OCCUPATIONAL EXPOSURE IN CANDU NUCLEAR POWER PLANT: INDIVIDUAL DOSIMETRY PROGRAM AT CERNAVODA NPP

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1.0 INTRODUCTION

Cernavoda NPP has two CANDU 600 reactors in commercial operation, first since December 1996 and the second one since November 2007.

For a CANDU 6 type reactor the major contributor (90%) to the external dose is gamma radiation. The major contributor to the internal dose of professionally exposed workers is the tritiated heavy water (DTO) – at least 40% of the total effective dose.

The main purpose of design and implementation of a "Monitoring, Evaluation and Recording of Individual Doses Program" (Individual Dosimetry Program) is to measure, assign and record all the significant radiation doses ($H_p(10)$, $H_p(0.07)$ and E_{50}) received by an individual during activities performed at CNE Cernavoda NPP and ensure that all the exposure are kept ALARA.

The results of personnel exposure to ionizing radiation are also used for:

- Estimation of real exposure of workers in order to demonstrate compliance with regulatory body's requirements;
- Evaluation and development of operating / working procedures, based on analysis of individuals and working groups monitoring results (identifying positive and negative aspects contributing to the development of a safer practices for radiation work);
- Providing information about radiological conditions at the working places in order to establish if they are under control or if operational changes improved or worsen radiological conditions;
- Providing information allowing workers to know how, when and where they have been exposed, and to motivate them to reduce their exposures;
- Providing information in order to evaluate doses in cases of accidental exposure;
- Completing medical records.

We provide dosimetry services for measurement, evaluation and recording of all significant ionizing radiation doses received by workers and visitors at CNE Cernavoda, due to the presence of radioactive sources or working with nuclear facilities.
For all the persons entering radiological controlled areas (CNE Cernavoda employees, short-term atomic radiation workers, contractors and visitors) Health Physics Department provides individual (external and internal) dosimetric surveillance.
Individual dose monitoring is provided by a licensed dosimetry service, approved by the Romanian regulatory body, National Commission for Nuclear Activities Control (CNCAN), at CNE Cernavoda.
Radiation Protection Program for Cernavoda NPP is designed insomuch as legal dose limits, established by our national regulatory body, for atomic radiation worker and for public, will not be exceeded.
CNE Cernavoda Dose Monitoring, Evaluation and Recording program is based on the latest ICRP recommendations: ICRP-35, 60, 66, 68, 78 and also, on the requirements of national laws and regulations.

2.0 EXTERNAL RADIATION DOSES MONITORING AND EVALUATION

2.1 External radiological hazards in CANDU 6 nuclear power plants

External radiological hazards are defined as ionizing radiation, generated outside the human body, which can penetrate the tissue at a depth greater than 7 mg/cm^2.
At CNE Cernavoda NPP we consider as external hazards: X rays, gamma, beta and neutron radiation.
For the major contributors (gamma and beta radiation) we provide routine individual monitoring for all the personnel working in radiological area. Neutrons can be considered as a minor contributor, with less than 10% contribution to the total collective dose.

2.2 A short look back

Since 1995, when the fresh fuel was loaded into the reactor core at Unit 1, the dosimetry services were constantly improved.
During Unit 1 new fuel loading activities in 1995 individual dosimetry surveillance was provided for 30 individuals using film dosimeters. These were read by a specialized laboratory, in Bucharest and the doses were recorded as "history" in the individual file.
Since "Radiation Island" was in effect, on February 26th, 1996, individual monitoring for external gamma and beta-gamma radiation exposure has been performed using thermo-luminescent dosimeters (TLDs).
Two type of thermo-luminescent dosimeters were in service at the beginning:

- neutrons insensitive, used by the workers with advanced radiation protection training, which can access radiological areas with no restrictions,
- neutrons sensitive, used by the workers with basic radiation protection training which can access reactor building only escorted by a qualified person; if they had to perform activities in areas with significant neutrons fields they had to change, temporarily, the dosimeters with insensitive ones.

Soon, all the dosimeters assigned to the workers were changed with neutrons insensitive ones. Those sensitive are still assigned only to the visitors which do not enter in reactor building.
During Unit 2 new fuel loading activities in February 2007 individual dosimetry surveillance was provided for 255 individuals using thermo-luminescent dosimeters.

