



Recent Progress in COG Health Physics R&D

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EPRI Radiation Protection Conference**



CANDU OWNERS GROUP(COG)

- CANDU Owners Group Inc. (COG) is a not-for-profit corporation for **co-operation**, mutual assistance and **exchange of information** for support, development, operation, maintenance and economics of CANDU technology.
- Membership in COG is open to all CANDU/PHWR owners/operators worldwide plus Atomic Energy of Canada Limited.
- Present members are:
 - ◆ Atomic Energy of Canada Limited; Bruce Power; Hydro Quebec; New Brunswick Power; Ontario Power Generation
 - ◆ Korea Hydro & Nuclear Power Company Limited; Nuclear Corporation of India; Nucleoelectrica Argentina Sociedad Anonima; Pakistan Atomic Energy Commission; Societatea Nationala Nuclearelectrica S.A; Third Qinshan Nuclear Power Company Limited



R&D PROGRAM

■ The COG Research and Development program has five technical areas:

- ◆ **Safety and Licensing:** Reactor physics and thermal hydraulics; reactor containment; behaviour of fuel and fuel channels under normal and accident conditions
- ◆ **Chemistry, Materials and Components:** Reactor chemistry; radiation fields and dose; SG and HX integrity, cleaning, metallurgy and NDE tools; improved components and materials
- ◆ **Fuel Channels:** Assessment of in-service flaws; deuterium ingress; hydride effects; diametral expansion; fitness for service guidelines; pressure tube lifetime
- ◆ **Health Safety and Environment:** Addresses issues on Radiation Monitoring, Dosimetry, Occupational Radiation Protection, Environmental Impacts, Emission Reductions, Waste Management and Pollution Prevention
- ◆ **Industry Standard Toolset:** Validation, development and maintenance of computer codes for the design, safety analysis and operational support of CANDU reactors



External Dosimetry

- **Objective:** Maintain an External Dosimetry R&D program and associated facilities, including type testing services
- **Drivers:** CNSC S-106, "Technical and Quality Assurance Requirements for Dosimetry Services in Canada"
- **Goals**
 - ◆ Carry out R&D to support measurement of external exposures from current and emerging hazards, as required by changing national / international standards
 - ◆ Maintain the type-testing facilities at CRL, develop improved operating procedures for type-testing, and provide type-testing services to the COG utilities



