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Risk and environmental impact assessments for the decommissioning of radioisotope thermoelectric generators (RTGs) in Northwest Russia

Statens strålevern
Norwegian Radiation Protection Authority

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Key words:
RTG, NW Russia, Strontium-90, decommissioning, risk and environmental impact assessment.

Abstract:
The report gives an overview of the risk and environmental impact assessments received through the Norwegian-Russian decommissioning project of RTGs in NW Russia. A number of 180 RTGs have been removed from NW Russia between 2001–2009.

Referanse:
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Emneord:
RTG, nordvest-Russland, strontium-90. driftsnedlegging, risiko – og miljøkonsekvensvurdering.

Resymé:
Rapporten gir en oversikt over risiko og miljøkonsekvensvurderinger mottatt gjennom det norsk-russiske prosjektet om driftsnedlegging av radioisotopiske termoelektriske generatorer (RTGer) in nordvest-Russland. 180 RTGer har blitt fjernet fra nordvest-Russland mellom 2001–2009.

Head of project: Ingar Amundsen.
Approved:

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Per Strand, director, Department for Emergency Preparedness and Environmental Radioactivity.

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Risk and environmental impact assessments for the decommissioning of radioisotope thermoelectric generators (RTGs) in Northwest Russia

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Protection Authority
Østerås, 2009

Acknowledgement

Norway's cooperation with Russia is aimed to improve the safety of waste storage facilities and nuclear installations to reduce the risk of future accidents, emissions and radioactive contamination. One important part of this work has been accomplished through the Norwegian-Russian RTG decommissioning project in Northwest Russia between 1998 and 2009.

The authors would like to express thanks to Per-Einar Fiskebeck at the Office of the County Governor of Finnmark and to colleagues at the All Russian Scientific Research Institute of Technical Physics and Automation (NIITFA) and Atomengineering for information received about risk and environmental impact assessments of the Norwegian-Russian RTG decommissioning project. We would also like to express thanks to all the collaborative organizations involved in the project (the Murmansk Regional Administration, the Russian Navy and other organizations). We would especially like to express our thanks to the Russian regulatory body Roztechnadzor for successful collaboration throughout the project.

Contents

1 Introduction

The Nuclear Action Plan is the Norwegian Government's most important instrument for collaboration with Russia concerning nuclear safety and the prevention of radioactive contamination as a result of nuclear activities in Northwest Russia. The main aim of the Nuclear Action Plan is the protection of health and the environment from potential accidents and releases from waste storage and nuclear facilities in Northwest Russia. The Norwegian Ministry of Foreign Affairs has had an administrative role in implementing and running the Nuclear Action Plan since it was implemented in 1995. As of January 2009, Norway has granted NOK 1.4 Billion for work on nuclear safety in Northwest Russia. The Norwegian Radiation Protection Authority (NRPA) has a role in advising the Ministry regarding the priorities and quality assurance of specific Nuclear Action Plan projects. In that respect, the NRPA examines impact assessments relating to measures included in the Nuclear Action Plan with a view to minimising the likelihood of accidents and adverse effects on health and environment.

A RTG in Northwest Russia ready for decommissioning (Photo: County Governor of Finnmark).

Since the early nineties, significant results have been achieved regarding the safety of Russian nuclear power plants and the handling, transport and storage of spent nuclear fuel and radioactive waste. Wider cooperation between the Norwegian and Russian supervisory and administrative authorities and regulators has also developed over this period.

A RTG lighthouse in Northwest Russia replaced with solar panel (Photo:The County Governor of Finnmark).

More than 1000 Radioisotope Thermoelectric Generators (RTGs) were manufactured in the former USSR mainly for the purposes of power provision for sea navigation and meteorological facilities. About 60 % of these have subsequently been removed (Kurchatov Institute, June 2009). The removal and safe disposal of RTGs and their replacement with solar panel technology in Northwest Russia is a priority area under the Nuclear Action Plan.

In 2005, a Memorandum of Understanding was signed by the Norwegian Ministry of Foreign Affairs and the Federal Atomic Energy Agency of the Russian Federation [1]. This provided the basis for the provision of funds by the Norwegian Ministry of Foreign Affairs for the dismantling of all RTGs in lighthouses in the counties of Murmansk, Arkhangelsk and the Nenetsk Autonomous Area (including Novaya Zemliya), and their replacement by solar panels or other alternative power supplies.

As of 1 January 2001, there were 180 RTGs in the Murmansk, Archangelsk and Nenetsk regions, including Novaya Zemliya, being used as power sources for lighthouses and sea beacons. In the Murmansk region there were 85 RTGs, in Arkhangelsk there were 64 RTGs, on Novaya Zemliya there were 4 RTGs and in the Nenetsk region there were 27 RTGs. The last remaining RTGs in Northwest Russia were decommissioned in September 2009. The present NRPA report provides an overview of the process of examining risk and environmental impact assessments for RTG decommissioning in the aforementioned regions between 2004 – 2009.

Map showing regions of interest in Northwest Russia in the Norwegian-Russian RTG decommissioning project from 1998 to 2009.

2 Background

2.1 Radioisotope Thermoelectric Generators (RTGs)

An RTG is a radioisotope device which transforms thermal energy from the decay of radioactive material into electricity. In Russia, RTGs are used in areas with harsh climatic conditions to supply power for unmanned automatic navigational aids such as lighthouses, radio beacons, and luminescent navigation markers. These are located on remote parts of the coast, on islands or in other areas where the use of conventional power sources is impracticable. Russian RTGs utilise large radioactive sources containing strontium-90 (Sr-90).

A RTG in Northwest Russia (Photo: County Governor of Finnmark).

2.1.1 Technical overview

Several types of RTGs were produced during the late 1970's and 1980's, although all types are based on a Radioisotope Heat Source (RHS). An RHS typically contains more radioactive material than the types of radioactive sources that may be encountered in typical industrial and medical applications. The RHS needs to be sealed within a multi-layered shielding system constructed of heat and corrosion- resistant materials. Figure 1 shows a schematic illustration of a typical RTG used in Russia. The RHS is shrouded with a cladding material of chromium-nickel steel surrounded by internal radiation shields utilising depleted

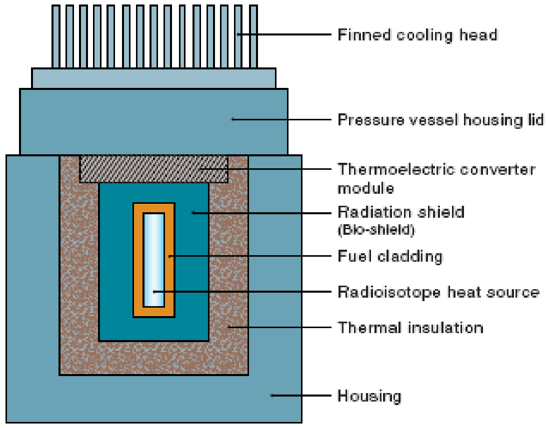


Figure 1. *Schematic illustration of a typical RTG [2].*

uranium, tungsten or sometimes lead. The robust multi-layer design of the RTG provides significant physical protection and thermal and radioactive shielding. Many RTG designs are hermetically sealed by argon arc welding of the inner and outer covers [18]**.** The Russian RTGs have a operational lifespan of between 10 and 20 years and a maximum surface temperature of about 500°C.

Sr-90 in the titanate form [$SrTiO_3$] is the primary material used as fuel in Russian RHSs. This is a solid ceramic material that is fire-resistant and has low solubility in water. Both the radioactive isotope Sr-90, with a half-life of 29.1 years, and its daughter nuclide, Yttrium-90 (Y-90) with a half-life of 64 hours, are beta-emitters and produce heat energy from their radioactive decay. However, x-rays can also be emitted as bremsstrahlung when the beta radiation is absorbed in nearby materials.

The number of high density solid fuel pellets of Sr-90 in the RHS is different for the various types of RTGs. RTGs also differ with respect to the output electric voltage, output electric power, mass, dimensions, activity and components of shielding, etc. Some of these parameters for different types of RTGs are shown in Table 1.

	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

Table 1. *Types and main characteristics of Soviet-designed RTGs [3].*

The RHSs typically contain activities ranging from 0.74 PBq (20 kCi) to 14.8 PBq (400 kCi), depending on the type of RTG [4, 5]. The most commonly used RTG type, Beta M, one of the first RTGs developed, contains a single pellet with an approximate activity of 1.3 PBq (35 kCi).

The composition of the RTGs and RHSs are demonstrated in the photographs to the right. The photograph on the top shows opened RTGs (with the Sr-90 heat sources extracted) and stripped of cooling fins at NIITFA. The photograph at the bottom shows the different types of casings for pellets (Sr-90 heat source) extracted from RTGs as well as a cut-away showing where the Sr-90 pellets are held.

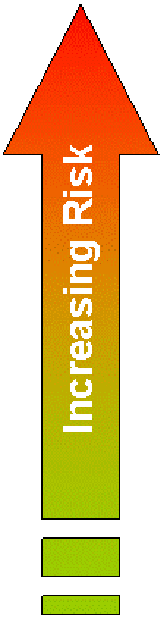
2.1.2 Security

The relatively limited physical protection around the RTGs and lack of maintenance and control make them easily accessible for intruders. The RTG is categorized by the International Atomic Energy Agency (IAEA) as one the radioactive sources with highest activity and therefore highest risk, as shown in Table 2 [6]. One reported problem with the Beta-M type design is that the components

Opened RTGs (with the Sr-90 heat sources extracted) stripped of cooling fins at NIITF (Photo: NRPA).

Different types of casings for pellets (Sr-90 heat source) extracted from RTGs as well as a cut-away showing where the Sr-90 pellets are held (Photo: NRPA).

Categorization of Radioactive Sources - IAEA Safety Standards



Category	Practice
1	RTGs; Irradiators Teletherapy; Gamma Knife
2	Gamma radiotherapy Brachytherapy (HDR/MDR)
3	Fixed industrial gauges (High-activity sources) Well logging
4	Brachytherapy (LDR exept eye plaques & permanent implants) Gauges (not high activity); Static eliminators; Bone densitometers
5	Brachytherapy (eye pl. perm implants; XRF; ECD)

Table 2. *Categorization of radioactive sources where category 1 shows radioactive sources with highest risks [6].*

are sometimes screwed together, not welded, leaving the RTG much more prone to tampering. A number of attempted thefts in recent years of steel metal parts from RTGs has demonstrated the potential for such radioactive sources to go astray. By removing the RTGs and replacing them with solar cell technology, the danger of loss and contamination of the environment is reduced.

