Strålevern Rapport 2005:4

Assessment of environmental, health and safety consequences of decommissioning radioisotope thermal generators (RTGs) in Northwest Russia.

Statens strålevern

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Key words:
RTG, Northwest Russia, Strontium-90, decommissioning.

Abstract:
The report gives an assessment of environmental, health and safety consequences of decommissioning radioisotopic thermal generators (RTGs) in Northwest Russia. It is based on information received from Russian authorities as well as NRPAs own independent evaluation.

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Emneord:
RTG, nordvest Russland, strontium-90, driftsnedlegging.

Resymé:
Rapporten gir en vurdering av miljø-, helse- og sikkerhetskonsekvenser ved driftsnedlegging av radioisotopiske termiske generatorer (RTGs) i nordvest Russland. Den baseres på informasjon hentet fra russiske myndigheter samt Strålevernets egen vurdering av disse aspekter.

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Assessment of environmental, health and safety consequences of decommissioning radioisotope thermal generators (RTGs) in Northwest Russia.

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Norwegian Radiation

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Østerås, 2005

Innhold

1 Introduction

The Norwegian government allocates funding each year to improve the safety and security of radioactive waste in Northwest Russia and prevent potential radioactive contamination from waste storages and nuclear facilities. Such activities are a part of the so-called Nuclear Action Plan (NAP), which is administered by the Norwegian Ministry of Foreign Affairs. As the Norwegian national radiation protection authority, NRPA takes an active part advising the ministry regarding priorities and quality assurance of specific NAP projects. An important aspect of NRPA involvement is to provide independent assessments of the health and environmental consequences of specific projects.

Decommissioning Radioisotope Thermo-electric Generators (RTGs) in Northwest Russia is a priority area under the Nuclear Action Plan. This NRPA Report presents findings from public health and environmental assessment work that has been undertaken as part of the joint Norwegian-Russian project to decommission RTGs in Northwest Russia. The report is based on information received from the All Russian Scientific Research Institute of Technical Physics and Automation (VNIITFA) as well as independent reviews and assessment. The aim of the report is to:

- review the scope and content of the existing Russian assessment, their proposed working procedures and quality assurance measures;
- analyse the potential worker, public and environmental risks associated with the RTG decommissioning project;
- make recommendations on improvements to the work specifications and their implementation.

1.1 Report structure

The report begins by giving some background information about the perceived necessity for the decommissioning project and the intended purpose of an environmental impact assessment. The existing Russian regulatory framework is then briefly discussed and the design and locations of RTG devices outlined. Russian impact assessment of the RTG decommissioning process is then reviewed and our independent impact assessment findings are given. Finally, alternatives are briefly discussed before the reports recommendations and conclusions are presented.

2 Background

Along the Arctic coast of Russia, in remote areas where electricity is not available, there are lighthouses powered by RTGs in which a radioactive strontium-90 source produces heat that powers a generator. RTGs are also used as power sources in radio beacons and weather stations and are found throughout Russia and other former Soviet countries. At the end of 2004 about 110 lighthouses with RTGs were situated in Murmansk and Arkhangelsk region. Some RTGs are equipped with more than one radionuclide heat source (RHS) such that there are about 150 RHS in these regions. The RTG-powered lighthouses on the Kola Peninsula are owned and operated by the Russian Agency for Sea and River Transport (earlier known as Mintrans) or the Hydrographic Department of the Northern Fleet.

The safe removal of RTGs is of great concern to the Norwegian authorities. Through the Nuclear Action Plan, the Norwegian Ministry of Foreign Affairs currently finances two projects to replace RTGs with solar panels and funds the waste disposal of removed RTGs. Both projects involve the Joint Norwegian-Russian Expert Group for Investigation of Radioactive Contamination (JNREG) and have the Office of the County Governor of Finnmark as project leader.

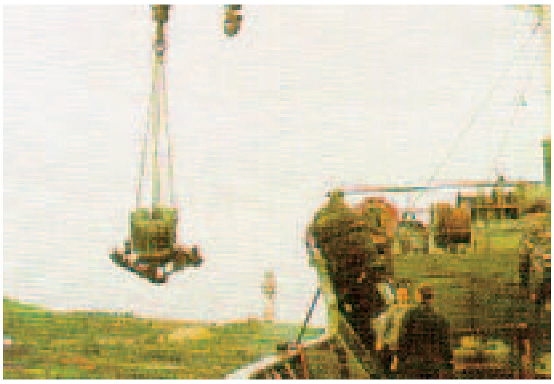
The process of replacing and disposal of the RTGs is carried out in several stages:

- An inspection and preparation of the RTGs *in situ* is carried out before transporting the RTG to Atomflot
- The RTG is then transferred by helicopter, boat and road to a temporary storage point near Murmansk

Helicopter transport of an RTG (Photo: Office of the County Governor of Finnmark).

- After a period of temporary storage the RTGs are transported to the Moscow region
- Here, the RTGs are transported by road and rail from a temporary storage point by ARC Izotop in Moscow.
- Then the enclosed radionuclide heat source (RHS) is extracted from the RTG at VNIITFA, inside a special chamber.
- The enclosed RHS is then transported by road and rail from Moscow to Mayak PA, Ural.
- Once at Mayak PA, the RHS containers are unloaded and the RHS is extracted from it's container
- The RHS is then finally stored at Mayak PA.

There are important security, environmental and radiological protection incentives for the RTG decommissioning project. The RTGs contain highly radioactive strontium-90 sources, which represent a local environmental and public hazard. Due to insufficient regulations for control and physical protection of the sources, many RTGs are accessible to intruders and the general public. A number of attempted thefts in recent years have highlighted security issues, since these radioactive materials may hypothetically be made available to terrorists.



Transfer of an RTG onto a ship for further transport (Photo: Office of the County Governor of Finnmark).

The Norwegian project financing RTG dismantling was initiated in 1995. In the five lighthouses that are closest to the Norwegian border, the RTG power source has been replaced with solar panels supplied by Norway. Altogether, 60 RTGs had been removed at the end of 2004 and 36 solar cells installed as a result of this project. RTGs are no longer being installed as power sources in lighthouses in Russia.

The progress of the decommissioning project has been as follows:

- Autumn 2003; NRPA in dialogue with FMFI to obtain an environmental impact assessment (EIA) from the Russian operator (VNIITFA), starting with a table of contents.
- 19 December, 2003; NRPA comments on table of contents received from VNIITFA.
- 13 April, 2004; NRPA received the EIA
- 7 May, 2004, NRPA asked for additional information
- 4 June, 2004, NRPA received the final version of the Russian impact assessment, with was also sent to the Russian Regulatory Authorities (NIERA).
- Summer 2004; NRPA in dialogue with NIERA regarding the EIA. Both authorities were in general agreement.
- 17 August, 2004, the NRPA finalized it’s independent assessment of the RTG decommissioning project.

3 Environmental Impact Assessments

In general, environmental impact assessment (EIA) is a process to predict the environmental effects of proposed initiatives before they are carried out. An environmental assessment should:

- identify possible environmental effects of proposed activities
- propose measures to mitigate adverse effects
- predict whether there will be significant adverse environmental effects, even after the mitigation is implemented
- study alternatives to proposed activities and the likely environmental consequences of alternatives
- invite public participation in discussions about possible impacts
- conclude which activity is preferred and inform the public of this decision

The main aims of impact assessments are to minimize or avoid adverse environmental effects before they occur and to incorporate environmental factors into decision making processes. Here, adverse environmental effects are understood to be detrimental effects on local and distant human populations, fauna and flora.

