ALARA & Management of internal exposures at CNE Cernavoda

NUCLEARELECTRICA
Puterea Viitorului

Catalina Chitu, Ion Popescu

Health Physics Department,

CNE Cernavoda, ROMANIA

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INTRODUCTION

- A careful planning of source term is applied at CNE Cernavoda to control radionuclides release in working environment, and to prevent radioactive material intake by workers.

- For a CANDU 6 type reactor tritiated heavy water (DTO) is the major contributor to the internal dose of professionally exposed workers contributing last years with up to 20% of the total effective collective dose.

INTRODUCTION

Minor contributors to internal doses could also be:

- 1) activation products as ^{95}Zr and ^{95}Nb (activated corrosion products from the zirconium alloys in fuel sheath and pressure tubes) and ^{60}Co (corrosion product from steel alloys reaching the active zone). Other activation products present in PHT are ^{51}Cr, ^{54}Mn, ^{59}Fe, ^{113}Sn, ^{124}Sb.
- 2) fission products as ^{131}I, and ^{137}Cs.

- Radiation protection programs provide adequate theoretical and instrumental basis for exposure control designed to minimize the combined external and internal dose i.e., total effective dose equivalent.

TRITIUM EXPOSURES CONTROL

Tritium generation

CANDU reactors are both moderated and cooled with heavy water (D_2O).

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.

Deuterium activatioan by thermal neutron flux is the major producer of tritium but other nuclear reactions, like ternary fission and reconversion of ^3He from ^3H decay could also produce small quantities of tritium.

TRITIUM EXPOSURES CONTROL

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Tritium generation

The **Moderator** is the largest in volume and the most irradiated D_2O system. Therefore about 97% of total tritium are produced in the moderator system.

The **Primary Heat Transport System** – PHT – is the other major heavy water system. 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 80%.

TRITIUM EXPOSURES CONTROL

D2O Management at CNE Cernavoda

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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.

- Tritium emissions control is achieved through the **water collecting systems and vapor recovery systems from the air** in the reactor building.
- Special measures are taken to **recover and upgrade** the small quantity of D_2O that does escape, since it is a valuable resource.
- The **reactor building** itself provides the **last barrier** for the tritium emissions in the environment.

TRITIUM EXPOSURES CONTROL

D_2O Management at CNE Cernavoda

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- **Air entering the reactor building is dried to minimize D_2O downgrading by dilution.**
- **Vapor Recovery System is designed to control tritium in air concentration, to recover heavy water, and to control the air circulation, providing atmosphere separation between different areas of the Reactor Building.**
- **Special dryers remove moisture from air before evacuation at the stack.**
- **A D_2O liquid recovery system is provided to collect D_2O leakage from mechanical components and to receive D_2O drained from equipment prior to maintenance.**

PARTICULATES / AEROSOLS EXPOSURES CONTROL

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Work control of activities with risk of internal contamination

- **The most frequent source for internal contamination is the presence of loose contamination with ^{95}Nb / ^{95}Zr, when primary heat transport system is opened for maintenance activities.**

- **Internal contamination of workers may occur due to intakes of radionuclides as a result of several activities, mainly during undressing or due to unexpected airborne contamination or unintended contact with contaminated equipment.**

- **The most common route of entry of a radioactive contamination into the body of a worker is by inhalation.**

PARTICULATES / AEROSOLS EXPOSURES CONTROL

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Work control of activities with risk of internal contamination

- **Routine monitoring of workplaces** is intended to demonstrate that the working conditions allow continuing the activities.
- For jobs with known contamination risk **preventive actions** intended to prevent the spread of contamination and internal contamination of workers are mentioned in **Radiation Work Permit**: set-up **of rubber areas / rubber change areas**, installing **ventilated tents with HEPA filers**, using adequate individual **respiratory protection equipment**, continuous **monitoring** of air borne radioactivity.