Radiological hazard as a result of unauthorised trespassing

The primary risk to health and the environment associated with RTGs is radiation exposure from an RHS following the removal or destruction of the outer casing and shielding. This potential risk has been exacerbated in recent years by insufficient regulation and control of the RTGs. Risk to the environment can also arise as a result of transportation accidents during the decommissioning process.

Due to its half-life of 29.1 years and the high levels of radioactivity involved, the Sr-90 fuel pellet can pose a radiological hazard for many decades. As relatively strong beta emitters, Sr-90 and Y-90 present two potential external radiation hazards via the beta rays themselves and the radiation they induce by interaction with the source and adjacent materials.

Direct skin contact with the RTG core, the RHS, may give rise to serious and sometimes life threatening burns depending on the strength of the source and the time spent in its vicinity. The radiation dose rates at the surface of an unshielded core can reach 10 Sv/h, which has the potential to deliver a lethal dose to humans within half an hour of exposure (see Table 3 for external radiation doses from shielded and unshielded Sr-90 sources).

There have been several break-ins and thefts from RHS 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 lack of legislation and regulatory supervision of the sources on the part of the Russian authorities.

As an example, in 1999 an RTG was found at a bus stop in the town of Kingisepp in the Leningrad region. It had been partially dismantled and the radiation dose rate at the surface of the core was 10 Sv/h upon recovery.

External Radiation Doses from RTGs			
	With shielding (design limit)	**With shielding** (measure of a typical Beta M RTG, NRPA 1995)	**Without shielding**
Surface Dose	0.002 Sv/h	0.000012 Sv/h	10 Sv/h
Dose 1 m from the source	0.0001 Sv/h	-	> 0.010 Sv/h

Tabell 3. *External radiation doses from Beta-M type of RTGs [4].*

In the summer of 2001, four people were hospitalised after receiving radiation doses during an attempt to dismantle the lighthouse near Kandalaksha, in Murmansk region. Three Beta M types of RTGs were found to have been stripped for valuable shielding material.

A group of woodcutters in Georgia found two unshielded Sr-90 sources in December 2001. The workers used the sources as "heaters" and were exposed overnight experiencing severe radiation burns and hospitalisation as a result.

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 found a number of RTGs in a nearby forest which had been installed during the Soviet period.

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, it was considered unlikely that any environmental harm would result, apart from to the 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-90 pellets and 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 on the Kola Fjord had been dismantled. The core had been left behind while the shielding material was 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.

In 2004, a RTG of the 1EU-1 type, which had also been stripped of shielding material, wasfound on the Island of Golets, not far away from Arkhangelsk.

In 2006, an RTG of the type IEU-2 was found at the Kola Bay where the surface exposure rate was 4 times greater than the normal level due to damage to the radiation shielding material. A special container for this RTG was constructed *in situ*.

All of these incidents demonstrate the importance of the safe removal of RTGs from the Russian Arctic coast. So far break-ins have been motivated by attempts 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 easily terrorists could gain access to radioactive materials [4, 5, 11, 15, 32].

Malevolent acts

Orphan sources (sources that have been misplaced or are out of the control of the responsible person) are a radiation hazard in their own right. They could also hypothetically be utilized by terrorist or other organisations with the intent to cause harm. A potential use could be as a Radiological Dispersal Device (RDD) (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 device could be to cause public anxiety or even worse, lethal outcome. Damage caused by the conventional explosives would be the most immediate effect of such a detonation, but the long-term effects arising from the radioactive component of such a bomb might also be severe, dependent on the area affected; the resultant radioactive contamination could affect the area for years or even decades. The most severe tangible impacts of an RDD are likely to be the consequent social disruption, the subsequent clean up of the contaminated area and economic costs.

There has been one report, by the Russian Ministry of Transportation's State Hydrographic Service (SHS), of an RTG explosion experiment using a powerful anti-ship explosive device [3]. The RTG was apparently destroyed, but the RHS, which was contained in it, remained undamaged [4].

Due to consideration of the aspects outlined in the next sections, it is essential to mention that RTG decommissioning in Northwest Russia has been a priority area under the Norwegian Government’s Nuclear Action Plan.

2.2 Nuclear Action Plan

The Joint Norwegian-Russian Expert Group (JNREG) was established in 1992 under the Joint Norwegian-Russian Commission on Environmental Protection. The main intention of the group was to focus on radioactive contamination in the Barents and Kara Seas. During the early 1990’s, the JNREG focused on the issue of nuclear safety in Northwest Russia. As a result of these activities, the Norwegian Government decided to establish the Nuclear Action Plan in 1995 to address the nuclear challenges in areas adjacent to or potentially affecting Norwegian territory.

The main focus areas in the Nuclear Action Plan are as follows:

- Emergency preparedness and environmental monitoring;
- Cooperation with Russian authorities;
- Non-proliferation and physical protection;
- Nuclear power plants;
- Spent nuclear fuel;
- Radioactive waste;
- Radioactive sources;
- Chemical weapons.

The Nuclear Action Plan was last revised in 2008 [7]. The following high level guidelines were presented by the Norwegian Government and are the basis for subsequent nuclear safety activities in cooperation with Russia. Such cooperative activities should:

- Reduce the risks of accidents and radioactive contamination from nuclear installations in Northwest Russia and prevent proliferation of radioactive materials;
- Be based on a holistic view and on risk and environmental impact assessments;
- Contribute to strengthen emergency preparedness;
- Focus on cost-effective practical work;
- Contribute towards strengthening Russian administration and administration organs;
- Contribute towards strengthening the dialog between responsible Russian regulatory bodies and the civil society concerning goals and means in the nuclear safety work;
- Be carried out with respect to Russian legislation, international norms and guidelines and in close dialog with all concerned supervisory regulations in Russia and with other donor countries.

At present Norway contributes to four main areas of commitment concerning nuclear safety activities in Russia:

- Co-operation between authorities in Russia and Norway;

- Removal and decommissioning of RTGs;
- Decommissioning of nuclear powered submarines;
- Rehabilitation of storage facilities at Andreev Bay.

The organization of work related to the Nuclear Action Plan is divided between the *Norwegian Ministry of Foreign Affairs*, *NRPA* and, the *project manager*, as illustrated in Figure 2. The Ministry of Foreign Affairs has the superior responsibility in forming strategies and priorities for the work. The nuclear safety work in cooperation with Russia is funded by yearly earmarked funds through the budget of the Ministry of Foreign Affairs. The NRPA has a directorate role in carrying out the Nuclear Action Plan within the areas of radiation protection, nuclear safety, emergency preparedness, non-proliferation and radioactive contamination.

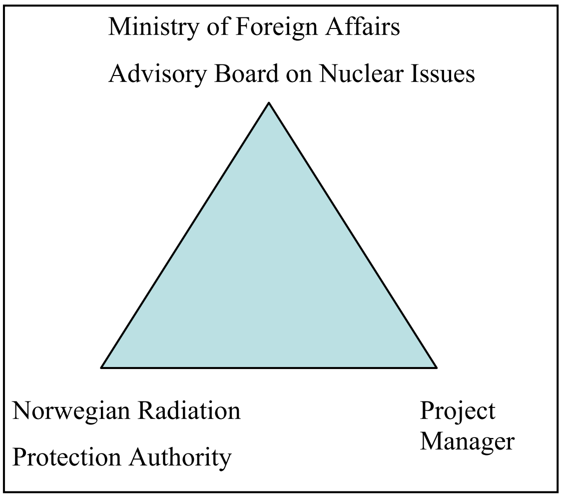


Figure 2. *Organization of the work related to the Norwegian Government's Nuclear Action Plan.*

The NRPA has established extensive collaboration with a number of Russian regulatory and supervisory authorities. The responsibility of the project manager is to make sure that the projects are carried out in a safe and secure way and within the planned timeframe and budget. In the process of choosing the project manager for a certain project, it is essential to consider the manager's competence for cooperation with Russia. The Office of County Governor in Finnmark, Rambøll & Storvik, the Norwegian Defence Research Establishment and Institute for Energy Technology are some of the project managers from the Norwegian side.

2.3 Norwegian focus on Risk- and Environmental Impact Assessment for nuclear safety projects in Northwest Russia

An Environmental Impact Assessment (EIA) is a systematic review of all phases of planned work with the goal of obtaining an overall overview of the work's potential consequences on the environment and health. Such assessments are also used to determine priorities and for planning how the work can be carried out to minimise the risks. A risk assessment is a process of evaluating a potential hazard, likelihood of suffering, or any adverse effects.

Risk assessments and EIAs are carried out as part of the decision making process and should take account of both alternative methods and systems for minimising possible consequences, so that the best environmentally executable approach can be chosen. An EIA should take account of man and the environment in general. Such an assessment should include consideration of individual and collective consequences, both for those involved in the work and for the general population in the area. These assessments should differentiate between the effects on the environment and health associated with planned actions and those due to unplanned incidents. Other factors can also be taken into account, such as the economical effects.

The Norwegian Parliament Decision on EIAs of May 12th 1999 requires EIAs on activities involving risks for radioactive contamination prior to allocation of funding. The objectives for performing and reviewing risk assessments and EIAs are to:

- Improve the safety and security of radioactive sources and waste.
- Reduce potential environmental radioactive contamination.

- Ensure that activities are carried out in accordance with international recommendations and Russian laws [8].

The EIAs received from Russian collaborators have provided an insightful view of projects in the planning phase. For decommissioning of RTGs, the assessments deal with the environmental, health and safety aspects of the decommissioning process: from the inspection and dismantling of RTGs to delivery of the dismantled radioactive sources to their designated locations.

