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PRELIMINARY SAFETY ANALYSIS AT THE DECOMMISSIONING OF THE WWR-M RESEARCH REACTOR

Following the demands established by the current Ukrainian legislation, the Decommissioning Concept for the WWR-M research reactor was recently approved. The Concept envisages a strategy of immediate dismantling; it identifies and justifies the main technical and organizational measures for the preparation and implementation of decommissioning, the sequence of planned works and activities, as well as the necessary conditions and infrastructure. Decommissioning requires proper planning and demonstration that all planned dismantling works will be carried out safely. Presented safety assessment is a mandatory component of the Concept and the most important element of the overarching technological scheme. The purpose of the safety analysis is to provide input for detailed planning on how to ensure safety during decommissioning. Based on the results of the safety analysis, the measures to ensure radiation protection are defined while justifying their necessity and sufficiency.

Keywords: research reactor, decommissioning, dismantling, radioactive waste, radiation safety.

1. Introduction

Decommissioning is the final stage of the life cycle of a nuclear installation and is to be performed by means of demolishing or reusing buildings and structures while removing the radioactive substances and the conversion of the site for limited/unrestricted use. The facility could be considered decommissioned upon reaching the approved final state. At the same time, the protection of personnel and the environment from radiological and man-induced impacts must be unconditionally guaranteed. Decommissioning is a complex process that includes decontamination, dismantling of equipment, demolition of structures, and radioactive waste management. Currently, the Ukrainian legislation establishes the requirements for ensuring the activities related to the decommissioning of the nuclear installation, as well as the activities directly related to the decommissioning.

The Decommissioning Concept for WWR-M research reactor was recently approved [1]. The concept covers the entire decommissioning process and represents the main guideline document throughout the whole decommissioning period; it identifies and justifies the main technical and organizational measures for the preparation and implementation of the reactor decommissioning.

The purpose of the safety analysis is to substantiate that during decommissioning radiation safety for the personnel, population and environment will be ensured at a level, not lower than provided by the norms, rules, and standards on nuclear and radiation safety. Based on the results of the safety analysis, the measures to ensure radiation protection are defined while justifying their necessity and sufficiency. The information and results of the analysis are consistently reviewed.

2. General requirements for the safety analysis

Safety provision during decommissioning is the most important element of the overarching technological scheme. Each planned activity during the performance of works is considered in terms of impact on the following safety components: radiation, fire, industrial, and others [2 - 7]. The personnel, public, and environment must be protected from the hazards originated by the decommissioning at all stages. Safety must be ensured in accordance with the requirements of current regulations, norms, rules, and standards. The radiation, fire, and industrial safety, as well as environmental safety [8, 9] during decommissioning, are provided by the following: 1) reactor systems that still continue operation in normal mode; 2) organizational and technical measures; 3) quality assurance system. A research reactor is considered safe if, during the operation and design basis accidents, both technical and organizational means ensure that the established dose from the internal and external irradiation for the staff and public, as well as the standards for the content of radioactive products in the environment, are not exceeded. Maximum allowed radiation doses to the personnel, dose limits for the public, and limits for the content of radioactive products in the environment during normal operation, violations of normal operation, and accidents are applied in accordance with the current radiation safety standards. The same definition of safety can be used in full for the activities during decommissioning.

Safety assessment at the reactor decommissioning is performed as follows [10 - 13]:

– definition of the decommissioning operations and their sequence in accordance with the chosen decommissioning strategy;

– identification of the safety problems that may arise during the normal decommissioning process and their engineering assessment;

– identification of the possible accidents and incidents that may occur during decommissioning, their engineering assessment, and identification of the most dangerous;

– assessment of the consequences for the staff and public, both during the normal decommissioning process and in the case of any incidents/accidents;

– comparison of the assessment results with the corresponding safety criteria;

– establishing measures to prevent and minimize the consequences.

The greatest difficulty in the development of the safety analysis report is performing a safety analysis for various accidents that may occur during decommissioning [14, 15]. Analysis of possible accidents at the reactor in operation to be performed by the design organization at the design stage. For design basis accidents, the initial events, sequence of events, and impact assessment should be determined.

