Uranium 2010

the future is U

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Uranium 2010

The Future is U

Volume II

Editors

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Symposium Organized by the Hydrometallurgy Section of the Metallurgical Society of the Canadian Institute of Mining, Metallurgy and Petroleum

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Foreword

The Third International Conference on Uranium is organized by the Hydrometallurgy Section of the Metallurgical Society of the Canadian Institute of Mining, Metallurgy and Petroleum (CIM) and constitutes its 40th Annual Hydrometallurgy Meeting. U2010 Conference is indeed an international conference with over 400 delegates from 26 countries. The conference features an exceptional line-up of plenary, luncheon, banquet and keynote speakers from the leaders of the uranium industry, academia and governments. Over 170 papers and posters covering various topics in the uranium fuel cycle are presented in the plenary and 25 sessions over three days. The tours to the state-of-the-art mines and mills in Northern Saskatchewan, the short course on the uranium processing, the trade show and the poster session add further strength to the conference. This conference builds on the success of two previous Hydrometallurgy Section meetings, namely, Uranium ’82 and Uranium 2000. This conference is the result of over three years of planning and efforts including the formulation of the Organizing Committee, many teleconference meetings and the hard work of the committee members to make things happen.

Our theme, “The Future is U”, fits very well with the state of the uranium industry as we know it today. In 2000, the spot price of uranium was around US$10 per lb., and currently it is higher than the US$40 per lb. level. Nuclear has been recognized as one of the important energy sources to minimize the generation of greenhouse gases. The developed countries are extending the useful life of the existing nuclear power reactors and/or considering new builds, and the developing countries are building or planning to build new reactors. In order to meet the uranium demands, producers are pushing the technology envelope to mine uranium from challenging geological settings and to mill more complex and refractory ores. New and existing technologies are being incorporated in the uranium processing flow sheets. On the other hand, existing operations are meeting the challenges of maintaining the day-to-day production and of the desire to increase production with minimal changes. At the same time, efforts are focusing on improving the environmental aspects of the operations, including air emission, effluent discharge and the management of waste rock and tailings. This is indeed an exciting and challenging time for the geologists, mining engineers, metallurgists, technical staff and managements involved in the uranium processing and nuclear industries.

As we write this foreword, U2010 Conference is only weeks away. The conference will provide an excellent opportunity for industry executives, representatives of universities and research institutes, design engineers, plant operators, regulators, policymakers, as well as metallurgical, environmental and health experts from all over the world to meet their colleagues, to discuss common interests and concerns, to network, to renew friendship or form new lasting friendships. The two-volume proceedings collect the papers on current state-of-the-art technologies on the uranium fuel cycle and it is the editors’ belief that the books will be a reference for years to come. We believe this is the first time more than 150 technical papers have been compiled into one conference proceeding on uranium processing and nuclear energy.

We thank the organizing committee for working hard over the last three years to put this outstanding conference together. In addition, we would like to recognize and thank all of our financial sponsors, and the support of our non-financial sponsors. We especially acknowledge Cameco and AREVA for their strong support of our activities and the conference overall.

The production of these two proceedings volumes was a major undertaking, which extended over many months and involved a large number of individuals. In this regard, we thank all of the authors who took the time to prepare their papers and presentations, and the session chairs for engaging the experts, obtaining and reviewing the papers. We acknowledge Lyn Porteous for putting the manuscripts in a standard and uniform format, and Justus Lam for proofreading the manuscripts. We appreciate the invaluable support from Brigitte Farah and Ronona Saunders of the MetSoc/CIM office. We also thank our wives for understanding and their support for our long hours of work during the preparation of the conference planning and proceedings.

