Improvements in neutron dosimetry at nuclear power plants

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The most widely adopted techniques world-wide for occupational neutron personal dosimetry are:

- **Solid State Nuclear Track detectors using polycarbonate (CR-39) to detect proton recoils (for intermediate and fast neutrons) or alpha products (from ^{10}B(n,α)^{7}Li reactions in a Boron rich irradiator) for thermal neutrons;**
- **Albedo dosemeters which incorporate a thermal neutron sensitive detectors (typically ^{6}LiF thermoluminescence detectors (TLD) or more recently using optically stimulated luminescence (OSL) detectors (aluminium oxide coated with $^{6}Li_2CO_3$)) which measure the reflected (albedo) thermal neutrons backscattered from the body.**

Both techniques have advantages and disadvantages in practical situations which have been discussed widely and are summarised in this poster. LANDAUER has been providing personal neutron dosimetry services to clients operating nuclear power plants for a number of years. Recently we have worked with a number of our clients to improve the reliability and accuracy of personal neutron dosimetry measurements. This has included:

- **Assessment of the extent of doses to workers in nuclear power plants (typically 99.7% receive less than 1 mSv);**
- **Improvements to the dosemeters and their analysis;**
- **Characterisation of environments in which neutron exposure is of concern;**
- **Field calibration of dosemeters;**
- **Comparison with other types of dosemeters and manufacturers.**

This paper will outline this work and draw together lessons learned and recommendations for the optimal assessment of personal dose in nuclear power plant environments.

Dosimetry systems

For personal monitoring of neutron dose-equivalent, LANDAUER uses different technologies.

Solid State Nuclear Track Detectors using polycarbonate (CR-39)

Two types of Neutrak® offer a wide range of energy response:

- Neutrak J detects proton recoils (for intermediate and fast neutrons);
- Neutrak T also detects thermal neutrons, using the addition of a boron radiator, which produces alpha particles from the ^{10}B(n,α)^{7}Li reaction.

Either of these variants can be incorporated into LANDAUER's standard photon dosemeters: Luxel+®, to become Luxel+ Ja or Luxel+Ta, or InLight®, designated InLight & Neutrak J or InLight & Neutrak T.

Albedo dosemeters

These are based on the InLight dosemeter and incorporate elements consisting of our standard Optically Stimulated Luminescence (OSL) detector material coated with $^{6}LiCO_3$.

	Advantages	Disadvantages
Neutrak	Wide energy response (Thermal to > 14MeV) No sensitivity to photons Less need for field characterisation Doses recorded permanently on the detectors	Limited dose response: ▪ 1 - 250 mSv for intermediate and fast neutrons ▪ 1 - 20 mSv thermal neutrons Variation in response as a function of angle. Assessment involves chemical etching in highly caustic solution, which is time consuming (typically 24 hours before a result can be obtained).
InLight OSLN	Easy/quick readout Ability to re-asses doses (OSL detectors) Re-use of dosemeters after annealing	Large dependence on response as a function of energy. Need for careful assessment of fields to establish accurate neutron correction factors (NCF) which range from 0.08 (high energy fields) to 5 (for moderated fields). Sensitivity to photons

Experience

Extent of doses to workers in the nuclear industry

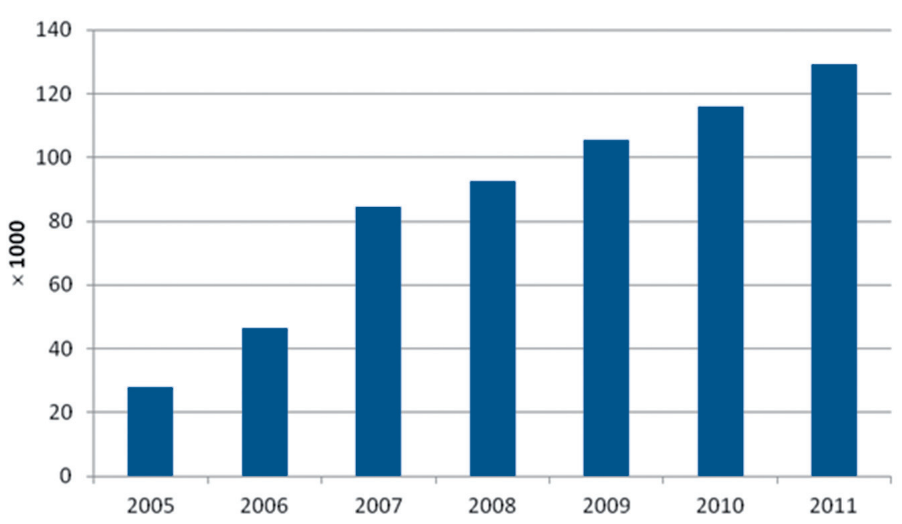
Comparison of the annual exposure to photons and neutrons (for 2009)[1].

