

Legacy Radioactive Waste Management and Development of a Radioactive Waste Processing Facility at the Vinča Site („Nuklearni objekti Srbije” LLC)

Danijela Soldatović, Dalibor Arbutina

„Nuklearni objekti Srbije” LLC

12-14 Mike Petrovića Alasa, Vinča-Belgrade, Serbia

danijela.soldatovic@nuklearniobjekti.rs, dalibor.arbutina@nuklearniobjekti.rs

ABSTRACT

The management of legacy radioactive waste at the Vinča site is performed under the responsibility of the „Nuklearni objekti Srbije” LLC, which, upon its establishment, was assigned responsibility for addressing legacy radioactive waste and for the implementation of the objectives of the VIND Programme. Legacy radioactive waste stored in the closed hangars H1 and H2 consists of waste generated during the operation of the Vinča Institute, including the nuclear reactor facility and research laboratories in which sources of ionizing radiation were used or produced. The waste inventory also includes institutional radioactive waste originating from the former SFRY, generated by hospitals, oncology and biology institutes, radiochemistry laboratories, and industrial applications, including radioactive lightning rods.

The removal and processing of legacy radioactive waste and disused sealed radioactive sources (DSRS) from hangars H1 and H2 are being carried out in the Radioactive Waste Processing Facility (WPF). Following processing, radioactive waste is transferred to the new storage facility (hangar H3) in compliance with established waste acceptance criteria (WAC). Conditioned DSRS are transferred to a dedicated secure storage (SS) designed for high-activity sources, following treatment in the WPF and, where required, in the hot cell of the RA reactor.

A license for the trial operation of the Radioactive Waste Processing Facility was issued by the Regulatory Authority in 2022. The first phase of the trial operation, conducted without radioactive and nuclear materials (cold phase), was initiated in 2022. The second phase of the trial operation, involving radioactive and nuclear materials (hot phase), was initiated in early 2025 and was successfully completed in the same year. Following the approval of the trial operation, documentation for the operational nuclear license was submitted in December 2025. In parallel, licensing documentation for the decommissioning of legacy hangars H1 and H2 was submitted to the Regulatory Authority.

Decommissioning activities are planned on the basis of the existing waste inventory and the current condition of the legacy storage facilities. Initial activities comprise radiological surveys and characterization of hangar H2 and its surroundings, performed without waste manipulation in order to establish safe working conditions. These activities are followed by the removal and conditioning of DSRS, the removal of waste packages and bulky items for treatment in the WPF, and their transfer to interim storage in hangar H3. Owing to its degraded structural condition, hangar H1 is planned for immediate decommissioning through systematic characterization, decontamination and dismantling, including the removal of all systems and equipment.

The continuation of legacy waste management and decommissioning activities is planned for 2026, subject to the issuance of the relevant regulatory licenses.

Keywords: legacy radioactive waste, radioactive waste processing, decommissioning

1 INTRODUCTION

Public Company „Nuclear Facilities of Serbia“ (PC NFS), current „Nuklearni objekti Srbije“ LLC), was established in 2009 under the Law on Protection from Ionizing Radiation and Nuclear Safety [1] to manage all nuclear facilities and assets in Serbia. These include two research reactors (RA, currently under decommissioning, and RB used for educational purposes), radioactive waste storage facilities (legacy hangars H0, H1, and H2, liquid waste tanks VR1–VR4, Ra Bunker) and the newly constructed hangar H3 and Secure Storage SS, and the Waste Processing Facility (WPF), all previously managed by the Vinča Institute, as well as a closed uranium mine managed by the Institute for Technology of Nuclear and Other Mineral RW Materials.

Legacy radioactive waste in Serbia comprises untreated solid waste stored in hangars H0, H1, and H2, as well as liquid waste contained in tanks VR1–VR4, all located at the Vinča Institute of Nuclear Sciences site, now under PC NFS. This inventory originates from the former Yugoslav nuclear program, with Vinča serving as the central radioactive waste management location, leading to the accumulation of significant quantities of waste. The material stored in hangars H1 and H2 mainly includes waste generated during the operation of the RA reactor and associated research laboratories where ionizing radiation sources were used or produced. In addition, the inventory contains institutional radioactive waste from the former SFRY, including waste generated by hospitals, oncology and biological institutes, radiochemistry laboratories, and various industrial applications such as radioactive lightning rods.