Saskatoon, Saskatchewan, Canada
August 2010

Ed Lam, John Rowson and Engin Özberk
Editors

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Regulatory Requirements and Expectations	Alice Wong, Kevin Scissons and Kevin Murphy
Environmental & Safety Advances & Best Practices	Arden Rosaasen, Kevin Himbeault and Brent Berg

Short Course Topic	**Lecturer**
Uranium Mineralogy & Implications for Processing Options	Gerhard Heinrich, Cameco
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Solution Purification I - SX – Chemistry, Important considerations	Gary Kordosky, Cognis
Solution Purification I - SX – Equipment Options and Choices	Gary Kordosky, Cognis
Solution Purification II - IX – from solution (from ISL) and RIP	Mikhail Michalenko, Purolite
Product Recovery from Solution (ppt'n etc.)	Bruno Courtaud, AREVA
Industry Trends in Extractive Metallurgy	John Goode, Aurora
Byproduct Management I - Liquid Effluent Treatment	Brett Moldovan, Cameco
Byproduct Management II - Solid Wastes, Tailings	Brett Moldovan, Cameco
Refining and Conversion	Andrew Oliver, Cameco
Environmental Compliance Strategies and Trends (Canada as base case with reference to other jurisdictions, US, Australia, etc.)	Dale Huffmann, AREVA
U-specific H&S Issues (Radiological monitoring and protection in the mine, mill, refinery, issues, solutions, trends)	Arden Rosaasen, AREVA

Editors' Biographies

Edmond K. Lam attended Queen's University where he received his B.Sc. degree in metallurgical engineering in 1977 and his M.Sc. degree in 1982 under the mentorship of the late Prof. W. Charles Cooper. Upon graduation, he worked at the Falconbridge Metallurgical Laboratories in Thornhill, Ontario. In 1983, he began his career in the uranium industry by joining the Key Lake Mining Corporation (now Cameco) as a mill metallurgist. He was involved in the startup of the Key Lake mill circuit and later was a member of the team that brought the mill to its nameplate capacity and beyond. He was involved in the development and implementation of the SX molybdenum removal circuit at the Key Lake mill. He spent two years at the Cameco R&D laboratories in Saskatoon. In 1992, he returned to the mill at the Cameco Rabbit Lake operation, when the mill successfully treated the Eagle Point ore and then the higher grade D-zone and A-zone ores. In 1997, he moved to southern Ontario and continued to pursuit his interest in R&D by joining the Cameco technology development department (now innovation & technology development – research centre). His area of work includes the evaluation of new deposits, the evaluation, troubleshooting and optimization of milling/refining processes, and water treatment processes. He is a long-time CIM member and is a member of the Hydrometallurgical Section committee of MetSoc.

John Rowson has spent almost his entire career in the uranium mining industry. He began working 40 years ago in the Beaverlodge mill, owned by Eldorado Nuclear Ltd., in Uranium City. In 1979, he joined Amok Ltée (now AREVA) for the start-up and operation of the Cluff Lake mill. He continued to work at the Cluff Lake site for nearly 14 years in the capacity of mill superintendent. In 1993, he relocated to the United States for COGEMA Mining Inc. (now AREVA) based in Casper, Wyoming. As General Manager, ISL Operations, he was responsible for the development and operation of ISL projects in Wyoming and south Texas. In 1997, he transferred back to Canada as General Manager for the start-up and operation of COGEMA Resources Inc.'s (now AREVA) McClean Lake operation. For the past eight years, he has worked at AREVA's Saskatoon head office engaged in a variety of scientific and technical roles at the executive level. Dr. Rowson possesses a Ph.D. in nuclear chemistry.

