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P01

Integrated Modeling Approach for Wasteform Degradation in Disposal Environments: Utilizing Phreeqc and GOLDSIM Software

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This research abstract proposes an exploration of the utilization of Phreeqc and GOLDSIM software for wasteform degradation modeling in a disposal environment. The objective of this study is to develop a comprehensive understanding of the long-term behavior and performance of wasteforms, specifically focusing on their degradation processes and potential impacts in a disposal setting.

The research methodology involves the integration of experimental data, theoretical modeling, and the combined use of Phreeqc and GOLDSIM software. Experimental data will be collected through laboratory analysis and characterization of wasteforms and disposal environment, including their chemical composition, physical properties, and degradation kinetics. These data will serve as input parameters for the modeling process.

Phreeqc, a geochemical modeling software, can be utilized to simulate the complex chemical reactions occurring within the wasteforms and the surrounding disposal environment. It will help to evaluate the dissolution, precipitation, and geochemical interactions of the wasteform components over time. The outputs from Phreeqc will be further integrated into GOLDSIM, a dynamic simulation software, to model the overall degradation behavior and predict the release of radionuclide from the wasteforms into the surrounding medium.

The outcomes of this research will contribute to a better understanding of wasteform degradation in disposal environments and its potential environmental impacts. By combining Phreeqc and GOLDSIM, the study aims to simulate the degradation processes, assess the long-term behavior of wasteforms, estimate the source term, and subsequently transport of radionuclide along environmental media pathways.

Furthermore, the research will provide insights into the optimization of waste management strategies by evaluating the performance of disposal facilities, including engineered barriers and monitoring systems. The modeling results obtained through Phreeqc and GOLDSIM will inform decision-making processes related to engineering design, long-term safety assessments, and regulatory compliance of disposal facility.

In conclusion, this research abstract proposes the utilization of Phreeqc and GOLDSIM software for wasteform degradation modeling in a disposal environment as part of the ICTP Workshop. The research aims to develop a comprehensive understanding of wasteform behavior, contribute to waste management strategies, and ensures the long-term safety and environmental sustainability of disposal facilities.

P02

Abstract

Activity Title: Management of ageing waste packages

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The management of ageing waste packages is a crucial aspect of ensuring the long-term safety and environmental impact of radioactive and nuclear waste repositories. This paper delves into the principles governing the ageing management of waste packages, focusing on degradation processes, waste form testing, durability determinations, and technical support for safety cases. The establishment of a conceptual degradation (durability) model is discussed, along with the requisite hydrologic and geochemical information necessary for accurate waste form degradation modelling and comprehensive assessment of potential environmental impacts.

A key aspect of this work revolves around the development of a conceptual degradation model. This model serves as a foundational framework, integrating various factors such as material properties, environmental conditions, and degradation mechanisms to project the long-term evolution of waste packages. Hydrologic and geochemical information play a pivotal role in refining this model, facilitating accurate simulations of waste form degradation under diverse environmental scenarios. The utilization of these data sets enables comprehensive assessments of potential impacts on the surrounding environment.

Model application and objectives form a critical juncture in the study, showcasing how the degradation model is employed to inform repository design, safety assessment, and regulatory compliance. By aligning model objectives with specific performance criteria, regulatory requirements, and safety standards, stakeholders can make informed decisions regarding waste package design, storage, and disposal strategies.

Incorporating case study examples from North Macedonia lends practical insight into the principles discussed. These case studies highlight real-world scenarios and challenges faced in waste package management, degradation modelling, and safety assessment within the context of North Macedonia. These examples illustrate the successful application of degradation models to predict long-term waste package behaviour, enabling informed decision-making and risk mitigation strategies.

In conclusion, the principles of ageing management of waste packages and degradation modelling are vital for ensuring the long-term safety and environmental impact of nuclear waste repositories. This work, including the North Macedonian case study, is instrumental in shaping effective strategies for the management of ageing waste packages and the safeguarding of both human health and the environment.

