BALANCING RISK: SITE REMEDIATION OUTSIDE THE ENVIRONMENTAL ASSESSMENT

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ABSTRACT

In Canada, an environmental assessment (EA) is typically required for physical works or physical activities that are to be undertaken at a given site, such as those that would be required when performing environmental remediation at an abandoned mine site. In general, the type of EA required under the Canadian Environmental Assessment Act (CEAA) tends to be commensurate with risk, whereby a comprehensive study is required for projects with the potential to cause significant adverse environmental effects.

Remediation of the Gunnar Mine Site, an abandoned uranium mine/mill in Northern Saskatchewan, is currently undergoing a comprehensive EA to develop plans for the sustainable remediation of the Gunnar pit, two waste rock piles, three areas of unconfined tailings and the mine site itself. The site was abandoned in 1964, with little to no remediation. As a result, buildings and structures present on the site deteriorated over time due to scavenging of building materials that had taken place and exposure to the harsh northern conditions.

To address the risks associated with buildings and structures in a timely manner, on July 23, 2010, the Canadian Nuclear Safety Commission (CNSC) issued an Order to address those that have failed a structural safety assessment to be taken down by no later than October 31, 2011 (prior to approval of the Gunnar EA). To accomplish this, it was necessary for the Saskatchewan Research Council (SRC) to plan the work in a safe and cost-effective manner, with consideration of both the short-term mitigative measures required under the Order and the long-term end-state of the Gunnar Mine Site following remediation. Work is proceeding on budget and ahead of schedule on the abatement and demolition of buildings and structures at Gunnar. An overview of the considerations taken, the project accomplishments and the lessons learned will be provided.

1 BACKGROUND INFORMATION

Uranium was first discovered in Canada on the north shore of Lake Superior in the mid-1800s, with Canada's first economic uranium discovery at Port Radium in Great Bear Lake, NWT. Subsequently, in the late 1940s, important uranium discoveries were made in the Uranium City area of northern Saskatchewan, and in the Elliot Lake area of northern Ontario during the early 1950s [1].

Until the early 1980s, most of Canada's uranium production came primarily from the Gunnar, Lorado, and Beaverlodge mining and milling sites near Uranium City, and at the Elliot Lake Mine in Ontario. Following depletion of ore supplies, uranium mines are typically closed. The Gunnar and Lorado mines/mills were closed in the mid-1960s, and the Beaverlodge Mine was closed in 1983. By 1996, the Elliot Lake Mine was also closed, and the Athabasca Basin in northern Saskatchewan became the sole region of uranium production in Canada, with uranium contents in the local ore bodies ranging from approximately 0.5% to over 20% (Figure 1).

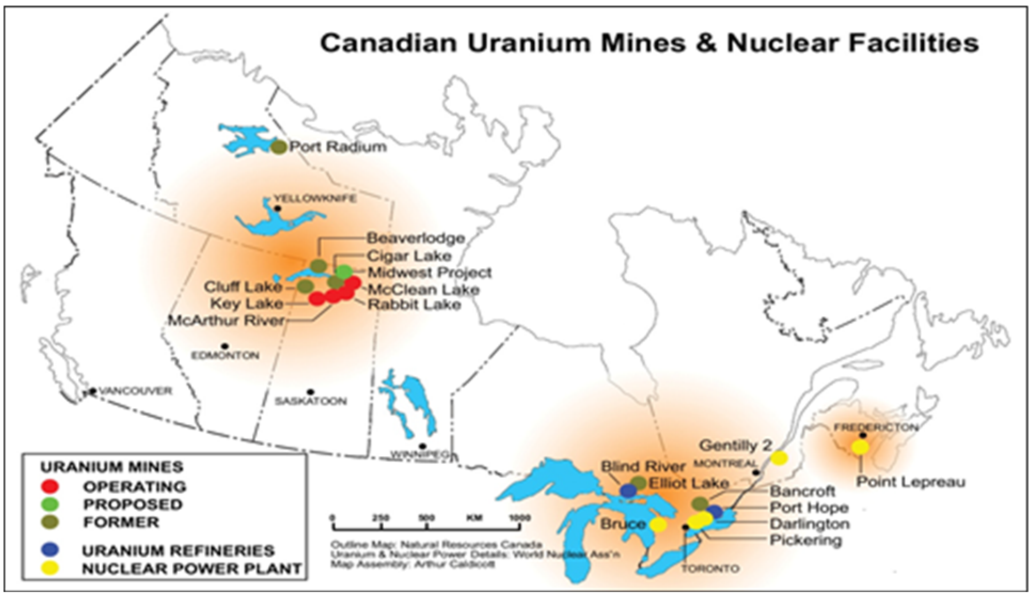

Figure 1. Main Canadian uranium mine sites and nuclear facilities (after [2]).

