The luminescence efficiency response of Al_2O_3:C, LiF:Mg,Ti and CaF_2:Tm detectors to high-energy heavy charged particles:

Results from 6th ICCHIBAN

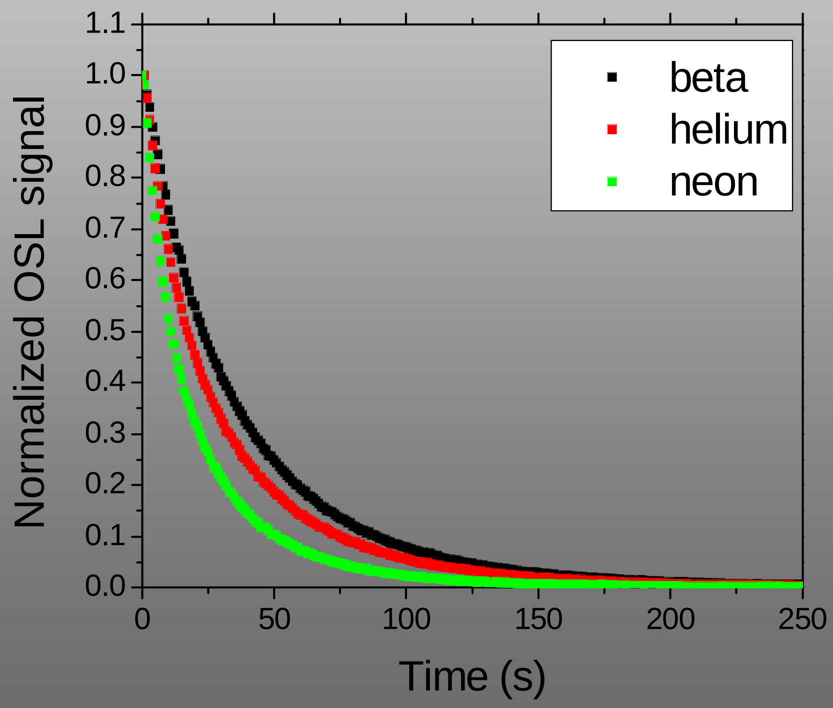
Ramona Gaza[1], Eduardo G. Yukihara & Stephen W.S. McKeever

Department of Physics, OSU, OK, USA
[1]Now at SRAG, JSC, NASA, Houston, TX, USA

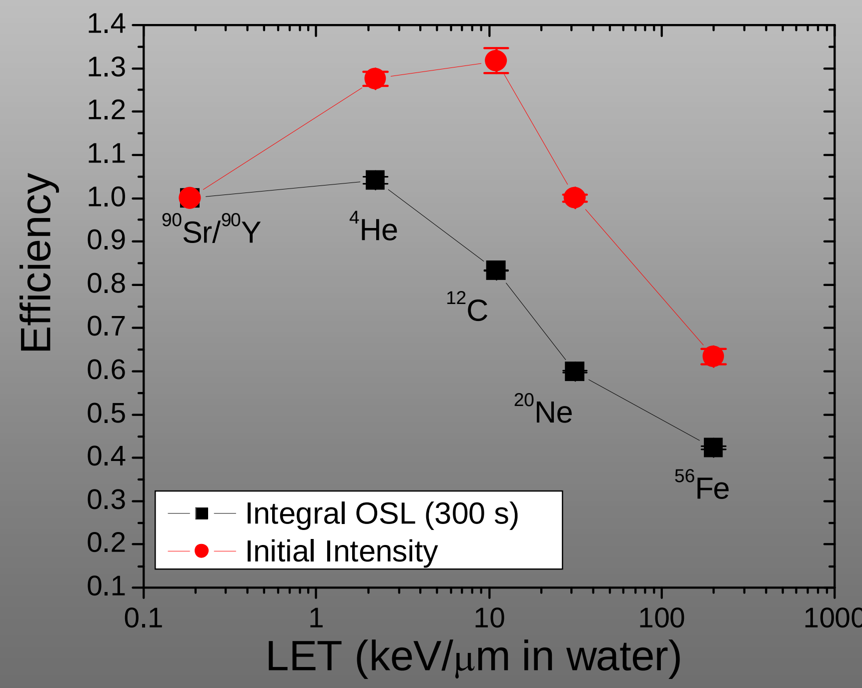
Background:

OSL from Al_2O_3 as a dosimetry method for space radiation fields (following NCRP-142): Results from Previous ICCHIBAN and HIMAC exposures

OSL decay curve shape depends on particle type for high LET particles



Efficiency depends upon OSL measurements method and form



LET-dependence:

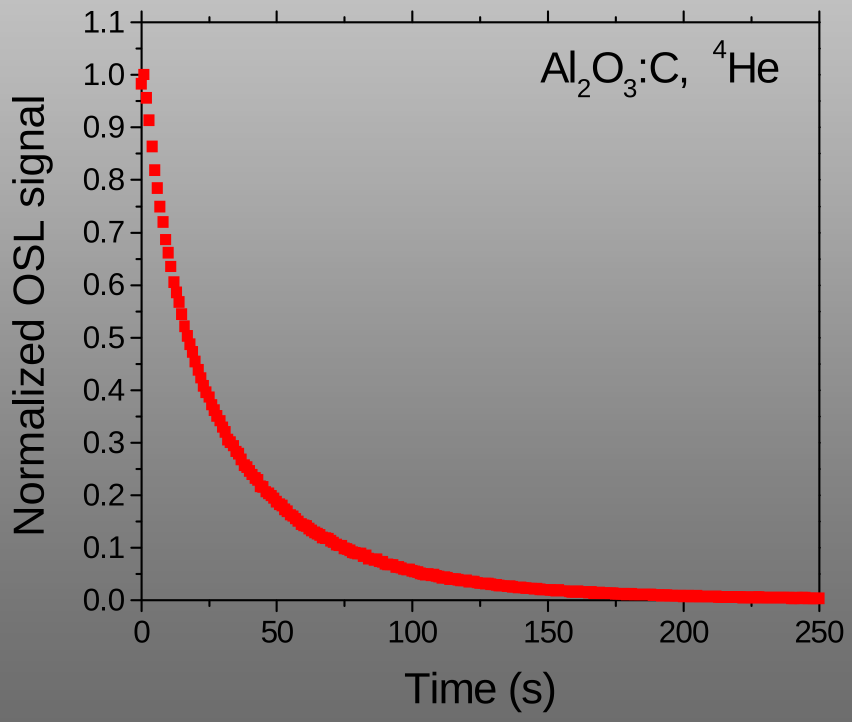
What parameters of the OSL decay curve depend on LET ?

- Ratio-*R* method: ratio of OSL area to initial intensity
- Ratio-τ method: ratio of t_1 by t_2 from a exponential fit of the OSL decay curves

$$R = \frac{D_\gamma(OSL\,300s)}{D_\gamma(OSL\,1s)}$$

$$I_{OSL} = \sum_k A_k \exp\left(-\frac{t}{t_k}\right)$$

$$R_\tau = t_1 / t_2$$



ICCHIBAN 6: Irradiations:

(a) *Single particles*

Particle	Nominal Energy (MeV/n)	LET (keV/ μ m in H_2O)	Nominal Dose (mGy)
^{12}C	135	24.4	50
^{40}Ar	500	93.9	50
^{40}Kr	400	451	50

(b) *Fragmentation:*

5 mg/cm^2 PMMA filter; 50 mGy nominal dose

(c) *Blinds:*

6 unknown exposures

Analysis:

Measured quantity: equivalent gamma dose calibrated against ^{60}Co (water) D_γ

$$D_\gamma = D_R \times \frac{I_{HCP}}{I_R}$$

luminescence intensity after HCP dose

reference ^{60}Co dose

luminescence intensity after gamma dose

Absorbed dose $$D = \frac{D_\gamma}{\eta}$$

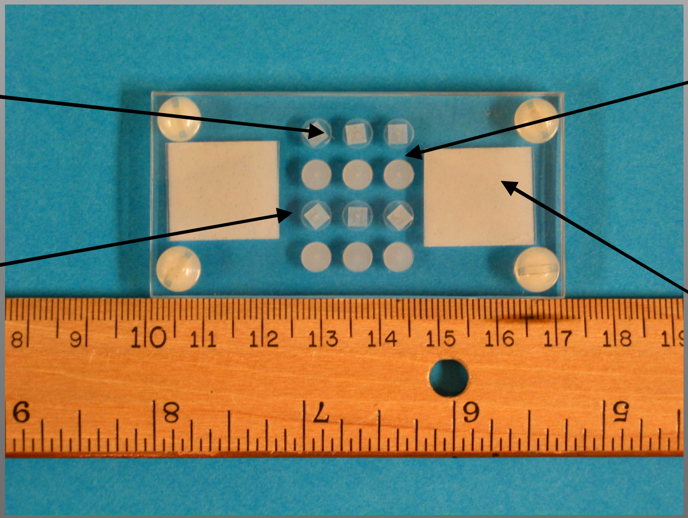
HCP dose

Luminescence efficiency $$\eta = \frac{I_{HCP} / D_{HCP}}{I_R / D_R} = \frac{D_\gamma}{D_{HCP}}$$