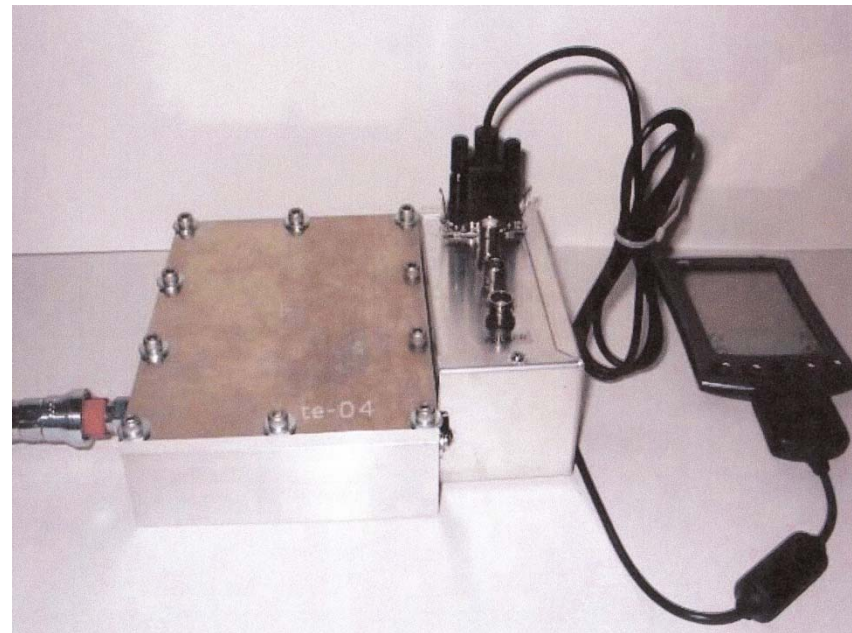
External Dosimetry

- **Evaluated the OSL technology for personal and environmental dose monitoring**
 - ◆ **Advantages:** meets most requirements i.e. photon and beta energy-angle and mixed photon energies response, linear over a wide dose range, minimal fading, response to temperature variations and exposure to light.
 - ◆ **Disadvantages:** not enough sensitivity for environmental monitoring applications; problems with response to mixed photon-beta fields; inhomogeneity of different batches of OSL material.
- **Characterized the response of a personal neutron dosimeter as a function of energy and angle**
 - Developed procedures to type-test neutron dosimeters and evaluated two neutron survey meters (EPD-N2 and Saphydose-N)
 - Commercial instruments not ideal, but neutron dose a small fraction of total.



External Dosimetry

- **Developed a personal neutron dosimeter and a compact data acquisition system**
 - ◆ A GEM detector configured as tissue equivalent proportional counters (TEPC), achieved a sensitivity of 75 counts/ μ Sv for ^{252}Cf neutrons.
 - ◆ A GEM-TEPC system with palm-pilot demonstrated feasibility of low power, compact and sensitive system for personal neutron monitoring.





External Dosimetry / Ongoing Work

- Improvements in procedures and instrumentation for routine external dosimetry
- Inter-comparison of the performance of whole body dosimeters used in CANDU facilities
- Maintaining the capability of neutron dosimetry and neutron instrument evaluation, including type-testing



Internal Dosimetry

- **Objective:** Biokinetic studies of uptake and metabolic processes of tritium and C-14 compounds; relative biological effectiveness (RBE) issues relating to tritium and alphas; development of bioassays, as needed by plant-life-extension operations
- **Drivers:** Regulatory issues; national/international CANDU marketing considerations; plant life extension activities
- **Goals**
 - ◆ Develop models and associated parameters for estimating dosimetric quantities for exposure to tritium and C-14.
 - ◆ Maintain CANDU internal dosimetry code IMBA Professional Plus, including training requirements.
 - ◆ Continue ongoing university collaborations to establish a knowledge base on RBE / weighting factors for tritium, and staff training capabilities.



Internal Dosimetry

- **Research using rats provided dosimetry data for inhaled tritiated and carbon-14 bearing organic compounds**
 - ◆ ICRP models overestimate uptake of radioactive methane; under-estimate tritium conversion to OBT
 - ◆ ICRP models, underestimate uptake and OBT conversion in liver relative to other tissues (carcass, brain, skin)
 - ◆ ICRP models, underestimates overall uptake and conversion to organically bound carbon in the liver, but provide a good estimate for organic fixation of C-14 in carcass, skin and brain
 - ◆ Data analysis continues, including analysis of studies on inhalation of tritiated emulsions





Internal Dosimetry

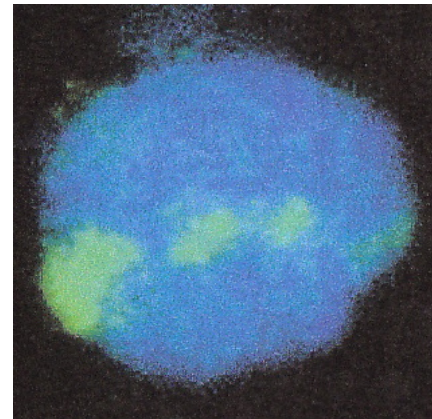
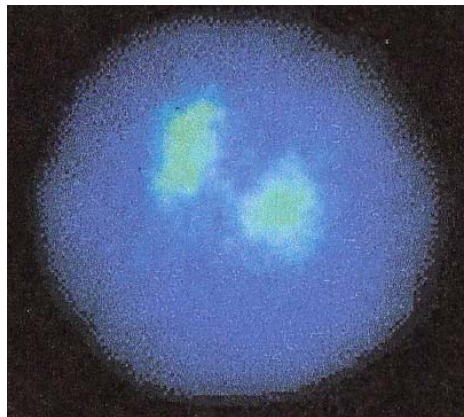
- **Developed IMBA CANDU Professional Plus, an internal dosimetry code for the CANDU environment.** IMBA (Integrated Modules of Bioassay Analysis) CANDU Professional Plus, is software modules that implement current ICRP biokinetic and dosimetric models for estimating intakes and doses specific to CANDU environments.
- **Explored the use of biological dosimetry**
 - ◆ Biological dosimetry is considered for estimating radiation exposures based on biological markers in the cells of exposed individuals.
 - ◆ Developed changes to standard procedures to increase efficiency and reliability of biological dosimetry for accident exposures



