

EUROPEAN COMMISSION

nuclear science and technology

Evaluation of Individual Dosimetry in Mixed Neutron and Photon Radiation Fields (EVIDOS)

Editor: Helmut Schuhmacher, Physikalisch-Technische Bundesanstalt (DE)

Final report (summary)

Work performed as part of the European Atomic Energy Community's R&T specific programme
Nuclear Energy, key action Nuclear Fission Safety, 1998-2002
Area: Radiation Protection

2005

Directorate-General for Research
Euratom

Objectives

The EVIDOS Project, supported by the European Commission within the Fifth Framework Programme, aimed at evaluating state-of-the-art dosimetry techniques in representative workplaces of the nuclear industry with mixed neutron/photon radiation. Seven European institutes with recognised expertise in radiation protection instruments and methods joined efforts with end users at nuclear power plants, at fuel processing and reprocessing plants, and at transport and storage facilities. A major task of the project was to develop methods to characterise the neutron component of mixed radiation fields at workplaces and to derive reference values of radiation protection quantities from energy and direction distributions of the neutron fluence.

Workplaces in the nuclear industry where workers can receive significant neutron doses were selected, and the following tasks were carried out:

- determination of the energy and direction distribution of the neutron fluence
- derivation of the (conventionally true) values of radiation protection quantities
- determination of the readings of routine and innovative personal dosimeters and of area monitors
- comparison between dosimeter readings and values of the radiation protection quantities.

The results from the project allow an evaluation of the accuracy of dosimetry in mixed neutron/photon radiation fields using routine and innovative dosimetric equipment.

Research performed

After some calibration measurements in simulated workplace fields, four measurement campaigns were performed in selected mixed-radiation environments representative of the nuclear fuel cycle (Table 1). These environments permitted a thorough testing of the dosimeters since the fields differed widely in terms of dosimetric and environmental parameters.

Table 1: Facilities visited and workplace fields investigated

Measurement period	Facility and location	Radiation fields
C0: 10 October – 26 November 2002	Simulated workplace fields, IRSN, Cadarache, France	IRSN CANEL IRSN SIGMA
C1: 1-3 April 2003	Nuclear power plant Krümmel, Germany	BWR Krümmel T - top BWR Krümmel SAR - control rod room Cask NTL M - centre of long side Cask NTL S - side
C2: 18-22 June 2003	Fuel processing plant Belgonucléaire, Dessel, Belgium and Research reactor VENUS, SCK•CEN, Mol, Belgium	Belgonucléaire 1 - bare MOX fuel rods Belgonucléaire 2A - unshielded rack Belgonucléaire 2B - shielded rack Belgonucléaire 3 - storage room SCK•CEN VENUS C - control room SCK•CEN VENUS F - side shielding wall
C3: 8-12 November 2004	Nuclear power plant Ringhals, Väröbacka, Sweden	PWR Ringhals A - inside containment PWR Ringhals L - entrance lock Cask TN D - centre of long side Cask TN N - centre of end plate
C4: 23-25 May 2005	Nuclear facility ¹	Nuclear facility 1 - door Nuclear facility 2 - corridor Nuclear facility 3 - inside room

In each workplace field, the angle-integrated energy distribution of the neutrons was measured with a Bonner sphere spectrometer. The methods of data analysis for this system, which are based on inverse methods (unfolding), were improved to include estimates of the uncertainties of the spectrometric results and of the derived dosimetric values.

New methods were developed for the characterization of work-places using direction spectrometry. This allowed a full characterisation of the radiation fields in terms of the neutron fluence (or fluence rate) as a function of energy and direction. Conversion coefficients were then used to derive the relevant radiation protection quantities, ambient dose equivalent, $H^*(10)$, personal dose equivalent in a slab phantom as used for calibration purposes, $H_p(10)$, and effective dose, E .

Results were obtained from a large number of dosimetric equipment including area monitors (Berthold LB 6411, Harwell Leake N91, Studsvik 2202, Wendi-2, SSI Sievert), active electronic personal dosimeters (Aloka PDM-313, PTB DOS-2002, Saphymo Saphydose n, Synodys DMC 2000 GN, Thermo Electron EPD-N, Thermo Electron EPD-N2) and other personal dosimeters (BTI PND and BDT, DIMNP HpSLAB, NRPB PADC, PSI CR-39, PSI DIS-N, Local TLD devices). These include commercial devices and instruments developed by the partners outside or within the project. Figure 1 shows some of the personal dosimeters used.