Engin Özberk is the vice president, Innovation and Technology Development of Cameco Corporation. He joined Cameco in February, 1997. Before that he has worked as consulting metallurgist for Sherritt International Corporation, Alberta (1988 – 1997); as senior project manager and senior process engineer for The SNC Group, Quebec (1979 – 1988); as research engineer for Noranda Technology Centre, Quebec (1974 – 1976) and as project engineer for Etibank, Turkey (1973). He has more than 35 years of research and development and project management experience in light metals, base metals and nuclear industries. He has lead or participated in numerous major metallurgical and chemical engineering projects in practically every continent. He has obtained his B.Sc., Metallurgical Engineering (1972), Middle East Technical University, Ankara, Turkey, and Master of Eng., Metallurgical Engineering (1979) and Graduate Diploma in Management (1978), both from McGill University, Montreal, Quebec. He is a CIM Fellow (1994) and recipient of CIM Distinguished Lecturer Award (2009), and Silver Medal (1997) and Alcan Award (2006) from the Metallurgical Society of CIM; he is a member of the Canadian Nuclear Society and recipient of the CNS Communication and Education Award (2007); and he is the recipient of the Extractive Metallurgy Science Award (1988) from the Minerals, Metals and Materials Society (TMS) of AIME of USA. He has authored or coauthored more than 40 papers. He has also chaired numerous international conferences and symposia, and professional development courses in Canada and abroad, as well as being the guest/invited speaker or lecturer at conferences and numerous universities. Currently, Engin is the President of the Canada Mining Innovation Council and chairman of the board of directors and he is a leading participant at the steering committee for "Feasibility Study for the Development of an International Science and Engineering Centre for the Mineral Sector in Saskatchewan". Engin is the co-chair of the Technical Advisory Committee of the UOIT Cameco Chair for Nuclear Fuel. Recently, Engin was appointed to the board of directors of the Pacific Institute for the Mathematical Sciences, (PIM). He is also the member of the Toxicology Centre Advisory Board of University of Saskatchewan, board of directors of the Saskatchewan Centre of Excellence in Transportation and Infrastructure, CANMET-MMSL Technical Advisory Committee, University Network of Excellence in Nuclear Engineering (UNENE) executive committee, the Business Development Advisory Committee (BDAC) for the Canadian Light Source, Advisory Board of Cameco NSERC Chair for Women in Science & Engineering of University of Saskatchewan and the Mining Association of Canada Science Committee. Engin served at Canadian Institute of Mining and Metallurgy (CIM) board of directors, as President of the Metallurgical Society of CIM and member of the executive team and board of directors.

Table of Contents

Uranium 2010 -The Future is U
Volume II

URANIUM PROCESSING - ION EXCHANGE

URANIUM REFINING AND CONVERSION – CHALLENGES AND ADVANCES

URANIUM FUEL MANUFACTURE

REACTORS

TAILINGS MANAGEMENT – CHALLENGES AND ADVANCES

TAILINGS – CHEMISTRY AND CHARACTERIZATION

DECOMMISSIONING

RADIATION SAFETY AND ADVANCES

REGULATORY REQUIREMENTS AND EXPECTATIONS

ENVIRONMENTAL AND SAFETY ADVANCES AND BEST PRACTICES

ADDENDUM

EPIDEMIOLOGICAL EVIDENCE AND RADIATION PROTECTION

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ABSTRACT

Objective scientific information should be the basis for understanding the health effects of uranium on workers and members of the public so stakeholders can make informed decisions about radiation protection. The Canadian Nuclear Safety Commission has participated in several recent epidemiological studies of the health effects of uranium workers and people living near uranium processing facilities. This presentation will discuss the findings, studies conducted elsewhere, international scientific consensus, gaps in knowledge, and plans for international collaborative studies. Finally, it will discuss the importance of epidemiological evidence for radiation protection and provide examples of how information has been communicated to stakeholders for evidenced-based decision making.

INTRODUCTION

The Canadian Nuclear safety Commission (CNSC) is a science-based regulatory agency. Objective scientific information should form the basis of regulation for the protection of health and safety of people and the environment. Good science is also a consideration in risk-based decision making.

Radiation protection regulations internationally and in Canada are based on the scientific reviews of international organizations such as United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and on recommendations of the International Commission on Radiation Protection (ICRP). A credible and effective regulatory framework can only be maintained through regular reviews of advances in science, by filling gaps in knowledge and ensuring relevance in the context of the regulated activities. Societal expectations for transparent regulatory decisions need to also be recognized.

In the context of uranium mining an important radiation protection issue is minimization of exposure to radon decay products (RDP). Epidemiological studies of underground uranium miner cohorts have been conducted in several countries. A combined analysis of 11 underground mining cohorts (Lubin et al 1995) [1] that included 4 Canadian cohorts, found an approximately linear relationship between RDP exposure and lung cancer mortality. The risk per unit RDP exposure decreased with increasing time since exposure, with increasing exposure rate and increasing age at risk. The BEIR VI Committee [2] adopted this model in 1999.

Since 2000, the CNSC has been involved in several important epidemiological studies of uranium workers. These include the following mine workers studies:

- The update of the Eldorado Uranium miners cohort study, which includes approximately 17,000 uranium workers from the Port Radium uranium mine in the Northwest Territories, the Beaverlodge mine in Northern Saskatchewan, the radium and uranium refinery and processing plant in Port Hope, Ontario [3].
- A feasibility study of modern Saskatchewan uranium workers [4].
- The update of the Newfoundland Fluorspar miners cohort study, which includes approximately 2,000 fluorspar miners exposed to radon from groundwater entering the mine [5].
- The update of the Ontario miners cohort study, which includes approximately 30,000 workers from Elliot Lake, Bancroft and Agnew mines.