Internal Dosimetry

Evaluated the premature chromosome condensation (PCC) assay for estimating chromosome damage by radiation

- Does not meet key criteria for a biodosimetry tool, i.e. an unequivocal and readily measurable end-point, a low background and a consistent dose response relationship. It is not a reliable or useful addition to standard assessment procedures

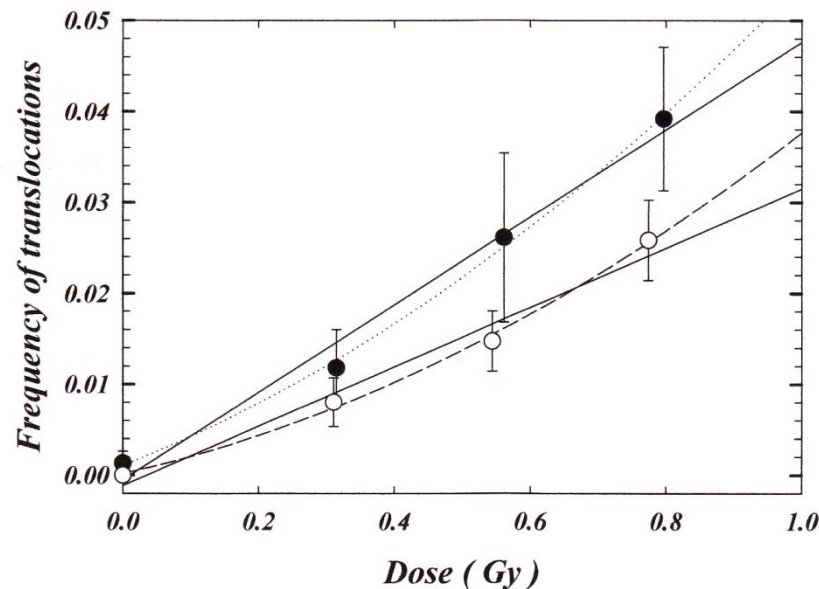
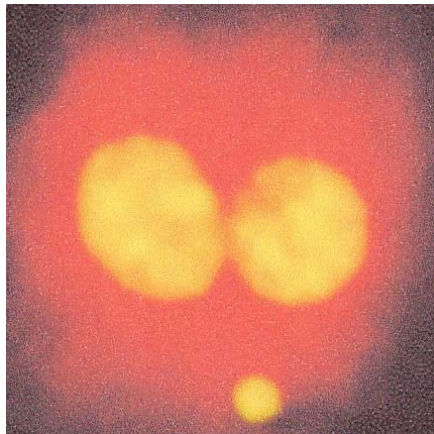




Internal Dosimetry

Micronuclei (MN) and chromosomal aberrations in human lymphocytes as a function of acute and chronic tritium dose rates. Lymphocytes were exposed to HTO (up to 0.9 Gy, at 0.6 and 0.01cGy/min)

- MN induction shows linear dose response for chronic exposures (open circles) and a curvilinear one for acute (closed circles).
- Application of linear model to all data gives induction rates for acute exposures that are higher than those for chronic exposure