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Work control of activities with risk of internal contamination

- **A strict control of contamination events allow to promptly identify gamma radionuclide intakes and initiating bioassay procedures for internal dose calculation.**
- **When the risk of contamination is identified prior performing the job, workers must be monitored at whole body counter before and immediately after the work. WBC requirement is documented in the Radiation Work Permit, and the workers are informed during pre-job briefing.**

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Work control of activities with risk of internal contamination

- **A root cause analysis performed in 2010 identified two main causes for most frequent contaminations: spreading of radioactive particles from contaminated protective equipment (tyvek hoods) during undressing, and temporary removal of individual respiratory protection equipment in order to communicate with co-workers, followed by putting the mask back on the mouth and nose.**
- **Procedures for undressing tyvek hoods used during activities with high risk of contamination were improved: assistance is provided to workers to undress protective clothes.**
- **Wireless ear-phones were purchased in order to allow communication without removing the mask.**

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Work Control for Alpha Contamination Risk Activities

Under normal operating conditions, transuranic nuclides (TRU) are not a contributor to radioactive contamination within a facility. The presence of alpha emitting radionuclides in working areas is related to fuel cladding defects, allowing the fission products to migrate into the primary heat transfer – PHT circuit.

Once in the reactor coolant, this material may be distributed throughout other areas of the facility creating accumulations of TRU which could have significant dose implications for personnel involved in work activities such as routine operations, maintenance, repair and refurbishment of equipment and systems.

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Work Control for Alpha Contamination Risk Activities

Because alpha-emitting nuclides generally have high internal dose conversion factors, they result in significantly lower limits and action levels, compared to beta/gamma nuclides.

Therefore, radiation protection personnel must consider quantifying the presence of alpha-emitting radionuclides, to ensure effective protection of workers and compliance with regulatory requirements.

The degree of impact depends primarily on the relative abundance of these radionuclides, and the frequency of occurrence in different areas of a facility.

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Work Control for Alpha Contamination Risk Activities

Management of defective fuel

The defective fuel is managed with special attention: is identified by continuous monitoring of radioactivity in fuel channels and it is promptly discharged to spent fuel bay.

There are two systems working together: Gross Fission Product (GFP) monitoring system and Delayed Neutron (DN) system, dedicated to the management of defective fuel.

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Work Control for Alpha Contamination Risk Activities

Management of defective fuel

Gross Fission Products (GFP) system continuously monitors the bulk coolant: detect the presence of failed fuel, monitor the ^{131}I activity and monitor noble gas activity (eg. ^{133}Xe)

Delayed Neutron (DN) system, locates low power defects below GFP threshold.

The Delayed Neutron monitor is used to locate the particular channel that contains the defect. The location of failed fuel bundle is determined by measuring the amount of delayed neutron activity in coolant.

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Work Control for Alpha Contamination Risk Activities

Areas with potential for alpha contamination

First step in designing CNE Cernavoda program for the control of alpha contamination was the characterization of gross alpha activity levels in the plant areas where TRU may be present in order to assign a proper Area Action Level (EPRI guides).

Areas, systems, equipment and activities having a potential of surface and air contamination with transuranics have been identified and alpha contamination has been characterized for nuclide identification and beta-gamma to alpha ratio determination. After each planned outage and each significant defective fuel discharge, contamination samples are measured to update alpha contamination status.

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Work Control for Alpha Contamination Risk Activities

Job control

Areas and activities having a significant risk of alpha contamination are identified and classified taking into account beta-gamma to alpha contamination ratio.

Specific Radiation Work Permits – RWPs are required and must state if work is to be conducted in an Alpha Level II or I area.

RWPs must establish specific monitoring requirements, and mitigation strategies (engineering controls as ventilated tents to confine contamination and HEPA filters to remove airborne alpha contamination, and respiratory protection).

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Work Control for Alpha Contamination Risk Activities

Job control

Usually tritium and alpha hazards are simultaneously present and CNE Cernavoda has good experience in building tented structures for tritium and contamination control. Respiratory protection is mandatory when work is done in ventilated tents.

Alpha contamination of airborne and surface is monitored before, during and after job completion using:

-Friskers - to measure alpha contamination levels on equipment, in areas and on personnel.

- Continuous Air Monitors CAM (MGPi) -to monitor airborne nearby working areas.

- NT 200 radiometers are used to count lower levels of alpha contamination and to determine beta-gamma to alpha ratios on lower activity smears.

SOURCE TERM CONTROL AND REDUCTION STRATEGY

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Radiation Monitoring System (RMS)

Remote monitoring technology can expand the list of RP protective barriers being used for worker protection. Cernavoda NPP Radiation Monitoring System (RMS) integrates several systems continuously measuring radiation levels in selected areas and processes.

