RADIATION SURVEILLANCE AND RADIATION DOSE CONTROL AT CERNAVODA NUCLEAR POWER PLANT

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În această lucrare vom evalua posibilitatea de utilizare a unor dozimetre personale electronice (EPD) pentru dozimetria neutronilor la Centrala Nuclearelectrică de la Cernavodă. În cadrul evaluări vom verifica dacă aceste dozimetrele au un răspuns corespunzator la câmpurile de radiații existente într-o centrală de tip CANDU și dacă prezintă o rejecție corespunzătoare la câmpurile gama pentru canalul de neutroni. Aceste evaluări au fost realizate în mai multe camere din Clădirea Reactorului de la Unitatea 1 a CNE Cernavoda în câmpuri mixte gama-neutroni. O zonă cu caracteristici speciale o reprezintă camera in care se afla componente auxiliare ale Sistemului de Transport al Căldurii care are un spectru specific bogat în neutroni epitermici. Pentru determinarea dozelor ambientale am folosit un monitor de neutroni model Eberline ASP-2/NRD, iar pentru verificarea rejecției gamma a fost folosit un iradiator tip Shepherd model 78.

În condițiile prezentate, toate EPD-urile evaluate au trecut testele, acestea având o bună corelare cu valoarea de referință ceea ce dovedește că pot fi utilizate pentru dozimetria personală de neutron, fiind necesar utilizarea unui factor de corecție dependent de spectrul de neutroni specific zonei de lucru.

The work presents the evaluation of new neutron electronic personal dosimeter (EPD) at the Cernavoda NPP. As the new EPDs should fulfill the specific conditions inside a CANDU nuclear power plant, they were also checked for gamma dose rejection in several neutron fields inside the power plant with focus on a specific location – Heat Transport Auxiliary Room, with a high level of epithermal neutrons. An Eberline ASP-2/NRD dosimeter was used as neutron field reference while gamma dose rejections were evaluated by a Shepherd 78 calibrator. In these conditions, all evaluated EPDs passed with a good degree of confidence to the reference value and proven that they are suitable for personnel deep dose evaluation with a relative neutron spectra correction coefficient.

Keywords: radiation protection; ALARA, neutron measurements; personnel dosimetry.

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1. Introduction

In the last years, the radiation surveillance, personnel dosimetry and dose tracking requirements at nuclear facilities have become more rigorous. The radiation protection programs, built on the ALARA (As Low As Reasonably Achievable) principle, require the use of direct-reading dosimeters to perform the activities classified as "Radiation work". These readings are used to record the received doses until the permanent dosimetry badge can be read and to alert, visual and acoustic, the worker for overexposures as well as to signal the high dose rate areas. Such devices are extensively used in European Union for radiation protection of workers with respect to the 96/29 European Union directive (based on the recommendations of ICRP [1]). This directive reinforces basic recommendations regarding exposure justification, optimization of protection and dose limitation, as well as the submission of certain practices involving ionizing radiation to a system of reporting and prior authorization. In the context of optimization, all exposures shall be kept as low as reasonably achievable and dose constraints should be used for radiation protection purposes.

In accordance with these principles, at the Romanian Cernavoda Nuclear Power Plant (NPP), the official dosimetry system in place is based on the Thermo-Luminescent Detectors (TLDs). Concurrently, another system of Electronic Personnel Alarming Dosimeters (EPD) for instant dose readings and alerts is in use too. Its selection was based on EPDs performances regarding linearity, accuracy as well as the absence of any interference with magnetic, radio frequency ore microwave fields.

Currently, at Cernavoda NPP, neutron doses are evaluated by using an Eberline ASP-2 dosimeter with a good gamma rejection and a response close to theoretical dose equivalent within the entire range of neutrons energies, *i.e.* thermal to fast, 10 MeV neutrons. Calibrated at Physikalisch-Technische Bundesanstalt (PTB)(Germany) facilities by means of Am-Be as well as of ^{252}Cf (bare and D_2O moderated) neutron sources, the Eberline dosimeter was used as primary standard. As Eberline monitor, do its size and weight, has a limited access to shafts and stairs, we have tried to overpass this inconvenience by using concurrently a system of two different kinds of EPDs to monitor the neutron fields inside NPP., system which must fulfill the compulsory requirements regarding a good gamma ray rejection and a perfect compatibility with the existing dose recording systems.

