A personnel neutron albedo dosimeter badge using aluminum oxide pellets

Bhaskar Mukherjee, Carolina Llina, Jamil Lambert

Accelerator Health Physics Group

Westdeutsches Protonentherapiezentrum Essen (WPE), Germany

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Introduction

Personnel neutron albedo dosimeter (PNAD) is mandatory for radiation workers at particle accelerator laboratories, high-energy medical linac and hadron therapy centres and nuclear reactor facilities.

The most common PNAD used today is based on a pair of TLD-600 (thermal neutron sensitive) and TLD-700 (gamma sensitive) thermoluminescent dosimeter chips (Karlsruhe Albedo Neutron Dosimeter).

The PNAD developed by WPE Health Physics Group basically consists of a pair of highly gamma sensitive α-Al_2O_3:C pellets commonly available as TLD-500 chips.

The pellets were housed in two small lead pouches of 2.5 mm wall thickness. The first pellet was covered with 0.2 mm thick Gadolinium foil and the second one was kept blank.

The pouch-pairs were attached to a 50 mm × 50 mm × 3 mm borated rubber pad and enclosed in a small PVC bag (70 mm × 95 mm) with mounting clip constituting the albedo dosimeter badge.

Principle of Albedo Dosimeter

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Thermoluminescent Dosimeters (TLD) are inherently insensitive to neutrons, in particular, within intermediate - fast energy range.

When the human body (hydrogenous tissue) is exposed to intermediate - fast neutrons, some of the incident neutrons are slowed down, back scattered and finally leave the body. These neutrons are called ALBEDO Neutrons.

Some TLDs are sensitive to slow (thermal) neutrons. When a suitable badge housing such TLD is worn close to the body it records the albedo neutrons. Hence, one can indirectly estimate the dose equivalent due to the incident (primary) fast neutrons. Here lies the principle of ALBEDO Dosimeter.

The commonly used (Karlsruhe) albedo dosimeter utilizes the ^{4}He dose due to $^{6}Li(n, \alpha)^{3}H$ reaction in ^{6}LiF (TLD-600) chip, where, σ = 9.32 kb

The Alumina-Albedo dosimeter developed at WPE utilizes gamma ray dose due to $^{157}Gd(n, \gamma)^{158}Gd$ reaction in Al_2O_3 (TLD-500) chip, where, σ = 255 kb

The Dose Equivalent response of albedo dosimeter is highly dependent on incident neutron energy spectra, hence, shall be individually calibrated for the neutron field of interest.

Karlsruhe Neutron Albedo Dosimeter

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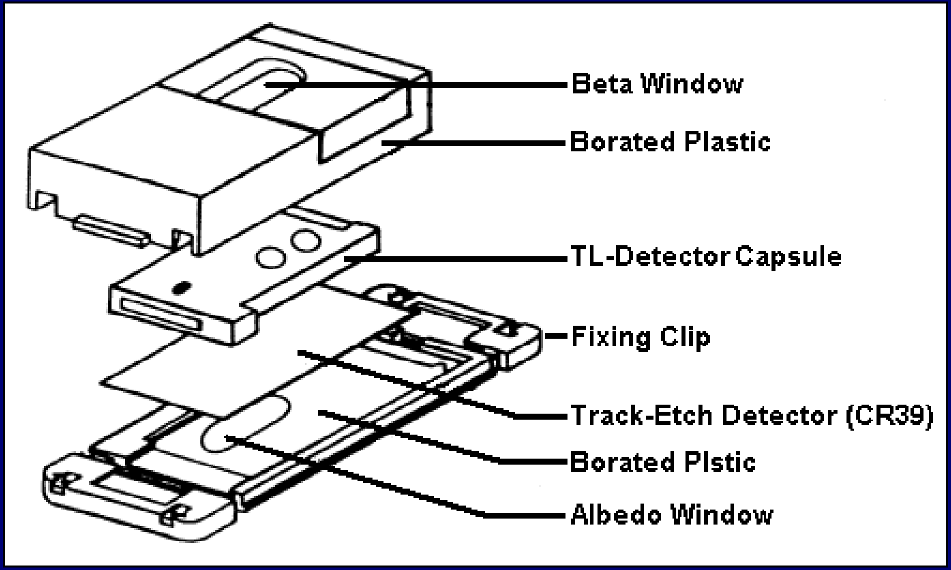
Most commmon personnel neutron albedo dosimeter (PNAD) used worldwide

