Nuclear Safety Institute of the Russian Academy of Sciences (IBRAE RAN)

Annex 9
Source Control Project, Phase III

Task 2
Milestone 7
Project Management Plan at Federal State Unitary Enterprise (FSUE) "Atomflot"

Risk Assessment at the Coastal Spent Nuclear Fuel (SNF) Reloading Facility of FSUE "Atomflot"

Final Report

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Report

Summary

Annex 9 (Source Control Project, Phase III) covers the activities for the development of the underlying methodology and the conduct of risk assessment for radiation and chemical hazardous facilities of the industrial North of Russia. Annex 9 continues work on the source control project, which was started in 2000 under the framework of Annexes 1 and 4.

Two major facilities of the North of Russia were chosen for the current project: FSUE "EE "Zvezdochka" (Severodvinsk, Archangelsk Region) and FSUE "Atomflot" (Murmansk).

Initial tasks included the organization and conduct of the first visit to the site; the selection of a facility to apply the risk assessment; and the preparation and conduct of training courses on the methodical foundations of risk assessment. This training was targeted to the personnel of facilities performing theses types of activities in the North-West Region of Russia.

The Project Management Plan (PMP) for FSUE "EE "Zvezdochka" was approved on November 9, 2005.

The PMP for FSUE "Atomflot" was approved on May 29, 2006.

The goal of Stage 7 of PMP for FSUE "Atomflot" is to prepare the final report on the risk assessment, which should include recommendations on the possible application of the ISO 14001 standard and the developed risk assessment methodology document.

This report is presented in accordance with the report documents of Stage 7 of the PMP for FSUE "Atomflot".

Input information

The work followed the Risk Assessment Methodology developed in the earlier Phases (I and II) of the Source Control Project (2000-2004).

The first stage of the project was conducted at a sewage facility of the town of Apatity in the Murmansk Region of the Russian Federation. A draft of the Risk Methodology Document for the chemically-hazardous industrial facilities was developed as a result of the project.

The second stage of the project was conducted at the fuel research department of the FSUE "SSC RF Nuclear Reactor Institute" in Dimitrovgrad in the Ulyanovsk Region. During the execution of this project, the risk assessment methodology was adapted to the radiation-hazardous facilities. The works conducted in the current stage are a part of the work described in the Risk Assessment Methodology Document.

Scope of Work

Nuclear- and radiation-hazardous works carried out at FSUE "Atomflot" are mainly connected with refueling ship nuclear reactors and the management of the removed SNF. The current project studies the reloading operations in detail.

In addition, this project focuses upon the following main tasks:

- Development of recommendations on introducing the ISO 14001 Environment Management System (EMS) standard at the facility and the use of the risk assessment methodology;
- Preparation of this final report.

Scope of Work Details

This section gives a brief description of the studied facility, the work performed, and the recommendations received in the process of project implementation.

More detailed information may be found in the reports on Stages 2-5, prepared according to the PMP for FSUE "Atomflot".

1. Brief Description of FSUE "Atomflot"

FSUE "Atomflot" is located on the bank of the Kola Gulf, two kilometers from the northern boundary of the city of Murmansk, and has a total site area of 17 hectares. The facility performs repair and maintenance of the nuclear propulsion units of nuclear icebreakers and is controlled by the Federal Agency for Sea and River Transport of Russia.

The icebreaker fleet is managed by JSC "Murmansk Shipping Company" (MSC), and "Atomflot" performs the maintenance of the ships. As documented by the official press-release of the Rosatom press office, an agreement on the transfer of the nuclear icebreaker fleet to Rosatom was reached in February of 2008. It is expected that when the contract of MSC on asset management of the icebreaker fleet expires in 2008, FSUE "Atomflot" will be also transferred to the state corporation of Rosatom in the framework of the nuclear industry reform.

FSUE "Atomflot" was established and developed as a facility fitted to carry out the repair and maintenance of nuclear-powered ships and nuclear maintenance vessels. The facility became operational in 1960. At that time it was performing maintenance of the first nuclear icebreaker "Lenin". The seventies marked extensive building activities and an increase in the facility capacity. As soon as the decision was made to expand the nuclear icebreaker fleet of USSR with new ships, the facility was expanded, and additional space and capacity were added.

Fig.1 Nuclear icebreakers and nuclear maintenance vessels at FSUE "Atomflot"

The first series of improvements became operational in 1981. They included a repair and technical building, technological mooring lines, a Solid Radioactive Waste (SRW) storage facility, and needed auxiliary systems. The productive capacity and engineering infrastructure were further developed in the following years to include new technological mooring lines, a special water treatment facility, an administrative building, and other auxiliary facilities. A coastal facility for long-term dry container storage of SNF was completed and commissioned in 2005. This Russian-British project was performed in the framework of the global partnership in the field of nuclear safety. Since then, no containers with SNF have been loaded into the facility due to some problems concerning contractual issues with the SNF user - JSC MSC.

FSUE "Atomflot" is the permanent base of nuclear icebreakers and Nuclear Maintenance Vessels (NMV). The enterprise executes the following functions:

- maintenance and repair of general and special ship equipment;
- recharging nuclear reactors;
- preparing SNF to transportation by railroad transport;
- acceptance and loading fresh nuclear fuel to FMB "Imandra";
- acceptance, processing and temporary storage of liquid and solid radioactive waste (RW).

The facility has 9 mooring lines with a total length of over 1 km and a floating pier. The depth at the mooring lines is 11.6 meters. The loading operations at the facility are carried out with the use of three portal cranes located at the mooring line, including a 100 ton KONE crane built in Finland, which is used for all SNF container reloading operations.

The facility has all the infrastructure required for the treatment of liquid and solid RW:

- SRW container storage facility with an internal volume of 400 m^3 with a section for burning flammable waste;

- high-level SRW storage pad with 216 cells (containers holding spent ion-exchange materials of the primary circuit and emergency protection rods);

- highly radioactive equipment storage pad with 12 cells (steam generators, primary circuit pumps – 12 cells);

- retractable core parts storage pad designed for special containers (3 containers);

- storage facility for acceptance and temporary storage of liquid RW (LRW), equipped with a LRW treatment installation and two vessels with a volume of 100 m^3 each;

as well as services, systems, and equipment for the monitoring and accounting of personnel exposure doses, and radiation monitoring at the site and in the vicinity of the facility (nuclear and radiation safety department, central laboratory, environment protection laboratory)

In 2000-2005 an automated radiation monitoring system of FSUE "Atomflot" was developed in the framework of the AMEC international project in cooperation with the Norwegian Institute of Energy Technology. The system includes gamma-radiation sensors, a radioactive aerosols monitoring station, a water radioactivity monitoring system, and an automatic weather station. Data of the dose rate from two sensors at the boundary of this site are automatically transmitted to the Murmansk territorial Automated Radiation Monitoring System (ARMS)

All works connected with SNF reloading are carried out at the coastal unloading facility, which is examined in the current project.

2. Technological procedure of SNF reloading

The procedure for managing SNF unloaded from the reactors of civil nuclear ships using the new equipment of FMB "Lotta" and TUK-18 (TUK-108/1) transport containers was introduced at FSUE "Atomflot" beginning in 1995. (See also Attachment 2)

Upon unloading of the reactor core from the nuclear icebreaker, the SNF is stored for at least 6 months at the FMB "Imandra". Then the fuel is reloaded to the storage holds of FMB "Lotta" for further storage. The total storage time for SNF from the time of its unloading to transportation of the fuel to the Production Association (PA) "Mayak" is at least three years. The current study examines the technological operations required for reloading of the fuel between the floating maintenance bases and loading of TUK-18 (TUK-108/1) from FMB "Lotta" to the special train.

Technological procedures for unloading SNF are determined by the corresponding regulations, which define the organizational measures to ensure nuclear and radiation safety, the sequence of technological operations, requirements for staffing and equipment, as well as the duties and the responsibilities of the personnel.