[1] Atanasovska Biljana, (2023)

P03

Analysis of Fuel Cycle Parameters and Depletion Characteristics in the NIRR-1 Reactor using R-Z Diffusion Theory Model

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This study presents a two-dimensional, multi-region R-Z diffusion theory model of the NIRR-1 system, aimed at analyzing fuel cycle parameters and understanding the fuel depletion characteristics of the NIRR-1 core. Reactivity rundown calculations were performed using a fast-running REBUS-ANL R-Z model to capture temporal variations during fuel depletion. The results revealed important parameters such as core excess reactivity, xenon worth, fuel depletion rate, and fuel cycle length. Reactivity rundown results for both highly enriched uranium (HEU) and low enriched uranium (LEU) cores were obtained and analyzed. In the case of the HEU core, xenon buildup was observed as fuel depletion progressed, reaching equilibrium concentration after approximately 3 days of continuous reactor operation. The reactivity worth of xenon equilibrium was estimated, and the reactivity loss per day due to fuel depletion was determined. Using these reactivity change rates, the number of hours the reactor could operate for different operational schemes was estimated. For example, an NIRR-1 HEU core operated at 15.5 kW for 6 hours per day, 3 days per week, and 48 weeks per year could be operated for approximately 2.49 years. The addition of top Be shim plates was required to restore the core excess reactivity and begin the next operational cycle. Similar calculations were performed for the LEU core, and the equilibrium xenon worth and reactivity change rates for fuel depletion were determined. The operational cycle length for an NIRR-1 LEU core operated at 17 kW for 6 hours per day, 3 days per week, and 48 weeks per year was estimated to be approximately 3.13 years. The addition of top Be shim plates was necessary to define the LEU fuel cycle. The study also provides an overview of the NIRR-1 reactor, highlighting its tank-in-pool design, use of 13% UO2-LEU fuel, light water as moderator and coolant, and metallic beryllium as reflector. The core consists of a cylindrical fuel assembly containing approximately 348 fuel elements, and a central control rod made of cadmium performs control and safety functions. The collective behavior of neutrons in the reactor core is described by the neutron transport equation, also known as the Boltzmann equation, which represents the balance between neutron gain and loss. The equation considers factors such as the neutron source, macroscopic total cross section, and angular neutron flux. Overall, this study provides valuable insights into the fuel cycle parameters and characteristics of the NIRR-1 core, facilitating better understanding and optimization of reactor operations.

Keywords: NIRR-1 reactor, fuel cycle parameters, fuel depletion, reactivity rundown, equilibrium xenon worth, R-Z diffusion theory model, highly enriched uranium (HEU) core, low enriched uranium (LEU) core, operational cycle length, neutron transport equation.

P04

PROGRESS ON THE ESTABLISHMENT OF THE CENTRALISED INTERIM STORAGE FACILITY IN RESPONSE TO SPENT FUEL MANAGEMNT SUSTAINABILITY IN SOUTH AFRICA.

Establishment of an above ground Centralised Interim Storage Facility.

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Abstract

South Africa's Spent Nuclear Fuel (SNF) is generated from Eskom's only two 1 840 MWe nuclear power reactors at the Koeberg Nuclear Power Plant (NPP) and from Necsa's only one research reactor (SAFARI-1) at the Pelindaba nuclear research site. The establishment of the Centralised Interim Storage Facility (CISF) follows recent reports from the power utility Eskom who runs the NPP at Koeberg that there is limited space for storing SNF on site. Moreover, the lifetime of the NPP has been extended to 2045 which implies that with time, constraints on storage at reactor site will be increased. However, the long-term storage will be established for all the nuclear reactors in the country.

The South African Radioactive Waste Management Policy and Strategy of 2005 recommends that South Africa must adopt the strategy of storing SNF away from the reactor in an above ground dry CISF, followed by a final disposal in a Deep Geological Repository (DGR). The CISF is envisaged to be built off site at the Vaalputs only Radioactive Waste Disposal facility. The facility will be sustained into time with continuous monitoring of radiation in lieu of the DGR for ultimate disposal. Management of SNF still pose a great challenge with many member states not yet having facilities for the final disposal of SNF and associated High Level Waste (HLW), mainly due to the economics associated with developing such required facilities. The project is still at a developmental phase with the feasibility study undergoing a review. It has been established that the project is lacking funds and human resources. The paper outlines the current progress, challenges, and plans for the establishment of the CISF in South Africa.