Based on pairs on ^{7}LiF: Ti,Mg (TLD700) and ^{6}LiF: Ti,Mg (TLD600) Thermolumi-nescent Dosimeters

Developed at the Nuclear Research Centre Karlsruhe, Germany (KfK 4303, 1988).

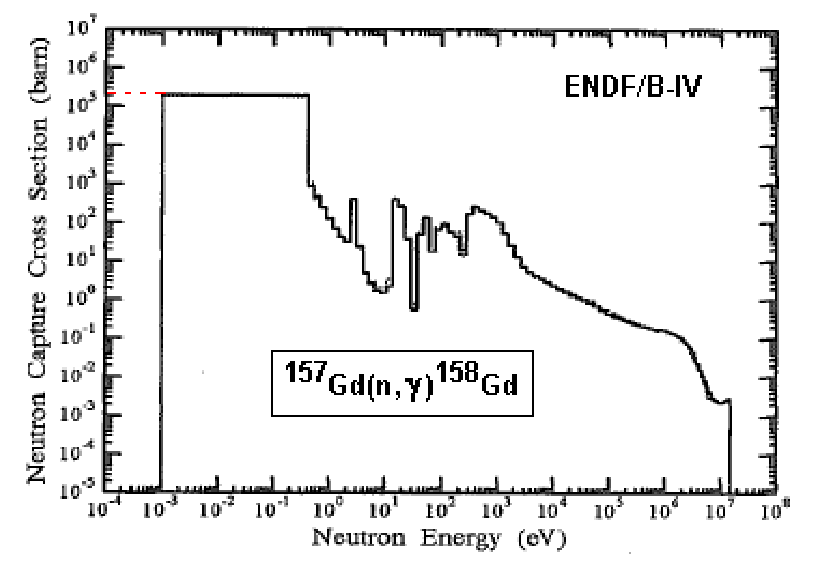
Expolded view of the Karlsruhe Personal Neutron Albedo Dosi-meter (PNAD) showing the major components



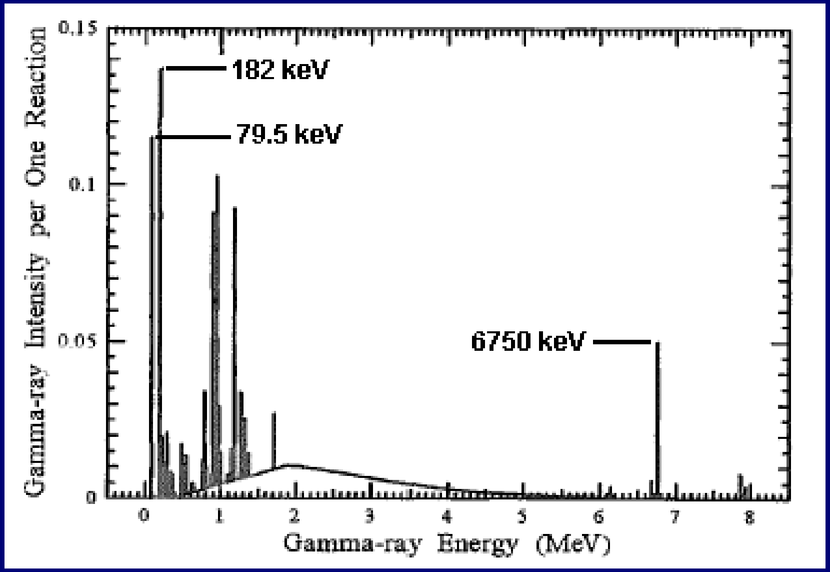
In adddition to LiF TLD pairs it also includes a SSNTD (solid state nuclear track detector) CR39.