3.1 The Russian regulatory framework

Information received about the Russian EIA process indicates that the regulatory requirements of the Russian and Norwegian systems are similar and accord generally with international practice (e.g., JNREG, 2001). General safety standards are similar to those recommended by the IAEA Basic Safety Standards (IAEA, 1996).

There are many stakeholders in the Russian regulatory regime. Thus, consistency of compliance requirements, coordination of regulatory control and transparency are obviously important. The terms public and state ecological expertise are slightly unclear in the Russian assessment information but the stated interaction of the two appears to demonstrate consideration of public stakeholder views at an early stage. Russian law requires that a pre-project EIA process takes place. No documents have been made accessible to date that cover this step of the process for RTG decommissioning.

Loading RTGs for transport by rail to Moscow region (Photos:Office of the County Governor of Finnmark)

4 RTG Structure

An RTG is a radioisotopic power device commonly used to provide electrical power to remote unmanned automatic systems, including navigational aids such as lighthouses and radio beacons located in desolate areas as well as satellites and equipment used during deep-space missions. Inside the RTG is a radionuclide heat source (RHS) that consists of one or several radioactive sources that decay, thereby generating heat which is transformed into electrical energy by a semiconductor thermoelectric converter. The RTGs used in Russian lighthouses utilise the radioactive isotope ^{90}Sr (Strontium-90), a beta-emitter with a half-life of 29.1 years, as a heat source. The ^{90}Sr cores consist of one or more compact, high-density solid fuel pellets, which are designed to be insoluble in both sea and fresh water. Together with the energy from ^{90}Sr radioactive decay, its beta-emitting daughter radioisotope, Yttrium-90 (^{90}Y is a radioactive by-product of ^{90}Sr decay and has a half-life of 64 hrs), also produces heat energy from its radioactive decay.

Figure 1a shows a schematic illustration of a typical RTG used in Russia. The RHS is larger than is typical of industrial and medical radioactive sources (i.e. contains higher levels of activity) and is designed to operate at much higher temperatures. It is therefore critical to maintain the integrity of the RTG, during both normal operating conditions and under accident scenarios. To achieve this, the RTGs are designed with a multi-layer protective structure as illustrated.

The multi-layer design of the RTG affords significant physical protection and thermal and radioactive shielding. The source cladding materials are quoted as chromium-nickel steel and the internal radiation shields as depleted uranium, tungsten or sometimes lead. Many RTG designs are hermetically sealed by argon arc welding of the inner and outer covers (VNIITFA, 2004).

Figure 1b shows a photograph of an opened RTG (with the ^{90}Sr heat sources removed) at VNIITFA. The RHS contained within the Russian RTGs is typically ^{90}Sr in the form of strontium titanate ($SrTiO_3$), chosen specifically as it is a high-temperature resistant, relatively insoluble ceramic. Figure 2 shows some example casings for the ^{90}Sr heat source as well as a cut-away showing where the ^{90}Sr pellets are held.

The melting point of the pure strontium titanate material is quoted as approximately 2060°C (VNIITFA, 2004: states a minimum of 1900°C) and it is classed as non-combustible. It has little or no chemical toxicity. The substance could only be a physical irritant if transformed into a powder, which is very unlikely when stored as an RTG core. In later RTG models, the strontium titanate RHS was replaced by strontium borosilicate glass.

The Russian RTGs have a lifespan of between 10 and 20 years and a maximum surface temperature of about 500 °C. Both ^{90}Sr and ^{90}Y are pure beta emitters. However, x-rays can also be emitted as bremsstrahlung when the beta radiation is absorbed in nearby materials. The ^{90}Sr cores have activities ranging from 740 TBq (20 kCi) to 14800 TBq (400 kCi), depending on the type of RTG. Due to its long half-life and high level of radioactivity, the ^{90}Sr fuel pellets should be considered as a radiological hazard for a very long time. As relatively strong beta emitters, ^{90}Sr and ^{90}Y present two potential external radiation hazards: the beta rays themselves and the radiation they produce in the source and adjacent materials.

into exposed flesh, but may give serious and sometimes life threatening burns upon skin contact, depending on the strength of the source. X-rays, which are long-range, high-energy radiation, can penetrate almost any material. RTG cores (i.e., the RHS) are shielded in a special capsule to reduce the radiation emissions (Figure 1a). Radiation on the surface of an unshielded core can reach 10 Sv/h, which can provide a lethal dose to humans within half an hour of exposure.

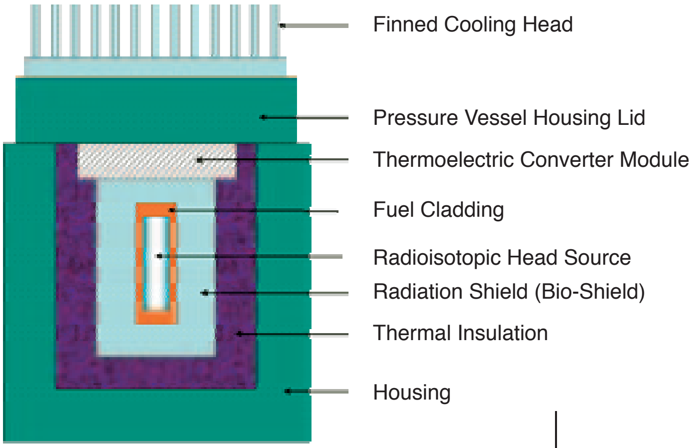


Figure 1a: *Schematic illustration of a typical RTG. (Lamp, 1994)*

Figure 1b: *Photograph of a typical RTG (with ^{90}Sr heat source removed (Photo: NRPA).*

Due to its chemical resemblance to calcium, ^{90}Sr is readily accumulated in bone tissue after ingestion or inhalation. In bone tissue, it has a long biological half-life and can cause necrosis and cancers of the bone and adjacent tissues.

Table 1 presents the range of RHS that have been produced in the FSU over the past 30 years. Beta-M type RTGs - one of the first designs originally developed in the late 1960s - have been used most frequently. Each Beta-M RTG contains 1 RHS. Today, around 700 RTGs of this type are in operation, 16 of which were part of the planned 2004 campaign.

Figure 2. *Example casings for the ^{90}Sr heat source. On the right-hand side the casing is cut away to reveal where the ^{90}Sr would be held (Photo: NRPA).*

Figure 3 shows a picture of several RTGs temporarily located on the Kola Peninsula, while Figure 4 illustrates RTGs in situ.

