SAFETY ANALYSIS AND ENVIRONMENTAL IMPACT ASSESSMENT FOR FOTON RTC DECOMMISSIONING

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ABSTRACT

In 2016 Sosny R&D Company prepared Safety Analysis and Environmental Impact Assessment Report for FOTON RTC decommissioning (Tashkent, Uzbekistan) within the full cycle of decommissioning activities following the preparation INN-3M research reactor LSNF (liquid spent nuclear fuel) for shipment and its shipment to Mayak PA in 2014 for reprocessing. The main goals of decommissioning are to dismantle all buildings and facilities on the RTC site, to remove all radioactive waste and industrial waste from the RTC site and to reclaim the land for further unrestricted use (to return the site to the greenfield status). The assessments made in the Safety Analysis showed that annual effective dose limits for the personnel and public will not be exceeded both in case of planned FOTON RTC decommissioning and in case of hypothetical design-basis and beyond design-basis accidents.

1. Introduction

Safety Analysis and Environmental Impact Assessment Report for FOTON RTC decommissioning were prepared in compliance with the regulatory documents of the Republic of Uzbekistan and IAEA recommendations on radiation and nuclear safety [1-4].
The main object of the RTC decommissioning is to increase level of radiation safety of Tashkent city and the Republic of Uzbekistan and to reduce threat of uncontrolled radioactive substances spread.
The main goals are to dismantle all buildings and facilities on the RTC site, to remove all radioactive waste and industrial waste from the RTC site and to reclaim the land for further use in the national economy.
Sosny R&D Company made comprehensive assessment of FOTON RTC decommissioning technology impact on personnel, public and environment components such as soil, water, air and wildlife.

2. Brief Description of RTC Decommissioning Procedure

The procedure for RTC decommissioning includes:
– Dismantling and conditioning of contaminated equipment and structural elements including tanks, pipelines, metal reinforcement, heat exchanger and pumps of the reactor vessel cooling system, tanks of the special sewerage system and reactor vessel;
– Dismantling of non-contaminated with radioactive substances metal structures and equipment;
– Preparation of RW-containing packages for transportation;
– Decontamination of the laboratory building rooms;
– Removal of the activated concrete layer in the laboratory building rooms;

– Release of all RTC buildings from regulatory control and subsequent dismantlement of all building structures;
– Gradual removal of RW-containing packages resulted from RTC decommissioning to the special responsible organizations of the Republic of Uzbekistan;
– Removal of the non-radioactive waste.

To perform the RTC decommissioning some special work areas for the personnel and special equipment will be arranged on the RTC site.

Analysis of alternatives of the planned activities allows asserting that in case of zero option (no decommissioning) the RTC cannot be released from regulatory control because of the high induced activity of individual items of equipment or some rooms; consequently it will pose a risk to the personnel, the public and the environment.

3. Main Systems and Equipment of the RTC

3.1 IIN-3M Reactor Facility

IIN-3M reactor facility of FOTON JSC is the modified pulse IIN type solution research reactor designed by the Kurchatov Institute Research Center [5]. The specific feature of pulse reactors is self-extinction of nuclear reaction by increasing the solution temperature and releasing the radiolytic gas.

IIN-3M reactor vessel is a cylindrical two-layer welded vessel of 790 kg. Its support section is made of carbon steel and lined with stainless steel inside. The reactor is assembled in the shielded reactor box. The access to the reactor box is performed through the floor hatch in the reactor hall. The walls of the room are 3 m thick and made of concrete with a density of 2400 kg/m^3. The total volume of concrete in the box is 1378 m^3. The reactor rests upon a raft of heavy concrete with a density of 4600 kg/m^3 (with addition of 50% of cast-iron shot).

Rooms adjacent to the reactor box have a common heavy concrete slab of 1.1 m thick (18.6 m^3 in volume).

A scheduled reactor shutdown was done on June 1, 2013.

In 2014 IIN-3M liquid SNF (uranyl sulphate water solution) was prepared for shipment and removed to Mayak PA for reprocessing. Technology and equipment for preparation of liquid SNF for shipment were developed by Sosny R&D Company.