¹ Due to security reasons, details of this facility and of its radiation fields may not be disclosed in this report.



Figure 1: Some of the advanced personal dosimeters for neutrons or for mixed neutron/photon radiation used within the project

Main achievements

The results from the project include spectra and dosimetric data for 17 different workplace fields (boiling water reactor, pressurised water reactor, research reactor, fuel processing, and storage of spent fuel), instruments and procedures to derive reference values for personal dose equivalent and other radiation protection quantities, and results on the dosimetric and technical performance of personal dosimeters for mixed radiation.

Characterisation of radiation fields

The measurements with reference spectrometry revealed significant differences in the energy distributions at the workplaces. While all distributions exhibit a similar structure – comprising a thermal peak, a fairly flat intermediate energy region and a peak from fast neutrons with a maximum between 100 keV and 1 MeV – the contributions of these neutrons to the fluence vary significantly.

The importance of the different neutron energies for dosimetry depends on the fluence-to-dose equivalent conversion coefficient. Because of its strong energy dependence, the contribution of high-energy neutrons to dose equivalent is dominant in all spectra. As an example, the spectrum with the largest contribution from thermal and intermediate-energy neutrons was found in a work-place at a research reactor: about 90% of the neutron fluence was found to be below 10 keV, but these neutrons contribute only about 25% of the ambient dose equivalent.

For the analysis of dosimeter results, the mean fluence-to-ambient dose equivalent conversion coefficient, h^* , was used as a parameter to indicate the "hardness" of a spectrum. Although, in principle, different spectra can lead to the same h^* , the use of a single parameter allows to categorise spectra for analysing the instruments' behaviour in the different radiation fields. Fig. 1 shows h^* for the different radiation fields. All spectra at the reactors are soft because they are affected by massive shielding between the reactor cores and the measurement positions. At the transport casks, two types of spectra were observed: hard spectra at one cask (NTL) and much softer spectra at another one (TN), which included an additional neutron

shield. For fuel processing, the spectra vary significantly depending on the specific shielding conditions. The values of h^* indicate that the simulated workplace fields are representative of fields with significant shielding (e.g. at reactors) but not of those with little shielding.

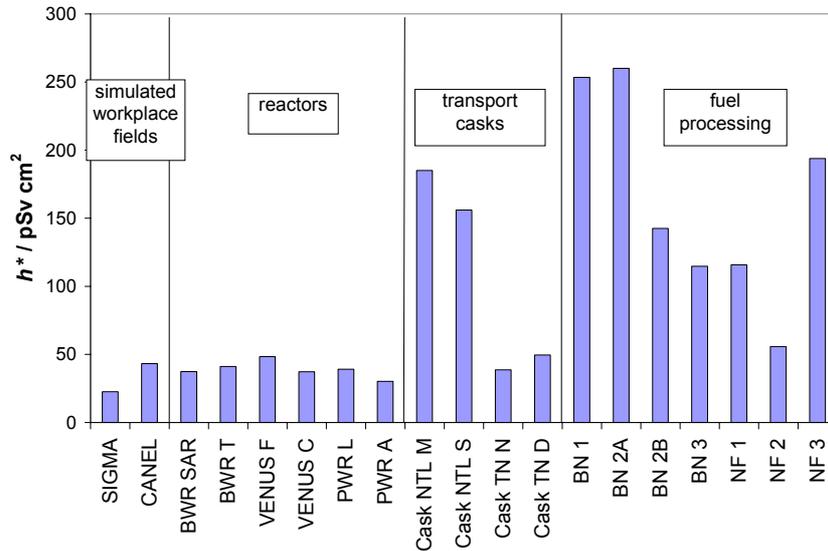


Figure 1: Mean fluence to ambient dose equivalent conversion coefficient, h^* , for the different radiation fields investigated

The ratio $H_p(10)/H^*(10)$, shown in Fig. 2, can be used as a simple indicator of the direction distribution of the neutrons. If neutrons primarily impinge perpendicularly to the front surface of the phantom, like in simulated workplace fields, this ratio is close to 1. The larger the contribution from neutrons from other directions of incidence, the smaller this ratio gets, since neutrons coming from these other directions of incidence are largely shielded by the phantom. A lowest value of 0.22 was observed for the control rod room underneath the core at the Krümmel power plant (BWR SAR), where a large isotropic component was present with the main contribution coming from the top. In general, the direction distributions in the investigated workplaces are more isotropic at reactors and more directional at transport casks and fuel processing. The particular results for each workplace are influenced by the specifics of its geometry, especially with respect to shielding and scattering materials.