The radiation risks for the staff and public are significantly reduced during decommissioning and it makes it possible to revise the emergency plans and optimize radiation protection by removing certain measures and restrictions that are not necessary for this stage. Optimization of the radiation protection will reduce the cost of maintenance in a safe condition as well as the overall decommissioning cost, respectively. At the same time, such optimization should be carried out without any reduction of the achieved safety level, which requires appropriate investigations and safety justifications.

3. List of planned decommissioning works

The planned decommissioning activities include the dismantling of equipment, segmentation of dismantled equipment and decontamination, and storage of radioactive waste and its transportation outside the site. Most of the planned dismantling works are actions of mechanical and thermal cutting.

Decommissioning activities that pose a significant radiation hazard were only considered among others, namely:

– dismantling/disconnection of the reactor vessel and its internals (heat column and channels) [16, 17];

– dismantling/disconnection of the large-scale equipment and components of contaminated systems (pumps, filters, heat exchangers, valves, secondary cooling circuits, water purification systems, etc.) [18 - 20];

– dismantling/disassembling/cutting of the large-scale components available after dismantling the reactor and all pipes, supports, and equipment installed on those pipelines;

– dismantling of all equipment (mechanical tools, stands, lifting devices and local vehicles, power supply system);

– demolishing of the concrete shielding, concrete reactor basement, and shielding walls of “hot-cells”;

– dismantling of the cooling pond (dismantling of the internal structure, aluminum tank, etc.);

– removal of the spent filters from the ventilation systems, pump-compressor pipe, and faulty ventilation equipment and air conditioners (in order to restore the ventilation system for use);

– dismantling/cutting of the ventilation stack and disassembling of all components of the ventilation system where the ventilation is no longer required;

– dismantling/disassembling/cutting of all auxiliary components and systems (including drainage system).

4. Hazard analysis

4.1. Risk analysis for the staff

According to the current regulations, the exposure of personnel during the implementation of the practical activity is divided into two categories: actual and potential. The actual exposure within the framework of the technological process envisaged by the decommissioning project always accompanies the practical activities or may have a high probability.

The potential exposure means the exposure considered in the planning of practical activities and could occur immediately after any initial event unforeseen by the normal technological process with the probability of less than $1\cdot10^{-2}\,\text{yr}^{-1}$ [21]. The potential exposure is possible only after some unpredictable initial event. The initial event, in turn, is the result of violations of the technology, equipment failures, personnel errors, and external influences (including natural). Any unforeseen or unplanned event that will lead to unplanned staff exposure or unplanned release of radioactive contamination beyond the permissible norms is considered an accident.

Analysis of activities under normal conditions indicates that some activities pose a radiation hazard to the involved staff [22, 23]. The main types of radiological hazards for the involved staff are:

○ Direct gamma-irradiation:

– risk of the direct irradiation (especially gamma-irradiation) occurs in case of cutting, dismantling/disassembling of the reactor and internals, components of the primary circuit and pipelines (especially pipelines under the reactor vessel), demolition of the concrete shielding, crushing of concrete, dismantling of the cleaning system filters and the ventilation system filters, as well as in the management of radioactive waste generated after dismantling;

– moreover, risk of the direct-gamma irradiation may occur in the case of dismantling/removal of the underground drainage pipeline and underground liquid waste tank (including the removal of the possibly contaminated soil for the purpose of site restoration).

○ Inhalation of the contaminated dust (suspended particles):

– inhalation of the contaminated dust or aerosols in the air may occur during the removal of soil layers or the paint from the walls, cutting and or dismantling of equipment, removal of the radioactive concrete, radwaste management, and decontamination using dry abrasive techniques.

○ Possible skin contact with the solid or liquid radioactive substances:

– risk of skin contact with solid radioactive substances may occur during the cutting and demolishing of some contaminated components (contact with cutting debris or small pieces of components). This risk is also possible if some slightly contaminated components are removed manually or when concrete is removed. There may also be a risk of skin contact with the contaminated soil/components sampling and analysis, etc.;

– skin contact with the liquid radioactive substances may occur during the release of the liquid radioactive waste remaining in the pipelines;

– direct skin contact with radioactive substances can also occur when loading radioactive waste.

