Implementation Of The Environmental Management Plan For The Dismantling Of Nuclear Powered Submarines At Zvezdochka Shipyard, Russia

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Abstract

Department of Foreign Affairs and International Trade Canada is funding the dismantling of twelve nuclear powered submarines (NPS) from the Russian Federation's Northern Fleet as part of the Global Partnership Initiative against weapons and materials of mass destruction. In this paper, work performed by Nuclear Safety Solutions Ltd. and its collaborators in support of these activities is described.

First, an environmental impact assessment of towing and dismantling NPS in the Kola Peninsula, and the Barents and White Seas was performed. The assessed activities included: towing of NPS from Naval Bases in Murmansk Region to the Zvezdochka shipyard (Severodvinsk); defuelling of onboard reactors; dismantling of NPS at Zvezdochka; and waste management. The assessment helped identify mitigation measures that could prevent the occurrence of adverse effects. Next, the project team defined and implemented an environmental management plan (EMP) based on the shipyard's existing environmental policy and the mitigating measures identified during the environmental assessment. Specific targets were defined to track the progress of the EMP implementation, and are described in this paper. During the study period, three Victor Class NPS were dismantled at Zvezdochka. The major benefits realized include: removal of spent nuclear fuel assemblies; treatment/decontamination of liquid and solid radioactive waste; and the cultivation of collaboration between Russian and Western expertise.

1. Introduction

Of the 248 submarines built by the Soviet Union and later Russia, 196 have been laid up so far. As of January 1st 2004, of the 117 submarines that have been withdrawn from active service in North West Russia, 56 still had to be dismantled. Altogether, Russia built over 450 naval nuclear reactors, of which two thirds were located in North West and one third in the Far East of Russia [1].

The Project to Dismantle 12 Out-of-service Nuclear Submarines ("the dismantling project") is a component of Canada's contribution to the broader Global Partnership Initiative against the proliferation of weapons and materials of mass destruction. Canada has joined other international partners, including the United States, Norway, Japan and the United Kingdom in securing the spent nuclear fuel (SNF) and the broad international initiative to rid the world's oceans of retired nuclear submarines.

The Canadian Foreign Affairs Minister announced on August 4, 2004 the signing of a $24.4-million contribution to assist Russia to dismantle its decommissioned nuclear submarines. Since the Minister's announcement, three Implementing Arrangements (IAs) were put into place within two years. This paper focuses on the work performed during the first IA.

The first IA was completed in September 2005. It covered the dismantlement of three nuclear powered submarines with two nuclear reactors per submarine as well as associated infrastructure projects. Most importantly, IA#1 included the defuelling of six nuclear reactors and the securing of over a thousand fuel assemblies. Table 1 summarizes the details of the submarines dismantled under IA#1.

Hull/ Factory #	**"K" Number**	**Class**	**Displacement**	**Reactors**	**In-Service**	**Out-Of-Service/Reactor Shutdown**
643	K-527	Victor III	4824 t	2 x 72 MWt VM-4 PWR (OK-300)	1981	1998
645	K-298	Victor III	4824 t	2 x 72 MWt VM-4 PWR (OK-300)	1982	1994
608	K-438	Victor I	3555 t	2 x 75 MWt VM-4 PWR (OK-300)	1971	1995

Table 1: Submarines dismantled during IA#1

In addition, the project removes the threat of radioactive and chemical pollution from deteriorating submarines stored afloat. The dismantling project consists of all operations and activities that are required for the defuelling and recycling of 12 Russian Victor class nuclear submarines at the Federal State Unitary Enterprise (FSUE) Zvezdochka shipyard in Severodvinsk, Russia, with Canadian financial assistance. Figure 1 shows the location of the shipyard, while Figure 2 displays a typical Victor class submarine. Department of Foreign Affairs and International Trade Canada has assigned Project Monitoring duties to Teledyne Brown Engineering (TBE), which in turn contracted Nuclear Safety Solutions Ltd. (NSS) to provide nuclear, environmental and marine engineering monitoring services.