Table 1 describes the Canadian cohorts.

Table 1 - Canadian uranium worker cohorts

Site	Activity	Timeframe	N
Beaverlodge	Uranium mine/mill	1950s-1980s	10,050
Port Radium	Radium and uranium mine/mill	1930s-1960	3,300
Port Hope	Radium and uranium refining and processing	1930s-present	3,003
Ontario	Uranium mine/mill	1950s-1990s	31,000
Newfoundland	Fluorspar mine	1930s-1978	2,070
TOTAL			49,423

The CNSC has also been involved in several recent descriptive studies of people living near radium and uranium processing facilities. Most recently, the CNSC prepared a comprehensive document on understanding health studies and risk assessments conducted in the Port Hope community from the 1950s to the present [6].

RESULTS AND DISCUSSION

A. Studies of Canadian Uranium Workers - Results and Status of Epidemiological Studies

Updated Eldorado Uranium Workers Study [3]

The Eldorado cohort consisted of 17,660 workers from Port Radium, Beaverlodge, Port Hope and other sites including head office, aviation and research and development (Figure 1). Workers included miners, mill workers and radium and uranium processing workers who worked anytime between the 1930s and 1981 for Eldorado.

The overall objectives of the Eldorado uranium workers study were to assess the relationship between radon progeny exposure and lung cancer risk. The dose response relationship and the modifying effects of age at risk, time since exposure and exposure rate were also assessed. The study also assessed the relationship with other causes of cancer and other causes of death. Worker's individual gamma radiation exposures and its relationship with cancer and other causes of death were also assessed.

Individuals' personal information and work histories were collected from personnel files. Radiation exposures were obtained from company records, reconstruction and linkage to the National Dose Registry of Canada for both radon progeny and gamma radiation exposure. Cause of death (1950-1999) and cancer incidence (1969-1999) information was obtained through probabilistic record linkage of the Eldorado cohort to the Canadian Mortality Database and Canadian Cancer Database, respectively. The standardized mortality (SMR) and cancer incidence ratio (SIR) was used to assess mortality and cancer incidence experience of the cohort in relation to the general Canadian male population. Poisson regression methods [7, 8] were used to characterize the radon progeny and lung cancer relationship, and the gamma radiation and cancer relationship. Modifying effects of the radon progeny and lung cancer relationship were investigated from the BEIR VI Committee model.

The study found that workers were as healthy as the Canadian general male population. There was an excess risk of lung cancer mortality and cancer incidence attributed to radon progeny exposure. Radon progeny is known to increase the risk of lung cancer. Worker's risk increases with increasing radon progeny exposure. However, the modifying effects had an important influence on the radon and lung cancer relationship. Risk decreased with increasing time since exposure, age at risk and increasing exposure rate. This pattern was seen for both lung cancer mortality and lung cancer incidence. Workers individual radon progeny exposure was not found to cause any other cancer or any other cause of death. Although high levels of gamma radiation are known to cause various cancers, in this study, workers' individual gamma radiation exposure were not found to cause cancer or any other causes of death.

The updated Eldorado cohort study was based on past uranium workers working between the 1930's and 1981. This included a time when little was know about the health effects of radon exposure and thus few measures were in place to reduce radon levels in mine workings. However, there were dramatic reductions in RDP levels from the 1970's onward as a result of increased knowledge of the health effects associated with RDP exposure (Figure 2). Regulation of uranium mining is based on the findings of such epidemiological studies. Implementation of radiation protection programs has resulted in significant reductions in radon exposures in current uranium mines, resulting in a high level of protection to workers.

The risk of getting lung cancer from working in current uranium mine is low because current radon progeny exposures are low and therefore the risk is low. Gamma radiation wasn't found to cause cancer or any other cause of death among the Eldorado workers.

