# MINIMIZING RADIOACTIVE WASTE THROUGH CHEMICAL DECONTAMINATION TECHNIQUES

D. GURAU*, I. IORGA, L. ZICMAN, L. DONE, E. NEACSU

Horia-Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH)
* *Corresponding author email*: daniela.gurau@nipne.ro

*Received April 20, 2023*

*Abstract.* Effective decontamination is crucial for managing radioactive waste, and it is important to find optimal practices that consider factors such as ease of use, reduction in secondary waste, and hazardous nature of the material. The study evaluates a chemical decontamination gel effectiveness in removing radioactive materials from commonly used materials at IFIN-HH. Artificially contaminated materials were tested, and the gel decontamination factor was evaluated. The gel has advantages such as easy application, high decontamination factor, and minimal contamination of radioactive materials, making it a promising method for efficient and safe management of radioactive waste.

*Key words*: chemical gel, decontamination, radionuclides, radioactive waste, radiation measurement, radiological contamination, gamma-ray spectrometry.

DOI: https://doi.org/10.59277/RomJPhys.2023.68.909

## 1. INTRODUCTION

The process of reducing, removing, or neutralizing radiological contamination is a complex undertaking that requires careful consideration from multiple perspectives. The chemical and/or mechanical processes used to achieve decontamination must be carried out under strict protective conditions to ensure the safety of all participants in the process. Decontamination is often a progressive operation, meaning that it may need to be carried out in stages to achieve optimal results. The use of protective equipment, such as respirators, protective clothing, and gloves, is essential to minimize the risk of exposure to radioactive materials. In addition to protecting workers, the decontamination process must also be carried out in a manner that minimizes the potential impact on the environment. This includes proper handling, transportation, and disposal of the contaminated waste generated during the process. Effective decontamination requires careful planning, proper selection of decontamination methods and materials, and ongoing monitoring to ensure that the process is carried out safely and effectively. It is essential to involve experienced professionals with specialized training in radiation safety and decontamination to ensure that the process is carried out in accordance with regulatory requirements and industry best practices.

Chemical decontamination is a common technique used in the management of radioactive waste. The process involves using chemical agents to remove or reduce the level of radioactive contamination on surfaces or equipment. Various chemical agents can be used, depending on the type of contaminant and the surface or equipment to be decontaminated. For example, strong acids or bases can be used to dissolve or remove radioactive materials from surfaces, while chelating agents can be used to bind and remove radioactive contaminants. Chemical decontamination can be used in conjunction with physical methods, such as pressure washing or scrubbing, to achieve optimal results. The decontaminated surfaces are then tested to ensure that the contamination has been successfully removed, and the waste generated during the process is managed in accordance with regulatory requirements. One of the benefits of chemical decontamination is that it can be used to treat large areas or complex equipment, and can be effective in removing contaminants that are difficult to access [1–4]. However, care must be taken to select the appropriate chemical agents and to ensure that the process is carried out safely and in compliance with regulations to minimize risks to workers and the environment.

The present study is an extension of the efforts that were started a few years back by Gurau and Deju [5, 6]. Their work aimed at establishing a program to assess the efficiency of decontamination of systems, structures, equipment, and components (SSEC) as part of the decommissioning process for the VVR-S nuclear research reactor located in Magurele-Bucharest, Romania. The previous study focused on evaluating the decontamination factor for different artificially contaminated surfaces with radionuclides $^{137}$Cs and $^{60}$Co (one radionuclide per sample) which were among the most significant radionuclides present in the VVR-S Nuclear Research Reactor from Magurele-Bucharest, Romania [7]. The decommissioning of the VVR-S reactor was carried out successfully between 2010 and 2020, and the removal and safe disposal of radioactive waste, including waste containing $^{137}$Cs and $^{60}$Co, were key components of the decommissioning process. The decontamination of equipment and surfaces contaminated with these radionuclides was also an important aspect of the decommissioning project. Effective decontamination techniques were used to minimize the generation of radioactive waste and ensure the safe management of the waste produced during the decommissioning process.