In the later years of the Nuclear Action Plan, risk assessments [30, 31] were undertaken for the transport of RTGs from Murmansk Oblast to the All Russian Scientific Research Institute of Technical Physics and Automation (NIITFA) in Moscow, where the RTGs are handled before final disposal. The transport includes transfer of the RTGs from the places of origin to ship by crane trucks, barges[1] and helicopters and further to trucks and railcars. Information regarding planned working procedures and associated dose rates and accident scenarios for the transhipments and temporary storage of RTGs were included in the EIAs received between 2004-2009 [18-29]. Figure 3 shows the steps in the risk assessments and EIAs.

Close contact between the developer of the EIAs and the governmental bodies responsible for health protection and environmental issues and nuclear safety is essential. In fulfilling these criteria, meetings between the NRPA and Norwegian and Russian project leaders (and the relevant cooperating donor countries) are held on a yearly basis to initiate that years' project. The first version of the EIA from the Russian party is received prior to the meeting. The NRPA undertakes a review of the EIA (in cooperation with the other donor countries) and requests additional information if necessary. The final version of the EIA is then prepared and reviewed, on the basis of which the NRPA makes recommendations to the Norwegian project leader for carrying out the project. The reviewing process of EIAs has contributed to strengthening the contact between the respective technical and regulatory authorities in Norway, Russia and other countries. The NRPA maintains close contact with the Russian regulatory authority (Rostechnadzor), throughout this process.

2.4 International Focus on RTG Decommissioning

A Contact Experts Group (CEG) for International Radwaste (Radioactive waste) Projects was established under the auspices of the IAEA in 1996 with the objective of promoting international cooperation and assistance in the field of resolving problems caused by radioactive waste and spent nuclear fuel left as a Cold War legacy in the Russian Federation.

The NRPA and the CEG Secretariat, in close cooperation with Rosatom[2] (the Russian Nuclear Energy State Corporation) organised a workshop on "Security and Safety of Radioactive Sources: Decommissioning and Replacement of RTGs" in Norway in February of 2005. The CEG workshop was attended by representatives from 9 Western countries, the Russian Federation, Japan and three international organisations: IAEA, the European Commission (EC) and the Nordic Environment Finance Corporation (NEFCO).

The workshop provided the basis for the establishment of an international coordination working group on RTG decommissioning under the leadership of Rosatom. As a result of this, the working group met in Russia in April 2005. The need for and desire for such a working group was also emphasized during the CEG workshop on "Problems of Decommissioning of RTGs" held in Russia in April 2008, and the working group was re-established as a result. This led to further meetings of the working group in September and December 2008 and in June 2009. At these meetings, the representatives of Western countries and the Russian parties provided information on the state of international cooperation (covering projects and regulatory issues) and plans for further activities on resolution of the RTG management problems in the Russian Federation.

[1] A barge is a type of a large, flat bottomed, scow suitable for transporting heavy loads.

[2] Previously Minatom (1992-2007).

Figure 3. *Steps in the risk and environmental impact assessments of the decommissioning of RTGs under the Nuclear Action Plan.*

In 2007, the Kurchatov Institute prepared a Master Plan for Decommissioning, Replacement with Alternative Power Sources and Disposal of RTGs for the Russian Federation [9]. The Master Plan was developed with financial support from Canada. In 2008, the Kurchatov Institute prepared the Developement of the RTG Master Plan 2007 and the plan for urgent measures for RTG management [10]. Based on these plans, the USA financed the preparation of the Draft Action Plan 2008 for implementation of the Master Plans on RTGs. These plans intend to serve as documents for the purpose of collaboration in the decommissioning of RTGs in the territory of the Russian Federation. The removal and safe deposition of RTGs in Russia has been a priority area for Norway and other donor countries, such as US, Canada and France. At present, about 400 RTGs remain in the territory of the Russian Federation, as shown in Figure 4 (Kurchatov Institute, June 2009). In Russia, RTGs have been located in four main regions: the Baltic region, the North-European region, Northern Sea Route and Far East. The distribution of total activity of operating RTGs in the Russian Federation in early 2007 is shown in Figure 5. In the Baltic region (Finnish Bay and Kaliningrad Bay), the Russian Navy financed the removal of 11 RTGs in 2007. The remaining 87 RTGs have been equipped with alarm systems, sponsored by the US Department of Energy. The RTGs in the Baltic region are owned by the Hydrographic Service of the Baltic Fleet of the Russian Navy.

The North-European region includes the coasts of the Barents and White Seas, and a small section of the Kara Sea coast. Since 2001, Norway and other countries, notably France and Canada (sponsored removal of 5 RTGs each through Norway), have rendered financial support for RTG decommissioning activities in this region. By the end of 2009, a total of 180 RTGs will have been removed from the Murmansk, Arkhangelsk and Nenetsk regions (including Novaya Zemlya) in Northwest Russia, mainly by Norwegian financial support. These RTGs were owned by the Hydrographic Service of the Northern Fleet of the Russian Navy and by the Ministry of Transport.

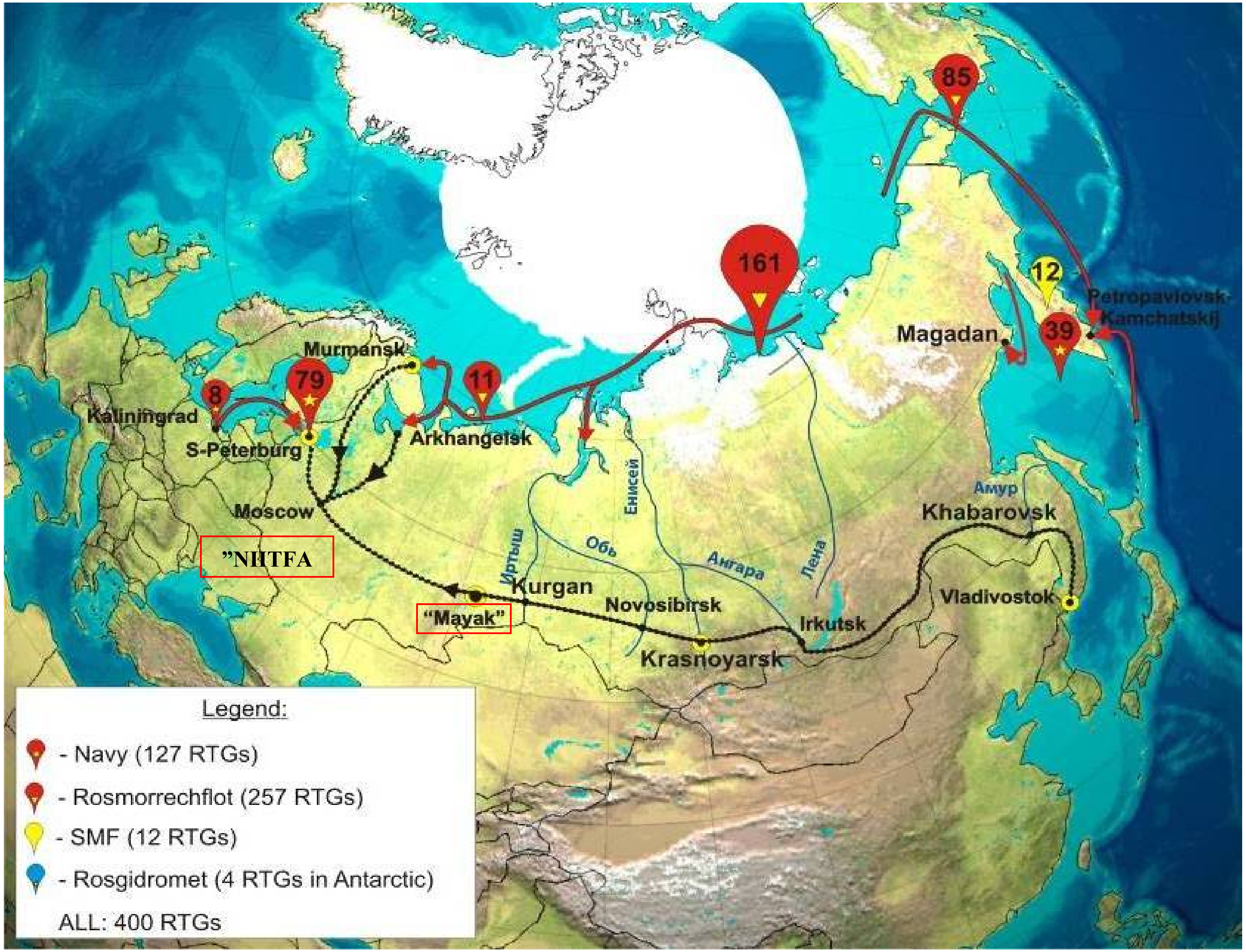


Figure 4. *A schematic map of the remaining RTGs in the territory of the Russian Federation showing the transport routes from the site of removal (red, yellow and blue markers) to the dismantling (NIITFA) and disposal (Mayak PA) facilities (Kurchatov Institute, June 2009).*

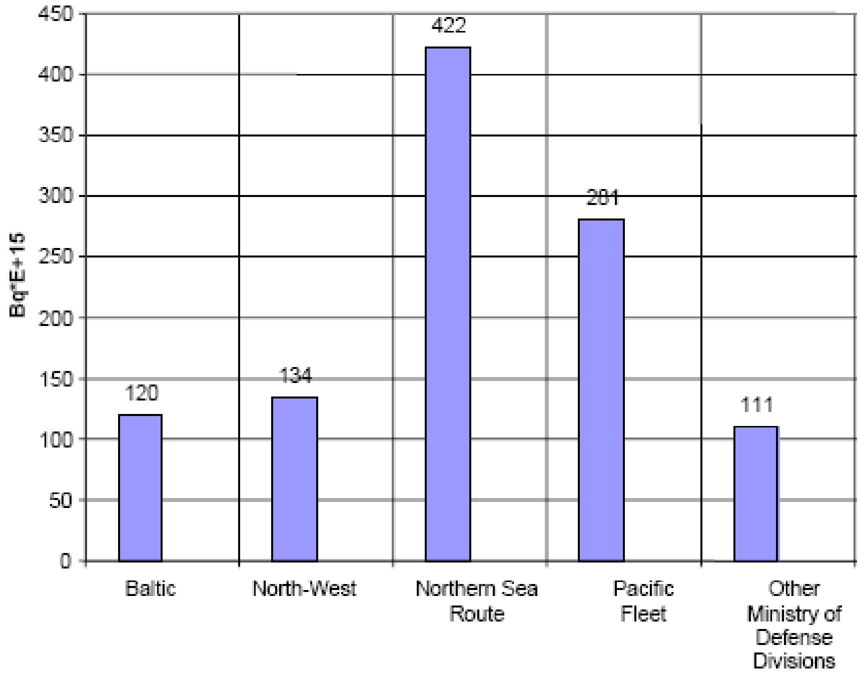


Figure 5. *Distribution of total activity of operating RTGs in the Russian Federation in early 2007 [9].*

The work in the Northern Sea Route (from the Barents Sea to Chukotka, including the Pacific coast of Chukotka) has been sponsored by the USA with financial assistance from Canada. The RTGs on this sea route are owned by the Hydrographic Enterprise of Rosmorrechflot under the Ministry of Transport.

