Dosimetry technology for measuring external radiation exposure of Norwegian reindeer

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1 Overview

- Wild organism radiation exposure can be estimated using computer models (evaluated via model inter-comparison studies) [e.g. 1,2] in order to assess the environmental impacts of ionising radiation.
- These model predictions require validation of external dose rates, which can be achieved by using attached dosimeters.
- However, few studies have attempted to measure dose in such a manner [e.g. 3,4].
- Furthermore, there are no published data on long-term effects combined with such dose measurements under field conditions. This impacts on our ability to interpret field effects observations.
- We have recently fitted reindeer in Norway with various dosimeters and a GPS collar to obtain data to validate existing dosimetry models.

2 Dosimetry technologies

- **Luminescence dosimeter**, the most widely employed passive system [5], include:
  - *Thermoluminescent dosimeter (TLD)* emits light when heated, the light being proportional to the radiation exposure of the TLD. There are many kinds of TL material such as lithium fluoride (LiF), calcium fluoride (CaF_2), calcium sulphate ($CaSO_4$), lithium borate ($Li_2B_4O_7$) and aluminium trioxide (Al_2O_3).
  - *Optical stimulated luminescent dosimeter (OSLD)* emits light by stimulating the phosphor materials with visible or near infrared light after exposure to ionising radiation. Aluminium trioxide doped with Carbon (Al_2O_3:C) is the main phosphor material of OSL.
  - *Radiohotoluminescent dosimeter (RPL)* uses silver activated phosphate glass as a luminescence material. After exposure when exposed to UV-light, fluorescence light is emitted.
- **Direct Ion Storage (DIS)** consists of two components; an ionisation chamber and a metal oxide semiconductor field effect transistor (MOSFET). It can be both an active or passive dosimeter for example the Instadose2. (https://www.mirion.com/products/instadose-2-dosimeter/)

3 Consideration of dosimeter properties for reindeer dose measurement in Norway

- Detector - The performance of individual materials used to record external exposure is dependent on their chemical and physical properties.
- Size & physical structure – The size of dosimeter and housing has to be in proportion to the reindeer and, in this case, fit to the GPS collars.
- Tissue equivalent material – This is materials having the effective atomic number (Z_{eff}) nearly the same that of soft biological tissues (Z_{eff}=7.42).
- Detection limit - The average doses limit for all Norway predicted by ERICA using data of caesium activity deposition in soil are about 30 µGy/year
- Fading - This is the loss of signal with time (e.g. weeks, months and years) after some materials are exposed to radiation. Fading will need to be accounted for as the dosimeters will be attached to the reindeer for 12 months
- Environmental effect – Moisture, humidity, temperature, snow depth and light may all affect the dosimeters

4 characteristic of dosimetry technologies

Dosimetry Technology	detector	Size	Effective atomic number (Z_{eff})	Detection limit	Fading	Environment effect
TLD	LiF:Mg,Ti	Very small (not longer than 4 mm)	8.2[5]	10 µSv[7], 10 µGy[5]	5 % per year[6], 5-10 % per year[7]	Generally environmentally robust[6]
	LiF:Mg,Cu, P			A few µSv[6], 0.5 µGy[5]	<5% per year[6], 3% per year[7]	Generally environmentally robust[6]
	CaF_2:Dy		16.3[5]	1 µGy[5]	16% in 2 weeks[7]	Good for environmental dosimetry application[8]
	CaF_2:Mn			10 µGy[5]	15% in 3 months[7]	Good for environmental dosimetry application and high dose[8]
	$CaSO_4$:Dy		15.3[5]	A few µSv[2], 1 µGy[5]	- 5-30% in 6 month for thermal fading and shows optical fading[6] - 2% in 1 month and 8% in 6 month[8]	Good for environmental dosimetry application[8]
	$CaSO_4$:Tm			A few µSv[2], 1 µGy[5]	5-30% in 6 month for thermal fading and shows optical fading[6]	Generally environmentally robust[6]
	$Li_2B_4O_7$:Mn		7.4[5]	A few tens to 100 µSv[6]	Less than 5% in 3 months[9] About 30% in a year[6]	Generally environmentally robust[6] - High sensitivity to light[5] - Sensitive to humanity[5]
	$Li_2B_4O_7$:Cu			A few tens to 100 µSv[6]	About 5-30% in a year[6] 10 % in 3 months and less than 5 % in a month[18]	
	Al_2O_3:C		10.2[5]	A few µSv[6], 0.5 µGy[5]	3% per year[7] Less than 3% per year[1]	Light sensitivity, may induce fading up to 40% with 300 lux (white light) for 5 hours[5]
OSLD	Al_2O_3:C	5 – 15 mm	10.2[5]	A few µSv[6]	Little fading[6, 9] 3% per year[7]	Strongly affected by light[6]
RPLD	Phosphate glass	8.5 – 12 mm	-	10 µGy[10]	Less than 5% per year[10]	Generally environmentally robust and insensitive to light unless UV light[11]
DIS dosimeter	Direct Ion Storage + MOSFET	30 – 50 mm	-	10 µSv[8], 1 µSv[6]	Little fading[9] Less than 2% in 90 days[12]	Generally environmentally robust unless used at high or low temperature[8, 12]