Table 1. *Types and main characteristics of Soviet-designed RTGs (adapted from Alimov, 2003).*

	RHS heat capacity watts	RHS initial nominal activity, kilocuries	RTG output voltage, volts	RTG mass, kilograms	Year of start of mass production
Efir-MA	720	111	35	1250	1976
IEU-1	2200	49	24	2500	1976
IEU-2	580	89	6	600	1977
Beta-M	230	35		560	1978
Gong	315	49	14	600	1983
Gorn	1100	170	7 (14)	1050 (3 RHS-90)	1983
IEU-2M	690	106	14	600	1985
Senostav	1870	288		1250	1989
IEU-1M	2200 (3300)	340 (510)	28	2 (3) x 1050	1990

4.1 RTG Locations

Altogether, a total of approximately 1000 RTGs used as energy source for lighthouses are spread along the Russian Coast. One reported problem with the Beta-M type design is that the components are sometimes screwed together, not welded, leaving the RTG much more prone to tampering. Eighty percent of them are found along the Northern Shipping Route going along the Siberian coast, most in the Western parts of Russia, but about 40 are located along the shoreline of the Sakhalin Island and 30 on the Kuril Island. About 150 RTGs are found in the Chukota Region.

The Siberian Territorial District has more than 100 RTGs, the bulk of which are concentrated on the Taimyr Peninsula. Another 153 RTGs are scattered along the shorelines of the Barents and the White Seas.

The current assessment covers the decommissioning of 23 RTG-powered lighthouses in the North-Western part of Russia.

According to information from the Russian authorities, 19 RTGs were listed for decommissioning in 2004. Ten of these were in the White Sea region (15 RHS in total), while the rest are in the Barents Sea region.

Figure 3. *Retired RTGs on the Kola Peninsula (Photo: Government of the Norwegian province Finnmark).*

Figure 4. *RTGs positioned along the Russian coast (Photo:Office of the County Governor of Finnmark).*

4.2 Security and orphan sources

An inspection of the lighthouses in eastern Siberia by Russian nuclear specialists revealed that many lighthouses were in poor condition. Also, the inspectors did not find all the RTGs, which indicated that Russian authorities do not have a full overview of RTG locations. This demonstrates the need for control of these sources and the importance of international cooperation for the regulation of radioactive materials.

Figure 5 shows the locations of the five RTGs that have already been replaced by solar cells.

Orphan sources (sources that are misplaced) are a radiation hazard in their own right, and they could also hypothetically be utilized by terrorist organisations with the intent to cause harm. A potential use could be a so-called "dirty bomb", where conventional explosives are used to disperse radioactive materials and thus contaminate the surrounding area. The main purpose of such a "dirty bomb" would be to cause public anxiety. Damage caused by the conventional explosives would be the most immediate effect of such a detonation, but the long-term effects might also be severe, dependent on the area affected: resultant radioactive contamination could affect the area for years or even decades. The most severe tangible impacts of a dirty bomb are likely to be the social disruption caused by evacuation, the subsequent clean up of the contaminated area and economic costs.

Map of the actual area with the population centres marked as red circles (from Barents Euro-Arctic Council)

Without a major explosion, radioactive contamination of the environment from a "dirty RTG bomb" is virtually impossible. There has been one recording by the Russian Ministry of Transportation's State Hydrographic Service (SHS) of an RTG explosion experiment using a powerful anti-ship explosive device (Alimov, 2003). The RTG was apparently destroyed, but the RHS, which was contained in it, remained undamaged.

4.3 Theft and orphan sources

There have been several break-ins and thefts from nuclear powered lighthouses in recent years. Most Russian RTGs are unguarded against potential thieves or intruders, and lack basic security measures such as fences or warning signs. Additionally, some of these incidents can be attributed to the Russian authorities' lack of legislation and regulatory documentation of the sources.

For example, in 1999 an RTG was found at a bus stop in the town of Kingisepp in the then Leningrad region. It had been ravaged by non-ferrous metal looters. The radiation dose level on the surface of the core was 10 Sv/h upon recovery. In the summer of 2001, four people were hospitalised after receiving radioactive doses during an attempt to dismantle the lighthouse near Kandalaksha in Murmansk region (Figure 6). They had been trying to extract non-ferrous metal from the lighthouse in order to sell it later as scrap metal. They were not aware of the fact that there was a strong radiation source inside the lighthouse. In February 2002, three shepherds from the village of Lia in the Tsalendzhikha region in West Georgia were exposed to high radiation doses after they stumbled upon a number of RTGs in a nearby forest, that were installed during the Soviet period.

Russia also has about 100 RTG lighthouses in the Gulf of Finland region. On 28 March 2003, specialists from the Leningrad branch of the Radon Special Combine recovered an intact RTG core from the seafloor in the Gulf of Finland, 100 kilometres from the Finnish coast. Thieves had stolen the generator from a lighthouse, removed about 500 kg of stainless steel, aluminium and lead that shielded the radioactive core, and dumped the core onto the ice. The core melted through the ice and was found near the shore, at a depth of about 1 m. Since the core was intact, environmental experts do not believe that it caused any harm, apart from to its immediate surroundings.

In September, 2003, service personnel from the Northern Fleet discovered an attempted theft at an RTG-powered lighthouse on the small island of Golets in the White Sea where the enclosure had been broken into. The lighthouse contained a particularly powerful RTG with six strontium cells - radiation dose levels of up to 1 Sv/h were measured at the surface of the RTG.

On 12 November, 2003, service personnel from the Northern Fleet discovered that the lighthouse at Olenia bay in the Kola Fjord was dismantled and everything besides the core had been stolen. The next day it was discovered that the same thing had happened on the Yuzhny Goryachnski Island, also in the Kola Fjord. In both cases the strontium sources were left nearby. A third break-in was discovered south of the entrance of Nerpa.

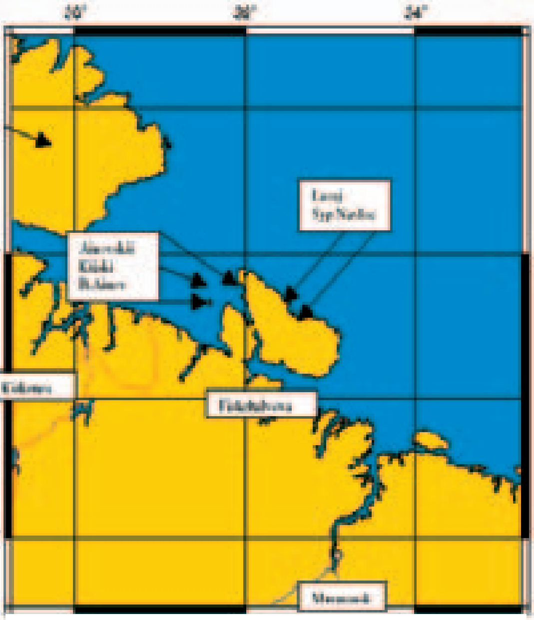


Figure 5. *Map showing the locations of the five lighthouses where RTG power sources have been replaced by solar panels.*

All of these incidents prove the importance of the safe removal of RTGs from Russia's Arctic coast. Up to now, these break-ins have been to steal the valuable metal shielding. The thieves have not been interested in the RTG cores, or perhaps not even been aware of their existence. However, these thefts demonstrate how easy terrorists can gain access to radioactive materials. It is also necessary to improve the Russian authorities' legislation and regulation of the sources.