Neutronic properties of Gadolonium

Reference: Y. Sakurai and T. Kobayashi. Jour. Nucl. Sc. Tech. Suppl. 2, pages 1294-1297 (August 2002)



The neutron capture cross section of ^{157}Gd



The prompt gamma energy spectrum of $^{157}Gd(n,\gamma)^{158}Gd$ reaction.

Alumina Albedo Dosimeter (This Work)

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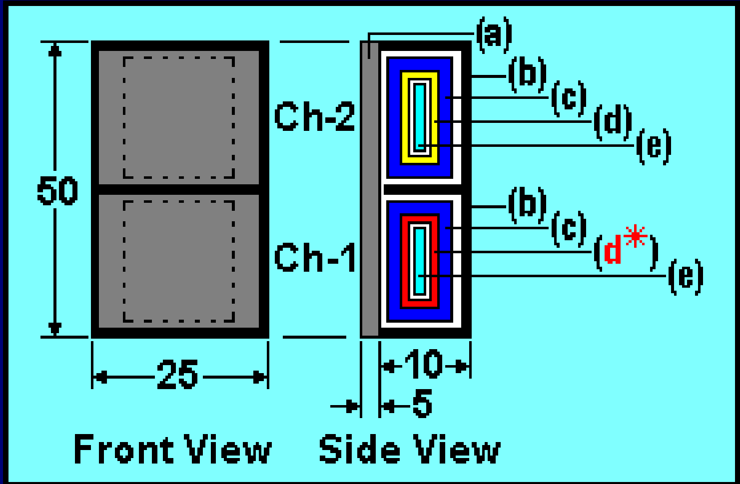
The Prototype and Components (dimensions are in mm)



(a) Boranated Rubber Pad (5mm)

(b) Acryl Box

(c) Lead Shield (2.5 mm)

(d) Cardboard Spacer

(d*) Gadolonium Converter Foil (0.2 mm)

