APPLICATION OF CANADA'S RADIOACTIVE WASTE POLICY FRAMEWORK TO LEGACY URANIUM MINES

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Abstract

In 1996, the Government of Canada established the Radioactive Waste Management Policy Framework to ensure that radioactive waste is managed responsibly. Under the Policy Framework, the owners of the wastes are responsible for the funding, organization, management and operation of disposal and other facilities required for their wastes.

For legacy uranium mines, many of which ceased operation more than 50 years ago, there are several factors to consider when applying the Policy Framework. In many cases, the company that operated the mine, or its successor, still exists and is addressing the wastes on its sites. However, in some cases, the site returned to the Crown when mining leases expired and the wastes are now the legal responsibility of either the provincial or territorial government.

When these legacy mines operated, the environmental regulations applied to the mining industry were not very stringent. However, it is not often practical or cost-effective to remediate legacy sites to the standards applied to modern uranium mines. Most of the sites pose a very low risk, due to the low-grades of ore that were mined, their remote locations, and the fact that contamination has spread and dissipated over the last 50 years and the environment will continue to improve over time through natural attenuation.

This paper will show, through examples of legacy uranium mines that have been successfully remediated, how cost-effective remediation strategies have been applied to ensure that the environment is protected from the low risk posed by these sites.

1. Introduction

1.1 History of Uranium Mining in Canada

Pitchblende, a uranium mineral, was first mined in Canada in 1933 at Port Radium, Northwest Territories, by Eldorado Gold Mines Limited [1]. The mineral was valued for its radium content (a decay product of uranium), which had medical uses. Pitchblende ore was shipped from the mine to Port Hope, Ontario, where the radium was extracted. The major constituent of the ore, uranium, had limited use and was initially discarded as waste [2]. Production of ore ceased in 1940 when a large stockpile had been built up and radium prices had declined [1].

In 1942, in response to a request to supply uranium for the Manhattan Project, the Canadian government entered into an agreement with Eldorado Gold Mines to reopen the mine at Port Radium and the processing facility in Port Hope[2]. The following year, due to the strategic nature of uranium during the Second World War, the federal government banned private companies from conducting uranium exploration and mining in the Yukon and Northwest Territories. Most provincial governments soon introduced similar bans [3]. Eldorado was nationalized in 1944 with the company becoming a Crown corporation renamed Eldorado Mining and Refining Limited, (later renamed Eldorado Nuclear Limited) [4]. Eldorado actively explored for uranium across Canada, and in 1946, discovered economic uranium deposits near Beaverlodge Lake in northern Saskatchewan [5].

In 1946, an international effort was underway to bring all uranium deposits under the control of the United Nations to prevent the proliferation of nuclear weapons [3]. Under the 1946 *Atomic Energy Control Act*, the Government of Canada established the Atomic Energy Control Board (AECB) as a regulatory agency to provide for "control and supervision of the development, application and use of atomic energy and to enable Canada to participate effectively in measures of international control of atomic energy" [3].

However, by 1947, the United Nations had failed to reach an agreement on preventing the spread of nuclear weapons and announced it would not be taking ownership of uranium resources [6]. The Cold War nuclear arms race began and the American and British governments sought uranium for military purposes. Although Eldorado had uranium deposits at Beaverlodge Lake, which were being developed, these alone could not be expected to meet the increased demand for uranium. In 1948, the AECB lifted the restrictions which prevented private companies from conducting uranium exploration and mining in the Northwest Territories and the Yukon, and several provinces soon lifted their bans [2]. This resulted in a boom in uranium exploration in which more than 10,000 radioactive occurrences were discovered across Canada [1].

Under the *Atomic Energy Control Act*, the AECB was given the authority to make regulations to control uranium mining activities in Canada. However, the provinces of Ontario and Saskatchewan objected to federal control of uranium activities since each province had detailed regulations governing mineral exploration and mining [2]. In order to address the provinces' concerns, the AECB regulations introduced in 1948 pertained only to the security issues regarding uranium mining, and all mining permits issued indicated that mining activities were to be subject to provincial and territorial mining regulations [3]. Under the AECB regulations to address security concerns, all uranium production had to be sold through Eldorado, and ore reserves and production data were to be reported to the AECB and kept secret [1].

