Customizing Radioactive Liquid Waste Treatment – case studies from laboratory to large scale systems - 25398

Martin Lerche[1], Anna-Elina Pasi[1], Antti Ketolainen[1]
[1]Nuclear Services, Fortum Power and Heat Oy, Finland

ABSTRACT

Various types of radioactive wastewater are produced during operation, dismantling and decontamination of a nuclear powerplant that challenge the capability and performance of the existing liquid waste treatment facilities. Regardless the waste type, the aim of radioactive liquid waste treatment is to reach maximum volume reduction, safely and cost efficiently. However, due to differences in the nuclear power plant design, waste management strategy and local regulations, there is no universal liquid waste treatment option available for all plants to use. Fortum's NURES® technology aims to tackle the challenge of varying parameters by using the core of its technology, the inorganic ion exchange materials, and customizing the treatment system case-by-case. The experience Fortum has gathered about liquid waste treatment optimization both as an operator and as service provider, has enabled to evolve the NURES® technology to a customizable radioactive liquid waste treatment solution.

When choosing the right technology for radioactive liquid waste treatment, the continuous improvement process (CIP), the best available technology (BAT) principles should be considered for optimal solution. In addition, the decreasing clearance levels for both radionuclides and harmful elements (e.g. boron), uncertainties in the electricity prices and local regulations for final waste disposal challenge the existing technologies and encourage alternative options for liquid waste treatment. Therefore, the NURES® radioactive liquid waste treatment technology has been evolved to be a versatile and scalable option applicable for various liquid waste treatment needs.

Combining decades of material science research with high quality engineering and experiences as a nuclear power plant operator has resulted in the development of the NURES® technology that goes beyond the ion exchange materials. As an example of adjustability of the solution, we present the recent cases where the NURES® solution has been successfully applied; a laboratory scale treatment system delivery with a treatment capacity of 40 L/h and a full-size, high capacity treatment option for a plant in operation or under decommissioning. The case studies demonstrate the versatility of the NURES® system, and the wide applicability of the materials for purification of contaminated solutions. Furthermore, we present the developments in our boron removal technology, BORES® which can be used to further decrease the volume of final radioactive waste. The aim is to present the improvements in the NURES® technology and the lessons learned from various industrial projects over the years that has led to a technology that can be modified and customized to fit the end users' needs.

INTRODUCTION

Importance of waste management optimization

As the nuclear renaissance is taking global dimensions, it is crucial to understand the importance of planning the entire life cycle of a nuclear power plant. One of the main drivers towards a successful nuclear renaissance is to ensure safe and efficient waste management which is often closely related to the social acceptance of nuclear energy [1]. The social acceptability of spent fuel and radioactive waste management is based on trust. Trust in the operator requires that the implementation of spent fuel and radioactive waste management is based on existing scientific knowledge, technical development and high-level expertise which is maintained by always striving for the most optimal solution. In Finland, the social acceptance reports show that in 2023, 68 % of the Finnish population was in support of nuclear energy whereas only 6 % were against [2]. These acceptance rates were at record high since the start of the continuous measurements in 1983. The year after, Olkiluoto 3, the fifth nuclear reactor in Finland started its operation [3] and Posiva Oy, the company responsible for the final disposal of spent nuclear fuel in Finland, started its preparations for demonstration of the encapsulation process executed successfully in 2024 [4]. These successes would not be possible without the high social acceptance maintaining the momentum but also the high competence of the nuclear experts developing efficient solutions.

The high social acceptance has allowed Finland to become one of the front runners in nuclear technology and especially nuclear waste management. As one of the Finnish nuclear operators and license holders, Fortum has taken the initiative to develop safe and efficient technologies for waste management optimization. One of the Fortum developed products is the NURES® radioactive liquid waste treatment technology which is based on inorganic ion exchange materials developed in the 1980s [4]. The goal of the NURES® technology is to provide maximum volume reduction of radioactive liquid waste and significant cost reductions in waste management. In addition to the NURES® materials themselves, the technology has been developed to provide entire waste treatment systems for radioactive liquid waste purification.

CASE STUDIES

Over the several decades of operating a nuclear power plant and onsite final disposal facility, Fortum has understood the importance of optimizing radioactive waste management and put significant efforts into optimizing and minimizing the waste produced at the Loviisa NPP. One of the areas recognized in the 1980s was the liquid waste management optimization and the significant cost savings resulting from waste minimization. For this, Fortum together with the University of Helsinki, developed an inorganic ion exchange material for cesium decontamination, CsTreat®. The material development continued and today the NURES® portfolio consists of four inorganic ion exchange materials listed in Table 1.