Internal Dosimetry

- **Evaluated the prospects of developing a biological personal dosimeter for tritium.** Reviewed a number of potential methods to measure tritium, mainly in the form of HTO vapor.
 - ◆ It was concluded that a personal tritium monitor capable of detecting exposures of 100 μSv cannot presently be constructed.
 - ◆ The *Medipix2* detector can detect doses of 1 to 5 mSv.
- **Evaluated the relative contribution of organically bound tritium (OBT) to total tritium dose** Based on a review of tritium dosimetry in the environment, for routine releases of HTO to air and water :
 - ◆ OBT contributes up to 20% of total tritium dose to members of the public, aquatic plants and animals, and non-cereal terrestrial plants.
 - ◆ Tritiated organics contribute <10% of occupational tritium dose to ARWs.
 - ◆ OBT makes up 85% and 42% of total tritium dose from cereals and terrestrial animals, respectively.
 - ◆ Uncertainty of OBT measurements in environmental samples is ~70%



Internal Dosimetry / Ongoing Work

- Analysis of data for inhalation of C-14 and tritiated oil aerosols and volatile organics
- Evaluation of the toxicity of LVRF and other new CANDU fuels
- Evaluation of the relative toxicity of gamma-rays and tritium in mice



Radiation Monitoring

- **Objective:** Improved radiation metrology and instrumentation for tritium, carbon-14, and actinides and fission products in workplace and environment, and to characterize contamination hazards in **CANDU life-extension activities**
- **Drivers:** Continuing need for improvements in measuring radiation in the workplace and the environment
- **Goals**
 - ◆ Continue R&D on new **instruments and methods for monitoring radiation in the workplace and the environment** (personal electronic neutron and tritium dosimeters, tritium and carbon-14 monitors)
 - ◆ Develop / demonstrate new instruments and methods to detect **surface contamination** for plant life-extension / decommissioning
 - ◆ Develop methodologies and instrumentation to **monitor activity in bulk low- level waste**



Radiation Monitoring

- **Completed a review of the National Dose Registry (NDR) database against those of the COG facilities**
 - ◆ Identified and resolved 12,400 discrepancies between values stored in NDR and those in databases maintained by COG facilities
 - ◆ Most discrepancies were associated with the early years of the facilities, e.g. for OPG
 - ~80% of discrepancies occurred in the 1970's, with ~45% attributed to records in OPG database but not NDR.
 - There were very few discrepancies in internal exposures >10mSv



Radiation Monitoring

- **Developed improved instruments to measure tritium in real-time and without interference from other beta emitters**
 - ◆ Selective detection of **tritium in air** is achieved with a double gas-electron-multiplier detector and multi-element signal readout electronics, capable of providing spatial information of the ion cluster distribution from radioactive events.
 - ◆ Developed a sensitive (37kBq/m³) instrument to measure **tritium in water**. Uses a gas-flow proportional counter, which samples every 15 min. and counts the sample for 5 min., a significant improvement to present method (sampling every work shift)



Radiation Monitoring

■ **Reviewed commercial instruments for monitoring alpha, beta, gamma and tritium activity** Ranked instruments according to criteria set by a survey of COG utilities. Three hand-held survey meters that met most of the criteria were reviewed in detail:



RAM R-200



RadEye G



RDS-30



Radiation Monitoring

- **Various locations of a CANDU reactor were sampled to identify radionuclides that personnel may be exposed to**
 - ◆ Most contaminated locations were the fuelling machine service room and the water scum line in the irradiated fuel bay, where activation and fission products (mainly Co-60 and Cs-137) were found.
 - ◆ Organic C-14 was higher than inorganic C-14.
 - ◆ Actinide activities varied as: $\text{Am-241} > {}^{240}\text{Pu-239}, -240 > \text{Pu-238} > \text{Cm-243}, -244 > \text{Cm-242}$.
 - ◆ Long-lived actinide activities were an order of magnitude less than that of the dominant gamma-emitters (Co-60 and Cs-137).



Radiation Monitoring / Ongoing Work

- Imaging systems to facilitate in the location and identification of surface contamination
- Interpretation of shutdown gamma-scan data for various reactor components
- Development of a simple Fe-55 swipe and / or real-time Fe-55 or C-14 activity in air monitor
- Characterization of doses to non-nuclear energy workers at CANDU facilities
- Development of a personal neutron-gamma dosimeter.