The VIND Programme was established by the Serbian Government in 2002 to decommission the RA research reactor at Vinča and safely manage the resulting spent nuclear fuel and radioactive waste. Implementation began in 2006 and achieved key milestones, including the removal, repatriation, and disposal of Russian-origin spent nuclear fuel, development of waste processing and storage facilities, conditioning and storage of disused sealed radioactive sources, and decontamination of old storage facilities. During 2009 and 2010, a new temporary solid waste storage hangar H3 and a Secure Storage facility (SS) for high-activity sources were constructed. The successful repatriation of spent fuel in 2010 marked a major milestone, enabling subsequent waste management activities. The ongoing decommissioning of Hangars H1 and H2 represents the current phase of this programme.

The main objective of the ongoing project is the removal, characterization, and processing of all radioactive waste and disused sealed radioactive sources (DSRS) originating from hangars H1 and H2, followed by their safe storage on-site. Treated radioactive waste will be stored in hangar H3 in accordance with waste acceptance criteria (WAC) after processing in the Waste Processing Facility (WPF), while conditioned DSRS will be placed in the Secure Storage (SS) designed for high-activity sources. The decommissioning plan is based on existing inventory data and the current condition of the facilities. Initial activities include radiological characterization, measurement of ambient dose rates, and contamination assessment in and around hangar H2, performed without direct waste manipulation to establish safe working conditions.

Subsequent activities involve the removal of DSRS and their transport to appropriate facilities (WPF or RA reactor hot cells) for conditioning, followed by the removal of drums and bulky waste for treatment. The final phase includes the decommissioning of hangar H1, which, due to its poor structural condition, requires immediate dismantling. The decommissioning strategy comprises three main steps: characterization, decontamination, and dismantling of the facility, including removal of all systems and equipment.

Equipment used for the decommissioning of hangars H1 and H2 was provided through IAEA and U.S. technical cooperation under the VIND project and remains in use by PC NFS. In accordance with International Contract No. 201500747, concluded in 2015 between the IAEA, PC NFS, and a Belgian consortium, preparatory activities for decommissioning were defined and financed through the IAEA Technical Cooperation Project “Radioactive Waste Processing and Decommissioning at Vinča Site” (SRB3004). These activities included the provision of equipment for radioactive waste characterization, handling, decontamination, and metal cutting, as well as

financial support for environmental impact assessments and the adaptation of the „Latransa” facility into the WPF. Funding relies primarily on the Serbian government, as the decommissioned facilities do not generate revenue.

2 LEGACY WASTE FACILITY

The legacy radioactive waste storage facilities, hangar H1 and hangar H2, are located on the premises of the „Nuklearni objekti Srbije” LLC, within the Institute Vinca/Radioactive waste complex. These facilities are located near the existing radioactive waste management infrastructure, including hangar H3, the SS facility, and the Waste Processing Facility (WPF). The site is located approximately 15 km from the center of Belgrade and less than 2 km from the Danube River. The layout and spatial arrangement of the facilities within the complex are presented in the site plan (Figure 1).



Figure 1: Disposition of the RW facilities, old hangars H1 and H2, new hangar H3 and SS, and WPF

2.1 Description of hangar H1 and the surrounding area of H1

Hangar H1, the first dedicated radioactive waste storage facility at the Boris Kidrič Institute in Vinča, was constructed in 1968 following a decision of the Federal Commission for Nuclear Energy to establish temporary storage for solid radioactive waste (RW). The facility is located on a levelled concrete plateau on a sloped terrain, approximately 20 m above the „Mlaka” stream. It is a prefabricated, single-span steel structure with corrugated galvanized sheet cladding, designed as a single-compartment storage hall. The principal dimensions of the facility are 32.0 m × 15.2 m, with a ridge height of 7.8 m and a usable internal height of approximately 4.5 m. Natural lighting is provided through longitudinal window strips, while access is ensured via sliding vehicle doors on both frontal facades. No internal lifting systems are installed. An auxiliary compartment (C1) was later added to provide additional storage capacity.