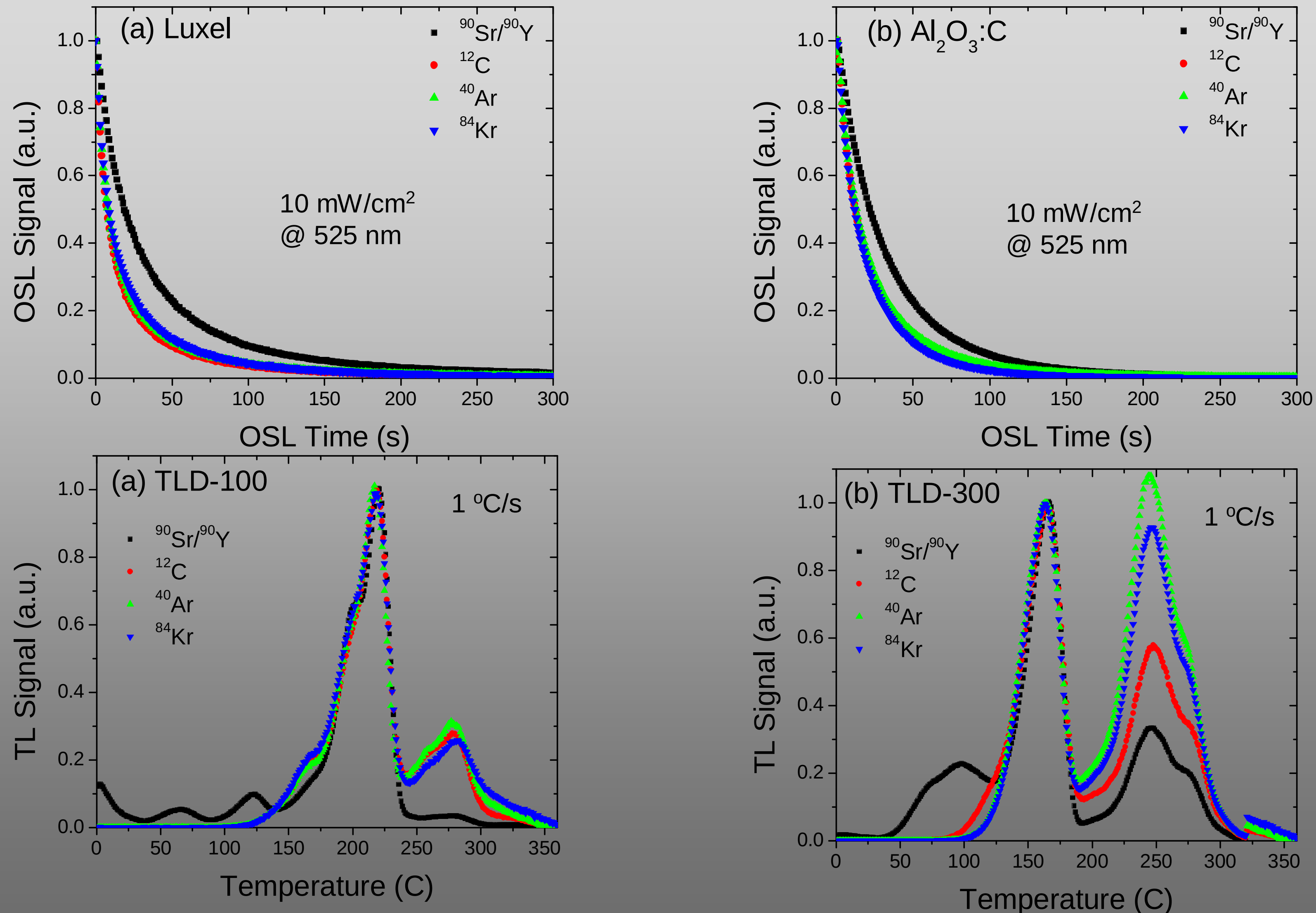
The detector packages:

6 Al_2O_3:C single crystals (chips),
2 Luxel™ dosimeters (Al_2O_3:C powder in polycarbonate film)
3 LiF:Mg,Ti (Harshaw TLD-100 chips)
3 CaF_2:Tm (Harshaw TLD-300 chips)

Lexan detector holders; 7.0 cm × 3.5 cm × 0.7 cm;
0.15 cm Lexan cover
Holders wrapped in black electric tape, 0.07 cm thickness