Feasibility Study of Modern Uranium Miners [4]

In the mid-1990s joint federal provincial environmental assessments were conducted for several new high ore grade uranium mines in Northern Saskatchewan. In its report, the Joint Federal and Provincial Panel on Uranium Mining Development in Northern Saskatchewan made several recommendations, including one to conduct ongoing epidemiological studies of present and future uranium miners. In response to this recommendation, the CNSC initiated in cooperation with provincial and the mining companies, and the mining companies a feasibility study to determine if such an epidemiological study could be conducted. This feasibility study was conducted by SENES Consultants in 2007. Workers from 1970 to 2000 were included in the study and the number of workers anticipated to be working in a Saskatchewan uranium mine was calculated up to 2030 based on past and current age and sex distributions of mine employees. The predicted number of lung cancers was calculated using baseline lung cancer rates, the age and sex distribution of the cohort, radon exposures and an excess relative risk model for the follow-up to 2030. Approximately 24,000 workers were estimated to spend some time working at a Saskatchewan mine by the year 2030. Very low workplace radon and other workplace exposures were estimated, based on workplace exposures from 1970 to 2000 from the National Dose Registry. Cigarette smoking and residential radon exposures were also calculated based on a Rabbit Lake Miners Smoking Survey, provincial smoking prevalence rates and residential radon data.

During this time (1970 to 2030), it was estimated that approximately 141 miners could expect to develop lung cancer, primarily due to cigarette smoking. One miner may expect to develop lung cancer from radon exposure in the workplace. The statistical power for a study of present day miners to detect any excess risk of lung cancer as a result of current occupational radon progeny exposures was expected to be extremely low.

This feasibility report was peer reviewed by external experts. Based on the findings of this study, it was determined that a study of current uranium miners was not feasible because current exposures were so low that no health effects were anticipated. Also, given the important influence of tobacco smoking and residential radon on lung cancer risk, it would be impossible to determine the small impact of occupational exposure on lung cancer risk based on the long latency period of lung cancer and the relatively short time workers are actually employed in a current uranium mine. It is unlikely such a study is to contribute significantly to the science and is of little merit in that regard.

Newfoundland Fluorspar Miners Study [5]

The relationship between radon and lung cancer mortality was assessed in a cohort of 1,742 Newfoundland fluorspar miners between 1950 and 2001; follow-up had been extended 11 years from previous analysis. The standardized mortality ratio (SMR) was used to compare the mortality of the cohort to similarly aged Newfoundland males. Poisson regression methods were used to characterize the radon-lung cancer relationship with respect to age at first exposure, attained age, time since last exposure, interactions with cigarettes smoking and exposure rate.

Overall, mine employees were as healthy as the general Newfoundland male population. In total, 191 lung cancers were observed among underground miners. Overall, workers had significantly higher rates of lung cancer and the risk of mortality increased with increasing radon progeny exposure. The excess risk of lung cancer decreased with attained age and time since exposure number of cigarettes smoked daily, exposure rate and duration of exposure.

An important strength of this study was that the effects of gamma radiation, thoron, and radioactive dust, common exposures in other miner studies, can be ruled out because the source of radon was from degassing from groundwater flowing into the mine [5, 9]. This study can also assess the impact of cigarette smoking on the radon and lung cancer relationship.

A previous analysis in this cohort found elevated death rates from coronary heart disease among those with higher cumulative radon exposure [10]. However, this finding was based on relatively small number of deaths and was not statistically significant. With the follow-up of this cohort until the end of 2001, 267 miners died from coronary heart disease. There was no trend evident between cumulative exposure to radon and the relative risk of death from coronary heart disease. This finding was unchanged after adjusting for the lifetime smoking status. Similarly, the cumulative radon exposure was found to be unrelated to deaths from circulatory system diseases [5, 11].

Results from this study should be interpreted with caution due to uncertainty associated with the estimation of radon exposure levels before ventilation was introduced into the mine, and the relatively small number of cancer and coronary heart disease deaths that precluded joint modelling of multiple risk factors.

The Updated Ontario Miners study

Initial work on the update of mortality and cancer incidence follow-up of approximately 30,000 Ontario uranium miners cohort is underway. The update will provide at least 20 years of mortality (1955 – present) and 30 years of cancer incidence (1969 – present) data not previously considered. Radon progeny exposures and gamma ray doses were obtained from company records. Exposures were estimated through reconstruction based on work history and ore grade, or through individual dosimeters. This information comes from the cohort's Mining Master File and linkage to the National Dose and Registry. This cohort will be linked to the Canadian Mortality Database and Canadian Cancer Database in September 2010.