The following organizational and technical measures are taken to increase the safety of all operations:

- All other hazardous works in the territory of the facility are suspended for the period of works on fuel reloading;
- Implementation of uninterrupted radio metering and dose metering monitoring for the period of works using the equipment approved for such kinds of works;
- Conduct of static and dynamic tests of the KONE portal crane with the load of at least 50 tons prior to the start of the works. The act of the tests is then drawn up and submitted to the nuclear and radiation safety inspections department;
- Limitation of fine rate of the cranes to 0.4 m/min;
- Testing the reliability of engagement and work of crane brakes in each container hoisting operation (after the container is lifted to the height of 200-300 mm the engagement of cross-arm hooks with the container trunnions is visually checked);
- Limitation of the maximum and minimum height of lifting the KB-650 (KP-400) and TUK-18 (TUK-108/1) containers (not more than 9 m above the mooring line level and at least 0.5 m over all the obstacles along the transportation route), and exclusion of TUK-18 (TUK-108/1) movement over the SFA storage facility of the floating maintenance bases;
- Provision of reliable double-way communication between the working places of the personnel engaged in the works.

The works on handling the TUK-18 (TUK-108/1) container are allowed for ambient temperatures in the range of –20^{o}C to +40^{o}C and windspeed of not more than 12 m/s.

3. Preliminary risk assessment

The preliminary risk assessment stage was used to study the various initial events and the possible accident evolution scenarios to select the most significant ones for further quantitative risk assessment. The following initial events have been selected: loss of power supply during SNF reloading, fire, extreme external impacts, fall of various equipment elements.

Total loss of Power Supply

The following elements of equipment used in SNF reloading require power supply:

- Lifting cranes;
- Electric motor of the system for removal of water from shrouds and TK-18 containers;
- Electric motor of TK-18 container airtightness monitoring system;
- Air-wrenches.

The electric substation supplying the power to the crane columns is classified as one category according to the Russian standards, i.e. it supplies power from two independent power sources. The switching of the feeders is automatic and takes about 0.3. sec. A diesel power supply station is located on the pier and is used in case power is lost from both supplies. Starting the diesel generator and switch to the reserve power takes 15 minutes.

In accordance with the requirements of it. 2.4 [1], the mechanisms of load lifting and change of the crane radius are equipped with closed type brakes, which are automatically disconnected if the actuators are engaged and automatically connected if the actuators are turned off. Thus the loss of power supply will cause the SNF container to stop movement until another power supply is engaged. Additional failure of relay protection and the control system will interrupt the operations for the duration of the loss of power supply. One of the causes of loss of power supply may be unsatisfactory condition of the cable lines, which were not properly verified by the personnel prior to start of the works on SNF transportation. In this case, the container may be lowered to the minimum allowed height manually.

Results of thermal calculations performed for TUK-108/1 transport package [2] at the least favourable long-term storage conditions (ambient temperature 38 °C, solar exposure and calm conditions) demonstrate that the packing of the I and II circuit of the transport package TUK-108/1 remain functional.

Loss of power supply to the system of water removal from shrouds and containers does not affect the safety of carried out works. The works are stopped until the power is restored or a reserve power supply is connected.

Loss of power supply to the electric motor of the TUK-18 airtightness monitoring system does not affect the safety of carried out works. The works are stopped until the power is restored or a reserve power supply is connected.

Failure of the air supply system feeding compressed air to the pneumatic air-wrenches does not affect the safety of carried out works, but leads to temporary interruption of the operation. The screws holding the lid of the TK-18 container may be screwed manually using the calibrated wrench.

Fire

The fire may occur as a result of both external impacts, and internal failures. The fire may lead to failures of the equipment, and power supply systems. The fire may be caused by short circuiting of the power supply cables, oil falling on hot sections of the equipment, and personnel errors during repair and restoring works.

The following safety measures should be taken to prevent the fire:

- Incombustible and fire resistant materials are used in the equipment.

- Storage and use of flammable materials is carried out under strict control;
- All fire-hazardous works (welding, etc) are carried out under strict control.

No repair works requiring open flame sources are allowed for the period of operations on management of SNF.

Fire at a load-lifting crane may lead to failure of its elements and, consequently, fall of the lifted SNF container.

Analysis of the amount of flammable materials stored at CUF and in its immediate vicinity demonstrated that the scale (temperature, time) of the potential fire connected with the process factors, will not be sufficient to cause loss of container airtightness (See Attachment 3).

TK-18 container may lose airtightness in a fire only as a result of extreme external impact, such as crash of an aircraft with a sufficient amount of fuel on board.

According to [3], the probability of an aircraft crash within an area of 10000 m^2 in any region of the country is assessed as 10^{-6} per year. The smaller area and the limited time of presence of the train loaded with TUK in the territory of the site allows assessing the probability of an aircraft crash as 10^{-8} per year and eliminating this event from further consideration.

Seismic impact

The new version of the seismic zoning maps of Russia (OSR-97, [4]) developed by the United Geophysics Institute of O.Yu.Shmidt of RAN in 1990-s is based on probabilistic assessment of the seismic hazard of the territory. The OSR-97 kit includes four types of maps for various periods of earthquake frequency - once per 500 years (map OSR-97-A). once per 100 years (map OSR-97 B), 5000 years (map OSR-97 C), and 10000 years (map OSR-97 D), which correspond to the various probabilities (10%, 5%, 1% и 0.5%) of the possible excess in the seismic intensity within 50 years.

The in-force Russian regulatory document for siting seismically stable nuclear power plants [5] requires the use of OSR-97-D maps to determine the magnitude of the maximal design-basis earthquake.

According to this map, Murmansk is located in the area where a design-basis earthquake of maximum magnitude of 7 points according to the MSK-64 scale is possible. Taking into account the soil conditions of the site, the magnitude of maximum design-basis earthquake was taken as 7 points according to MSK-64 scale in compliance with the Appendix No. 7 NP 031-01.

Maps of OSR-97D correspond to the seismic effect on the surface of once per 10 000 years in average. The probability of the event within 50 years is 0.5% and within a year 10^{-4}. Taking into account the average duration of the most hazardous operations, we can take the probability of a maximum design-basis earthquake during reloading SNF as less than 10^{-6} year $^{-1}$.

The calculations in accordance with NP 031-01 requirements showed that a maximum design-basis earthquake will not lead to overturning of the TUK-18 package. Qualitative description of the damage to buildings and structures in case of a 7 points design-basis accident given in literature, allows assuming that a crane and the TUK-18 may fall on the mooring line or onto the train during the works. However, if no additional failures occur, the resistance of the structures to mechanical damage (see Attachment 3) most probably will not be exceeded. This, along with the low probability of the initial event, eliminates the seismic impact from further consideration.

Fall of equipment elements containing Spent Fuel Assemblies (SFA)

The following events connected with the fall of equipment elements containing SFA are possible for the technological procedure used:

- fall of a base container during reloading of a shroud loaded with SFA between the floating bases or during loading of TUK-18 (TUK-108/1) at FMB "Lotta";

- fall of the TUK-18 (TUK-108/1) container during its unloading from the reloading compartment and loading to the TK-VG-18 carriage or storage facility of FMB "Lotta".

These operations are characterized by engagement of large quantities of nuclear and radioactive materials in the presence of highly stable safety barriers (as for the case of reloading of TUK-18 (TUK-108/1) containers) or use of smaller quantities of hazardous materials with relative reduction of the stability of safety barriers (reloading of separate SFA shrouds).

Fall of a base container loaded with SFA During the fall of the container, regardless of the technological operation used, special guiding devices are installed on TUK-18 or the cells of the FMB storage facility.

The guiding device strength assessment demonstrated, that a fall of the reloading container onto the guiding device leads to its deformation but not destruction and thus, taking the gap as 400 mm, it does not affect the position or the integrity of SFA and other fuel element claddings. Deformation of shroud and loss of fuel elements airtightness, leading to release of 30% of RNG activity to the environment were assumed during the fall of the reloading container. Assessments for the most significant radionuclide, Kr-85, show total activity around 1 TBq in the absence of fire.

Fall of TUK-18 package. Only a single TUK-18 package is transported at a time according to the technological procedure. The package is sealed and monitored for airtightness prior to transportation. The amount of water inside the package should be lower than the allowed values. As the fall height cannot exceed 9 m, the container will not be destroyed in this case. However, the current event may lead to formation of micro-fractures and partial loss of airtightness of some of the fuel element claddings. The possible damage of the rubber packing and the increased concentration of radionuclides in the air inside the container may cause the increased release into the environment.