The Far East region is stretched from Vladivostok in the South to Anadyr in the North. The USA has been sponsoring work in this region since 2005. The RTGs found in this region are owned by the Hydrographic Service of the Pacific Fleet of the Russian Navy.

2.5 Russian Regulatory Framework

The Russian regulatory regime consists of several stakeholders where the Government of the Russian Federation is the fundamental base. The Federal ministries are mainly responsible for legislative activity in their sphere and the coordination of subordinate agencies and services. The federal agencies are mainly responsible for licensing, permits, etc. in their established sphere. The federal services have controlling functions.

Such a service is *Rostechnadzor* which is the Federal Environmental, Industrial and Nuclear Supervision Service of Russia. Roztechnadzor last upgraded the regulatory framework for the safe decommissioning and disposal of RTGs in collaboration with the NRPA in 2007. The main intention behind this upgrade was to take account of the magnitude of the problem, the high hazard associated with the RTGs, the upcoming work on their decommissioning and disposal, and the lack of experience in this area. The upgrade of the regulatory framework involved focusing on the regulatory requirements and regulations and the threat/hazard assessment needed to license the activity and authorisations (permits) for employees of the operating organisations. Further, the importance of supervision regarding radiological safety and emergency preparedness was also emphasized. Other important topics were physical protection during RTG decommissioning and EIA review for RTG dismantling, transportation, temporary storage and disposal [5, 17].

The Russian legislation regarding EIA is based on the 1991 Environmental Protection Law, the 1995 Federal Law on Ecological Expertise and the legislation adopted pursuant to these laws and normative acts of the Russian Federation. According to the Federal Law on Ecological Expertise, all documents presented on ecological matters in Russia must include an EIA [8]. The regulatory requirements of the Russian and Norwegian systems are similar and accord generally with international practice. General safety standards are similar to those recommended by the IAEA Basic Safety Standards [14].

3 Environmental Impacts and Risk Assessment

Since the inception of initiatives towards the removal and replacement of RTGs as power sources, the NRPA has been in receipt information from the relevant Russian bodies. This demonstrates an awareness of the potential health and environmental impacts at each step in the RTG decommissioning process. For each year since 2004 formal EIAs and risk assessments have been prepared [18-29].

The EIAs for 2004 and 2005 presented detailed annual plans for RTG decommissioning, but from 2006 onwards the EIAs addressed a forward 3-year projection), together with the locations, condition and number of RTGs to be removed and dismantled. The EIAs from 2004-2009 also provided information as to transport requirements and routes, and the organisations involved in the decommissioning process.

The risks associated with each of the steps in the decommissioning process were addressed for each RTG to take account of location, history, operating and physical condition of the unit, methods of transportation appropriate etc.

In general the EIAs and risk assessments were designed such that they:

- Identify possible adverse impacts, prior to undertaking activities;
- Offer alternative courses of action, where appropriate.

Such information was prepared by the NIITFA and made available to the NRPA for review. In general the level of information provided increased throughout the programme. For instance, optimisation of ecological and radiation safety during the RTG decommissioning work was included explicitly within the EIA in 2005 [21, 25]. External dose rates (both in proximity to the RTGs and at locations relevant to transport considerations) were included in 2006 [22]; and comparison of transport routes was introduced from 2007 [30, 31], partly as a consequence of the different transportation routes available for different locations. Furthermore, there has been evidence that the work procedures were improved during the course of the programme, with consequent reduction of the risks, as a consequence of experience gained.

General provisions related to the transportation of radiation sources and specific requirements for the transportation of RTGs by certain routes have also been provided to the NRPA. Such provisions include detailed requirements as to packaging, labelling and external dose rates. As an example of such requirements, the gamma dose rate at the package surface is required to not exceed 2 mSv/h, while that at 1 m should be less than 0.1 mSv/h.

The main steps in the RTG decommissioning process are described in the following section in relation to the EIA and risk assessment process. Hereafter, "EIAs" will indicate a collective term for the suite of EIAs provided to the NRPA between 2004 and 2009.

3.1 Overview of Decommissioning of RTGs: Operational Procedures

In general, a number of distinct steps can be identified in the decommissioning process (see Figure 6 [10]):

- Inspection of RTGs in-situ, to determine status.
- Removal of RTGs from their operational locations and transport to a temporary storage point (step 1-3 in Figure 6).
- Transfer from the temporary store to a dismantling facility (step 4 in Figure 6).
- Extraction and packaging of the RHSs (step 5 in Figure 6).
- Onward transport of packaged RHSs for processing and extended storage (step 6 in Figure 6).
- Processing of RHSs for extended storage prior to disposal (step 7 in Figure 6).

All steps of the decommissioning work are subject to safety rules and norms. Most steps are required to be conducted in accordance with a system of job permits and under supervision. The assessment and hazard reduction measures identified for each step are summarised in the following sections. Where relevant, specific requirements relating to different RTG types are also summarised.

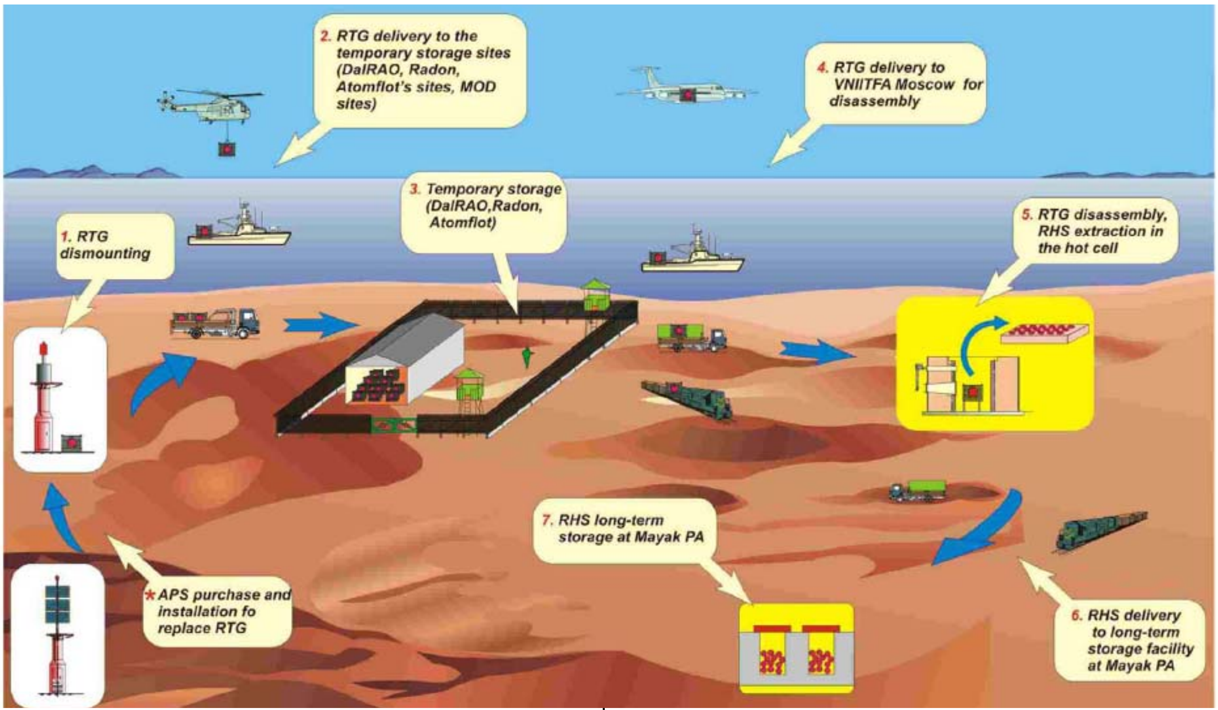


Figure 6. *A schematic figure of the steps in the RTG decommissioning process [10].*

3.1.1 Inspection

Prior to commencing any physical work, an audit is undertaken to ensure that the necessary background agreements, approvals and regulatory permissions are all in place. It also includes confirmation that all receiving organisations have suitable arrangements in place (whether for transport, temporary storage, dismantling or final conditioning for disposal). This is followed by an inspection of each RTG, to determine the physical state of the unit and to assess the external dose rate at specified distances.

Based on this initial inspection, a tailored approach to transport and dismantling is developed. For example, the following information is collated for individual RTGs and presented in detailed tables appended to the EIAs:

- Operations to be undertaken;
- Initial status of the RTG at inspection;
- Possible emergencies;
- Possible status after emergency;
- Estimation of emergency consequences;
- Emergency mitigation measures;

RTGs are constructed to withstand harsh environments and to offer a low risk with respect to loss of integrity. Nonetheless, both accidental and deliberate damage to the units can occur. In such cases, emergency mitigation measures must be taken, as outlined in more detail in Section 3.3.2.

Measurement of radiation doses during inspection of a RTG in Northwest Russia (Photo: County Governor of Finnmark).

An annual audit of compliance is also undertaken for each step of the RTG decommissioning against the programme plan, and temporary storage conditions are inspected. These activities are undertaken by Russian authorities.

Removal of a RTG from its original placement in Northwest Russia (Photo: County Governor of Finnmark).

3.1.2 Transport

Routes

The locations and transport routes for each batch of RTGs, and for each step of the operation, are specified in advance within the EIAs, together with countermeasures where appropriate (see Appendix 3 of Reference (Ref) [18], Section 2 of Ref [21], Section 4 and Annex 2 of Ref [22], Section 4 of Ref [26] and Section 4 of Ref [27]). Figure 7 illustrates the various options of routes and vehicles for transport of RTGs from place of origin to designated dismantling and disposal facilities.

