

Main Problems of Spent Nuclear Fuel and Radioactive Waste Management in the Russian Federation¹

Introduction

The end of the Cold War has left behind a legacy of substantial amount of radioactive waste (RW) and spent nuclear fuel (SNF), and an impressive number of retired nuclear submarines (NS) and nuclear service ships. Russian Federation experiences great problems related to remediation of this nuclear legacy, which currently constitutes major concern of the whole world community both in terms of environmental safety and non-proliferation of nuclear materials. A number of problems call for actions to solve them, however resources of the Russian Federation are limited and an effective international assistance is required.

Upon the initiative of the Nordic countries a Contact Expert Group (CEG) was established in 1996 under the IAEA auspice. CEG serves as a forum for discussion of problems, exchange of information and presents recommendations on specific international projects in the Russian Federation. Detailed information on composition and activities of the CEG could be found at the IAEA website: <http://www.iaea.org/worldatom/Programmes/CEG/index.html>.

Several years ago CEG established a special international working group for analysis of the RF general strategy on SNF and RW management in order to identify main problems and select priorities. Results of this work confirmed that main problems in Russia are caused by the Cold War legacy and in particular, by mass retirement of NS, which took place in 90-ies. The following three high priority areas for international cooperation were identified /1/:

1. Remediation of the former naval bases in northwestern Russia.
2. SNF removal from the retired NSs and safe management of SNF.
3. Management of high-level waste at the nuclear fuel cycle facilities.

Further activities of the CEG member-countries concentrate on the first two areas.

General Strategy of the Russian Federation

Special Federal Programme “Nuclear and Radiation Safety of Russia” for 2000-2006 was developed and is being implemented in the Russian Federation in order to solve problems of SNF and RW management. Russian Government assigned Minatom to coordinate this Programme. Its main objective to provide nuclear and radiation safety of the state and reduce radiation risk from nuclear facilities and radiation sources to the socially acceptable level. The Programme covers all aspects of nuclear and radiation safety of SNF and RW management /2/.

Besides, the Concept for Integral Dismantling of NS and Surface Vessels with Nuclear Power Installations was developed. This concept defines main problems and technical policy of Minatom in the given area. The concept has passed the environmental review and was endorsed by all authorities involved, including Russian Ministry of Defence and the State Nuclear Regulator (Gosatomnadzor) /4/. The concept has the following basic principles:

- unconditional provision of nuclear and environmental safety on the basis of current legislation at all stages of the Programme implementation;
- priority of the SNF discharge from NSs and its further reprocessing at Mayak plant;

¹ This document was prepared by the CEG Executive Secretary in January 2003 on the basis of the CEG meeting materials, conference papers and publications.

- implementation of “delayed” dismantling of radioactive equipment of the NS nuclear installations through creation of reactor compartment (RC) modules, which should be stored for up to 70 years, with possibility of further disassembling;
- maximum possible recycling of non-contaminated materials produced during the NS dismantling;
- temporary use of free volumes in reactor compartments for storage of solid radioactive waste (SRW) generated within the course of NS dismantling until the time when centralised SRW storage facilities are available.

In further development of this Concept, a draft of the Programme on Integral Dismantling of NSs (herebelow - the Programme) has been elaborated. The Programme covers issues of the integral dismantling of NSs and nuclear service ships, retired from the Navy, provision of safe NS storage afloat, establishment of infrastructure for conducting the NS dismantling and for SNF and RW management, and environmental remediation of the SNF and RW temporary storage sites /3/. At the moment the Programme are being reviewed by the RF Government.

Dismantling of Nuclear Submarines

Number of NSs built in the Soviet Union is greater than in the rest of the world, however now majority of them is withdrawn from operation within the relatively short period of time. Russia was not prepared for such intensive process, therefore abilities of the shipyards where NS dismantling is being conducted, capacities of the waste processing installations and other infrastructure facilities, available at that time, were not adequate to solve the problem of the NS decommissioning within the reasonable time frame. Besides, financial possibilities of the Russian budget were insufficient too.