(e) Alumina Pellets

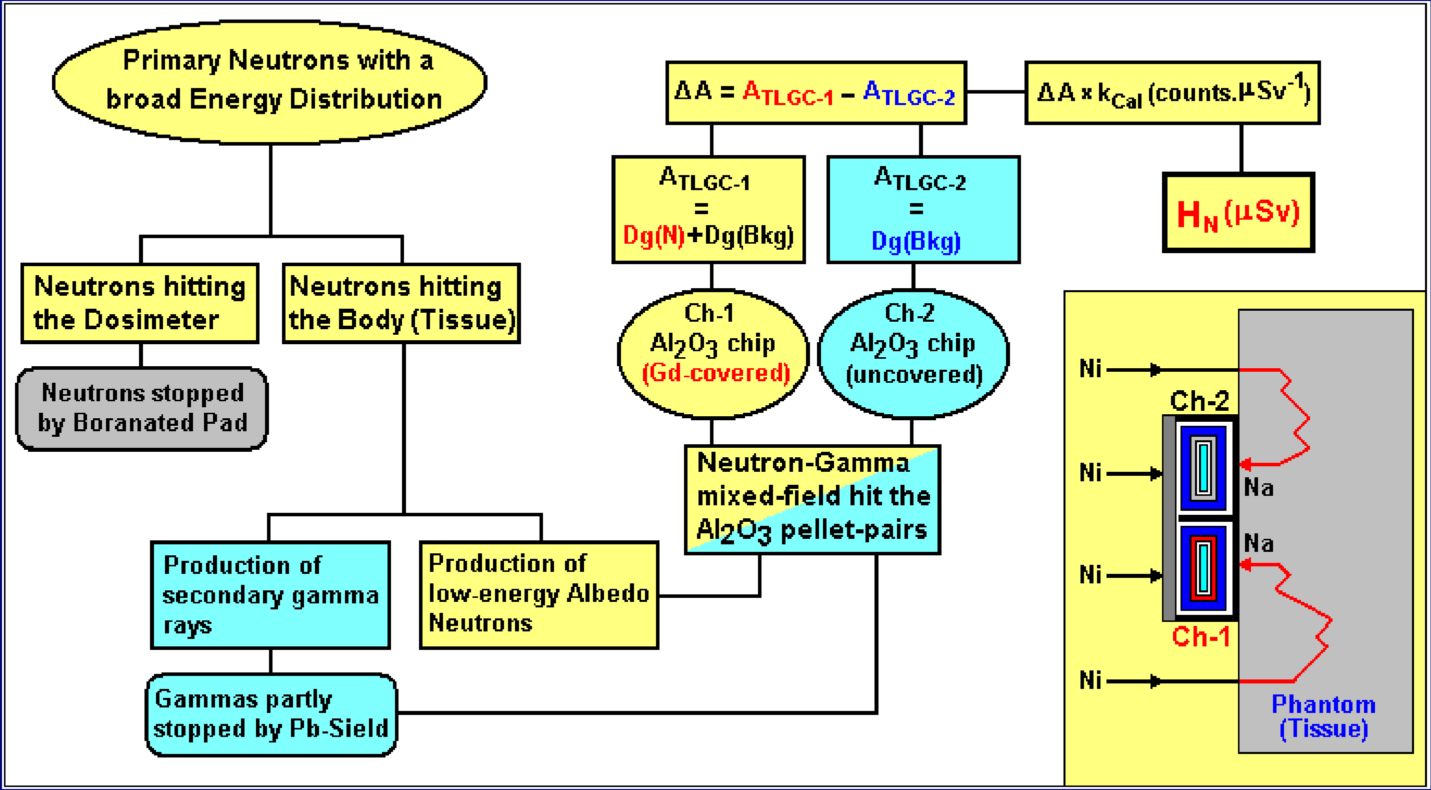
The WPE Albedo Dosimeter Badge (front view)

(PCT / EP201 / 003184)

The WPE Albedo Dosimeter Badge (rear view)

Alumina Albedo Dosimeter (principle)

Operation Flowchart and Functional diagram (inset)



A_{TLGC} = Area under Thermoluminescence Glow Curve (counts)

k_{Cal} = Calibration Factor (counts.μSv^{-1})

Ni = Incident neutrons

Na = Albedo neutrons

TLD Evaluation

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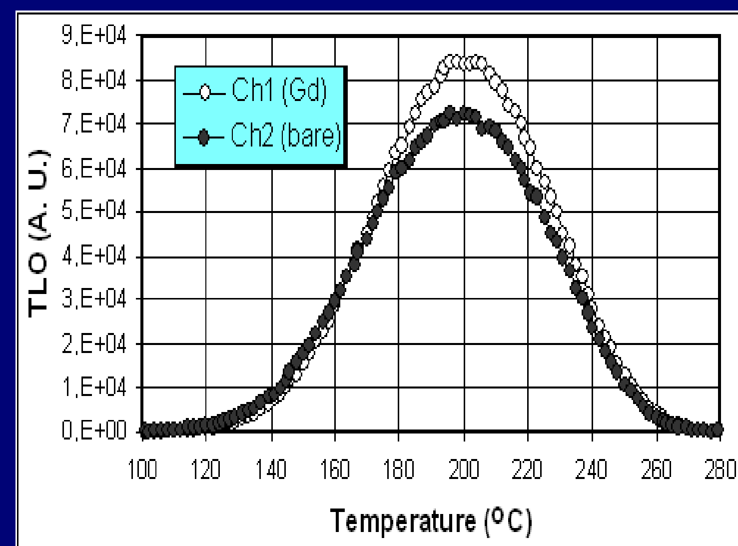
General view of the TL- Dosimetry evaluation setup including annealing ovens, located at the WPE Health Physics Laboratory.