This study seeks to build upon their findings and expand upon their program and the results aim to provide valuable information for optimizing decontamination practices within the Radioactive Waste Management Department from IFIN-HH and improving the overall management of radioactive waste.

It is important to note that the study used artificially contaminated materials to simulate the conditions present in the radioactive waste treatment process. Therefore, the results of the study may not fully reflect the challenges and complexities associated with the decontamination of real radioactive waste materials. However, the findings from this study can provide important insights into the effectiveness of decontamination methods and guide further research in this area.

## 2. METHODS AND MATERIALS

### 2.1. CHEMICAL DECONTAMINANT

DeconGel 1101 is a chemical gel developed and manufactured by CBI Polymers Inc. that effectively decontaminates surfaces and materials contaminated with radioactive or hazardous substances [8, 9]. This product functions by binding with and encapsulating the contaminants, removing them from the surface or material. The gel's versatility enables its application on a variety of surfaces such as concrete, metal, glass, and plastic. DeconGel is non-toxic, non-flammable, and biodegradable, which makes it safe for use in numerous applications such as nuclear power, research and development, and hazardous materials management. It can be applied to surfaces and left to dry, after which it can be peeled off, taking with it the contaminants that have been absorbed. The product's capability to bind and encapsulate contaminants offers a safe and effective approach to decontamination in hazardous material environments.

### 2.2. SAMPLES

Initially, the materials were selected based on their frequency of occurrence in the flow of radioactive waste treatment. Subsequently, the larger components were trimmed to facilitate their utilization in the contamination procedure (see Fig. 1).

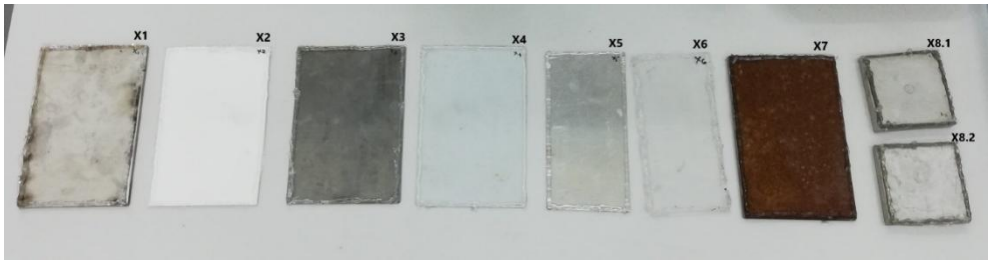


Fig. 1 – Samples materials.

To prevent contamination and facilitate the application of the gel, silicone was employed to form a seal along the edges of the samples.

Table 1 provides a comprehensive overview of the type of material examined in the study, including their physical properties and specific observations. The table presents information on various materials that were analysed, such as carbon steel (OLC), plastic1, stainless steel, painted steel, aluminium, plastic2, rusty steel, smooth surface concrete, porous surface concrete. The physical properties of each material, such as volume, weight and density were also provided. Additionally, the frequency of encountering it as radioactive waste and porosity were noted.

*Table 1*

Samples characteristics

| Code | Material | Volume ($cm^3$) | Weight (g) | Density ($g/cm^3$) | Freq. as rad. waste | Observation |
|---|---|---|---|---|---|---|
| X1 | Carbon steel (OLC) | 85.71 | 953.91 | 11.13 | often | relatively soft, medium porosity |
| X2 | plastic1 | 57.14 | 66.03 | 1.16 | quite often | slightly hard, low porosity |
| X3 | stainless steel | 42.86 | 312.41 | 7.29 | quite often | hard, low porosity |
| X4 | painted steel | 28.57 | 127.1 | 4.45 | often | slightly hard, low porosity |
| X5 | aluminium | 42.86 | 88.81 | 2.07 | less | slightly soft, medium porosity |
| X6 | plastic2 | 28.57 | 50.98 | 1.78 | often | slightly hard, low porosity |
| X7 | rusty steel | 114.29 | 1142.77 | 10.00 | often | slightly hard with soft surface, high porosity |
| X8.1 | smooth surface concrete | 100.00 | 230.23 | 2.30 | quite often | slightly hard with soft surface, medium porosity with smooth surface |
| X8.2 | porous surface concrete | 100.00 | 232.75 | 2.33 | quite often | slightly hard with soft surface, high porosity with rough surface |