Figure 6. *Burns on the ground where the RTG had been left after being taken from the lighthouse in Kandalaksha (2001) Photo: The Hydrographic Department of the Northern Fleet).*

5 Russian impact assessments

In the EIA process the importance of the justification of a practice, the adequacy of guaranteed funding for both the practice and the consequent radioactive waste management requirements (to internationally acceptable standards) is paramount. The Russian regulatory system has adopted the IAEA regulations for safe transport of radioactive materials. However, the Russian impact assessment information made available to NRPA does not look at possible alternatives to the proposed project and the assessment of their radiological implications (i.e. optimisation of the project to minimise risks of elevated doses and ecological impact). This information might be contained elsewhere though, in any case, the alternative options for this project are limited.

The Russian standards for permissible levels of ^{90}Sr in the environment are presented below (Tables 2 and 3). Table 2 presents the maximum permissible intakes of ^{90}Sr into organisms and the maximum concentrations allowable in air and water, taken from Russian legislation (documents NRS-76/87 and NRS-99).

At Level A in Table 3 no precautionary protection measures are required according to Russian legislation. If environmental concentrations exceed Level A but are below Level B, protection measures are decided upon after taking into account the nature of the incident with respect to local conditions. If contamination levels exceed Level B (Table 3) then protection measures are activated even if they would affect the local population and economic and social functioning in the affected area.

The Russian impact assessment information also lists the following legislative and normative national and international documents that shall be adhered to at all stages of an RHS life cycle.

- Safety manual for safety precautions when designing, manufacturing and using radionuclide power generators for some kinds of application on land and sea: Series of editions on Safety No.33, IAEA, Vienna (1970).
- Rules of safe transport of radioactive materials: Series of editions on safety: (IAEA, 1996; 2003).
- Sanitary rules on the design and operation of radioisotope powered supplies. No. 1901-78, Ministry of Health of USSR (1978).
- Radiation safety norms and basic sanitary rules for radiation safety assurance. (NRS 76/87, BSRRSA-72/87, NRS-99, BSRRSA-99) Ministry of Health of USSR
- Safety rules for trans-portation of radioactive substances (STTRS-73), Moscow, Atomizdat (1974).
- GOST 18696-90. Radio-nuclide thermoelectric generators. Types and the general technical requirements
- GOST-20250-83. Radio-nuclide thermoelectric generators. Acceptance procedures and test methods
- GOST 16327-88. Transport packages for radioactive substances. General technical requirements.

Additionally, according to the Russian information the following safety norms have been adopted for transport of RHS and RTGs. It is not stated if all existing RTGs conform to these standards.

- Thermal influence: exposure to heat (800 °C for 30 mins with subsequent cooling in air (item 728, IAEA, 1996; 2003))
- Mechanical influence: free-fall from height of 9 m on to a steel plate and falling from 1 m onto a spike (item 727, IAEA, 1996)
- Superfluous pressure from a water column not less than 2 MPa (item 730, IAEA, 1996)

***Table 2**. Maximum permissible intakes of ^{90}Sr into organisms and the maximum concentrations allowable in air and water, taken from Russian legislation*

Legal document	Limit of annual uptake into organism μCi/year *(kBq/year)*		Permissible concentration of ^{90}Sr Ci/l *(kBq/l)*	
	Through lungs	Through gut	Air	Water
NRS-76/87	0.29 *(10.7)*	0.32 *(11.8)*	4.0×10^{-14} *(1.5×10^{-6})*	4.0×10^{-10} *(1.5×10^{-2})*
NRS-99	0.542 *(20)*	0.352 *(13)*	7.3×10^{-14} *(2.7×10^{-6})*	

***Table 3.** Action levels of ^{90}Sr in food during the first year after an accident.*

Radionuclide	Specific activity of radionuclide in food (kBq/kg)	
^{90}Sr	Level A 0.1	Level B 1.0

The RTG is also classified as a special form radioactive material (i.e., as a total package inclusive RHS and all cladding materials) and as a IAEA Class B(U) container which should provide a considerable level of protection from accident damage.

5.1 Evaluation of the Russian impact assessment information

The Russian RTG assessment information received by NRPA presented an adequate description of the RTG project and representation of the hazards and risks associated with the project. It considered mainly the human impact - omitting to discuss in detail any impacts on flora and fauna despite two extensive appendices on the subject.

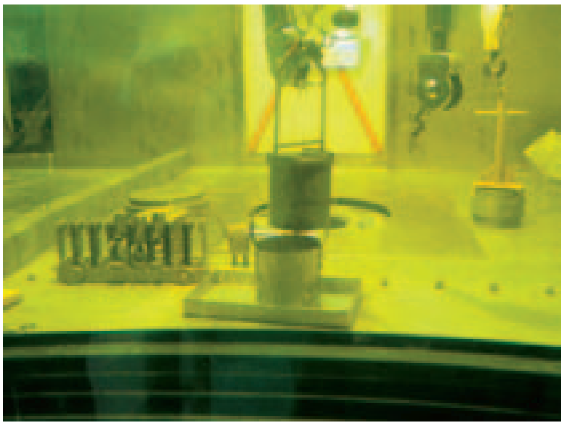
The submitted Russian information covered only part of the required scope for the Russian EIA process. The need for justification for the project, the comparison of risks from alternative options and a description of the necessary safety, monitoring and control procedures during dismantling and transport may be covered elsewhere though no such documentation was received.

The levels of planned radiation control are only briefly touched on in the Russian documents. There is also some ambiguity as to which organisation shall have overall control for the RTG project. Indeed, it is indicated that control is transferred throughout the project between several organisations. The large number of organisations (both military and civil) involved in the process leads to a concern that consistent compliance with regulations may be difficult to achieve in practice. This is a key risk area for the project that could increase the likelihood of loss or theft of sources and unplanned exposures.

The information received suggests that transportation will be in containers and vehicles that comply with Russian transport regulations and in turn with the standards set in IAEA radioactive material transport regulations. According to IAEA Transport Regulations, RTGs containing more than 900 TBq ^{90}Sr should be transported under "special arrangements" where alternative safety precautions are taken into account. It is assumed that the competent Russian authorities account for this, especially with regard to helicopter transport of RTGs. It is also assumed that the Izotop and Mayak facilities are operated to civilian Russian safety standards that are covered by separate EIAs to international standards and are therefore outside the scope of this report.

Contingency plans for the removal of a leaking or damaged source are not included in the report and are assumed to be contained elsewhere. They should cover procedures for the protection of workers and the general public in the event that such a situation is found when arriving at the site. The operators should be equipped with suitable monitoring equipment to help determine whether any additional hazard exists and the RTG is breached. If so, the most important first step will be to make the source safe. This could involve establishing an exclusion zone, the use of remote handling equipment and additional shielding.

The level of control needed for containment of the sources and transfers of responsibility must be clear and a consistent approach to regulatory requirements and compliance set out and verified at all stages. The possibility of accidents at each stage of transport and their environmental implications and required remedial actions need to be assessed and certified as acceptable.



Removal of a radioactive core at VNIITFA – The National Institute for Research on Technical Physics and Automatisation in Moscow. (Photo: Office of the County Governor of Finnmark)

Confidence that the overall control system works would be enhanced by the inclusion of previous evidence that the work involved with the decommissioning of RTGs, their transportation, the conditioning of the radioactive sources and their placement in temporary storage awaiting disposal, has:

- been achieved without incident or non-compliance with the certification processes required for the many intermediate stages of the work and
- demonstrated that interaction between civilian and military authorities has worked well.