Table 1. The core of NURES® ion exchange technology [5,6]

Material	Structure	Main radionuclide(s)	Operating pH
CsTreat	hexacyanoferrate	**Cs**, Ag	1-13
SrTreat	modified titanium oxide	**Sr**, Pu, Zn	>7
CoTreat	modified titanium oxide	**Co**, Ni	4-8
SbTreat	zirconium oxide	**Sb**, Tc, I	<8

In addition to the material development, Fortum has also engineered treatment systems utilizing the NURES® materials. The experience gained from Fortum's own NURES® treatment system in Loviisa NPP as well as successful collaborations worldwide has increased the knowhow not only in relation to ion exchange but also process engineering. This has resulted in a technology that is easily tailored to meet the capacity, size and decontamination requirements. The next sections introduce some of Fortum's recent liquid waste treatment system deliveries from small scale laboratory system to a fully engineered and semi-automatic NURES® delivery to a NPP under decommissioning.

Laboratory Scale NURES® System

In addition to nuclear power plants, several other entities produce various amount of radioactive liquid waste which requires treatment. One of Fortum's recent system deliveries was to a Nordic nuclear research center that conducts research related to nuclear energy and materials. The sample preparation and analysis produces liquid waste with varying composition and activity concentrations. Furthermore, the radionuclide composition also differs depending on the research activity. The main radionuclides, however, are those that NURES® materials are designed for and therefore, they reached out to Fortum to customize a treatment system that can be used periodically to treat moderate volumes of liquid waste with changing composition.

The equipment delivered to the research center weighs 105 kg and has dimensions of (W) 800mm×(H)1200mm×(L)300 mm. The column volume is 1250 mL (see Figure 1). The inlet and outlet are located on two sides of the equipment with hoses that are used to pump the liquid in and out of the system. The facility can be operated with maximum three NURES® columns in series at a time. The columns can also be bypassed depending on the composition of the incoming liquid. The system can be used periodically when needed without compromising the performance of the columns. The treatment capacity of the system is optimally at 10-20 BV/h but can be increased to maximum of around 40 BV/h. To optimize the decontamination, the system is also equipped with two pH adjustment pumps that can be used to inject base or acid to increase or decrease the pH before the liquid enters the column. This ensures that the NURES® materials perform at optimum conditions and provide sufficient decontamination factors.

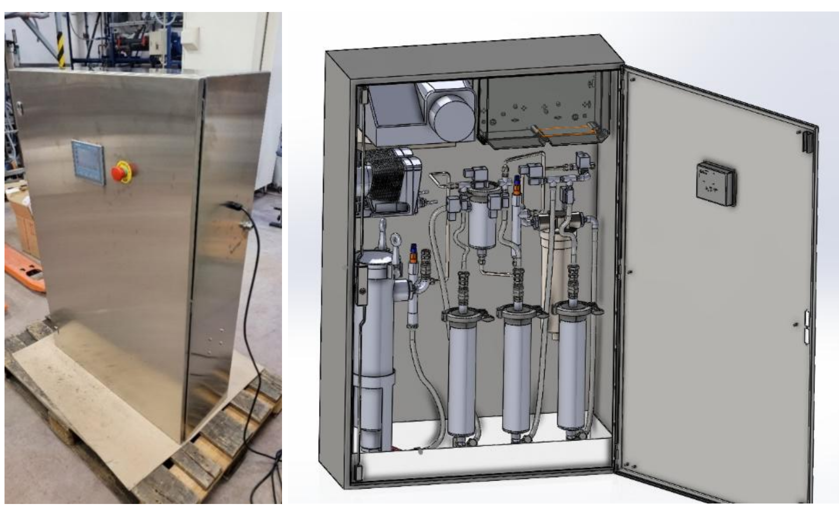

Figure 1. Laboratory scale NURES® system

Customized Columns for Contaminated Metal Dust

In September 2011, during the normal operations at Duferco La Louvière steel plant in Belgium, a cesium source was accidentally entered into the melting furnace, causing the metal dust to become contaminated. The radioactive material was quickly identified and the 600 tons of metal dust contaminated with cesium was separated for treatment. The activity in the contaminated dust varied from 1 Bq/g to 10 Bq/g Instead of disposing the entire 600 tons of contaminated metal waste, it was decided that the best available technology would be applied and the volume of disposable radioactive waste minimized. This was done by dissolving the cesium from the metallic waste to aqueous solution followed by Fortum's NURES® treatment.