Strengths and Limitations of Epidemiological Studies with the Canadian Cohorts

The Canadian uranium workers cohorts have several important strengths. The existing historical uranium worker cohorts have had recent improvements to quality of identifiers, work histories and exposure estimates. Overall, the Canadian cohort is relatively large with approximately 50,000 past workers. Canada has high quality population-based mortality and cancer incidence data vital for follow-up of workers. Likewise, the National Dose Registry can be used to obtain other occupational radiation exposures and update more recent radiation exposures. Canada has over 60 years of long-term follow-up of mortality information. National mortality is available from 1950 onward with cause of death information, and 1940-1950 with fact of death information. Likewise, over 40 years of long-term follow-up of cancer incidence is available, 1969 onward.

Limitations include the fact that early exposures were estimated, there is limited information on tobacco use and limited information on other occupational exposures. Finally, the historic high workplace exposures (such as those in Port Radium) do not reflect today's work environment. However, long term health effects of moderate and low exposures (such as those in Beaverlodge and Ontario) are increasingly important since they best reflect current miners' exposures. Given the lack of feasibility of conducting studies of current miners, long term follow-up of uranium workers with moderate to low exposure is essential to understand gaps in our current understanding.

B. Studies of People Living Near Canadian Uranium Processing Facilities

The radium and uranium processing industry has operated in Port Hope, Ontario, Canada since 1932 [6]. Waste management practices during the early period did not fully limit the spread of contamination. From 1976 to 1981, the most serious contamination in Port Hope homes and businesses was remediated. As a result, over 100,000 tons of waste were removed and sent to a licensed waste management facility, while 600,000 tons of waste was left in Port Hope at 11 large storage sites. A federally funded clean up project has been initiated to deal permanently with this remaining volume of waste. Since 1984 good waste management practices are in place. Despite better environmental performance of the current uranium processing operations, there remains concern within some members of the community about the health impacts that may have been caused by the presence of low level radioactive waste in residential and public areas

Tremendous efforts have been expended in Port Hope to study the health of the community and its residents, including over 30 environmental and 13 epidemiological studies. Data from these studies span a period of more than 70 years.

In response to public concern, the CNSC undertook a study using a weight of evidence approach to determine the likelihood of adverse health effects on human health from the presence of uranium facilities in Port Hope Ontario. The weight of evidence approach is an assessment method that includes reviewing site-specific doses, epidemiological studies and chemical specific toxicity data to evaluate exposure and potential health effects in a community [12].

For this study CNSC staff reviewed and synthesized the results of over 30 environmental to assess the potential effects associated with past and present activities of the radium and uranium industry in Port Hope and compared them with national and international benchmarks to assess potential risks. The 13 epidemiological studies were also reviewed to assess the radiation risk of mortality and cancer incidence of Port Hope residents and nuclear workers compared to similar communities and the general population. For this paper only a summary of results associated with radiation exposures and uranium is presented. The entire study is available from the CNSC [6].

Based on a review of the scientific literature on health effects of uranium and radiological contaminants present in Port Hope, plausible health effects were identified (Table 2).

Table 2 - A Plausible health effects in Port Hope associated with the nuclear industry

Contaminants of Potential Concern	Most Plausible Health Effects	Supporting Evidence
Uranium (UO_3, UF_6)	Kidney disease	The main potential health effect of uranium is kidney disease. Uranium at very high levels can cause kidney disease in animal experiments. In humans, very high levels of uranium can cause changes to kidney cells, which are largely reversible. Scientific reviews of over 40 epidemiological studies concluded there was no evidence to link occupational or environmental uranium exposures to kidney disease or any other cause of death or cancer.
Radon Radon decay products UO_2	Lung Cancer	Radon and its decay products, and long-term radioactive dust (UO_2) are known to cause lung cancer. No other type of cancer or other cause of death is known to be associated with radon exposure.
Radium (Ra-226)	Bone Cancer	Radium, if ingested, can deposit in the bone and cause bone cancer at very high levels, with a threshold of about 10 Sv.