4.2. Risk analysis for the public

While analyzing the location of the reactor site, selected decommissioning option, planned procedures, and measures for dismantling, it has been found that there is a low probability of radiation hazard to the public during decommissioning, mainly for the following reasons:

– performance of all types of decommissioning activities in those areas that ensure retention of the radioactive substances (inside the reactor building, which is specifically sealed and localized);

– availability of measures to control the releases into the environment (filters on the ventilation stack are providing the collection of radioactive substances);

– use of the local suction systems during the concrete crushing in order to avoid the dust spreading to the environment;

– use of the local suction system inside the body of the cutting tool to avoid the spread of radioactive particles generated by cutting to the environment;

– administrative measures to protect the public, mainly, restricted access to the working areas, control of radioactive discharges, etc.).

4.3. Analysis of risks due to events and incidents

While analyzing the planned activities and identified hazards, the following types of possible incidents during decommissioning were identified:

○ incidents due to internal causes;

○ incidents due to external causes that may be:

– cases due to reasons at locality;

– cases due to reasons onsite;

– natural phenomena.

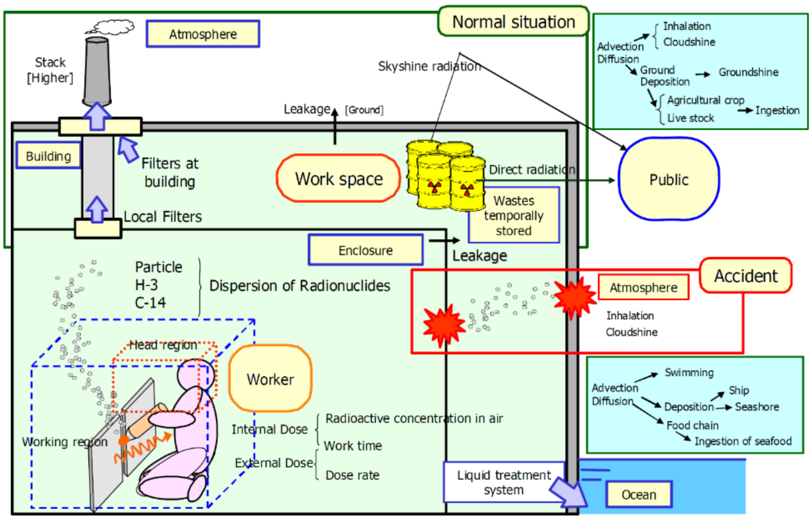

Fig. 1. Exposure pathways. (See color Figure on the journal website.)

Possible exposure pathways resulting from the discharges of radionuclides and radiation during dismantling activities under normal conditions and accidents are shown in Fig. 1 (taken from [24]).

5. Potential consequences for staff under normal conditions

Staff involved in the decommissioning activities may receive increased doses due to direct exposure, inhalation of the radioactive material, or skin contamination. Almost all emissions into the interior (and atmosphere) as a result of decontamination and dismantling works will come from the operations executed inside the reactor hall and the pump-house of the primary cooling circuit.

The exposure doses were calculated for the workers performing individual tasks in both of these areas. To calculate the estimated dose values for the workers performing specific tasks each of them was assigned to one of three categories:

– dismantling operations: there are two different ways of exposure, one through the inhalation dose obtained from breathing, and the other through the external radiation dose from the radioactively contaminated surfaces;

– shredding and decontamination operations: it is assumed that during shredding and decontamination operations the staff will use respiratory protection and personal protective equipment (PPE). Thus, the exposure of the worker can occur through external exposure;

– transport and packaging operations: it is assumed that such operations (including control) will result in minimal resuspension of radionuclides, as most of the time all components are packed in plastic.

The assessment was conducted for each of the three categories of tasks. The exposure doses for the main decommissioning tasks were evaluated in terms of the external dose caused by direct radiation from radiation sources and contaminated surfaces, as well as the internal dose caused by air pollution. It should be emphasized that dose assessments were provided for planning purposes only. During the implementation of works, the impact assessments and controls will be constantly developed and revised based on measurements and in accordance with the requirements of the radiation protection program.

The highest dose rates (> 2 μSv/h) in the reactor hall and in the pump-hall of the primary cooling circuit are observed in the areas where the majority of work on the dismantling is planned. Dose rate distribution maps in both these premises are shown in Fig. 2.