3.2 ISSLEDOVATEL and RKhM-γ-20 Gamma-Facilities

The RTC has two gamma-facilities, which contain encapsulated Co-60 gamma-ray sources of GIK-7-2 type. Decommissioning of these facilities was performed prior to the RTC decommissioning described in this document.

3.3 Buildings and Facilities on the RTC Site

The RTC site is separated from the main Foton site. The RTC site is surrounded by a concrete fence. The following facilities are located on the RTC site:
− Reactor building;
− Gamma-facility building;
− Isotope storage facility;
− Security checkpoint;
− Former foundry;
− Storage facilities;
− Utility facilities;
− Firefighting water pool.

The controlled access area is the whole RTC site (approved by the Center of Sanitary Supervision and Disease Control of the Republic of Uzbekistan).

3.4 Ionizing Radiation Sources

According to the comprehensive engineer and radiological survey main gamma radiation sources on the RTC site are as follows:

- Reactor vessel,
- Equipment for discharge and temporary storage of uranyl sulphate water solution;
- Activated concrete of the reactor box,
- Tank equipment of the gas removal and cooling system,
- SRW located in the isotope storage building.

The activities related to the activated concrete removal from the RTC premises can lead to the personnel internal exposure.

The main source of the public exposure will be aerosols released via the active ventilation system during the activities related to the activated concrete removal from the RTC premises. Maximum ADER close to the reactor vessel is 246 μSv/h. Maximum ADER at the distance of 1 m from the reactor vessel is 52 μSv/h. The highest ADER for gamma-radiation at the distance of 1 m from the equipment for discharge and temporary storage of uranyl sulphate water solution is 30 μSv/h.

3.4.1 Activated Concrete in the Reactor Box

Calculation of the Reactor Box Concrete Activity

Reactor box is made of two types of concrete: heavy reinforced concrete (floor in Room 001 and Room 002 of the reactor building, and part of the ceiling in Room 001) and reinforced concrete (walls and ceiling in Room 001 and Room 002). Scale 6.1.2 software package (TRITON module) was used to calculate the specific activity of the concrete to be removed. This software can be used to calculate the induced activity of the materials during irradiation based on the reactor history (initial data consists of fuel composition, operating power, reactor uptime and reactor downtime).

The specific activity reference level in concrete samples after removal of the activated concrete layer must correspond the values accepted in safety requirements and regulations.

It was conservatively decided to remove 45 cm layer (4.05 m^3) of heavy reinforced concrete from the floor in Room 001 and 10 cm layer (1.15 m^3) in Room 002. The total volume of the heavy reinforced concrete to be removed is 5.2 m^3.

It is necessary to remove concrete only from the walls and the ceiling in Room 001. The layer to be removed is 20 cm and 15 cm respectively. Thus the volume of the reinforced concrete to be removed is 7.2 m^3 (walls) and 1.35 m^3 (ceiling) in Room 001. The total volume is 8.55 m^3.

The maximum value of the specific activity of radionuclides in the concrete to be removed from the floor and walls is given in Table 1.

Room	Specific Activity, Bq/kg				
	^{152}Eu	^{154}Eu	^{60}Co	^{134}Cs	^{54}Mn
Floor in Room 001	$2.87\cdot10^4$	$1.92\cdot10^3$	$4.65\cdot10^3$	$4.14\cdot10^2$	$5.98\cdot10$
Floor in Room 002	$1.43\cdot10^3$	$7.62\cdot10$	$2.02\cdot10^2$	$1.72\cdot10$	$1.80\cdot10$
Walls and ceiling in Room 001 and Room 002	$9.52\cdot10^3$	$5.77\cdot10^2$	$1.24\cdot10^3$	$1.67\cdot10^2$	$3.43\cdot10$

Tab 1: Specific Activity of the Concrete to be Removed

Estimation of Dust Formation during Removal of Activated Concrete from Room 001 and Room 002