5 Summary of suitable dosimeters for reindeer in Norway

Dosimetry Technologies	Dosimeter	Size and physical structure	Effective atomic number (Z_{eff})	Detection limit	Fading	Environment effect
TLD ✓	LiF:Mg,Ti	/	//	/[2]	//	//
	LiF:Mg,Cu, P ✓	/		//	//	//
	CaF_2:Dy	/	/[1]	//	/[3]	//
	CaF_2:Mn	/		/[2]	/[3]	//
	$CaSO_4$:Dy	/	/[1]	//	/[3]	//
	$CaSO_4$:Tm	/		//	/[3]	//
	$Li_2B_4O_7$:Mn	/	//	/[2]	/[3]	/[4]
	$Li_2B_4O_7$:Cu	/		//	/[3]	/[4]
	Al_2O_3:C	/	/[1]	//	//	/[4]
OSLD ✓	**Al_2O_3:C**	/	/	//	//	/[4]
RPLD ✓	**Phosphate glass**	/	/	//	//	//
DIS dosimeter (Instadose 2) ✓	**Direct Ion Storage + MOSFET**	//	/	//	//	/

Remark: X = disqualified / = qualified without any condition /[No.] = qualified with conditions // = very qualified
(/[1] = qualified with appropriate filters, /[2] = qualified when the detection limit are in ranges of average dose in the area, /[3] = qualified when high fading correction is controlled, /[4] = qualified but need to be covered by robust holder)

(circled ✓) → It qualifies to be used in the experiment

6 Attaching dosimeters to reindeer

- Four types of dosimeter considered as the suitable dosimeter are chose to fit into aluminium boxes as follows:

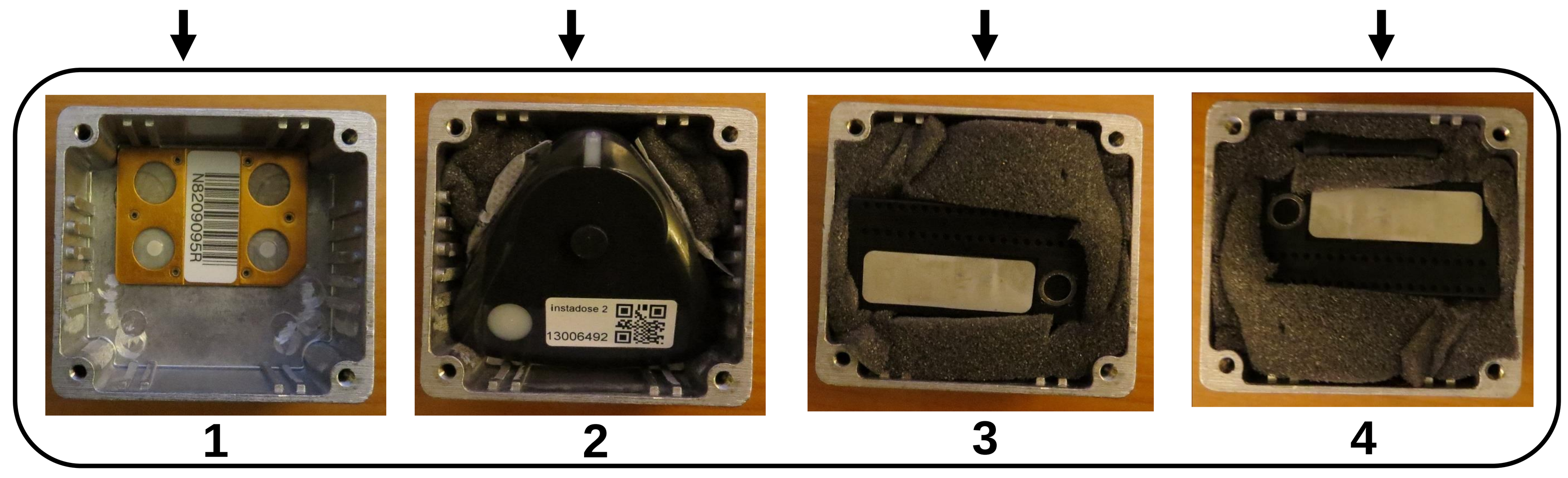
  - Thermoluminescent dosimeter, TLD (*LiF:Mg, Cu,P*); Public Health England, UK
  - Optically stimulated luminescent dosimeter, OSLD (*Al_2O_3:C,* Aluminium trioxide doped with Carbon); Thailand Institute Nuclear Technology, Thailand
  - Radiophotoluminescent dosimeter, RPLD (*glass rod*); AGC Techno Glass Corporation, Japan
  - Instadose 2 (*direct ion storage, DIS*); Mirion Technologies, USA
- Dosimeter boxes were mounted on 15 reindeer collars to measure external absorbed doses over 12 months