The TLD Glow curves of Ch1 (Gd-covered) and Ch2 (bare) TLD-500 chips. The increased signal in Ch1 caused by the gammas produced by thermal neutron capture in the Gd foil.

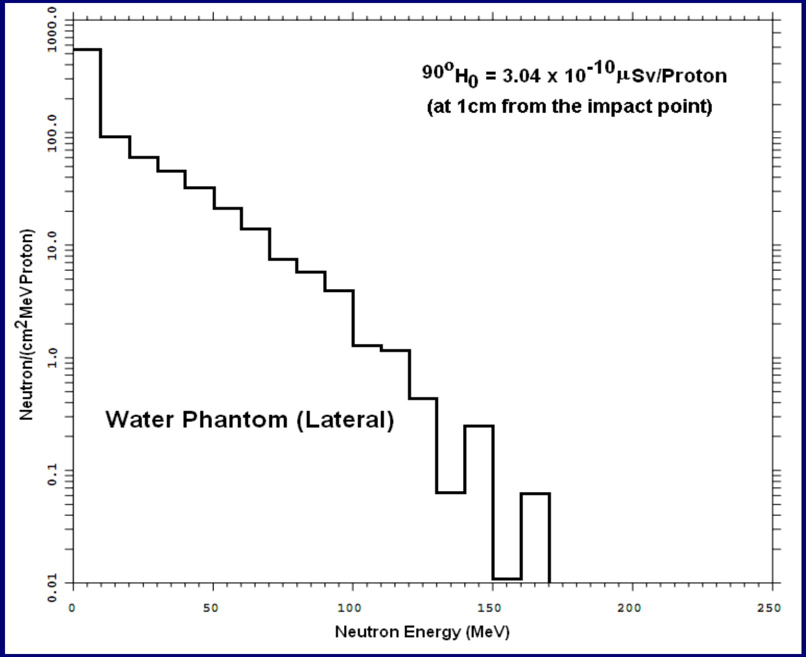


Dosimeter Calibration using fast neutrons

Neutrons were produced by bombarding a water phantom with 230 MeV protons

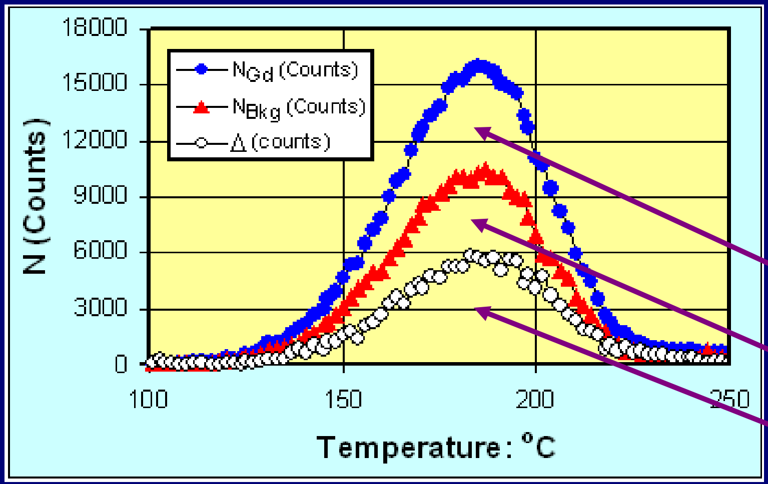
The dosimeter badge was attached to a plastic jar (30 cm dia, 40 cm high) filled with water and a Neutron monitor WENDI 2 (Wide Energy Neutron Detection Instrument) placed next to it (2m from phantom).

The system was irrradiated with neutrons to dose equivalent (DE) levels of 256, 308, 512, 716 and 1190 μSv. After the end of each run the badge was removed, corresponding neutron DE was read and a new badge was attached to the jar.