Nowadays, mine closure is strictly regulated, although many of the older mines have not been decommissioned properly and were abandoned without remediation. For example, although current uranium mining/milling practices are focused on proactive management to ensure environmental protection through control of process, monitoring and adaptive improvement of processes, in the past, regulatory practices were not carried out in accordance with today's regulatory standards, creating a number of legacy sites that require remediation. These include a number of abandoned mine sites in the vicinity of Uranium City, SK that are primarily distributed across an area of some hundreds of square kilometers around Uranium City, and include the Gunnar Mine/Mill Site, the Lorado Mill Site and thirty-six "satellite" mine sites that fed the mills at Gunnar and Lorado with uranium ore (Figure 2). These uranium mines and mills operated from 1953 to 1964, during which more than 6 million tons of ore was processed at the Gunnar and Lorado mills. The rehabilitation of these sites is being conducted under Project CLEANS (Cleanup of Abandoned Northern Sites) (http://www.saskcleans.ca).

Figure2. Project CLEANS site locations

Project CLEANS is a multi-year project to assess and reclaim the abandoned uranium mines/mills in northern Saskatchewan. The Saskatchewan Research Council (SRC) is managing the remediation of these sites on behalf of the Governments of Saskatchewan and Canada, and is communicating regularly with governmental agencies on the Federal, Provincial, and local levels, as well as with resident communities. The objectives of the project are: to eliminate or reduce public safety hazards and environmental risks at each site now and in the future; to develop sustainable remediation options that are technically and economically feasible; and to establish a responsible and cost-effective environmental monitoring program, while minimizing the long-term care and maintenance at the sites. Project endpoints (or desired outcomes of the remediation efforts) are as follows:

- The site does not pose public health or environmental risks;
- Flora and fauna adjacent to and within the site are not significantly impacted by contaminants;
- Traditional use of resources adjacent to and within the site can be safely conducted; and
- The desire is to have the site managed through the institutional controls program for long-term care and maintenance.

To accomplish this, key components of the remediation have been identified to include: the demolition of buildings and structures that have deteriorated since mine closure in the mid-1960s (Gunnar); rehabilitation of the Gunnar pit, which contains approximately 3 million m^3 of water exceeding surface water quality objectives for uranium and radium-226 (Ra-226); remediation of waste rock piles containing ore fragments and a heterogeneous distribution of contaminants (Gunnar); and establishment of engineered covers on unconfined tailings that are terrestrial and partially submerged in nearby lakes (Gunnar and Lorado). The gamma dose rates on the tailings and waste rock surfaces vary from approximately 2 to 15 μSv/h, and will ultimately be contoured and shielded through the establishment of engineered vegetative covers. The key contaminants of potential concern (COPCs) at the sites are uranium and its progenies, with minimal contributions from selenium and arsenic.

The current paper is focused on the status of the clean-up of the Gunnar Mine/Mill Site, highlighting remediation efforts in the context of short- and long-term protection goals.

2 PROJECT HISTORY

The Gunnar uranium mining and milling site (Gunnar Mine Site), which is located on the north shore of Lake Athabasca in northern Saskatchewan, ceased mining operations in 1963 [3]. The site had been operated by the former Gunnar Mining Limited and had commenced uranium production in 1955. Uranium ore was initially mined from an open pit from 1955 to 1961, and later, from an underground operation between 1957 and 1963. The Gunnar Mine Site officially closed in 1964, with little or no decommissioning of facilities. At the time, a channel was blasted between Gunnar Pit and Lake Athabasca to allow flooding of the open pit and sub-surface workings, the shaft was plugged with concrete, and the mine site abandoned, with all buildings, tailings, and waste rock piles left on site "as is" (Figure 3) [4].