In late 2004, Nuclear Safety Solutions Ltd. (NSS), completed an environmental assessment (EA) of the dismantling project with support from Golder Associates Ltd. (Canada), TBE (USA), and NIPTB Onega (Russia). The EA was conducted under the Canadian Environmental Assessment Act (CEAA) and independently audited by the Canadian government due to the DFAIT funding of the work. A series of public meetings to seek local views on decommissioning programs funded by western donors was held in Severodvinsk and Moscow in 2004 and 2005 [1]. Public consultation was also performed in Canada. The EA recommendations were documented in the Environmental Management Plan (EMP) related to the dismantling project, which then became part of the contractual agreement for submarine dismantling. This paper highlights the major environmental milestones achieved, summarizes the progress against the EMP targets during IA#1, and describes the lessons learnt in the course of project implementation.

Figure 1: Location of the Zvezdochka Shipyard

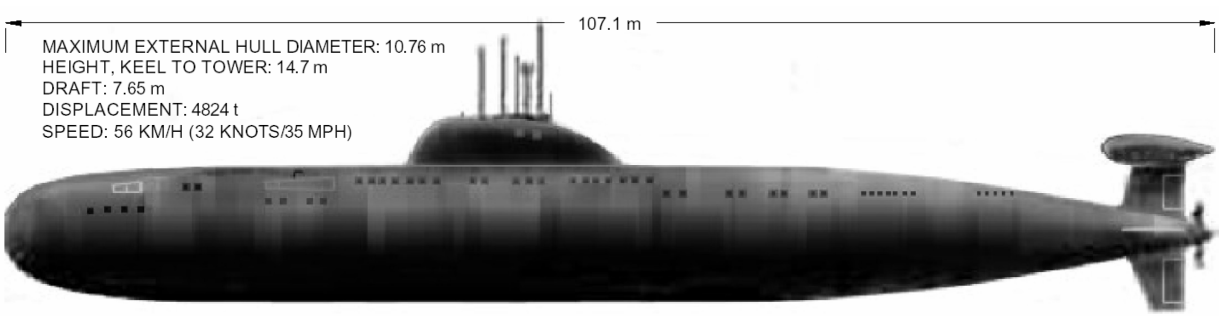

Figure 2: Victor Class Submarine

2. Environmental Assessment For The Dismantling Project

2.1 Project Works And Activities

The dismantling project encompasses a chain of activities beginning with the preparation of a submarine for transport to Zvezdochka and ending with the salvage of uncontaminated materials, shipment of Spent Nuclear Fuel (SNF) for reprocessing at the Mayak Chemical Combine ("Mayak"), and receipt of a reactor compartment at Saida Bay for long-term, secure management (provided by funding from the German government). For the purpose of the EA and the EMP, the project works and activities listed in Table 2 were considered. Table 2 also outlines the dismantling process.

Works and Activities	Details
Preparation for Transit	Crew training, draining and depressurizing systems; inspection and modification of a submarine to ensure buoyancy during towing
Transportation of Submarine	Towing a submarine from its point of origin to Zvezdochka
Arrival and Acceptance	Mooring of a submarine at Zvezdochka
Preparations for Reactor Defuelling	Breaching of Reactor Vessel; Removal of flammable materials and some radioactive waste; metal work in preparation for bringing crane-borne defuelling tools to the reactor
Reactor Defuelling	Opening reactor lid, removing SNF from the reactor and transferring the fuel to specially-designed transport containers
Management of Spent Fuel	Loading special rail cars with filled transport containers to transport SNF by rail to the reprocessing facility at Mayak
Preparation for Submarine Dismantlement	Moving the defuelled submarine to either the docking basin (and its slipways) or to a floating dock; final clean-out of the submarine and preparation for major cutting and disassembly
Construction of Three-Compartment Unit	Cutting out the reactor compartment and one compartment to either side to create a seaworthy package containing the remaining radioactive components of the submarine
Dismantlement of Fore & Aft Compartments	Processing the submarine components remaining after formation of the three-compartment unit
Preparation of Reactor Compartment for Transportation	Outfitting the three-compartment unit for towing
Transportation of Reactor Compartment	Towing the three-compartment unit from Zvezdochka to Saida bay (near Murmansk) for long-term management
Management of Radioactive Wastes	Processing of radioactive wastes by existing facilities at Zvezdochka
Management of Non-Radioactive Wastes & Products	Processing of non-radioactive wastes and saleable products by existing facilities at Zvezdochka

