NUCET NUCLEAR ENERGY AND TECHNOLOGY

Nuclear Energy and Technology 10(2): 117–122
DOI 10.3897/nucet.10.130134

Research Article

Specifics of radioactive waste management at the power unit No.2 of the Armenian nuclear power plant*

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Academic editor: Yury Kazansky ♦ **Received** 3 March 2023 ♦ **Accepted** 20 June 2024 ♦ **Published** 5 July 2024

Citation: Hakobyan MT, Avakyan NR, Ksenofontov AI (2024) Specifics of radioactive waste management at the power unit No.2 of the Armenian nuclear power plant. Nuclear Energy and Technology 10(2): 117–122. https://doi.org/10.3897/nucet.10.130134

Abstract

This paper discusses a detailed description of the management of radioactive waste (RW) generated during operation at power unit No. 2 of the Armenian NPP during the design and additional (extended) life of the Armenian NPP power unit. The resulting RW of different types (solid, liquid, gaseous) and of different classes, from very low to high activity, which are regulated according to the rules and norms of radiation safety, are described. Options for the preparation of RW for long-term storage with solid medium-active and low-active RW at the industrial site of the Armenian NPP are considered. The principles of continuous step-by-step improvement of safety through modernization are proposed, which implies performing analyses of compliance of the power unit with the requirements of modern safety regulations, including international ones, based on modern technologies, IAEA recommendations, probabilistic safety assessments and analysis of local and international operating experience, lessons learned from accidents and incidents at nuclear power plants, elimination of deviations from existing standards and rules. It is proposed to introduce new technologies and facilities for processing intermediate storage of RW before disposal, improve and modernize existing storage facilities, and create new storage volumes that ensure the safe operation of the Armenian NPP power unit, including extending the service life and decommissioning of power units.

The omissions in the management system that create difficulties in handling RW in the Republic of Armenia are indicated. The models of increasing the safety level of RW storage at nuclear power plants by introducing a unified RW management system are formulated, which will reduce the formation of RW of various types and activities, improve and expand the system of safe management of RW and SNF in the Republic of Armenia.

Keywords

NPP, nuclear energy, radiation safety, radioactive waste management

Introduction

The Armenian NPP (ANPP), the region's only nuclear facility, has been in operation in the Republic of Armenia for forty years (since 1976) (Hakobyan and Ksenofontov 2022). Being closely watched by neighboring countries and international organizations, the ANPP has been extremely conscious of its responsibility for ensuring all safety standards and for avoiding the potential negative effect on the environment from the nuclear technologies used at the facility.

It should be noted that the ANPP's WWER-440 reactor (V-270 design) has been improved against its prototype

* Russian text published: Izvestiya vuzov. Yadernaya Energetika (ISSN 0204-3327), 2024, n. 1, pp. 28–41.

units (Novovoronezh 3 and 4, and Kola 1 and 2). No incidents have been recorded in the course of the ANPP's 14-year operation, involving a nuclear or radiological safety violation under the INES international nuclear event scale (IAEA-INES-2008 2008) developed by the IAEA and the OECD/NEA.

This has undoubtedly been achieved thanks to special emphasis placed on safety issues and continued safety improvements practically since the early days of the ANPP operation.

With regard for the development of regulatory requirements for the NPP safety, a principle is implemented for the continuous phased improvement of safety via upgrades. The upgrading strategy is based on analyzing the power unit compliance with current regulatory requirements on safety and probabilistic safety analyses, and on reviewing the local and international experience of operation, and the lessons learned from accidents and incidents at NPPs. Upgrades are planned with regard for the IAEA guidelines (IAEA Safety Standards 2023), as well as for international experience in activities for improving the safety of the NPPs in operation (IAEA Safety Standards 2010).

Long-term operation of the ANPP's unit 2 in the course of its design and extended life has proved it to be highly reliable, and has confirmed the adequacy of the design safety principles selected. High structural margins adopted for the reactor facility and the results achieved in safety improvements are expected to form the basis for the decision to prepare for another unit life extension.

The general ANPP safety improvement program lays emphasis on environmental issues, including safe handling of radioactive waste (RW) and spent nuclear fuel (SNF) (Decree of the Government of the Republic of Armenia No.631 2019). Due to the complexity of the issues under consideration and high labor input and cost they entail, these issues are addressed involving a variety of national and international organizations, as well as specialized foreign institutes.

The key goals of a stable NPP life support system are to:

- introduce a single RW management system;
- increase the level of the population and environment safety against the radiation exposure risk;
- prevent emergencies with radiological consequences and mitigate such consequences if any;
- establish a national operator to provide services as currently required.