The conventional way of using ion exchange technology is to use columns through with the radioactive liquid is pumped. This is also how NURES® technology is applied in Loviisa NPP where the columns used for cesium decontamination have a volume of 8 liters. The columns are placed inside a lead shielding to ensure safe operation (see Figure 2). The columns can be easily removed from the shielding when exhausted by detaching the hoses and lifting the column. Fortum provided Duferco with 16 NURES® CsTreat® columns specifically designed to separate radioactive cesium from aqueous solutions. Fortum also consulted Duferco in commissioning of the columns. CsTreat® usage in Duferco's steel plant differs from the typical use of NURES® technology that is mainly utilized in nuclear waste decontamination. However, this project proves that the technology can also be used for other purposes and is not limited to nuclear power plant waste only. In this case, Fortum designed and delivered the columns for the specific customer needs. The columns were later installed into the treatment line.

The process of treating the radioactive waste from the incident is ongoing and Fortum's CsTreat® is showing exceptional results. CsTreat® is not just an intermediate solution for waste management but a final solution which can bring the problem to an end in the coming years. After the decontamination process is completed, the used columns will be further processed.

Figure 2. Example of a NURES® column (left) and lead shielding (right)

High Capacity Liquid Waste Treatment System for Decommissioning

The years of development of NURES® technology combined with high level engineering was utilized in a system delivery of a full size mobile treatment facility to Grafenrheinfeld NPP, Germany. As many of the plants in Germany, Grafenrheinfeld was already under decommissioning in 2020 when the project was initiated and had a variety of liquid waste to waiting treatment. Grafenrheinfeld had approximately 1300 m^3 of radioactive waste requiring treatment and they were seeking a cost efficient treatment solution to minimize the cost of final disposal as well as operating cost. Fortum was contacted and after extensive testing, NURES® treatment facility was installed onsite to treat the liquid waste. The liquid waste contained several radionuclides e.g. Sb-125, Mn-54, Co-60, Ag-110m, Te-123m, Cs-134, Cs-137. with activity concentration ranging from 10,000 Bq/m^3 to 100,000,000 Bq/m^3. The 3D model picture of the treatment facility is presented in Figure 3.

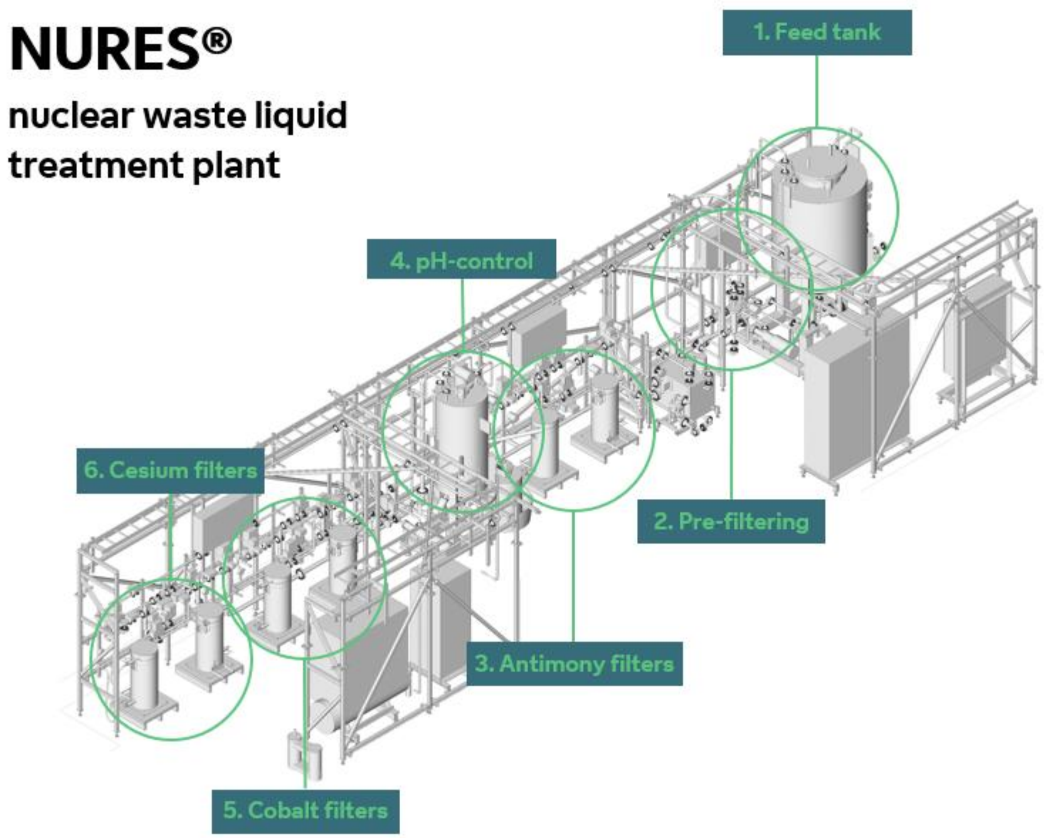

Figure 3. 3D model of the NURES® liquid waste treatment facility in Grafenrheinfeld, Germany