To comply with international best practice (IAEA, 2004) the competent authorities should be able to provide a list of all of the RTGs in service and storage with evidence of an auditable record system that demonstrates control of the sources by named holder, activity, date of acquisition or disposal and annual leak tests.

An alternative to RTGs: A lighthouse fitted with a solar panel that generates electricity (Photo: Office of the County Governor of Finnmark)

Demonstration of secure storage/ emplacement is also a requirement. A system for recovery and disposal of orphaned sources is also required. Because of the remote location of the RTGs there is evidence that a loss of control over the sources locations may have occurred. The time scale for the decommissioning all existing RTGs will be long and therefore the security of these sources should be improved as soon as possible.

In summary, the Russian impact assessment information made available regarding decommissioning RTGs in Northwest Russia adequately identifies potential environmental impacts and possible adverse consequences of the proposed activities, including some information about possible mitigation strategies that could be adopted in the event of an accident. The documents also demonstrate the robust nature of undamaged RTGs, indicating that, with proper handling and consideration of the Russian and international guidelines and legislation for handling and transport of radioactive materials, the decommissioning process should be achievable without causing radioactive contamination of the environment.

The submitted information did not, however, review the cost-effectiveness of the proposed activities, or possible alternative options, as would be expected in an EIA. There was also no evidence of public participation or of a separate EIA dedicated to the decommissioning work started in 1995. These omissions may of course be covered in other, non-submitted documents.

6 Independent Assessment

6.1 Operational Risk Assessment

An operational Risk Assessment has been performed based on the list of operational steps presented earlier. The risk assessment covers all aspects from the work on the RTG site, the transportation phase to the preliminary storage place FSUE Atomflot, the transportation phase to ARC Izotop and finally the transportation phase to the final destination location at PA Mayak.

Particular industrial safety issues involve hazards during lifting procedures and transfer steps between the various forms of transport, particularly when using helicopters, scows and cranes have been evaluated. Adequate levels of control during each of these activities have been partly demonstrated in the Russian report.

The risk assessment discusses the following items:

- Hazard Description
- Cause(s)
- Consequence
    - Safety
    - Personnel
    - Environment
- Existing safeguards
- Recommendations

6.2 Radiological criteria used in assessments

6.2.1 Workers

The IAEA Basic Safety Standards (IAEA, 1996) for workers are as follows:

The occupational exposure of any worker shall be controlled so that the following limits are not exceeded:

- an effective dose of 20 mSv per year averaged over five consecutive years;
- an effective dose of 50 mSv in any single year;
- an equivalent dose to the lens of the eye of 150 mSv in a year; and
- an equivalent dose to the extremities (hands and feet) or the skin of 500 mSv in a year.

For apprentices of 16 to 18 years of age who are training for employment involving exposure to radiation and for students of age 16 to 18 who are required to use sources in the course of their studies, the occupational exposure shall be controlled so that the following limits are not exceeded:

- an effective dose of 6 mSv in a year;
- an equivalent dose to the lens of the eye of 50 mSv in a year; and
- an equivalent dose to the extremities or the skin of 150 mSv in a year.

6.2.2 Public

Current IAEA guidelines (IAEA, 1996) are that the radiological dose to members of the public from artificial sources should not exceed:

- an effective dose of 1 mSv in a year;

- in special circumstances, an effective dose of up to 5 mSv in a single year provided that the average dose over five consecutive years does not exceed 1 mSv per year;
- an equivalent dose to the lens of the eye of 15 mSv in a year; and
- an equivalent dose to the skin of 50 mSv in a year.

If, after an accident, the additional dose due to the RTG were likely to exceed this limit, then countermeasures might have to be considered, taking account of the other risks and the potential decrease in dose that might be achieved.

6.2.3 Environment

A developing international consensus on issues including conservation, sustainability and biodiversity (IAEA, 2002) coupled to the protected status attributed to many plants and animals within national legislation (Pentreath, 1999), has led to an urgent requirement for methods to quantify the environmental impact of radioactivity explicitly (NRPA, 2002). Recent activities have focussed mainly on the development of a system that allows the transfer of radionuclides in ecosystems to be assessed, subsequent dose-rates for reference organisms to be calculated and predicted radiobiological effects to be contextualized through consideration of background exposures and experimental data. This work has been conducted by international bodies (e.g. IUR, 2002; ICRP, 2004) and by research consortia (e.g. Larsson, 2004). The most recent evidence suggests that, although minor effects may be seen at lower dose-rates in the most sensitive species and ecosystems, the threshold for the appearance of statistically significant effects for biota in most studies is approximately 100 μGy h^{-1} (Real *et al.*, 2004).

6.3 Radiological protection issues

Sr-90 and Y-90 are beta emitters; beta particles are absorbed by the source and surrounding shielding, which gives off low energy Bremsstrahlung radiation. The external dose design limit is 2000 µSv/hour at the unit surface, and 100 µSv/hour at 1 metre from the surface. Recent measurements of a typical RTG (NRPA, 1995) found up to 12 µSv/hour at the surface, which is well below the design limit. This presents only a small radiation risk to members of the public, since they would need to stand close to the surface of the RTG for well over 80 hours to exceed the IAEA annual limit of 1 mSv/year. Doses to workers would need to be controlled to meet the limit of 20 mSv/year. Remote handling of the RTG is recommended where possible. However, any direct handling procedures while the RTG is intact are unlikely to last longer than 80 hours for any individual worker.

The outer shielding has been removed from some RTGs by metal scavengers. The external dose for these sources will be very much higher (>10 mSv/hour 1m from the source), without their additional shielding. These present a greater risk to members of the public and workers, and could easily lead to high exposures.

6.4 Radiological Consequence Assessment

Some original RTGs contained up to 14800 TBq of Sr-90. Our assessment is based on a typical example observed by the NRPA during a visit to Russia in 1995 of 4100 TBq (original activity), which was conservatively assumed to have been installed only 10 years ago. The observed

RTG had actually been installed in 1984. Assuming 10 years since installation, radioactive decay will have reduced the source to about 3200 TBq.

The source consists of a cylinder (136 mm diameter, 156 mm long), weighing 11.5 kg. It is made of strontium titanate ($SrTiO_3$), of which 15% was originally radioactive $^{90}SrTiO_3$. Sr-90 decays to Zr-90, via the short-lived radionuclide Y-90. About 3% of the assumed source would now be zirconium titanate.

6.5 Key Accident Scenarios

The following key scenarios have been identified:

1. Drop into the sea. Two sub-scenarios:
    a. The RTG remains intact, so that the source is not directly in contact with seawater, and the shielding reduces external doses.
    b. The RTG is broken, leading to direct contact of the source with seawater, and enhanced external doses due to failure of the shielding. This scenario is more likely close to the coastline, where the RTG container could be dropped onto rocks. It could also occur if there was a fire on the ship that damaged the container prior to it falling into the sea.
2. Drop onto the shoreline, but only in very shallow seawater. If this occurs during direct loading then the RTG should not be damaged. If it occurs during a helicopter transit then it will be assumed that the RTG is damaged as for scenario 1.b
3. Drop onto or accident on land, away from the sea. The RTG could be damaged if this occurred during a fire or crash, or was dropped from the helicopter.

Helicopter transport of an RTG (Photo: Office of the County Governor of Finnmark).