Figure 3. Gunnar pit and headframe shaft. Left panel: 1963; Right panel: 2009

Uranium ore originating from the open pit and sub-surface mines at Gunnar was generated from a total of over 8.5 million tons of rock that had been mined and processed. This resulted in some 2.2 to 2.7 million m^3 of waste rock and over 5 million tons of unconfined tailings that were directed to nearby valleys, depressions, and lakes, covering a total of over 70 ha of land (Figure 4).

In the late 1980s, Saskatchewan Environment and Public Safety established the Abandoned Mines Remedial Action Program [5-6]. Abandoned mines were identified, including those in the vicinity of Uranium City, and some remediation work was performed. Currently, stricter environmental regulations, compared to what had been acceptable using past practices make it necessary to revisit these sites to perform additional remediation and cleanup.

In 2006, SRC was requested to manage the clean-up of the Gunnar Mine Site on behalf of the Governments of Canada and Saskatchewan.

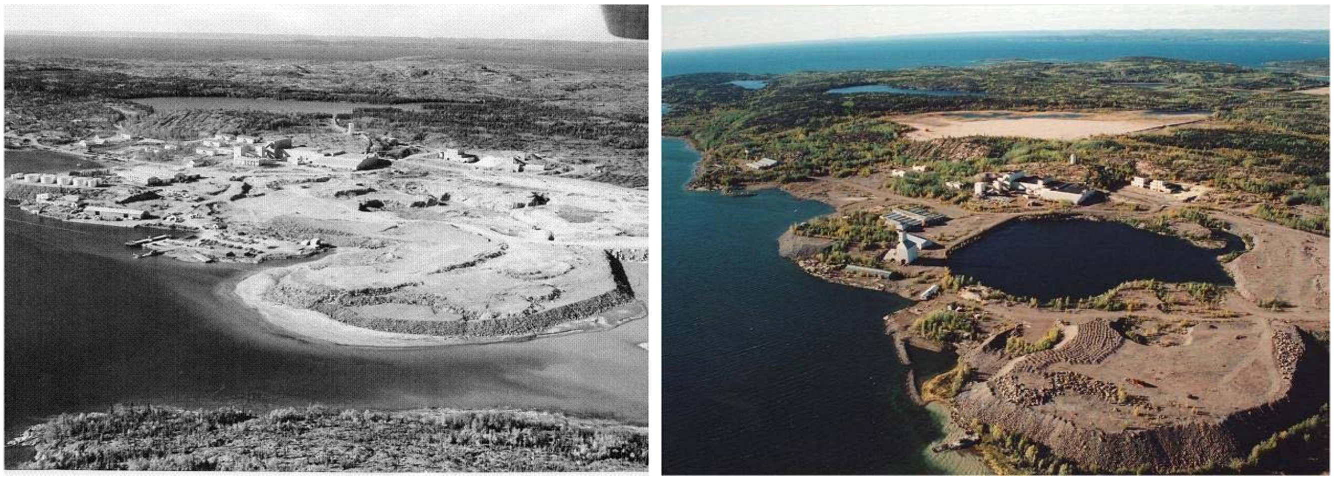

Figure 4. Gunnar Mine Site. Left panel: Gunnar Site in progress during 1955 (with no headframe yet); Right panel: Abandoned Gunnar Site in 2009

3 CURRENT STATUS

The remediation of the Gunnar Mine Site is being undertaken to address short-term, relatively high risk situations, while ensuring that sustainable remediation solutions can be implemented in the longer term to address relatively lower risk concerns in a sustainable way.

Potential hazards to humans, plants and animals, and the natural environment from existing conditions on the Gunnar Mine Site fall into four fundamental categories: physical hazards (such as those associated with the buildings and structures); chemical hazards (both associated with the buildings and structures on the Mine/Mill Site and as releases to the receiving environment); radiological hazards (from the buildings and structures, as well as in the receiving environment); and biological hazards (including those associated with the buildings and structures, as well as wildlife). These hazard categories can be addressed in the context of four key components on the Gunnar Site, which include: (i) the hazards to the public associated with remaining buildings and structures; (ii) the waste rock piles; (iii) the unconfined tailings deposits; and (iv) the flooded pit. Of these items, it has been determined that the physical hazards pose the highest risk (or probability of impact), followed by the chemical hazards and radiological hazards, respectively [7]. Biological risk can be addressed through use of personal protective equipment (PPE) as the work is conducted, along with measures taken during work planning.