In 1952, Eldorado offered private mining companies up to $7.25/lb U_3O_8 for uranium ore delivered to the Beaverlodge mill. However, these ores had to contain at least 0.21% uranium, and only four small private mines were put into production between 1954 and early 1955 in response to Eldorado's offer [5]. Higher uranium prices were needed to bring large low-grade deposits into production as they required a large capital investment for on-site milling facilities. In late 1953, the United States Atomic Energy Commission (USAEC) indicated that it would offer special price contracts of up to $10.50/lb U_3O_8 which would allow private mining companies to recover the development costs for uranium mills [7]. The first of these special price contracts was awarded in 1954 and resulted in the development of the Gunnar mine and mill in Saskatchewan which began uranium production in September 1955 [5]. This was soon followed by major mine and mill developments in Ontario.

As the private uranium mining industry grew, some of the AECB regulations pertaining to security issues were removed. In 1956, the AECB lifted the restriction on private companies publically disclosing uranium reserves and production, and in 1958, the AECB began allowing private companies to sell limited quantities of uranium directly to friendly countries for research purposes [1]. By 1958, 19 uranium mills (Table 1) were operating in Canada and production peaked at more than 12,239 tonnes of uranium metal (tU) [8].

Table 1: Legacy uranium mine sites with mills in Canada. (Modified from [1, 9])

Mine/Mill Name	Mill Capacity (tonnes/day)	Production Dates	Estimated Tonnes of Tailings
Elliot Lake District, Ontario			
Nordic	3,356	1957-65	12,000,000
Quirke	2,721	1956-61, 1966-90	46,000,000
Can Met	2,721	1957-60	2,600,000
Denison	5,442	1957-92	63,800,000
Milliken Lake	2,721	1958-65	150,000
Lacnor	3,391	1957-60	2,700.000
Panel	2,721	1958-61, 1979-90	16,000,000
Spanish American	1,814	1958-59	450,000
Pronto	1,361	1955-60	2,100,000
Stanleigh	3,300	1958-61, 1983-96	19,950,000
Stanrock	3,300	1958-69	5,750,000
Bancroft Area, Ontario			
Bicroft	1,270	1956-63	2,000,000
Dyno	1,088	1958-60	600,000
Faraday/Madawaska	1,088	1957-64, 1976-82	4,000,000
Beaverlodge, Area, Saskatchewan			
Eldorado	1,814	1953-83	10,000,000
Gunnar	1,814	1955-64	4,400,000
Lorado	680	1957-60	360,000
Northwest Territories			
Port Radium	272	1943-60	907,000
Rayrock	136	1957-59	71,000

The uranium mining boom was short-lived as USAEC, the major purchaser, soon had sufficient quantities of uranium to meet its needs and the Canadian contracts were not extended [2]. Uranium continued to be supplied under contracts with the British government; however these contracts were much smaller. By 1961, only 8 uranium mines/mills remained in operation in Canada [1]. In 1962, the requirement that uranium be sold through Eldorado was lifted, but with decreasing demand, only 4 mines/mills remained in operation by 1965 [4].

Increased demand for uranium in the late 1970s for nuclear power resulted in the reopening of several mines in Ontario and the development of new mines and mills in Saskatchewan. Production reached 12,393 tU by 1988 [8]. However, uranium prices decreased significantly in the 1990s and the last operating Ontario mine/mill closed in 1996. Saskatchewan is now the sole uranium producer in Canada with all current production from the high-grade McArthur River and Cigar Lake mines.

