Preparation for the Recovery of Spent Nuclear Fuel (SNF) at Andreeva Bay, North West Russia – 13309

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ABSTRACT

Andreeva Bay is located near Murmansk in the Russian Federation close to the Norwegian border. The ex-naval site was used to de-fuel nuclear-powered submarines and icebreakers during the Cold War.

Approximately 22,000 fuel assemblies remain in three Dry Storage Units (DSUs) which means that Andreeva Bay has one of the largest stockpiles of highly enriched spent nuclear fuel (SNF) in the world. The high contamination and deteriorating condition of the SNF canisters has made improvements to the management of the SNF a high priority for the international community for safety, security and environmental reasons.

International Donors have, since 2002, provided support to projects at Andreeva concerned with improving the management of the SNF. This long-term programme of work has been coordinated between the International Donors and responsible bodies within the Russian Federation.

Options for the safe and secure management of SNF at Andreeva Bay were considered in 2004 and developed by a number of Russian Institutes with international participation. This consisted of site investigations, surveys and studies to understand the technical challenges. A principal agreement was reached that the SNF would be removed from the site altogether and transported to Russia's reprocessing facility at Mayak in the Urals.

The analytical studies provided the information necessary to develop the construction plan for the site. Following design and regulatory processes, stakeholders endorsed the technical solution in April 2007. This detailed the processes, facilities and equipment required to safely remove the SNF and identified other site services and support facilities required on the site. Implementation of this strategy is now well underway with the facilities in various states of construction. Physical works have been performed to address the most urgent tasks including weather protection over one of the DSUs, installation of shielding over the cells, provision of radiation protection infrastructure and general preparation of the site for construction of the facilities for the removal of the SNF.

This paper describes the development and implementation of the strategy and work to improve the safe and secure management of SNF, preparing it for retrieval and removal from Andreeva Bay.

INTRODUCTION

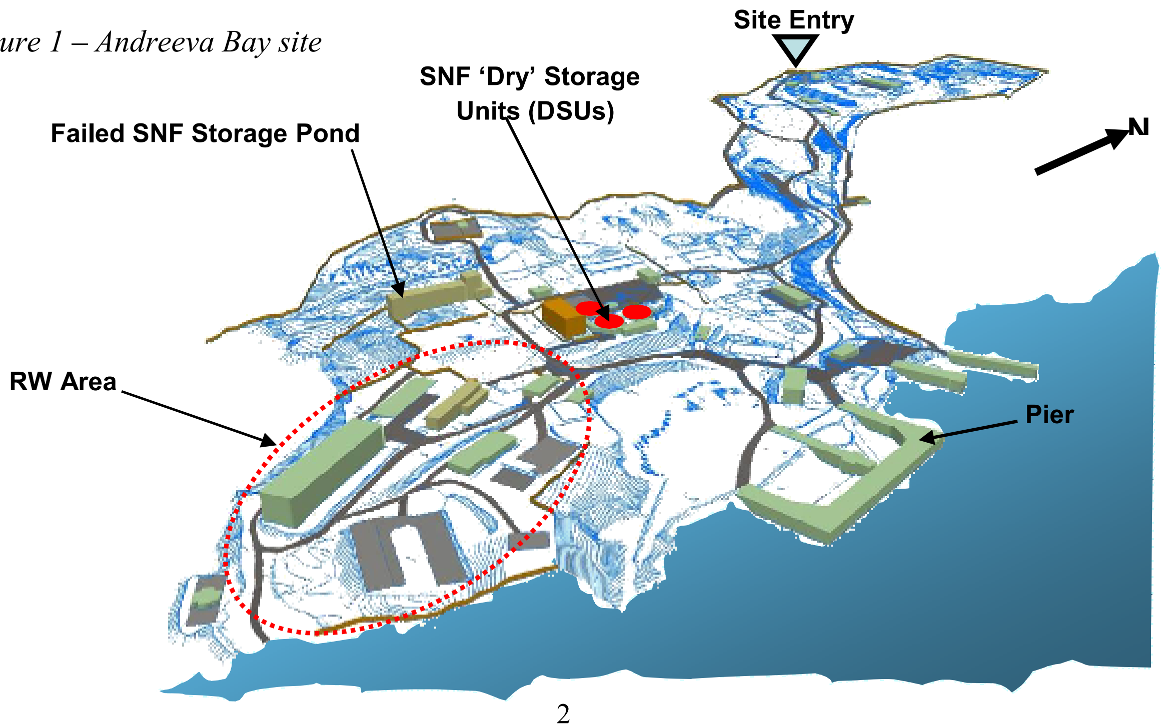
The former Soviet naval base at Andreeva Bay in the Murmansk region of NW Russia has one largest stockpiles of spent nuclear fuel (SNF) in the world. Approximately thirty tonnes of SNF, comprising over 21,000 assemblies (equivalent to the fuel from around 90 reactor cores) remains in a hazardous and deteriorating condition. By comparison, the fissile content from the HEU at Andreeva Bay is approximately twice that that remains in the sarcophagus of Unit 4 Chernobyl.

