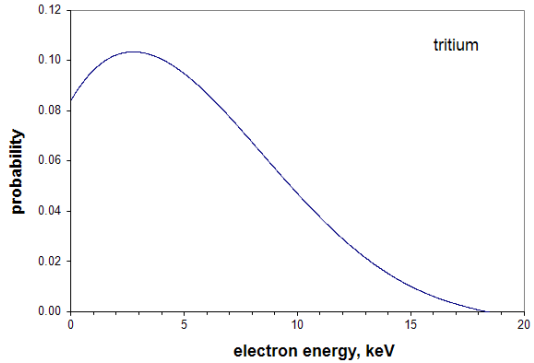
Assuming the ratio of $\overline{y_D}$ representing the ratio of RBEs

Calculating single event distribution $f_1(y)$ and associated parameter $\overline{y_D}$ for spherical sites (*d = 10nm to 1μm*)

Simulation starts with random sampling an electron with *E* from the spectrum:

OBT:

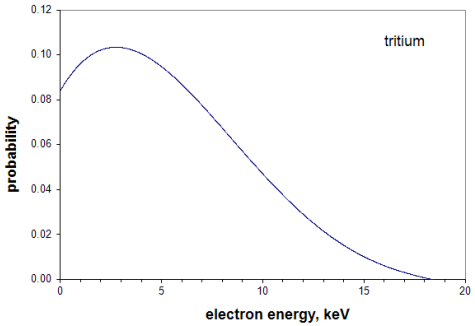
- an electron has equal probability to start at any point within the sphere and isotropic in direction;
- energy imparted to the sphere is scored event by event for more than 100,000 events;
- $\overline{y_D}$ is then calculated from the distribution $f_1(y)$.





