# Occupational External and Internal Exposure Monitoring in the Public Company "Nuclear Facilities of Serbia"

Ivan Knežević, Nevena Zdjelarević, Dragana Čekerevac Mirković

***Abstract*—This paper presents actual occupational external and internal exposure monitoring techniques and methods being used in the Public Company "Nuclear Facilities of Serbia", the only nuclear operator in Serbia. This monitoring system consists of a set of stationary multifunctional Geiger-Mueller monitors installed on site, hand-held instruments, electronic and thermo-luminescent personal dosimeters for external, alongside with whole body counter and gamma spectrometry system for internal exposure control. Additionally, the paper shows representative results of the occupational exposure monitoring for 2016, under the Radiation Protection Programme.**

***Index Terms*—radiation safety, radiation protection, ionizing radiation, occupational exposure control**

## I. Introduction

Public Company "Nuclear Facilities of Serbia" (PC NFS) is the only nuclear operator in Serbia, which was founded by the Government of the Republic of Serbia in 2009, with main purpose to manage and maintain all nuclear facilities and activities in the country, in accordance with the *Law on Radiation Protection and Nuclear Safety* [1]. Nuclear facilities operated by PC NFS are the following (Fig.1): RA research reactor planned for final shutdown, RB experimental reactor, two old radioactive waste storages (hangars H1 and H2) under the licence for final shutdown, new radioactive waste storage hangar H3 and secure storage SS in operation, waste processing facility (WPF) under the licencing process for operation, and uranium legacy contaminated site - old uranium mine Gabrovnica, planned for remediation.

The Radiation Protection Programme is being developed and implemented by the Department for Radiation Safety and Environmental Protection in PC NFS, which has the prime responsibility for protection and safety. Occupational monitoring programme is being applied on persons working with sources of ionising radiation or who are in the ionizing radiation fields in the course of their work.

The three general principles of radiation protection are justification, optimization of protection and application of dose limits. For facilities and activities considered to be justified, the benefits that they yield must outweigh the radiation risks to which they give rise. Radiation protection must be optimized to provide the highest level of safety that can reasonably be achieved. Justification and optimization of protection do not in themselves guarantee that no individual bears an unacceptable risk of harm. Consequentely, doses and radiation risk must be controlled within specified limits. Therefore, all three principles are necessary to achieve the desired level of radiation safety.

Occupational monitoring includes individual and workplace monitoring. Individual monitoring consists of the measurements of radiation doses received by individual workers, including both monitoring due to internal and external exposure. Workplace monitoring is used to determine the potential for exposure of personnel to ionizing radiation, including the magnitude of any likely doses. Workplace monitoring is used for identification of controlled and supervised radiation areas. Occupational monitoring is used to verify the effectiveness of radiation control practices [2,3,4].


Fig. 1. Public Company "Nuclear Facilities of Serbia" site.

## II. Monitoring Techniques and Methods

External exposure control is the measurement of radiation field or doses due to radiation sources or waste that are outside the exposed worker`s body.

For monitoring of external exposure PC NFS has its own authorized personal dosimetry service under a quality measurement system, which uses thermoluminescent dosimeters (TLD) based on standard materials (MTS-N (LiF:Mg,Ti) and MCP-N (LiF:Mg,Cu,P)). TLD is a conventional mean of monitoring the whole body exposure to beta, X and gamma radiation. Contemporary measurement equipment used is *RADOS* semi-automatic TLD Reader (type RE-2000). RE-2000 is a universal and high precision TLD-

Ivan Knežević is with the Public Company "Nuclear Facilities of Serbia", 12-14 Mike Petrovića Alasa, 11351 Vinča, Belgrade, Serbia (e-mail: ivan.knezevic@nuklearniobjekti.rs).

Nevena Zdjelarević is with the Public Company "Nuclear Facilities of Serbia", 12-14 Mike Petrovića Alasa, 11351 Vinča, Belgrade, Serbia (e-mail: nevena.zdjelarevic@nuklearniobjekti.rs).

Proceedings of 4th International Conference on Electrical, Electronics and Computing Engineering, IcETRAN 2017, Kladovo, Serbia, June 05-08, ISBN 978-86-7466-692-0

reader, based on photon counting method, for processing of dosimeter cards and single chips (shown in Fig.2). It can automatically process up to 200 dosimeter cards or 800 single TL-elements at one load [5,6].

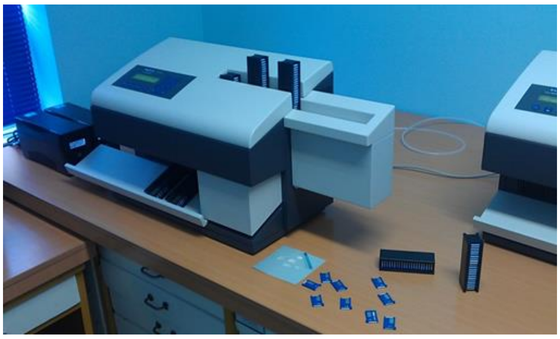

Fig. 2. Thermo-luminescent dosimeters *RADOS* reader type RE-2000.