The original design facility was to prevent the spread of contamination and minimize radiation exposure, primarily through structural enclosure and spatial separation from other facilities (Figure 2). During the 2008 reconstruction, as part of the project to improve the nuclear safety system at the location, due to problems with the sliding doors, a new, non-standard pedestrian door, measuring 0.8 m x 1.5 m, was installed within the sliding doors (Figure 3).

Before the establishment of a dedicated national regulatory framework, radioactive waste management practices were based on available knowledge from leading international nuclear institutes and relevant International Atomic Energy Agency publications addressing safety ([2] - [4]) and handling and storage techniques. Hangar H1 was in regular operation from 1968 to 1982, and during that period, the facility did not have the formal status of a nuclear facility.

Current assessments indicate significant structural degradation (notably, corrosion of facade and roof elements), impaired functionality of access systems, and inadequate confinement. The facility does not meet modern safety requirements, particularly with respect to defense-in-depth and the multiple barrier concept, and its structural envelope represents a compromised and, in some aspects, the only remaining safety barrier.



Figure 2: View of hangar H1 from the direction of hangar H2 - before the installation of pedestrian doors



Figure 3: View of the front door hangar H1, after installing the pedestrian door

2.1.1 RW and DSRS in H1 and the surrounding of the H1

Various types of radioactive waste (RW) and disused sealed radioactive sources (DSRS) are stored in Hangar H1. The largest quantity of RW, originating from different sources and with varying compositions, is packaged in standard 200 L drums. According to available records, hangar H1 has been in operation since 1968. RW and DSRS in hangar H1 were stored without a defined arrangement, and most packages are degraded and in very poor structural condition. Although hangar H2 was commissioned in 1982, storage of RW and DSRS in hangar H1 continued during the 1990s.

Finally, in accordance with a decision issued by the competent national authority in 2006 (the so-called „zero license”), hangar H1 was designated as closed for an indefinite period. A comprehensive overview of the radioactive waste (RW) inventory within hangar H1, including its spatial distribution (Figure 4), is presented in Table 1, based on available historical records ([5], [6]). Representative photographs of the interior of hangar H1, depicting disused sealed radioactive industrial sources, are provided in Figure 5, including sources such as ^{137}Cs , ^{60}Co , and selected ^{192}Ir . The red squares denote the locations of disused sealed radioactive sources originating from lightning protection systems.

Table 1: Inventory of the RW and DSRS in the H1 [5,6]

RW stream [5]	DESCRIPTION	Estimated amount	Estimated activity	Zone in Fig. 7
E1	RW from different laboratories and medical institutions	330 m ³	unknown	1 and 8
E2	Technological, irradiation and ventilation channels (aluminium and stainless steel) from reactor RA	40 m ³	unknown	2
E3	Plastic bags and plastic containers with „yellow cake“	10 m ³	11 kBq per gram of „yellow cake“	2
E4	Lead containers with radioactive sources ^{60}Co and ^{137}Cs , and lightning rod sources ^{60}Co and $^{152,154}\text{Eu}$	300 pieces	unknown	4
E5	RW from the laboratory for material sciences (contains 105 kg metallic uranium)	4 m ³	1.36 GBq	6
E6	Transuranic liquid wastes and several grams of 6.7 g ^{239}Pu in the form of nitric acid solution	0.117m ³	(17.3 – 286.8) GBq ^{*)}	unknown
E7	Waste from HOT laboratory	20 m ³	unknown	3
E8	Glove boxes from laboratory 060	6 m ³	unknown	5 and 9
E9	Another bulky RW	unknown	unknown	2, 5, 6, 7 and 9
E10	„Open“ beta sources	unknown	unknown	unknown
E11	Sources with radium	unknown	unknown	unknown
E12	Neutron sources	unknown	unknown	unknown

*The estimated activity of plutonium depends on the burnup of the fuel from which the Pu was extracted (approximately 1,000 MWd/t for weapons-grade Pu, and 30,000–40,000 MWd/t for Pu from nuclear power reactors).