P05

MANAGEMENT OF RADIOACTIVE WASTE IN ALBANIA

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ABSTRACT

In Albania, radioactive sources are used in medicine, industry, agriculture, research and teaching process. In 1999, a new radioactive waste storage facility for the management of radioactive waste was built in the territory of the Institute of Applied Nuclear Physics (IANP) in Tirana. In this storage facility are accepted for processing and temporary storage radioactive waste and sources of non-nuclear origin in accordance with the national / international radioactive waste acceptance criteria. Albania has a legal and regulatory framework according to international standards in the field of radioactive waste management (Law no. 8025, dated 9.11.1995 "On protection from ionizing radiation" amended with no. 9973, dated July 28, 2008. The Radiation Protection Commission (RPC) is the Regulatory Body that defines the policies related to the treatment of radioactive waste and sources in Albania. The Radiation Protection Office (RPO) has been established as the executive body of the RPC. RPO has established a national inventory of radioactive waste and sources. IANP is the institution responsible for the processing and management of all radioactive waste and disused sources, produced in Albania. IANP is licensed by the RPC for these activities: import - export, transportation, treatment, conditioning and temporary storage of radioactive sources and wastes. IANP has in use and temporary storage radioactive sources of category I-V and performs transport of radioactive materials in accordance with the new regulation on transport in Albania, No.815, dated 16.11.2016 "On the safe transport of radioactive materials". Treatment of radioactive waste and sources is carried out in accordance with Decision no. 638, dated 7 September 2016, of the Council of Ministers "On the adoption of the regulation on the safe handling of radioactive waste in the Republic of Albania". The security assessment of the storage facility for temporary storage and management of radioactive waste is made taking into account its impact on employees, the public and the environment and in accordance with the Decision of the Council of Ministers no. 877, dated 30.10.2015, on the adoption of the regulation "On security of radioactive sources in the Republic of Albania". The storage capacity of this facility will be sufficient for Albania's needs over the projected 30-year operating period.
According to Decision No.435 dated 14.10.2015 "On approval of the document of strategic steps for the safe management of radioactive waste in the Republic of Albania", a study will be undertaken to determine the location and construction of a radioactive waste disposal facility in our country.

Keywords: Radioactive waste; radioactive sources; treatment; conditioning; temporary storage.

P06

Radiation protection proprieties study of a new mixtures based on concrete by using experimental results, Monte Carlo Simulation MCNPX and DOSIMEX

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Radioactive sources are widely used in many fields such as agriculture, industry, research, medical, sciences, and nuclear power plants... etc. to ensure radiation protection of workers, environment and public against ionizing radiations, researchers are continually seeking to enhance and develop new materials with high proprieties in term of efficiency of radiation protection point of view and also to respond to socioeconomic, physical and mechanical factors.
In this study we are going to simulate some mixtures by Monte Carlo Transport Particle (MCNP). And then irradiate the elaborate samples with radioactive sources such as Co-60 and Cs-137 in order to validate our theoretical calculation.
This new development of concrete mixture will be used as radiation shielding on activities involving radioactive isotopes of gamma and X ray like as Prompt Gamma Activation Analyses PGAA, Also during manipulation of radiation sources of calibration or in the walls of laboratories. It can be used also at the immobilization and containment of radioactive waste.
In this study, first we will compare the characteristics of photon attenuation by Barite extracted from five ore sites such as Zagora, Agdz. Tijjekht, Ras Kammouna, Tinejdad at Drâa-Tafilalet region of Morocco.

[1] M. Essalhi, D. Mrani, A. Essalhi1, A. Toummite1, H. Ali-AmmarB Evidence of a high quality barite in Drâa-Tafilalet region, Moro co:
a nonupgraded potential 2018

[2] Sara Naamane ⇑ , Zakia Rais, Mustapha Taleb The effectiveness of the incineration of sewage sludge on the evolution of physicochemi-
cal and mechanical properties of Portland cement, 2016

P07

Radioactive Waste Management for Various Types of Nuclear Power Plants in Europe

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Given the escalating global population, there is a projected increase in global energy consumption. In light of this, there is a pressing need to develop a comprehensive strategy that anticipates the potential adverse environmental repercussions linked to heightened energy usage. These repercussions are exemplified by the emission of greenhouse gases (GHGs). Consequently, there has been a notable upsurge in the demand for energy sources that are sustainable, renewable, and environmentally friendly [1].