Evaluation of these hazards and remediation of the Site to address them is discussed in the context of short- and long-term mitigation of risk in the sections that follow.

3.1 Short-term Remediation Efforts

In Canada, an environmental assessment (EA) is typically required for physical works or physical activities that are to be undertaken at a given site to address risk, such as those that would be required when performing environmental remediation at an abandoned mine site. In general, the type of EA required under the Canadian Environmental Assessment Act (CEAA) tends to be commensurate with risk, whereby a comprehensive study is required for projects with the potential to cause significant adverse environmental effects. Remediation of the Gunnar Mine Site requires a comprehensive study review under the CEAA.

In 2010, the Canadian Nuclear Safety Commission (CNSC) deemed that the relatively high risks associated with the buildings and structures on the Gunnar Site, which have been deteriorating since the mid-1960s when the Site closed, require mitigation in the short term to ensure Public safety. Deterioration occurred due to scavenging of building materials that had taken place and exposure to the harsh northern conditions. To address the risks associated with buildings and structures in a timely manner, on July 23, 2010, the Canadian Nuclear Safety Commission (CNSC) issued an Order to take down those that have failed a structural safety assessment by no later than October 31, 2011 (prior to approval of the Gunnar EA). Abatement and demolition of buildings and structures was, therefore, undertaken in parallel with finalization of the EA for the Gunnar Mine Site and is being managed outside the EA process. In doing so, work is being planned and conducted in a safe and cost-effective manner, with consideration of both the short-term mitigative measures required under the Order and the long-term end-state of the Gunnar Mine Site following remediation.

3.1.1 Abatement and Demolition of Buildings and Structures

Buildings and structures on the Gunnar site that have been taken down in compliance with the CNSC Order included the headframe, collar house and bin house, which supported the underground workings, uranium mill and associated industrial complex, acid plants, storage area with residual elemental sulfur, maintenance warehouse, acid tanks, water tanks, and other industrial, office, and residential buildings (Figures 5-7). The headframe and mill were contaminated by radioactive materials, with a gamma dose rate at some localities in the buildings reaching up to 10 μSv/h [8-9]. Many of the buildings and structures contained various types of asbestos, including its friable and non-friable forms, and measures had to be taken to protect workers from the associated inhalation risks. SRC directly hired an asbestos expert to provide oversight during the work due to the relatively high asbestos-related risks on the job. Protection of workers from inhalation risks associated with friable asbestos also provided protection from inhalation of radioactive particulates. In addition, recent surveys found the presence of relatively small quantities of hazardous materials and substances (hazmats), including PCBs, elemental sulfur, carbon tetrachloride (CCl_4) and others [8]. These are to be transported off-site for disposal in an approved disposal facility.

Figure 5. Before (left panel) and after (right panel) photos of the wooden structures following remediation efforts in 2010 at the Gunnar Mine Site.

Figure 6. Before (left panel) and after (right panel) photos of the demolition of the Gunnar Mill Complex following remediation efforts in 2011 at the Gunnar Mine Site.

Prior to initiation of abatement and demolition of the buildings and structures on the Gunnar Mine Site, a structural safety assessment was conducted to identify associated risks and hazards that required consideration during work planning [10]. In addition, it was necessary to develop detailed safe work plans, including: An Occupational Health and Safety (OH&S) plan [7]; a hazardous substances and materials inventory [8]; a demolition plan [9]; and a waste management plan [11], which are available on the Project CLEANS web-site. Establishment of barriers [12-13], removal of overhead and other hazards [14], securing of the hazmats [15] and securing of the site itself were also carried out to ensure public safety under the Order.

Figure 7. Before (left panel) and after (right panels) photos of the demolition of the Gunnar Headframe following remediation efforts in 2011 at the Gunnar Mine Site.

3.2 Long-term Remediation Efforts

Long-term remediation of the Gunnar Mine Site is being planned through the preparation of a comprehensive study review. As discussed above, remediation of the buildings and structures has been undertaken under a CNSC Order, whereas remediation of the demolition debris, waste rock, tailings and pit are being addressed through the EA process.