Waste management at the Armenian NPP

Operations involving radioisotopes were started in the Republic of Armenia in the 1950s and reached the peak level in the mid-1980s in nearly all sectors and fields of economy (health care, industry, science and education, agriculture, geology, etc.), leading thus to radioactive waste generation (Law of the Republic of Armenia No.285 1999).

Generation of radioactive waste caused by nuclear technologies dates back to the commencement of operations at the Armenian NPP units. To isolate radioactive municipal waste from the biosphere, a radioactive waste storage facility was built in the 1950s by resolution of the Yerevan City Council. However, after landslide phenomena were detected in the storage facility area, a decision was made to build a new near-surface storage facility at the ANPP site, which was put into operation in 1980.

Operation of the new facility suggested collection of solid and liquid waste formed, transportation of waste to the storage facility, its grouting up to a state acceptable for long-term storage, and placement of grouted waste in reinforced concrete casks (RB-122-16 2016).

Since the storage facility was operated with major design deviations (no waste grouting equipment and dedicated remotely controlled manipulators), the license issued in 2009 permitted the facility to be used only for storing low and intermediate level municipal radioactive waste.

Later on, the Armenian NPP unit in the process of decommissioning became a major source of RW generation. In 2017, in accordance with the resolution by the Government of the Republic of Armenia, criteria were defined for the safe RW and SNF handling (Decree of the Government of the Republic of Armenia No.203 2005).

Radioactive waste of different types (solid, liquid, gaseous) and different classes (in a range from very low to high level, Fig. 1 (Decree of the Government of the Russian Federation No.1069 2012) is generated in the course of the Armenian NPP operation. Waste is formed in the process of daily room cleaning and decontamination within the controlled access area (CAA), equipment decontamination and repair, CAA repair operations, etc. RW also includes non-decontaminationable or in-pile irradiated parts of process components, measuring tools, pipeline valves, overalls and personal protective equipment, etc., contaminated in excess of permissible levels.

The Armenian NPP design did not initially include areas for reprocessing solid radioactive waste (SRW) generated in the process of operation, and the RW formed has been stored to date without being treated in the on-

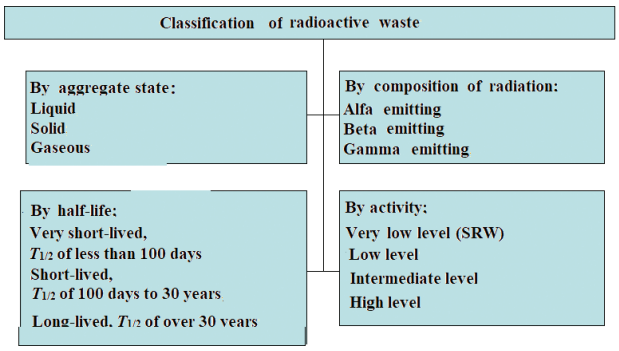

Figure 1. Classification of RW.

site storage facilities for low, intermediate and high level SRW to be stored throughout the ANPP design life.

Table 1 shows the classification of radioactive waste by its specific activity according to the Radiation Safety Rules approved by the Government of the Republic of Armenia in 2006 (Decree of the Government of the Republic of Armenia No.1489 2006). The radioactive waste management system comprises the RW collection, sorting, reprocessing, conditioning and storage stages (NP-002-15 2015).

Table 1. Radioactive waste classification by specific activity

Waste category	Specific activity, kBq/kg		
	Beta emitting nuclides	Alfa emitting nuclides (transuranic incl.)	Transuranic radionuclides
Very low level	below 10^2	below 10^1	below 1
Low level	10^2 to 10^3	10^1 to 10^2	1 to 10^1
Intermediate level	10^3 to 10^7	10^2 to 10^6	10^1 to 10^5
High level	over 10^7	over 10^6	over 10^5

Management of liquid radioactive waste

Radiation safety standards define liquid radioactive waste (LRW) as organic and inorganic liquids, slimes (slurries) and slags unfit for further use, the specific activity of radionuclides in which, if taken in with drinking water, is ten times as high as the respective intervention levels.

The following LRW handling flowchart is used at the ANPP (Fig. 2).

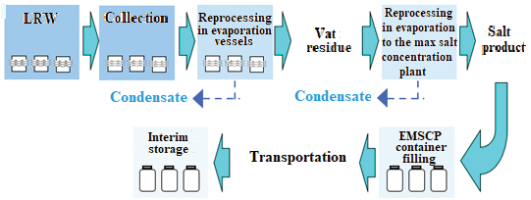

Figure 2. ANPP LRW handling diagram.