This aids RP personnel in assessing plant conditions and provide alarms for operation and maintenance personnel to take appropriate actions in two situations:

- mitigating the consequences by preventing the inadvertent release of radiation in case of a plant event and,

- unexpected exposure to radiation of plant personnel.

SOURCE TERM CONTROL AND REDUCTION STRATEGY

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Radiation Monitoring System (RMS)

The RMS connect the on-line radiation monitoring equipment to a computerized interface allowing remote monitoring, remote control capability and maintaining integrated short and long-term database.

RMS interface with the following systems: Fixed Gamma Area Monitoring, Fixed Contamination Monitoring, Portable/ Semi-portable Radiation Monitors, Fixed Tritium in Air Monitoring, Liquid Effluent Monitor, Gaseous Effluent Monitor, and Post Accident Air Sampling and Monitoring. Information is transferred in real time.

The RMS is only having a support function for the radiation monitoring equipment, which are stand-alone devices being able to operate independently. All the RMS components are located in accessible areas or in mild environmental conditions.

SOURCE TERM CONTROL AND REDUCTION STRATEGY

Tritium in Air Monitoring System (TAM)

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The specificity of Cernavoda RMS not existing in other CANDU stations consists in integration of a “state of the art” remote Tritium in Air Monitoring – TAM System, designed to allows:

- quick detection and monitoring of tritiated water leaks,

- systematic and reproducible monitoring data for source control and

- personal exposure assessment.

Among CANDU stations, Cernavoda TAM system distinguishes by the accuracy of measurement results. To achieve this goal a long term monitoring of noble gases activity concentrations have been performed to provide the most appropriate correction factor for noble gases compensation.

SOURCE TERM CONTROL AND REDUCTION STRATEGY

Tritium in Air Monitoring System (TAM)

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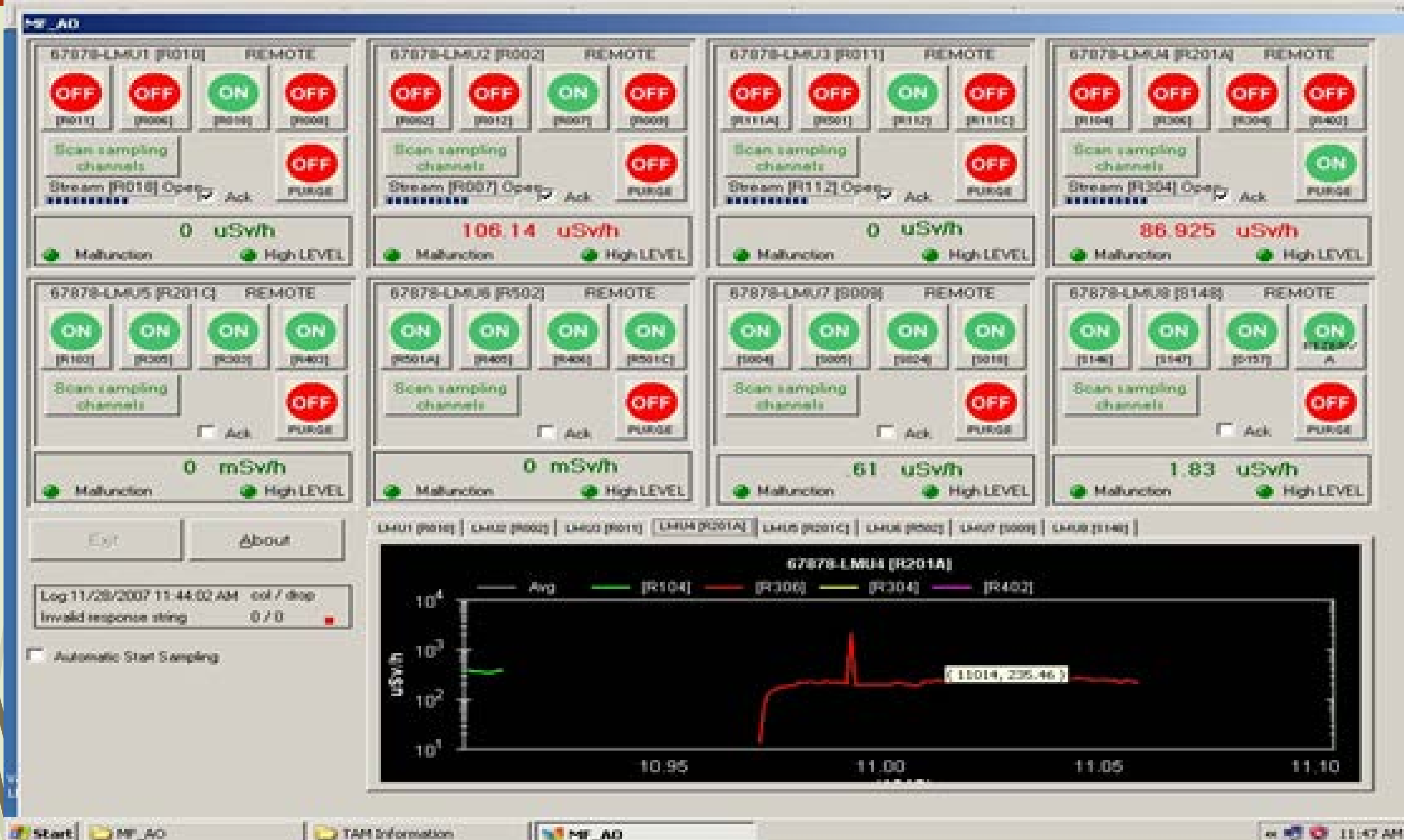