### 2.3. SAMPLES CONTAMINATION

A volume of 5 ml of a radionuclide mixture solution, consisting of $^{60}Co$, $^{133}Ba$, $^{137}Cs$ and $^{241}Am$ at pH 0.5, was applied to the prepared samples using a pipette while working in a specialized environment with protective equipment. The solution was carefully dripped onto the surface of the sample to ensure maximum coverage. The samples were left undisturbed for a sufficient period to allow the contaminant solution to fully penetrate the surface and for the surface to dry. The specific activities of the radionuclides used in the solution at the time of the experiment were: 8.55 ± 1.28 Bq/ml for $^{60}Co$, 31.5 ± 3.8 Bq/ml for $^{133}Ba$, 46.5 ± 6.1 Bq/ml for $^{137}Cs$ and 66.1 ± 9.3 Bq/ml for $^{241}Am$. Following contamination, the samples were placed into labeled sealed bags to prevent any potential external contamination and for identification. Protective measures were taken throughout the process to ensure safety.

Diverse behaviours were noted during the contamination process across distinct samples.

The information presented in Table 1 serves as a valuable resource for understanding the characteristics of different materials and their potential impact on the radioactive waste stream. Was easily observed, that in the case of X1, X2, X3 and X6 samples (carbon steel, plastic1, stainless steel, plastic2) the contaminant exhibits a high affinity for surface adhesion, indicating that it readily binds to and

accumulates on surfaces. This may be due to the chemical and physical properties of the contaminant and the surface, such as surface energy, charge, and roughness, which promote adhesion. Specifically, X7, X8.1, and X8.2 samples (rusty steel, smooth surface concrete, and porous concrete), underwent chemical reactions upon contact with the contamination solution. The contaminant exhibits a propensity to penetrate deeply into the material due to their unique properties. Rusty steel, for instance, possesses a rough and porous surface that can trap contaminants and promote their infiltration into the material. Similarly, smooth surface concrete and porous concrete may facilitate the penetration of contaminants through their relatively low surface roughness and high porosity. Aluminium, specifically the X5 sample, is considered an unusual material to decontaminate due to its distinctive characteristics. Its chemical reactivity makes it challenging to remove contaminants from both the surface and within the material structure. This includes the difficulty of removing oxides, organic residues, and corrosion products from aluminium. In case of X4 sample (painted steel), the presence of paint can offer some level of protection for the underlying steel. However, it's important to note that the paint layer itself can be easily contaminated by radioactive or other hazardous materials.

### 2.4. RADIATION MEASUREMENT

To evaluate the activity, gamma spectrometry was performed using a laboratory gamma spectrometric system equipped with an Ortec HPGe detector. The system comprised a hyperpure germanium detector, p-type GEM60P4-95 model with a crystal diameter of 7.44 cm and a length of 7.36 cm, a DSPEC jr.2.0 digital analyser, a lead castle, and Maestro32 and GammaVision32 acquisition and analysis software package.

Practice does not recommend using a geometry-specific efficiency calibration curve for another geometry. Therefore, efficiency calibration curves must be created for all source-detector measurement geometries. Since it was not possible to use experimental calibration using standard reference sources for the measurement geometries involved in the study, the procedure for evaluating the detection efficiencies was carried out with the help of the GESPECOR software which is based on direct calculation using a complex model of the detector and the processes physical factors involved, without the need to use values of experimentally evaluated efficacies [10]. As the obtained results are highly influenced by the uncertainty of the detector data, the initial step of the process involved checking the detector parameters, which had been optimized in a previous stage of the study.