Drains formed in the course of the ANPP operation are reprocessed in evaporation vessels to be purified for further distillate use or discharge into the household sewage system. The vat residues formed in evaporation vessels as the result of the drains reprocessing are collected in the vat residue tanks (VRT) and reprocessed in the evaporation-to-the-maximum-salt concentration plant (EMSCP) (Figs 3, 4). The concentrated vat residue in the form of liquid "syrup" enters then the metal container and, being cooled, crystallizes into a solid monolithic fire-safe product placed in the intermediate level SRW storage facility in a dedicated casing (NP-019-15 2015).

LRW is stored in the liquid radioactive waste storage facility, which receives vat residues from the evaporation vessels and depleted ion-exchange resins from active water treatment systems 1, 2 and 4.

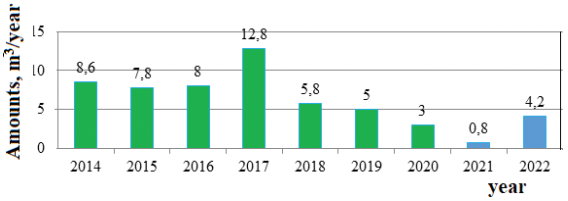

Figure 3. Formation of salt melt from EMSCPs (by years).

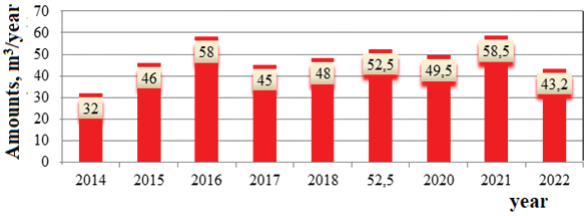

Figure 4. Formation of vat residues at the ANPP (by years).

The storage facility comprises

- six vat residue tanks;
- two high level sorbent tanks.

The storage facility capacity is 4140 m^3, including:

- vat residue tanks of 3300 m^3 (effective capacity 2820 m^3);
- high level sorbent tanks of 840 m^3 (effective capacity 700 m^3).

Radioactive waste is managed in accordance with the "Procedures for the Radioactive Waste Management" approved by a decree of the Government of the Republic of Armenia in 2009 and the requirements of regulatory legal acts that govern the field of activity in question (Decree of the Government of the Republic of Armenia No.1219 2006). In accordance with the Armenian NPP life extension program, it is planned to upgrade the plant for reprocessing liquid radioactive waste by evaporation to the maximum salt at the UGU-200 plant with a capacity of 200 kg of waste per hour, which requires the plant safety systems to be improved to minimize risks and prevent potential accidents, measures to be taken to reduce the environmental impact to result in much smaller final amounts of evaporator concentrate, and energy-saving technologies and processes to be introduced to cut the energy consumption. The RW Management Program developed at the ANPP will deal with the issues involved in reprocessing of liquid and solid RW to provide capabilities for its final disposal.

Management of solid radioactive waste

The ANPP operates an SRW handling system that provides for the SRW collection, sorting, transportation and safe storage in respective storage facilities (NP-020-15,

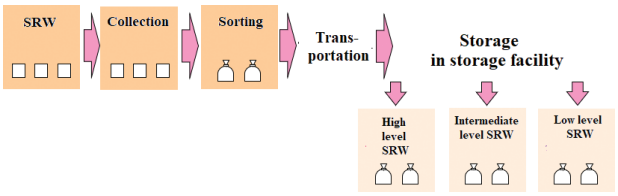

Figure 5. SRW handling flowchart.

2015) (Fig. 5). No solid radioactive waste is reprocessed at the ANPP.

The SRW storage facility with an effective capacity of 78.34 m^3 occupies a part of the instrumentation room. High level SRW includes:

- combustible waste (paper, rubber, flexible PVC, textiles, etc.) ≈ 5%;
- noncombustible waste (metal, spent sources, instruments, parts of process components) ≈ 95%.

The SRW storage facility with an effective capacity of 1001.2 m^3 is situated inside the special building. Intermediate level SRW includes:

- combustible waste (paper, rubber, flexible PVC, textiles, etc.) ≈ 20%;
- noncombustible waste (metal, metal chips, thermal insulation, building refuse, slit, activated resin, EMSCP containers) ≈ 80%.

