CNE CERNAVODA - MANAGEMENT OF INTERNAL TRITIUM EXPOSURES

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1.0 Introduction

CNE Cernavoda must provide radiological monitoring of the work environment and the monitoring of individual exposure of the professionally exposed workers and visitors, as a result of licensed practices.

Workers' exposures to tritiated heavy water have a significant contribution to professional exposure in every CANDU power plant. Through his policy, CNE Cernavoda committed to keep the doses ALARA for both public and workers and, as a consequence, to assume adequate measures in order to decrease the doses. The efficiency of implementing the radiation protection program at Cernavoda NPP is commensurate by the collective dose, a strategic performance indicator, observed also by the regulatory body, CNCAN.

CNE Cernavoda developed a special strategy in order to control workers internal exposures to tritium and dedicated programs are running to implement this strategy: improvement of radiation protection practices, increasing equipment performances, leakages prevention through maintenance program and finalize the de-tritiation facility.

This paper presents the actual situation of workers internal exposures and emphasize the results of the ALARA policy promoted by Cernavoda NPP management.

During normal operation of a CANDU nuclear power plant significant tritium quantities are generated. Through design solutions that have been implemented we manage to control the tritium losses from the reactor systems and keep them as low as achievable.

2.0 Tritium generation

CANDU reactors are both moderated and cooled with heavy water (D2O).
The thermal neutron flux in the CANDU reactor is the major producer of tritium but other nuclear reactions could also produce tritium as listed below.

a. Activation reactions

1) ${}^{2}_{1}\mathrm{H} + \mathrm{n} \rightarrow {}^{3}_{1}\mathrm{H}$

2) ${}^{6}_{3}\mathrm{Li} + \mathrm{n} \rightarrow {}^{3}_{1}\mathrm{H} + {}^{4}_{2}\mathrm{He}$

3) ${}^{10}_{5}\mathrm{B} + \mathrm{n} \rightarrow {}^{3}_{1}\mathrm{H} + 2\,{}^{4}_{2}\mathrm{He}$

b. Ternary Fission

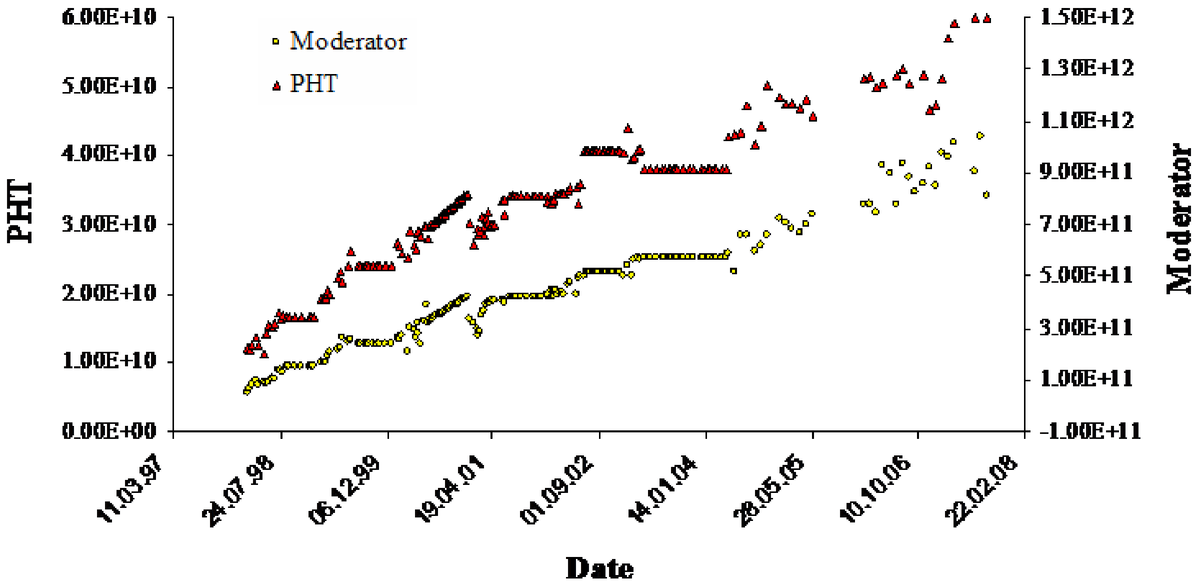
c. Reconversion of ^{3}He from ^{3}H Decay

Activation of deuterium is by far the most important mechanism which is responsible for the production of about 89 TBq of tritium per MW(e) per year compared to only 0.7 TBq of tritium per MW(e) per year produced by ternary fission. Most of the tritium present in CANDU reactors is in the form of tritiated heavy water – DTO.