1.2 Regulation of Uranium Mining

The provincial and territorial mining regulations were not very stringent during the 1950s and early 1960s when the legacy uranium mines were in operation. Other than worker protection for radiation and radon gas exposure [3], there were no specific measures in the provincial or territorial regulations during the time that were specific to uranium mining. As with other metal mines, tailings were simply deposited in lakes or depressions and water was not usually treated before discharging to the environment. It was not until the mid-1970s that significant environmental concerns regarding mining, including uranium mining, began to be raised. In response, the AECB introduced regulations covering all aspects of uranium mining, requiring that operating mines be licenced federally and that tailings be managed to protect the environment [4]. In the 1990s, AECB regulations expanded, requiring operating uranium mines to have decommissioning plans backed with financial guarantees in place during their operation [10]. The Canadian Nuclear Safety Commission (CNSC), which succeeded the AECB in 2000, has extended these regulations and requires that all closed uranium mining sites with tailings be licensed.

1.3 Canada's Radioactive Waste Policy Framework

During the 1970s, concerns regarding radioactive waste began being raised as well as concerns on nuclear safety and the effects of radiation. In the 1980s, the federal government recognized that long-term management solutions for radioactive wastes would be required to ensure that the health of people and the environment continues to be protected. However, in some circumstances, progress on radioactive waste management solutions was being held up because of a lack of certainty on roles and responsibilities. Particular examples related to responsibilities for long-term management of nuclear fuel waste, historic waste, and potentially abandoned uranium mine and mill tailings [11].

In 1996, after conducting public consultations across Canada, the Government of Canada developed a comprehensive Radioactive Waste Policy Framework which clarified the institutional and financial arrangements required for the effective management of radioactive waste by waste producers and owners, with the following set of principles [11]:

- *The federal government will ensure that radioactive waste disposal is carried out in a safe, environmentally sound, comprehensive, cost-effective and integrated manner.*

- *The federal government has the responsibility to develop policy, to regulate, and to oversee producers and owners to ensure that they comply with legal requirements and meet their funding and operational responsibilities in accordance with approved waste disposal plans.*

- *The waste producers and owners are responsible, in accordance with the principle of "polluter pays", for the funding, organization, management and operation of disposal and other facilities required for their wastes. This recognizes that arrangements may be different for nuclear fuel waste, low-level radioactive waste and uranium mine and mill tailings.*

Under the Policy Framework, the responsibility for legacy uranium mines was made clear. For most legacy uranium mines, mining leases had not expired and the mining companies or their successors (i.e Rio Algom, Denison, Canada Eldor) are the owners of the wastes on those sites. The mining leases for the Port Radium mine and the Rayrock mine in the Northwest Territories expired and the federal government has become the owner of the wastes and was responsible for their remediation. Similarly, Saskatchewan has become the owner of wastes from legacy sites where provincial mining leases expired and the private companies that operated the sites no longer exist (i.e. Gunnar, Lorado). The federal government has entered into agreements with Ontario and Saskatchewan to assist with the decommissioning of sites for which the private operator either no longer exists or is unable to provide funding. In the case of Ontario, the private companies have been able to fund the decommissioning and implementation of the agreement has not been required. In Saskatchewan, an agreement provides funds to assist the province with the remediation of the Gunnar mine site.

2. Risks Associated with Legacy Uranium Mine Sites.

It is important to note, that the risks posed by most of the legacy uranium mine sites are very low. Ore grades mined at the time were usually less than 0.2%U [1] and the tailings and waste rock therefore have relatively low specific activity compared to modern mines where ore grades can approach 20%U. Many of the legacy sites are remote, limiting exposure to the public, and the remediation activities that have been implemented at most of the sites to date are sufficient to protect the public and environment.

Uranium mining operations are not substantially different from other metal mining operations that produce tailings. All tailings contain certain elements which could have adverse environmental effects if not managed properly. Thus, the methods for the management of uranium tailings are similar to those used for other mines. However, since uranium mine tailings have higher levels of radionuclides, management of radiation and radon emissions must also be considered [12]. These concepts are often not well understood by the public and it is therefore important to clearly communicate to the public the small risk posed by uranium tailings under reasonable exposure scenarios. For example, after public consultation, a site-specific gamma radiation criterion of 2.5μSv/h was accepted in 2005 for the remediation of the Port Radium mine site [13], rather than a generic objective of 1.0 μSv/h (above the upper range of background averaged over a 1 hectare area) which was used for decommissioning the Cluff Lake mine. Port Radium is remote, with limited access, and it is unlikely that any visitors would occupy the site long enough to exceed an annual dose limit of 1 mSv/a.