The study assessed the efficiencies of rectangular sources with varying dimensions emitting energies from $^{60}$Co, $^{133}$Ba, $^{137}$Cs and $^{241}$Am by taking into account the detector's optimal parameters, geometry, and sample characteristics. It should be noted that the standard version of the GESPECOR program lacks the capability to calculate efficiencies for parallelepipedic sources. To address this limitation, a tailored option was created to enable accurate estimation of efficiencies

for parallelepipedic sources. Subsequently, the calculated efficiencies were employed to assess the activities of the contaminated samples in Bq.

### 2.5. SAMPLE DECONTAMINATION

DeconGel 1101 was applied to the surface of the contaminated samples using a laboratory spatula in a controlled area with protective equipment. The coated samples were then allowed to dry for a period sufficient for the gel to reach a state where it can be readily removed from the surface. Empirical data gathered during the course of this study indicated that the ideal duration for drying was 72 hours. After this time, dry uniform sheets of DeconGel were obtained and subsequently subjected to spectrometric analysis. In Fig. 2, the samples obtained after the application of the DeconGel 1101 and after its drying are presented.

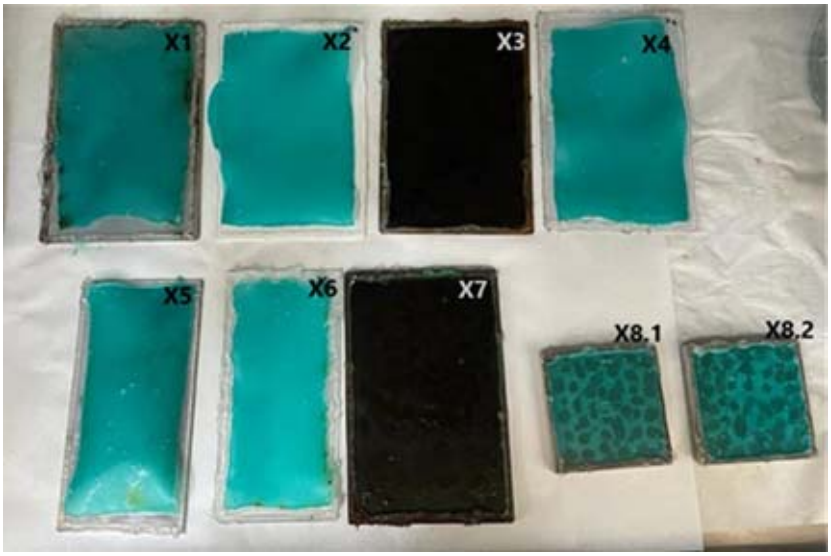


Fig. 2 – Samples treated with DeconGel dried and ready for processing.

## 3. RESULTS AND DISCUSSIONS

To evaluate the percentage removal of contamination, several steps have been taken. First, the initial level of contaminant was measured before treatment. This represents the baseline level and was determined by measuring the contaminant before treatment using gamma-ray spectrometry technique. Then, level of the contaminant after treatment was measured using the same technique as baseline measurements. This can be names the post-treatment level. For each type of sample, the background was assessed and taken into account during measurements. The

activity levels of contaminated samples, dry DeconGel sheet, and decontaminated samples were all quantified and the result obtained are presented in Table 2.