The activated heavy reinforced concrete of Room 001 and Room 002 has to be fragmented by the demolition hammer, the concrete breaker and the hydraulic shears (metal reinforcement removal). The significant dust formation occurs when the demolition hammer and the concrete breaker are used.
The HEPA-filter efficiency is 2.000 m^3/h (0.55 m^3/sec). Time required to remove a layer of activated concrete (0.5 m^3) is 270 minutes. The space of Room 001 and Room 002 where the concrete removal operations have to be performed is 27 m^3 and 34.56 m^3 respectively. The wall with the doorway separates these rooms. The volumetric activity of radionuclides in the air during the concrete removal from Room 001 and Room 002 doesn't exceed 14 Bq/m^3 for ^{60}Co, 5 Bq/m^3 for ^{152}Eu and 0.08 Bq/m^3 for ^{134}Cs.

3.4.2 Tanks of Gas Removal and Cooling System

According to the measurement of the tanks of the gas removal and cooling system the charcoal filter has the highest specific activity of ^{137}Cs that is 1.2 kBq/g ($1.2 \cdot 10^6$ Bq/kg). The total volume of charcoal is 0.5 m^3.

3.4.3 SRW in the Isotope Storage Building

The ADER close to the SRW in the well of Room 001 in the isotope storage building is 30 μSv/h. The ADER on the surface of the metal boxes with the fire-prevention sensors and other equipment, which is subject to disposal, is 3.5 μSv/h. The excessive ADER of 10 μSv/h was detected on the surface of the metal target in Room 002.

4. Current Radiation Conditions on the RTC Site

The comprehensive radiological survey of the RTC site of FOTON JSC was conducted as the preparation activity for the RTC decommissioning. According to the survey results the average value of ADER on the RTC site is 0.08 μmSv/h. This value corresponds to the background values. The surface contamination of the RTC site measured by the direct method is 0.212 Bq/cm^2 for beta-emitting radionuclides and 0.059 sec^{-1} for alpha-emitting radionuclides. Both values are within the background level limits.
Based on the results of gamma-spectrometry of liquid samples and soil samples the specific activity doesn't exceed accepted values [7].

5. Personnel Dose Rate Assessment

The calculation results of the individual and collective external exposure of the personnel during RTC decommissioning in all operation areas have showed that the collective dose doesn't exceed 8 mSv for all workers except a fitter, who removes activated concrete layer in Room 001 and Room 002 of the laboratory building. Based on the calculation the recommendations were made regarding the quantity of the personnel.
While removing activated concrete the personnel use Class FFP3 full face respirators (high filtration efficiency) with Class P3 disposable aerosol filters. Class FFP3 ensures no more than 5 % penetration of aerosols through the respirators. The duration of removal and packing of 0.5 m^3 of activated concrete is 425 min. The volume of the concrete removed from Room 001 and Room 002 is 13.75 m^3. The total individual dose of internal exposure of the personnel during removal and packing of the activated concrete from Room 001 and Room 002 will be 4 μSv.

6. Environmental Impact Assessment

6.1 Radiation Impact Assessment

The main source of the radionuclides released into the environment during the RTC decommissioning will be aerosol dust released during the activated concrete removal in the laboratory building. Table 2 provides the activity of the most important radionuclides containing in the dust released during the activated concrete cutting and removal from the floors, walls and ceilings of Room 001 and Room 002 at the laboratory building calculated assuming the fact that the air purification system (total decontamination factor of HEPA filter is K=95 %, capacity is 4000 m^3/h) is completely functional. The calculations were performed using Scale 6.1.2 software package (Triton module).

Radionuclide	Activity of Daily Radionuclide Release, Bq/day	Activity, Bq
^{152}Eu	$6.76 \cdot 10^{2}$	$1.08 \cdot 10^{4}$
^{154}Eu	$4.34 \cdot 10^{1}$	$6.95 \cdot 10^{2}$
^{60}Co	$1.01 \cdot 10^{2}$	$1.61 \cdot 10^{3}$
^{134}Cs	$1.06 \cdot 10^{1}$	$1.70 \cdot 10^{2}$
^{54}Mn	1.89	$3.02 \cdot 10^{1}$

Tab 2: Activity of radionuclide release in atmosphere

The CAP-88-PC software package was used to analyze the ground level concentration of the radionuclides generated during the RTC decommissioning and to access the possible public exposure. The CAP-88-PC is a standard specialized software designed for the assessment of dose and risk from nuclear facility radionuclide emissions to air in order to be in compliance with the standards. It is recommended by the U.S. Environmental Protection Agency. The input data was the information on the annual average meteorological environment in Tashkent and the parameters of the emission source: the tube height is 6.7m; release rate is 5.8 m/s; the tube diameter is 0.35 m.