Typical display of TAM monitoring results (instantaneous and historical values) on remote PC

SOURCE TERM CONTROL AND REDUCTION STRATEGY

Tritium in Air Monitoring System (TAM)

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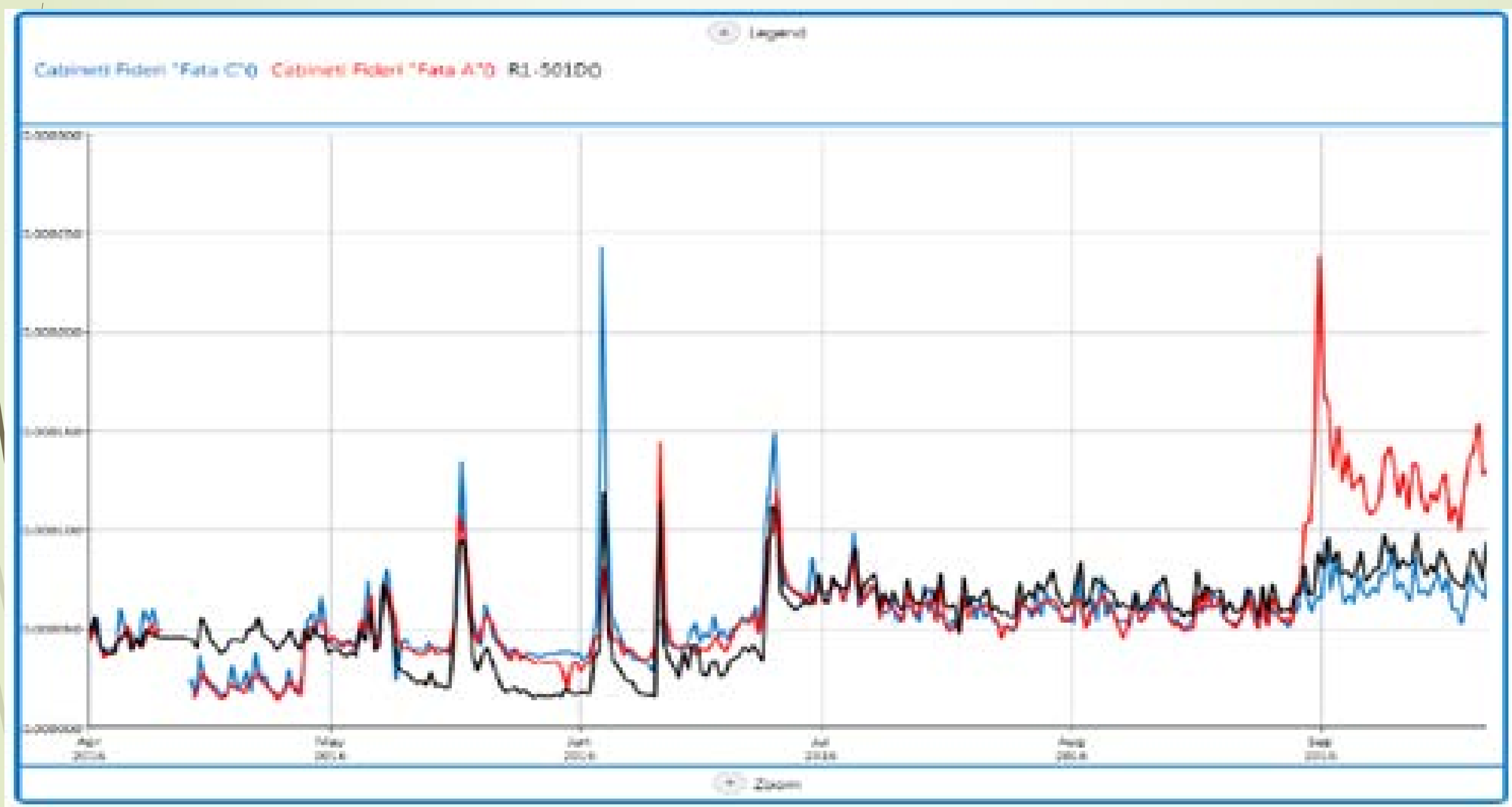