Considering that the total usable volume of Hangar H1 is 2,160 m³, it is estimated that approximately 20–30% of its capacity is occupied. In the mid-1980s, RW was solidified within Hangar H1, not due to a lack of storage space, but to reduce radiation dose rates, which ranged from 0.2 mSv·h⁻¹ to 10 mSv·h⁻¹.

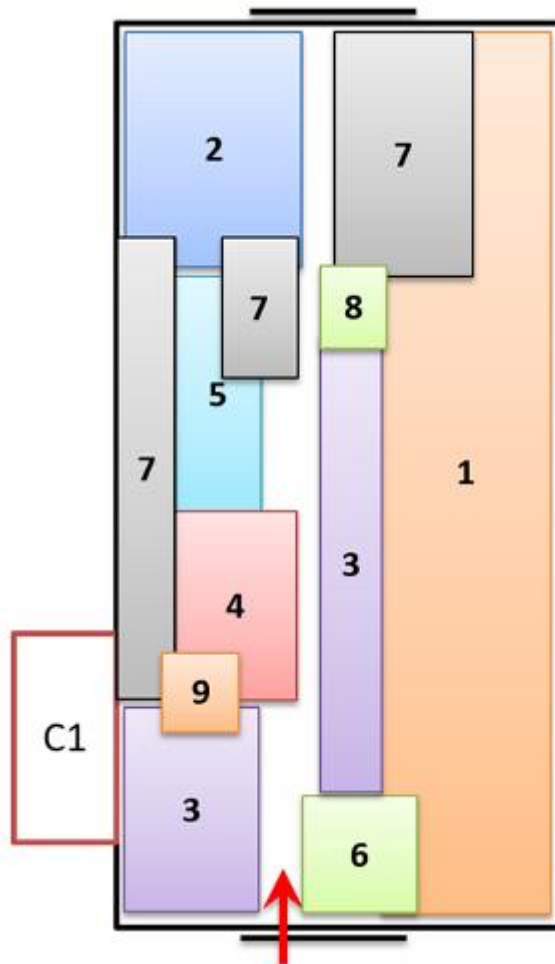


Figure 4: Assumed position of the RW and DSRS in the H1, divided into zones



Figure 5: Photos of the interior of hangar H1- used sealed industrial radioactive sources

2.2 Description of hangar H2 and the surrounding area of H2

Hangar H2, Figure 6, has overall dimensions of 10.5 m × 37.6 m and comprises two principal sections. The first (larger) section is a steel-framed hall clad with corrugated sheet metal, with overall dimensions of 10.5 m × 30.1 m. The second section, measuring 10.5 m × 7.5 m, is a reinforced concrete structure consisting of six interconnected rooms, linked by internal openings and, in one part, by a staircase. This concrete section was originally constructed as a facility intended for the treatment of radioactive waste (RW), however, it has never been commissioned for that purpose. A schematic representation of the concrete section of H2, including its layout and dimensions, is provided in Figures 7 and 8.

For the purposes of the sanitary checkpoint, Figure 6b, a prefabricated, demountable structure composed of steel profiles was constructed, with plan dimensions of 6 m × 6 m and a height of 3.2 m. The structure is equipped with two access doors designated for the passage of materials and personnel, with dimensions of 2.2 m × 2.4 m and 2.0 m × 2.4 m, respectively.



Figure 6: a) Photos of hangar H2 before b) after adding the assembly-disassembly structure at the material inlet and outlet