In addition to external exposure, personnel who work with unsealed radiation sources or radioactive waste may also receive exposure from radioactive material which is taken into the body and accumulated in specific organs. Moreover, internal doses received by the organs or the whole body can be significant even for small intakes of radioactive material.

Therefore, both the external and internal exposure must be assessed in order to determine the total effective dose for the individual.

Internal dose cannot be measured directly; it can only be inferred from measured quantities such as the body activity content or excretion rate. Committed effective dose is then calculated using dose coefficients for radionuclides of interest.

The body gamma activity content is measured with Whole Body Counter (WBC). WBC is the monitoring system that is able to determine the content of gamma radionuclides in the body of examined person (shown in Fig.3). This device consists of a detection chamber and electronic unit for processing and analysis. The high-efficiency *Bicron 8H4Q/(3) 3LSS/X* large scintillating sodium iodide detector doped with thallium NaI(Tl) in Al cladding with three photo-multiplication tubes is positioned inside of 0.2 m thick steel protective chamber. WBC is calibrated with a standard known as a phantom containing a known distribution and known activity of radioactive material. This system can accurately perform in vivo activity measurements and as such is a very important health and safety tool for nuclear facilities and for post accidental measurement of people potentially internally exposed to radiation. In vivo measurement of the whole body is carried out by setting the worker on a tilted chair in front of the large area detector for 45 minutes [7,8].

The committed dose from an intake of radioactive material is also determined indirectly by measuring the activity excreted from body. In PC NFS, measurements of urine samples are used to monitor soluble materials that readily enter but are then cleared from the blood and systemic circulation of the body. Urine sampling is accumulated over a period of 24h to obtain average excretion rates.

Fig. 3. WBC NaI(Tl) scintillating detector in steel protective chamber.

Activity measurement of the urine samples was done by using a high-resolution coaxial semiconductor detector with high-purity germanium crystal *HPGe ORTEC GEM 50*, with 50% relative efficiency at 1332 keV (shown in Fig.4). The detector was shielded by lead in order to achieve a background level as low as possible. Energy and efficiency calibration was done before the measurement. The calibration source was a mixed gamma standard-type MBSS 2 in Marinelli geometry of 0.5 L, developed by the *Inspectorate for Ionizing Radiation Czech Metrological Institute*, with the isotopes $^{241}$Am, $^{109}$Cd, $^{57}$Co, $^{139}$Ce, $^{113}$Sn, $^{85}$Sr, $^{137}$Cs, $^{88}$Y, $^{203}$Hg, and $^{60}$Co. Energy of gamma lines of the radionuclides is very suitable for the calibration and covers the region of interest, i.e. from 30 to 3000keV. The quality assurance of measurements was carried out by daily efficiency and energy calibration, repeating each sample measurement. The counting time was 86 000 s. Correction for radioactive decay and background, as well as the analysis of results, were performed using software packages *ORTEC Gamma Vision-32 Model A66-B32 Version 6.01*. For all peaks, the minimum detectable activity MDA value is calculated [9,10].

Fig. 4. Gamma spectrometry *ORTEC GEM 50* system.

## III. Results

Occupational external and internal exposure monitoring results are presented for the several different groups of employed people in the PC NFS working with radioactivity, including engineers (radiation safety engineers – SE, engineers responsible for radioactive waste treatment and storage - WE), technicians (dosimetry technicians – ST, radioactive waste storage technicians - WT) and radiation safety officer (RSO).

Results of the estimated effective dose of ionizing radiation based on TLD system are shown in Table I. The effective doses ranged from 0.956 mSv to 1.25 mSv for the year 2016.

TABLE I
ANNUAL EFFECTIVE DOSE RECEIVED IN 2016

| Employee | Annual Effective Dose received in 2016 [mSv] |
|---|---|
| ST 1 | 1.16 |
| ST 2 | 0.956 |
| ST 3 | 1.108 |
| SE 1 | 1.132 |
| SE 2 | 1.25 |
| WT 1 | 1.189 |
| WT 2 | 1.145 |
| WT 3 | 1.154 |
| WE 1 | 1.076 |
| WE 2 | 1.174 |
| RSO | 1.184 |

After the occupational internal exposure monitoring using in vivo whole body gamma radionuclide activity measurements, the presence of artificial radionuclides in the bodies of professionally exposed workers has not been detected. The specific activity has been calculated for the natural radionuclide $^{40}$K which is present in the blood. The specific activities of $^{40}$K in whole body are presented in Table II.