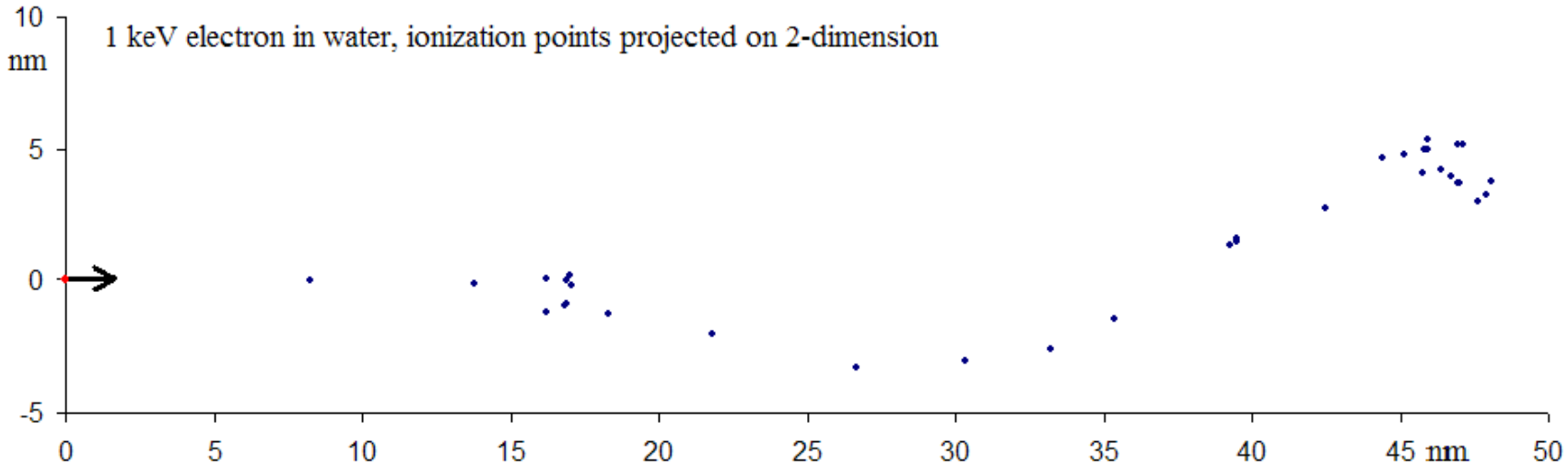
Radiation Quality of OBT

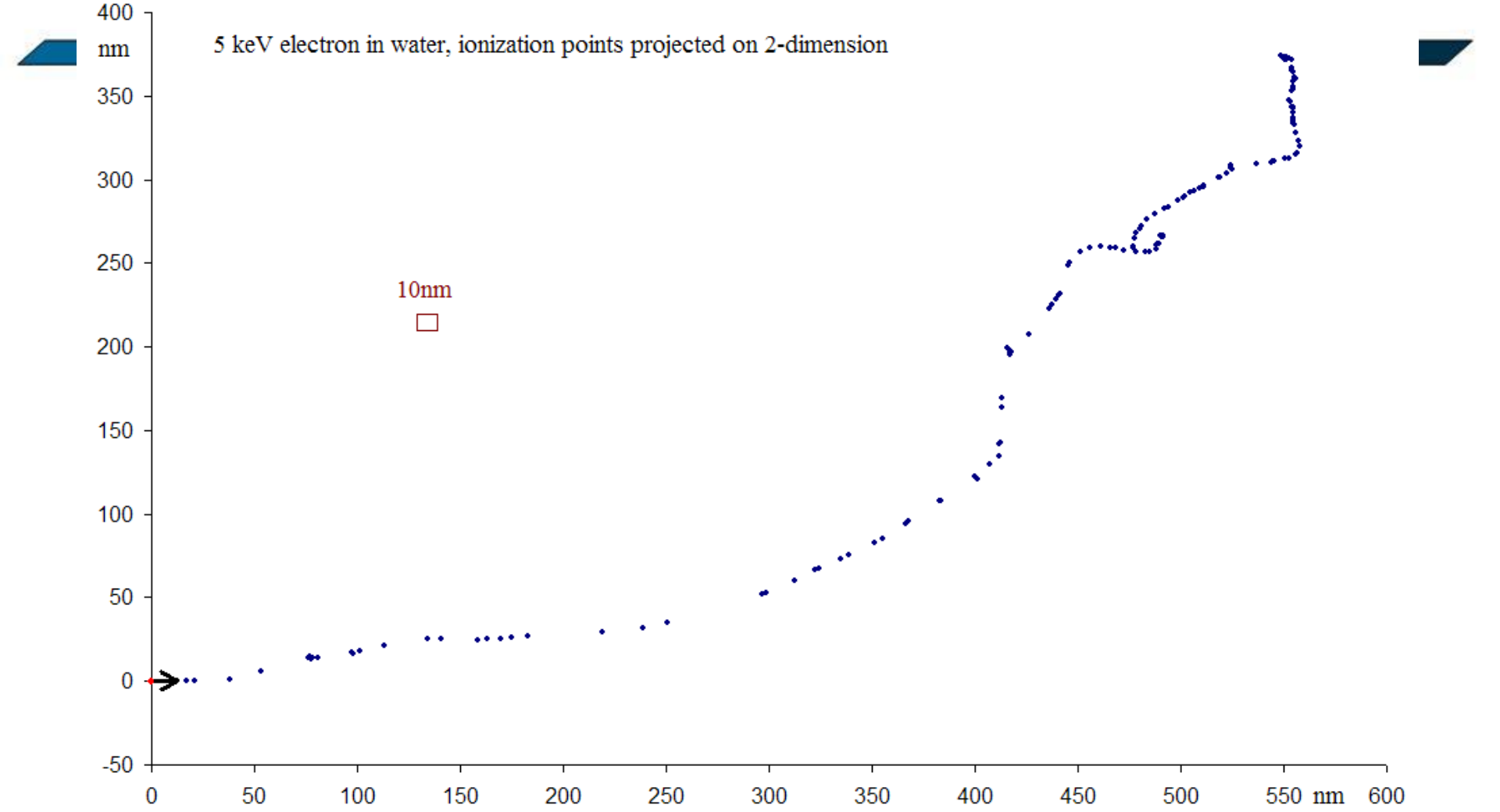
Simulation starts with random sampling an electron with *E* from the spectrum:



HTO:

- all energy deposits from the entire electron track are simulated and recorded point by point;
- the spherical site is placed randomly along the electron track and centered at a transfer point;
- energy imparted (all transfer points within the sphere) is scored event by event;
- $\overline{y_D}$ is then calculated from the distribution $f_1(y)$.