The base was established between 1961 and 1963 for storage of fresh fuel and SNF, solid radioactive waste (SRW) and liquid radioactive waste (LRW) arising from nuclear-powered submarines and icebreakers. SNF was initially stored in an above-ground fuel storage ponds.

In 1982, a serious leak in the ponds was discovered resulting in the radiological contamination of the building and its immediate surroundings. Following unsuccessful attempts to limit the loss of contaminated water it was decided that the fuel could no longer be safely stored in the ponds. As an emergency measure, three unused 1,000 m^3 storage tanks originally built for liquid waste were hastily adapted for use as temporary 'Dry' Store Units (DSUs) for the SNF. About 1,000 steel cylinders, each of 25-27 cm diameter and 4.5 metres long were set indiscriminately within each tank. Concrete was poured between the cylinders or *cells* to set them in place. Each cell was to hold a single SNF canister containing up to seven Spent Fuel Assemblies (SFAs).

The DSU tanks 3A, 2A, and 2B were put into operation immediately as they were completed in 1983, 1985, and 1986 respectively. Shield plugs were placed over the cells after the fuel canister had been transferred but most of these were ill-fitting. Transfer of the SNF from the failed ponds was completed in 1989.

Figure 1 – Andreeva Bay site



The structure of DSU tank 3A differs significantly from that of tanks 2A and 2B in that there was no steel roof. For years the only weather protection was a cover of concrete slabs supported approximately one metre over the surface and covered with bitumen and roof felt.

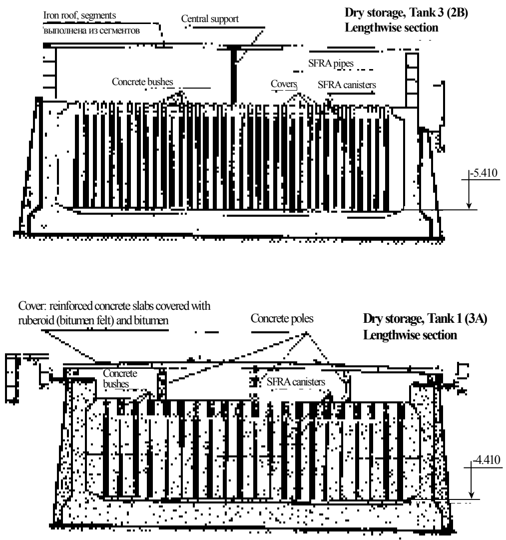
Figure 2 – SNF Store under construction in the mid 1980's

Figure 3 – Transferring SNF from the failed pond to the DSUs

The concrete tanks were originally intended as short term, temporary solution for storage of fuel until a proper facility could be built. Although the protection around the tanks had a design life of four years against corrosion, no proper storage was implemented due to lack of funds. As a consequence of lack of maintenance, the DSUs deteriorated and flooded from the ingress of snow melt water and precipitation.