Within this context, nuclear energy emerges as a potentially pivotal component of the energy landscape. Its capacity to produce substantial amounts of consistent and dispatchable electricity and heat, without direct carbon dioxide (CO_2) emissions, positions it as an established technology with relevance for the energy system. However, the adoption of nuclear power remains a contentious and debated subject. Various types of nuclear power plants and diverse techniques for managing radioactive waste wield differing impacts on the energy system. Key factors influencing this landscape include safety, cost, flexibility, and geographical location.

This research initiative is aimed at elucidating the role of diverse nuclear power plant types and radioactive waste management techniques in shaping the future of the energy system in Europe and particularly Netherlands. To address this inquiry, an exhaustive collection of pertinent information and data related to distinct types and designs of Nuclear Power Plants (NPPs) and radioactive waste management techniques is required. Subsequently, using the IESA-Opt model, the analysis delves into the data to determine optimal NPP selections for different regions, timeframes, and consumer contexts. Furthermore, the research endeavors to identify the radioactive waste management technique that aligns most suitably with considerations of cost, location, safety, and environmental impact.

In essence, this research strives to provide valuable insights into the intricate interplay between various nuclear energy facets and their role in shaping the forthcoming energy landscape. Through systematic analysis and informed decision-making, it aims to contribute to the formulation of a sustainable and efficient energy framework.

[1] A. Fattahi, J. Sijm, A. Faaij, J. Renewable and sustainable Energy Reviews. **1**, (2021).

P08

The evolution of radioactive waste management in Italy

Joint ICTP-IAEA Workshop on Degradation Modelling of Disposed Radioactive Wasteforms 18 - 22 September 2023

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Radioactive waste management is a critical aspect for ensuring the safe disposal and containment of radioactive materials generated mainly from past power applications and plant decommissioning but also from various industrial, medical, and research activities. In Italy, the former are under the responsibility of SOGIN, while ENEA is in charge for the management of the latter. In this context, the evolution of waste acceptance criteria (WACs) has been progressed adapting to scientific advancements, regulatory changes, and societal concerns. This work examines the development of waste acceptance criteria in Italy and highlights key milestones in the country approach to radioactive waste management. Nuclear power in Italy has been characterized by recurrent stop-and-go operations throughout the last 65 years [1]. Almost all the radioactive waste (RW) produced by nuclear plants, the last active until the nineties, is kept in the locations of origin or sent abroad for reprocessing and conditioning. Furthermore, non-electro-nuclear RW spread all over Italy generated by medical, R&D activities, and industrial purposes are managed by ENEA that supervises the Integrated Service (IS) for the management of RW generated from no power applications which include low- and medium-level medical radioactive sources and waste as well as high-activity sealed radioactive sources. The IS is by law responsible for radioactive waste collection, transport, characterization, storage, treatment, and conditioning. In January 2023 Isin, the Italian national inspectorate for Nuclear Safety and Radiation Protection, has published the final version of the technical guide 33 (TG 33) [2] for the radioactive waste management in Italy. The evolution over the time of requirements established for the acceptance of conditioned waste for the national repository [2], the site criteria [3], and the localization of the potentially suitable areas in the Italian territory are the landmark of the Italian approach to the management of RW before the actual construction of the national repository. Compared to the past, when the first technical guide (TG26) was emitted, the RW categories now are five. Differently the previous TG26 counted only three categories. Even the requirements and the standards of wasteforms for each category has been updated. New WACs has been also established, e.g., the depth of penetration of water under pressure test (UNI EN 12390-8:2019) once not expected in TG26 now is contemplated in TG33 for heterogenous LLW and for ILW.