Fall of equipment elements

The following equipment elements may fall during the transport and technological operations on SNF management at the pad of FSUE "Atomflot", leading to damage of the SFA or fuel element claddings:

1) Guiding device onto the fully loaded TK-18 container. Such a fall may occur when the guiding device is removed from the container upon completion of TK-18 container loading;

2) Container lid on the container with shrouds fully loaded with SFA. The fall may occur when the container lid is installed on the container upon completion of the loading operations.

3) Guiding device cross-arm on the guiding device. The fall may occur when the cross-arm is moved for connection with the guiding device.

4) Container lid cross-arm on the container lid installed on the loaded container. The fall may occur when the cross-arm is removed from the container lid.

5) Elements of the portal crane structure, including the counterbalance, and TUK-18 onto the loaded container or a train with SNF.

Fall of elements 3 and 4 are not taken into account in subsequent analysis, as their weight is substantially lower than that of the base container (see previous section).

Fall of the container lid (2) may also be taken out of the consideration as the weight of the lid is three times lower than the weight of the guiding device, and the height of their fall is nearly the same.

4. Quantitative risk assessment

Five scenarios listed in table 1 were selected as the most significant scenarios for quantitative risk assessment.

Table 1. Initial events for detailed assessment of emergency situations

Scenario number	Initial event
1	Fall of a TUK Container
2	Failure of container carriage
3	Fall of reloading container loaded with SFA
4	Fall of a Guiding Device or a Container Lid inside the Container TUK-18 (TUK-108/1)
5	Fall of technological equipment onto the loaded container or a train loaded with SNF

Here we will consider failure of the container carriage as derailment, overturning, or fall of three TUK-18 (TUK-108/1) containers caused by incorrect installation or impact of a falling TUK on the carriage.

4.1. Fall of a TUK Container

As the fall height cannot exceed 9 m, the container will not be destroyed in this case. However, the current event may lead to formation of micro-fractures and partial loss of airtightness of some of the fuel element claddings. The possible damage of the rubber packing and the increased concentration of radionuclides in the air inside the container may cause the increased release into the environment. Fig. 2 shows the general accident evolution diagram

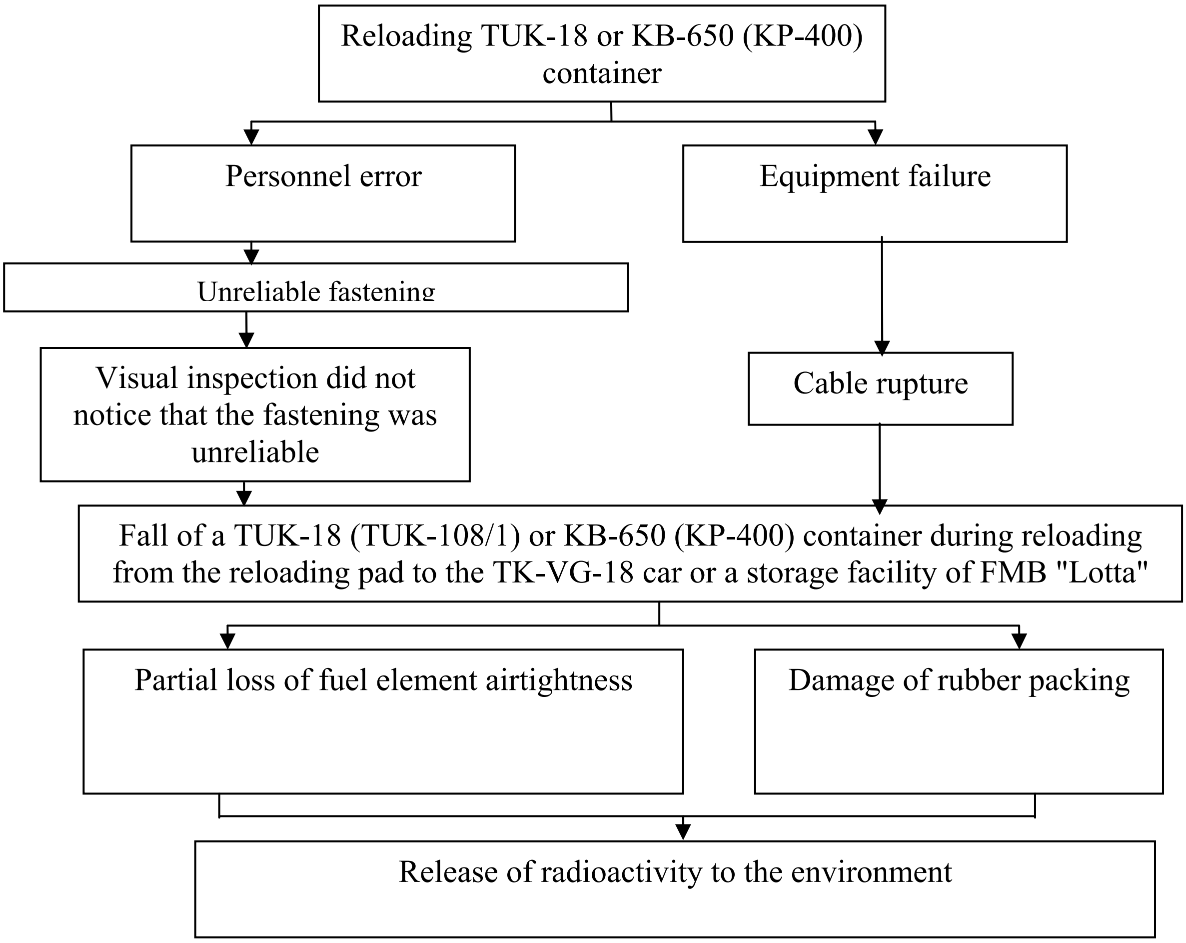

Figure 2. Diagram of the accident "Fall of a TUK or a reloading container loaded with SFA"

"Event tree" method and quantitative risk assessment were selected as a technique for detailed risk analysis. Fig. 3 shows an event tree for a scenario with a personnel error as an initial event.

Initial event personnel error (unreliable fastening)	Unreliable fastening unnoticed	Fall of a TUK or KB-650 (KP-400) container	Partial loss of airtightness	Damage of rubber packing	Final condition-release to the environment	Probability

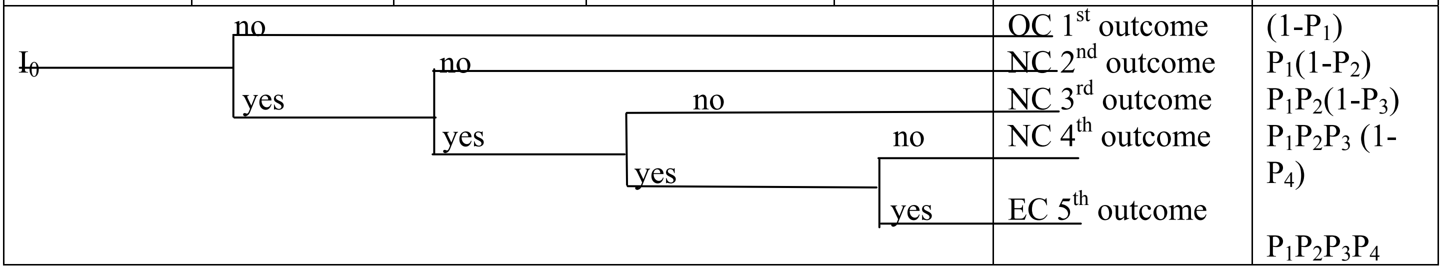

Figure 3. Event tree for a scenario with a personnel error as an initial event

The following abbreviations are used hereafter for the event tree: OC – operating condition, NC – non-operating condition, EC – emergency condition, P_i – failure probability, (1-P_i) – probability of faultless operation.

For this case an emergency condition is obtained by a sequence of events with a total probability being the product of conditional probabilities:

$R(I_0) = P_0 \bullet P_1 \bullet P_2 \bullet P_3 \bullet P_4$,

where P_0 is the probability of an initial event.