For Canadian legacy uranium mines, it is unlikely that extensive remediation efforts could significantly improve environmental conditions. The peak flow of contaminates from these sites occurred during their operation (i.e. discharge water) and the most easily leachable contaminants would have been removed during the first decade after mine closure [14, 15]. Over the last 50 years, these sites have been in a steady state and contaminants have dissipated over a wide area through the groundwater, making complete remediation difficult. Other than applying covers to reduce radiation exposure, treating discharging groundwater and addressing physical hazards at these sites, there is often very little else that can be done that will result in an appreciable improvement in site conditions beyond their current state. A large remediation effort could in fact, have adverse effects, such as increased mobility of contaminants due to disturbance of wastes or to changes in the water table, after steady-state conditions become unbalanced.

It is also important to understand the goal of remediation. It is not to return a mine site to its pre-mining condition, as that is not usually achievable. For many sites, lakes may have been completely or partially filled with tailings and it is not practical to restore the lake to its original condition. An unnecessarily large remediation project may increase the footprint of the disturbed area, especially if large volumes of materials will be required from off-site. It is more feasible and cost-effective to remediate a site to create a landscape that is compatible with the surrounding environment, which for most sites in Canada, would include lakes, rocky terrain and areas which could naturally vegetate.

3. The Importance of Cost-effective Remediation Plans

A key principle of the Radioactive Waste Policy Framework is that wastes should be managed in a cost-effective manner. Whether remediation is to be funded by a private company or by government, cost is a significant factor for any project. Ultimately tax payers are responsible for legacy remediation work that must be funded by governments and shareholders are responsible for private-sector remediation work. The cost of decommissioning and remediation is a consideration when determining the economic feasibility of a new mine, since the company is required to provide a financial security for those costs. As a result, modern mines are designed and operated so that remediation costs are minimized using methods such as treating wastes when they are generated or recycling process water. For legacy uranium mines, the costs of complying with today's regulatory requirements were not considered when they were developed and operated.

The inclusion of the consideration of costs in the Radioactive Waste Policy Framework is consistent with the "graded approach" for decommissioning which is encouraged by the IAEA [16]. In the graded approach, the remedial work conducted and the regulatory control applied should be commensurate with the risks posed by the site. This approach has been adopted by most of the world's nuclear regulators, including the CNSC. In the graded approach, efforts are directed to those areas which present the highest risk from a dose perspective. It also recognizes that eliminating all risks is not usually feasible and that managing risks should be a key goal.

Cost-benefit analysis is an important tool for developing a suitable remediation option. The cost and benefits of all potential remediation options need to be compared to leaving the site in its current state so that the analysis can be assessed on an incremental basis [12]. It is also important that the remediation criteria used are appropriate for the site. Generic criteria are by their nature, conservative, and site-specific criteria, supported by risk analysis, are successfully used to develop more cost-effective remediation plans. It should be noted that "As Low As Reasonably Achievable" (ALARA), allows for the consideration of economics factors, and if an option is not cost-effective, it is unlikely to be considered reasonably achievable, especially if the additional cost would be substantial.

4. Remediation of Legacy Uranium Mine Sites

4.1 Costs for Remediating Legacy Uranium Mines

Most of Canada's legacy uranium mine sites have now been successfully remediated, and provide an indication of the relative costs to be expected for remediating legacy sites. The main factor in the cost of remediating these sites is the amount of tailings, as the cost of decommissioning of buildings and other structures is similar for each site. Table 2 indicates that on a per unit cost basis (2016 Canadian dollars), costs of remediation, including the decommissioning of buildings and other structures, ranged from \$1.06 on a per tonne of tailings basis for mine/mill sites in Elliot Lake, to \$3.30 on a per tonne of tailings basis for the Beaverlodge (Eldorado) mine/mill sites. This is comparable to costs for remediating other metal mine sites containing tailings. For example, in 1995, it was estimated that the cost to remediate acid-generating tailings in Canada (not including decommissioning of buildings) would be between \$0.80 – \$1.70 per tonne of tailings (\$1.19 - \$2.50 in current Canadian dollars), although remediation costs are site specific [17], with unit costs for small and remote sites being higher.