2.3 Whole Body Exposure to Gamma and Beta-Gamma Radiation

For all the persons entering radiological controlled areas Health Physics Department provides routine, individual dosimetry surveillance.
Individual gamma and beta-gamma dosimeters are thermo-luminescent type and they consist of four detectors: three of them are made of $Li_2B_4O_7$ enriched with ^7Li and ^{11}B which make them neutrons insensitive, and the fourth made of $Li_2B_4O_7$ enriched with ^6Li and ^{10}B, very neutrons sensitive.
The main advantage of the lithium borate is that it has an effective atomic number (Z=7.4) very close to that of soft tissue (Z=7.7), thus the energy absorption is very similar to that of soft tissue.
First element ($^7Li_2\ ^{11}B_4O_7$), covered only by a very thin mylar sheet (14 mg/cm^2), is used to estimate shallow individual dose equivalent Hp(0.07) due to beta-gamma radiation. The corresponding window on the badge provides a supplementary filtration of 3 mg/cm^2.
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.
Due to the fact that the first three elements are insensitive to neutrons, the deep gamma dose and shallow beta-gamma dose can be read out directly.
The fourth element ($^6Li_2\ ^{10}B_4O_7$), is used only to confirm the presence of neutron fields, as the response depends on the neutron energy spectrum and this is different in various location in the plant. Filtration is the same as for second and third element.
The TLDs are read once a month (the monitoring interval is four or five weeks).
Gamma and beta-gamma radiation background is determined using a batch of TLDs and it is subtracted from the value read on each individual TLD.

Also control dosimeters, irradiated to a known dose, are used to determine and correct the fading (loss of dose information).

Since TLD is passive dosimeter, when entering / working in variable or heterogeneous gamma radiation fields, beside TLD, an electronic, direct reading, Personal Alarm Dosimeter (PAD) is used.
Personal Alarming Dosimeters, PADs provide:

- immediate readout of gamma dose received,
- dose control by means of alarm set-points,
- back-up information for dose records if the TLD result is not available.
- dose accounting for specific jobs.

At the end of a monitoring period the doses recorded by the TLDs are compared with those measured with PADs (since they are worn together when significant exposure to gamma radiation may occur) to check for any abnormal discrepancies between the two doses. If such discrepancies exist investigations are conducted to determine the causes and the correct dose information. The approved personnel dosimeter used by CNE Cernavoda NPP for official dose records is the TLD.

2.4 Whole Body Exposure to Neutrons

When entering / working in areas with significant neutron dose rates an integrating portable neutrons monitor is used both as field instrument to measure neutron fields and as a personal neutron dosimeter. This dose will be assigned to every person working in that location.
The instrument used is a proportional counter for neutron.
Each person working in neutron fields has to fill up a Dosimetry Information Form in order to give the dose information to the Dosimetry Lab technicians which record the dose in the DOSERECORDS database.
There is also an alternative method to evaluate the neutron doses that have not been reported, involving the use of the fourth element of the individual TLD ($^{6}Li_2$ $^{10}B_4O_7$), very sensitive to neutron fields.

2.5 Exposure of the Extremities

When contact beta-gamma dose rate exceed 10 times the dose rate at the level of the chest, thermo-luminescent extremities (hands or / and feet) dosimeters are used.
The extremities dosimeters are also thermo-luminescent, made by natural $Li_2B_4O_7$. They are used in pairs to measure the dose received by hands and / or feet.
The extremities dosimeters are read in the Dosimetry Lab at the station, by the technicians and the dose is recorded in the DOSERECORDS database.

3.0 INTERNAL DOSIMETRY PROGRAM

Cernavoda Nuclear Power Plant is a CANDU 6 type NPP. CANDU is a Canadian design power reactor, which employs natural uranium as fuel and heavy water as a neutron moderator and as thermal agent.
The thermal neutron flux in the CANDU reactor, by activation of deuterium, is the major producer of tritium but other nuclear reactions could also produce tritium (ternary fission, re-conversion of ^{3}He from ^{3}H Decay).
The major contributor to the internal dose of professionally exposed workers is the tritiated heavy water (DTO), as vapors, which is present at many work locations.
The minor contributors to the internal doses are:

1) activation products as ^{95}Nb and ^{95}Zr (corrosion products from the Zircaloy in fuel sheath and pressure tubes) and ^{60}Co (corrosion product from other alloys in the systems in the active zone)
2) fission products as $^{131}I1$, ^{133}I, ^{135}I and ^{137}Cs.