The data given in paper [6] for safety analysis of complex technical systems and personnel were used to assess the probability of personnel errors. The paper gives a probability scale for erroneous personnel actions (see fig.5.4, [6]), allowing assessment of error probability out of a set number of criteria (time available for decision-making, stress factor, difficulty of making decisions, interface, instructions quality, etc.). The scale was obtained by analyzing the most probable personnel errors. The analysis of results was used to develop a database showing nominal values of personnel error probabilities under normal working conditions and for the whole spectrum of characteristics, including general situation (regime) and psychophysical conditions. The probability of personnel error (incorrect fastening) was assessed as $P_0 = 2{,}4 \bullet 10^{-3}$ for the following assumptions: available time – adequate, stress factor – medium, decision making difficulty – easy, interface – adequate, construction quality – good.

The P_1 probability of not noticing the incorrect fastening of the container was assessed according to the erroneous action probability table (see table 5.6, [6]). The table allows assessing the probability of an erroneous action based on the decision-making time. According to the data of the table, the probability of qualified personnel making erroneous actions for the short time of fulfillment and decision-making (5 to 60 min) is approximately 10^{-3}.

The P_2 probability of a container falling in case of a failure of a single binding will be conservatively assessed as 1.

The P_3 probability of SFA partially loosing airtightness will be conservatively assessed as 1.

Research carried out in report [7], show that the overall service time of rubber packing of metal-concrete structure (MCS) loaded with SNF is 50 years. However, in the case a container falls from a height of 9 m or more, partial failure of rubber packing becomes possible, accompanied by a leak with an equivalent diameter of 3.3 mm. Therefore, we will use 1 as a conservative assessment for probability P_4 of rubber packing failure.

Thus the probability of scenario 1, with a personnel error as an initial event may be assessed as:

$R(I_0) = 2.4 \bullet 10^{-3} \bullet 10^{-3} \bullet 1 \bullet 1 = 2.4 \bullet 10^{-6}$.

Fig. 4 shows an event tree for a scenario with an equipment failure as an initial event. An emergency condition is reached in case of outcome 4.

Initial event equipment failure (cable fatigue)	Fall of a TUK-18 or KB-650 (KP-400) container	Micro fracturing and partial loss of airtightness	Damage of the rubber packing	Final condition-release to the environment	Probability
I_0	no			OC 1st outcome	$(1-P_1)$
	yes	no		NC 2nd outcome	$P_1(1-P_2)$
		yes	no	NC 3rd outcome	$P_1P_2(1-P_3)$
			yes	EC 4th outcome	$P_1P_2P_3$

Figure 4. Event tree for scenario 2 with an equipment failure as an initial event

Assessment of the cable rupture probability was a difficult task due to a number of causes. There were no such accidents in Russia, the service life of the portal crane (20 years) has expired, and no expertise of welding joints and metal structures was carried out. The condition of the crane is actually assessed by performing static and dynamic tests with the load of at least 50 tons. An act is drawn up upon completion of the tests, which is submitted to the nuclear and radiation safety inspections department of Rostehnadzor.

The probability of this scenario was also assessed on the basis of the standards of faultless operations (0.9999), which is recommended in [8] for the elements of hoisting equipment in the cases when a failure may lead to an accident.

The fact that the service life of the crane has expired will be taken into account by reducing the reliability parameter by 95% . It means that the probability of a failure due to any of the reasons, including a cable rupture will be assessed as $P_0 = 10^{-4}/0.05 = 2 \cdot 10^{-2}$ year^{-1}.

The comparison of probability of accidents caused by personnel errors and equipment failure, demonstrate the decisive role of technical factor. Therefore, the probability assessment was further carried out only for the scenarios with an equipment failure.

Such a situation is not typical for Russia. According to the data of Rostehnadzor for 2003-2006, in Russia in average 70% of the accidents with the hoisting mechanisms are caused by the technical factor (unsatisfactory condition of the equipment and mechanisms) and about 30% are caused by organizational and other factors.

The estimate of radioactive substances release and its consequences assumed [9] that in normal operation conditions the number of not airtight fuel element is 1% of the total number of elements and the release of krypton-85 from these elements does not exceed 30% of the total quantity contained. It was conservatively assessed that in emergency conditions 100% of the fuel elements may have lost airtightness and 1% of the activity accumulated under the fuel element claddings could be released into the inner cavity of the container. Assessments show, that the damage of the rubber packing caused by the impact of the fall may lead to formation of a leak with an equivalent diameter of 3.3 mm. In this case the rate of release to the environment under the atmospheric pressure will be $3 \cdot 10^{-4}$ m^3 per week.

The expected values of the release as the result of the accident are given in Table 2.

Table 2. Release of the radionuclides into the atmosphere as a result of a fall of TUK loaded with SFA

Radionuclide	Activity of Radionuclides in SFA, Bq	Specific Activity of Radionuclides in the Gas Medium, Bq/m^3	Release to the Atmosphere, Bq/week
^{85}Kr	$3.0 \cdot 10^{13}$	$2.2 \cdot 10^{14}$	$6.5 \cdot 10^{10}$
^{134}Cs	$1.6 \cdot 10^{13}$	$3.9 \cdot 10^{12}$	$1.2 \cdot 10^{9}$
^{137}Cs	$2.3 \cdot 10^{14}$	$5.6 \cdot 10^{13}$	$1.7 \cdot 10^{10}$
^{60}Co	$8.0 \cdot 10^{10}$	$1.9 \cdot 10^{9}$	$5.8 \cdot 10^{8}$
^{55}Fe	$4.0 \cdot 10^{10}$	$1.0 \cdot 10^{9}$	$2.9 \cdot 10^{8}$

Assessment of the radiological consequences of this scenario was carried out using the Nostradamus program, which implements the Lagrangian method, under the assumption that the duration of the release was 1 week. Calculations show, that the annual exposure dose for the population at the distance of 1 km from the source will amount several hundredths of millisievert, which is about two orders of magnitude lower than the annual limit of doses set by

NRB-99 [10] for the population. Thus, the current scenario may be classified as level 2 of the INES scale for the criterion of damage to the multilayer protection.

4.2. Failure of Container Carriage

Failure of a container carriage may lead to its overturning and, consequently, to fall of three TUK-18, TUK-108/1 containers. The failure of a container carriage may be caused by faulty condition of the car itself or presence of obstacles on the railway. The data of the technical documents show, that the container retains integrity and the rubber packing remains undamaged in case of a car overturning. Thus, such a sequence of events will not lead to an accident with radiological consequences. Such an accident may be classified as level 0 according to the INES scale, as all three safety barriers will remain intact.

4.3. Fall of a base container loaded with a SFA shroud

According to the used technological procedures, such a scenario is possible for reloading of the fuel from the storage facilities of FMB "Imandra" to the storage facilities of FMB "Lotta". Either К6295 crane manufactured by KONE or "Zhdanovets" crane are used in the works. Taking the indeterminacy of the assessment into account, we will consider the accident probabilities for both technological procedures to be equal.

This scenario is realized only in case of rupture of two cables of double polyspast used in the lifting crane. Each of the cables will hold the container from falling.

Preliminary analysis and the quantitative assessment for scenario 1 showed that the fall of the base container may be the result of an equipment failure due to wear. Extreme external impacts or a fire leading to a rupture of cables are improbable for the period of execution of the works.

The works are carried out by qualified personnel with observation of all procedures, including:

- use of specially designed gripping devices (cross-arms) certified for operations with the specific equipment;
- check of the correct fastening of the gripping device with the transported load after it is lifted to the height not exceeding 300 mm;
- monitoring of correct implementation of the operation instructions by service personnel carried out by the head of works.

In order to reduce the probability of crane operator errors, the crane is equipped with devices limiting the lifting height, lifting rate and boom turn rate. Blocking operations is used for the same purpose - the cranes allow execution of only one operation at a time.