Table 2. Total decommissioning and remediation costs for legacy uranium mine facilities in Canada (buildings, waste rock and tailings). Modified from [12].

Site, Closing Date	**Tailings millions of tonnes**	**Total Cost, 2016 Canadian Dollars**	**Unit Cost $/tonne**
Northern Saskatchewan			
Beaverlodge (Eldorado), 1985	10,000,000	$33,000,000	$3.30
Elliot Lake, Ontario			
Denison, 1999	*63,800,000*	*$54,000,000*	*$0.85*
Panel, 1999	*16,000,000*	*$21,000,000*	*$1.31*
Quirke, 1999	*46,000,000*	*$35,000,000*	*$0.76*
Stanleigh,1999	*19,950,000*	*$28,000,000*	*$1.40*
Stanrock, 1999	*5,750,000*	*$22,000,000*	*$3.83*
Elliot Lake Total	151,500,000	$160,000,000	$1.06

4.2 Remediation of the Beaverlodge Mine and Mill Sites

The Beaverlodge operation, near Uranium City, Saskatchewan, included several mines and a milling facility. It was operated by Eldorado Nuclear Ltd. a federal Crown corporation between 1952 and 1983. Beaverlodge was the first uranium mining facility in Canada to be closed with an approved decommissioning plan, with work completed in 1985 [18].

It has been more than 30 years since the closure of the Beaverlodge sites and ongoing monitoring has shown that the environment has improved as predicted and most water quality objectives have been met [18]. The site is currently managed by Cameco Corporation on behalf of Canada Eldor Inc. a subsidiary of the federal Crown corporation, Canada Development Investment Corporation. Canada Eldor is responsible for the federal government's financial liabilities related to sites that were operated by Eldorado Nuclear Limited.

The current objective for managing the Beaverlodge sites is to sufficiently address the remaining site risks so that the properties can be returned to the province under Saskatchewan's Institutional Control program [19]. In 2009, efforts began to develop and assess options to address the remaining risks at the sites. Various remediation options were developed and costed and workshops held with stakeholders, including representatives from local Indigenous communities to select the preferred options. Consensus was reached that the options chosen "needed to be reasonable and realistic from a cost perspective in relation to the predicted benefit" [19]. It was recognized that recovery of the environment will occur over a long-term and that cost effective approaches were appropriate for the site.

The resulting remedial plan for Beaverlodge includes low-cost activities, such as sealing flowing boreholes and diverting water flow, which are predicted to provide significant environmental benefits [20]. Cameco is following the IAEA graded approach to remediation as the options chosen will reduce risk, provide an environmental benefit which is commensurate with the cost, and are technically feasible. High-cost options, such as building a water treatment plant, were deemed not to be reasonable or cost-effective when improvements are predicted to occur naturally over the long term under current site conditions. Many stakeholders also agreed that covering waste rock piles was not justified "due to the minimal benefit achieved, the lack of borrow material in the area and the high cost" [19].

The experience from Beaverlodge clearly demonstrates that most stakeholders support the use of cost-effective remediation approaches and accept that significant environment improvements at legacy sites will occur over the long term.

4.3 Remediation of the Elliot Lake Mine and Mill Sites

Between 1958 and 1984, Elliot Lake, Ontario was Canada's largest uranium producing district. However, as a result of lower uranium prices and the development of higher grade mines in Saskatchewan, the last of the 11 mines and 10 mills developed in Elliot Lake closed in 1996.

The Elliot Lake sites were decommissioned in the 1990s under plans that were approved by the AECB, the forerunner of the Canadian Nuclear Safety Commission (CNSC). The long-term care and maintenance of the sites are the responsibility of Rio Algom and Denison Mines Inc. who operated the mines.