Scenario 1.a: Drop into the sea, structurally intact

If the RTG remains structurally intact (i.e. no significant cracks in the shielding or container) then there will be no water ingress. Even minor water ingress should not lead to significant loss of radioactivity, because there will be virtually no exchange of ^{90}Sr between the container and the surrounding water – once the container is full, there will be no advective or turbulent diffusion between the two, leaving just molecular diffusion through very small cracks. In this case, external radiation from the Bremsstrahlung will be the only significant contributor to radiation dose.

In the longer term, corrosion could degrade the container and shielding leading to a release of activity, and possibly increased direct irradiation; although this would be mitigated by radioactive decay (half-life of Sr-90 is 29.1 years). In effect, this is similar to Scenario 1.b, except that there could be a considerable delay, possibly years or even decades, before corrosion significantly degrades the container structure. Even then, the RTG shielding will protect the source for some time.

If there are no significant cracks in the shielding or container, then the external radiation at the surface will be similar to that currently measured. The external dose at the surface of an RTG was measured as 12 μSv/hour at the top and 5 μSv/hour at the side (NRPA, 1995). It is reasonable to assume that some species would reside close to the surface of the container, because they would be attracted by the heat. Nevertheless, the equivalent potential doses to fauna and flora would still be very much lower than recently suggested threshold levels for significant effects to biota.

Since there would be no significant escape of radionuclides from the container in this scenario, there is no pathway to human intake, at least in the short term.

Scenario 1.b: Drop into the sea, cracked RHS container and/or RTG

Even though the RHS container and RTG are cracked, there would have to be considerable damage for there to be a significant loss of radioactivity from the source. The seawater would get into the container, possibly reaching the source through cracks in the shielding. However, once the container was fully flooded there would probably be little exchange of ^{90}Sr. Moreover, the exposed area of the source would likely be only a small fraction of the surface area. Experiments have shown that dissolution from the surface of the pellets is very slow due to the source being fairly stable and not very soluble, and the high concentration of calcium (chemically similar to ^{90}Sr) in seawater (VNIITFA, 2004). Thus, the expected dissolution of radioactivity from the source would be slow.

Experiments on ^{90}Sr pellets without any shielding showed that the maximum dissolution rate from the source is about 1 μg/cm^2/day, after the initial loss of surface dust. We have conservatively assumed 2 μg/cm^2/day. If the entire source was exposed in equivalent conditions, then the dissolution rate would then be around 500 MBq Sr-90 per day. If this could easily disperse into the adjacent waters, then it could cause heavy contamination. Using dispersion calculations supplied by the Russians, the following concentrations have been derived, assuming a constant source over a long period (Table 4):

Table 4. *Concentrations in Sea Water (Bq/m^3) of ^{90}Sr from an exposed RHS source*

Vertical distance from source (m)	**Horizontal distance from source (m)**		
	1,000	**10,000**	**100,000**
1	11600	1000	35
5	1260	840	34
10	680	680	34
100	95	95	28

Thus, for example, benthic organisms within a kilometre of the source could experience Sr-90 activity up to 12 kBq/m^3, and fish swimming 10 m from the seabed could experience activity up to 700 Bq/m^3. These values are absolute maximums; actual concentrations are more likely to be at least 100 times lower.

Sr-90 generally accumulates in biota (mainly in the bones). For example, in fish, concentrations are around 17 times higher (per kg tissue) than in the water (per kg water). The concentration factor for crustaceans is around 25, and for mammals, such as seals and whales, it is around 320. For seals and whales, this gives a concentration of up to 360 kBq/kg, if they stay within 1 km of the source. Using EPIC internal dose conversion coefficients (EPIC, 2003) for seals, this corresponds to an internal dose rate of 40.7 μGy/hour. This is still below recently suggested threshold levels for biota and as this calculation is made using very conservative assumptions, it is concluded that internal doses will not be a significant hazard.

External doses may be higher due to the cracks in the RTG reducing the effects of shielding. External doses to humans on the RTG surface may be up to 10 mSv/hour. This would equate to doses to biota that were much higher than threshold doses. Also, the heat from the source could attract some species close to, or even on, the container surface.

In this scenario, the radioactivity could enter the food chain, specifically via fish which are subsequently eaten by people. This is not expected to be a significant source of doses to humans however. As noted previously, ^{90}Sr concentrates in the bones (which are generally not eaten) so only about 10% of the ^{90}Sr in the fish (gross weight) will be eaten in processed food. In order to reach the dose limit of 1 mSv/year, a 12-17 year old child (the most vulnerable group for ^{90}Sr intakes) would have to eat about 10,000 kg of frozen fish from the contaminated area in a year.

Scenario 2: Drop onto shoreline, cracked container and/or RTG

As for the two previous scenarios, there could be some release of radioactivity into the water. However, this should only occur for a very short period, because the RTG is likely to be recoverable. Before it is recovered, the losses from the RTG might be higher than in the offshore scenario, because there will be higher mechanical action of the water on the RTG (leading to greater mixing, and possibly more erosion and dissolution from the source), but the concentrations will quickly dissipate once the source is removed.

An RTG under helicopter transportation (Photo: Office of the County Governor of Finnmark)

Prior to removal, the RTG could give high external doses, as in Scenario 1.b; up to 10 mSv/hour at the surface, if the RHS is exposed. It would be accessible to terrestrial animals for a short period, as well as to humans. This could therefore exceed threshold doses, although probably only for a few days, at most, before the RTG is recovered. As for Scenario 1, the RTG could attract animals because of the heat given off, although there is no reason to believe this is more likely than when it was in use on land.

Scenario 3: Drop onto land, cracked container and/or RTG

This is a similar to Scenario 2, except that there would be no release to sea. There could be a very small release to land or streams if rainwater could get into the RTG and escape, but the period over which this might occur would be short before the RTG is recovered.

7 Environmental Impact Assessment

In this section, we shall review the environmental status in the area, related to previous discharges of radioactive materials.

Environmental status in the air

The atmospheric nuclear weapons tests in the late 1950s spread contamination mostly in the upper stratosphere. The radioactive material moved slowly to the lower atmosphere (troposphere) especially in the spring. The average residence time for radionuclides in the Arctic stratosphere was approximately one year.

The levels of radionuclides in the atmosphere have decreased since 1980 when the last atmospheric test was carried out by China. The levels increased again due to the Chernobyl accident in 1986 but have declined in recent years, though not as much as expected, possibly due to resuspension of radionuclides by wind.

Environmental status in the sea

A major contribution of radioactivity over time has been inflow from the rivers. Several large Russian rivers flow into the Arctic Seas (Ob, Yenisey and Lena), all of which discharge water from very large catchment areas. This has provided a large source of global fallout related radioactivity. In addition, there are three large military complexes (Mayak, Tomsk and Krasnoyarsk) which have river connections to the Kara Sea via the Ob and Yenisey Rivers. These facilities were used for the production of weapons-grade plutonium and have also been used for reprocessing radioactive wastes etc., closely linked to the Soviet nuclear weapons program. Operations at these nuclear facilities, which started during the late 1940s/early 1950s, have resulted in contamination of the local and far-field environments. At Mayak for example, about 100 PBq of high level liquid radioactive waste was discharged directly into the Techa River, which eventually discharges into the Kara Sea via the Ob River, during the period 1949 – 1956 (JNREG, 1997). Weapons-grade plutonium has also been documented at the outlet of the Yenisey River (Oughton et al., 2004), probably resulting from operations at the Krasnoyarsk facility.