*Table 2*

Activity and uncertainty for contaminated, dry sheet and decontaminated samples

| Sample | Radio-nuclid | After contamination | | After decontamination | | Dry gel sheet | |
|---|---|---|---|---|---|---|---|
| | | Λ (Bq) | u (%) (1σ) | A (Bq) | u (%) (1σ) | A (Bq) | u (%) (1σ) |
| X1 | $^{60}$Co | 12.4 | 10 | 1.7 | 13 | 11.7 | 11 |
| | $^{133}$Ba | 47.6 | 10 | 7.2 | 10 | 41.3 | 10 |
| | $^{137}$Cs | 75.8 | 10 | 12.9 | 10 | 67.9 | 10 |
| | $^{241}$Am | 18.3 | 10 | 6.1 | 23 | 23.0 | 19 |
| X2 | $^{60}$Co | 23.0 | 10 | 1.1 | 25 | 19.6 | 11 |
| | $^{133}$Ba | 90.1 | 10 | 2.5 | 12 | 75.4 | 10 |
| | $^{137}$Cs | 130.4 | 10 | 2.5 | 13 | 102.9 | 10 |
| | $^{241}$Am | 34.2 | 13 | 2.7 | 35 | 30.8 | 22 |
| X3 | $^{60}$Co | 21.4 | 10 | 1.0 | 23 | 10.3 | 19 |
| | $^{133}$Ba | 80.4 | 10 | 1.7 | 17 | 39.5 | 17 |
| | $^{137}$Cs | 122.5 | 10 | 3.2 | 17 | 102.9 | 15 |
| | $^{241}$Am | 40.6 | 15 | 3.4 | 40 | 37.1 | 22 |
| X4 | $^{60}$Co | 22.7 | 10 | 1.0 | 18 | 18.8 | 13 |
| | $^{133}$Ba | 91.2 | 10 | 1.7 | 18 | 72.4 | 11 |
| | $^{137}$Cs | 129.4 | 10 | 3.1 | 16 | 107.3 | 10 |
| | $^{241}$Am | 31.1 | 17 | 1.2 | 44 | 24.3 | 17 |
| X5 | $^{60}$Co | 36.0 | 10 | 7.2 | 13 | 30.4 | 11 |
| | $^{133}$Ba | 142.0 | 10 | 19.0 | 10 | 126.2 | 10 |
| | $^{137}$Cs | 217.8 | 10 | 26.6 | 10 | 192.3 | 10 |
| | $^{241}$Am | 34.7 | 13 | 9.8 | 18 | 30.0 | 15 |
| X6 | $^{60}$Co | 20.5 | 10 | 1.5 | 21 | 20.8 | 10 |
| | $^{133}$Ba | 85.3 | 10 | 1.0 | 17 | 89.3 | 10 |
| | $^{137}$Cs | 121.8 | 10 | 1.2 | 14 | 126.4 | 10 |
| | $^{241}$Am | 31.6 | 16 | 5.3 | 51 | 40.4 | 14 |
| X7 | $^{60}$Co | 24.8 | 11 | 4.3 | 14 | 14.6 | 12 |
| | $^{133}$Ba | 89.7 | 10 | 15.5 | 12 | 59.7 | 11 |
| | $^{137}$Cs | 129.9 | 10 | 18.5 | 11 | 90.0 | 10 |
| | $^{241}$Am | 48.6 | 15 | 6.8 | 18 | 35.2 | 14 |
| X8.1 | $^{60}$Co | 23.6 | 10 | 20.2 | 10 | 3.5 | 12 |
| | $^{133}$Ba | 103.7 | 10 | 90.5 | 10 | 15.4 | 11 |
| | $^{137}$Cs | 152.4 | 10 | 90.7 | 10 | 62.9 | 10 |
| | $^{241}$Am | 100.7 | 18 | 104.2 | 11 | 56.5 | 26 |
| X8.2 | $^{60}$Co | 24.9 | 10 | 18.5 | 10 | 6.7 | 11 |
| | $^{133}$Ba | 106.2 | 10 | 81.6 | 10 | 24.8 | 10 |
| | $^{137}$Cs | 154.5 | 10 | 89.5 | 10 | 65.4 | 10 |
| | $^{241}$Am | 118.4 | 14 | 47.0 | 15 | 54.1 | 20 |

The percentage of contamination removed with DeconGel (Df) was calculated using the decontamination factor calculated with following formula:

$$Df = \frac{Ci - Cf}{Ci} 100 \quad (1)$$

where Ci is the amount of contamination present before using DeconGel, Cf is the amount of contamination present after using DeconGel 1101. Table 3 presents the contamination factors obtained using DeconGel, along with the corresponding uncertainties that were calculated to provide a measure of the precision and accuracy of the results.