CANDU reactors, such as those of Cernavoda NPP, are characterized by neutron spectra rich in low energies ranging from thermal up to 2 MeV. As the fluency/dose ratio is highly dependant on the neutrons energy, the main task in

Table 1

The main characteristics of MGP™ DMC2000GN EPD, as furnished by the manufacturer

Gamma channel				
Energy range (KeV)			Angular response (% ^{137}Cs)	Dose rate linearity (%)
Min	Max	% ^{137}Cs		
50	6000	10	IEC 1283	30
Neutron channel				
Energy range (eV)				
Min			Max	
0.024			15 E+6	

using EPDs consists of a confident evaluation of their behavior in this particular kind of neutron fields..

For this reason, any personnel dosimetry program should be related to the measurement of neutron doses received by workers. In order to identify the best solution for personnel neutron dosimetry, dose evaluations using different neutron dosimeters were performed at Cernavoda NPP, in different locations, in an attempt to cover the most representative neutron spectra.

Accordingly, in this paper we present and discuss our results regarding the performance of two different types of neutron dosimeters at Cernavoda NPP.

2. Material and methods

2.1 Dosimeters

The commercially available gamma and beta ray dosimeters are based on Geiger-Müller tubes, silicon diodes or Direct Ion Storage detectors. Regardless the detector utilized, all dose recording systems should be calibrated with respect to a higher class detectors taken as reference, in accordance with the IEC 1283 international regulations [2].

In these conditions we have selected of set of 5 exemplars of MGP™ DMC 2000 GN (Mirion Technologies) EPDs. This EPD, developed by MGP Instruments under PTB license, uses two silicon detectors for the determination of photon and neutron personal dose equivalent (Table 1). The neutron detector is covered by converters and absorbers to improve its energy response (polyethylene and ^{6}LiF) and an albedo shield that surrounds the detector/converter assembly. The neutron sensitivity is 0.5 counts/μSv.

We have selected also 20 exemplars of **Panasonic UD-814AR9 ™** TLDs, each containing four different detectors: three of them made of $^{7}Li_2{}^{11}B_4O_7$ are neutrons insensitive, and the fourth, neutron sensitive contains $^{6}Li_2{}^{10}B_4O_7$. The main advantage of the lithium borate is its almost tissue equivalent as its effective atomic number of 7.4 is very close those of soft tissue of 7.7. The first element, covered only by a thin Mylar sheet (14 mg/cm^2), is used to estimate the beta-gamma radiation shallow individual dose equivalent Hp(0.07), with a supplementary filtration of 3 mg/cm^2 due to badge window.

The second and the third elements ($^7Li_2{}^{11}B_4O_7$) are used to measure deep individual dose equivalent Hp(10) due to gamma radiation. Filtration is 160 mg/cm^2 on the TLD plus 85 mg/cm^2 on the protective badge.

As the first three elements are insensitive to neutrons, the deep gamma dose and shallow beta-gamma dose can be read out directly.

Only the fourth element containing $^6Li_2{}^{10}B_4O_7$ which can detect neutrons by means of a $^6Li(n,\alpha)^3H$ reaction was effectively used for neutron dosimetry (Table 2), but, because its response depends on the neutron energy spectrum, its use was restrain only confirm the presence of neutron fields. Filtration is the same as for second and third element.

2.2 Dose measurements

The portable Eberline ASP2/NRD neutron dosimeter was used as reference for the evaluation of the 4th TLD element and all EPDs. Accordingly, for calibration, we have used three isotopic neutron sources: ^{241}Am-Be (α, n), ^{252}Cf (bare and D_2O moderated). All the measurements were performed under stable irradiation conditions so that the instrument was read out every 30 s to 60s, displaying the dose equivalent rate. The calibration factor for H*(10) was determined by using the bare ^{252} Cf source at a neutron ambient dose equivalent rate of 431 μSv/h.