3.2.1 Waste Rock Piles

The total volume of waste rock present at the Gunnar Mine Site is estimated to be 2.2 to 2.7 million m^3, covering an area of approximately 10 Ha [4]. The waste rock consists of two partly separated piles, including the south pile located along the shoreline of Lake Athabasca (known as the 'South Waste Rock Pile'), and the 'East Waste Rock Pile' to the northeast. The waste rock piles include mine waste rock and overburden generated from surface stripping of the open pit. The more westerly of the two major lobes of the South Waste Rock Pile appears to extend well into Zeemel Bay of Lake Athabasca. The waste rock contains heterogeneous inclusions of uranium ore, with a gamma dose rate on the waste rock piles that varies from 0.5 to 3 µSv/h on average, and maximum values of up to 10 µSv/h. By comparison, an average radiological (gamma) closure criterion of 1 µSv/h averaged over a 10,000 m^2 (1 ha) area at 1 m above the ground surface, with a maximum criterion of 2.5 µSv/h, being proposed, based on those developed by AREVA Resources Canada for Cluff Lake.

A number of active surface seepage areas have been found around the bases of the two waste rock piles, with elevated uranium levels that cannot be accounted for by contributions of uranium from areas upgradient of the piles. Depending upon the location of these seepages, contaminants, including uranium and Ra-226, are being released to Athabasca Lake via Zeemel Bay, as well as directly into Lake Athabasca itself, with possible groundwater seeps that drain directly into the lakebed [4]. For example, the Zeemel Bay seepage area, which flows continuously into the bay, contains elevated uranium concentrations of 9,000 µg/L (on average) that exceed the Saskatchewan Surface Water Quality Objective (SSWQO) of 15 µg/L. Elevated levels of uranium progenies (such as Ra-226, which exceeds the WQO of 0.11 Bq/L by approximately an order of magnitude), lead, and selenium are also released into the lake via the seeps. Conservative estimates of contaminant load to the lake from the Zeemel Bay Seep are listed in Table 1. Additional contaminant loads are being contributed to the receiving environment through seepage areas at a number of locations along the bases of the two waste rock piles on the Gunnar Mine Site.

Table 1. Estimated load to the Lake Athabasca via the Zeemel Bay Seep.

		Estimated Load (kg/yr)						
Parameter	**Measurement**	**U**	**Pb**	**Se**	**Ra-226**	**Th-230**	**Po-210**	**Pb-210**
Estimated load	Minimum	$1.4\cdot10^3$	0.57	1.85	$1.4\cdot10^8$	$4.5\cdot10^7$	$3.2\cdot10^7$	$5.7\cdot10^7$
	Maximum	$2.8\cdot10^3$	1.1	3.65	$2.7\cdot10^8$	$8.8\cdot10^7$	$6.3\cdot10^7$	$1.1\cdot10^7$

The relatively high concentrations of uranium and its progenies in the Zeemel Bay Seep are likely due to leaching from localized uranium ore inclusions that have been exposed on waste rock surfaces, although waste rock-to-water partition coefficients ($K_{D\ (waste\ rock/\ water)}$) are expected to vary widely over orders of magnitude due to different solubilities of radionuclides (Table 2). In addition, contaminated debris, which has been placed on the top of the East Pile, could be leaching and contributing to contaminant seepage into Lake Athabasca.

The remediation options being considered to address the waste rock include covering the piles in place, or relocating the waste rock to an engineered, lined landfill, to the Gunnar Main tailings area, or into the Gunnar Pit (following dewatering of the pit). As part of the remediation, clean water from the upstream watershed will be diverted away from the waste rock piles.