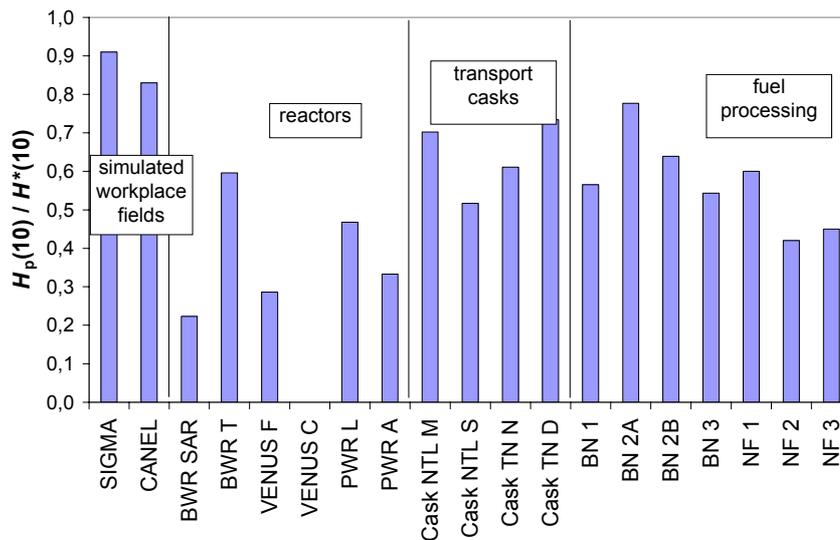


Figure 2: Ratio of personal dose equivalent, $H_p(10)$, (with the front surface of the slab phantom facing the assigned reference direction) of the to ambient dose equivalent, $H^*(10)$, for the different radiation fields. For position VENUS C, $H_p(10)$ data are not available because measurements with the direction spectrometer could not be performed

The photon dose equivalent rates were measured with a FHT 191 N ionisation chamber and with low-pressure proportional counters. The fractions of photon to total ambient dose equivalent ranged from about 4 to 80 % in the workplace fields investigated.

Radiation protection quantities

The reference method used to determine $H^*(10)$ of neutrons in unknown radiation fields was Bonner sphere (BS) spectrometry. BS spectrometry was chosen for this project because it is well established, it has been benchmarked against other methods, e.g. calculations, and it allows $H^*(10)$ to be determined with small uncertainties in the order of 5 % (one relative standard uncertainty) provided that the response matrix of the spectrometer is known precisely and that data analysis is performed carefully.

A reference method to determine $H_p(10)$ does not exist, yet. The direction spectrometers developed in this project are still research tools for which further validation is needed. The results from these instruments were improved by using angle integrated spectra from BS as pre-information. In this case, the uncertainties are in the order of 30 %. The results were in agreement with those from transport calculations performed for simulated workplace fields and for workplace fields at the VENUS research reactor. An alternative method to determine $H_p(10)$, which may result in similar uncertainties, is based on a superheated drop detector located at 10 mm depth inside a slab phantom (HpSLAB). However, further research and validation is needed for this device.

Dosimeter results

The area monitors yielded responses between 0.5 and 1.5, with a slight under-response in harder spectra. Despite the small underestimation in terms of $H^*(10)$, these instruments do

provide generally conservative estimates of $H_p(10)$ or E . In highly scattered fields, the overestimates can be substantial.

For the personal dosimeters, a significant spread of the results was observed (Fig. 3). While the best results were obtained in hard spectra, many dosimeters over-responded significantly in soft spectra. The new active (electronic) personal dosimeters (APDs) do not generally give better results than passive ones in terms of the spread of responses – at least for the workplace fields investigated. APDs show, however, a much lower detection limit. In reactor fields, 20 μSv can be measured with a statistical uncertainty of 10 % with most APDs.