For the sake of conservatism it was assumed that the RTC dismantling and decommissioning activities will last for a year. The expected annual effective dose of the public was assessed taking into account the specified daily emission (Table 3).

Exposure	AED, µSv
Internal exposure from radionuclides taken in by food	$3.03 \cdot 10^{-4}$
Internal exposure from inhalation of radionuclides in the radioactive cloud	$8.59 \cdot 10^{-5}$
External exposure from radiation under the assumption that the plume is correctly approximated by a semi-infinite cloud	$8.62 \cdot 10^{-7}$
External exposure from the ground surface	$1.57 \cdot 10^{-3}$
Total internal exposure	$3.89 \cdot 10^{-4}$
Total external exposure	$1.58 \cdot 10^{-3}$
Total	$1.96 \cdot 10^{-3}$

Tab 3: Expected Annual Effective Dose of Public during RTC Dismantling and Decommissioning

If a person is exposed to all sources of radiation (external and internal) at the same time the annual effective dose to the critical group of the public shall not exceed 1 mSv per year on average over any consecutive 5 years but not more than 5 mSv per year. The calculated values of effective dose meet this requirement.

6.2 Assessment of Chemical Impact on Atmosphere

Release of Chemical Contaminants during Activated Concrete Removal in Room 001 and Room 002 of the Laboratory Building

The demolition hammers, the concrete breaker and the hydraulic shears are used for fragmentation of reinforced concrete covering, walls and floors of Room 001 and Room 002 of the laboratory building.
The total volume of the activated concrete to be removed is 13.75 m^3. The RTC was built from the concrete reinforced with A400 steel bars of 187 kg/m^3. The volume of steel bars in the contaminated concrete is 0.184 m^3, the total length is 4500 m. For the sake of conservatism it was assumed that the concrete would be cut each 10 cm and it would take 9 hours to cut 1 m^3 of the reinforced concrete.
The pollutants typical for plasma cutting of alloyed steel were used for calculations. In case of the plasma cutting the quantity of air pollutants is much higher in comparison with the cutting by hydraulic shears.
The ground level concentrations of pollutants 100 m far from the emission source in the point of maximum ground-level concentration are given in Table 4. All calculated values do not exceed the threshold limit values of pollutants concentration in the ambient air of populated areas stated by the Sanitary Norms and Regulations of Uzbekistan.

Air Pollutant	**Chrome oxide**	**Iron oxide**	**Carbon oxide**	**Nitrogen dioxide**
Ground Level Concentration, mg/m^3	$4.03 \cdot 10^{-7}$	$9.66 \cdot 10^{-6}$	$4.80 \cdot 10^{-6}$	$2.11 \cdot 10^{-5}$
TLV per month, mg/m^3	0.003	0.06	3.5	0.05

Tab 4: Ground Level Concentrations of Pollutants at 100 m distance from the Emission Source and their Threshold Limit Values [8]

Release of Pollutants during Transport Operations

During the on-site RTC decommissioning the transport equipment will be used to perform the following work (Table 5):
- demolish the building and facilities located on the RTC site,
- remove the remained foundation of the buildings and facilities located on the RTC site,
- load the SRW(LRW)-containing packages for further removal for disposal or reprocessing,
- remove the SRW and the LRW from the RTC site.

Vehicle	Quantity	Operating Time, machine-hour
Tipper truck	2	510
Excavator	1	720
Hydraulic breaker	1	720
Bulldozer	1	160
30 t truck crane	1	120

Tab 5: Type, Quantity and Operating Time of Transport Equipment

It was conservatively assumed that all transport equipment use Euro 0 diesel fuel.