The SRW storage with an effective capacity of 17051 m^3 is situated at the NPP site. Low level SRW includes:

- combustible waste (paper, rubber, flexible PVC, wood, footwear) ≈ 75%;
- noncombustible waste (metal, thermal insulation, building refuse) ≈ 25%.

Table 2 shows the RW storage filling levels, and Figs 6, 7 show the dynamics of the solid RW formation at the Armenian NPP.

Considering the amounts of radioactive waste formed in the process of the Armenian NPP operation, there is an objective need for building a low and intermediate level RW disposal facility.

To manage solid RW in an effective manner and reduce the SRW amounts formed, it is necessary to introduce sorting systems (depending on the waste composition: combustible and compressible waste) and minimize the waste amount (waste incineration, compaction and fragmentation).

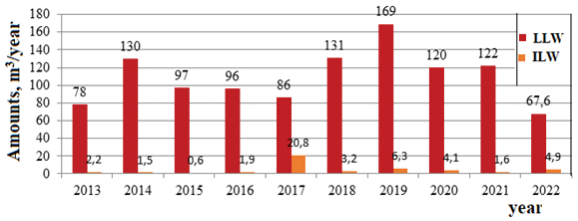

Figure 6. Solid RW formation at the Armenian NPP.

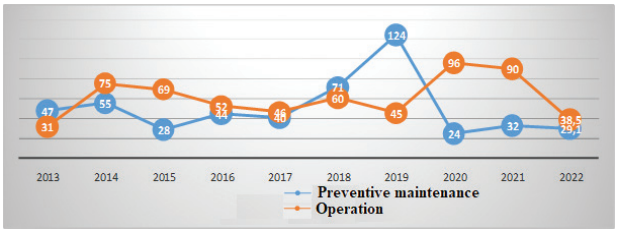

Figure 7. Solid RW formation at the ANPP in the operation and preventive maintenance periods, m^3/year.

As part of the activities to extend the life of the Armenian NPP's unit 2, the "Program for Managing the RW Existing at the ANPP and Formed in the Course of the ANPP Unit 2 Extended Life" (the Program hereinafter) was developed. The Program presents more than 50 measures and the schedule for their implementation for the RW management, including the following:

- development and implementation of the RW accounting and control system;
- upgrading of the liquid radioactive waste processing system;
- modification of the vat residue evaporation-to-the-maximum-salt concentration plant;
- purchasing the required number of licensed metal containers for accommodation of the EMSCP salt melt;
- mechanical reprocessing of crystalline precipitates in the vat residue tanks (VRTs 1 through 6), and in the high level sorbent tank (HLST 1), which includes waste filtration, centrifugation, sedimentation, washing and drying;
- upgrading of the solid radioactive waste reprocessing system, which includes the introduction of innovative treatment methods for improving the efficiency of the solid radioactive waste reprocess-

Table 2. RW storage filling levels

No.	RW category	Storage (warehousing) point	Storage filling level, m^3	Storage capacity, m^3
1	Solid low level waste	Solid low level waste storage facility	7104.8	71051.0
2	Solid intermediate level waste	Solid intermediate level storage facility	490.86 (including 380.06 m^3/1756 EMSCP salt melt/containers/)	1001.32
		EMSCP container interim storage area	435.16 (1978 EMSCP containers)	Not more than 3000 containers
3	Solid high level waste	Solid high level waste storage facility	37.64	78.34
4	Liquid intermediate level waste (evaporation vessel vat residues)	VRTs 1–6, HLST 1	2416.6	3170
5	Liquid intermediate level waste (slit, pulp)	HLST 2	267.0	350

ing system, development of precision methods for optimizing separation of radioactive and nonradioactive components so that to reduce the amount of waste, introduction of technologies for safe storage and transportation of waste using improved containers and monitoring systems, development of methods for reducing the amount of solid radioactive waste, including processes for recycling and reuse of materials;
- modification of the RW characterization and certification system;
- design, construction and commissioning of the integrated SRW reprocessing facility;
- development of a method to reprocess the EM-SCP salt melt and spent ion-exchange resins from HLST 2;
- providing facilities for storage of conditioned RW;
- modification of the solid low level waste storage facility (compartments 1 and 2);
- purchasing the required number and range of LLW storage casks;
- construction of a new storage facility for storage of conditioned RW;
- purchasing the required number and range of licensed non-retrievable shielded casks (NRSC).

Implementing the measures presented in the Program will ensure safe handling of LLW and ILW accumulated at the ANPP and formed during the extended life of the Armenian NPP's unit 2.