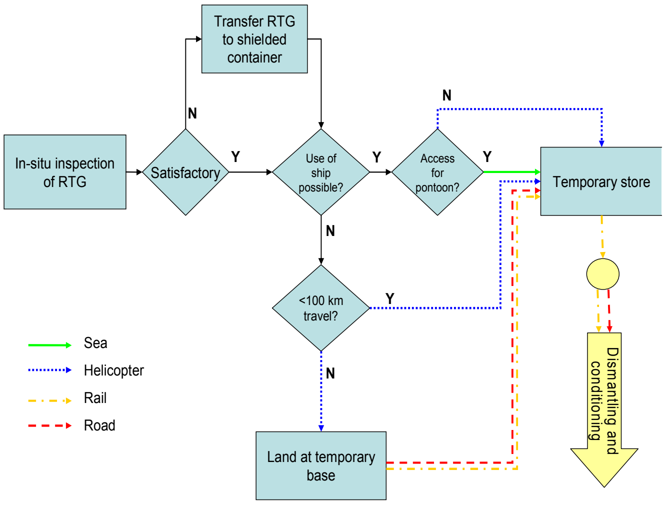


Figure 7. *Optimising transport arrangements. Various options of routes and vehicles for transport of RTGs from place of origin to designated dismantling and disposal facilities.*

Method

The choice of a suitable means of transfer of units from their operational location, temporary storage or from one means of transport to another, involves a number of considerations, primarily based on accessibility.

The transport of units from operational locations to the designated storage area is preferentially carried out by barge and ship. The service is carried out by the Russian Navy under authorisation. Only where this is clearly impractical is transport undertaken by helicopter.

Helicopter transport of a RTG (Photo: County Governor of Finnmark).

Within the programme, the decision to transport by helicopter is subject to a robust justification analysis. Transport by helicopter requires special slinging arrangements to be made for the RTG container, under authorisation [28]. In some instances, the helicopter freight may be restricted. In these cases, the freight may entail the use of an interim base with subsequent transport by rail to the designated store (see Appendix 3 of Ref [18]). A 'decision tree' for the transport arrangements is summarised in Figure 7.

Packaging of RTG

Once the transport route has been determined, the RTG is dismounted and placed in a container. Typically, this requires a team of six persons working close to the RTG for around 3 hours. For an RTG in satisfactory condition the external dose rate at 1 m is not more than 0.1 mSv/hour, implying a maximum individual dose of 0.3 mSv for each RTG prepared.

For units which are not assessed as satisfactory, the RTG is transferred to a shielded container prior to transporting. Dose rates are assessed before work is undertaken and subject to optimisation measures.

From coast to barge

RTGs situated on the coast are lifted onto barges intact, using a variety of rollers, jacks and tow lines (Appendix 3 of Ref [18]). After loading onto the barge, a buoy is secured to the RTG to assist in the event of accidental loss of the unit under transportation.

Transport of a RTG from a coastal region in Northwest Russia on to a barge(Photo: County Governor of Finnmark).

From barge to ship

RTGs loaded onto a barge are subsequently transferred to a larger ship. The ship is anchored as close to the shoreline as is deemed safe, in order to minimise the distance traversed on barge. The RTG is transferred to the ship using a lifting crane (see Appendix 3 of Ref [18]). During this operation, a minimum crew is maintained on the barge as a safety precaution in case of an accidental drop of the unit (see Section 3.3).

Once on board the ship, the RTG is secured in place. A number of RTGs are transferred in each load.

RTGs are then secured on board ship at a location removed from the crew to further reduce any external exposures during transport.

From coast by helicopter

Where it is clearly impractical to use a barge for transport of RTGs from the cost, a helicopter is used. In this case, the RTGs are slung under a helicopter, using an external bracket (Appendix 3 of Ref [18]). For safety reasons, no more than one RTG is transferred by helicopter at a given time. If the route of the helicopter passes over a water body, a buoy is fixed to the container prior to fastening the RTG, in order to assist in case accidental loss of the unit occurs.

All transport by helicopter is subject to the identification of suitable landing and loading sites (Section 3, Ref [21]). In order to minimise the risks involved, such transfers are undertaken at the lowest possible speed and height and under favourable weather conditions; and over an approved route (e.g. water depth not exceeding 50 m) [25].

RTGs transported by helicopter are landed at an interim landing step for collection by the Russian Northern navy for onward transport. A single collection of up to 10 RTGs can be transferred by the navy. RTGs are loaded using lifting cranes.

From ship to temporary storage location

RTGs transferred by ship are taken to a temporary storage location, e.g. at Atomflot (Appendix 3 of Ref [18], [20]), Kandalaksha port [27] prior to onward movement (see Section 3.1.3 for further details). Units arriving at the storage location are unloaded by crane and transferred to the temporary storage point by an electric trolley. Atomflot is additionally used for storage of damaged RTGs. These units are transferred to Atomflot by rail in specially constructed transport containers (Appendix 3 of Ref [18]).

All the RTGs temporary stored are then subsequently transferred to special rail wagons for onward freight by rail to the redistribution centre at Izotop, Moscow [19].

Transport of RTGs by ship in Northwest Russia (Photo: County Governor of Finnmark).

Transport of RTGs from ship to rail wagon at RTP Atomflot (Photo: County Governor of Finnmark).

Transport to dismantling location and further to treatment, storage and disposal facility

RTGs arriving at Izotop are reloaded from rail wagons onto lorries for delivery to NIITFA for subsequent dismantling (see Section 3.1.4). Dismantled RHSs are placed in a transport container and transported from NIITFA via road back to Izotop. At Izotop, containers are reloaded onto rail wagons and transported to Mayak. The turnround time at Izotop is of the order of three days.

On receipt at Mayak, for further conditioning prior to extended storage and disposal, wagons are unloaded and the RTGs stored in a shielded facility (see Section 3.1.5). Once the RTGs are unpacked, the empty transport containers can be cleared for return and re-use.

Transport containers for RTGs (Photo: County Governor of Finnmark).

3.1.3 Temporary storage

Storage of RTGs is short term only. All RTGs received at the storage location are scheduled for onward transport within 1 week of receipt [19]. The security and safety arrangements for storage at f. ex. Atomflot are nonetheless subject to detailed review (section 10 of Ref [17]). This includes detailed specification of:

- The responsibilities of particular individuals,;
- Number of personnel involved in particular operations:
- The equipment to be used to perform given operation, and for personal protection;

- Actions to be taken in the event of emergencies;
- Relevant norms and standards.

3.1.4 Dismantling

Izotop acts as a distribution centre for reloading of RTGs from train onto lorries for delivery to FSUE NIITFA. The RTGs are temporarily stored at NIITFA for 1-2 months, depending on the dismantling procedure and the return of transport containers from Mayak to NIITFA [22].

At present, the only permanent 'hot cell' facility for removing RHSs from RTGs is at NIITFA, in the Moscow Region. This facility is used for RTGs from the Northwest area and part of the Northern area (i.e. covering all the RTGs in the Norwegian Governments RTG decommissioning programme in Northwest Russia.

Preparation of road transport of RTGs (Photo: County Governor of Finnmark).

After removal of the RHSs, the depleted uranium (DU) RTG cases are stored in NIITFA. The DU may be either used to manufacture radiation shielding and shielded containers for other types of radiation equipment, or transferred for specialised disposal.

3.1.5 Processing for disposal

The dismantled RHSs are temporarily stored at Mayak for a period of up to 2 months, depending on the throughput of high level wastes for vitrification. [19].

Receipt and processing

RHS containers arriving at Mayak are unloaded, the RHSs are removed from the containers; and examined for their compliance with the accompanying documentation (the disposal certificate issued by NIITFA).

The RHSs are categorised as high-level radioactive waste (HLW), and are programmed for storage and disposal as part of the overall HLW programme within Mayak. The total number of RTGs and RHSs received at Mayak for processing is illustrated in Figure 8 [12]. This includes all units, not just those received as part of the Norwegian RTG decommissioning programme.

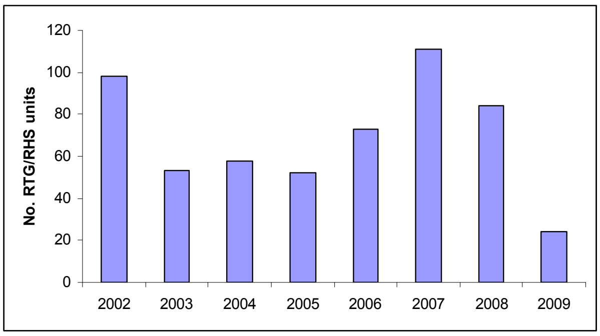


Figure 8. *Number of RTG/RHS units received at Mayak for conditioning and storage / disposal by May 2009 [12].*

Treatment is similar to that for vitrified HLW generated from the Mayak vitrification plant and can be summarised as:

- Reception and initial storage of RHS in transport containers;
- Repackaging and transfer of RHS to canisters containing vitrified HLW;
- Placing full canisters into the vitrified HLW storage facility (se Figure 9).

The storage facility is on the surface, above ground water levels. It is adjacent to the vitrification building and is connected with it by a transportation corridor. Cans with vitrified waste are delivered to the storage facility by a remotely controlled crane. The storage facility consists of concrete bays with stands for vitrified waste vessels arranged at a distance from each other. Each bay is designed to be filled with vitrified waste over several years. Containers are loaded into the stands through hatches which are closed with concrete plugs.

The radioactive sources from RTGs are sent to the facility at Mayak for final deposition (Photo: Master Plan, Kurchatov Institute, 2007[10]).

3.1.6 Storage and disposal

Cans containing vitrified waste and/or the RHS are placed in tubes (3 cans, stacked, per tube) and two filled tubes, in turn, are stacked in each storage stand, as illustrated in Figure 9 [12].