Vehicle	Emission Class	Specific Emission, g/kg					
		CO	VOC Hydrocarbons in terms of $CH_{1,85}$	NO_x Nitrogen oxides in terms of NO_2	PM Solid particles in terms of carbon	SO_2	CO_2
Trucks weighing more than 3500 kg	0 (Euro 0)	30.0	10.0	50.0	4.0	1.6	3020

Tab 6: Specific Emissions of Pollutants when 1 kg of Diesel Fuel is Burnt

While calculating the emissions of transport construction equipment to be used for the RTC decommissioning it was accepted that:
- Work is performed in a warm season;
- Vehicle speed at the RTC site is up to 5 km/h;
- Base rate of fuel consumption for all vehicles mentioned above is 50 L/100 km;
- Distance within the RTC site in one direction is 0.65 km;
- Increase in fuel consumption during operation at low speed is 35 %;
- Diesel fuel density is 0.86 kg/l.

The total weight of pollutants emitted by all vehicles during the RTC decommissioning, their ground level concentrations and threshold limit values of concentrations are given in Table 7.

Compound	Emission in the Period of Decommissioning, t	Ground Level Concentration, mg/m^3	Threshold Limit Value of Concentration, mg/m3
CO	7.79E-03	1.01E-02	5
VOC	2.60E-01	3.37E-03	1.2
NO_x	1.30E+00	1,69E-02	0.6
PM	1.04E-01	1.35E-03	0.15
SO_2	4.15E-02	5.40E-04	0.5
CO_2	7.84E+01	1.02E+00	–

Tab 7: Emission of Air Pollutants during the RTC Decommissioning

6.3 RW Production and RW Management

Low-level waste (LLW) and intermediate-level waste (ILW) will be generated during the RTC decommissioning.

Low level SRW:
- Reactor vessel;
- Heat-exchanger of the reactor vessel cooling system;
- FP-1 filter housing and FP-2 filter housing;
- other metal and non-metal RW loaded into 0.2 m^3 metal barrels and 0.4 m^3 Big-Bags;
- Activated concrete from Room 001 and Room 002 loaded into 1.3 m^3 Big-Bags.

Intermediate level SRW:
- Charcoal filter (final decision on its category will be taken at the characterization stage).

The low level LRW is water of the reactor vessel cooling system. The LRW will be drained into 0.02 m^3 plastic cans. Secondary low level SRW will be generated during the RTC decommissioning. It will be packed into 0.4 m^3 Big-Bags. It is an industrial vacuum cleaner and associated bags, the used PPE and cloth.

RW amount is given in Table 8.

Package with RW	Dimensions	Quantity, pcs	RW Weight, t
SRW			
1. Reactor vessel wrapped in PE film	Diameter – 450 mm Height – 1885 mm	1	0.7
2. Heat-exchanger of the reactor vessel cooling system wrapped in PE film	Diameter – 130 mm Length – 2400 mm	1	0.09
3. Carbon filter wrapped in PE film	Height – 1100 mm Diameter – 420 mm	1	0.12
4. FP-1 filter housing wrapped in PE film	Height – 1000 mm Diameter – 650 mm	1	0.28
5. FP-2 filter housing wrapped in PE film	Height – 1000 mm Diameter – 650 mm	1	0.3
6. 0.2 m^3 metal barrel	Diameter – 570 mm Height – 880 mm	5	0.95
7. 0.4 m^3 Big-Bag	Length (width) – 600 mm Height – 125 mm	15	1.415
8. 1.3 m^3 Big-Bag	Length (width) – 1090 mm	28*	38.4
Total			42.325
LRW			
9. 0.02 m^3plastic cans	–	110	2.2

Tab 8: Content and Quantity of RW-containing Packages

All RW generated during the RTC decommissioning will be transferred to the temporary storage area. Then all SRW will be removed for disposal and all LRW will be removed for reprocessing.