On the basis of a comparison of levels of exposure of members of the public to uranium and radiation doses (Table 3) with benchmarks protective of human health it was concluded that kidney disease; lung cancer and bone cancer were highly unlikely

Table 3 - Exposure of Port Hope Residents to Radiation

Annual Radiation Doses	mSv/year
Radon (indoor) in Port Hope (1955–1993)	0.69-0.99
Gamma (indoor) in Port Hope (1955–1993)	0.25–0.27
Cameco Port Hope Conversion Facility (2007)	0.064
Cameco Fuel Fabrication Facility (2007)	0.004
Worldwide annual average effective dose from natural radiation sources (2000)	2.4 (typical range is 1–10)

The thirteen epidemiological studies conducted on Port Hope residents and nuclear workers covered the time period prior to 1966, the time period of remediation of the low level radioactive waste (1976 to 1981), the period of the solvent extraction plant (1967 to 1984) when uranium emissions were elevated and current times (from 1984 to the present) when the implementation of mitigation measures significantly reduced uranium emissions. The studies assessed all causes of death, all cancers and all birth defects. All studies are fully described in the CNSC report [6].

The epidemiological studies provided no evidence of excess kidney disease or bone cancer. During the entire period that the radium and uranium refining and processing industry has been operating in Port Hope, there has been no statistically significant excess kidney disease mortality in residents or in radium or uranium workers. Similarly there has been no statistically significant excess bone cancer incidence or mortality in residents or in radium or uranium workers. No relationship has been found between workers' occupational radiation exposures and kidney disease or mortality or bone cancer incidence or mortality.

Excess lung cancer incidence was found in Port Hope women between 1986 and 1996. However, evidence is not strong enough to link this to the Port Hope nuclear industry. There is no statistically significant excess lung cancer incidence or mortality in Port Hope nuclear workers, nor a relationship between workers' occupational radiation exposures and lung cancer. The case-control study of lung cancer in Port Hope relative to domestic radon exposure [14, 15] showed no conclusive evidence of an increased risk of lung cancer from residential radon exposure. Additionally, there was no statistically significant excess lung cancer mortality in Port Hope residents from 1956 to 1997 [16] and no statistically significant excess lung cancer incidence in Port Hope men from 1971 to 1996, or in Port Hope women from 1971 to 1981 [13]

Findings from the environmental and epidemiological studies conducted in Port Hope are consistent and support each other. Findings of the studies conducted in Port Hope were consistent with the international understanding of the human health effects of radiation and toxicity of uranium and other contaminants present in the town at low levels. These findings are also consistent with over 40 epidemiological studies of similar populations with similar exposures worldwide [18 - 26].

The weight of evidence approach used in this study provided a transparent and structured framework for conducting an interdisciplinary analysis of the numerous health and environmental studies that had been conducted in Port Hope over the last 30 years. By considering all the available lines of evidence and their relative strengths we concluded that there was no evidence that adverse health effects have occurred or are likely to occur in Port Hope as a result of the operations of the nuclear industry

CONCLUSIONS AND PERSPECTIVES

A – Communication of Findings

Under the Nuclear Safety and Control Act, the CNSC has a mandate to disseminate objective scientific information on the health effects of regulated activities. CNSC staff has undertaken a number of activities aimed at communicating the findings of the epidemiological studies described above to different audiences.

Presentations have been made in scientific fora, to radiation protection and health professionals, and federal and provincial government representatives. Information was provided to mine and mill workers, health and safety committees, union representatives, and members of the public through various outreach activities. Information has also been provided to the media, community stakeholder groups and members of the public. Scientific articles have been published in peer reviewed journals. Finally the recent *UNSCEAR 2006 Annex E on Radon in Homes and the Workplace* includes recent updated Canadian studies [27].

All of these activities and the development of different communication tools (radio and television, magazines, fact sheets, reports, WEB pages) are essential for the CNSC to remain an effective, credible and trusted regulator. In the last two to three years, the CNSC has increased efforts to produce scientific and regulatory information that is accessible to a wide audience.