3.1 Internal dosimetry for DTO

Exposure to an atmosphere contaminated by tritiated water results in intake of that substance both by inhalation and by absorption through the intact skin, in a ratio assumed to be 2 to 1.
Vapors of tritiated water are considered to be of SR-2 absorption class that means the tritiated water is instantaneously absorbed into body fluids and uniformly distributed among all the soft tissues and is eliminated with a nominal half time of 10 days. In addition a very small fraction is incorporated in non - exchangeable form and eliminated with a much longer half time.
Tritium (H-3) is a pure beta emitter, with an average energy of beta radiation of 0.0057 MeV. Its presence in the body can be detected by measuring the urine samples using the liquid scintillation counting and it presents no detection problems.

Professionally exposed workers are subject to a combination of acute and chronic tritium exposure and DTO dosimetry program at Cernavoda NPP is based on multiple sample results. Body DTO concentration is integrated over time and multiplied by the dose rate per unit concentration factor as in relation (3.1).

$$E = 5.8 \cdot 10^{-2} \sum_{i=0}^{k-1} [(C_{i+1} + C_i)/2] \cdot (t_{i+1} - t_i) \qquad (3.1)$$

where E is the effective dose in mSv. The tritium in urine concentrations Ci are given in MBq/L, and the time is expressed in days.
The committed dose (mSv) associated with a ^{3}H concentration C (MBq/L) in case of an acute intake is computed as follows:

$$E_{(50)} = 0.84 \cdot C \qquad (3.2)$$

where the dose factor 0.84 was computed by using tritium physical characteristics, anatomic and metabolic data for Reference Man.

Bioassay monitoring for internal dosimetry of DTO is relatively simple involving the sampling of a single void urine sample. The method consists of mixing 1 mL of urine sample with 10 mL of scintillation cocktail. This mixture is well shacked for 10 minutes to ensure the homogeneity of the sample and then measured by the liquid scintillation spectrometer.
A monthly frequency of bioassay submission is used at Cernavoda NPP for professionally exposed workers who are infrequently exposed or exposed to low tritium levels (urine concentration remains below 10 kBq/L).
If the urine tritium concentration is greater than 10 kBq/L weekly sampling will be required.
When concentration exceeds 1.2 MBq/L, the investigation level, daily sample submission is required.

In case of acute exposures, which significantly exceed chronic levels, the most important error in dosimetry arises from the estimation of the time of intake. Therefore special monitoring is required when planned exposures to DTO are foreseen; the worker should submit additional samples before and after the task completion. When working conditions are unexpectedly changing and could produce abnormal exposures to DTO, all the personnel involved will submit additional samples.
Dose assignments resulting from routinely measured weekly and monthly urinary levels of tritium oxide are based on the method of linear interpolation unless it is known that there has been no exposure between samples (vacation).
In case of acute exposure dose-mitigating actions are recommended by the Occupational Medicine Specialist in consultation with Dosimetry Program responsible. The primary treatment for reducing internal dose from a tritiated water uptake is to accelerate the turnover of body water. This can be done by substantially increasing the fluid intake rate of an individual through oral or intravenous means, and/or using diuretics. Cernavoda NPP experience intakes indicating that a sustained drinking regime gave a clearance half-time of about 5 – 6 days compared with a 10 day normal clearance half-time.

3.2 Internal dosimetry for minor contributors

The minor contributors to the internal doses, radioactive contaminants in the air as gases and suspended particles (aerosols) and on the surfaces (as loose contamination) are:

1) activation products as ^{95}Nb and ^{95}Zr (corrosion products from the Zircaloy in fuel sheath and pressure tubes) and ^{60}Co (corrosion product from other alloys in the systems in the active zone)
2) fission products as ^{131}I, ^{133}I, ^{135}I and ^{137}Cs.

The most frequent internal contaminations are due to the presence of loose contamination with ^{95}Nb / ^{95}Zr, when primary heat transport system is opened.