Table 2: Project Works and Activities

In addition, two accident categories were also assessed in the EA:

- **Conventional Accidents**, which included representative accidents with a reasonable probability of occurrence which do not result in a release of radioactivity (sinking, fire, spill of hazardous liquid etc.); and
- **Nuclear Accidents**, which included representative accidents (with a reasonable probability of occurrence) which do result in a release of radioactivity.

2.2 Scope of the Environmental Assessment

The spatial boundaries of the EA study encompass the city of Severodvinsk, Kola Peninsula and adjacent areas of the Barents Sea and White Sea (see Figure 1). The existing environment is described in detail for the local study area, shown on Figure 3:

Figure 3: Local Study Area

2.3 Major Findings of the Environmental Assessment

Under normal conditions, a total of 65 interactions between the project works and activities and the environment resulting in possible measurable change were identified for detailed assessment. These included radiation doses to workers and releases to the atmospheric environment, as well as a number of effects from the identified representative malfunctions and accidents. The likely effects associated with each of these 65 measurable changes were considered and mitigation measures to eliminate, reduce or control any adverse effects were identified. The detailed assessment identified no residual adverse effects in view of mitigation measures. Fifteen (15) positive effects were identified, including three key benefits:

1. Transfer of highly-enriched SNF from a floating submarine to Russian fuel cycle facilities ashore, which ensures appropriate safeguards.
2. Removal of environmental risks associated with open-ended long-term storage of nuclear powered vessels afloat.
3. Provision of employment at Zvezdochka shipyard in Severodvinsk and in the locations in Murmansk region where the submarine will be prepared for towing.

Detailed assessments of nuclear and conventional accidents were also carried out for the sinking of a submarine, fire, and a large spill of hazardous liquids. Changes in the environment were determined to be local and temporary. Detailed analysis showed that, given mitigation measures, representative accidents of each type were unlikely to lead to residual adverse effects.

In order to ensure that the mitigation measures are implemented, Department of Foreign Affairs and International Trade commissioned the Environmental Management Plan, which is constantly updated and ensures that the progress is monitored on a regular basis.

3. Environmental Management Plan For The Dismantling Project

3.1 Objectives

The objectives of the EMP are to assist FSUE Zvezdochka to:

1. **Minimize pollution**, including radioactive & non-radioactive discharges to air, land & water;
2. **Minimize waste generation**, including maximizing recycling & reuse;
3. **Enhance occupational safety**, including minimization of radioactive & conventional accidents;
4. **Enhance off-site public safety**;
5. **Manage waste safely**, including treatment/storage/disposal of radioactive & chemical wastes; and,
6. **Monitoring and Transparency.**

Section 4.1 summarizes the key activities that demonstrate the achievement of these objectives.

3.2 Specific Targets of the EMP

In order to meet these six major goals, the EMP specified several targets against which progress was measured. These included both radiological and non-radiological targets. This paper only addresses radiological targets, which are described in detail below.

- *To identify and eradicate the source of tritium leak at Zvezdochka.*
  Under normal operations, there are to be no radioactive discharges to groundwater. However, monitoring revealed the continuous presence of tritium in the groundwater.