The Moderator is the largest in volume and the most irradiated D_2O system. Most of the Moderator is contained in the calandria and about 90 percent of the Moderator D_2O will permanently be in the neutron flux. Therefore, in a typical CANDU reactor, about 97% of total tritium are produced in the moderator system. The Primary Heat Transport System – PHT – is the other major heavy water system. Only about 5% of the heat transport system heavy water is in the neutron flux at any moment and the tritium growth rate is much lower than for the moderator (about 3% of total). Being subject to a higher leakage rate PHT system contribution to both the tritium dose to professionally exposed workers and the tritium emissions to the environment is about 50%.

Fig. 1 presents the evolution of tritium concentration for Moderator and PHT at Cernavoda Unit 1 since 1997 till 2008.

Fig. 1 Tritium concentration for Moderator and PHT



3.0 Tritium emissions control for CANDU project

The design features in support of tritium control can be considered as conceptual barriers which prevent or minimize occupational exposure to and/or environmental emissions of tritium.
Figure 2 ilustrate the succession of the necessary barriers for the control and the containment of the tritium inside the instalation.

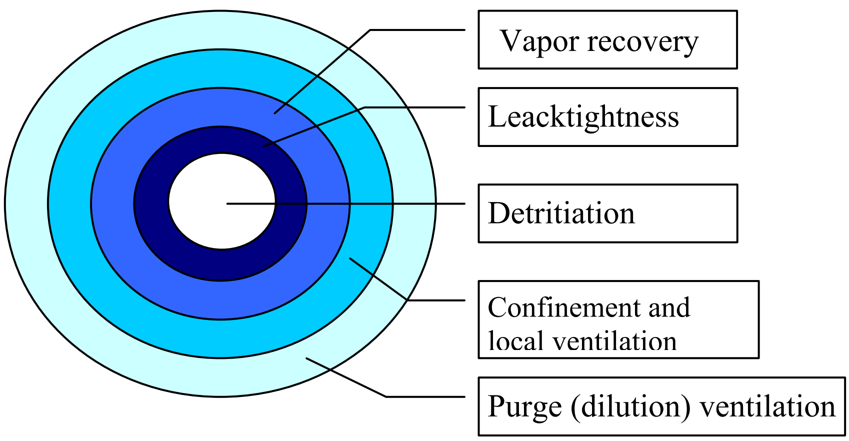


Fig. 2. Conceptual barriers for ^3H control in a CANDU power plant

3.0 D_2O Management at CNE Cernavoda

The leaks from tritiated heavy water systems (moderator and primary heat transport) or their auxiliaries are the main sources of tritium in the reactor building air atmosphere. Despite all protective measures (design, procedures and rules), operating experience to date of CANDU reactors has indicated that DTO is the major contributor to the internal dose of professionally exposed workers.

Tritium emissions control is achieved through the fluids collecting systems and recovery of the water vapors from the air in the reactor building.

The station is designed to prevent the loss of D_2O from the reactor systems. Operating experience with modern CANDUs demonstrates that only a small fraction of the D_2O escapes during operation. Special measures are taken to recover and upgrade the small quantity of D_2O that does escape, since it is a valuable resource.

At Cernavoda Unit 1, after three consecutive years (2004, 2005 and 2006) of major concern on individual and collective internal doses, due to the increase of tritiated water vapours concentration in the Reactor Building, corrective and preventive actions and recommendations, aiming both work planning (exposure control) and technical aspects, worked efficiently and at the end 2007 internal dose contribution to the total collective dose was reduced to 30.7%.