The neutron spectrum was simulated using MCNPX 2.6 code as shown above.

Dosimeter Calibration using fast neutrons (cont.)



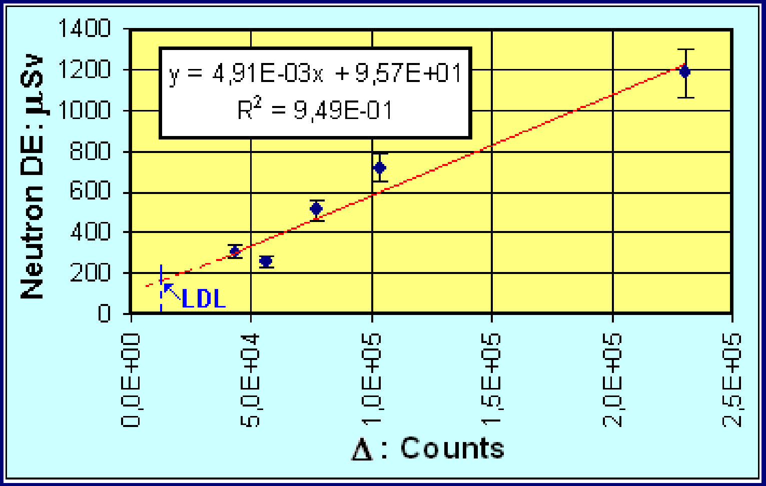
The TL-Glow curves (TLGC) were evaluated at a linear heating rate of 5 °C.s^{-1} using a modified Harshaw Model 3500 TLD reader.

H_N = 512 µSv

A_{TLGC} (Gd) = 1.43 x 10^5 counts

A_{TLGC} (Bkg) = 6.58 x 10^4 counts

Δ = A_{TLGC} (Gd) - A_{TLGC} (Bkg) = 7.72 x 10^4 counts



For calibation purpose we have irradiated the prototype badge five different neutron DE levels: 256, 308, 512, 716 and 1190 µSv.

Dosimeters were evaluated and neutron DE are plotted as a linear function (inset) of TLGC area difference (Δ).

The lowest detection level (LDL) for the minimum measureable Δ (1.25 x 10^4 counts) calculated to be 157 µSv.

Al_2O_3 dosimeters are extremely photosensitive and prone to triboluminescence, hence, shall be handled very carefully during packaging in a dimly illuminated room.

Summary and Conclusions

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At West German Proton-therapy Centre Essen (WPE) we have developed a novel personal neutron albedo dosimeter (PNAD) based on Aluminium Oxide (Alumina) TLD (TLD-500) covered with thin Gadolonium foil.

Gadolonium (^{157}Gd) possesses a very high thermal neutron cross section to produce gamma rays via the $^{157}Gd(n,\gamma)^{158}Gd$ reaction. On the other hand, TLD-500 is highly responsive to gamma rays.

The combination of the above phenomenon is the fundamental principle of the TLD-500 based PNAD.

Summary and Conclusions

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Like the conventional PNAD (Karlsruhe-PNAD) which are made of TLD-600 (^{6}LiF: Ti,Mg) and TLD-700 (^{7}LiF: Ti,Mg) chips, the incoming neutrons in the case of WPE-PNAD are also blocked by a boronated rubber sield.

Unlike Karlsruhe-PNAD the WPE-PNAD have no albedo window, both TLD pellets are covered with 2.5mm thick lead shielding to supress the background gammas.

WPE-PNAD was calibated in-situ using the fast-neutron field produced by bombarding a water phantom irradiated with 230 MeV protons.

The lowest detectable neutron dose (LDD) equivalent of WPE-PNAD was evaluated to be 157 μSv.

An extra TLD-500 will be added to the next version to record the gamma dose.

We are planning to evaluate the TLD-500 chips in OSL mode, thereby lowering the LDD value substantially.

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Thank you for your attention

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