No accidents connected with the fall of a container loaded with assemblies have occurred at FSUE "Atomflot". Three such accidents occurred over the whole period of works on reloading reactor cores in Russia (and the Soviet Union). The overall scope of works carried out over this period included reloading 1000 cores, or approximately 250000 SFA. Taking into account the overall amount of annual works at the facility, the probability of a fall of a reloading container loaded with SFA may be assessed as

$R(I_0) = 3 / 250000 \times 15 \times 7 = 1.3 \cdot 10^{-3}$ year^{-1}.

According to a conservative assessment, 30% of krypton-85 and 1% of cesium-134, 137 from the total quantity of radionuclides inside the fuel elements may be released into the inner cavity of the container as a result of an accident connected with heavy mechanical damage of SFA. Release of cobalt and iron radionuclides in the form of finely dispersed aerosol is taken as 0.1% in case of a failure of SFA inside the container. To assess the consequences of the accident, we assume that all the volatile radionuclides were released into the atmosphere. The radionuclide composition of the release, with account for the assumptions made, is given in table 3.

Table 3. Radionuclide composition of the release in case of fall of a base container holding SFA shroud, Bq

Kr-85	Cs-134	Cs-137	Co-60	Fe-55
$1.3 \cdot 10^{12}$	$2,3 \cdot 10^{10}$	$3.3 \cdot 10^{11}$	$8.0 \cdot 10^{7}$	$4.0 \cdot 10^{7}$

Calculation of the radiological consequences of this scenario of the accident was carried out using the Nostradamus program for the following release parameters and weather conditions:

Altitude of the release – 20 meters;

Duration – 0.1 hour;

Windspeed - 3 m/s;

Wind direction – towards the nearby residential areas of Murmansk (at the distance of approximately 1.5 km);

Weather stability category D according to Pasquille-Guifford classification, no precipitations.

The results of assessment of radiological consequences (along the track axis) for this accident scenario are given in table 4.

Table 4. Radiological consequences of an accident scenario with the fall of a guiding device or a TUK lid

R, km	^{137}Cs Contamination density, Ci/km^2	Effective Dose from the Cloud, mSv	Effective Dose from the Surface over 10 days, mSv	Effective Dose over 10 days, Children, mSv	Effective Dose over 1 year, Children, mSv
1	1,1	0,000130	0,016	0,018	0,66
2	0,38	0,000053	0,0055	0,0061	0,22
3	0,21	0,000031	0,0031	0,0034	0,12
4	0,13	0,000019	0,0019	0,0021	0,08
5	0,09	0,000013	0,0013	0,0014	0,05

As we can see in Table 4, the maximum effective dose for the population is less than the annual dose limit (1 mSv/year) set by NRB-99 [10], but is comparable with this value. Thus, the current scenario may be classified as level 3 of the INES scale for the criterion of off-site impact. Taking into account the indeterminacy of the assessments performed for this scenario, detailed dosimetric inspection of the surrounding territory in order to identify and decontaminate the sections with locally high exposure doses will be required. This scenario is also characterized by high exposure dose rates experienced by the personnel performing the works on mitigation of the consequences of the accident.

4.4. Fall of a Guiding Device or a Container Lid inside the Container TUK-18, TUK-108/1

If the guiding device or a container falls and directly hits the centre of an open and fully loaded TK-18 container with a 90° edge, the central shroud holding 7 SFA will be damaged.

No cases of fall of a guiding device were recorded during the whole period of works on reloading of reactor cores.

The following sequence of events is required to realize this scenario. The first one is the failure of one of the three bindings. This must be immediately followed by a 90° turn of the guiding device with subsequent failure of the two remaining bindings. Furthermore, the device should fall directly into the center of the container. All of these events must happen immediately one after another in very short time intervals.

Assessment of the dynamic load on the remaining two cables was carried out by resolving differential equation of rotary motion in model geometry.

This assessment can be used to state that the simultaneous rupture of the two remaining cables is not a determined consequence of the first failure. These events can be considered as independent and caused by the wear of equipment or personnel errors. If a second binding fails, the binding of the third cable will follow immediately, as the allowed load will be exceeded.

The probability of the "required" orientation of the guiding device may be assessed using the geometric dimensions of the internal cavity, shroud and the diameter of the guiding device as 0.1 for the angular variable X 1/7 - for the probability of hitting the centre.

Thus the probability of this scenario 1 may be assessed as

Probability of a failure of the first binding ($2 \bullet 10^{-2}$) X probability of a failure of the second binding ($2 \bullet 10^{-2}$) X probability of the "required" orientation of the guiding device ($0.1 \bullet 1/7$) = $6 \bullet 10^{-6}$ year^{-1}.

Similar scenario should be realized for the fall of the container lid. The weight of the lid is three times lower. However, due to indeterminacy of assessments, we will consider the consequences of both scenarios to be equal. Thus, total probability of this scenario can be assessed as $1.2 \cdot 10^{-5}$ year^{-1}.

In order to assess the maximum consequences of the event we will take the case when the lid falls into the fully loaded TUK-18 (TUK-108/1). The impact is taken by the central SFA shroud, which is deformed, leading to loss of airtightness of SFA shrouds inside the container.

The damage of the shroud will be similar to the scenario of a fall of a container loaded with SNF, which is described above. Taking the indeterminacy of the assessments into account we will consider the severity of consequences for both scenarios to be equal.

Maximum effective dose for the population will be about 1 mSv/year, thus being within the dose limit set by NRB-99 [10]. Thus, the current scenario may be classified as level 3 of the INES scale for the criterion of off-site impact.

4.5. Fall of technological equipment onto the loaded container or a train loaded with SNF

Fall of technological equipment capable of damaging the TUK inside the train car is considered in this scenario. Such equipment may include crane support, crane arm, the cabin and the turning mechanism, and the counterweight. According to the utilized technological procedure, the counterweight of the crane can never be transported over the train during reloading containers from FMB "Lotta", and, therefore it cannot fall onto the car. Still, fall of a counterweight, as well as fall of the other equipment elements in question will simultaneously lead to a fall of TUK.

Fall of TUK inside the container as a result of a cable rupture or a fall of counterweight, if assessed conservatively, will lead to partial damage of TUK packing, damage or overturning of car, accompanied by fall of two more containers. The most severe radiological consequences can be expected for simultaneous fall of technological equipment and TUK onto the loaded special train.

Fall of equipment elements may be caused by latent defects of metal structures, welded joints, rails, which were not found during inspection prior to the carried out works or a combined failure of safety equipment (lifting height limit, braking system).

There were no cases of such accidents at the facility. The service period of К 6295 KONE crane is over 20 years. Such a situation is typical for Russia. About 900 portal cranes are operated in Russia according to the data of Association of commercial ports of Russia. Over 80% of the cranes have service life of over 12 years and about 40% have passed their authorized amortization term (25 years). Therefore, we will use the statistics of such accidents in Russia to assess the probability of an event.

Table 5 gives statistics of accidents with portal cranes in Russia for the past 10 years. The information was received from the Russian HSE Agency Ltd., which provides consulting services in the field of industrial, fire and environmental safety, labor protection and prevention of emergency situations.

Table 5. Statistics of accidents with portal cranes at the ports of Russia in 1998-2007

Description of accident	Nmbr
Fall of arm during loading/unloading works caused by unsatisfactory condition of the equipment	1
Fall of arm and the turning platform during loading/unloading works caused by overloading	2
Fall of crane support during loading/unloading works caused by unsatisfactory condition of the equipment	2
Fall of crane support during loading/unloading works caused by overloading	1
Fall of the turning platform during maintenance works on replacement of the collar bearing	1
Fall of the crane support (no detailed description)	1
Total over 10 years	8

The data given in table 5 are in agreement with the annual Rostehnadzor reports. According to these reports, there were 4 accidents with portal cranes in Russia in 2003-2006.

It is obvious, that the statistics does not reflect the cases when the failures were not detected or did not lead to an accident.

According to HSE Agency Ltd., there were 8 accidents with portal cranes in Russia over the last 10 years, including 3 caused by overloading. Taking into account the fact that no overloading can take place during fuel reloading, and the total number of cranes, the probability of a fall of crane elements can be conservatively assessed as $6 \bullet 10^{-4}$ $year^{-1}$.