3.1 CANDU project

Moderator enclosure is the most important primary barrier for tritium control, and the requirements for air drying are the most restrictive from the entire plant. The dew point in the moderator enclosure is required at – 40^oC or lower for a leak rate up to 1 kg/h.

The reactor building itself provides the last secondary barrier for the tritium emissions in the environment.

Air entering and leaving the reactor building is dried to minimize D_2O downgrading and loss respectively.

Special dryers are designed and are used to remove moisture from different ventilation systems of a CANDU reactor in order to maintain tritium in air concentration and gaseous tritium emissions below the limits established by the national authorities.

Vapor Recovery System is designed to control tritium in air concentration and to recover heavy water loss from PHT and Moderator Systems and to control the air circulation, providing atmosphere separation between different areas of the Reactor Building.

These areas are segregated into three groups, each group serviced by one portion of the system:

1) Areas where access is required only during reactor shutdown
   - Fuelling machine operating areas
   - Boiler room, including shutdown cooler areas
   - Moderator room (exclusive of enclosure around equipment)
2) Areas designed for access during reactor operation
   - Fuelling machine maintenance locks
   - Fuelling machine auxiliary equipment room
   - Monitoring rooms

A D_2O liquid recovery system is provided. Heavy water and light water systems are segregated as much as possible, due to the fact that the moderator tritium concentration is much higher.

D_2O Collection System is designed to collect D_2O leakage from mechanical components that may occur in any area of the reactor building and to receive D_2O drained from equipment prior to maintenance.

The D_2O upgrading system separates a mixture of H_2O and D_2O into:

• An overhead distillate, richer in light water than the feed
• A bottom product, richer in heavy water than the feed.

The upgrading system accepts mixtures varying from 2 percent to 99 percent D_2O and upgrades them to reactor grade 99.8 percent D_2O. The overhead distillate has a concentration of less than 1 percent D_2O.

3.2 Operating / administrative measures

The main objectives of the tritiated heavy water management process are:

– Careful control of the equipment leak rate;
– Early detection of the D_2O leaks (there have been established operational limits for tritium concentration in air); tritium on-line detection was implemented in Unit#2 and is in progress in Unit#1;
– Heavy water leaks can be detected using:
    - Humidity measurements;
    - Tritium measurements; or
    - Combined analysis.
– Air drying and vapors collection are used to control ^3H concentration in air;
– On-site upgrading tower for purifying the water that has been collected and recover heavy water;
– Radiation protection procedures protect the workers against radioactive heavy water exposures;
– After ~15 years of operation a detritiation facility it is desirable.

4.0 Tritium exposures control

Health Physics staff analyze and review the documentation of the modifications performed in order to improve the systems and equipment's performances and to get a clean working environment.

Taking into account the operation experience in Unit 1, Health Physics Department staff participated actively to establish the configuration of the radiation protection systems provided for Unit 2, thus the number of the modifications / improvements proposed for Unit 2 is significant lower than those for Unit 1.

4.1 Fixed Tritium in Air Monitoring System (TAM)

Before the commercial operation, in Unit 2 the "Tritium in Air Monitoring" was operational and integrated in the Radiation Monitoring System.

Tritiated water vapor is a health hazard and its early detection in nuclear plants is important because it has all the characteristics of water vapor in atmosphere. By detecting tritiated water vapor, the monitoring system serves the following purposes:

- detects heavy water leakages;
- indicates levels of tritium in radiological area;
- Decreases the exposure of plant personnel by preventing the entrance in those areas where tritium dose rates unexpectedly increased and reducing time spent by radiation control staff for air sampling.

The Tritium in Air Monitoring System contains 8 fixed Local Monitoring Units (LMU). Each LMU is sampling air from 4 locations with a potential tritium hazard.

The LMU is controlled either locally or remotely, through the Radiation Monitoring Systems (RMS) network and by a software application dedicated to this system.

The system performs the following functions:

- Continuous sampling of the air from various locations in Reactor Building and Service Building where high-level of tritium is expected.
- Performs tritium concentration measurements on the continuous samples and compare the measurement results with a preset value (set point) established by operator.
- Displays tritium concentration activity (Bq/m^3) or on request, equivalent dose rate (Sv/h).
- When the set point is exceeded or a failure occurs, the system alarms remotely in the Main Control Room through DCC, throughout the RMS network and to Radiation Control Service, by visual and acoustic signal.
- Performs "non-routine" tritium concentration measurement using the temporary sampling lines and semi-portable Tritium Monitors.