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[2] Guida Tecnica ISIN N.33, “Criteri di sicurezza nucleare e radioprotezione per la gestione dei rifiuti radioattivi”. Gennaio 2023

[3] Guida Tecnica n. 29 ISPRA, “Criteri per la localizzazione di un impianto di smaltimento di rifiuti radioattivi di bassa e media attività” 2014

P09

Thermal spike effects in swift heavy ion irradiated zirconolite

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Zirconolite considered as a potential candidate for the immobilization of high level radioactive wastes, has been studied with swift heavy ions (120 MeV Au^{9+}) to account its behaviour in electronic regime [1]. *In-situ* X-ray diffraction (XRD), offline SEM and TEM microscopy have been employed to analyze the structural damages so produced by irradiation in single phase prepared samples of monoclinic zirconolite structure (2M-type) [2]. Step-wise structural modifications in the form of loss of crystallinity, broadening of diffraction peaks along with appearance and enhancement of broad amorphous hump have been observed in irradiated XRD patterns. The trend of fluence dependent amorphous fraction infers the formation of ion tracks due to thermally induced spikes in the lattice along the ion trajectory. Further, the track diameter determined from thermal spike model calculations is ~7 nm, which is found to be similar as observed from XRD, SEM and TEM analysis. Irradiation induces strains and defects/vacancies along with swelling of the crystal lattice. Besides, complete amorphization is not achieved even on irradiation at the highest fluence of 1×10^{14} ions/cm^2. Moreover, nano-grain formation has been observed at such a high fluence.

[1] M. Gupta, P.K. Kulriya, R.C. Meena, S. Neumeier, S.S. Ghumman, Nucl. Instr. Meth. B 453 (2019) 22-27.
[2] M. Gupta, P.K. Kulriya, R. Shukla, R.S. Dhaka, R. Kumar, S.S. Ghumman, Nucl. Istr. Meth. B 379 (2016) 119–125.

P10

Study of a Monte Carlo method for calculating the activity concentration of radioactive wastes

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In the classification and disposal of radioactive waste, determining the level of radioactivity in waste is a crucial step. Typically, this is addressed through on-site sampling and laboratory analysis. The advantages include comprehensive analysis, broad coverage of measurable parameters, and accurate sample analysis results. However, the disadvantages include time-consuming and labor-intensive sampling and challenges in ensuring representative samples. To enhance efficiency and cost-effectiveness in waste sorting, Monte Carlo simulation can be employed when waste morphology is known, media composition and contaminant nuclides are readily identifiable, and medium density and nuclide distribution are relatively uniform. By calculating the air absorption dose rate of the waste body using the Monte Carlo method and integrating it with on-site measured dose rate levels, it is possible to swiftly estimate the radioactive activity concentration of nuclides within the waste body.

P11

Modeling of shields for radioactive waste

MA Nazari Jahromi

Clays are known as one of the main materials for the constructing waste landfills. The reason for using clays is its unique properties like availability, low cost, self-healing, and low hydraulic permeability. We have used MCNP software to investigate the effects of different additives to radiation shielding of the landfills.

Hard minerals, containing iron, and lead were simulated in different concentrations inside the clay. The attenuation coefficient for the materials were obtained, and compared with the results of XCOM.

The results show that there are close agreements between the attenuation coefficient values of XCOM, and MCNP simulations.

P12

Title: Integrating Artificial Intelligence in Degradation Modelling of Disposed Radioactive Wasteforms

Abstract: The disposal of radioactive waste is a significant environmental and health concern, and accurate modelling of waste degradation is essential to ensure safe disposal. Traditional methods for modelling degradation rely on empirical data and manual input, which can be time-consuming and prone to errors. In recent years, the integration of artificial intelligence (AI) techniques in degradation modelling has shown promising results.

This poster explores the potential of AI in degradation modelling of disposed radioactive wasteforms. Specifically, the use of machine learning algorithms and deep learning neural networks to predict degradation rates and estimate the remaining lifespan of wasteforms will be discussed. Additionally, the use of data mining techniques to identify patterns and correlations between degradation factors will be highlighted.