Although these levels are below Russian regulatory limits, they indicate either a continuous tritium leak or historic contamination within the Zvezdochka site. The source of tritium in groundwater is likely due to leakage from one of the industrial discharge pipelines from the liquid waste treatment facility. This source of leakage is consistent with the lack of other radionuclides in the measurements as only tritium is present in discharges in significant quantities. However, it is also possible that one of the historic radioactive waste storage sites is the source of the leak. In this case, other more radiotoxic nuclides would be present in the groundwater; the lack of other radionuclides in the monitoring samples could be the result of different migration rates of radionuclides from the source (tritium has the highest migration velocity because it is not absorbed). Therefore, it is necessary to first identify and then eradicate the source of the tritium leak.

- *To confirm the commitment to expeditious recovery of a sunken submarine if monitoring data warrants.*
  This target was set because of the potential of release of hazardous substances into the sea from a sunken submarine.
- *To develop capability for determining concentrations of pure-beta emitters (^{14}C, ^{63}Ni, ^{35}S, etc.) in liquid waste.*
  At present, the radiometric laboratory of the shipyard's Nuclear and Radiation Safety department produces results without a qualified measurement methodology for the specific activity of ^{14}C and ^{63}Ni. Not resolving the issue may result in the suspension of the discharge of the already-treated water from the liquid waste treatment facility to sea, as without clear identification of ^{14}C concentrations, the entire stock of the treated water may be classified as liquid radioactive waste according to Russian regulations.
- *To develop and approve a refurbishment project for the solid radioactive waste storage facility.*
  The project will require the retrieval, conditioning and packaging of all wastes currently stored, followed by the decommissioning of the waste store itself. The retrieval will likely be remote due to dose rates in the vicinity of the wastes stored within the building.
- *To ensure that there are plans for long-term management of the solid radioactive waste.*
  Although all radioactive waste storage facilities are designed for short-term buffer storage, there are no current plans to direct these wastes to national long-term storage and disposal facilities in the foreseeable future. Although such facilities exist in the region, they are currently used exclusively for the disposal of institutional (non-nuclear cycle) wastes.
- *To review procedures for monitoring radioactive waste inventories.*
  Improvement in the waste management practices could be achieved by collating all the hazardous chemical and radioactive waste inventory data.
- *To collate accurate worker-dose data and to reduce collective worker dose to 3 man-Sv, and to introduce the ALARA principle (As Low As Reasonably Achievable).*
  The available data suggest that there may be some scope to reduce overall exposure of the work force by introduction of ALARA principle and dose targets for each operation. It may be necessary to review equipment needs to ensure that high dose-rate operations involving spent fuel management can be undertaken remotely or with fewer personnel involved in the immediate vicinity of SNF containers. The number of workers involved in radiologically hazardous activities appears to be unjustifiably high. Measures need to be taken to eliminate any incentives to workers for receiving higher doses.

- *To review air quality, discharge effluent and stormwater data to optimize monitoring efforts and target any necessary corrective actions.*
  This measure is needed for monitoring the long-term effects of FSUE Zvezdochka operation and appropriately focusing any corrective actions.

4. Implementing Arrangement #1 And Progress Made In Meeting EMP Targets

4.1 Major Environmental Milestones

In the course of IA#1, FSUE Zvezdochka achieved a number of major environmental milestones:

- Removal of spent nuclear fuel from reactors of laid-up submarines, placement into TK-18 or TUK-108 casks and transfer to Mayak (see Figure 4)

A - Preparation for defuelling

B - Loading of transfer flask with SNF assembly into SNF cask

C - Cask transfer to interim onsite storage

D - Transfer of SNF to Mayak

Figure 4: Spent Nuclear Fuel Management

- Treatment of Liquid Radioactive Waste (LRW), including primary coolant, spent decontamination solutions, shielding tank water and mixed effluents through filtration, selective sorption, evaporation and reverse osmosis (see Figure 5)
- Decontamination or size reduction and packaging of Solid Radioactive Waste (SRW) (see Figure 6)

Large quantities of non-radioactive, hazardous waste have been safely managed in this project, including thousands of mercury lamps, and several tonnes of acids, alkaline electrolyte, freons and hydraulic liquids. Furthermore, rubber and metallic scrap from dismantled submarines have been processed and sold for reuse.