Due to an energy-dependent response of TLD, the uncorrected reading can only be used in radiation fields with the similar neutron spectrum to calibration one. To be used in neutron fields with different spectra, a field-specific correction factor should be applied. In the case of ^{252}Cf (D_2O) the correction factor experimentally determined was equal to 1.21 ± 0.06.

The neutron fields inside the power plant arise primarily from two sources: neutrons produced by fission in the reactor that leak through the shielding and neutrons produced by (γ,D) reactions. Both kinds of neutrons are further scattered by various building structures so that, the neutron fields significantly differ from

Table 2

Experimental values of the correction coefficients

Neutron field	Correction factor	
^{241} Am-Be (α, n),	0.87 ± 0.17	
^{252} Cf (D_2O)	0.66 ± 0.09	
^{252}Cf	1.21 ± 0.06	

one location to another.

By taking into account that in some areas both gamma and neutron fields are present, it was necessary to evaluate the influence of gamma field on neutron dosimeters. For this purpose we have used a Shepherd 78 calibrator consisting of a shielded chamber, four attenuators and two ^{137}Cs sources, one of 1.48 10^{13}Bq and the other on of 4.81 GBq.

Final measurements concerning EPDs and TLDs were performed inside of reactor building, in Heat Transport Auxiliary Room, at 100% reactor power. TLDs were placed on the chest of a 30cm SLAB type water phantom filled with water while EPDs were located on the floor, near Eberline ASP2/NRD dosimeter.

3. Results and discussion

3.1. TLD Passive dosimeters

The Final results concerning our measurements are reproduced in Table 3. As its results from these data, there are great discrepancies between ASP2/NRD and TLD indications, proving TLDs unsuitability for neutron dosimetry, their readings showing only the presence of the neutron field, but not at all neutron dose values.

Table 3

Results of the TLD and portable neutron meter intercomparison

Measurement location (room number)	Computed Dose rate* (mSv/h)	ASP2/NRD indication		TLD measured dose (mSv)
		dose (mSv)	dose rate (mSv/h)	
R-009	0.08 ± 0.01	0.52	0.03	3.51
R-010	0.01 ± 0.004	0.50	0.03	6.04
R-501 A	0.64 ± 0.03	0.62	0.53	2.74
R-501 B	0.64 ± 0.03	0.52	0.35	3.71
R-501 C	0.64 ± 0.03	0.56	0.56	2.99
R-501 D	0.64 ± 0.03	0.50	0.06	1.39
R-501 HTP	0.64 ± 0.03	0.52	0.26	1.66
R-405	0.07 ± 0.01	0.44	0.12	10.55
R-405 (in the middle)	0.07 ± 0.01	0.50	0.02	2.68
R-406		0.500	0.111	16.86
R-406 (in the middle)		0.480	0.031	4.10

* Average values taken from literature [4].

As its results from these data, there are great discrepancies between ASP2/NRD and TLD indications, proving TLDs unsuitability for neutron dosimetry, their readings showing only the presence of the neutron field, but not at all neutron dose values.

3.2 DMC 2000GN evaluation

The first step in DMC 2000GN evaluation consisted of checking their performances regarding gamma ray rejection (Table 4). Of 5 initial DMC 2000GN, only three of them were selected for further measurements, and of these, only one showed to be insensitive to gamma ray field.