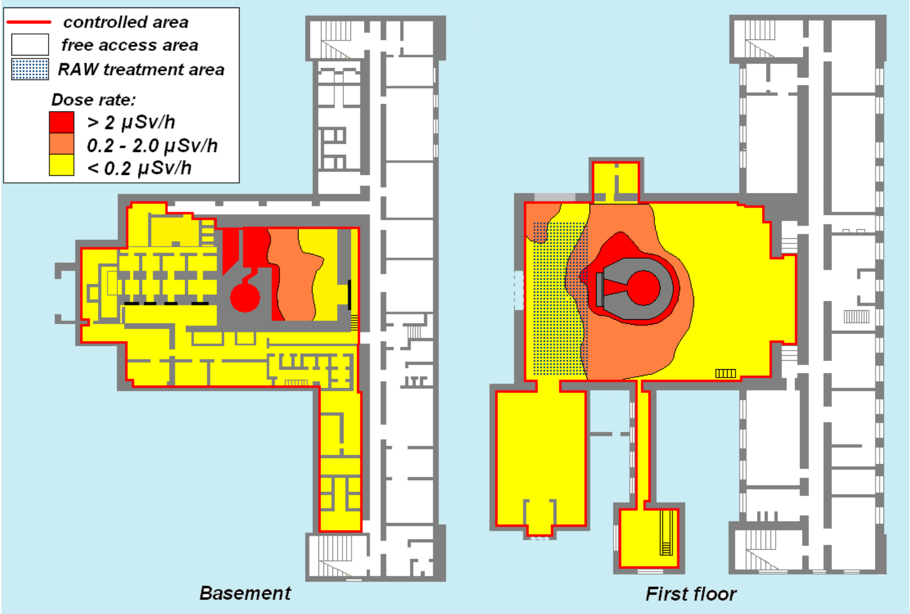

Fig. 2. Dose rate distribution maps. (See color Figure on the journal website.)

Internal dose due to air pollution. Assessment of the exposure dose due to the air pollution during the cutting of structures and crushing of concrete was performed for the values of activity concentration for the artificial origin radionuclides, including the external irradiation, dust inhalation and ingestion (direct and indirect).

6. Possible consequences due to events and incidents

The safety analysis has identified all possible risks that may arise as a result of dismantling, including the consideration of appropriate protection measures and possible mitigation measures. As a result of this analysis, a preliminary list of possible types of normal and radiological events and incidents was compiled. There were three events identified that may lead to the release of activity into the environment and seems that are not possible to be minimized: 1) falling of dismantled component or waste container; 2) power outage; 3) fire.

Falling. The consequences of falling are highly dependent on the place. If the waste container or component is kept inside the premise, then the activity is kept inside by means of exhaust ventilation. If the event occurs during loading on the vehicle, then it is possible to spread contamination in the atmosphere. However, all components of the waste will be coated to prevent the spread of contamination, and it can be assumed that any spread of contamination can only occur as a result of the fire.

If contamination inside the component or pipeline is formed during operation, then such contamination is likely to be strongly fixed on the surface. In this case, when the component falls, the share of the released activity should be small. There are very little data on releases that occurred from the contaminated surfaces for elements that were not broken or dropped. Share of 10^{-3} relies on the explosive force parallel to the surface. Based on the fact that the force when the load falls from the maximum possible height will be much less, it is reasonable to assume that the maximum share for this case will be 10^{-4}. Moreover, not all activity inside the component will turn into aerosols. For example, the heat exchanger is provided with internal partitions that ensure the maximum heating transfer during operation. Aerosol particles inside the heat exchanger are settled on the partitions before they are ejected; therefore, if the design is known, only contaminants from the open openings should be considered when emitting. Even for open pipes, most of the aerosols formed will settle inside the pipe before they are discarded.

The effect of a *power outage* will cause a disconnect of the exhaust ventilation. However, a general power outage will also stop the dismantling work. The shutdown of the exhaust ventilation system is to be noticed immediately and workers stop work.

Fire. To determine the worst possible consequences of a fire accident, it was assumed that a large contaminated component was engulfed in flames, and discharges occurred through a hatch at ground level and not through a ventilation stack. The only possible accident that was identified is a plane crash. However, the frequency of such incidents is negligibly low that no need to assess the consequences.