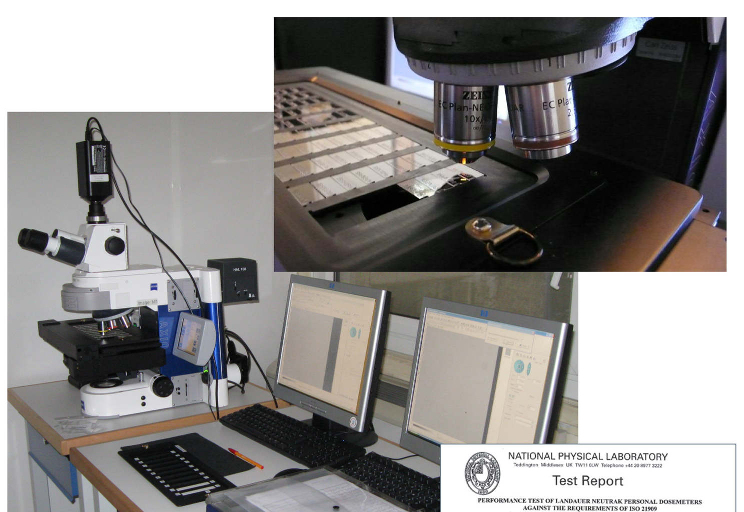
Number monitored	Percentage in dose range Hp(10)/ mSv					Collective dose man.mSv
	<0.05	<0.1	0.1 - 1	1 - 6	>6	
Neutron						
9050	97.3		2.6	0.1	0.04	70
Photon						
107050	66.0	28.4	5.1	0.5	0.5	42000

99.7% of workers are exposed to less than 1mSv.

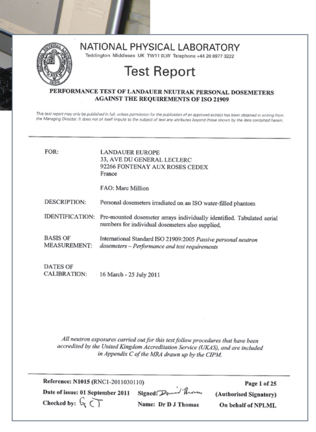
Evolution of the utilisation of neutron dosemeters

Number of Neutrak dosemeters analysed by LANDAUER in Paris from 2005 – 2011[1].





Automatic counting for Neutrak

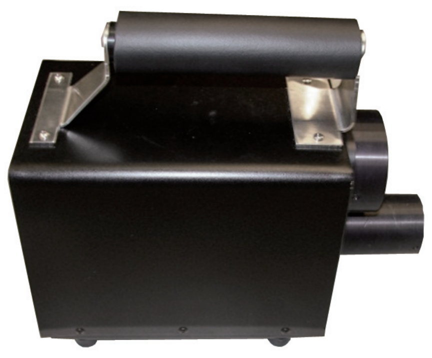


NPL Test report

Improvements to the dosemeters and their analysis

- Automatic counting for CR-39 Neutrak dosemeters
- Limit of detection for Neutrak dosemeter reduced to 0.1 mSv
- Independent performance test for compliance with ISO 21909:2005 carried out at the National Physical Laboratory (NPL) in the UK[2].
- Development of Albedo OSL dosemeter