The ANPP's RW management system, which represents a set of organizational, technological and engineering measures aims at effective management of radioactive materials and includes the following key stages: collection, classification, processing, conditioning. It involves the use of modern technologies, taking into account the specific nature of each waste type and stringent compliance with regulatory requirements for ensuring human and environmental safety. The system will make it possible to handle VLLW, LLW and ILW, as well as LRW generated in the process of the ANPP decommissioning.

The final goal of the Program is to make the ANPP's RW management system compliant with the requirements of the Republic of Armenia's nuclear regulations and standards, and the requirements of the IAEA safety standards (Vedernikova et al. 2019).

Solution ways

Management of radioactive waste is a complex and essential problem requiring a scientific and technological approach for minimize risks and ensuring human and environmental safety. Presented below is an analysis of the technological aspects involved in radioactive waste management, which considered the key engineering and scientific methods aimed at safe and effective management of materials containing radioactive elements:

- studies to determine suitable geological formations for the long-term RW disposal taking into account geochemical, hydrogeological and engineering aspects;
- development of materials capable of preventing the migration of radioactive substances and providing for their isolation from the environment;
- studies into the development of effective chemical treatment methods for extraction of valuable elements from spent fuel elements;
- use of mathematical models to predict the distribution of radioactive substances in the environment and estimate risks for humans and ecosystems;
- development of precision technologies for detecting radioactive substances to ensure safety and early response to potential leakage;
- development of manufacturing processes to reduce radioactive waste generation and improve the efficiency of using nuclear resources;
- development of innovative transportation methods leading to the smallest possible risks for personnel and the environment;
- development of efficient legal and regulatory mechanisms for control and management of radioactive waste.

The establishment of a national operator for performing the function of radioactive waste management will make it possible to implement the RW and SNF management system in accordance with the management structure adopted in most countries across the world with nuclear technologies.

Ensuring safe management of RW requires:

- reduction in the amount of RW and their safe and reliable storage throughout the Armenian NPP life;
- construction of VLLW storage facilities;
- construction and operation of near-surface RW burial grounds.
- Implementing the above strategy will contribute to:
- upgrading the RW management system;
- reducing generation of different RW types and activity caused by the Armenian NPP operation;
- reducing the cost of the RW management system operation;
- operating and decommissioning the Armenian NPP in a safe and reliable manner with the introduction of a low and intermediate level RW storage/disposal system;
- reducing the harmful effects of ionizing radiation on the Armenian NPP personnel and reducing the harmful effects of radiation on the environment;
- providing prerequisites for the construction of a burial ground for high level radioactive waste to facilitate as well the Armenian NPP decommissioning;
- reducing the financial burden involved in the need for keeping safe the RW management system facilities for future generations;
- improving, perfecting and expanding the SNF safe management system in the Republic of Armenia.

Conclusions

The paper considers the peculiarities of liquid and solid radioactive waste handling at the Armenian NPP's unit 2. Issues of handling the RW generated in the process of operating the ANPP's unit 2 in the course of the unit design and extended life are discussed, and measures are proposed for addressing the issues under consideration, including upgrading of the LRW reprocessing plant, which requires the LRW treatment process to be improved and involves improvement of the plant safety system for reducing risks and preventing potential accidents, as well as introduction of measures to reduce the adverse environmental impact, and development of a document that analyzes issues involved in treatment of both LRW and SRW to enable final waste disposal. Effective management of SRW and reduction of the waste amounts formed requires that waste amount minimization systems are introduced. To make it easier to manage different types of waste and unify waste management methods, it is necessary to classify radioactive waste in accordance with its physical, chemical, radiological and biological properties. The country needs to develop its own national classification of radioactive waste in accordance with the objectives defined in this field for introducing, in a harmonized manner, a unified national radioactive waste management policy and implementing successfully the selected strategy.

If implemented, the proposed solutions will contribute greatly to the introduction of a stable RW management system in the Republic of Armenia, and will make it possible to shape a new culture of radioactive waste management while placing emphasis on environmental protection, effective use of resources, providing high-quality services to business entities, and ensuring safe environmental conditions.

The ultimate goal is to make the ANPP's RW management system maximally compliant with the current nuclear regulatory requirements in effect in the Republic of Armenia and the requirements of the IAEA safety standards.

To this end, a package of activities has been under way to update the issues at hand for analyzing the existing non-conformities.

The principles and technologies discussed aim to ensure effective and safe radioactive waste management at nuclear plants while minimizing the environmental impact and ensuring compliance with safety standards.

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