Minatom and Russian organizations reached some progress during the last 5 years. 190 NSs were retired by the beginning of 2002, and 97 NSs were defuelled. 68 NSs were dismantled and RC modules were formed. Now these modules are stored afloat. 122 NSs are in the waiting mode, and 93 NSs out of that number still have SNF on board. According to the Dismantling Concept, main resources were concentrated on the NS defuelling. In 2000 and 2001 defuelling rate was 18 NSs a year, while before 2000 only 3-5 NSs were defuelled annually.

Rate of the NS dismantling increased respectively. Starting from 2001 Russian Federation allocates up to 50 million US\$ annually on implementation of the Programme, however this money is not sufficient. According to Russian estimates, about 3.9 billion US\$ would be required for completion of the whole Programme within the future 10 years /4/.

It should be noted that substantial number of NSs are stored in the waiting mode for 10 and more years, and physical condition of many submarines does not provide their safe storage afloat without additional means, which creates substantial risk of the NS sinking with further radiation consequences for the environment. Multi-purpose submarines of the first and second generations belong to this category. These submarines were built in much greater number than the strategic submarines /5/.

At the moment dismantling of NSs is being conducted at the ship-repair yards (SRY) Zvezdochka and Sevmash in Severodvinsk, Zvezda in Primorsky Territory, Nerpa at Kola Peninsula and at the shipyards that belong to the Navy and are located at Kola Peninsula, at Kamchatka and in Primorsky Territory. SNF discharge from NSs is being conducted at the

SRY sites by the floating technical bases (PTB), which belong to the Navy, and by PTB Imandra, which belongs to Murmansk Shipping Company (MSCO). Besides, two coastal complexes for NS defuelling will be commissioned in 2003. These complexes were built under the RF-US Common Thread Reduction (CTR) Programme at Zvezdochka and Zvezda shipyards. Each complex can defuel 4 or more NS a year (depending on the NS type). In addition about 10-15 NSs could be defuelled by PTBs in a year. Therefore, currently available NS defuelling capacities are capable to increase the NS defuelling rate, however such increase would require substantial additional funding both for defuelling itself, and for further SNF transportation and reprocessing at Mayak plant.

It should be noted also that possibility for dismantling the NSs, located far from the SRYs where they are to be scrapped, became more difficult. Transportation of these NSs to the place of dismantling in many cases is very complicated because of bad technical condition of these subs and low buoyancy margin. In many cases using pontoons could solve this issue, but transportation of these subs on a long distance is a big problem.

For example, 55 NSs are to be dismantled in the Pacific region now, and 21 NSs out of this number are located on Kamchatka Peninsula. Dismantling capacity of the SRY No 49, located there, is about one sub per year /4/. Therefore, it is foreseen that the capacity of the SRY No 49 will be increased and at the same time part of NSs will be transferred to Zvezda SRY, which is located near Vladivostok. The distance between these two points is more than 2000 km by sea, which makes transportation of the majority of subs very problematic. Possible solution is to transport the subs using special dock, but such dock is not available in this region.

Minatom of Russia plans to maintain the defuelling rate at the level of about 18 NSs annually and dismantle approximately the same number of subs, which makes it possible to defuel all subs by 2007 and dismantle all NSs by 2010 in case sufficient finance is available /4/. In order to reach these goals substantial foreign assistance is needed.

The most significant Western assistance in the area of NS dismantling was provided in the frame of RF-US CTR Programme. The main objective of this Programme is supply of equipment, reconstruction of the infrastructure, and finance of activities to dismantle up to 41 strategic submarines. For period 1998-2002 340 million US\$ were allocated for these activities, and during this time 23 strategic submarines are to be dismantled /3/. In addition to direct financing of the NS dismantling work, CTR Programme paid for substantial upgrading and repair of the equipment and the infrastructure used at the enterprises, which conduct the dismantling, including repair of the PTBs which perform the subs' defuelling.

Unfortunately international cooperation on dismantling of the multi-purpose nuclear submarines is not conducted. It is planned to dismantle one Victor-class submarine at Zvezda shipyard under finance of the Government of Japan. However currently RF-Japan cooperation is on hold.