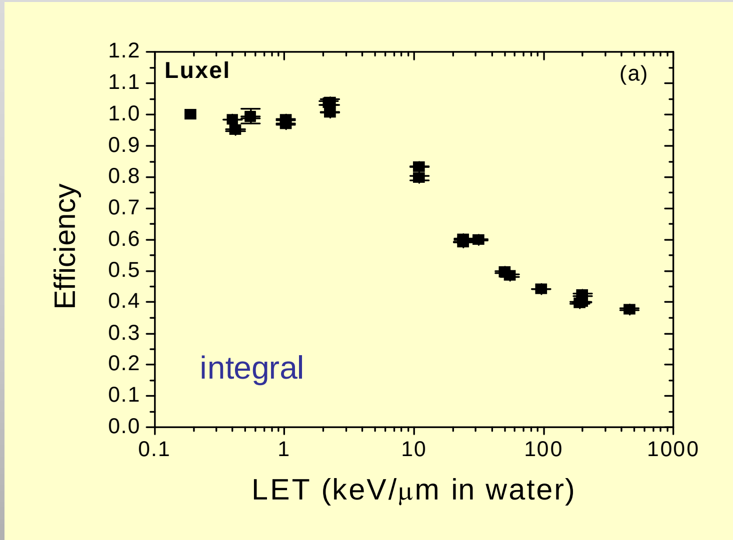


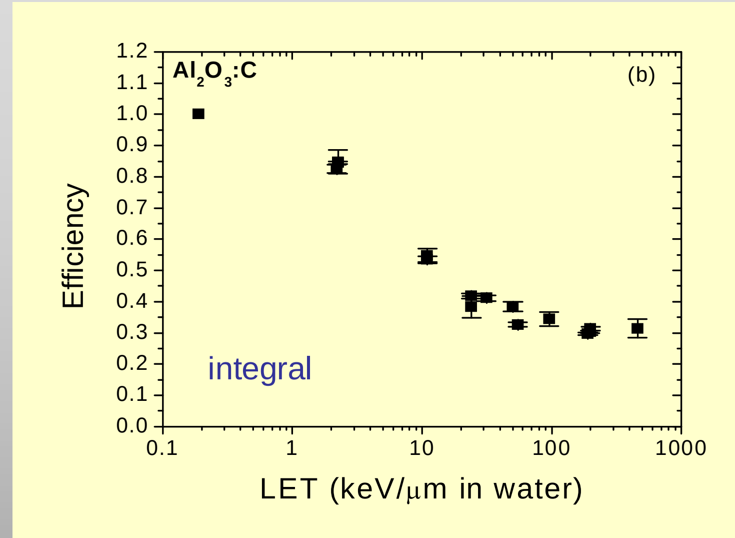
Data:

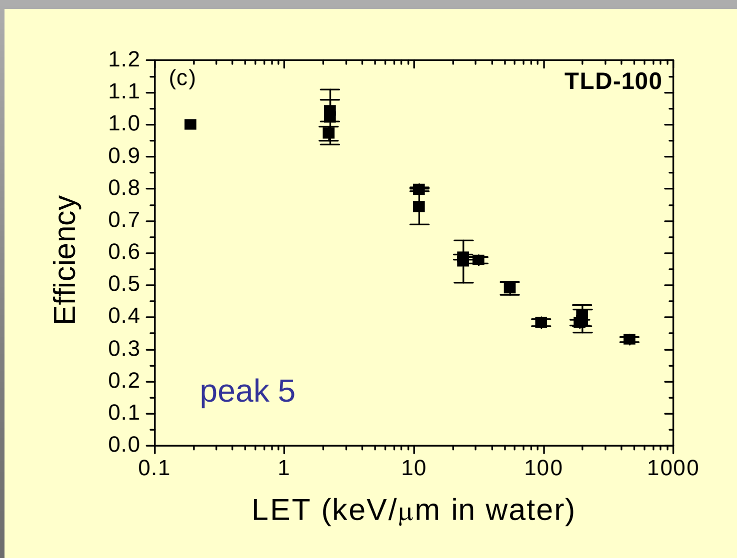


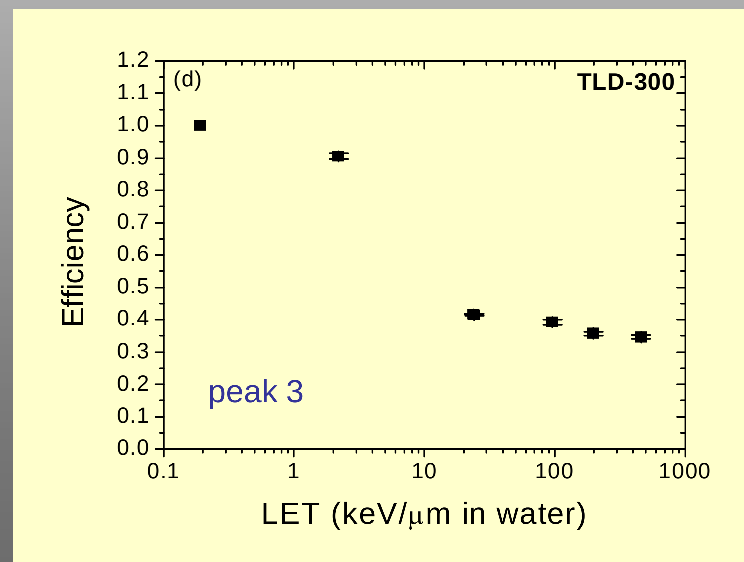
(a) Luxel
^{90}Sr/^{90}Y
^{12}C
^{40}Ar
^{84}Kr
10 mW/cm^2
@ 525 nm
OSL Signal (a.u.)
OSL Time (s)
(b) Al_2O_3:C
^{90}Sr/^{90}Y
^{12}C
^{40}Ar
^{84}Kr
10 mW/cm^2
@ 525 nm
OSL Signal (a.u.)
OSL Time (s)
(a) TLD-100
1 ^{o}C/s
^{90}Sr/^{90}Y
^{12}C
^{40}Ar
^{84}Kr
TL Signal (a.u.)
Temperature (C)
(b) TLD-300
1 ^{o}C/s
^{90}Sr/^{90}Y
^{12}C
^{40}Ar
^{84}Kr
TL Signal (a.u.)
Temperature (C)