*Table 3*

Percentage of contamination removed and their uncertainties

| Sample | Radionuclid | Df (%) | u(%) (1σ) | Sample | Radionuclid | Df (%) | u(%) (1σ) |
|---|---|---|---|---|---|---|---|
| X1 | $^{60}$Co | 86 | 17 | X6 | $^{60}$Co | 93 | 23 |
| | $^{133}$Ba | 85 | 14 | | $^{133}$Ba | 99 | 20 |
| | $^{137}$Cs | 83 | 14 | | $^{137}$Cs | 99 | 17 |
| | $^{241}$Am | 67 | 25 | | $^{241}$Am | 83 | 53 |
| X2 | $^{60}$Co | 95 | 27 | X7 | $^{60}$Co | 83 | 17 |
| | $^{133}$Ba | 97 | 16 | | $^{133}$Ba | 83 | 16 |
| | $^{137}$Cs | 98 | 16 | | $^{137}$Cs | 86 | 15 |
| | $^{241}$Am | 92 | 37 | | $^{241}$Am | 86 | 24 |
| X3 | $^{60}$Co | 95 | 25 | X8.1 | $^{60}$Co | 14 | 14 |
| | $^{133}$Ba | 98 | 20 | | $^{133}$Ba | 13 | 14 |
| | $^{137}$Cs | 97 | 20 | | $^{137}$Cs | 40 | 14 |
| | $^{241}$Am | 92 | 43 | | $^{241}$Am | -3 | 21 |
| X4 | $^{60}$Co | 96 | 21 | X8.2 | $^{60}$Co | 26 | 14 |
| | $^{133}$Ba | 98 | 20 | | $^{133}$Ba | 23 | 14 |
| | $^{137}$Cs | 98 | 19 | | $^{137}$Cs | 42 | 14 |
| | $^{241}$Am | 96 | 47 | | $^{241}$Am | 60 | 21 |
| X5 | $^{60}$Co | 80 | 17 | | | | |
| | $^{133}$Ba | 87 | 14 | | | | |
| | $^{137}$Cs | 88 | 14 | | | | |
| | $^{241}$Am | 72 | 22 | | | | |

From Table 3 it can be observed that X1, X2, X3, X4, X5, X6 and X7 (carbon steel (OLC), plastic1, stainless steel, painted steel, aluminium, plastic2 and rusty steel) samples present the majority of decontamination factors greater than 80% which indicate that the decontamination process was effective in removing a significant amount of radioactive contamination from surface samples. This is generally considered to be a high level of decontamination, and may be sufficient

to meet regulatory standards for safe handling and disposal of radioactive waste. The decontamination factors for $^{241}$Am were less than 80% for X1 (carbon steel (OLC)) and X5 (aluminium) samples, with values of 67% and 72%, respectively. This means that the decontamination process was not fully effective in removing $^{241}$Am contamination from the X1 and X5 samples and the process removed only a portion of the $^{241}$Am contamination from the samples, leaving a significant amount of contamination behind.

The small radioactive decontamination factor of $^{241}$Am on carbon steel refers to the difficulty in removing or decontaminating $^{241}$Am radioactive contamination from the surface of carbon steel. Carbon steel is a commonly used material in the nuclear industry and is known to adsorb or retain radioactive particles from the environment. $^{241}$Am is an radioactive isotope of americium that emits alpha particles, which are highly ionizing and can pose health risks if ingested or inhaled. The small Df for $^{241}$Am on carbon steel suggests that the decontamination process was not effective in removing the radioactive contamination from the surface of the material. This could be due to several factors, such as the strength of the bond between $^{241}$Am and the carbon steel surface or the presence of impurities on the surface that interfere with the decontamination process.

The small radioactive decontamination factor of $^{241}$Am on aluminum materials refers to the difficulty in removing or decontaminating $^{241}$Am radioactive contamination from the surface of aluminum. Aluminum is a commonly used material in various applications, including in the nuclear industry, due to its excellent strength-to-weight ratio and corrosion resistance. The low decontamination factor observed for $^{241}$Am on aluminum materials indicates that the process used to remove the radioactive contamination from the surface of the material was not successful. This could be attributed to a variety of factors, including the extent of the bond between the $^{241}$Am and the aluminum surface, or the existence of surface impurities that interfere with the decontamination process. Additionally, aluminum can form a thin, protective layer of oxide on its surface, which can impede the effectiveness of decontamination processes. The oxide layer can prevent the decontaminating agent from reaching the contaminated surface, making it difficult to remove the radioactive contamination.