Figure 4 – Dry Storage Units in year c2000

Figure 5 – Sectional views through DSUs 2A (above) and 3A (below)



Sampling of the water in the DSUs revealed the presence of Cs-137, Sr-90 and α-radionuclides proving contact between fuel and water. High salinity (up to 1700 mg/l) was measured in the water and is believed to have accelerated fuel degradation and corrosion of the canisters and DSUs themselves. It is thought that seasonal fluctuations of the water level have resulted in Cs-137 deposits in the corrosion layer in the cells lying between 20 and 100 cm below the top of the tanks. This and contamination over the surface of the concrete between the cells are the major source of radiation rather than direct shine from the SFAs. The radiation level over the top of the tanks is irregular. Peak values underneath the concrete beams of DSU tank 3A measure 42 mSv/h. Heavy contamination over the surface and up the inside of the tank walls, suggest that it has flooded at some time since the fuel was first placed and contaminated the ground around the DSUs. Generally, DSU tanks 2A and 2B are less contaminated and have lower activity levels than DSU 3A.

No facilities or equipment existed on the site to properly manage the fuel. This presented both an environmental and security hazard. When naval operations at Andreeva Bay ceased in 1993, funding for maintenance became scarce. Lapses in security led to the alleged theft of 1.8 kg of enriched uranium in 1993, recovered later that year. In 1998 the ecological rehabilitation of the site was made a Russian State objective and after years of neglect, responsibility for the coastal maintenance bases was transferred from the Russian Navy to Minatom (the Ministry of Atomic Energy) in 2000. The special Northern Federal Enterprise for Radioactive Waste Management (SevRAO) was established within Minatom to provide administrative oversight and management of the facilities at Andreeva Bay and two other coastal bases on the Kola Peninsula.[1]

The realisation of plans to improve the situation at Andreeva Bay is an excellent example of international cooperation. The Russian authorities have worked closely with the international community and received support from a number of sovereign countries including the UK, Norway, Italy and Sweden to help rehabilitate the Andreeva Bay site. Financial aid also comes from internationally funded programmes such as the Northern Dimension Environmental Partnership (NDEP) Support Fund administered by the European Bank of Reconstruction and Development (EBRD) and TACIS managed by the European Commission's Joint Research Centre.

STRATEGY FOR SNF MANAGEMENT

Initially, the work required a number of site investigations, surveys and studies to understand the technical challenges at Andreeva Bay necessary for the development of an SNF management strategy. It was also important that the aspirations of stakeholders, including those of the donors providing financial assistance, were taken into account when deciding on the most appropriate solution.