Table 2. Site-specific K_D estimates for Gunnar waste rock and seep*

Contaminant	Waste Rock (per unit dry weight) (mg/kg or Bq/kg)	Seep Water (mg/L or Bq/L)	Site-specific K_D Values Gunnar (L/kg)
Uranium	432	10.1	43
^{230}Th	11,000	0.32	34,900
^{226}Ra	6,900	0.96	7,190
^{210}Po	6,900	0.23	30,700
^{210}Pb	6,800	0.40	17,000

*$K_D = (C_{solid\ phase} / C_{liquid\ phase})$

3.2.2 Unconfined Tailings

During past operations of the Gunnar Site, the mill tailings were discharged from the Mill as a pulp into a small lake located approximately 500 m to the north of the Mill. This area is currently referred to as the Gunnar Main tailings. The basin eventually filled with tailings solids and a small, rocky outcrop was blasted to allow the tailings to flow from the Gunnar Main area to a small depression referred to as the Gunnar Central Tailings. Once this relatively small basin was filled, the tailings continued to flow downhill, eventually entering Langley Bay of Lake Athabasca (Figure 8, left panel).

In total, over 4.4 million tons of tailings (3.3 million m^3) were released to the environment and left unconfined (Figure 8, right panel). The tailings contain residual uranium with progenies (Table 3) and have a gamma dose rate that varies from 5 to 15 µSv/h (1 m above the surface). Contaminants that are present in the tailings are being geochemically transported from the Gunnar Main tailings to Langley Bay in Athabasca Lake, approximately 3 km north of the Gunnar Mine Site.

Work is underway to develop site-specific revegetation technologies that can ultimately be applied in the establishment of engineered covers on the Gunnar Site. In addition, detailed work is being planned to develop engineered designs for the covers.

Figure 8. Overview of Gunnar unconfined tailings areas (left panel) and photo of wind blow at the surface of the Gunnar Main tailings (right panel) in 2008.

Table3. Chemical Characteristics of Gunnar Main Tailings Deposit

Fraction	Percent of total by dry weight	Sulphate, water soluble (µg/g)	^{210}Po (Bq/g)	^{230}Th (Bq/g)	^{226}Ra (Bq/g)	^{210}Pb (Bq/g)	Uranium (µg/g)	Selenium (µg/g)	Lead (µg/g)	Arsenic (µg/g)
>500 µm	12%	133,000	21	20	28	29	188	1	222	17
250-500 V	21%	28,000	10	13	16	18	57	0.5	128	11
125-250 µm	33%	28,000	11	11	20	15	83	0.7	138	12
45-125 µm	28%	104,000	20	19	22	25	84	1.1	260	20
< 45 µm	6.0%	75,200	9.9	11	14	17	61	0.7	179	13

3.2.3 Flooded Pit

Initially, mining was conducted on the Gunnar Site in an open pit, and later, continued through use of underground workings (Figure 3). The pit was flooded following the cessation of mining activity through blasting and excavation of a channel through the bedrock land bridge that separated the pit from the Lake Athabasca. The flooded pit is currently a stagnant water body with a depth of over 100 m, a volume of approximately 3 million m^3 and is some 300 m wide. The pit is connected to the underground mine workings through a stope. Once the pit was flooded, the blasted channel was backfilled with waste rock, although this barrier is highly permeable and does not impede water flow from the pit to the lake. As a result, seasonally, during times of peak water levels, water from the pit can enter Lake Athabasca.

Uranium concentrations in pit the water vary from 320 to 960 µg/L, which exceeds the SSWQO of 15 µg/L. Radium-226 concentrations in the pit water vary in the range of 0.06 to 1.6 Bq/L, which can also exceed the WQO (0.11 Bq/L). Lead-210 and Po-210 levels are in the range of 0.02 to 0.64 Bq/L and 0.005 to 0.32 Bq/L, respectively. There is a weak water flow from the pit to Lake Athabasca, resulting in the release of contaminants into the lake.

The pit supports self-sustaining populations of northern pike (*Esox lucius*), ninespine stickleback (*Pungitius pungitius*), and possibly, white suckers (*Catostomus commersoni*) and longnose suckers (*Catostomus catostomus*).

Options that have been considered for remediation of the pit include leaving the pit "as is", conducting water treatment over time to address uranium and Ra-226 concentrations in pit water, and dewatering the pit, so that it can serve as a site for the waste rock and demolition debris. Regardless of the option, clean water from upstream will be diverted to minimize water flow into the pit.