The benefits of integrating AI in degradation modelling of disposed radioactive wasteforms include increased accuracy, efficiency, and reduced costs. This approach can also lead to the discovery of previously unknown relationships between degradation factors and inform future waste disposal strategies.

References:

1. Y. Zhang, J. Yang, and Z. Liu, “A review of artificial intelligence in radioactive waste management,” J. Environ. Radioact., vol. 192, pp. 23–29, 2018.
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3. S. Khodayarifard and S. Zakeri, “Application of artificial neural networks in prediction of leaching behavior of radioactive wasteforms,” Environ. Monit. Assess., vol. 186, no. 9, pp. 5621–5631, 2014.

Radioactive Waste Management at the Armenian NPP

Lead Engineer of Ageing Management Group of the Armenian NPP, Yervand Stepanyan

National Legislative Bases in the field of Radioactive Waste Management:

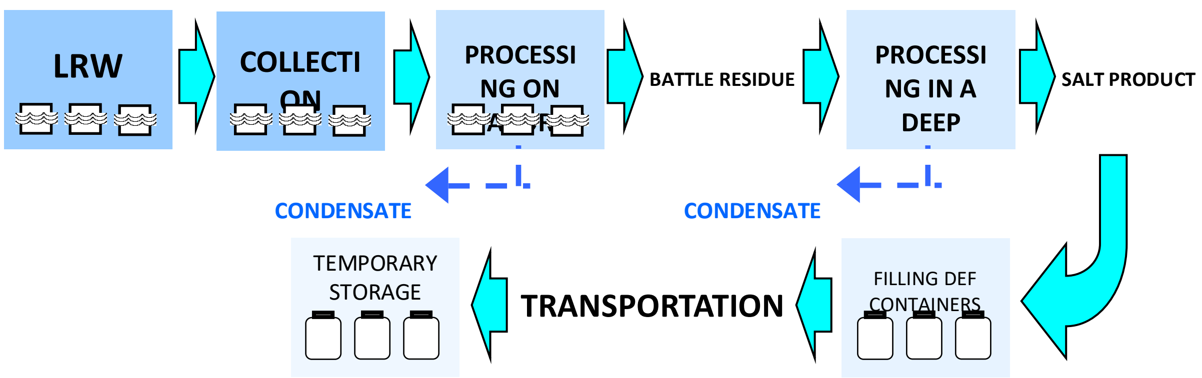
- Law of the Republic of Armenia "On the Safe Use of Atomic Energy for Peaceful Purposes". ՀՕ-285 01.02.1999
- Law of the Republic of Armenia "On Licensing". ՀՕ-193 08.08.2001
- "Radiation Safety Standards". Decree of the Government of the Republic of Armenia 1219-Ն 18.08.2006
- "Order of Radioactive Waste Management". Decree of the Government of the Republic of Armenia 631-Ն 04.06.2009
- "Radiation Safety Rules". Decree of the Government of the Republic of Armenia 1489-Ն 18.08.2006.

Relevant Regulatory and Operational Documents which includes:

- Regulatory documents, national norms and standards;
- Quality Assurance Programme and Administrative Management Programme for RW Management at the ANPP;
- Guidelines, procedures and programmes for RW management at the ANPP.

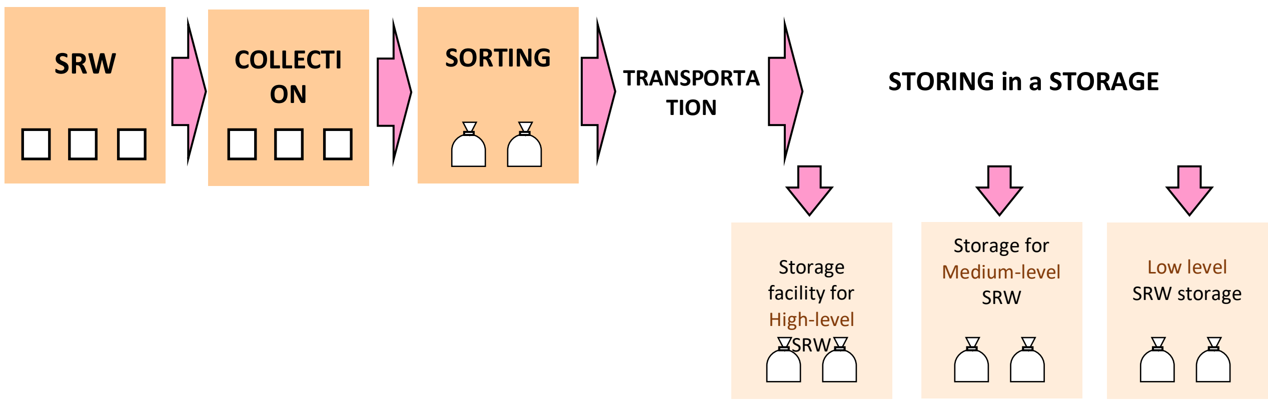
These documents define procedures for RW management, people in charge, RW transportation routes, their accountancy, and methods for monitoring the condition of storage facilities.