Efficiencies: (includes all data from ICCHIBAN 2, 4 & 6, & Proton)





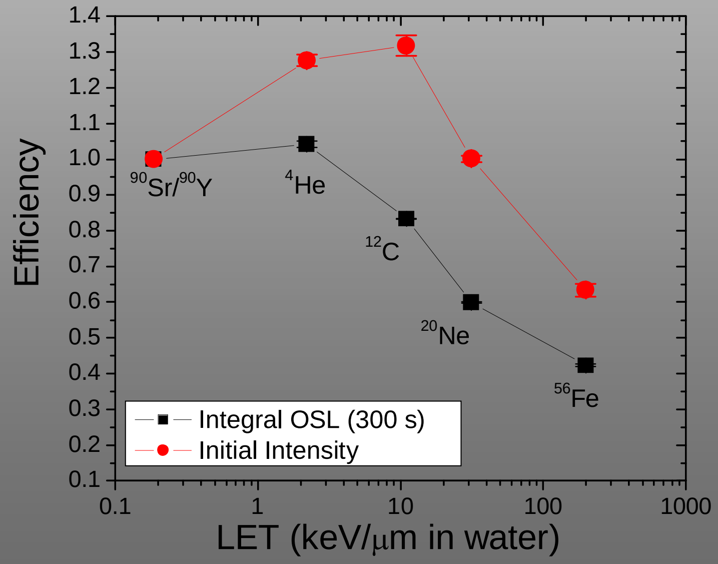




Fragmentation Results: (Equivalent gamma doses to water; uncorrected)

	Luxel™		Al_2O_3:C (chips)		LiF:Mg,Ti (TLD-100)		CaF_2:Tm (TLD-300)	
Ion	Integral OSL (300 s)	OSL Initial Intensity	Integral OSL (300 s)	OSL Initial Intensity	Peak 5 height	Area HT Peak	Peak 3 height	Area HT Peak
^{12}C	38.2 ± 0.0*	69.3 ± 0.4	30.2 ± 1.3	48.3 ± 5.6	41.0 ± 1.3	336.7 ± 13.5	27.9 ± 0.3	104.0 ± 1.3
^{40}Ar	23.9 ± 0.1	38.4 ± 0.2	18.5 ± 0.8	24.4 ± 2.7	28.3 ± 3.5	224.5 ± 15.5	20.1 ± 0.3	60.0 ± 0.9
^{84}Kr	21.5 ± 0.1	32.0 ± 0.3	17.8 ± 0.5	24.3 ± 1.9	21.1 ± 0.2	154.7 ± 3.8	20.2 ± 0.1	54.6 ± 0.5

(* smaller than 0.05)

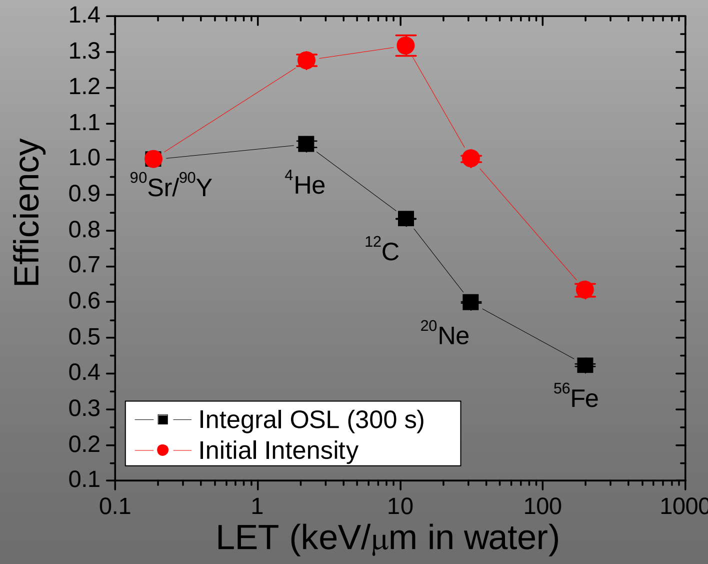


Fragmentation Results: (Equivalent gamma doses to water; uncorrected)