The following topics could be considered as possible cooperative projects: upgrading of the shipyard capacities to conduct the dismantling; NS transportation to the place of their dismantling; building of the ship for NS transportation or lend of such ship for temporary use. However, the most effective assistance, which will speed-up the NS dismantling process, and first of all of the multi-purpose NSs, is direct finance of the dismantling activities.

SNF Management

According to the Russian Dismantling Concept, all SNF discharged from NS is being reprocessed, which in the maximum extent reduces the final volume of high-level RW and excludes proliferation of nuclear materials.

As it was mentioned above, SNF is discharged from NSs by the on-shore defuelling complexes and by PTBs. At the on-shore complexes SNF transferred directly to transportation casks. When PTB is in use, SNF transfer to the casks is conducted at transshipment bases, where the casks are loaded into railcars, and then transported to Mayak plant for reprocessing. At Mayak plant SNF is transferred into the buffer storage, from which SNF goes to the reprocessing line.

New 40-tonne metal-concrete SNF cask TUK-108 has been developed, produced and tested under the AMEC Programme (Arctic Military Environmental Cooperation between Russia, Norway and USA). This cask is intended for SNF transportation and temporary storage. Later 48 such casks were produced under Russian finance. These casks, together with SNF casks type TUK-18 available before, provide SNF transportation to Mayak plant from the Far East and the Northwest regions. Further 25 TUK-108 casks will be produced shortly under finance of the CTR Programme. This park of SNF casks gives opportunity to maintain the NS dismantling rate, which has been reached already.

Accumulation pads for SNF casks were built at Zvezdochka and Zvezda shipyards (under CTR Programme) in order to provide stable SNF transportation. In addition to this similar pad is being constructed now at Atomflot enterprise in Murmansk under the frame of AMEC Programme.

Two special trains for SNF cask transportation are in use now. Each train is able to transport 12 SNF casks (which corresponds to SNF from more than one NS). One train was built and commissioned in 2002 under finance of the Norwegian Government. This substantially increased the rate of SNF transportation. These two SNF trains are being used very intensively; therefore in order to have some stand-by capacity a new SNF train will be built under the CTR Programme.

Therefore, available equipment for SNF transportation with due regard of its planned extension, reliably provides the NS defuelling rate which has been reached.

SNF reprocessing is being conducted at Mayak plant in Chelyabinsk region. Before 2000 capacity of the NS fuel reprocessing line was not sufficient and created a bottle-neck for the NS dismantling. In 2000 this line was substantially upgraded, including installation of new vetrification plant, and currently Mayak plant could reprocess SNF from up to 20 NSs a year. A weak link in the whole SNF management chain now is the SNF buffer storage at Mayak plant, which is nearly filled. Therefore, in many cases SNF from NS delivered to Mayak plant goes directly to reprocessing. In order to accept fuel during unplanned shutdowns of the reprocessing line or in case of its planned maintenance it is necessary to accumulate the SNF casks at the plant site.

This problem is being solved now. An agreement was reached with the American side that an interim SNF casks storage for 154 40-tonne casks would be constructed within the frame of CTR Programme. This will provide opportunity for permanent NS defuelling and SNF

transportation to Mayak plant. Now the main problem related to SNF reprocessing is lack of money to finance SNF reprocessing work at Mayak plant.

In addition to NSs waiting dismantling, spent nuclear fuel is stored at the coastal technical bases at Andreeva Bay and in Gremikha – in the northwestern Russia, and at Sysoeva Bay in Primorsky Territory. All these coastal bases belong to Minatom’s organizations - SevRAO and DalRAO respectively. In addition to that substantial amount of SNF (including the icebreakers’ one) is stored for quite a long time on board of Lapse, Lotta and Imandra ships, which belong to MSCO and are located in Kola fiord near Murmansk. Total amounts of the accumulated fuel are given in Table 1. SNF equivalent to one reactor core is used as a unit. Majority of submarines has two reactors with approximately 455 spent fuel assemblies (SFA) for one NS /1/.