Radioactive waste at the Armenian NPP is generated during daily cleaning and decontamination of the premises of the Controlled Access Area (CAA), during equipment decontamination and repair, during maintenance activities in the CAA, etc.
The RW also includes parts of process equipment that cannot be decontaminated or irradiated in the reactor, instrumentation, pipeline or protection fittings, overalls and personal protective equipment contaminated above acceptable standards, ventilation system filters, spent sources of ionizing radiation, appliances, water from special laundry rooms, sanitary locks, sanitary inspections, etc.
Liquid Radioactive Waste handling by following scheme:



Liquid radioactive waste is processed on water purification system evaporators. To reduce the volume of LRW at the deep evaporation facility (DEF), the distillation residue is processed to a salt concentrate, which is poured into metal barrels in a hot molten state, turning into a monolith after cooling.
DEF containers are located in a reactor auxiliary building, in a solid intermediate level waste storage facility and at a site for temporary storage of DEF containers on the roof of the reactor auxiliary building.

Solid Radioactive Waste handling by following scheme:



As part of the activities to extend the life of the power unit 2 at the Armenian NPP, a "Programme of measures for management of radioactive waste present at the ANPP and generated during the additional life of the power unit 2 of the Armenian NPP" was developed.
The programme presents more than 50 measures for the management of radioactive waste available at the ANPP and generated during the additional life of the ANPP power unit 2 and a schedule for their implementation.
The term for the implementation of activities is planned to finish until 2026.

Significant activities that are planned in the framework of LTO

1. Construction of a hangar-type storage facility for low-level radwaste and medium-level radwaste storage in non-retrievable shielded canisters:
- Siting;
- Designing;
- Equipment and material procurement;
- Construction and commissioning.
2. Supply of non-retrievable canisters.
3. Replacement of deep evaporation facility (DEF):
- Equipment and materials procurement;
- Designing;
- Implementation of construction and installation activities, commissioning activities and required tests.
4. Procurement of 1000 pieces of metal canisters to contain salt cakes generated during processing at DEF.

P14

Volatilization and Precipitation of Troublesome Elements during HLLW Vitrification

Kai Xu, **Chenchen Niu, Wenfeng Song, Ziqiang Jia, Liyan Xu**

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Vitrification has been considered the primary option for immobilization of the high-level radioactive liquid waste (HLLW), because of the relative simplicity of the process, the structural flexibility, and the good long-term durability of glass. However, the high temperature (~1150 °C) of glass melting would induce the loss of volatile species including radionuclides (such as Tc) and non-radioactive elements (such as Na and B) [1,2]. The loss of radionuclides would bring about the environmental issues, while the loss of Na and B would cause fluctuations in composition and consequently affects the properties of the glass products. On the other hand, since the high density and the low solubility of platinum group metals (PGM, including Ru, Rh and Pd) in the glass, PGM could easily precipitate in the bottom of the glass melter that would cause serious operation accidents during vitrification of HLLW [3]. In order provide the fundamental basis for the safe and efficient operation of the HLLW melter, this work will present our recent studies on the volatilization behaviors of Re (surrogated for Tc) and non-radioactive elements including Na and B during HLLW vitrification, as well as the precipitation behaviors of PGM in the simulated glasses.

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