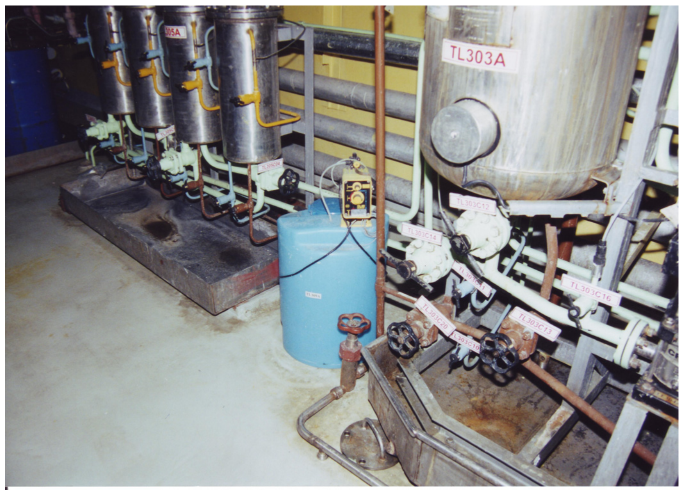

Figure 5: Liquid Radioactive Waste Management (Reverse Osmosis Equipment)

Figure 6: Solid Radioactive Waste Management - Intermediate Level Waste containers (left) and Low Level Waste containers.

4.2 Progress in meeting EMP targets through IA#1 activities

Table 3 provides details of progress made towards the targets listed in Section 3.2.

Target	Details
	Completed Targets
To identify and eradicate the source of tritium leak at Zvezdochka	FSUE Zvezdochka demonstrated that the source of the leak has been identified/eradicated. A marked decrease in concentrations was observed after repairs to the wastewater pipe from the liquid waste treatment facility.
To confirm the commitment to expeditious recovery of sunken submarines if monitoring data warrants	Complete
To review procedures for monitoring radioactive waste inventories	A functional paper-based system for monitoring radioactive waste inventory exists. Further improvements can be achieved via an electronic waste-tracking database system (see also the "Opportunities for Improvements" section).
	In-Progress Targets
To collate accurate worker-dose data, reduce collective worker dose and minimize risk of potential public exposure	A comprehensive system for monitoring effective worker dose exists. There is evidence that effort to reduce worker doses, especially during defuelling, has been made. There are additional needs to: - develop an automated system for radiation monitoring in the Restricted Access Areas, Controlled Area, and the surrounding plant and populated areas - procure a portable radiological laboratory to facilitate on site measurements during normal operation and after an accident. - ensure regular surface contamination monitoring (swipe tests) in all areas where potential contamination may occur.
To review air quality data to optimize monitoring efforts and target any necessary corrective actions	An extensive air, sediment, ground-, and seawater monitoring system exists. Sampling has been witnessed on several occasions and the collected data is reviewed on a monthly basis. See Section 4.3 for details.
	Targets not yet met
To develop capability for determining concentrations of pure low-energy beta emitters in liquid waste	FSUE Zvezdochka has requested Canadian assistance to develop a procedure which can then be certified with the Institute of Mendeleeva in Russia.
To develop and approve a refurbishment project for the solid radioactive waste storage facility	FSUE Zvezdochka is developing a concept to remotely retrieve radioactive waste by an overhead crane, followed by conditioning/packaging retrieved waste and decontaminating this facility. FSUE Zvezdochka is looking for funding for this concept. ROSATOM (the Russian nuclear regulator) plays a key role in defining funding priorities.
To ensure that there are plans for long-term management of the solid radioactive waste	Provision of a central radioactive waste storage or disposal facility is ROSATOM's responsibility.

Table 3: Status of EMP Targets

It is important to note that the two in-progress targets in Table 3 are ongoing tasks that can (strictly speaking) be marked as "completed" only at the end of the dismantling project.