Tritium Monitors provide compensation for other radioisotopes, including reactor produced noble gases and natural radon.

Even the tritium concentration in Unit 2 systems is still low the TAM system already proved its efficiency by prompt detection of increased level of tritiated water vapor in the air of some rooms in the Reactor Building and Service Building.

A similar Tritium in Air Monitoring System was installed at Unit 1, system which contains 4 fixed Local Monitoring Units. Each LMU is sampling air from a specific area (5 to 11 separate locations). In order to improve the system efficiency, will be implemented one supplementary Local Monitoring Unit, so the system will contain 5 Local Monitoring Units.

4.2 Radiation protection and operation procedures improvements

Routines and maintenance activities have been carefully reviewed as per ALARA principle, especially those including frequent access in the boiler room.

As a result the time spent in the reactor building was limited, tritium dose rate limit for using respiratory protection was decreased, some activities were postponed and routines and activities performed by the operators, maintainers and health physics technicians in the boilers' room were optimized.
Respiratory protection is mandatory for estimated tritium committed doses above 0.03 mSv.

The new revision of the "CNE Cernavoda Dosimetry Program" established an investigation level of 0.3 mSv committed dose was for unanticipated personnel exposures" besides the level of 1 mSv when the exposed person is not allowed to perform activities with tritium exposure risks.

4.3 ALARA Process

CNE Cernavoda management is committed to continuously improve the safety standards in order to protect environment, population and personnel.

ALARA is an important element of the global approach to radiological protection and plant management commitment to ALARA has been clearly stated by the reference document "Radiation Protection Policy and Programs".

ALARA Committee responsibilities, members and working rules are clearly defined.
ALARA structure relies on Radiation Protection compartments which provide technical support, supervision, doses and contamination control, data bases.

Department managers are encouraged to review current procedures and develop new ones as appropriate to implement the ALARA concept.

Daily planning meetings and other routine assessments address radiation protection problems for current operating and maintenance activities, equipment, and facilities.

Starting 2006 specific performance indicators for the internal dose for the entire plant and major working groups have been established, allowing a better management of the internal exposures.

4.4 "TOP TEN" Process

Tritium doses accurately reflect the rigor of performing activities in respect for radiation protection procedures. Tritiated water leaks became at this moment a specific one and, therefore, it requires a constant surveillance.

Tritium management – decreasing tritium concentration in all the radiological controlled areas in order lower the contribution of the internal dose to individual and collective total effective dose - was included in a special program implemented to solve the most important technical problems of the plant: "Top Ten".

The second position in this list was taken by the tritium management. An action plan was been set, aiming: improvement of radiation protection practices to protect workers against tritiated heavy water, increasing equipment performances, leak prevention through maintenance programs and finalizing the de-tritiation facility.

The main aspects followed are:

- Provide portable air dryers for local control of tritium concentration in air;
- Installing a drying unit at the entrance of the air in the reactor building;
- Containing the leaks of the Hansen couplings;
- Using passive collectors method for tritium monitoring;
- Replacing rupture disks with safety valves.

5.0 Results and conclusions

By implementing the programs and processes previously described, at the end of 2009 internal dose contribution to total dose was 14%, decreased from a maximum of 61% in 2004 (Fig. 3). Internal collective doses followed the same trend during the last three years (Fig. 4).