4 SUMMARY

The Saskatchewan Research Council (SRC) is managing the cleanup of the Gunnar Mine/Mill Site, the Lorado Mill Site and 36 satellite mine sites that had fed uranium ore into these two regional mills on behalf of the Governments of Saskatchewan and Canada. In doing so, work is being done to address both short- and long-term remediation objectives to secure the site, while ensuring its long-term sustainability. SRC will ultimately hold licences from the Canadian Nuclear Safety Commission (CNSC) for the Gunnar and Lorado sites as the Proponent for these sites.

Work is proceeding on budget and ahead of schedule on the abatement and demolition of buildings and structures at Gunnar, and work is well underway on the environmental assessment and development of licensing packages for the Site. An overview of the considerations taken, the project accomplishments and the lessons learned has been provided.

5 REFERENCES

[1.] Lamb, W.K., "The Canadian Encyclopedia", 2007. http://www.thecanadianencyclopedia.com. *Historica Foundation*. 1 Sep 2007.

[2.] Tilman, A. "On the Yellowcake Trail: History of uranium mining in Canada." http://www.watershedsentinel.ca/content/yellowcake-trail-part-one-history-uranium-mining-canada. Watershed Sentinel. June/July 2009.

[3.] Gunnar Mines Limited. "The Gunnar story", September 1957.

[4.] BBT Geotechnical Consultants Ltd., "Gunnar Field Study", BBT Geotechnical Consultants Ltd., Saskatoon, Saskatchewan, Report No. S84-00195, Vol. 8, Appendix 7, 1986.

[5.] Peach, I., Hovdebo, D., "Righting past wrongs: The case for a Federal role in decommissioning and reclaiming abandoned uranium mines in Northern Saskatchewan.", 2003, The Saskatchewan Institute for Public Policy, December, 2003, Public Policy Paper 21.

[6.] Athabasca Land Use Planning Interim Advisory Panel, "Athabasca land-use plan: Background document. ISBN 0-9681947-4-5, 2003. http://www.environment.gov.sk.ca/adx/aspx/adxGetMedia.aspx?DocID=687,683,621,247,94,88,Documents&MediaID=295&Filename=Athabasca+LUP+background+appendices.pdf&l=English

[7.] SRC (Saskatchewan Research Council), *Saskatchewan Research Council Gunnar Mine Rehabilitation Project: Occupational Health & Safety Assessment (Action 1)*, 2010. SRC-12194-320-2010L5. August 31, 2010.

[8.] SRC (Saskatchewan Research Council), 2010. *Saskatchewan Research Council Gunnar Mine Rehabilitation Project: Inventory of Hazardous Substances and Materials (Action 6), 2010.* SRC-12194-320-2010L10. September 30, 2010.

[9.] SRC (Saskatchewan Research Council), *Saskatchewan Research Council Gunnar Mine Rehabilitation Project Demolition Plan (Action 8), 2010.* SRC-12194-320-2010L12. October 15, 2010.

[10.] SRC (Saskatchewan Research Council), *Saskatchewan Research Council Gunnar Mine Rehabilitation Project: Structural Safety Assessment of Buildings and Other Structures (Action 2), 2010.* SRC-12194-320-2010L9. September 30, 2010.

[11.] SRC (Saskatchewan Research Council), *Saskatchewan Research Council Gunnar Mine Rehabilitation Project: Waste Management Plan (Action 9), 2010.* SRC12194-320-23L10. December 22, 2010.

[12.] SRC (Saskatchewan Research Council), *Installation of Fencing Around Buildings and Structures on the Gunnar Mine Site that Failed the Structural Safety Assessment (Action 3), 2010.* Saskatchewan Research Council, Saskatoon, SK. SRC-12194-320-2010L15. October 31, 2010.

[13.] SRC (Saskatchewan Research Council), *Securing of Openings to Buildings (Action 4), 2010.* Saskatoon, SK. SRC-12194-320-2010L6. August 31, 2010. .

[14.] SRC (Saskatchewan Research Council), *Removal of Overhead Hazards (Action 5), 2010.* Saskatchewan Research Council, Saskatoon, SK. SRC-12194-320-2010L16. October 31, 2010.

[15.] SRC (Saskatchewan Research Council), *Collection and Securing of Hazardous Substances at the Gunnar Mine Site (Action 7), 2010.* Saskatchewan Research Council, Saskatoon, SK. SRC-12194-320-2010L17. October 31, 2010.