From 1961 to 1990, annual mean concentrations in sea water show that the rivers have transported about 1.4×10^{15} Bq of ^{90}Sr to the Kara Sea (AMAP, 1997).

In addition to these sources, there are large quantities of spent nuclear fuel, and radioactive waste that have been bdumped in the vicinity of Novaya Zemlya.

Another major direct input to the marine environment has been from European nuclear processing plants like Sellafield on the shore of the Irish Sea. The releases of ^{137}Cs from Sellafield are virtually mirrored in the levels found in the Barents Sea with a time lag of five years. The levels peaked in 1980-85 (approximately 20-40 Bq/m^3) and had decreased to less than 5 Bq/m^3 in 1995.

As a result of the underwater nuclear tests in the period 1955 – 1961, the bottom sediment in areas such as Chernaya Bay (and south western parts of Novaya Zemlya) are contaminated by elevated levels of radioactive plutonium and caesium, as well as other radioactive isotopes. However, the mobility of radionuclides in sediment is low and at present may only cause insignificant exposure for people (AMAP, 1997). The concentration of radionuclides in the sediment has not increased in the Chernya Bay area and the concentration of e.g. plutonium is similar to other contaminated sites like Bylot Sound (where a B-52 bomber crashed carrying atomic warheads) and the Irish Sea.

Environmental status on land

Elevated levels of radionuclides have been measured in the Barents Sea area, both in soil and in biota such as lichens and in animals. This is mainly due to the atmospheric nuclear bomb testing, with the largest activity concentrations occurring before 1962. Large-scale accidental releases, like the Chernobyl incident in 1986, have contributed to the contamination, but to a smaller extent than the nuclear bomb tests.

Long-lived radionuclides in the air will eventually fall to the ground, or be washed out by rain and snow. Deposition levels therefore follow the same trends as the air measurements.

Lichens and mosses, with large surface areas that gather moisture directly from the air, are particularly effective in accumulating radionuclides from atmospheric fall-out. The levels of ^{90}Sr and ^{137}Cs in lichens in Greenland, Arctic Finland and Russia peaked in 1965-69.

The concentration of ^{137}Cs in reindeer meat peaked in the mid 1960s. After that, the levels decreased until the Chernobyl accident in 1986 when there were significant increases in Norway, Sweden and northwest Russia. The levels have now stabilized again and are expected to decrease slowly in the future (AMAP, 1997).

Summary

There are elevated levels of radionuclides in the atmosphere and in both the marine, freshwater and terrestrial environments in the Barents Sea area. The elevated levels are mainly due to the tests of nuclear weapons, both in the atmosphere, in the sea, on the ground and underground.

The levels peaked before 1980 and a decrease in the concentrations has been observed during the last 25 years, with the exception of the Chernobyl accident in 1986 which lead to temporarily increased levels.

7.1 Environmental impacts related to normal decommissioning operations of RTGs

The different steps in the process in transporting RTGs from the operating site and to the disposal site, have been described earlier (Section 2). The environmental risk associated with the transportation of RTGs has been discussed by scientists from the Russian Federation on Atomic Energy and the Ministry of Natural Resources and our independent assessment largely concurs with their findings.

The dominant radioactive material used in RTGs is strontium 90 titanate. It is a chemically stable fuel element that is not affected by extreme weather conditions or high temperatures. It does not adhere strongly to soil particles or to sediment and potential radioactive contamination will most likely end up in the water phase.

Being close to an intact RTG is considered a controllable health hazard as the radioactive material is well contained and shielded (AMAP, 2002). This conclusion is verified by Russian scientists in the Russian documents.

Decommissioning of RTGs, using safe methods will not contribute to elevated levels of radionuclides in the environment or pose a threat to humans, providing that vandalised RTGs or RTGs partially stripped of their protecting shielding are handled carefully to prevent excessive radiation exposures before being transported.

7.2 Environmental impacts related to accidental releases

The different Key Accident Scenarios have been described earlier in this report (Section 6). The scenarios considered are:

1. Drop into sea
    1.1. RTG intact
    1.2. RTG partly or totally broken
2. Drop onto shoreline or in very shallow seawater
3. Drop onto or accident on land

Damage to RTGs has happened during past few years, partly due to transportation accidents and partly due to theft of some of their components, usually the valuable metal shielding. The potentially dangerous effects to the environment are radiation effects if the RHS is exposed to air or water, either by natural degradation processes or by human activities.

At least three RTGs (Beta-M type) have been found completely dismantled with their protective covers stolen. The RHS were found close to the sites: one was found underwater at a depth of about 3 m, close to the shore, the second one was found near the shoreline while the third RHS was found in the sea about 200 meters from the lighthouse.

In addition to these incidents, some lighthouses have been reported vandalized with their RHS stolen. However, these RHS have supposedly been recovered later and sent back to VNIITFA.

Two RTGs are still lying on the sea bottom after helicopter incidents, both in the Sakhalin region.

As previously stated, the RTGs are well protected; the RHS does not dissolve in water and has a high melting point. The only source for radiation exposure is if the protection is partly or completely removed, either due to accidental drops or to vandalism.

7.2.1 Accidental releases to air

This is unlikely to happen as the ^{90}Sr-titanate fuel cell has a high melting point (~2060 °C) and a low evaporation rate up to 1200°C. The fuel is also stable when under conditions of burning / fire.

7.2.2 Accidental releases to soil

A dropped, or vandalized, RTG could in theory lead to exposure of the ^{90}Sr-titanate fuel source. As the material has a very low dissolution rate (about 10^{-6} g/cm^2/day) the potential for major contamination through dissolution is negligible. This is partly due to the fact that RTGs should be relatively easy to recover quickly once located on land.

7.2.3 Accidental releases to sea

There have been examples of RHS being dropped into the marine environment after the RTGs have been stripped of its metals. These have, as far as we know, mostly been recovered.

As previously stated, there are two RTGs accidentally dropped from helicopters that still have not been recovered. Samples of sea water in the areas where these were lost have not shown any increased levels of ^{90}Sr (AMAP, 2002). Over the longer term it is possible that the sea water will penetrate the protective layers and a contamination situation can occur. This can result in accumulation of ^{90}Sr by sea organisms and finally be a potential source of doses to humans via seafood.

If the RSH is totally exposed, the intensity of contamination from such an object can, because of low solubility, be counted as relatively constant. Our independent assessment suggests that such low dissolution rates and levels of activity are not likely to result in large concentrations in edible marine foodstuffs, nor will they deliver sufficiently large doses to ecological receptors to have a significant impact on aquatic populations.

8 Alternative options

8.1 Leave in Situ

One decommissioning option is always "Leave *in Situ*", meaning that the remaining RTGs should be left on their location and none should be transported and decommissioned at a final destination point. This will obviously minimise the risk of accidental radiation exposure during the transportation phase.

However, there are certain aspects of security and maintenance that would need to be identified, especially:

- **Present Status**. A complete survey of all RTGs along the Russian coast must be conducted to register the present status of the equipment and, importantly, their security and containment. Reports have shown that the status of some RTGs is unsatisfactory, some have been vandalised and /or attempted stolen.