4.3 Environmental Sampling Results

FSUE Zvezdochka has an extensive environmental monitoring programme. Regular sampling takes place on- and off-site to determine concentrations of radioactive substances in air, groundwater, surface water, soil and sediments. Radioactive discharges to sea as well as environmental concentrations of radionuclides (such as ^{137}Cs, ^{60}Co, ^{90}Sr, and ^{3}H) have all been less than 1% of their respective annual regulatory limits. Likewise, discharges of Kr-85 to air have been well within annual limits (<30%).

4.4 Opportunities for Improvements

Several opportunities for improvement have been identified over the course of completing IA#1 and implementing the EMP. The key opportunities were as follows:

1. The marine sampling programme is currently limited to sampling and analysis of seawater and sediments. It is recommended that sampling of marine biota should also be conducted to address the concerns of local population.
2. Solid Radioactive Waste storage facilities are rapidly filling up. In the absence of a national radioactive waste storage/disposal facility, FSUE Zvezdochka may have to construct a new SRW storage facility and implement further measures to minimize SRW volume. In addition, the shipyard was provided with information on western decontamination technology such as Vacu-blasting. The use of such technology would result in significant reductions in the quantity of solid radioactive waste as well as secondary liquid radioactive waste.
3. A training course for key personnel of FSUE Zvezdochka was conducted to demonstrate western safety and waste management systems and equipment.
4. Portal monitors are being installed in order to ensure that no radioactive materials leave the site accidentally,. The overall system would include portal monitors for vehicles, for railway traffic and, eventually, pedestrian monitors.

5. Conclusions – Lessons Learned

Dismantling of twelve nuclear powered submarines from the Russian Federation's Northern Fleet is proceeding as part of the Global Partnership Initiative against weapons and materials of mass destruction. An Environmental Management Plan based on the shipyard's existing environmental policy and the mitigating measures identified during the environmental assessment was developed. The following approach has been instrumental in ensuring good environmental performance for the project:

1. **Selection of a local facility with a good infrastructure in place**. FSUE Zvezdochka is unique in the region in that it has the following facilities.
   - **A land-based defuelling facility**. Most defuelling facilities in this region are not land-based; that is, the submarine is defuelled by another floating vessel. This causes stability problems and results in higher quantities of liquid radioactive waste, involves interim storage of spent nuclear fuel in a floating storage vessel

and requires a larger number of fuel movements to ensure that the fuel is eventually transferred ashore.

- **Liquid and solid waste treatment facilities**. Availability of these facilities at the shipyard minimizes the period required to store untreated, unpackaged and unconditioned waste and removes the need to transport this waste to another site.

2. **Selection of a local facility whose management is committed to preserving environment.** FSUE Zvezdochka has a highly qualified environmental team who have been instrumental in ensuring consistent environmental performance. Their existing environmental policy statement seeks to constantly improve the ecological situation and to prevent environmental pollution, and to develop and introduce an environmental management system compliant with the ISO 14001 standards.
3. **Formation of a partnership**. Environmental and safety recommendations made by the Canadian monitoring team are always discussed with FSUE Zvezdochka. Joint decisions are then taken to determine the most efficient, logical, and environmentally sound path to meet the objectives of the recommendation. FSUE Zvezdochka benefits from the use of best practice, experiences, and technology from the west, while Canada fulfills its commitment to non-proliferation of weapons and materials of mass destruction.
4. **Encouragement for addressing environmental issues**. Canada continues to monitor the implementation of the EMP as the project progresses. Some of the infrastructure funding has been specifically allocated to address EMP targets.

Environmental and nuclear safety monitoring visits have taken place on a regular basis since March 2005. The overall environmental performance has been good and the management at FSUE Zvezdochka has demonstrated commitment to continuous environmental improvement by investing into state-of the art waste treatment and storage facilities.

6. References

[1] Gerchikov M, Dutton M et al. "Strategic Environmental Assessment Report For Strategic Master Plan of Northern Dimension Environmental Partnership (Nuclear Window) – Executive Summary." *EBRD Contract 14073REV, 2005*. http://www.nssl.ca/SEA/Executive%20Summary%20Issue%204.pdf.