Fall of heavy equipment elements onto the special train can take place only when the container is lowered into the car, and both the crane arm and the train are located along the same line. It can be assumed that the duration of the loaded crane arm passage over the train is 1/3 of the total time of the operation, which includes lifting, transport and lowering the container into the car. Thus, the probability of fall of the heavy technological equipment elements can be assessed as $2 \cdot 10^{-4}$ $year^{-1}$. It should be kept in mind, that if the load of the cranes at commercial ports is taken into account, the latter assessment will be sufficiently lower.

The consequences will be most severe for the scenario with a fall of a crane support. In this case, 3 heavy elements may fall onto the train: TUK, crane support and the counterweight. According to expert assessments, such a scenario will lead to destruction of 1 container car and damage of 4 TUK-18, TUK-108/1 containers.

FSUE CBSE performed a technical report [11] on analysis of the TUK-108/1 strength at the accumulation pad of Maintenance Technological Enterprise (MTE) "Atomflot" (at present FSUE "Atomflot"), which showed that the following damage can happen in case of such an accident.

- The falling counterweight of the portal crane destroys the inner and outer lids of the container, two diaphragms of the spacer grids and contracts the SFA shrouds;
- The containers elastic properties allow the bottom of the container to remain intact, only the shock absorbing elements of the bottom are crushed.

It was conservatively assessed that in emergency conditions 100% of the fuel elements may have lost airtightness and 1% of the activity accumulated under the fuel element claddings could be released into the inner cavity of the container. Assessments show that the damage of the rubber packing caused by the impact of the fall may lead to formation of a leak with an equivalent diameter of 3.3 mm. In this case the rate of release to the environment under the atmospheric pressure will be $3 \bullet 10^{-4}$ m^3 per week.

The expected values of the releases as the result of the accident with the fall of the technological equipment are given in Table 6.

Table 6. Release of the radionuclides into the atmosphere as a result of a fall technological equipment onto the special train

Radionuclide	Radionuclide content in TUK, Bq	Specific Activity of Radionuclides in the TUK Gas Medium, Bq/m^3	Release to the Atmosphere, Bq/week
^{85}Kr	$3.0 \cdot 10^{13}$	$2.2 \cdot 10^{14}$	$2.5 \cdot 10^{11}$
^{134}Cs	$1.6 \cdot 10^{13}$	$3.9 \cdot 10^{12}$	$4.8 \cdot 10^{9}$
^{137}Cs	$2.3 \cdot 10^{14}$	$5.6 \cdot 10^{13}$	$6.8 \cdot 10^{10}$
^{60}Co	$8.0 \cdot 10^{10}$	$1.9 \cdot 10^{9}$	$2.3 \cdot 10^{9}$
^{55}Fe	$4.0 \cdot 10^{10}$	$1.0 \cdot 10^{9}$	$1.2 \cdot 10^{9}$

Assessment of the radiological consequences of this scenario was carried out using the Nostradamus program, which implements the Lagrangian method, under the assumption that the duration of the release was 1 week. Calculations show that the annual exposure dose for the population at the distance of 1 km from the source will not exceed 1 millisievert, which is about an order of magnitude lower than the annual limit of doses set by NRB-99 for the population. Thus, the current scenario may be classified as level 3 of the INES scale for the criterion of effect on the population.

5. Risk matrix

Table 7 gives the results of quantitative risk assessment for the most significant scenarios of accidents possible during SNF reloading works at FSUE "Atomflot".

Table 7. Results of quantitative risk assessment at during SNF reloading works at FSUE "Atomflot"

Scenario number	Initial event	Probability, $year^{-1}$	INES scale level
1	Fall of a TUK Container	$2.0 \cdot 10^{-2}$	2
2	Failure of container carriage	–	0
3	Fall of reloading container loaded with SFA	$1.3 \cdot 10^{-3}$	3
4	Fall of a guiding device or a container lid onto TK-18 container	$1.2 \cdot 10^{-5}$	3
5	Fall of technological equipment onto the train loaded with SNF	$2.0 \cdot 10^{-4}$	3

Risk matrix was drawn up in accordance with the Risk assessment methodology document, developed during the work on Phase II of the Source control project. Priority matrix of corrective actions for SNF reloading works at FSUE "Atomflot" is given in fig. 5. The scenario numbers in fig.5 correspond to table 7.

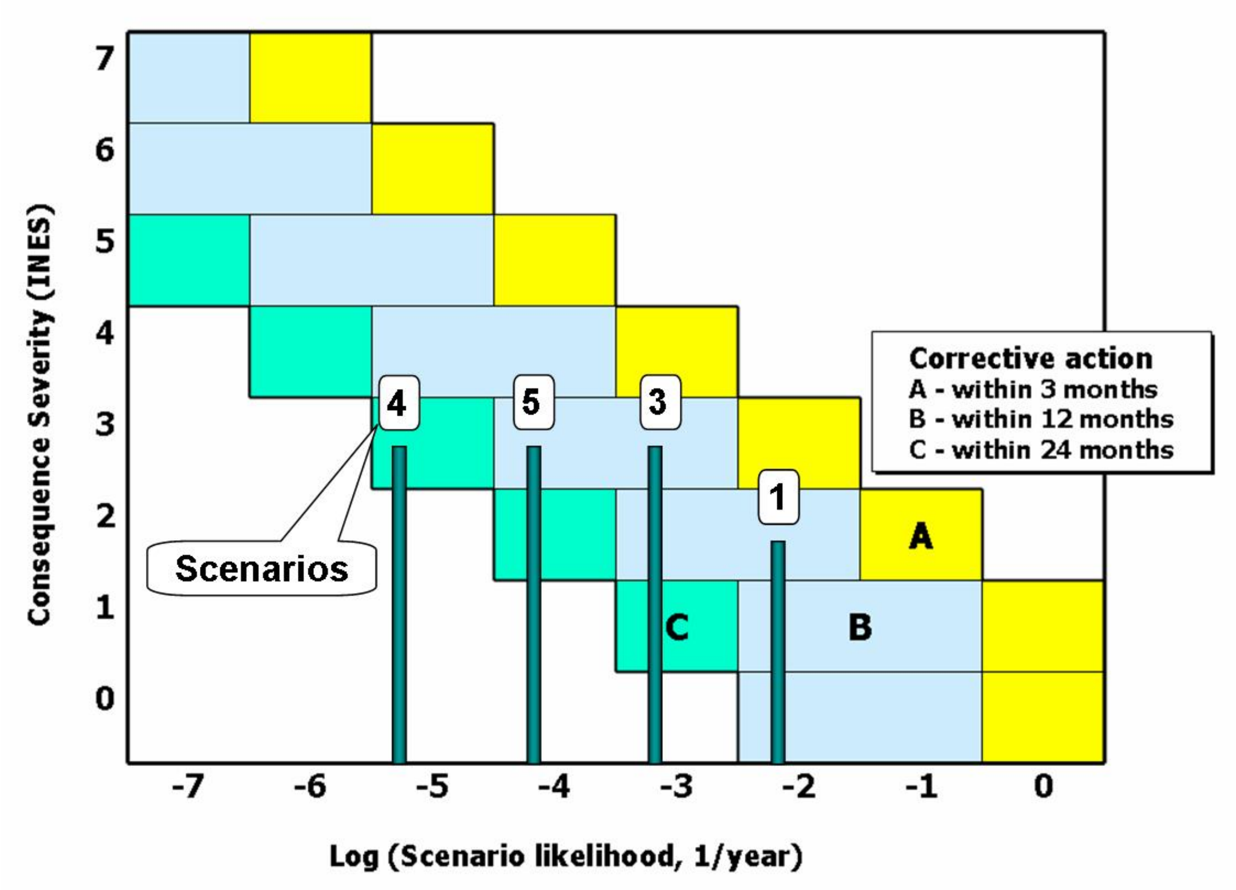

Fig. 5. Risk matrix for SNF reloading works at FSUE "Atomflot"

Analysis of the matrix allows making a conclusion that this facility is characterized by acceptable of safety. There are no scenarios which require implementation of urgent (within 3 months) corrective actions. Taking into account the assumptions made and indeterminacy of the assessments, all of the scenarios, with the exception of scenario 4, are of the same level of significance and require planned correction measures to reduce the risk of an accident. The actions should first be aimed at increasing the reliability of the elements and mechanisms of hoisting equipment. The lower priority of scenario 4 (fall of a guiding device or a container lid into the container) is determined by the procedure of works and the additional conditions required for its realization. In general, the corrective actions for scenarios 1, 3, 5 will also in most cases lower the risk of scenario 4.