Table 1: Amount of Stored SNF

Storage location	Amount of SNF	SNF type ²	Comments
North-West Russia			
Andreeva Bay	~ 100 cores.	PWR	SNF is stored in the dry storage units and in 52 old-design casks located at the open pad.
Gremikha	6 cores	LMC	It is planned to accept 3 more cores.
Gremikha	~ 2 cores	PWR	SNF is stored in the old-design casks located on the open pad.
MSC ships: Lapse	~ 1.5 cores	PWR	SNF is damaged but Mayak plant agreed to reprocess it. Including ~ 6 cores of unprocessable Zirconium fuel Including ~ 0.5 core of unprocessable Zirconium fuel.
Lotta	~ 8 cores	PWR	
Imandra	~ 2.5 cores	PWR	
Total in the region	~ 120 cores		
Far East			
Sysoeva Bay	~ 20 cores	PWR	
Total in the Russian Federation	~ 140 cores		Including ~ 6.5 cores of unprocessable icebreakers’ fuel.

Notes:

1. It should be noted that certain amount of fuel is stored for a short time on board of PTBs during some time from NS defuelling till loading of SNF into casks. On the same reason actual amount of SNF onboard of Lotta and Imandra could deviate from the specified in the Table1.

2. So called ”unprocessable Zirconium fuel” were used in some icebreaker reactors of PWR type. This SNF should be stored until techniques for its reprocessing has been developed, or until its disposal.

It is clear from the Table 1 that the amount of SNF accumulated in the storage facilities is smaller than the stored on board of NSs, waiting decommissioning (about 170 reactor cores). However it should be noted that the SNF storage conditions in the NS reactors generally is

² SNF type depends on type of the reactor: PWR - pressurized water reactor; LMC - reactor cooled by liquid metal coolant.

much better than in the storages, therefore, SNF removal from the storage facilities is an urgent task.

In Andreeva Bay SNF is located in dry storage units (DSU), which are not suitable for long-term storage. DSU do not provide reliable isolation of SNF from impact of the environment; a number of storage cells are filled with water; current state of majority of SFAs is not known.

At the moment it is planned to conduct detailed engineering and radiation surveys of the SNF storages and to produce feasibility studies in order to define an optimal techniques for discharge and removal of SNF. These activities are being conducted with UK assistance. Besides, in the frame of UK-RF cooperation it is planned to build protection of DSU from atmospheric precipitation. Unloading of the old-design casks, stored on the open pad, is a separate problem.

Norway finances large-scale work on upgrading of the infrastructure, which is necessary for safe management of SNF and RW at Andreeva Bay. Detailed list of projects on SNF management at Andreeva Bay is to be defined after completion of the feasibility studies, but support of Norwegian and Russian efforts on establishing of the infrastructure is required now.

State of SNF management in Gremikha base substantially differs from the Andreeva Bay facility. Gremikha base was intended primarily for unloading of spent reactor cores (SRC) of reactors with liquid-metal coolant (LMC). Specific features of these reactors are high enrichment of fuel (about 90%), and unloading of the whole reactor core as one piece during refuelling. Because of the high enrichment, SRCs constitute serious proliferation issue. 6 SRCs are in the interim storage at the site now, and three more SRCs are planned to accept. Unloading of SRC from the reactor is performed in the dry dock with the use of special equipment for preliminary heating of the coolant before SRC removal from the reactor.

Before SRC is transferred to Mayak plant for reprocessing, it should be disassembled to separate fuel rods. This operation could be conducted remotely at a special installation, which is available only in the Institute of Physics and Power in Obninsk in Kaluga region. At the moment construction of the similar installation at Gremikha is being discussed as a possible option.

Transportation of SRC is also a big problem, because there is no suitable cask for SRC transportation now (design documentation for this cask has been developed).

Upgrading of the dock and the SRC unloading equipment in Gremikha will be completed soon. This work is conducted under the Russian finance. SRC storage also requires upgrading and repair. Substantial work should be done for upgrading of the infrastructure at the site.

In addition to SRCs about 800 SFAs of PWR-type reactors are being stored at the Gremikha base site. This SNF is located in old-design metal casks on the open pad from 60-ies. State of SNF inside casks is not known, but it is expected that the storage condition are extremely unacceptable. Management of this fuel and further handling of the casks is very complex technical task and should be carried out in the same way as at Andreeva Bay.