To remove contaminants from aluminum surfaces and from within the material matrix, various techniques can be used, including mechanical cleaning (such as brushing or sandblasting), chemical cleaning (such as acid or alkaline cleaning), and electrolytic cleaning (using an electric current to remove contaminants). The choice of technique will depend on the type and extent of the contamination, as well as the desired level of cleanliness and the properties of the aluminum material being cleaned.

In the case of X8.1 and X8.2 (smooth and porous surface concrete) samples, the situation was more critical because the decontamination factors for all the radionuclides involved in this study, were smaller than 60%. This was because,

concrete is a porous material, which means that it contains small openings or spaces that allow contaminated solution to pass through. When the radioactive solution come into contact with concrete, it seeped into the sample volume and was absorbed by the pores in the concrete. This makes it more difficult to remove the contamination because it was embedded deep within the material. Furthermore, the deeper infiltration of the radioactive solution caused a chemical reaction with the concrete, which maked it more difficult to remove the contamination. This resulted in a decrease in the effectiveness of the decontamination process for concrete samples. The chemical reaction created a bond between the radioactive material and the concrete, maked it more difficult to separate them. Overall, the porous nature of concrete and the potential for chemical reactions make it more challenging to remove radioactive contamination from concrete surfaces.

## 4. CONCLUSIONS

The Radioactive Waste Management Department at IFIN-HH is responsible for the safe management of institutional radioactive waste. The department has developed and implemented a comprehensive radioactive waste management program that ensures the safe handling, storage, transportation, and disposal of radioactive waste.

The study examined the effectiveness of decontamination methods in removing radioactive and hazardous materials from the most frequently encountered materials in the waste stream, with the ultimate goal of developing effective waste management strategies.

The decontamination factor Df is a technique used to measure the effectiveness of a decontamination process in reducing the level of radioactivity in a contaminated material. The decontamination factor refers to the ratio of the amount of radioactivity before and after decontamination. The higher Df is, the more effective the decontamination process is at removing radioactive materials. By using an effective decontamination technique, the amount of radioactive waste that needs to be disposed of can be reduced. Chemical gels have been found to be effective in removing radioactive ions from contaminated surfaces, and this process can be applied in the treatment of radioactive waste as well. In this study, the decontamination with chemical gel technique has been improved and adapted to identify optimal decontamination practices for various stages of radioactive waste management through the use of indirect measurement methods and data analysis.

DeconGel 1101 used in this study is a commercial product that is commonly used for decontamination of radioactive surfaces. The efficiency of radioactivity decontamination with DeconGel 1101 depends on various factors, such as the type and level of radioactivity, the surface being decontaminated, the amount and application of DeconGel, and the effectiveness of the removal process. However, the studies carried out in this work have shown that DeconGel 1101 can be

effective in reducing radioactivity on various surfaces like carbon steel (OLC), plastic1, stainless steel, painted steel, aluminium, plastic2, rusty steel, smooth surface concrete and porous surface concrete.

The analysis revealed that for samples X1 through X7 (which comprised carbon steel (OLC), plastic1, stainless steel, painted steel, aluminium, plastic2 and rusty steel), the majority of decontamination factors exceeded 80%. This indicates that the decontamination process successfully eliminated a significant proportion of the radioactive contamination present on the surface samples.

The decontamination factors obtained for the $^{241}$Am isotope were found to be below 80% for two of the sample types, namely X1 (carbon steel (OLC)) and X5 (aluminium). The small radioactive decontamination factor of $^{241}$Am on carbon steel and aluminium samples indicates the difficulty in effectively removing radioactive contamination from the surface of the material, posing a potential health risk to those exposed to the contaminated surface. The presence of an oxide layer on aluminum surfaces can further impede the effectiveness of decontamination processes.