The working team recommends considering strengthening the crossarms of the coastal diesel generator leading to the crane columns, as their damage may not be found by the personnel before the start of works on SNF transportation. While the loss of power supply does not lead to an accident with significant consequences, if the base container remains hooked in the air, it will lead to additional exposure of the personnel.

6. Recommendations on the Use of Risk Assessment Methodology at FSUE "Atomflot"

The methodology developed in the framework of the Source Control Project (Phases I-II) was applied for assessment of accident risks during SNF reloading works at FSUE "Atomflot". The experience of application of risk assessment methodology allowed making the following conclusions and recommendations:

1. The risk assessment methodology document describes in detail the step-by step procedures of assessment and decision-making on corrective actions.
2. Taking into account the universal approach taken in the methodology and the experience of its application, it can be recommended for other hazardous process facilities of FSUE "Atomflot" with other hazard sources. The appropriate risk matrixes are available.
3. The methodology contains a description of possible methods of quantitative and qualitative risk assessment, recommendations for selection of a specific method, but does not state any requirements for their application. The specialists of the facility should use the method that’s most familiar for them.
4. The specialists of the facility should have methods or software capable of assessing the severity of consequences in accordance with the categories set by the risk matrix.
5. Experience of other facilities performing similar operations should be used if input data for risk assessment are limited.
6. The current methodology can be useful in introduction of the ISO 14001 standard at the facility at the stage of identifying and ranking the significant environmental aspects. Both the risk matrixes described in the methodology and the approaches based on qualitative criteria recommended by the ISO 14001 standard may be used in the process. In any case, the approach chosen for ranking the events should facilitate reaching the objective - development of a more effective program for risk management and potential risk reduction.

8. Recommendations on Introduction of ISO 14001 standard at FSUE "Atomflot"

Recommendations for introduction, and the potential advantages of an Environmental Management System (EMS) at a nuclear- or a radiation-hazardous facility are described in detail in the final report on the Source Control Project, Phase II. The current report contains recommendations for a specific facility – FSUE "Atomflot".

The observations and studies performed in the framework of the works under Phase III allow making a conclusion that the facility has a good position for development and certification of an environment management system complying with the requirements of GOST R 14001-2007.

An effective document management system is functioning at the facility. Instructions and standards of conduct of hazardous works, specifying the rules of the works, responsibilities, and the limits of operation parameters, are available to the personnel. The requirements of regulatory documents are fully observed during the radiation-hazardous works, including the requirements to environment protection. Environmental safety enhancement program is being realized at the facility, and the system of training and advanced training of the personnel of the facility includes environmental training. FSUE "Atomflot" performs several programs conforming to the requirements of ISO 9001 standard (quality management systems). The central facility laboratory carries out measurements and environment monitoring. The facility submits quarterly and annual reports on radiation safety.

FSUE "Atomflot" and the nuclear icebreaker fleet of Russia will soon be transferred to the icebreaker and technological complex "Atomflot" to be organized under the control of the state corporation Rosatom.

Solution of environmental problems was an important part of Minatom of Russia activities in the last decade. The order of the Minister of the RF for Atomic Energy No. 67 of 19.02.2003 approved the Fundamentals of the Environmental Policy of Minatom of Russia. According to the document, introduction of international standards in the field of environment protection and environmental safety was one of the directions of enhancing environmental safety management and nature-protection activities at the facilities of the branch.

Transfer to Rosatom will inevitably bring reorganization and structural changes in the management of the facility. The management of the state corporation and the facility could use the situation to an advantage by introducing some important elements of the environment management system into the management structure of the facility, and by allocating the required resources. Such important elements at the first stage include the organizational structure, environmental policy, planning of nature-protecting activities in accordance with the environmental policy and the set targets, document management.

Conclusion

Final report on risk assessment for the works connected with SNF transportation at FSUE "Atomflot" was prepared at the current stage of the project. The report includes a brief description of the studied facility, the performed works and the results received in process of carrying out the project, as well as the recommendations. The more detailed information may be found in the reports on stages 2-5, prepared according to the PMP for FSUE "Atomflot".

The executed analysis of accident risks in transportation of SNF at FSUE "Atomflot" shows that the facility has an acceptable level of safety. The main objective of the activities should be maintaining the current level of safety and gradual risk reduction, which can be done in the framework of annual safety assurance programs.

Attachment list

#1 Abbreviations list

#2 NMV (summary)

#3 Characteristics of the safety-critical equipment

#4 References

Abbreviations list

(Attachment 1)

ARMS	–	Automated Radiation Monitoring System
CA	–	Control Area
CBSE	–	Construction Bureau of Special Engineering
CPS	–	Control and Protection System
FMB	–	Floating Maintenance Base
FSUE	–	Federal State Unitary Enterprise
JSC	–	Joint Stock Company
LRW	–	Liquid Radioactive Waste
MSC	–	Murmansk Shipping Company
MTE	–	Maintenance Technological Enterprise
NM	–	Nuclear Maintenance
NMV	–	Nuclear Maintenance Vessel
NPU	–	Nuclear Propulsion Unit
NRHF	–	Nuclear and Radiation Hazardous Facility
NS	–	Nuclear Submarine
PA	–	Production Association
PMP	–	Project Management Plan
Rostehnadzor	–	Federal Service for Environmental, Technical and Nuclear Supervision
RW	–	Radioactive Waste
SFA	–	Spent Fuel Assembly
SGP	–	Steam Generating Plant
SI VPNIIKET	–	Head Institute "All-Russian Research and Design Institute for Power Technology"
SNF	–	Spent Nuclear Fuel
SRW	–	Solid Radioactive Waste
TUK	–	Transport Container

NMV (summary)

(Attachment 2)

At the current time Murmansk Shipping Company operates 6 nuclear maintenance vessels. They are used to carry out operations involving recharge of nuclear reactors, storage of spent and fresh nuclear fuel, temporary storage of liquid and solid radioactive waste, transportation of SNF and RW. NMV are federal property. All vessels are based at FSUE "Atomflot".

Currently the operations involving reloading, temporary storage and transportation of fresh and spent nuclear fuel are carried out by FMB "Imandra" and "Lotta".

Name of Ship	Launch Date	Max Length, m	Width, m	Displacement, t	Crew, men
"Imandra"	1981	130	17	9700	100
"Lotta"	1960	122	16	7000	60

Floating maintenance base "Imandra", commissioned in 1981, is used for nuclear icebreaker re-charging. FMB "Imandra" is equipped with a storage unit for technological channels (capacity – one reactor core), and six tanks for interim storing of spent nuclear fuel, the tankage allows accepting six cores (1530 SFA). The "dry" method of SFA storage is used, i.e. the SNF are cooled by the air inside the shrouds, whilst the shrouds are cooled by distillate.

There are 12 tanks of 545 m^3 total volume for LRW storage at FMB "Imandra".

Spent fuel goes to the storage of FMB "Lotta" after holding in the storage of FMB "Imandra". FMB "Lotta" was built in 1961 and reequipped in 1984. There are 2 storage holds with 6 sections each for storage of spent nuclear fuel. One section has the capacity to hold 68 SFA shrouds. Total storage capacity is 816 shrouds (4080 SFA for the storage of 5-place shrouds), which corresponds to 12 cores of civil nuclear icebreakers.

In 1993 "Lotta" was reequipped, and now it can accept shipping casks of TUK-18 type for spent nuclear fuel. "Lotta" is a unique vessel in the region that can operate the containers of this type. At present it is used for operations on fuel transportation to "Mayak" where the fuel is reprocessed both for the of MSC and the North Fleet. The vessel may hold up to 7 TK-18 containers, including 6 at the storage compartment and 1 at the reloading chamber.