7. Analysis of Abnormal Equipment Operation during Decommissioning

In this analysis the scenarios of the abnormal equipment operation were considered, caused by the following initial events.
Design-basis accidents:
Internal initial events:

- Failure of transport and process equipment components,
- Loss of the physical barriers efficiency,
- Combustion of chemical solvents or waste generated during the dismantling activities,
- Failure of the radiation monitoring system,
- Human error when using the technical equipment and material and during the dismantling activities;

External initial events: loss of electric power.
The initial event for the beyond design-basis accident is an earthquake with the intensity corresponding to the maximum credible earthquake (MCE).
The design-basis accidents that can occur with the drop of 1.3 m^3 Big-Bags filled with SRW and with the failure of the filters of the special ventilation system are the most critical for the radiation safety.
The radiation dose estimations for the public as a result of accidents were done using the HotSpot 3.0.3 software developed in the U.S. Lawrence Livermore National Laboratory and intended to calculate dissipation of radiation material emissions into the atmosphere as well as to give the first order of estimations of doses after explosions, fires and short-term

emissions. This software allows to estimate consequences of surface nuclear explosions, secondary raise of nuclides in contaminated areas, etc.
The software models were developed to make forecasts at small (less than 10 km) distances and short emission durations (few hours).
The HotSpot libraries allow to specify emissions of any radionuclide or a mixture. The HotSpot implements the Gaussian dispersion model which is the main tool for primary calculations of atmospheric dispersions.

7.1 Design-Basis Accidents

Drop of 1.3 m^3 Big-Bag Filled with SRW

The maximum amount of radioactive substances during the transport and process operations will be localized in a 1.3 m^3 Big-Bag filled with the fragments of activated reinforced concrete to the volume of 0.5 m^3.
The personnel exposure induced by the drop of the package mentioned above was assessed using the following conservative assumptions:
- The package drops in the room of the laboratory building,
- The package is fully destroyed. 100 % of radioactive aerosols released into the work area air,
- Radioactive substances are uniformly distributed in the work area air,
- Time of personnel presence in the room from the accident identification till the personnel evacuation is not more than 3 min,
- The personnel use Class FFP3 full face respirators with Class P3 disposable aerosol filters (penetration of aerosols not higher than 5%), purification efficiency of the HEPA filter is 95%.

The computation results demonstrate that the maximum internal exposure dose during evacuation from the working area after the drop of the 1.3 m^3 Big-Bag will not exceed 0.25 mSv that satisfies accepted standards of personnel radiation safety.
The maximum radiation dose for the public in case of this accident at the worst weather conditions (atmosphere of Pasquill Stability Class A and calm) will not exceed 2.6 μSv at at the distance of 22 m from the emission source. This value is less than the minimum significant dose limit equal to 10 μSv [6].

Failure of Special Ventilation System Filters

Loss of filter effectiveness and/or filter seal failure will cause the emission of radioactive substances into the air through the special ventilation system.
All values of the public exposure in case of this design-basis accident are less than the minimum significant dose limit equal to 10 μSv.

7.2 Beyond Design-Basis Accidents

The seismic impact is an external initial event. It can effect all items of equipment to be used for the RTC decommissioning. The most critical ones are seismic loads on the equipment components which failure cause a demolition of physical barriers (the special ventilation system, the laboratory building, etc.) preventing the release of ionizing radiation and radioactive substances into the environment.
The scenario considered a drop of the package with RW inside the laboratory building. The maximum radiation dose to the public will make up 0.12 mSv at the distance of 100 m from the emitting source under the worst weather conditions (atmosphere of Pasquill Stability Class F and a calm). That is less than the annual potential dose limit for the public which is equal 0.2 mSv (as a result of design and beyond design-basis accidents) [6].

8. Conclusions

The calculations show that annual effective doses for the personnel and public specified in [6] will not be exceeded as a result of the FOTON RTC decommissioning. Also annual effective doses of potential exposure (due to design-basis and beyond design-basis accidents) of the personnel and public (i.e. 4 mSv and 0.2 mSv respectively) will not be exceeded. All accidents considered in the Report are evaluated as Level 0 events according to the IAEA International Nuclear Event Scalĕ (INES)

The concentration of chemical contaminants released in the air does not exceed the limits specified in the corresponding regulations.

Consequently, the RTC decommissioning performed in accordance with the developed technology has no significant impact on the personnel, the public and the environment.

9. References

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