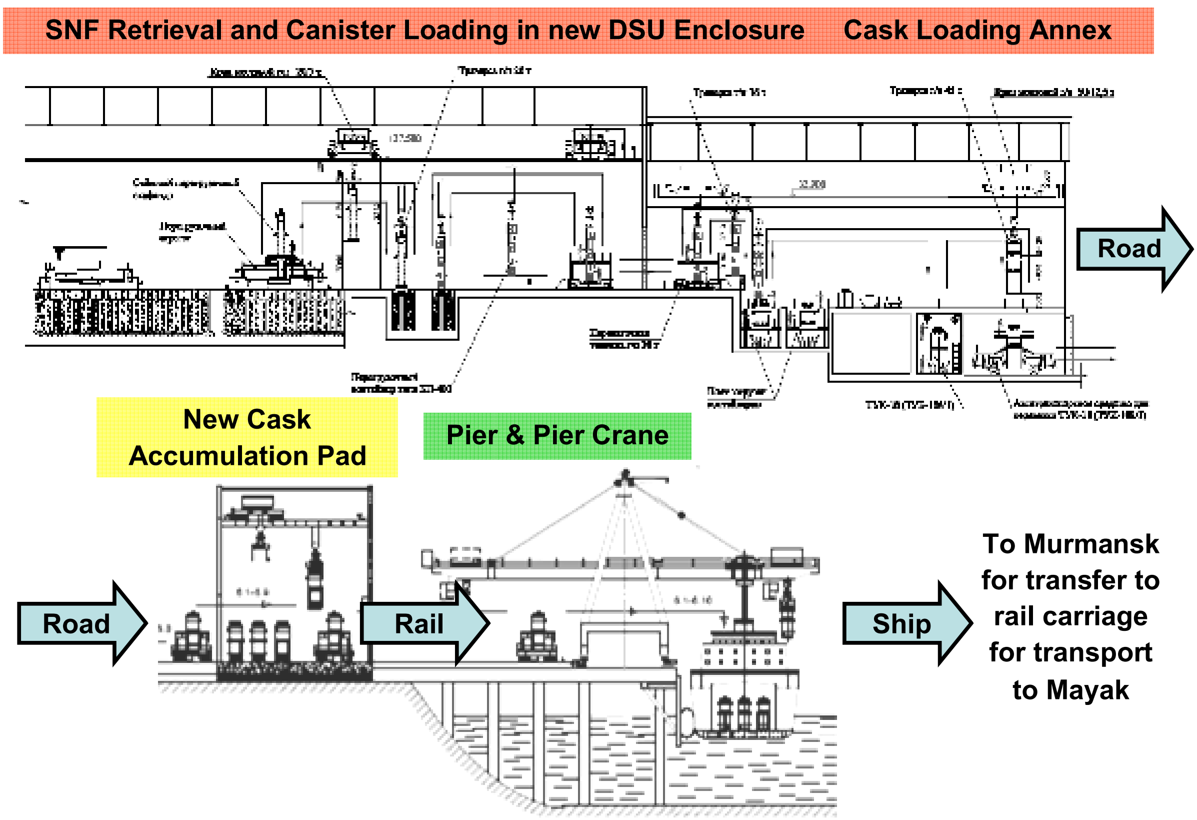
[1] Minatom was to become the State Atomic Energy Corporation "Rosatom" (ROSATOM) in November 2007 and SevRAO has since become part of RosRAO.

After optioneering alternative strategies for SNF management in 2004, it was decided that the most absolute long term solution would be to remove the fuel from the site altogether. After some years to develop the solution and attain regulatory approval in the form of an OBIN (Justification of Investment) and further refinement to the strategy to conceptualise a complex of new buildings for SNF management and support activities, the technical approach was finally agreed and endorsed by stakeholders in 2007. Fundamentally, the approach is to,

- Remove individual fuel assemblies from corroded canisters within the storage cells to avoid any risk of nuclear criticality, and place into new canisters;
- Where individual fuel assemblies cannot be removed, withdraw canisters after first draining the water and overpack them;
- Load the new canisters into certified casks for transport to Mayak RT-1 facility for reprocessing.

Analysis of the logistics transferring the SNF from Andreeva Bay to Mayak has shown that removal of SNF from the site will be at a rate governed by on-site processes and not by external factors such as capacity for temporary storage of SNF, number of transport casks or availability of the reprocessing facility. Retrieval of the fuel may take 10 to 20 years and is predominantly determined by the shear quantity of SNF in the DSUs and efficiency of the processes.

Figure 6 – Agreed SNF Retrieval and Handling Process



A new containment over the DSUs will be required to provide a safe environment for the deployment of bespoke SNF retrieval equipment, to recover, repack and ultimately remove the SNF from the site.

Additional facilities are also required to support the strategy for SNF removal, many of which are currently under construction as of December 2012. A new storage pad to shelter the casks under cover prior to shipment off site will be completed in 2013. A new facility for general workshops and storage, as well as the means to decontaminate and maintain the specialist equipment used for the removal of the SNF was completed in 2011. General development of the site continues, including installation of utilities and infrastructure, procurement of a crane on the pier and cask transport equipment. All these projects are in progress. Provision of new radwaste management facilities are also underway that will treat the 25,000m^3 of legacy radwaste existing on the site and be available for the operational arisings from SNF retrieval.