The total term of SNF storage at the floating bases "Imandra" and "Lotta" prior to the sending of the fuel to PA "Mayak" is at least three years. According to the regulations, the storage period aboard FMB "Imandra" is at least 6 months, and the fuel may be reloaded to the storage facility of FMB "Lotta" for further storage and reloading into the transport containers or railroad train.

Characteristics of the safety-critical equipment

(Attachment 3)

The current section gives summarized description of the equipment used for transport and technological operations on management of SNF at the coastal unloading facility of FSUE "Atomflot".

Portal Cranes

All technological operations on transportation of TUK-18 (TUK-108/1) between FMB "Lotta" and TK-VG-18 carriages are carried out using the "KONE" K6295 portal crane with a lifting capacity of 100/16 t.

Technological operations on reloading the fuel from the storage holds of FMB "Imandra" to the storage holds of FMB "Lotta" and loading of TUK-18 (TUK-108/1) containers are carried out using the base container KB-650 (KP-400). The operations are carried out by the personnel of the facility and the crews of the FMB using the crane KONE K6295 or "Zhdanovets" crane with the lifting capacity of 40/5 t.

Transport package TUK-18

Transport package TUK-18 is designed to provide safe transportation of irradiated FA by motor, railroad and sea transport within the territory of the Russian Federation.

The container is operated in accordance with the following technical documents of the design and manufacturing organizations:

"Technological regulations for loading SFA into the protected container TK-18 and management of TUK-18 package within the territory of SEE "Zvezdochka", HI VNIPIET inv. No. 98-01487, 1998.

TK-18 container. Configuration and operation manual. DB of Izhora Plant. 1051.02.00.000 TO, 1989.

Shrouds. Configuration and operation manual. DB of Izhora Plant. 1051.36.00.000 TO, 1989.

Technical Report. Analysis of the strength and heating of naval TUK MCC in case of accidents during SNF management within the territory of temporary SNF transfer locations at MTE "Atomflot" and facility "09", Severodvinsk, FSUE CBSE, 2000.

Technical Report. "Additional analysis of safety of TUK-108/1 management at the accumulation pad for temporary storage of containers loaded with naval SNF at MTE "Atomflot". FSUE CBSE, 2000.

Transport radiation-protected package TUK-18 includes the transport radiation-protected container TK-18, a set of "ChT" shrouds (with a capacity to hold three, five, or seven spent FA depending on the type).

TK-18 transport container

Transport radiation-protected container TK-18 is designed for assorted placement, storage and transportation of SFA in seven "ChT" type or 24M shrouds, which are loaded into the removable part of the container.

The container consists of the shell, the removable part and the lid. The container shell is a thick-walled vessel made of corrosion-resistant steel. Two pivots for fastening the container to the cross-arm are located in the upper part of the shell. The container is equipped with damping elements: cones, teeth, edges. The medium ring with twenty welded support ribs is used as a supporting platform when the container is loaded into the container carriage TK-VG-18 (TK-VG-18A). Three medium lengthwise ribs are welded uniformly every 120° between the medium and lower rings. Six lengthwise ribs with 40 mm diameter holes for slings used to move the container are welded to the external surface of the container between the lower ring and the supporting ring.

The lid is a welded element with damping ribs welded to the upper and ribs with holes for remote fastening of the lid with the cross-arm. Two rubber packings are located at the lower surface of the lid with a through hole between them used for container airtightness monitoring. In transport position the hole is closed by a plug with copper lining. The lid is fixed to the container shell with 24 bolts.

The removable part is used for assorted location of the shrouds. The welded structure of the removable part includes a base with four sockets for shrouds, the central tube and six supporting elements and diaphragms. A tube for extraction of water from the container is welded inside one of the supporting elements. The design of the removable part ensures fixed position of the shrouds during transport and technological operations with the container.

Specifications of TK-18 container are given in table A3.1.

Table A3.1. Specifications of TK-18 container

Parameter	Value
Container height, mm	4582
Outer diameter, mm	1405
Wall thickness, mm	315
Bottom thickness, mm	250
Lid thickness, mm	144
Container capacity, shrouds	7
Weight of empty container, kg	37470
Material of the shell, lid, supports, pivots, ribs	corrosion-resistant steel
Material of the removable part	corrosion-resistant steel

TK-18 container fully corresponds to the requirements of Russian standards [12] and to IAEA rules for safe transportation of radioactive materials (1985). The container provides safe transportation of SFA shrouds both in regular and emergency conditions. Equivalent dose rate at any point of the outside surface of the container does not exceed 2 mSv/hour in normal transportation conditions.

Mechanical impacts caused by a fall and external thermal impact are considered as design-basis accidents in the technical documentation.

According to the design data, transport container TK-18 is capable of retaining integrity in case of free fall on a rigid foundation from the height of 9.0 m. In case of such impact, the container retains strength and airtightness, while the release of activity from the inner cavity corresponds to the requirements of it. 2.3.6.b of OPBZ-83 [12].

Additional strength calculations [13] for fall of TK-18 from the height of 14.5 m onto ship deck with subsequent hit of the base (lower) ring of the container on the hard bottom of the sea demonstrated that the container does not lose airtightness and the release of activity from the inner cavity corresponds to the requirements of it. 2.3.6.b of OPBZ-83 [12]. Total height of fall of TK-18 container in the calculations was 26.8 m.

Additional research carried out for assessment of the protective properties of the container in case of fall from beyond design-basis heights are given in [14]. The calculations showed that:

In case of a fall of transport package from the height of $17 \text{ m} \le H \le 30 \text{ m}$ onto a hard surface the container shell remains intact;

The integrity of the inner lid and the bolts used for its fixing is guaranteed for the case of fall of the transportation package from the heights 17 m and 30 m onto a hard surface. The joint is not opened.

Thermal calculation of TUK-108/1 [2], showed that, in accordance with the requirements of OPBZ-83 [12], the TUK-108/1 package prepared for transportation may remain in the seat of fire (flame temperature of 800°C) for 30 minutes. The maximum temperature of the fuel claddings of the most heated SFA does not exceed the allowed values. The calculated temperature of metal reaches 328 ÷ 360°C near the packing of the outer lid and 160°C at the inner lid.

Additional studies carried out by the Developer of rubber elements of transport packages, given in report [11], demonstrated that the upper temperature limits for the rubber packing is:

in normal operation conditions - 115°C;

in emergency mode - 220°C (for a short period of time);

These data were used in report [15] to demonstrate that in the case of a design-basis accident, when TUK-108/1 is located in the seat of fire (flame temperature 800°C) for 30 minutes, the first (internal) airtight circuit remains functional, while the loss of the radioactive contents from TUK-108/1 package does not exceed the allowed values.

SFA shrouds

The shrouds are used for regular placement of SFA.

"ChT" type shroud is a welded structure consisting of a tube block and a plug. The tube block is a welded metal structure made of tubes welded to the shell and lower grate. Spacer grids are installed along the height of the tube block. The bottom is welded to the lower grid. A tube with an outlet leading to the shroud shell is welded into the lower grate for removing water from the shroud. The plug is used to seal the internal cavity of the shroud and is made of a lid with rubber packing and a welded case with a gripping device. The gripping device is used to hook and move the shroud. The shroud is made of corrosion-resistant steel.

Guiding Device

The guiding device is designed to aim and orient the reloading container with shroud sockets in the removable part of the protected TK-18 container in process of its loading with SFA and to ensure biological protection of the personnel in process of this operation. Specifications of the guiding device cross-arm are given in table A3.2.

Table A3.2. Specifications of the guiding device

Parameter	Value
Weight of the guiding device, kg	8300
Biological protection thickness, mm	at least 325
Allowed load on the guiding device, kg	15000
Material of the main elements	corrosion-resistant steel

Guiding device cross-arm

The cross-arm is used for transportation of the guiding device of the protective container TK-18 or the guiding device support using load-lifting crane. The load-hooking elements of the cross-arm are equipped with latches preventing its accidental unhooking with the guiding device. Specifications of the guiding device cross-arm are given in table A3.3.

Table A3.3. Specifications of the cross-arm

Parameter	Value
Weight, kg	157
Capacity, t	10
Operating temperature range of the cross-arm	$- 20^0C – + 40^0C$

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(Attachment 4)

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