The following tasks could be regarded as cooperative projects in Gremikha: upgrading of the infrastructure for unloading and removal of SNF from the site, discharge of SRC from NS

with LMC reactors, development of the cask and other engineering means for SRC transportation, production of a feasibility study on SRC management, removal of SNF from the old-design casks, etc.

As for the floating SNF storages, major environmental problem is caused by the Lapse ship, which contains on board damaged fuel discharged from the Lenin icebreaker. Technical state of the ship requires urgent removal of SNF and further remediation of the ship. This is a difficult engineering task because the state of SNF does not permit its removal using normal techniques.

During many years this topic is a subject of international cooperation, which until now was limited to evaluation of possible technical solutions and discussion of interaction with the regulatory authorities /6/. In June 2002 an agreement was signed between NEFCO (Nordic Environment Financial Corporation) and the Russian Federation in addition to already available bilateral agreements between RF and other Western donors of the project, including European Commission, Norway, the Netherlands and France. Recently it was decided to conduct first phase of the project. At this phase all design documentation will be developed and all necessary endorsements will be arranged. Actual removal of SNF and supply of the necessary equipment will be carried out at the second phase.

Remediation of the Sysoeva Bay site in Primorsky Territory and removal of SNF from this facility is also a priority task for the Far East Region. However general state of infrastructure and SNF storages at this site is much better than in Andreeva Bay, and the volume of the accumulated SNF is several times smaller. Nevertheless, the risk of radioactive release into the environment is substantial, and some improvements should be done there.

Management of Radioactive Waste

Relatively small amount of RW is generated during the NS dismantling: about 50m³ of liquid radioactive waste (LRW) and about 30m³ of solid radioactive waste (SRW) per submarine. However in some cases RW is generated in substantially greater amounts. LRW is being treated with further solidification. Necessary capacities for LRW management were created recently both in the Primorsky Territory (floating treatment plant “Landysh”, built under Japanese assistance), and in the northwestern Russia: facilities at Zvezdochka SRY (under CTR Programme) and at Atomflot enterprise (AMEC Programme). Therefore, the problem of the LRW dumping in seas at the Minatom facilities was practically solved.

Regarding the SRW management, the situation is following. SRW is temporarily stored in places of its accumulation – at SRYs and at Naval coastal bases. Substantial volumes of SRW generated during the NS dismantling is mainly loaded into the reactor compartments (RC), which are formed during the NS dismantling, for temporary storage. Therefore, SRW practically is not accumulated at the shipyards where NSs are being dismantled.

In order to improve SWR management, a mobile SRW treatment plant was developed and produced under the AMEC Programme. This facility will be commissioned at Polyarninsky. Russian organizations have developed technical design and feasibility studies (TEO) for construction of the SRW repository at Novaya Zemlya. This design was endorsed by all authorities involved and passed the international peer review, which confirmed acceptability of the engineering decisions. Further production of a detailed design is temporary on hold.

Substantial amount of SRW has been collected at the ex-naval coastal bases, where SRW is being stored in many cases on open pads and in storages, which do not correspond to the current safety requirements. Total amount of RW at Andreeva Bay and Gremikha sites is about 5 000 m³ of SRW and up to 3 300 m³ of LRW. Amount of waste at the Far East is smaller.

International cooperation on management of the accumulated SRW is being conducted now mainly at Andreeva Bay, where the work has been initiated under the Swedish assistance on integral engineering surveys of the storages and production of the feasibility studies. Besides, 450 containers for SRW interim storage and transportation were produced at Zvezdochka SRY under the AMEC programme, and a facility for SRW sorting and interim storage was constructed at Zvezda SRY under the CTR Programme.

The following SRW issues could be solved under international cooperative projects: conditioning, safe interim storage and removal of SRW and LRW from the coastal bases at Andreeva Bay, Gremikha, Sysoeva Bay and Gorbyshechya Bay; improvement of SRW management at SRYs, where NS dismantling is being conducted; establishment of Regional Centres on SRW management in the North-West and the Far East; construction of the Regional SRW repository at Novaya Zemlya and building of special vessel for transportation of SRW casks.