- **Site Security**. Warning signs should be posted around the RTGs and there should be a physical structure (e.g. a fence) preventing people or animals gaining access to the RTGs.

- **Maintenance**. Any signs of corrosion or cracks in the protective shield must be repaired. Scavengers might have tried to remove parts of the protective shield.

- **Monitoring**. A monitoring programme should be established together with a programme for maintenance.

There are obviously several options involving partly decommissioning the RTGs: removing some of the RTGs which are in a bad state and leaving others *in situ*. However, an evaluation of the different options and a ranking is beyond the scope for this study.

The scavenging of scrap metal from RTGs (and other orphan sources) could result in whole or part RTGs ending up in scrap metal smelters. There is no information as to whether the Russian scrap metal industry have installed radiation detectors at scrap metal collection points and foundries to pick up such events, as recommended under the IAEA code of conduct on the safety and security of radioactive sources (IAEA, 2004).

8.2 Partial Dismantling and Disposal

Another option involves partial dismantling and disposal, defined as a removal of the RTGs from location and a transportation phase to the final destination without any dismantling of the protective shield or other components. Some of the pros and cons for his options are listed below:

- **Safety**. As the number of handling operations are reduced, excluding a step involving dismantling prior to sending the RHS to its final destination, this option will reduce the risk for accidents and operator exposure.

- **Security**. The risk of theft or vandalism will be reduced as no intermediate storage facility is needed.

- **Waste management**. The RHS is protected by a shielding composed of different metals depending on the type of the RTG. There are a few hundred kilos of valuable metals surrounding each RHS and as there is a general tendency in the community to try to reduce waste. Therefore, recycling these metals would be a good pro-option (and also saving money).

- **Site capacity**. The RHS part of the RTG is only a small percentage of the total weight and volume. However, if the protective shield is removed, the RHS must be kept in a suitable container. There is no information available to us on the size and costs of suitable protective containers.

9 Recommendations

The following recommendations are proposed:

- The level of control needed for containment of the sources and transfers of responsibility must be clear and a consistent approach to regulatory requirements and compliance set out and verified at all stages. The possibility of accidents at each stage of transport and their environmental implications and required remedial actions need to be assessed and certified as acceptable.
- An organisation chart should be prepared for the operation to reflect responsibilities during operation. If the project organisation changes during the operational steps, a proper handover must be ensured to transfer experience and to maintain cargo security. The number and competence of crews to be involved in each part of the operations should be specified.

- The stepwise operational procedure described in the Russian documents should be clarified and a checklist prepared as a means to ensure that necessary preparation has been taken place, and that required equipment is in place and in a condition as specified for the task. Identified risks to be highlighted for each operational sequence. The checklist should be signed off by the responsible person. It should be considered that the procedure and checklist is accompanying the RTG package until it has reached the final destination. The procedure should be based on existing reports and analysis performed for the project.
- A pre-job briefing should be performed to ensure that involved personnel fully understand the tasks and sequence of events.

- Contingency plans for the removal of a leaking or damaged source are not included in the submitted documents and are assumed to be contained elsewhere. They should cover procedures for the protection of workers and the general public in the event that such a situation is found when arriving at the site. The operators should be equipped with suitable monitoring equipment to help determine whether any additional hazard exists and the RTG is breached. If so, the most important first step will be to make the source safe. This could involve establishing an exclusion zone, the use of remote handling equipment and additional shielding.

- Confidence that the overall control system works would be enhanced by the inclusion of previous evidence that the work involved with the de-commissioning of RTGs, their transportation, the conditioning of the radioactive sources and their placement in temporary storage awaiting disposal, has:
  - been achieved without incident or non-compliance with the certification processes required for the many intermediate stages of the work and
  - demonstrated that interaction between civilian and military authorities has worked well.

- To comply with international best practice (IAEA, 1996; 2003; 2004) the competent authorities should be able to provide a list of all of the RTGs in service and storage with evidence of an auditable record system that demonstrates control of the sources by named holder, activity, date of acquisition or disposal and annual leak tests. Demonstration of secure storage/ emplacement is also a requirement. A system for recovery and disposal of orphaned sources is also required. Because of the remote location of the RTGs there is evidence of a loss of control of the sources that this project is addressing. The time scale for the completion of the project is long and there is a requirement to improve security of these sources as soon as possible.

- Transport safety is very important to minimise risks of accidental exposures. Therefore, helicopter transport where RTGs are suspended under the aircraft should be carefully considered and preferably over short distances.

10 Conclusions

As the ^{90}Sr heat source is well protected in a RTG of good stand it is deemed highly unlikely that a hypothetical accident connected to the planned decommissioning of RTGs will cause radiation exposures to the surroundings. If, in the unlikely event of a breach being caused to the RTGs multiple protective layers during an accident, the ^{90}Sr source is exposed to air or water, the resultant spreading of radioactivity will be very limited due to the low solubility of the ^{90}Sr titanate matrix. The ^{90}Sr titanate also has a high melting point, indicating that the risk of radioactive contamination due to fires is also negligible.

Considering the accident scenarios reviewed in this report, the likely worst-case for humans would be direct contact with an exposed ^{90}Sr heat source. However, in this instance it is also likely that the exposed RHS will be localised quickly and the proper authorities can then ensure the safe removal of the RHS. In the event of an RHS being lost in the sea during transport, it is considered not to be worthwhile searching extensively for the RHS to attempt a removal, though the surrounding area could be monitored to check if any radioactive contamination occurs.

In the event of somebody tampering with an unmonitored RTG (especially the type Beta-M, where the casing might be screwed together, not welded), it is possible that they will receive high, perhaps lethal doses if they expose the ^{90}Sr heat source. To improve security around the RTGs, it is suggested that appropriate fencing should be installed around RTGs with warning signs that make clear the hazardous nature of the RHS. Additional welding, especially on Beta-M RTGs that are not designated for removal during the first stages of the current decommissioning programme, could also ensure the security of the RHS. The decommissioning and replacement of all RTGs along the Russian Artic coast is a long-term project. Therefore, increased security and monitoring of RTGs is of paramount importance.

This report concludes that the decommissioning project should continue, as leaving the RTGs unmonitored and in situ could potentially lead to a risk of undesired access to radioactive materials. However, it is important to ensure that the relevant authorities and organisations are clear over their separate responsibilities throughout the entire process of inspecting, collecting, and dismantling of the RTGs, as well as storage and disposal of the radioactive waste generated from decommissioning. Radiation protection guidelines should be reviewed and amended where necessary with correct procedures and checklists to ensure compliance.

As a first step in working with the regulatory aspects of RTG decommissioning, the NRPA has recently started a new cooperation with NIERA. The aim of this cooperation is to upgrade the existing regulatory framework of the Russian Federation for the safe decommissioning and disposal of RTGs, with a focus on the following priority areas:

1. Regulatory requirements and regulations,
2. Licensing and authorisations,
3. Supervision over the radiological safety, and
4. Emergency preparedness.

Other areas such as preparation and certification of the personnel and information to be made available to the public may also be considered during this collaboration.

A new lighthouse running off solar power

(Photo: Office of the County Governor of Finnmark).

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