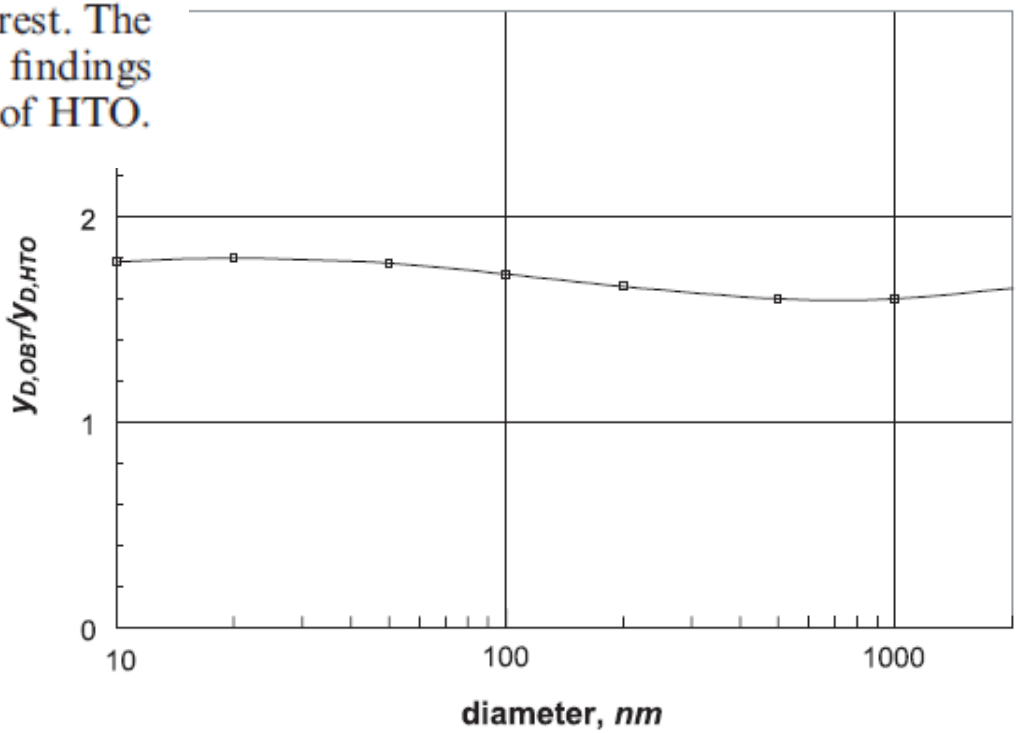

5 keV electron in water, ionization points projected on 2-dimension
nm
400
350
300
250
200
150
100
50
0
-50
10nm
0
50
100
150
200
250
300
350
400
450
500
550 nm
600



Radiation Quality of OBT

CONCLUSION

The dose mean lineal energies of OBT are about a factor of 1.7 higher than those of HTO in a wide range of target dimensions of biological interest. The results are consistent with radiobiological findings that OBT is about twice as effective as that of HTO.