Characterisation of environments in which neutron exposure is of concern



Example of an ambient monitor

- Energy distribution
  - Spectrum measurement using eg NPobe (BTI)
  - Range from fission spectrum to 1/e to highly thermal
- Fluence estimation
  Using ambient monitors eg: Wendi II, FHT 752, Studsvik 2202D or Eberline
- Directional distribution
  Calculation assuming Unidirectional and Isotropic ⇨ estimate of directional dose equivalent

Field calibration of InLight OSLN and Neutrak dosemeters

Example neutron calibration factors for the Albedo dosemeter in a US NPP are given in the table below[4]:

Description	Neutron correction factor (NCF)
Highest level in containment- direct line of sight to top of Steam Generator	1.568
Highest level in containment- direct line of sight to top of Steam Generator	1.580
Highest level in containment- direct line of sight to top of Steam Generator	1.580
Operating floor, mostly open grating above, some obstruction	1.595
Operating floor, mostly open grating above, some obstruction	1.581
Operating floor, mostly open grating above, some obstruction	1.573
Below grade, 12" of concrete above	1.482
Basement level	1.608
Basement level	1.572
Average	**1.571**
Standard deviation	0.036
Coefficient of Variation	0.023

Example neutron correction factors for InLight Alebedo (OSLN) and Neutrak dosemeters in French nuclear facilities[1]:

Work station	Comment	Neutron correction factor (NCF)	
		Albedo dosemeter	Neutrak CR-39 dosemeter
MELOX	Powder mixing	0.67	1.57
MELOX	Press	0.84	1.58
MELOX	Grinding and shaping	0.71	1.65
MELOX	Intermediate site	0.74	1.60
PWR site 1	Various	0.1 - 0.3	
PWR site 2		0.3	

Comparison of personal dosemeters in real fields[3]

	Personal Dose Equivalent, Hp(10)/μSvh^{-1}		
	D_2O vapour recovery room	Heat transport Auxiliary room	Boiler room
Reference determination	**11.3 ± 1.2**	**73 ± 11**	**65 ± 9**
Thermo EPD N2 - Front	77 ± 11	385 ± 54	127 ± 18
DMC 2000 GN - Front	46 ± 6	251 ± 11	135 ± 20
Bubble - Front	41.7 ± 2.2	219 ± 11	
Albedo - Front	24.2 ± 2.8	514 ± 72	140 ± 10
HPA CR-39 – Front	10.5 ± 2.0	76 ± 4	44 ± 3
LANDAUER CR-39 - Front	13.1	133	80
LANDAUER FNTD - Front	11.3 ± 1.4	40 ± 5	17 ± 2

Concluding remarks

Whilst exposure to neutrons is limited to a relatively small number of employees and the overall dose is small in comparison with photon dose, it is nonetheless important to monitor individual's doses accurately. However, achieving the same level of accuracy as for photon doses is very difficult, if not impossible. Several methods have been developed for neutron dosimetry which have their own advantages and disadvantages. In the case of albedo dosemeters, neutron correction factors determined by an assessment of the of the radiation field are essential, but difficult to determine. However, the dosemeters are very easy to assess and in the case of LANDAUER's OSL technology can be re-assessed many times before being annealed and re-used. Solid State Nuclear Track Detectors, using CR-39 polycarbonate material, are less dependent on field characterisation, but take longer to assess and that assessment relies on chemical etching at high temperature in very caustic solution. There remains a wide divergence of the doses measured by various dosemeters in the same fields.

References

(1) M. Million, C.N. Passmore, and M. Kirr, Dosimétrie neutrons avec calibration sur faisceaux Opérationnels. Presented at 4th Forum Européen de Radioprotection, September 2010.

(2) National Physical Laboratory Test Report. Performance test of LANDAUER Neutrak personal dosemeters against the requirements of ISO 21909. Reference N1015 (RNC1-2011030110).

(3) V. Cauwels, F. Vanhavere, D. Dumitrescu, A. Chirosca, L. Hager, M. Million and J. Bartz, Characterisation of neutron fields at Cernovada NPP. Presented to IRPA13, May 2012.

(4) C.N. Passmore, OSL albedo neutron dosimeter. Presented to 27th International Dosimetry and Records Symposium, June 2008.