The fuel handling / fueling machine operators are monitored with Whole Body Counter four times a year.
Nuclear operators, maintenance services workers, radiation control service technicians, chemical lab technicians and NDE lab technicians are monitored once a year.
Employees which are not involved very often in activities in contaminated areas are monitored every three years. New employees are monitored at the very beginning of activity in the radiological zone
In case of a job with an important risk of internal contamination every worker involved is monitored at the Whole Body Counter prior the beginning of work and immediately after the end of that special activity.
Calculation method of committed dose E_{50} due to intake of beta – gamma emitting particulates is based on ICRP recommendations.

4.0 MONITORING OF WORKPLACES

Routine monitoring of workplaces is intended to demonstrate that the working conditions allows continuing the activities and there have not been changes that compel modification of the operating procedures.
Routine program includes monitoring of:
- beta, gamma and neutrons dose rates;
- tritium in air concentration;
- aerosols (alpha, beta, gamma);
- iodine in air concentration;
- surface contamination level.

There is kept an electronic database (HAZARDINFO) containing information about all the radiological hazards, accessible for all the staff of the plant.

5.0 DOSE LIMITS

Dose limits are based on provisions in Radiation Safety Fundamental Norms 14/2000 elaborated by CNCAN and recommendations in ICRP 60.
The annual effective dose limit applicable at CNE Cernavoda is more restrictive (18 mSv) than legal limit (20 mSv).
Dose Control Point (DCP) is an internal administrative limit, a very useful tool for control and limitation of occupational exposure to ionizing radiation. It represents half of the effective dose available until administrative limit of 18 mSv/year is reached (at the beginning of a dosimetric year the DCP is 9 mSv, and it decrease while the received dose increase).
This limit cannot be exceeded (in single exposure) without Station Health Physicist approval.
Target values are established annual for collective doses, for the entire plant and for compartments with major contribution to the plant collective dose.
Also, after a thorough evaluation, there are established dose targets for those tasks / jobs involving significant exposures of the workers.
There has been implemented a dose control system in order to identify areas with radiological problems and take corrective measures as soon as possible.

6.0 DOSE RECORDING AND REPORTING SYSTEM

CNE Cernavoda NPP provides dosimetry services for measurement, evaluation and recording of all significant ionizing radiation doses received by workers and visitors at Cernavoda NPP, due to the presence of radioactive sources or working with nuclear facilities. For all the persons entering radiological

controlled areas (station employees, short-term atomic radiation workers, contractors and visitors) Health Physics Department provides individual (external and internal) dosimetric surveillance.
Cernavoda NPP provides recording and storage of atomic radiation workers' individual monitoring results as per national regulatory body requirements.
Dose records storage for atomic radiation workers is an essential part of the radiation exposure monitoring. Records are proving the conformity with regulatory body requirements, ALARA's efficiency and providing data regarding doses distribution, assessment of exposure tendencies, provide data for medical, legal and epidemiological purposes, and contribute to the development of monitoring program and procedures.

Doses management is performed through a number of programs and a database („home-made”) called DOSERECORDS, for correct and complete dose recording, on electronic and paper format. The system also keeps all the analytical results of dose measurements and non-dosimetric information (personal identification data).
DOSERECORDS system allows for each employee, health physics staff and regulatory bodies access to dose information, and to generate reports asked by the management of the plant, regulatory bodies, in order to demonstrate that the system performances can be appropriately assessed.

Since Unit #2 fuel load and first criticality efforts have been made for the integration of both units radiation protection programs and systems related to personnel dosimetric surveillance (i.e. Personal Alarm Dosimeters databases and computers serving Liquid Scintillator Counters for tritium analysis in urine samples, in Unit 1 and Unit 2, were connected with the unique DOSERECORDS system). Also DOSERECORDS was adapted to support and work with dose information from both units. This unique dosimetric surveillance system allows us to ensure that individual dose limits are not exceeded no matter an employee works in Unit #1, Unit #2 or both units.