B - Collaborative International Study

A number of scientific and regulatory issues still need to be addressed to ensure our regulatory framework remains effective. They are issues such as: low RDP exposures (<100 WLM), the health effects of gamma radiation, long-live radioactive dust, and other carcinogens within the mine environment (e.g. arsenic), improvements in dosimety, cancer incidence, other cancer sites (leukaemia, extra-pulmonary cancers), other causes of death (cardiovascular disease), uncertainty, modifiers of risk and confounding factors. Conducting such complex multidisciplinary studies is important but presents challenges in terms of resource availability but also the need for large cohorts to ensure studies have the required statistical power.

Several countries, including Canada, France, Germany, Czech Republic and the United States, have recently been involved un updating their uranium miner cohort studies. These studies represent over 100,000 workers in uranium mines, mills and refining and processing facilities. Since 2008, discussions have been underway to conduct a collaborative international study. The three European countries have been involved in the ALPHA RISK project, which conducted analysis of the three combined country studies. The CNSC and other Canadian stakeholders have initiated work to be able to enter into an international collaborative study.

C - Relevance to Canada

Canada is a leading uranium producer and as such the CNSC must ensure that its regulatory framework reflects current understanding of health risks associated with occupational and public radiation exposures as a result of this industry. Uranium miner studies are the basis of current radon progeny radiation protection regulations. Past studies included miners exposed to high levels of RDP because of the absence of radiation protection measures (no ventilation, no dose limits and no radon measurements). It is difficult to study current miners because exposures are so low. Cohort studies of miners with moderate to low radon exposures (<50 WLMs) and quality exposures are the key group to follow-up. Canadian miners represent the North American lifestyle. Current information on the health of Canadian miners is critical for Canadian and international knowledge (CNSC, UNSCEAR, ICRP) to ensure current radiation protection programs are appropriate to protect worker's health in today's mining environment. The uranium mining industry is expanding with several planned projects undergoing environmental assessments and initial licensing stages in northern Saskatchewan, Quebec and the Nunavut. Some of these projects are in regions of Canada with little or no uranium mining experience posing challenges to communicate regulatory requirements and their scientific basis transparently and credibly, using communication and information tools that are addressed at a lay audience.

The CNSC's commitment to dissemination of objective scientific and regulatory information and to advancing the scientific understanding of the potential health effects of uranium mining, refining and processing will position us well to meet societal expectations during this time of uranium industry growth.

Figure 1 - Location of uranium mine, mills and processing facilities in Canada

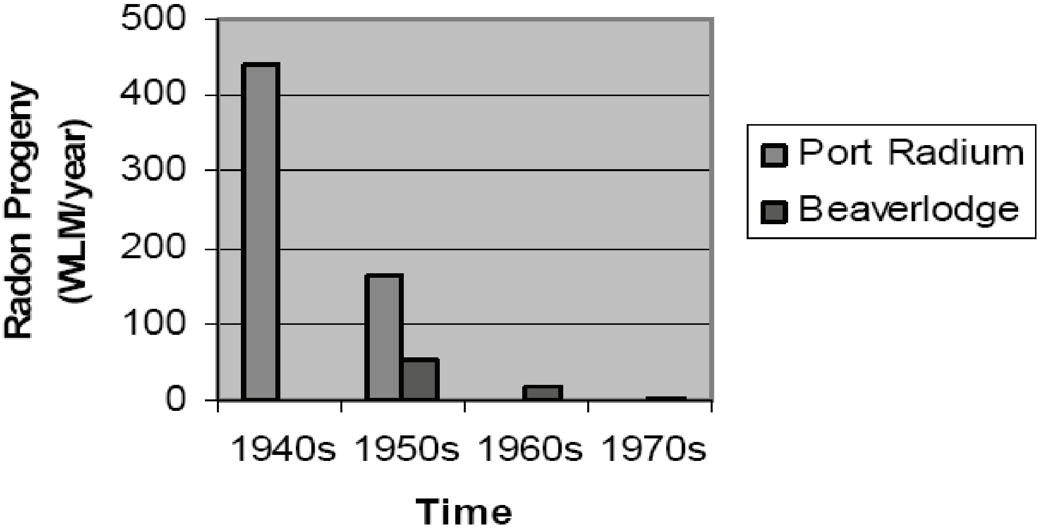

Figure 2 - Average radon progeny exposures in the Eldorado cohort during the period 1940-1970

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