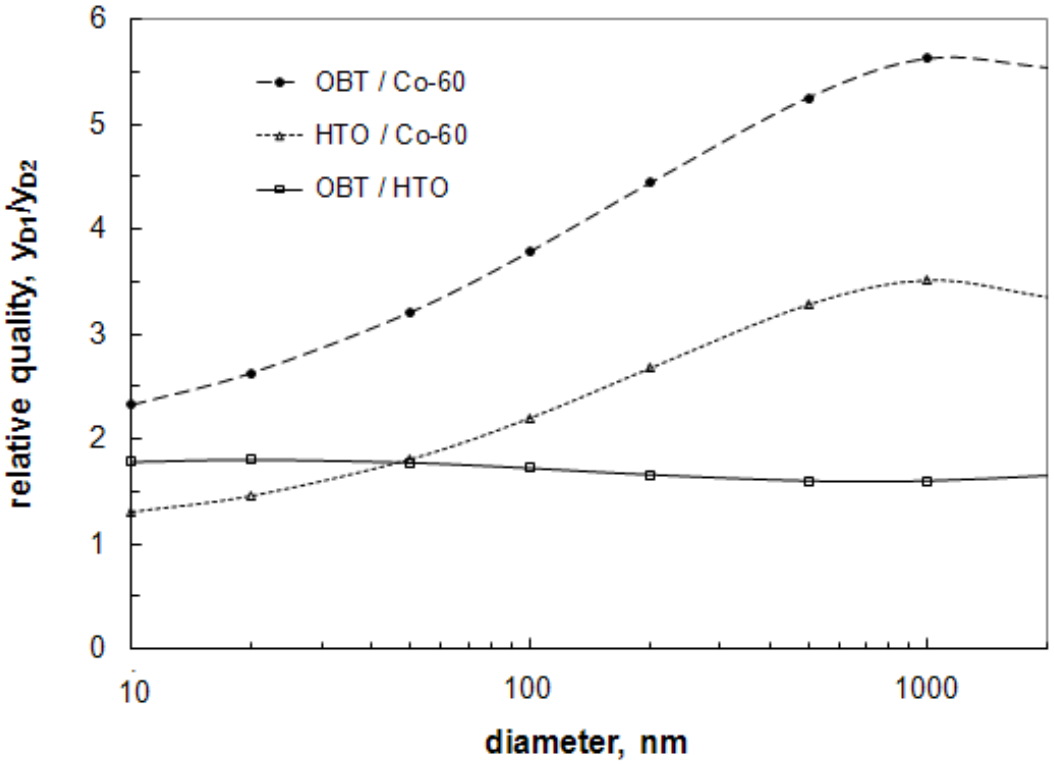


Ratios of the y_D for OBT to the y_D for HTO in spherical regions



Radiation Quality of OBT

For ^{60}Co gamma rays, $\overline{y_D}$ is calculated in the similar way as for HTO, from all secondary electron tracks along a photon path of 20μm.



For site sizes 10nm to 1μm,

Compared to ^{60}Co gamma rays

RBE ≈ 1.3 ~ 3.5 for HTO

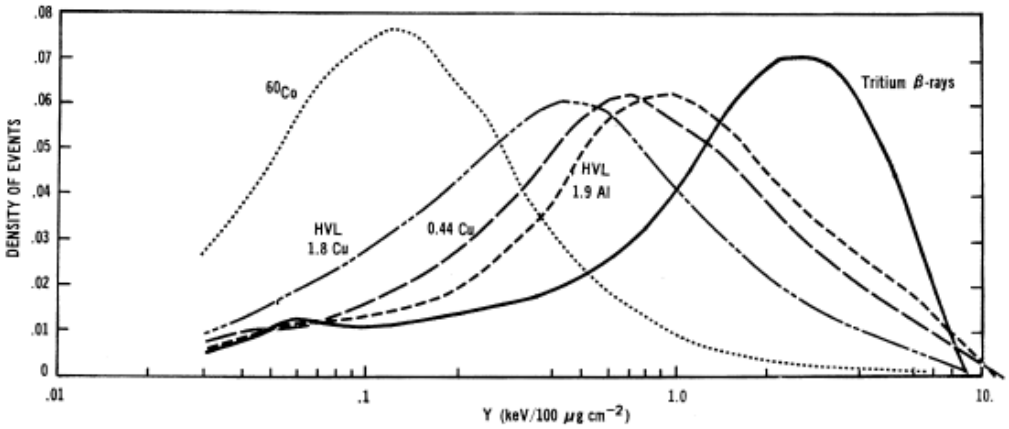
RBE ≈ 2.3 ~ 5.6 for OBT



Microdosimetry of Tritium

Measurement of event spectra from 250kVp x-rays, ^{60}Co gamma rays and tritium beta rays using a grid-walled proportional counter

William H. Ellett and Leslie A. Braby at the 3rd Symposium of Microdosimetry, 1971



Probability density of single events occurring in spheres of 92µg/cm^2 in diameter.