In the event of a fire, two factors should be considered – the emission fraction and the duration of the fire. It is recommended to take into account the proportion of aerosol emissions $6 \cdot 10^{-3}$ with a weighted fraction of 0.01 [25], which generally gives a weighted proportion of $6 \cdot 10^{-5}$. As expected, this value is smaller compared with the incineration of the contaminated combustible waste (paper, plastic, etc.), for which the proportion is $5 \cdot 10^{-4}$.

The length of the affected area is limited by the size of the fire and openings of tanks, vessels, etc. Since the premise does not contains combustible materials the only source of fire is the equipment located inside the room. If the electric Brokk is used, the ignitable media will be limited to oil and other hydraulic fluids (if they are flammable). In this case, fire is not extended and will affect only a limited small number of components.

7. Potential consequences for the public and environment

Radiation impact on the environment during normal work execution inside the reactor building will be caused by the gas-aerosol release through the ventilation stack. The release of radioactive substances outside the reactor will be minimized by using filters for air purification. Work performance outside the reactor will cause the gas-aerosol release into the environment directly from the locations for the fragmentation of dismantled structures, as well as from the other workplaces (e.g., when performing work on the dismantling of external networks). Taking into the nature of the work, including the use of new (non-contaminated) materials, data on the contamination of both dismantled equipment and workplaces, as well as the use of air filters, it can be concluded that the execution of the planned works inside the reactor hall will have practically no impact on the environment.

The maximum values of contamination were taken into consideration (conservative approach) for estimating the amount of emission. The emission values have been determined taking into account that the dust suppression (the coefficient of efficiency for the dust suppression is taken equal to 0.01) will be running before the start of work and during the execution phase. Gas-aerosol discharge occurs at the level of the ventilation stack.

Regarding the unplanned release of a radioactive substance into the environment, it was decided that the most probable route is due to a fire inside the reactor hall. This causes the radioactive cloud formation due to the soil surface radioactive dust resuspension and atmosphere spreading. The radiation effects on the environment under emergency conditions are considered to be extremely small. Therefore, these risks and consequences must be minimized and controlled by applying the recommended precautions.

The consequences of transport accidents followed by the spread of activity are classified as limited (normal contamination, localized impact) due to the nature of low activity waste and the limited amount of radioactive material. Measures to minimize the impact on the site could be applied immediately to localize the impact on the environment and to collect waste. Therefore, the additional risk arising from the transport of radioactive waste from the reactor building will not significantly change the current risk levels.

The Decommissioning Concept foresees the fulfillment of all requirements of the construction, sanitary-hygienic and ecological normative documents and standards, as well as the implementation of protective measures that will ensure the minimization of environmental impact on the environment. It is expected that the planned activity will have an impact, which is classified as “insignificant” or “small” because it does not exceed the permissible limits on the environmental components established by the sanitary norms and rules, as well as other legislative acts of Ukraine. Impact on climate, geological environment, soils, flora, and fauna is not expected. No additional land allotment or change of purpose of the land plot is required. The negative impact of the object on the man-made environment is not expected.

Analysis of the consequences of potential accidents shows that the effective doses due to all exposure pathways due to accidental emissions will not exceed the lowest limit of justification for countermeasures 1 mSv. Moreover, the annual effective dose due to emergency situations, assigned to the population located in the adjacent sanitary protection area of the reactor, will not exceed the established dose limit of 40 μSv/yr.

Taking into account the absence of the excessive impact on the environment during the planned activities both in normal operation and in case of possible accidents, as well as the lack of alienation of land resources, the restoration, and corrective measures are not foreseen. Thus, significant factors are absent that affect or may affect the state of the environment in the planned performance of works and in case of accidents. In compliance with the basic safety rules and subject to the appropriate organization, the emergency is excluded.