The liquid was relatively clean from chemicals except for some amount of salt. The pH of the liquid is 4-5 which was optimal for Sb removal but increased to about 6 by adding NaOH for optimal performance of CoTreat and CsTreat. The treatment capacity of the NURES® system was set to 20 to 30 m^3 of liquid per week with a flow of approximately 20 BV/h using 12 liter NURES® columns. The decontamination factors remained high throughout the treatment and the outcoming liquid was monitored carefully to optimize the column exchange frequency. Figure 4 shows the DF as a function of volume treated as well as the release condition parameters calculated by Equations 1 and 2. The treatment of the entire 1300 m^3 took around 2 years and a total of 12 NURES® columns were used. The volume reduction from 1300m^3 to around 150 L was achieved and the used NURES® material fits into one German style final disposal container. After the NURES® treatment, the decontaminated wastewater could be disposed of in a conventional treatment plant.

$$\text{Global DF} = \frac{c_i(\text{incoming})}{c_i} \quad (1)$$

$$\sum_i \frac{c_i}{c_{E,i}} \leq 1 \quad (2)$$

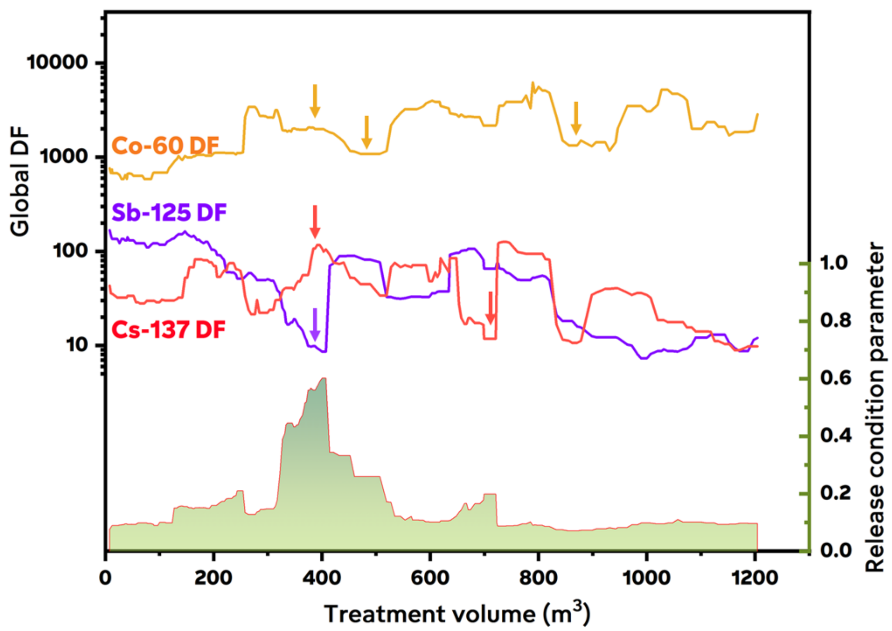

Figure 4. The global decontamination factors (DF) for Co-60, Sb-125 and Cs-137 in Grafenrheinfeld.

BORES® boron removal technology

In Loviisa NPP, the NURES® treated liquid waste results in clearance level boric acid waste containing about 70 g/L boric acid which, based on the Finnish regulations, can be released to the environment. However, due to differing local requirements, the release of boric acid containing liquids is not always possible. This is especially the case in NPPs located next to a river or another small water body where the boron release limits are lower than in the sea. Fortum has recognized this issue and developed a boron removal technology, BORES® alongside NURES®. By combining the two products, the liquid waste from PWRs can be treated to a level where the final liquid waste can be released to the environment. The BORES® technology is currently used in Hungary where around 75% of boron is removed before NURES® CsTreat® treatment. With this, the final liquid becomes cleared for release.

SUMMARY

Decades of experience as an operator of not only two nuclear reactors but also radioactive waste disposal facility has provided Fortum extensive knowledge on nuclear waste management optimization. The close collaboration of researchers and engineers has resulted in NURES® ion exchange technology that has evolved into a radioactive liquid waste treatment product that can be tailored to the customers' needs. Not only can NURES® be used to NPP waste but also radioactive waste produced by other facilities. The scalability of the technology allows the utilization of the high performance ion exchange materials from laboratory scale to treatment facilities in a nuclear power plant. The product is ever evolving and the goal is to continue the development towards minimizing radioactive liquid waste.

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