During the planning of decommissioning in the 1990s, several options were considered for addressing the tailings areas. Of particular concern was acid generation of the tailings which often posed a greater environmental risk than the radiological hazards. Potential options for the Denison Mines sites, which included soil cover, water cover, removal of tailings, or raising the water table within the tailings, were evaluated on the basis of environmental, economic and social impacts [21]. Complete removal of tailings was eliminated by Denison as a viable option due to excessive costs, feasibility and environmental concerns [21].

For most of the Elliot Lake sites, water cover was chosen for decommissioning tailings areas. Water cover was relatively easy to construct at most sites and it virtually eliminates acid generation as well as radiation and radon emissions [21]. In addition, water cover is an effective barrier to intrusion and can be maintained easily at low cost. Additional land would not be disturbed and water cover is compatible with the pre-mining conditions in the area. For sites in which water cover was not practical, soil cover, and/or raising the water table to reduce acid generation were the methods used.

Implementation of the decommissioning plans for the Elliot Lake sites has required the construction and maintenance of containment dams and water treatment facilities. Monitoring has shown that the approach has been highly successful, with noticeable improvements in water quality in the tailings management areas. Water discharging from the sites is currently meeting provincial drinking water quality objectives for nearly all parameters [22].

The Elliot Lake sites contain about 80% of Canada's uranium tailings. Remediation activities have been highly successful and the improvement in water quality has exceeded expectations to date. Although water treatment will be required for several decades, the approach has been very cost-effective, with per unit costs similar to those for other metal mines. Furthermore, the sites continue to be monitored and maintained at a reasonable cost. Water quality continues to improve and the requirements for water treatment are reducing.

5. Conclusions

Canada's legacy uranium mines were developed and operated in the 1950s and the 1960s when environmental regulations applied to mining activities were not as stringent as they are today. Fortunately, the ore was very low grade and, the sites do not currently pose a significant risk. However, the mining practices used at the time would not be considered acceptable today and there is a need to ensure these sites are being managed properly, especially in the context of gaining public support for the development of new uranium mines.

Canada's Radioactive Waste Policy Framework requires that owners responsibly manage their wastes. This has been largely achieved through the regulatory process in which the waste owners are responsible for developing decommissioning plans and for providing financial guarantees to fund those plans. In 2000, the CNSC began requiring that all former uranium mine sites be licensed and be remediated, if necessary, to reduce environmental and human health risks.

Consistent with the IAEA graded approach to remediation, costs should be a consideration when managing legacy uranium mine sites. Owners are expected to address risks in a cost-effective manner; they are not expected to go beyond what is reasonably achievable. In response, owners of legacy uranium mine sites have developed and successfully carried out cost-effective remediation plans which meet regulatory requirements. Experience from the legacy sites that have been remediated to date has shown that costs for remediating need not be excessive, and should be similar to the cost of remediating other metal mines of comparable size.

6. References

[1] J.W. Griffith, The Uranium Industry – Its History, Technology and Prospects", Mineral Report 12, Mineral Resources Division, Department of Energy, Mines and Resources, Ottawa, Ontario Canada, 1967, 335p.

[2] O.J.C. Runnalls, Ontario's Uranium Mining Industry – Past, Present and Future, Mineral Ontario Mineral Policy Background Paper No. 13, Ontario Ministry of Natural Resources, Toronto, Ontario Canada, 1981, 182p.

[3] R.M. Duncan, "The Atomic Energy Control Board and the uranium mining industry", Proceedings of the 79th Annual General Meeting of the Canadian Institute of Mining and Metallurgy, Ottawa, Ontario, Canada, 1977, April 20.

[4] G.H.E. Simms, A History of the Atomic Energy Control Board, Minister of Supply and Services, Hull, Quebec, Canada, 1981, 223p

[5] R. Bothwell, Eldorado, Canada's National Uranium Company, University of Toronto Press, Toronto, Ontario, Canada, 1984, 515p.

[6] Atomic Energy Control Board, Second Annual Report of the Atomic Energy Control Board of Canada, 1947-48, Atomic Energy Control Board, Ottawa, Ontario, Canada, 1948, 16p.