The difficulty in aluminium decontamination is due to several factors, including its relatively high surface energy, low porosity, and the tendency of some contaminants to strongly adhere to its surface. Therefore, it is important to develop effective decontamination techniques that can remove contaminants from aluminium to prevent potential exposure and environmental contamination. When the contaminant displays a strong tendency to adhere to surfaces has important implications for decontamination strategies and waste management practices, highlighting the need for effective methods that can remove the contaminant from surfaces to minimize potential exposure and environmental impact.

DeconGel 1101 is a powerful tool for removing radioactive contaminants from surfaces, but it may not be able to eliminate all traces of radioactivity in every situation. The effectiveness of DeconGel 1101 can depend on factors such as the type and level of radiation present, the type of surface being treated, and the specific application of the product. Furthermore, proper handling and disposal of both the DeconGel 1101 and any radioactive waste generated during its use are crucial to ensure safety and compliance with regulatory requirements. Improper disposal of radioactive waste can pose serious risks to human health and the environment, so it is important to follow established guidelines and procedures for handling and disposing of radioactive materials. Anyone using DeconGel 1101 or other products for managing radioactive waste should be well-trained in their proper use and disposal, and should always prioritize safety and compliance with regulations.

It is important to note that while DeconGel 1101 can be effective in reducing radioactivity on surfaces, it may not completely eliminate all radioactive contaminants. Overall, DeconGel 1101 can be a useful tool for radioactivity decontamination, but the specific effectiveness of the product in a given situation will depend on various factors and should be evaluated on a case-by-case basis.

*Acknowledgements.* The authors would like to thank to colleagues from Radioactive Waste Management Department from Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH) who contributed in preparation of samples, contamination experiments, measurements and analysis.

REFERENCES

1. Z. Zhang, H. Chen, X. Chen, X. Wang, Y. Zhang, *Investigation on the decontamination efficiency of DeconGel 1101 for radioactive contamination on different surfaces*, Journal of Radioanalytical and Nuclear Chemistry **311**(2), 1239–1248 (2017).
2. Y. Huang, Y. Chen, Y. Zhu, Y. Hu, *Study on the decontamination efficiency of DeconGel 1101 for nuclear reactor floor decontamination*, Journal of Nuclear Materials Management **49** (1), 69–77 (2021).
3. J.Y. Kim, J.H. Kim, *Decontamination effectiveness and surface damage characteristics of DeconGel for various materials*, Journal of Environmental Radioactivity **196**, 121–126 (2019).
4. V.V. Egorov, V.V. Nikolaev, *The study of the possibility of using DeconGel to clean surfaces of radioactive contamination in the decommissioning of nuclear facilities*, Atomic Energy **124** (3), 216–220 (2018).
5. D. Gurau, D. Radu, *Radioactive decontamination techniques used in decommissioning of nuclear facilities*, Romanina Journal of Physics **59** (9–10), 912–919 (2014).
6. D. Gurau, D. Radu, *The use of chemical gel for decontamination during decommissioning of nuclear facilities*, Radiation Physics and Chemistry **106**, 371–375 (2015).
7. E. Ionescu, D. Gurau, D. Stanga, O.G. Duliu, *Decommissioning of the VVR-S Research Reactor – Radiological Characterization of the Reactor Block*, Romanian Reports in Physics **64** (2), 387–398 (2012).
8. K.J. Hanley, *Evaluating the surface protection and decontamination efficiency of DeconGel 1101 toward Cs-137 spilled on biological, salt-covered, rusty, wet and solid painted surfaces*, 2010, https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/nv9356013.
9. M. Sutton, R.P. Fischer, M. Thoet, M. O'Neill, G. Edgington, *Plutonium Decontamination Using CBI Decon Gel 1101 in Highly Contaminated and Unique Areas at LLNL*, LLNL-TR-404723, Contract DE-AC52-07NA27344, US, 2008.
10. O. Sima, D. Arnold, C. Dovlete, *GESPECOR: A versatile tool in gamma-ray spectrometry*, Journal of Radioanalytical and Nuclear Chemistry **248**, 359–364 (2001).