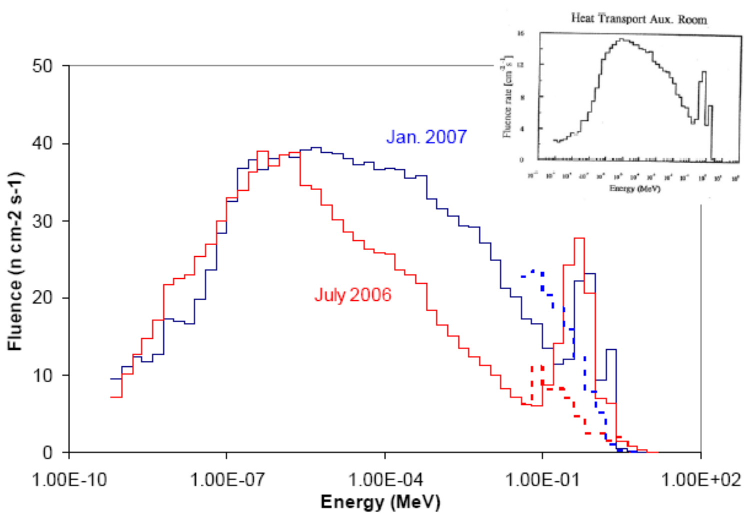

Fig. 1. Neutron spectra at one location chosen for this study.

This issue was supplied to the producer to modify the calibration factor in order to increase gamma rejection.

We have also checked the performances of three EPD in the case of pure neutron fields as those whose energy spectrum is reproduced in Fig. 1 (gamma dose rate are low in that area,). By using the correction coefficients previously

Table 4

The indications of EPD (DMC 2000GN) and portable neutron meter on neutron detector when was exposed at gamma field

Gamma dose rate (mSv/h)	Indications on neutron detector on neutron channel			
	EPD#1 (mSv/h)	EPD#2 (mSv/h)	EPD#3 (mSv/h)	ASP-2/NRD (mSv/h)
4.52	1.025	0.58	0	0
369.59	25.82	70.02	0	0
516.68	130.8	315.85	0	0

calculated (Table 2), we have been able to determine the local absorbed dose, values reproduced in Table 5. As it results from these data, there is a good coincidence within experimental uncertainties between ASP-2/NRD and the all three EPD used for this test.

It is worth mentioning that all measurements were performed such that to fulfill both national and IAEA regulations concerning neutron field dosimetry.

4. Conclusions

Knowledge of the energy and of the geometry for neutron and gamma fields has to be taken into account to correctly measure dose equivalent based on energy spectrum distributions. Spectrometry results in different working areas may help users to adapt radiation protection instruments to their working conditions. In this manner, more accurate dosimetry values could be obtained by applying a correction coefficient to values measured by the ^{241}Am-Be calibrated portable neutron meter/neutron EPD, or by calibrating the neutron EPD and the portable neutron meter in a more appropriate field. There are advantages in having available calibration fields that resemble the field in which the dose equivalent measuring instruments are intended to be used.

The passive TL detectors show a greater dependency on the neutron field they are exposed and simple dosimeters (TLD with one neutron element) are not suitable for complex neutron fields specific to the CANDU type reactor. The Panasonic UD-814AR9 TLDs are not relevant for neutron dosimetry and their readings only indicate the presence of the neutron field. Specific TL detectors like the ones used in [5] show a similar dependency as EPD’s to the neutron spectra and need a location specific correction coefficient.

The results of the evaluation performed on the 3 EPD (DMC 2000GN model) demonstrate that the neutron personal electronic dosimeters should be carefully used in mixed gamma-neutron fields. In neutron-gamma mixed fields,

Table 5

Results of the neutron EPD and portable neutron meter intercomparisons with computed doses from literature [4]

Computed Dose (room 405)* [mSv]	Exposure time [h]	ASP-2/NRD (mSv)	EPD#1 (mSv)	EPD#2 (mSv)	EPD#3 (mSv)
0,173	2.5	0.185	0.143	0.203	0.169
		0.223	0.185	0.243	0.252
		0.192	0.143	0.164	0.148
		0.160	0.185	0.197	0.208
		0.167	0.173	0.211	0.152
	Average	0,185 ± 0,022	0,165 ± 0,018	0,203 ± 0,025	0,185 ± 0,039

the indication on neutron channel is influenced by the gamma dose rate values. Given that a CANDU plant, in accessible area, gamma dose rate are low, we can use this type of dosimeter without problems. In case that one employee must to enter in high gamma dose rate (at least few mSv/h), is mandatory to select and used only the dosimeters which have a good gamma field rejection. Otherwise, the indication on neutron channel will be overestimated.

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