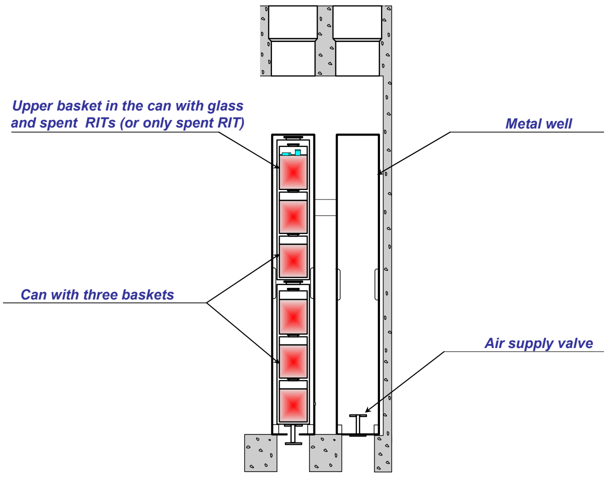


Figure 9. *Layout of cans in the storage facility at Mayak [12].*

Air temperature is managed by blowing cooling air through the annulus between the tube and the internal surface of the stand. The heated air (up to 90°C) is then circulated through channels running above the stands and, after filtering, is released into the atmosphere. During the first year of operation of a storage cell the air circulation is assisted by use of fans. Subsequently, as the decay heat decreases, natural convection is sufficient to maintain an acceptable temperature.

At present, it is envisaged that the RHSs and vitrified product containers will be stored for 50 years, followed by disposal in an underground facility. However, if necessary, there is capacity to store HLW in the current facility for 100 years prior to final disposal.

According to the conditions currently laid out for disposal of the vitrified waste in deep geological formations, the activity in any canister must be such that before the canister is accepted its energy release should not be greater than 0.9 kW. This limitation on heat transfer is determined by an operating requirement that the temperature of the receiving dry well or trench wall should not exceed 100°C. Based on these limitations, the time is calculated after which the cans with items can be put into deep geological formations.

Upgrade to facilities

A number of instances are recorded at Mayak where there were suspected seal failures associated with the RHS and potential release of radioactivity. As a consequence a number of modifications to the receipt and handling procedures were introduced, to provide additional shielding, and further improvements to the facilities were proposed during 2008 [13].

Assessments of the potential environmental impacts of routine decommissioning operations and potential impacts of accidents are generally undertaken in advance. The main aims are to avoid or minimize adverse health and environmental impacts, before they occur, and to incorporate environmental factors into decision making processes.

In the event of loss of radioactive material from the RHS to the environment, it is likely that any potential radioactive contamination will occur in the water phase.

The dominant risk therefore arises from accident scenarios. Figure 10 shows a graph illustrating the risk of RTG loss and its main part RHS during the decommissioning phase of an RTG lifecycle [10].

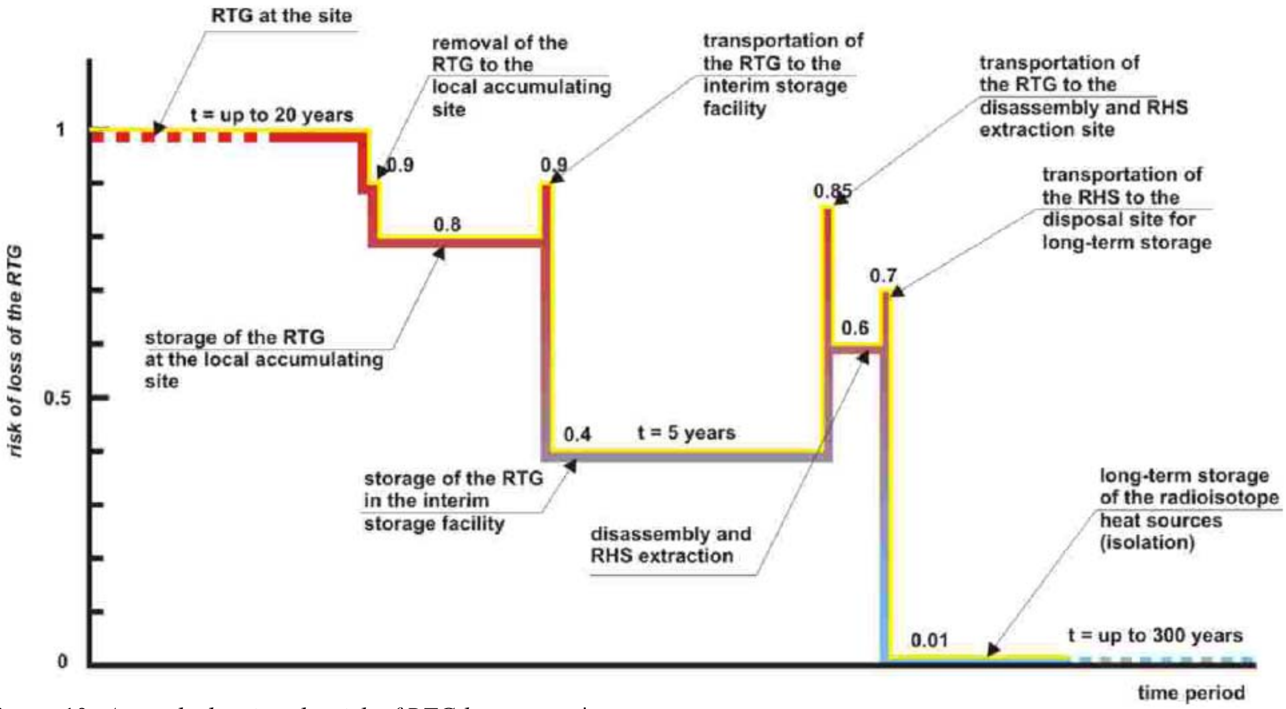


Figure 10. *A graph showing the risk of RTG loss and its main part RHS during the decommissioning phase of a RTG [10].*

3.2 Risk Assessment

3.2.1 Transportation risks

Detailed risk assessments were undertaken in 2007 and 2008 to determine the probability of a road or rail accident occurring during transit of containers from Murmansk to Moscow.

The specific risks determined depend on the number of containers, loading assumptions for rail carries or lorries, distance and any interim transfer operations. The highest risks (of the order of $3 - 5 \times 10^{-4}$ h^{-1}) are associated with transfer operations. The risks of a severe rail or road accident were estimated to be 1.8×10^{-8} and 1×10^{-5} $(y\ km)^{-1}$, respectively. However, taking account of the additional loading-unloading operations and the required for train transportation, the overall risk associated with severe accidents during transportation by road was estimated to be 3×10^{-3} and 4×10^{-3} for rail transport in 2007. The risk for rail transport was estimated to be slightly lower in 2008, based on movement of 15 containers (to 1.8×10^{-3} $y^{-1)}$, but remained the same for road transport, as illustrated in Figure 11.

Whilst there is little difference between road and rail transport options with respect to the risk of an accident occurring, the environmental and economic impact of a rail accident may be higher due to the potential scale of a single consignment.

The severity of the impact of a transport accident for the public was assessed based on the estimated external dose rate, the number of persons likely to be exposed, proximity to the RHS containers and the duration of exposure. Where an accident is assumed to occur as a result of, or be exploited for, criminal or terrorist activities the worst case scenarios could lead to people being in near proximity to unprotected sources for some hours, leading to fatal exposures. This aspect led to the subsequent placement of greater emphasis on the need for physical security regarding transport arrangements [30, 31].

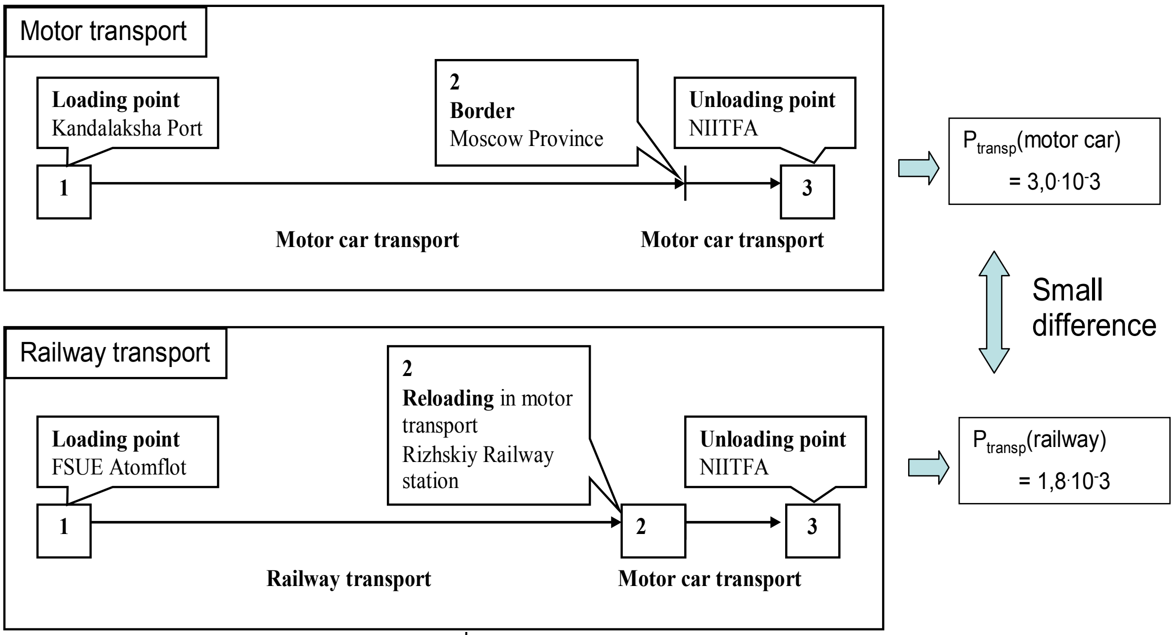


Figure 11. *Risk assessment calculations for transport by road or rail in 2008, showing little difference in the risk estimates [30, 31].*

3.2.2 *Operational experience*

As a result of a real accident in September 2004[3] [20], where two IEU-1 RTGs with RHS-90 (radioactivity ~4.3 × 10^{15} Bq) were dropped onto rocks from an altitude of 50 m after emergency release from the external load carrier of a helicopter, the level of gamma radiation measured from the RTG was approximately 0.8 mSv/hour at 2 m, and 52–55 µSv/hour at 5 m. No strontium-90 release from the RTG was registered.