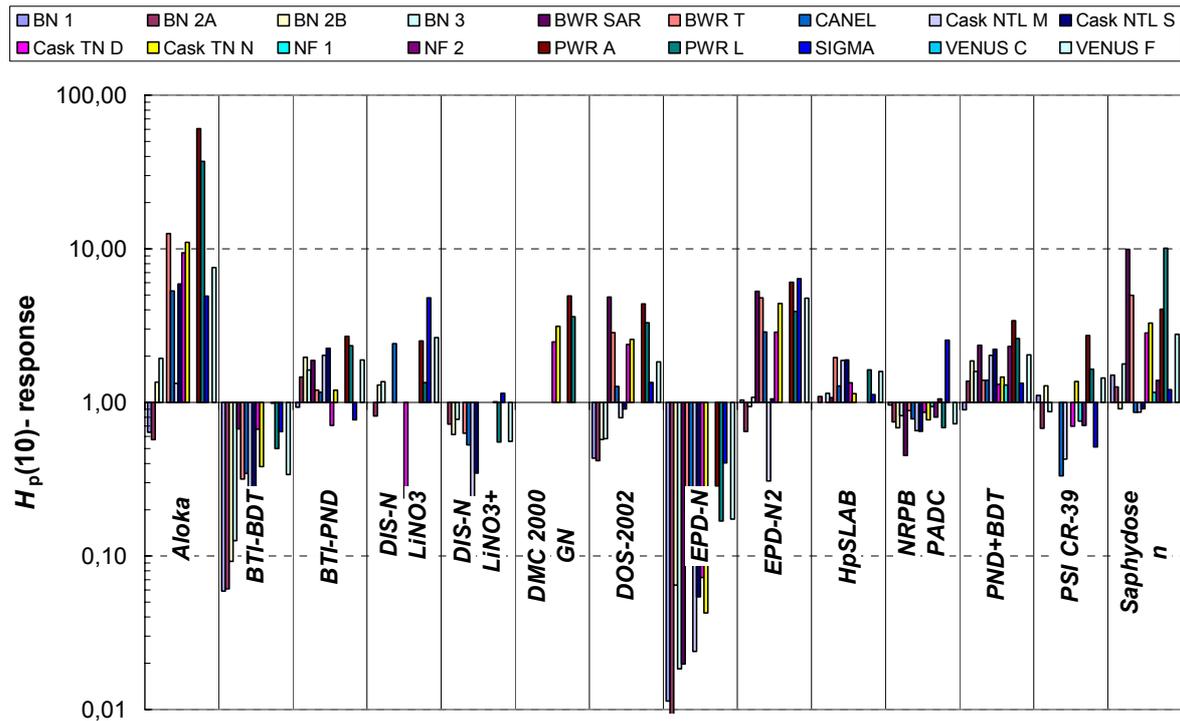


Figure 3: Measured response of personal dosimeters in the different radiation fields for irradiation at 0° (phantom facing the main direction of radiation incidence)

If the application is restricted to highly scattered fields at reactors, then a field-specific calibration (e.g. using a simulated workplace field) improves the results for some area monitors and personal dosimeters. However, further analysis is needed to understand why this procedure does not lead to improvements with all instruments.

Exploitation and dissemination

The results from the project were described in presentations at several conferences and in more than 40 publications.

The dosimetric results represent important information for manufacturers of personal dosimeters, indicating the possible need and guidelines for improvement of their products. Indeed, some of the results obtained have already been used for that purpose.

Two direction spectrometers were developed within the project. Due to the restricted applications of these instruments and the considerable effort needed to transfer these into routine devices, exploitation in the form of commercial devices does not appear imminent.

tine devices, exploitation in the form of commercial devices does not appear imminent. The spectrometers are, however, available on request for investigations.

The HpSLAB instrument appears potentially suitable for being developed from a laboratory research tool into an easy-to-operate reference device for the measurement of personal dose equivalent of neutrons in unknown mixed radiation fields. Further work is being performed on this issue and contacts with potential manufacturers will be established.