Evolution of tritium level (mSv/h) in 1R-501 and horizontal feeders cabinets, Unit 1, 2016 – TAM historical log file

SOURCE TERM CONTROL AND REDUCTION STRATEGY

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Characterization of alpha source term

The alpha source term characterization was performed initially by assuming that all gross alpha activity is generated by the most restrictive nuclide in the mixture (^{241}Am).

In the second stage the alpha nuclide distribution for specific areas of the plant was determined by radiochemical analysis, mainly for areas where significant levels of "old/aged" alpha contamination could be present: spent fuel bay, fuel handling working areas, temporary and interim radioactive waste storage, decontamination facilities.

SOURCE TERM CONTROL AND REDUCTION STRATEGY

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Characterization of alpha source term

The up-to-date understanding of the facility TRU presence has been obtained through a detailed characterization of plant contamination and by the evaluation of historical events related to fuel defects.

The monitoring results indicate that CNE Cernavoda accessible contaminated areas are classified in present as Level 2 and 3 Areas (significant and low alpha contamination).

For these areas the alpha emitters' exposure is not likely to exceed 10% of the total internal dose in case of an internal contamination.

SOURCE TERM CONTROL AND REDUCTION STRATEGY

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Source Term Reduction Strategy

- **Contamination control by:**
  - ✓ **reducing the surface of contaminated areas in Zone 1**
  - ✓ **eliminating some permanent Rubber Areas.**
  - ✓ **rigorous control of installing using, and uninstalling of Rubber Areas and ventilated tents.**
- **Chemistry control of radioactive circuits**
  - ✓ **maintain in service at full capacity all the purification systems,**
  - ✓ **manage the ion exchange and mechanical filters replacing in order to provide high efficiency retaining of the activated corrosion products and to contribute to the reduction of gamma radiation fields, and of radiation doses,**
  - ✓ **Planning of PHT ion exchange resin replacement no later than 6 month before the planned outages to increase the filtering capacity of dissolved species.**

SOURCE TERM CONTROL AND REDUCTION STRATEGY

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Source Term Reduction Strategy

- **Fuel Handling Machine purification system:**
  - **Some components of Fuel Handling Machine are made of stellite (a Co-Cr alloy which could generate ^{60}Co). Fuel Handling Machine purification system must ensure a good filtering capacity for heavy water entering Fuel Handling Machine circuits. Mechanical filters on heavy water supply circuit have been upgrades to 2 microns, improving also the operation of the machine.**
- **Tritium source term control and reduction:**
  - **strict heavy water leak control,**
  - **liquid collection systems**
  - **water vapor recovery through containment air drying.**
- **Hot spots control**
  - **Hot spots in accessible areas are posted, shielded or, if possible eliminated by system or component flushes.**

RESULTS & CONCLUSIONS

At Cernavoda NPP the operational radiation protection programs correlates assessment of workplace conditions, contamination control measures and individual internal exposures monitoring in a way that allows us, first of all, to prevent as much as possible internal contaminations with beta / gamma and alpha radionuclides.