IMPLEMENTATION OF THE SNF STRATEGY

The physical work associated with the SNF strategy implementation can be described in four stages,

- limit the deterioration of the DSU storage facility and monitor the conditions
- radiological isolation of the DSU tanks
- Construction of an enclosure over the DSUs suitable for fuel movement
- Installation and commissioning of bespoke SNF retrieval equipment

Limiting Deterioration of the SNF

The original metal covers over tanks 2A and 2B provided basic weather protection; however the cover arrangement over DSU 3A was less effective as described earlier as there was evidence of water ingress.

Radioactive contamination of the flood water within DSU tank 3A was noted to have been increasing progressively from 1999 suggesting that the fuel was degrading. It is thought that seasonal fluctuation of the water level inside the DSU cells was also leaving fuel deposits in the tide mark leading to an increase of radiation levels over and around the tank.

Water samples from the DSU were analysed and geological and hydro-analysis confirmed that the water was most likely not entering underneath or through a breach in the subterranean sides of the DSU, but instead directly from the sky and/or surface run-off. Installation of a temporary weather-proof cover over the DSU tank 3A was therefore considered a priority for stabilisation of the SNF and immediate environment.

Figure 7 – Concrete beams and bitumen asphalt over DSU 3A covered provided poor weather protection

Figure 8 – Temporary weatherproof cover installed in 2004 had a stabilising effect on radiation levels

With funding from the UK, a new temporary cover was installed over DSU 3A in 2004. This included services such as an active ventilation system, water monitoring and an ASKRO radiation monitoring system.

Radiological Isolation

The high radiation levels around the DSUs needed to be addressed before construction of the new SNF handling facility could safely commence. For example, workers would have exceeded their annual exposure limit of 20 mSv within a single shift while working over DSU 3A, or less than one hour once the existing concrete slabs were removed to gain access for retrieval of the SNF.

Various options were considered for biological shielding over the DSUs. An early proposal for DSU 2A and 2B was to simply replace the plugs and decontaminate the concrete surfaces of the tanks. However, this was unsuitable for DSU 3A due to the high radiation fields and limitations on personnel access. Considerations for SNF retrieval drove the final decision to a consistent solution for all three tanks. Biological shielding was designed to ensure both safe conditions for construction of the new facility and to provide a removable platform during the operational phase of fuel removal.

An alternative option to place engineered plugs over each of the cells and cast a monolith concrete shield over the top of the tanks was discounted due to the uncertainty over the integrity of fixing against the existing DSU surface. Any disturbance or failure of the plugs would have resulted in the cells filling with concrete and entombing the fuel canisters.

Figure 9 – Inside DSU 2A. Radiological conditions meant only brief access was allowed

Figure 10 – Inside DSU 2B. Shield plugs were ill-fitting and snow could enter

The chosen design of biological shielding took the form of profiled steel plates of suitable thicknesses to attenuate the activity over each DSU to less than 12 μSv/h. Installation of the shielding over DSU 2A and 2B was carried out semi-remotely using a Bobcat and was completed in 2009 with funding from the UK.

Figure 11 – Inside DSU 2B, Steel biological shielding was installed in 2010

Figure 12 – Steel biological shielding greatly improved radiological conditions

The activity over DSU 3A however, was too high to adopt the same installation approach taken for the other two tanks. Instead operations needed to be carried out remotely from temporary process control modules. A Brokk 90 robotic manipulator and a rail mounted, remotely controlled HIAB crane were used to first remove the old concrete slabs, then clean up the contaminated debris and finally install the shield plates. The £4.7 million contract for this work was funded jointly by the UK and Norway and successfully completed in April 2012. The project was extremely successful: radiation levels over DSU 3A have been dramatically reduced from peak readings of 42 mSv/h underneath the concrete beams, down to 7.44 μSv/h over the horizontal shielding.

Figure 13 –DSU 3A with attached temporary process modules to carry out remote operations

Figure 14 – Inside DSU 3B during installation of biological shielding

Figure 15 – Inside DSU 3B remote removal of debris using Brokk 90 robotic manipulator

Construction of a New DSU Enclosure

The design for the new facility underwent regulatory review and received State Expert Approval November 2010. Construction is planned to start in 2013. To date, much preparatory work has been carried out including demolition of the KPM-40 site crane and ground clearance.