Estimated RBE based on dose average of specific energy imparted by single events in spherical sites

Site diameter (100 μg cm^{-2})	^{60}Co	250 kVp HVL 1.8 mm Cu	Tritium
0.6	0.5	1	1.6
1	0.4	1	1.5
2	0.4	1	1.3
3	0.4	1	1.1
5	0.4	1	1

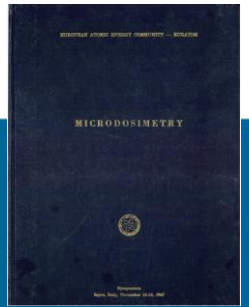




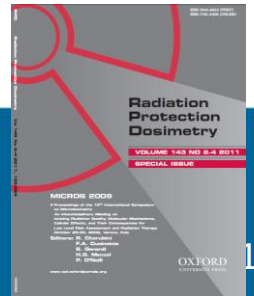




1st 1967



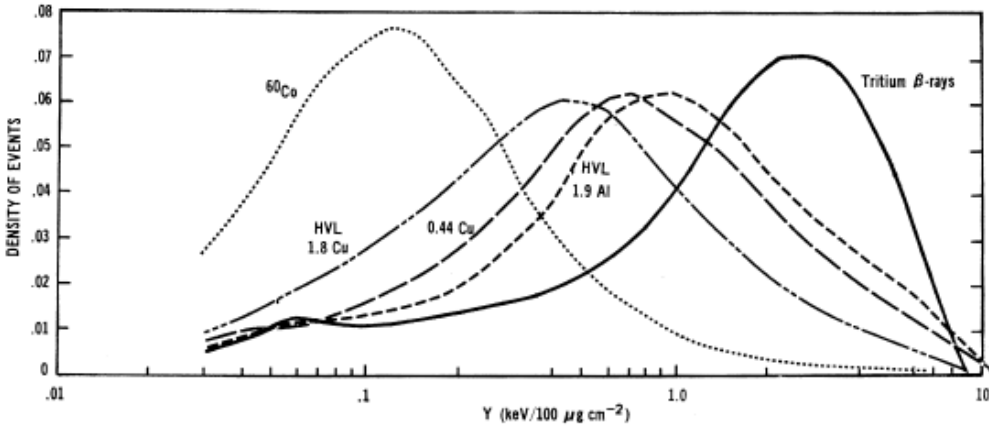
=> 15th 2009



Radiation Quality of OBT

To experimentally determine the event spectra from tritium, tritiated methane (concentration of a few ppm) was added to counting gas.

The exposure geometry in this case corresponds to a spherical site in a randomly labelled medium.



Probability density of single events occurring in spheres of 92µg/cm^2 in diameter.

Estimated RBE based on dose average of specific energy imparted by single events in spherical sites

Site diameter (100 μg cm^{-2})	^{60}Co	250 kVp	Tritium
		HVL 1.8 mm Cu	
0.6	1	2.0	3.2
1	1	2.5	3.8
2	1	2.5	3.3
3	1	2.5	2.8
5	1	2.5	2.5

For ^{3}H incorporated in spherical cells of 1 µm

$$RBE|_{Co\text{-}60} \approx 3.8$$



Summary

Because tritium emits low energy electrons,

electrons < 1 keV deposit all their energy within 50 nm,
electrons of about 100 eV have the highest LET,

the energy deposition (energy imparted ε from single events) of tritium incorporated into target volume (subcellular structures, such as DNA) is much denser than the energy deposition averaged over all possible segments of electron tracks from tritium up to 18 keV.

At low dose and low dose-rate (single event spectra), tritium bound to sites of biological interest can deliver higher doses than uniformly distributed tritium.

From microdosimetric point of view

on average

Compared to ^{60}Co gamma rays

RBE ≈ 2 for HTO

RBE ≈ 4 for OBT



Thanks



For comments and further discussion

contact: jing.chen@hc-sc.gc.ca