	Luxel™		Al_2O_3:C (chips)		LiF:Mg,Ti (TLD-100)		CaF_2:Tm (TLD-300)	
Ion	Integral OSL (300 s)	OSL Initial Intensity	Integral OSL (300 s)	OSL Initial Intensity	Peak 5 height	Area HT Peak	Peak 3 height	Area HT Peak
^{12}C/BF	**47.7**	**53.8**	30.2 ± 1.3	48.3 ± 5.6	41.0 ± 1.3	336.7 ± 13.5	27.9 ± 0.3	104.0 ± 1.3
^{40}Ar/BF	**53.3**	**51.2**	18.5 ± 0.8	24.4 ± 2.7	28.3 ± 3.5	224.5 ± 15.5	20.1 ± 0.3	60.0 ± 0.9
^{84}Kr/BF	**53.7**	**64**	17.8 ± 0.5	24.3 ± 1.9	21.1 ± 0.2	154.7 ± 3.8	20.2 ± 0.1	54.6 ± 0.5

(* smaller than 0.05)

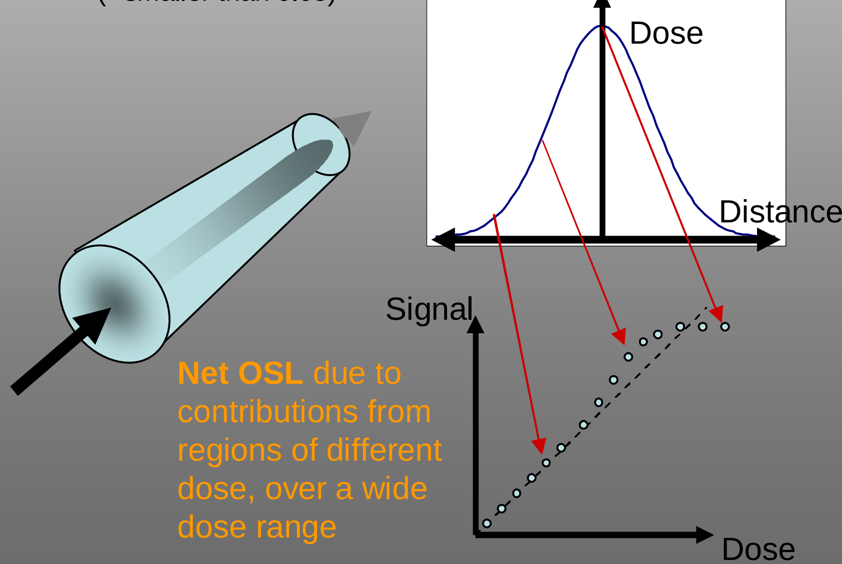
if doses corrected using LET and efficiency of the *primary* particle

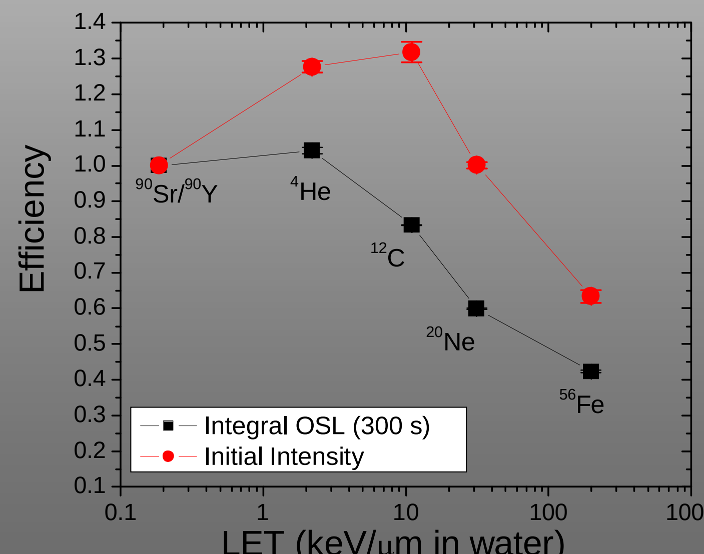


Fragmentation Results: (Equivalent gamma doses to water; uncorrected)