The new DSU Enclosure is designed as two connected structures comprising the main hall and an annex for cask handling. The main hall over the DSU tanks is formed by two spans of 54m overall width, 108m in length and 22.5m height to ridge. This structure houses ancillary services and operational facilities within a three storey and single storey arrangement at the North and South gables. The cask handling annex is 19.8m span by 24.1m and 27.4m high, connected at the North East corner. Here, certified transport casks are prepared and loaded with SNF canisters before transferring to the cask storage pad where they will stay until offloaded onto a ship. The structure and safety systems of the DSU Enclosure are of a nuclear category and the design is seismically qualified.

Figure 16 – Model of the new DSU Enclosure planned for construction starting 2013

Figure 17 – Main hall of the DSU Enclosure with space to perform SNF retrieval and repacking into new canisters

Funding for the construction of the DSU Enclosure is secured from the NDEP programme. Currently, the construction contract is under negotiation as of December 2012. The general site plan indicates that the facility will be commissioned in 2015.

SNF Retrieval Equipment

Retrieval of the SNF is far from straightforward due to the high radiation, difficulties of accessing the SFA and the possibility of an uncontrolled criticality event. Although criticality is an unlikely scenario, such and event would be serious and would probably register as a Level 4 incident on the Nuclear Event Scale.

Figure 18 – View looking down into cells (shielding lid / plug removed) showing examples of various SNF canister heads which must be removed to gain access to the Spent Fuel Assemblies.

(i) Latch obscured by debris, (ii) Latch heavily corroded, (iii) Canister rim deformed.

The fuel canister geometry is designed in such a way to avoid uncontrolled criticality. At Andreeva Bay however, both the fuel and the fuel canisters have degraded. Analysis has shown that criticality can only occur under specific circumstances.

- At least 10.6 litres of water must be present to act as the moderator.
- A canister breach must allow the fuel to come in contact with the water.
- More than the equivalent of four fuel assemblies from the seven within a typical canister must have degraded.
- A disturbance must occur to uniformly mix water and fuel outside of the canister.

The requirement for fuel and water to mix means criticality cannot occur under static storage conditions i.e. the fuel particulate is not able to concentrate at the bottom of the cell in a critical geometry while the canister remains in place.

Various measures were considered to mitigate the risk of criticality during dynamic conditions of SNF retrieval. The selected solution was to remove the fuel elements individually as a single SFA has insufficient fissile content to cause a reaction. Operations will be time consuming and in-situ removal of the canister head remains a formidable technical challenge due to the poor state of canisters, confined arrangements within the cells and adverse radiological conditions.

Following building construction, bespoke retrieval equipment will be deployed. A rail mounted shielding platform will provide the base to support gamma gates, shielded flasks, assembly retrieval equipment and so forth. The concept design for this machine is illustrated below.