TLD (LiF:Mg,Cu, P)

DIS dosimeter (Instadose 2)

OSLD (Al_2O_3:C)

RPLD (glass)



Assembling dosimeters in the aluminium box

7 Dosimeter box attachment test to reindeer collars

- A dosimeter box are tested on a reindeer collar before being fitted to the reindeer in Norway to ensure that would not interfere to reindeer.

Attaching a dosimeter box to the example reindeer collar

References

[1] Beresford, N. A., Barnett, C. L., Brown, J. E., Cheng, J. J., Copplestone, D., Filistovic, V., . . . Yu, C. (2008). Inter-comparison of models to estimate radionuclide activity concentrations in non-human biota. *Radiation and Environmental Biophysics, 47*(4), 491-514. doi:10.1007/s00411-008-0186-8

[2] Beresford, N. A., Barnett, C. L., Brown, J. E., Cheng, J. J., Copplestone, D., Gaschak, S., . . . Yu, C. (2010). Predicting the radiation exposure of terrestrial wildlife in the Chernobyl exclusion zone: an international comparison of approaches. *J Radiol Prot, 30*(2), 341-373. doi:10.1088/0952-4746/30/2/S07

[3] Beresford, N. A., Gaschak, S., Barnett, C. L., Howard, B. J., Chizhevsky, I., Strømman, G., . . . Copplestone, D. (2008). Estimating the exposure of small mammals at three sites within the Chernobyl exclusion zone – a test application of the ERICA Tool. *Journal of Environmental Radioactivity, 99*(9), 1496-1502.

[4] Kubota, Y., Takahashi, H., Watanabe, Y., Fuma, S., Kawaguchi, I., Aoki, M., . . . Yoshida, S. (2015). Estimation of absorbed radiation dose rates in wild rodents inhabiting a site severely contaminated by the Fukushima Dai-ichi nuclear power plant accident. *J Environ Radioact, 142C*, 124-131. doi:10.1016/j.jenvrad.2015.01.014

[5] Thompson, I. M. G., Botter-Jensen, L., Deme, S., Pernicka, F., & Saez-Vergara, J. C. (1999). *Radiation Protection 106: Technical recommendation on measurements of external environmental gamma radiation doses*. Retrieved from Luxambourg:

[6] Bartlett, D. T., & Tanner, R. J. (2005). *Adequacy of external dosimetry methods and suitability of personal dosemeters for workplace radiation fields*. Retrieved from Health Protection Agency:

[7] Kortov, V. (2007). Materials for thermoluminescent dosimetry: Current status and future trends. *Radiation Measurements, 42*(4–5), 576-581. doi:http://dx.doi.org/10.1016/j.radmeas.2007.02.067.

[8] Lake Mary, F. (2014). Recent Developments in Direct Ion Storage Dosimeters. Retrieved from http://hpschapters.org/florida/11PPT.pdf

[9] Hidehito, N., Yoshinori, T., & Yuka, M. (2011). *Environmental Background Radiation Monitoring Utilizing Passive Solid Sate Dosimeters, Environmental Monitoring*. Rijeka, Croatia: InTech.

[10] David Y.C., H., & Shih-Ming, H. (2011). *Radio-Photoluminescence Glass Dosimeter (RPLGD),* . Rijeka, Croatia: InTech.

[11] Ranogajec-Komor, M., Knežević, Ž., Miljanić, S., & Vekić, B. (2008). Characterisation of radiophotoluminescent dosimeters for environmental monitoring. *Radiation Measurements, 43*(2-6), 392-396. doi:10.1016/j.radmeas.2007.11.020

[12] Mathur, V. K. (2001). Ion stoeage dosimetry. *Nuclear Instruments and Methods in Physics Research, B*(184), 190-206.

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