Since 1996, when operation of Unit 1 started till 2013 most of internal exposures excepting tritium, were below the recording level of 0.1 mSv and, only very few internal contaminations led to doses above this value. Since 2014 till now no internal contamination led to recordable doses.

RESULTS & CONCLUSIONS

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Unit 1: magnetite removal activity

During Planned Outage of Unit 1 in 2016, a mixed team of Cernavoda NPP, BWXT and CANDU Energy performed removal of magnetite layers from U tubes of all four Steam Generators.

Due to the potential of high risk of contamination with alpha emitters, appropriate measures have been put in place in order to minimize the spread of radioactive material and to prevent internal contamination of personnel involved in these activities:

1. The workers have been assisted by highly trained RP personnel from Radiation Protection Department;

2. All the process areas that could potentially lead to leaks of contaminated materials have been isolated with ventilated tents;

RESULTS & CONCLUSIONS

NUCLEARELECTRICA
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Unit 1: magnetite removal activity

3. CAMs (Continuous Air Monitors) installed at the exit of contaminated areas to continuously measure the volumetric specific activity of both beta and alpha emitters and to notify the personnel working in the area on radiological conditions changes;

4. Radioactivity measurements performed on samples from contaminated areas to evaluate beta/alpha ratio and radionuclides mixture composition: gross alpha and beta counting, gamma spectroscopy measurements; in-situ gamma spectroscopy measurement has been performed on magnetite volumetric samples and on unshielded magnetite containers to evaluate contributions of ^{60}Co, ^{95}Zr / ^{95}Nb to overall beta-gamma emitters activity;

RESULTS & CONCLUSIONS

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Unit 1: magnetite removal activity

5. Any access to contaminated areas with **adequate protective equipment**: particulate filters, plastic suits; Tyvek suits used to cover the plastic suits in order to minimize the risk of internal contamination during undressing the plastic suits;

6. A **complex pre-job briefing** was held before starting activity with all workers involved. **Daily,** during the activity, every crew attended pre-job briefing **focused at immediate tasks and radiological hazards**, to refresh radiation protection measures and improve radiation protection practices.

7. **Teledosimetry** used to control individual received doses. No worker exceeded any individual gamma dose limits and no EPD dose alarm received. The collective dose received 154 man mSv, was a satisfactory performance versus the estimated collective dose, 132.5 man mSv.

RESULTS & CONCLUSIONS

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Unit 1: magnetite removal activity

8. **Periodical whole body counting** has been carried out for all personnel working in contaminated areas.

One person has been identified with internal contamination: Whole body counting identified ^{95}Zr and ^{95}Nb; the content of alpha emitters has been estimated by considering beta/alpha ratio and the level of ^{95}Nb in beta-gamma mixture specific to smear samples.

Based on alpha/beta-gamma activity ratio measurements on contamination samples an intake of 1.3 Bq ^{241}Am was calculated. The total internal dose was 0.057 mSv (below recording level).

RESULTS & CONCLUSIONS

NUCLEARELECTRICA
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Unit 1: magnetite removal activity

In conclusion we managed to perform a very complex activity having a high contamination risk without significant internal or external (Personal Contamination Event) events.

RESULTS & CONCLUSIONS

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Performance indicators

In order to provide an effective monitoring program of internal exposure there were established few performance indicator related with these types of events:

- **Internal collective dose**
- **Maximum individual internal dose (number of person with internal doses above approved target in that year)**
- **Personnel Contamination Events (inside Radiation Controlled Area - RCA)**
- **Internal contaminations with radio-nuclides other than tritium (leading to doses above recording level 0.1 mSv/month)**
- **Unexpected contamination of surfaces**
- **Personnel contamination identified at the exit of the RCA.**