8. Radiation protection plan during decommissioning

The radiation protection plan will be implemented to ensure the radiation safety of personnel, the public, and the environment during decommissioning. This plan applies to all work related to the dismantling, disassembling, and demolishing of the reactor’s premises and surrounding area [26]. The plan provides for the following administrative and engineering measures:

- dose limit of the total external and internal radiation for the staff of category A is set to 20 mSv/yr. Current International Commission on Radiological Protection (ICRP) guidelines establish the concept of dose limitation (below dose limits). In the case of decommissioning, it is advisable to set a limit based on factor 2 to determine the working time in areas with a high dose rate, resulting in a dose limit of 10 mSv/yr (this corresponds to the daily dose limit of 35 μSv);
- the current regulation does not impose any restrictions on the order of dose accumulation during the year, except for the exposure of women of reproductive age. At the systematic exposure, i.e. at the permanent work in a zone of ionizing radiations, it is necessary to establish as though intermediate norms: maximum admissible doses of irradiation for the quarter, month, and week. First, it will allow for evenly distributing the dose load of each employee during the year, and secondly, to intervene quickly and redistribute work among employees, i.e. to evenly distribute the dose load between them. To distribute the dose load evenly throughout the year, it is necessary that the dose per quarter was 2.5 mSv, per month – 0.8 mSv, per week – 0.2 mSv. With a 6-hour working day (36-hour working week) and uniform irradiation throughout the working day, the maximum allowable dose is 5.5 μSv;
- the purpose of the staff dose planning consists of their maximal achievable reduction without exceeding the individual dose limit of 20 mSv/yr. Based on the organizational and technical measures implemented, doses under the control level (10 mSv/yr) can be reached;
- all operations will be executed in compliance with the requirements of current radiation safety regulations;
- works will be performed in the conditions established by the relevant rules of radiation hygiene, i.e. radiation control, presence of protective barriers, sanitary locks, etc. will be provided;
- premises and work areas for the dismantling works will be properly allocated to radiation zones with restricted access of staff not directly involved in such works; to prevent the spread of radionuclide contamination between the work areas, all movements between areas are carried out through the special sanitary check-points;
- minimization of the exposure time provides by the following:
  - reuse of existing access routes;
  - maximal use of remote methods;
  - limiting the time of activity in the work area, for example, by optimizing the number of cuts during dismantling;

– maintenance and repair of the contaminated equipment will be conducted after decontamination in a clean area at the maximum distance from the ionizing radiation sources:.

○ minimization of the secondary radioactive waste generation;

○ local ventilation and dust extraction system will be used in addition to the standard ventilation system;

○ manipulators, mobile protective screens, temporary barriers, etc. will be used for the radiation-hazardous work;

○ mandatory use of personnel protective equipment is provided;

○ radiometric mapping of the work area;

○ radiation monitoring to detect spots with the increased dose rate:

– individual dosimetry control of external radiation;

– measuring the level of radionuclide contamination by:

1) periodic measurement of the contamination levels (wall and floor surfaces);

2) dose rate measurement at the work areas, in the reactor building, and on the site;

3) measurement of aerosol radioactivity in work areas and in the environment;

4) control of radiation emissions into the environment; measures will be implemented to prevent uncontrolled emissions and pollution of the reactor site;

– measurements of the radionuclide content for the internal dose calculations;

○ continuation of operation of the external radiation monitoring system;

○ radwaste accounting and control; the arrangement of a temporary area for the radwaste storage before shipment;

○ use of the quality assurance system;

○ in case of incidents/emergencies, the dismantling works will be suspended and the following actions will be taken:

– staff will be removed from the work areas;

– measures aimed at stopping the incident/emergency situation and minimizing the consequences, for example, it is possible to turn off the ventilation system if it contributes to the spread of contamination inside or outside the building;

– providing first aid to the injured;

– radiometric control at the site boundaries to measure contamination of hands, clothing, and footwear;

– decontamination of staff removed from the site;

– assessment of the radiation levels on the premises, on the site, and in adjacent territories.

The main criteria for the effectiveness of radiation protection will be zero number of cases exceeding the established annual dose limit. The individual dose, the number of people exposed, and the probability of exposure should be as low as reasonably achievable (ALARA). Additional criteria should be considered:

– maximum and average annual effective doses of the external and internal exposure;

– reduction of the collective dose;

– reduction of the individual exposure doses;

– reduction of the radioactivity of aerosols;

– reducing the number of violations related to exceeding control levels.

9. Conclusions

The preliminary safety assessment has been performed to substantiate the organizational and technical solutions intended for the decommissioning of the WWR-M reactor. It is an integral part of the Decommissioning Concept. In the future, this assessment will be developed and improved; in its final form, it will be presented as the Safety Analysis Report together with the Decommissioning Project.