	Luxel™		Al_2O_3:C (chips)		LiF:Mg,Ti (TLD-100)		CaF_2:Tm (TLD-300)	
Ion	Integral OSL (300 s)	OSL Initial Intensity	Integral OSL (300 s)	OSL Initial Intensity	Peak 5 height	Area HT Peak	Peak 3 height	Area HT Peak
^{12}C	38.2 ± 0.0*	69.3 ± 0.4	30.2 ± 1.3	48.3 ± 5.6	41.0 ± 1.3	336.7 ± 13.5	27.9 ± 0.3	104.0 ± 1.3
^{40}Ar	23.9 ± 0.1	38.4 ± 0.2	18.5 ± 0.8	24.4 ± 2.7	28.3 ± 3.5	224.5 ± 15.5	20.1 ± 0.3	60.0 ± 0.9
^{84}Kr	21.5 ± 0.1	32.0 ± 0.3	17.8 ± 0.5	24.3 ± 1.9	21.1 ± 0.2	154.7 ± 3.8	20.2 ± 0.1	54.6 ± 0.5

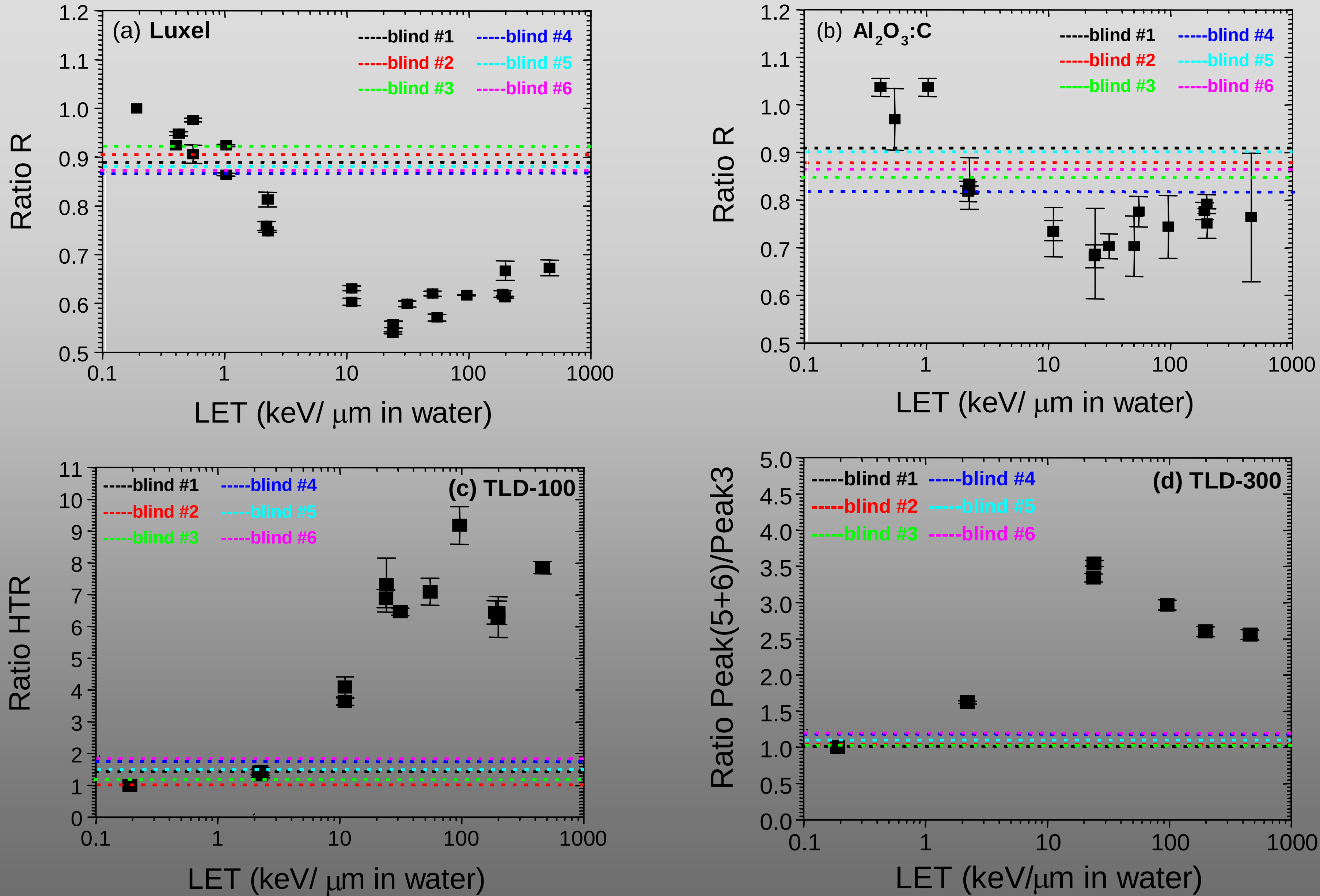
(* smaller than 0.05)





Blind Exposures: (Equivalent gamma doses to water; uncorrected)