Figure 19 – Sectional view of the SNF canister in its cell

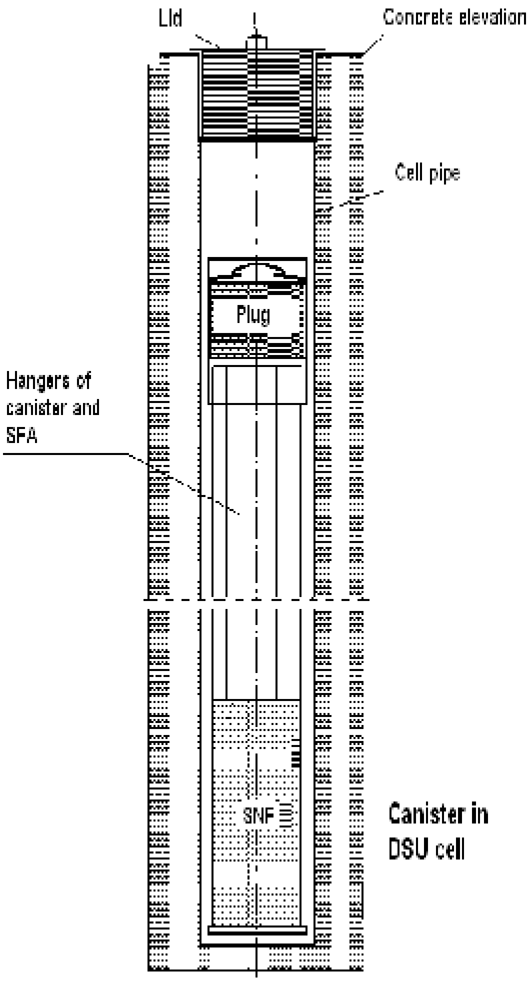


Figure 20 – Model of SNF retrieval / transfer cask on the retrieval machine platform

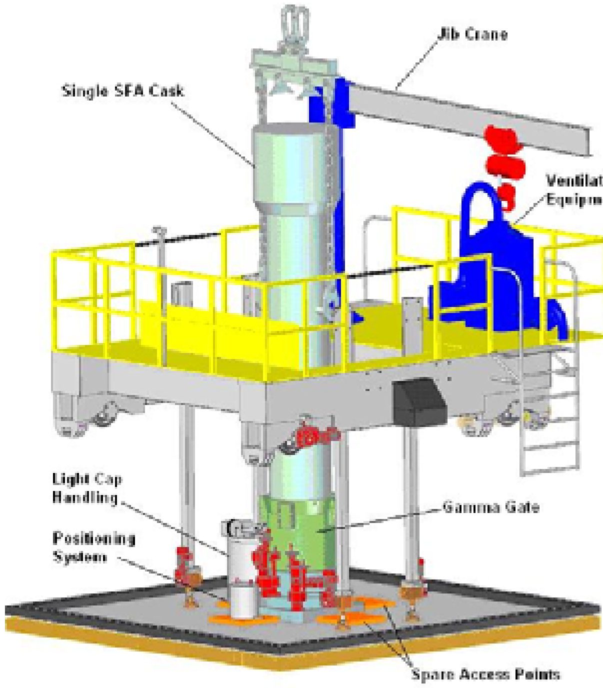
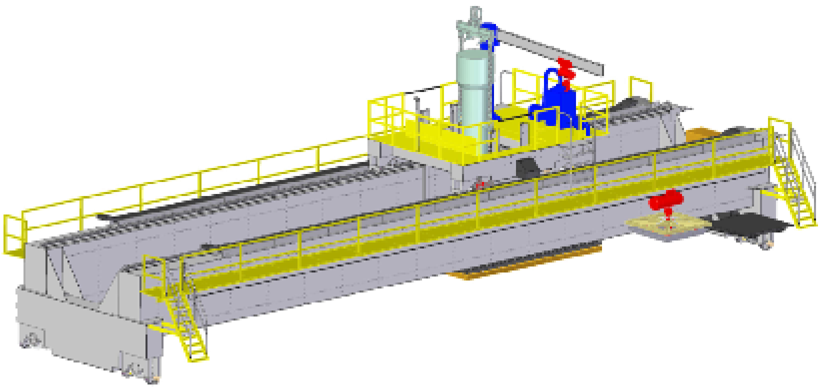


Figure 21 – Model of the retrieval machine platform to be installed in the DSU Enclosure Sectional



CONCLUSIONS

With ongoing assistance from the international community, the Russian Federation is implementing a long term plan for the rehabilitation of the Andreeva Bay site. This has involved the demolition of redundant facilities, stabilization of legacy buildings that remain functional and construction of new facilities aimed at improving the SNF and waste management.

Significant progress has been made to date towards the improvement of SNF management at the site. Arguably, the most important achievement has been stabilisation of the current radiological conditions around the DSUs.

The long term strategy agreed among international stakeholders involves the total removal of the fuel inventory from the Andreeva Bay site. Technical solutions have been developed and funding is secured for its realisation. Retrieval of the SNF from the DSUs might start as early as 2015 following construction of the DSU Enclosure and commissioning of retrieval equipment, and will possibly continue until 2030.

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