TABLE II
WHOLE BODY COUNTING RESULTS

| Employee | Body Mass [kg] | Specific Activity of $^{40}$K [Bq/kg] |
|---|---|---|
| ST 1 | 72 | 63.1±22.8 |
| ST 2 | 81 | 71.1±25.7 |
| ST 3 | 76 | 61.6±22.3 |
| SE 1 | 55 | 41.3±15.0 |
| SE 2 | 80 | 63.2±22.7 |
| WT 1 | 92 | 101.3±36.5 |
| WT 2 | 90 | 94.7±34.1 |
| WT 3 | 65 | 56.7±20.4 |
| WE 1 | 98 | 92.3±33.2 |
| WE 2 | 80 | 70.1±25.2 |
| RSO | 65 | 47.9±17.2 |

Results of gamma spectrometry analysis of the urine samples are shown in Table III. All activity concentrations of radionuclides $^{137}$Cs, $^{226}$Ra, $^{232}$Th and $^{40}$K are expressed in units Bq/l. The activity concentration of the radionuclide $^{40}$K in urine samples ranged between (50 ± 4) Bq/l and (110 ± 10) Bq/l. Measured activity concentrations for radionuclides $^{137}$Cs, $^{226}$Ra and $^{232}$Th was below the Minimum Detectable Activity (MDA), 0.4 Bq/l for $^{137}$Cs, 2.8 Bq/l for $^{226}$Ra and 2.5 Bq/l for $^{232}$Th. The uncertainty is presented as a combined standard uncertainty with the level of confidence of 95% (k=2), where the counting uncertainty, uncertainty for the expert judgment, as well as the detector efficiency uncertainty were identified as the most significant uncertainty components.

TABLE III
SPECIFIC ACTIVITY OF URINE SAMPLES

| Employee | Specific Activity [Bq/l] | | | |
|---|---|---|---|---|
| | $^{137}$Cs | $^{226}$Ra | $^{232}$Th | $^{40}$K |
| ST 1 | < 0.4 | < 2.8 | < 2.5 | 73±7 |
| ST 2 | < 0.4 | < 2.8 | < 2.5 | 60±5 |
| ST 3 | < 0.4 | < 2.8 | < 2.5 | 55±5 |
| SE 1 | < 0.4 | < 2.8 | < 2.5 | 50±4 |
| SE 2 | < 0.4 | < 2.8 | < 2.5 | 65±6 |
| WT 1 | < 0.4 | < 2.8 | < 2.5 | 110±10 |
| WT 2 | < 0.4 | < 2.8 | < 2.5 | 90±5 |
| WT 3 | < 0.4 | < 2.8 | < 2.5 | 50±4 |
| WE 1 | < 0.4 | < 2.8 | < 2.5 | 95±9 |
| WE 2 | < 0.4 | < 2.8 | < 2.5 | 75±6 |
| RSO | < 0.4 | < 2.8 | < 2.5 | 50±5 |

## IV. CONCLUSION

This paper presents the results of the occupational external and internal exposure monitoring for 11 professionally exposed workers in PC NFS.

The individual control of external exposure by personal dosimetry showed that the annual dose limits of personnel, prescribed in Radiation Protection Programme of PC NFS, national legislative and regulations [1,2] and international standards [3,4], are not exceeded.

The obtained results of activity concentrations of radionuclides in the investigated urine samples, as well as in the whole body showed that there was no internal contamination of the personnel in the PC NFS.

## REFERENCES


[1] *Law on Radiation Protection and Nuclear Safety*, Official Gazette of the Republic of Serbia 36/09 and 93/12.

[2] *Rulebook on Limits of Exposure to Ionizing Radiation and Measurements for Assessment of the Exposure Levels*, Official Gazette of the Republic of Serbia 86/11.

[3] *Radiation Protection and Safety of Radiation Sources: International Safety Standards*, IAEA Safety Standards, GSR-Part 3, 2014.

[4] *Occupational Radiation Protection*, IAEA Safety Standards, Safety Guide DS453, draft, 2013.

[5] *Radiation protection instrumentation - Passive integrating dosimetry systems for environmental and personal monitoring - Part 1: General characteristics and performance requirements*, IEC CEI 62387-1, 2007.

[6] *Assessment of Occupational Exposure due to External Sources of Radiation*, IAEA Safety Standards, Safety Guide, RS-G-1.3, 1999.

[7] *Zaštita od zračenja - Monitoring lica profesionalno izloženih riziku od unutrašnje kontaminacije radioaktivnim materijalom*, SRPS ISO 20553, 2011.

[8] *Methods for Assessing Occupational Radiation Doses Due to Intakes of Radionuclides*, IAEA Safety Standards, Safety Report Series, SRS 37, 2004.

[9] *Kvalitet vode – Određivanje koncentracije aktivnosti radionuklida – Metoda gama spektrometrije visoke rezolucije*, SRPS ISO 10703, 2016.

[10] *Measurement of Radionuclides in Food and the Environment*, IAEA Safety Standards, a Guidebook, TRS 295, 1998.