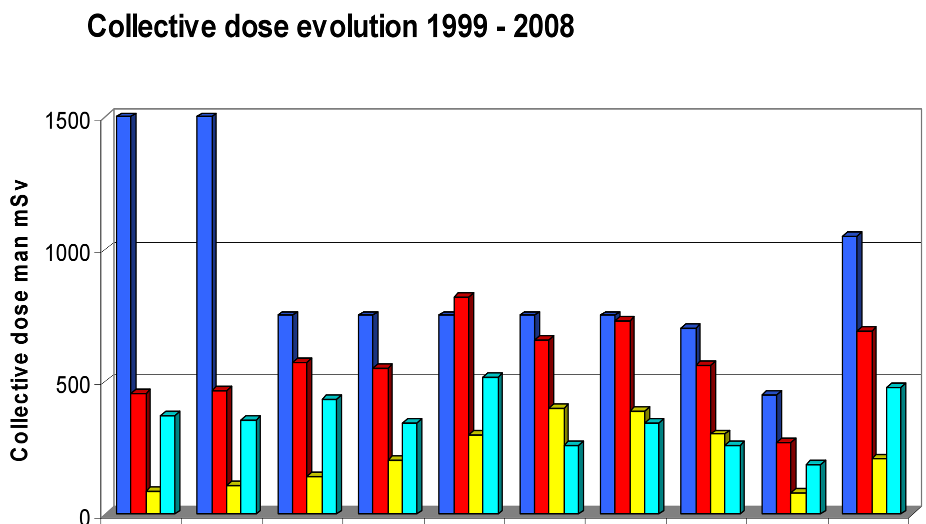
Since the dose is a measure of the potential detriment on the health of an individual following the exposure of the human body to ionizing radiation, as a conservative decision from the radiation workers protection point of view, at the begining of 2008 we decided to lower the recording levels for deep individual dose equivalent Hp(10), shallow individual dose equivalent Hp(0.07) and effective internal dose E_{50}, from 0.17 mSv per month to 0.1 mSv per month.

7.0 RESULTS OF THE IMPLEMENTATION OF RADIATION PROTECTION PROGRAM

The actual levels of individual and collective effective doses due to external and internal exposures reveal the effectiveness of implementation of the Radiation Safety Policies and Principles established by the management of the Cernavoda NPP.
During 12 years of operation, most of the exposures (76%) were below the Recording Level and the majority of recordable doses (60%) were less then 1 mSv. Any legal or administrative individual dose limit has not been exceeded (Table 1).
Since the objective of the optimization of radiological protection is to reduce individual and collective doses, the most relevant indicator is the dose (collective or individual).
The station's exposure control program continues to be in full compliance with the regulatory requirements. In particular, the station exposure control level of 18 mSv/calendar year is below the single year regulatory limit of 20 mSv / year.
The trends (Figure 1) indicate that only for 2003 collective dose was over target due to planned outage extended duration and activities with major radiological impact.
The increasing number of employees under dosimetric surveillance did not caused a comparative escalation of the collective doses and the number of exposed workers (those with doses above recording level). And, we must take into consideration that the 688 man mSv for the year 2008 represents the collective dose for both Unit#1 and Unit#2 and with an extended planned outage in Unit#1.
The actual levels of total effective doses due to internal and external exposures reveal the effectiveness of implementation of the Radiation Safety Policies and Principles, based on the ALARA principles.

Table 1 Total effective dose distribution by dose interval

Year	0.0	>0.0 <1.0	1.0 – 5.0	5.0 – 10.0	10.0 – 15.0	15.0 – 20.0	Over 20.0 mSv
1999	1258	209	135	10	0	0	0
2000	1304	191	173	6	0	0	0
2001	1332	264	171	16	0	0	0
2002	1484	312	162	14	0	0	0
2003	1520	372	254	22	0	0	0
2004	1774	328	210	16	0	0	0
2005	1912	273	212	20	3	0	0
2006	2074	292	175	14	0	0	0
2007	3033	285	62	6	0	0	0
2008	2159	679	184	19	1	1	0



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Total effective dose target man mSv (collective)	1500	1500	750	750	750	750	750	700	450	1050
Total effective dose man mSv (collective)	456.53	466.2	574.86	550.48	818.28	656.71	731.59	561.06	270.83	688.64
Internal effective dose man mSv (collective)	85.42	110.81	141.42	206.43	298.02	398.26	389.3	302.27	83.34	209.3
External effective dose man mSv (collective)	371.11	355.39	433.44	344.04	520.27	258.45	342.29	258.79	187.49	479.34

Figure 1 Cernavoda NPP Collective dose evolution 1999-2008

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