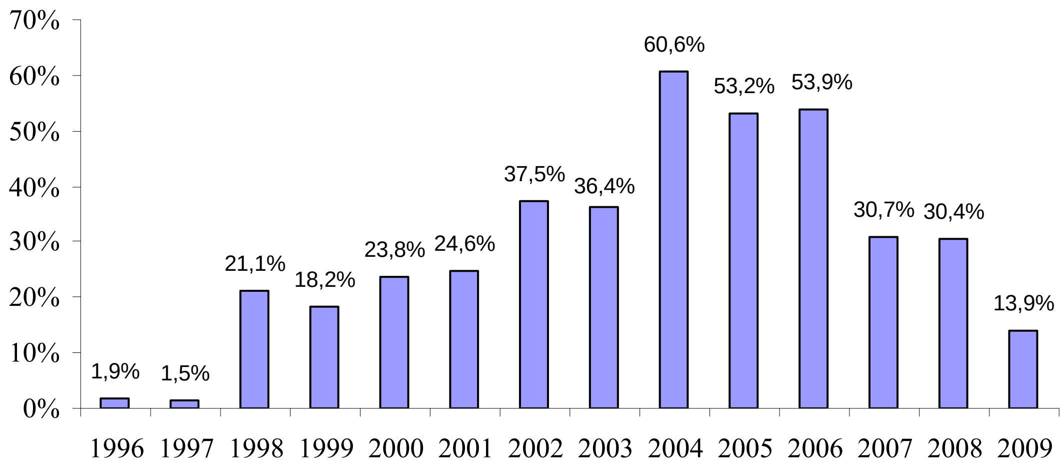


Figure 3 Internal dose contribution (%) to total dose

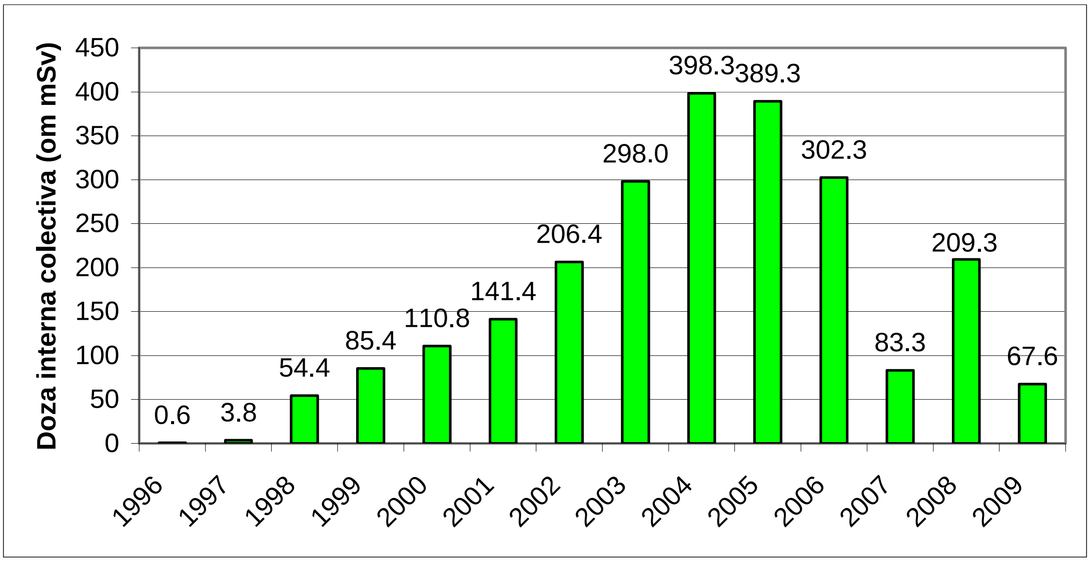


Figure 4. Internal collective dose evolution

The actual levels of individual and collective doses due internal exposures reveal the effectiveness of implementation of the Radiation Safety Policies and Principles established by the management of the Cernavoda NPP, based on the ALARA principles.

During nearly 14 years of operation, most of the exposures were below the Recording Level and the majority of recordable doses were less then 1 mSv, as can be observed from Table I.

These results demonstrate that tritium risks can be controlled and maintained at reasonable levels by an appropriate ALARA policy of the plant management.

Table I Internal 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
1999	1324	236	23	0	0	0	0
2000	1377	243	32	0	0	0	0
2001	1418	327	37	0	0	0	0
2002	1570	343	57	1	0	0	0
2003	1579	505	83	0	0	0	0
2004	1809	379	135	3	0	0	0
2005	1947	331	138	4	0	0	0
2006	2102	348	94	1	0	0	0
2007	3174	183	16	0	0	0	0
2008	2559	435	45	1	1	0	0
2009	2383	292	10	0	0	0	0

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