It should be noted that at the moment 41 nuclear service vessels are need to be dismantled. These vessels are substantially contaminated and pose a real threat for the environment. Considerable amount of SRW will be generated during the dismantling, and this SWR should be safely handled. International assistance to this work is required.

Management of reactor compartments (RC), which are being produced during the NS dismantling, is a separate issue. As it was mentioned above, components of the reactor installation, including the reactor vessel, are not disassembled, but remain inside the RC. These components are very radioactive because of their direct activation and the corrosion products activity. Part of the components (e.g. reactor internals, control rods, etc.) is a high-level SRW.

During dismantling three compartments are cut out of the NS hull and sealed – RC and two adjacent compartments, which provide buoyancy of such module. Then three-compartment modules are towed to places of their interim storage afloat. Such approach does not provide required period of the RC storage (up to 70 yr) until the time when further disassembling and recycling of RC is possible, and presents substantial potential hazard for the environment. In total 68 RC modules were produces by now, including 57 modules located in the North-West (mainly in the Sayda Bay) and 21 modules – at the Far East (mainly in the Razboynik Bay).

In future it is planned to apply on-shore RC storage approach, as it is currently accepted in the US and France. Design activities are being carried now for realisation of such approach and construction of the on-shore RC storage facility at Sayda Bay. In addition it is necessary to build a special vessel for the RC transportation (weight of one RC is about 600-800 tonne) and an accumulation pad for RC at the site of Nerpa SRY, which is located near the Sayda Bay. International assistance is required for financing of this project.

Other Problems

Between the problems left beyond the frame of the description above, the most important is a safe long-term storage of NSs, which were seriously damaged as a result of severe accidents. At the moment there are three such NSs and they are all located in Primorsky Territory. One NS can be dismantled according to current techniques with use of additional protection measures, while the other two NSs should be kept for quite a long time (up to 300 yr) in order to reduce the radiation intensity inside the NS compartments to the levels, which will permit the NS disassembling /4/.

At the moment these NSs are stored afloat, and this poses serious risk for the environment, because physical protection barriers of these NSs are seriously damaged. On the basis of evaluation of different options for isolation of the damaged NSs, performed by Russian experts, it was suggested to construct a special shelter on-shore and locate the damaged NSs inside it. This shelter will provide reliable protection of the NSs from the external impacts, and safe and monitored NS storage during the time necessary /3/.

The following topics are suggested for international cooperative projects: production of the feasibility study (TEO) and design documentation, construction of the shelter and supply of necessary equipment. All work could be completed in 5-7 years in case necessary financing is available. Total cost of this work is about 50 million US\$.

List of Priority Projects

The list of priority projects given below is prepared on the basis of information presented above and in accordance to the presentation of the Head of the RF delegation at the 15th CEG meeting.

1. Dismantling of multi-purpose nuclear submarines with low buoyancy margin.
2. Remediation of coastal bases in Andreeva Bay, Gremikha and Sysoeva Bay, including establishment of necessary infrastructure for unloading of the storage facilities, removal of SNF and RW, remediation of the former SNF storages and decontamination of the territory.
3. Dismantling of the nuclear service vessels.
4. Construction of the on-shore RC storage facility in Sayda Bay and in Razboynik Bay.
5. Management of spent reactor cores of reactors with liquid-metal coolant.
6. Safe isolation of damaged NSs.
7. Creation of regional centers for SRW management.
8. Construction of regional repository for SRW in the North-West of Russia.

List of acronyms

AMEK	- Arctic Military Environmental Cooperation (US-Norway-RF Programme)
CEG	- IAEA Contact Expert Group
CTR	- Common Threat Reduction (US-RF Programme)
DSU	- dry storage unit
LMC	- liquid-metal coolant
MSCO	- Murmansk shipping company
NS	- nuclear submarine
PTB	- floating technical base
RC	- reactor compartment
RF	- Russian Federation
RW	- radioactive waste
PWR	- pressurised water reactor
SFA	- spent fuel assembly
SNF	- spent nuclear fuel
SRC	- spent reactor core
SRW	- solid radioactive waste
SRY	- ship repair yard

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