RESULTS & CONCLUSIONS

Performance indicators

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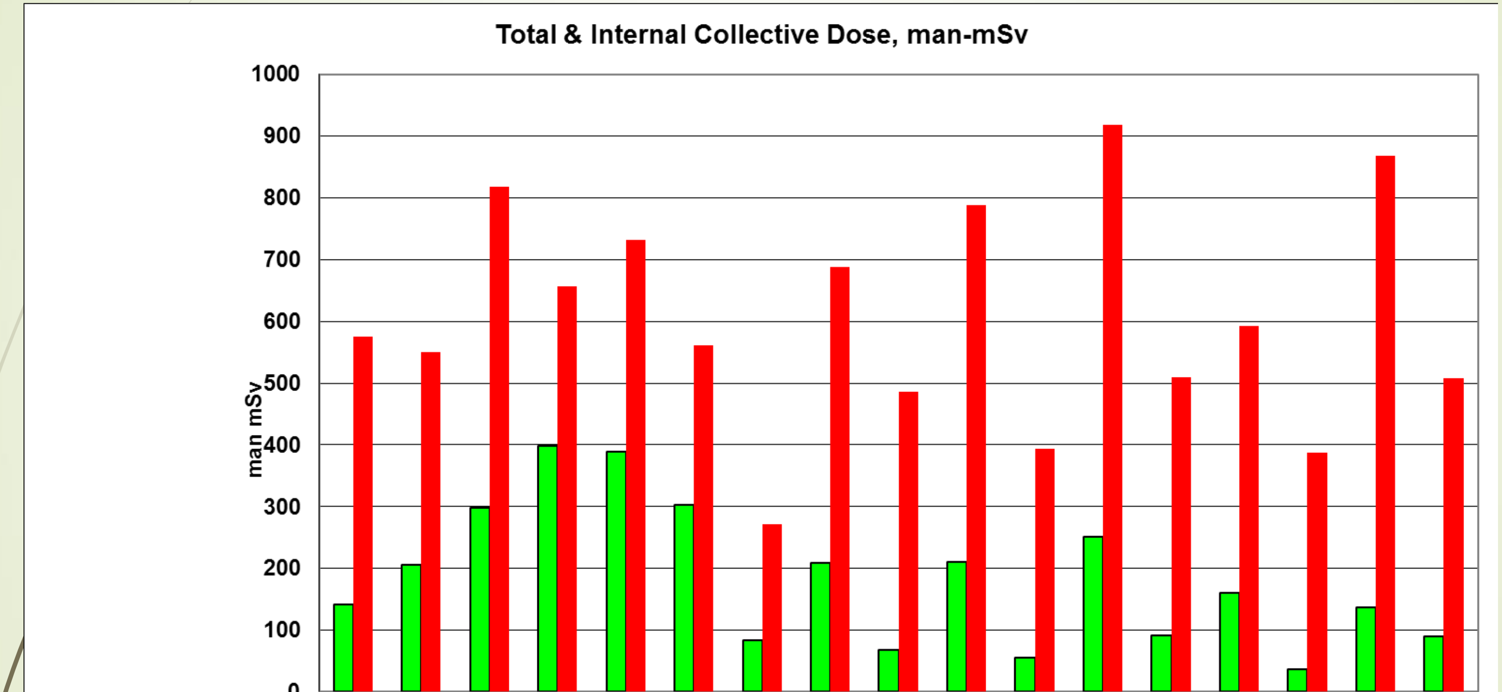
Trend analyses reveal a positive evolution of this indicator, as a result of an efficient control:

	2010	2011	2012	2013	2014	2015	2016	2017
Maximum individual internal dose	0	0	0	0	0	0	0	0
Personnel contamination identified at the exit of the RCA	6	1	6	6	4	7	5	10
Personnel Contamination Events	-	-	-	-	-	0	0	0
Unexpected contamination of surfaces	10	6	4	2	2	6	4	2
Internal contaminations with radio-nuclides other than tritium	18	0	1	2	0	0	0	0

RESULTS & CONCLUSIONS

Performance indicators



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Internal collective dose	141.42	206.43	298.02	398.26	389.3	302.27	83.34	209.3	67.6	210.3	56.2	250.8	92.3	160.3	36.4	137.1	89.57
Collective dose	574.86	550.48	818.28	656.71	731.59	561.06	270.83	688.6	485.3	787.3	392.98	917.9	509.1	592.3	388.1	867.9	507.5

Evolution of total and internal collective doses

CONCLUSIONS

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International Peer review mission

2016 - OSART mission

The team identified as a good practice the Radiation Monitoring System (RMS), which integrates a remote Tritium in Air Monitoring (TAM) System, having the unique feature to promptly identify and estimate heavy water leak rate in different locations.

Regarding radiation work control, OSART team makes a suggestion that the plant should consider improving the contamination control of field activities.

Thank you for your attention!

Questions?