	Luxel		Al_2O_3:C (chips)		LiF:Mg,Ti (TLD-100)		CaF_2:Tm (TLD-300)	
Blind	Integral OSL	Initial Intensity	Integral OSL	Initial Intensity	peak 5 height	Area HT Peak	peak 3 height	Area HT Peak
#1	107.1 ± 0.5	120.2 ± 1.7	104.1 ± 8.6	114.0 ± 11.7	88.0 ± 1.3	112.1 ± 3.5	128.9 ± 1.1	137.4 ± 1.0
#2	107.0 ± 0.3	117.9 ± 0.2	103.1 ± 4.9	116.6 ± 11.7	110.7 ± 9.1	122.6 ± 6.5	127.5 ± 0.7	136.9 ± 1.4
#3	107.0 ± 0.3	117.1 ± 0.4	109.7 ± 6.6	129.8 ± 15.5	105.2 ± 12.5	116.1 ± 9.5	125.9 ± 0.9	135.1 ± 1.5
#4	91.8 ± 0.3	105.5 ± 0.4	85.1 ± 3.6	104.1 ± 7.2	66.9 ± 2.1	107.7 ± 10.3	89.1 ± 0.6	122.0 ± 1.1
#5	103.2 ± 0.4	115.1 ± 08	110.6 ± 1.4	121.6 ± 1.1	100.9 ± 12.5	132.5 ± 8.3	126.7 ± 0.8	135.6 ± 0.9
#6	139.9 ± 3.7	160.3 ± 4.5	124.1 ± 12.2	142.2 ± 18.3	121.3 ± 4.2	191.9 ± 7.8	141.4 ± 0.9	196.1 ± 0.7


(a) Luxel
-----blind #1
-----blind #2
-----blind #3
-----blind #4
-----blind #5
-----blind #6
Ratio R
LET (keV/ μm in water)
(b) Al2O3:C
-----blind #1
-----blind #2
-----blind #3
-----blind #4
-----blind #5
-----blind #6
Ratio R
LET (keV/ μm in water)
(c) TLD-100
-----blind #1
-----blind #2
-----blind #3
-----blind #4
-----blind #5
-----blind #6
Ratio HTR
LET (keV/ μm in water)
(d) TLD-300
-----blind #1
-----blind #2
-----blind #3
-----blind #4
-----blind #5
-----blind #6
Ratio Peak(5+6)/Peak3
LET (keV/μm in water)

Blind Exposures: (Equivalent gamma doses to water; uncorrected)

	Luxel		Al_2O_3:C (chips)		LiF:Mg,Ti (TLD-100)		CaF_2:Tm (TLD-300)	
Blind	Integral OSL	Initial Intensity	Integral OSL	Initial Intensity	peak 5 height	Area HT Peak	peak 3 height	Area HT Peak
#1	107.1 ± 0.5	120.2 ± 1.7	104.1 ± 8.6	114.0 ± 11.7	88.0 ± 1.3	112.1 ± 3.5	128.9 ± 1.1	137.4 ± 1.0
#2	107.0 ± 0.3	117.9 ± 0.2	103.1 ± 4.9	116.6 ± 11.7	110.7 ± 9.1	122.6 ± 6.5	127.5 ± 0.7	136.9 ± 1.4
#3	107.0 ± 0.3	117.1 ± 0.4	109.7 ± 6.6	129.8 ± 15.5	105.2 ± 12.5	116.1 ± 9.5	125.9 ± 0.9	135.1 ± 1.5
#4	91.8 ± 0.3	105.5 ± 0.4	85.1 ± 3.6	104.1 ± 7.2	66.9 ± 2.1	107.7 ± 10.3	89.1 ± 0.6	122.0 ± 1.1
#5	103.2 ± 0.4	115.1 ± 08	110.6 ± 1.4	121.6 ± 1.1	100.9 ± 12.5	132.5 ± 8.3	126.7 ± 0.8	135.6 ± 0.9
#6	139.9 ± 3.7	160.3 ± 4.5	124.1 ± 12.2	142.2 ± 18.3	121.3 ± 4.2	191.9 ± 7.8	141.4 ± 0.9	196.1 ± 0.7

- Primarily low-LET blind exposures
  - Blind #4 higher LET mix than others
    - Need greater definition of efficiency values at low LET

Conclusions:

1. Efficiencies depend upon material, physical form, readout method, and data analysis.
2. OSL decay-curve shape contains information about LET.
3. For single particle irradiation, can use this to determine corrected absorbed dose (and therefore dose equivalent).
4. For mixed fields, difficult to determine "mean LET" (and therefore corrected absorbed dose and dose equivalent) when strong contribution to the OSL signal from high-LET components.
5. OSL signal from blind exposures dominated by low-LET components.
6. Future experiments: need (1) greater definition of efficiency in low-LET region; (2) information from CR-39.