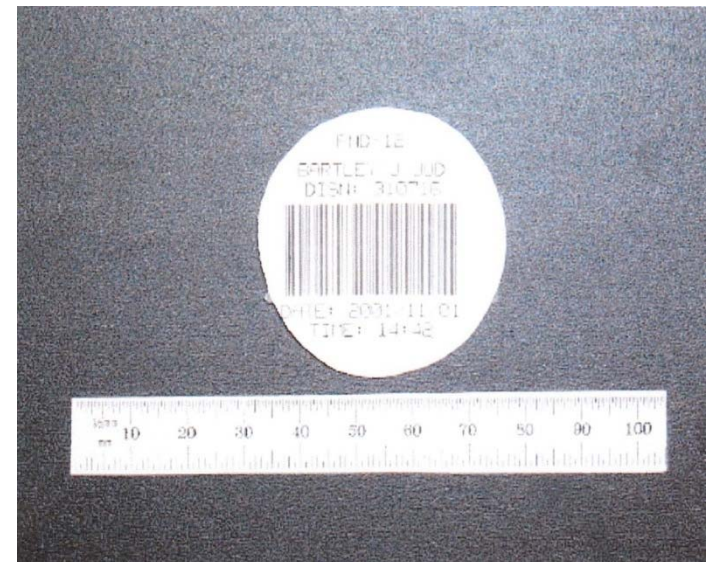
Occupational Radiation Protection

- **Objective:** Technologies and procedures for reducing dose to station staff, in accordance with ALARA, as required by radiation protection regulations
- **Drivers:** ALARA principle
- **Goals:**
 - ◆ Improve understanding of radiation sources, through R&D and OPEX, in order to **reduce occupational exposures** in routine and plant-life extension operations.
 - ◆ Improved **personal protection equipment** (clothing, tritium respirators, decontamination materials), including communication and remote monitoring systems for the CANDUs
 - ◆ Develop **work procedures** that consider technological and human factors enhancements, to minimize radiation exposure; and ALARA software, to evaluate effectiveness of **radiation dose management**.
 - ◆ **Source-term reduction technologies**, such as advanced resins and filtration media, and alternative materials to replace stellite components.



Occupational Radiation Protection

- Chain of custody procedures at AECL, OPG, HQ and NBP, and US Limerick NGS were benchmarked, as well as reviewed practices at Canadian medical and government facilities, and recent advances in tracking of dosimetry samples.
 - ◆ A key concern was problems with extremity TLDs (lost TLDs and linking dose to an individual).
 - ◆ Barcodes, single point of issue of personal dosimeters, and barcoded TLDs for controlling access to various zones improved chain of custody.





Occupational Radiation Protection

- **Developed strategies to reduce worker dose at the reactor face**
 - ◆ An overall dose reduction of 5 to 10 or higher can be achieved depending on the method.
 - ◆ Strategies to reduce reactor face fields included: Full system decontamination of PHTS and sub system decontamination of headers, feeders and core components.
- **Reviewed US PADS and UK systems for radiation worker dose passbook; recommended the US PADS system for Canada**
 - ◆ Both systems meet primary need to track dose information for outside workers.
 - ◆ The US PADS is more compatible with Canadian regulatory requirements. Even though more expensive, will still enable significant cost savings over the current practice, especially if the non-dose related parameters (security clearance, training and medical records) are also used



Occupational Radiation Protection



- **An intermediate tritium suit is under development** (HTO vapor protection factor ≥ 10 , aerosols protection factor ≥ 100 , plus other safety requirements)
 - ◆ Two suit versions : A self-contained version, which includes a station air purification system; and a second version, with an air purification system in a transportable suitcase
 - ◆ In parallel, a compatible, commercially available wireless communication system has been identified and successfully tested for application with these suits.



- Reactor face fields characterization studies
- Source-term radionuclide characterization for reactor systems
- Speciation and quantification of cobalt entering the HTS from fuelling machines
- Studies to replace the fuelling machine stellite ball bearings
- Radiation effects on activity transport
- Development of tritium plastic suit ensemble