[7] D.A. Cranstone and R.T. Whillans, "An analysis of uranium discovery in Canada. 1930-1983", Uranium Resources and Geology of North America, Technical Document 500, International Atomic Energy Agency, Vienna, Austria, 1989, pp. 29-48

[8] Nuclear Energy Agency, Forty Years of Uranium Resources, Production and Demand in Perspective, Organisation for Economic Co-operation and Development, Paris, France, 2006, 276p.

[9] Low-Level Radioactive Waste Management Office, Inventory of Radioactive Waste in Canada, Low-Level Radioactive Waste Management Office, Ottawa, Ontario, Canada, 2012, 47p.

[10] J.N. Douglas, Evaluation of Assurance Alternatives of Licensees. Atomic Energy Control Board, Ottawa, Ontario, Canada, 1995, 79p

[11] P. Brown, "The nuclear fuel cycle, radioactive waste and Canadian policy", Public Confidence in the Management of Radioactive Waste: The Canadian Context, Workshop Proceedings, Ottawa, Canada, 14-18 October, 2002, Nuclear Energy Agency, Organisation for Economic Co-operation and Development, Paris, France, 2003, pp 37-41.

[12] OECD/NEA- IAEA, Environmental Remediation of Uranium Production Facilities, Organisation for Economic Co-operation and Development, Nuclear Energy Agency, Paris, France, 2002, 323p

[13] G.M. Wiatzka and C.F. Gravelle, "Northern mine decommissioning – case study of remedial works for closure of Port Radium, Canada's original uranium mine", Proceedings of Waste Manage 2010 Conference, 2010 March 7–11, Phoenix, Arizona, USA.

[14] R. Laliberte, I. Ludgate, and R. Knapp, "Denison Mines - 10 years after closure," Proceedings of Mining and the Environment III, Sudbury, Ontario, Canada, 2003 May 25-28.

[15] M. Wiber, A. Coggan, R. Mansell, and R. Knapp, "Fifty years environmental record at Elliot Lake, Ontario Canada", Waste Management Decommissioning and Environmental Restoration for Canada´s Nuclear Activities: Current Practices and Future Needs, Ottawa, Ontario, Canada, 2005 May 8–11.

[16] IAEA, Use of a Graded Approach in the Application of the Management System Requirements for Facilities and Activities, TECDOC-1740. International Atomic Energy Agency, Vienna, Austria, 2014, 90p.

[17] GEOCON, Economic Evaluation of Acid Mine Drainage Technologies, Mine Environment Neutral Drainage (MEND) Report 5.8.1, 1995, 71p.

[18] K. Himbeault, R.L.J. Phillips, P. Vanriel, K. Wells, and B.E. Halbert, "Decommissioning and reclamation of the Beaverlodge uranium mine/mill operation: ecosystem in recovery", Waste Management Decommissioning and Environmental Restoration for Canada´s Nuclear Activities: Current Practices and Future Needs, Ottawa, Ontario, Canada, 2005 May 8–11.

[19] Cameco Corporation, Beaverlodge Mine Site Path Forward Report, Cameco Corporation, Saskatoon, Saskatchewan, Canada, 2012, 254p

[20] M. Webster and D. Hockley "Stakeholder engagement and additional remediation of the decommissioned Beaverlodge uranium mine site". British Columbia Mine Reclamation Symposium, Vancouver, British Columbia, Canada, 2013 September 16-19..

[21] I. Ludgate, P. Primeau, R. Laliberte, R. Pedlar, "The decommissioning of the Denison uranium facilities in Elliot Lake", Waste Management Decommissioning and Environmental Restoration for Canada´s Nuclear Activities: Current Practices and Future Needs, Ottawa, Ontario, Canada, 2005 May 8–11.

[22] Canadian Nuclear Safety Commission, History of uranium mining in the Elliot Lake region of Ontario and associated effects on water quality and fish intended for human consumption. Canadian Nuclear Safety Commission, Ottawa, Ontario, Canada, 2015, 32p.