The present safety assessment aims to identify the potential radiation hazard consequences during the WWR-M reactor decommissioning, both for normal working situations and incidents.

In normal decommissioning works, the analyzed cases are considered as being acceptable because the maximum dose received is less than the dose limit set by the current regulations. For incidents caused by internal events, the maximum exposure doses for the staff during each incident show values that fall within acceptable limits.

The safety analysis under normal working conditions and incidents showed that the exposure doses of staff are within the established safety criteria. The works associated with receiving the increased exposure doses are related to dismantling operations. It can conclude that these kinds of work will require the involvement of significant human resources in order to reduce the dose per employee. Most dismantling tasks will result in a dose below 2 mSv and this is not a problem. However, some tasks will generate results a worker dose more than 5 mSv. When the dose exceeds the threshold, it is recommended for employees to be limited to one task per year. Other tasks performed by these individuals should be performed at a lower dose load. This will reduce the dose load on the worker in accordance with the ALARA principle. Even if these doses are below the limit of the worker's annual exposure dose of 20 mSv/yr, measures must be taken to minimize exposure.

Radiation's impact on the environment could be due to the radioactive aerosols released into the atmosphere during the dismantling tasks. An assessment of the potential radiation impact on the environment under normal conditions of decommissioning works was performed. The assessment predicted a total aerosol release into the environment of 260 kBq throughout the decommissioning project. The potential radioactive impact on the constituent elements of the environment (flora, fauna, aquatic environment, atmosphere, and geological environment) outside the reactor site as a result of radioactive releases is estimated to be extremely low and, accordingly, will not be considered.

Assessment of the radiological consequences of accidents/incidents that may occur as a result of the decommissioning project implementation indicates that the maximal allowable accident may lead to an aerosols activity releasing in $1.12 \cdot 10^6$ Bq, i.e., a value of less than 1 % of derived emission limits for the radionuclide contained in the gaseous effluents.

Radioactive waste generated during the planned activity will be either very low-level (primary and secondary) or low-level (secondary) waste (either VLLW or LLW). The estimated radiological consequences of a transport accident are accompanied by small radioactivity releasing (localized areas of radioactive contamination) due to low waste activity and quantities. Appropriate measures will be taken to minimize the impact on the site to localize the impact and collect the dispersed waste. Accordingly, the additional risk associated with the transportation of radioactive waste will not significantly change the existing level of risk at the site.

The potential non-radioactive impact on public health is formed as a result of the aerosol emissions from the waste shredding and transportation of dismantled materials on the site. The planned activity will not cause the formation of other significant types of non-radiation effects that may affect the constituent elements of the environment or public health. The environmental monitoring program will be reviewed to monitor the nitrogen oxide emissions. The existing environmental control program, including radioactivity monitoring, is considered sufficient for the planned activities.

Accordingly, one can conclude that during the implementation of the planned decommissioning activities any significant impact on staff (both directly involved and staff on-site) is not expected as well as this activity will not have any negative impact on the public and on the existing radiation situation around the reactor site.

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ПОПЕРЕДНІЙ АНАЛІЗ БЕЗПЕКИ ПРИ ЗНЯТТІ З ЕКСПЛУАТАЦІЇ ДОСЛІДНИЦЬКОГО РЕАКТОРА ВВР-М

Відповідно до вимог чинного законодавства нещодавно була затверджена Концепція зняття з експлуатації дослідницького реактора ВВР-М. Концепція передбачає стратегію негайного демонтажу і визначає та обґрунтовує основні технічні та організаційні заходи щодо підготовки та здійснення зняття з експлуатації, послідовність запланованих робіт та заходів, а також необхідні умови та інфраструктуру. Виведення з експлуатації вимагає належного планування та демонстрації того, що всі заплановані роботи по демонтажу будуть проведені безпечно. Представлена оцінка безпеки є обов’язковою складовою Концепції та найважливішим елементом загальної технологічної схеми. Метою аналізу безпеки є надання вихідних даних для детального планування того, як забезпечити безпеку під час зняття з експлуатації. За результатами аналізу безпеки визначаються заходи щодо забезпечення радіаційного захисту з обґрунтуванням їхньої необхідності та достатності.

Ключові слова: дослідницький реактор, зняття з експлуатації, демонтаж, радіоактивні відходи, радіаційна безпека.

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