The calculated dose rate at 1 m was 3.2 mSv/hour (i.e. approximately 30 times higher than for an RTG in 'satisfactory' condition, Section 2.1.2, Table 3). This value was used to calculate the emergency dose to which personnel would be exposed during operations to recover a damaged RTG.

In such a case, the repair team labour time for detection, repair, packing and preparations for transportation by helicopter is estimated to be about 6 hours (i.e. 36 man-hours for a 6-person team). If these operations were all conducted close to the RTG (i.e. ~1 m) the received dose would be 20 mSv. This falls at the upper end of the IAEA Basic Safety Standards value for workers (expressed as a limit per year averaged over 5 years, with a maximum of 50 mSv in any one year) [14]. In practice, it is unlikely that any single individual would spend the full time in such close proximity to the unit.

3.2.3 *Environmental transfer*

The chemical and physical characteristics of strontium titanate ensure that its accumulation and transfer within the terrestrial environment is likely to be limited, even under accidental conditions. Its dissolution rate, in the event of damage to the RTG, is of the order of 10^{-6} g/cm^2/day, such that the potential for major contamination due to dissolution is negligible, A damaged RTG located on land would also be relatively easy to recover [4]. As a consequence, the opportunity for dissolution would be relatively short-lived.

[3] A further accident involving the loss of two Efir-MA type RTG was also reported for 2004. The Russians reported this accident and indicated that a photographic record is available. Monitoring data were not presented.

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

Table 4. *Maximum permissible intakes of Sr-90 into organisms and the maximum concentrations allowable in air and water, taken from Russian legislation.*

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

Table 5. *Action levels of Sr-90 in food during the first year after an accident.*

If an RTG is dropped into the sea, it is possible that sea water will penetrate the protective layers if the RTG is not removed within the first years. In such circumstances, depressurization could give rise to significant concentrations of strontium-90 in the adjacent area of water and accumulation in sea foods can arise. However, the low dissolution rate of the titanate and dilution effects are unlikely to lead to high concentrations in marine foods or to deliver significant doses to marine organisms [4]. A worse-case intake over the course of 1 year of 3.7×10^{-8} Ci (1.37×10^{3} Bq) of strontium-90, which is a factor of 10 lower than the established annual limit of intake specified in Russian norms (RSN-99) [18].

Russian standards for permissible levels of Sr-90 in the environment

The Russian standards for permissible levels of Sr-90 in the environment are presented in Tables 4 and 5. Table 2 presents the maximum permissible intakes of Sr-90 into organisms and the maximum concentrations allowable in air and water, taken from Russian legislation.

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 [4].

3.3 Accident Scenarios

A total of 32 potential accident scenarios have been identified and evaluated within the EIAs conducted for the Norwegian-Russian RTG decommissioning programme in Northwest Russia [19]. Thermal impacts arising due to fire, drop from a height or into the sea have been those considered to be of greatest potential risk to the environment [30, 31].

The greatest risks are related to transfer elements in the transport of RTGs from the

White Sea region, the Barents Sea and the recovery and transport of RTGs at a temporary North Fleet storehouse and one RTG in temprorary storage at Atomflot. Subsequent information within the EIA's considered risks associated with transport from relevant locations.

As part of the EIA process the following generic accident scenarios were identified as offering the highest potential credible impacts.

1. Drop into the sea.
    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 1b.
3. Drop onto land, away from the sea. The RTG could be damaged if this occurred during a fire or crash, or was dropped from the helicopter [4, 19].

The causes of the potential accidents include capsizing of transport barges and ships, loss from a helicopter in transit or falling during lifting operations. Additional risk scenarios have included the deliberate vandalism of RTGs, degradation of seals, loss of gases to atmosphere or erosion of the fuel source with subsequent leakage. Only deliberate actions have been considered likely to give rise to a release of radionuclides to the environment [30, 31].

In each case, the status or condition of the RTG following the postulated accident was estimated; the consequences of the accident determined and risk reduction measures identified.

The types of accident scenarios identified were comprehensive and could be applied for all transport operations. However, specific updates and risk calculations were introduced as applicable to the locations and types of RTGs included for dismantling in each subsequent year.

The following potential accident scenarios, associated with the transportation of RTGs by special railway carriages, were also considered in order to consider the risks to escort persons [19]:

1. Collision with a vehicle carrying inflammable liquids or explosives – the consequences in this being mitigated by the fact that the greater weight of the train would not lead to any harm to those escorting the RTG;
2. Railway accident due to (a) derailment or (b) collision with cargo trains carrying inflammable liquids or explosives.

In the risk reports it was concluded that such risks are greater for transportation by rail due to the fact that the escort personnel all occupy the same vehicle. In addition, the risks of rail accidents are not determined by the actions of the escort.

The theft of the RTG following such accidents was considered to be unlikely due to their weight (600 – 2000 kg) and the fact that the temperature of the RHS (300 degrees C) would necessitate special handling equipment [30, 31].

3.3.1 Risk reduction measures

The physical form of the RHS is intended to make it very unlikely that significant dispersion or leaking of activity could occur except under extreme conditions such as:

- Very severe impact or crushing;
- Very intense and/or prolonged fire;
- Long term immersion in water (e.g. in the sea); or
- Explosion.

To reduce these risks, both design and operator controls were identified and implemented as a result of the EIA process.

Design standards

According to IAEA standards used within the EIA process, an RTG should be designed, as a minimum, to withstand a fire of 800°C for 30 minutes, to withstand a fall from 9 m onto a flat (steel) surface or a fall of 1 m onto a spike, and to withstand a pressure (e.g. from submersion) of not less than 2 MPa. In practice, the EIAs have indicated that the strontium titanate core will not melt below 1900°C and the stainless steel container is considered to be resistant to corrosion even at sustained temperatures of 900°C in air (e.g. more than twice the operating temperature of an RHS). Tests were also undertaken on a number of simulated RHSs. These included heating up to 1100°C for 2 hours, ground drop tests onto a steel plate from 9 m and 25 m and drops from 'helicopter' heights of 300 m and 900 m onto concrete. No loss of integrity was noted in any of these tests.

A 'destruction' test was undertaken by heating the container to 400°C, then impacting the container edge-on at 80 km/s onto armoured plate. This resulted in cracks to the sealing cover and deformation of the cylinder, although no loss of the simulated fuel source was noted.

Operational experience summarised within the EIA's provides reassurance that no instance of gaseous emissions or leaching of the fuel source has been identified to date under normal operating conditions.

Operator standards

The EIAs have identified key operator actions to reduce handling and transport risks and have included the implementation of technical and administrative measures to prevent (as far as possible):

- Accidents or incidents that could damage RTGs or RHS packages;
- Unauthorised access to RTGs or RHSs;

at all steps of the decommissioning process.

Additional information provided from 2005 and 2006 also indicated that all RTGs are attached to a buoy when being prepared for transport, whether by ship or helicopter[1]. In the event that a unit is lost under water the buoy is intended to aid recovery by marking the location of the unit.

3.3.2 Development of emergency countermeasures

Where loss of an RTG or RHS is postulated to occur, there is a risk to the environment, to local populations (both through direct exposure and via the food-chain or drinking water) and to recovery teams.

A number of calculations have been undertaken within the EIA process to determine possible routes for exposure and dose rates incurred following loss of a unit on land, and within coastal or river waters. These demonstrated that the main risk to people would arise from external exposure. Emergency countermeasures proposed included establishing evacuation zones prior to recovery of the unit.

Where an RTG or RHS is damaged but remains within operation control (e.g. units previously transferred for temporary storage as a result of damage, or units found to be damaged in the initial inspection at the place of operation), the primary risk is to the handling team.

In the event that a lost unit requires recovery, or where a damaged unit is being packaged prior to further operations, the first step identified within the EIA is to analyse the external dose rate. This will depend on the nature and cause of the damage and will determine subsequent actions.

For example, an RTG dropped during transport by helicopter from a height of 100 metres onto rocks will experience stresses close to the test case specifications for RTG construction. Although these tests indicate that no loss of radioactivity will occur, some loss of integrity cannot be ruled out and emergency provisions were established against such an event.

In the event that an RTG is lost in water during helicopter transit, detailed arrangements are in place to recover it [19]. The buoy, which is attached prior to transfer, will help location. The RTG would be recovered by a vessel from the Northern Navy Hygrographic Service, with the help of personnel from the Russian Navy and other rescue services.

4 Work performed in Northwest Russia in collaboration with Norway

By the end of 2008, *169 RTGs* had been removed from Murmansk, Archangelsk and Nenetsk regions in Northwest Russia (see Figure 22) under Norwegian funding, which commenced in 1995. From the Norwegian side, the work was headed by the Office of County Governor of Finnmark and from the Russian side it was headed by the Murmansk Regional Administration. The programme of RTGs to be dismantled has been agreed annually since 2001. The remaining *11 RTGs* from Nenetsk region and Novaya Zemliya were removed in September 2009, as shown in Table 6. Figure 12 shows the locations of the RTGs in the Norwegian-Russian RTG decommissioning programme in Northwest Russia. The RTGs were located across the coastal regions of the Barents Sea, the White Sea, the Kola Peninsula and the Kara Sea [21].

Frequently evaluations of the infrastructure to facilitate removal and decommissioning of the RTGs in areas covered by Norwegian-Russian cooperation demonstrated that the capacity existed to facilitate fulfilment of the project within the designated timeframe.

Initial inspections prior to the removal of RTGs in the period from 2001 until 2009 showed that 8 RTGs of the 180 were found defected (see Section 2.1.2 for further details). Six of these RTGs were stripped for shielding material, and the shielding materials of two RTGs were damaged. For all of these RTGs, results of the surveillance and monitoring results were provided. The dose rates, results of leak tests and the nature of the faults identified were reported. For example, the 1EU-2 type RTG with damaged shielding marterial, carried some indication of corrosion of the depleted uranium shielding, which may have been caused by defects in the welding or mechanical impacts. A helicopter transportation package was designed which included a shielding container containing iron shot, and four radial channels welded to the bottom of the container to secure the container and ensure no loss of shielding. Further transportation was undertaken by special motor vehicles from the Northern Navy and a special rail carriage for transfer to NIITFA for subsequent disassembling, examination and removal of the RTG before transportation to Mayak for disposal [15, 32].

Table 6. *Number of RTGs removed each year from*

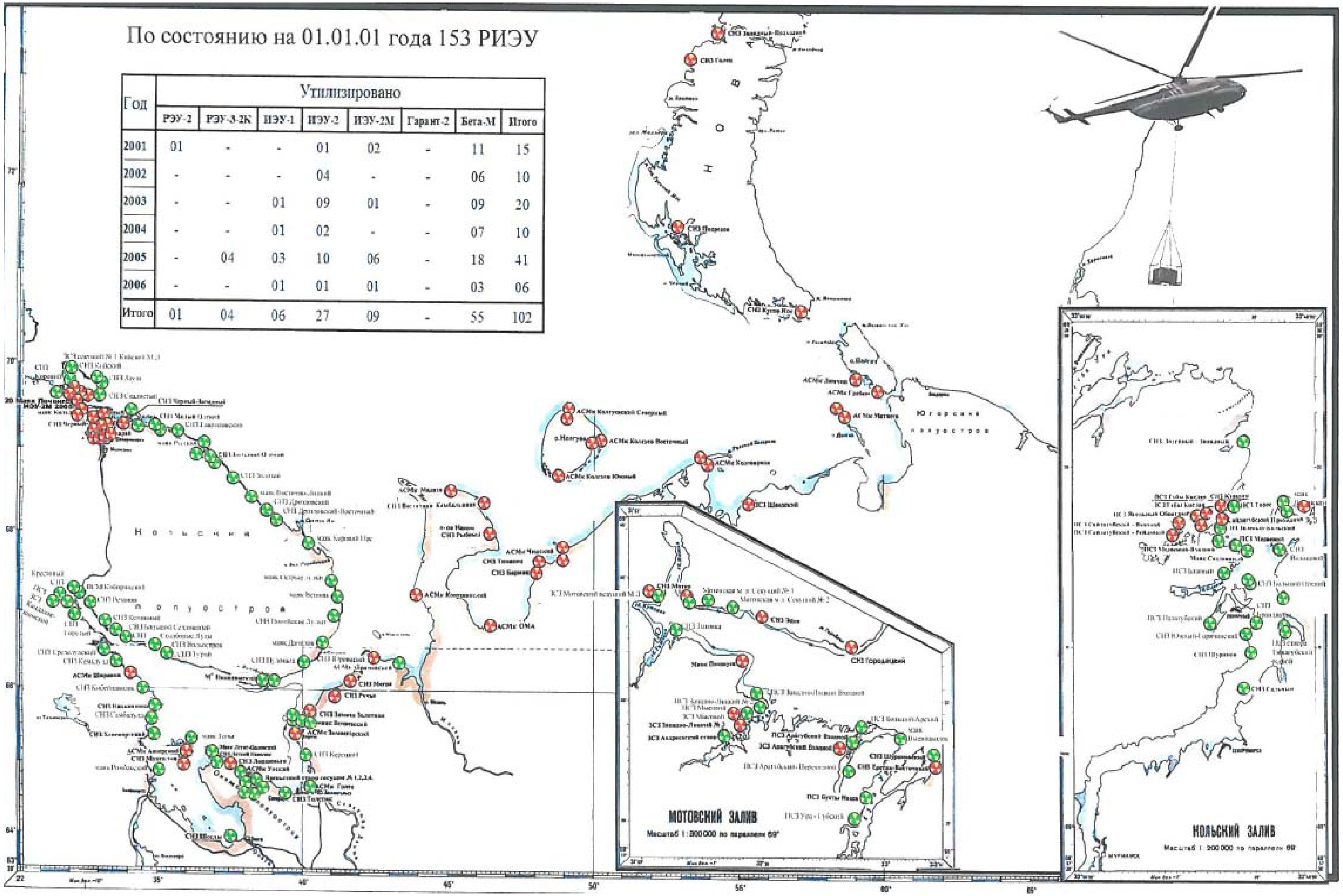
Number of RTGs removed from Murmansk, Arkhangelsk, Nenetsk regions and Novaya Zemliya each year	
Year of removal	Number of RTGs
2001	15
2002	10
2003	20
2004	10
2005	41
2006	6
2007	21
2008	46
2009	11

2001 until 2009 in the Norwegian-Russian program for removal of RTGs from Murmansk, Arkhangelsk and Nenetsk regions and Novaya Zemliya [32].

4.1 Russian Organisations Involved

Since RTGs belong to a number of different authorities, there is a need for inter-departmental coordination of RTG decommissioning activities. The following organisations have been involved in RTG decommissioning activities:

- NIITFA.
- FSUE ”Izotop”
- FSUE “Atomspetstrans”
- Mayak PA
- FSUE of nuclear- powered navy of Transport Ministry of Russia
- Murmansk Regional Administration
- Northern Fleet, Hydrographical Department
- Russian Agency for Sea and River Transport (Mintrans)



Год	Утилизировано							
	РЭУ-2	РЭУ-3-2К	ИЭУ-1	ИЭУ-2	ИЭУ-2М	Гарант-2	Бета-М	Итого
2001	01	-	-	01	02	-	11	15
2002	-	-	-	04	-	-	06	10
2003	-	-	01	09	01	-	09	20
2004	-	-	01	02	-	-	07	10
2005	-	04	03	10	06	-	18	41
2006	-	-	01	01	01	-	03	06
Итого	01	04	06	27	09	-	55	102

Figure 12. *Loactions of RTGs in Murmansk, Arkhangelsk and Netetsk regions including Novaya Zemliya. Green icons represent removed RTGs and red icons represent remaining RTGs per. 1 January 2005. At present, all of these RTGs (180 pieces) are removed and replaced with alternative energy power, solar panels [21].*

4.2 Defective RTGs

Only a small number of the 180 RTGs removed from Northwest Russia, under Norwegian financial support, have caused handling problems at NIITFA. The condition of these RTGs has been related to internal mechanical damage of the RTGs and the long-term thermal loads to which the RTGs have been subject to over their operational lifetime.

Some of the RTGs of the type REU-3-2K required special considerations when dismantling and processing the radioactive heat source for disposal. The REU-3-2K contains multiple heat sources. A plan was drawn up with Mayak for the containment and storage/disposal of these units, which required a delay in acceptance (the units being recovered in 2005 but Mayak receiving them in 2007) [23].

Disassembling the Gorn and Gong types of the RTGs at NIITFA has been challenging due to contamination of the external RHS or the damage of the shielding material. When the uranium protection of the RTG is lost, the RHS is prone to reaction with air, leading to oxidation of the metal, and corrosion. This also results in the damage and expansion of the shielding material so that the extraction of the RHS from the RTG becomes impossible. The enlarged size of the damaged RTGs also make them fitting into transport containers, for further transport to and final disposal at Mayak PA, problematic [18-29].

A defective RTG of type Gorn in Northwest Russia (Photo: County Governor of Finnmark).

The Gong and Gorn types of RTGs were treated in the same way as the REU-3-2K units. One additional damaged IEU-2 type RTG also required special handling and packaging prior to acceptance at Mayak.

A method was chosen for handling damaged RTGs at NIITFA included construction of containers which could contain the RHS and the whole RTG.

4.3 Dose Reports

Reports on doses to individual workers involved in dismantling and decommissioning the RTGs have been supplied as part of the supplementary information as the project evolved. These reports indicate that workers received less than 10 μSv (which is comparable with dose values in Table 3 in Section 2.1.2) as a result of loading containers for transport. The reports also confirm that no surface contamination was detectable on workers overalls [29].

These results are consistent with very low measured dose rate external to containers certified during radiation monitoring surveys. For instance, surface dose rates on an RTG were of the order of 100 μSv (0.0001 Sv) per hour (significantly below the design specification), falling to less than 10 μSv per hour at some 3 m from the unit. Within the cab of a lorry used to transport containers, dose rates less than 1 μSv (0.000001 Sv) per hour were reported.

In the event of the loss of a unit, while hypothetically some organisms could be attracted by the heat, the potential dose would remain low by comparison to threshold levels [16].

5 Conclusions

The Norwegian government's focus on Risk- and Environmental Impacts Assessments for nuclear safety projects in Russia provides a systematic review of all phases of planned works potential consequences on the environment, health and safety. At their most comprehensive and effective, EIAs are carried out as part of the decision making process and should take account of both alternative methods and systems for minimising possible consequences, so that the best environmentally executable approach can be chosen. The requirements of an EIA for projects involving radioactive materials in Russia, Norway and the Western European nations are similar.

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.

The robust nature of the RTG unit and its low potential for significant releases of activity to the environment under normal conditions has been demonstrated. Potential accident scenarios have been identified and counter-measures introduced to reduce risks and mitigate hazards. Handling of damaged or partially dismantled units has been considered and provisions made on a case by case basis. The scope and depth of information provided by the relevant Russian bodies has evolved and progressed during the scope of this project.

As the Sr-90 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 Sr-90 source is exposed to air or water, the resultant spreading of radioactivity will be very limited due to the low solubility of the Sr-90 titanate matrix. The Sr-90 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 worstcase for humans would be direct contact with an exposed Sr-90 heat source. However, in this instance it is also likely that the exposed RHS will be localized quickly and the proper authorities can then ensure the safe removal of the RHS.

Being close to an intact RTG is a controllable health hazard as the radioactive material is well contained and shielded. Under normal conditions, decommissioning of RTGs, using prescribed methods, will not contribute to elevated levels of radionuclides in the environment or pose a threat to humans.

There has been evidence that the work procedures were improved during the course of the programme. As a result of experience gained throughout the decommissioning project, a reduction in the risks has been achieved. Close dialog with the Russian regulatory and supervisory authorities has been essential which has resulted in improved regulatory basis and inspection work. The feedback from NRPA throughout the reviewing process of the risk and environmental impact assessments aimed to reduce the risks in the decommissioning project.

The Norwegian-Russian RTG decommissioning project in Northwest-Russia involved the removal of 180 RTGs and replacement with solar panels. As unsecured RTGs pose a radiation risk to human and environment due to extremely high activities, significant nuclear safety work has been accomplished. There were no accidents during the decommissioning project.

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