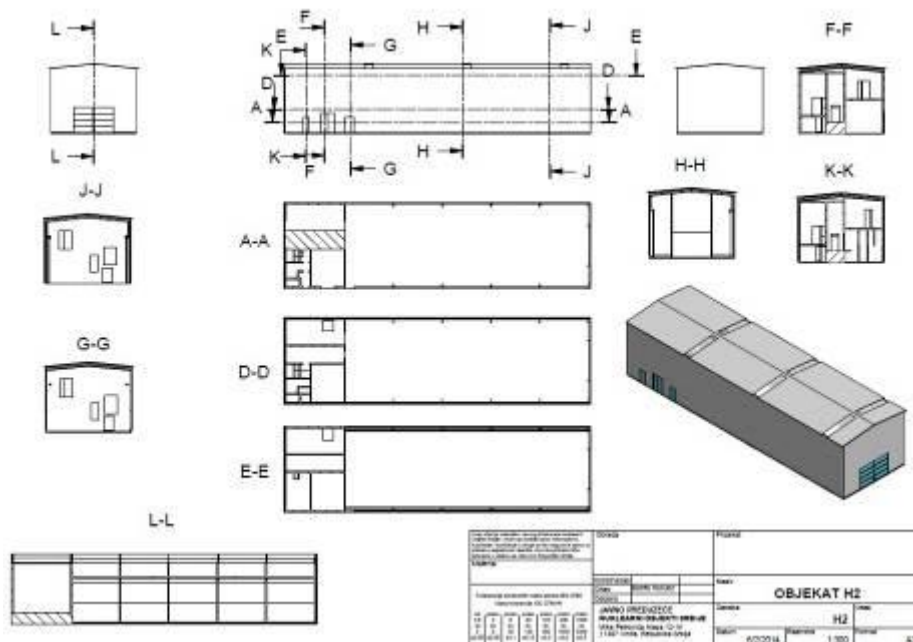


Figure 7: Sketch of different cross-sections of the hangar H2

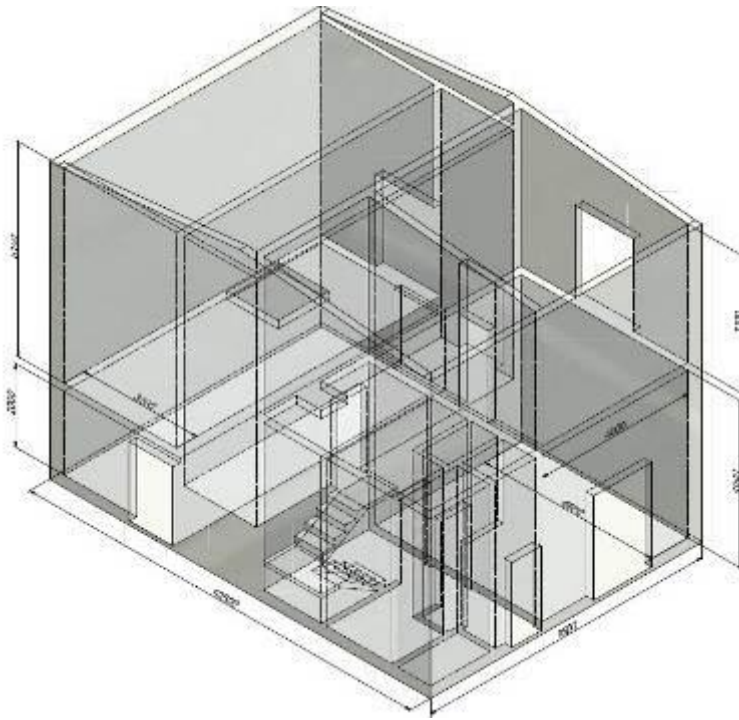


Figure 8: Sketch of the concrete part of the hangar H2

At the interface between the two principal sections (steel-clad and reinforced concrete), four openings are identified, as shown in cross-section “G–G” in Figure 7. Considering hangar H2 as a whole, a total of five doors are present: three located within the concrete section and two within the steel-clad section. The primary folding door (D1 in Figure 9), situated on the north-western side of H2 facing the plateau and hangar H1, serves as the main access point for personnel and equipment and is intended to be used for the import and removal of radioactive waste (RW). The dimensions of door D1 are 486 cm in width and 320 cm in height. A secondary door (D2 in Figure 9), located in the steel-clad section on the north-eastern side, measures 100 cm × 203 cm and functions as an auxiliary access point, designated for personnel entry and exit. In the north-eastern concrete section, two additional doors (D3 and D4 in Figure 9) are present. Door D3 provides access to a dedicated room used for the storage of equipment and unused filtration units, which, according to available documentation, were originally intended for installation as part of a radioactive waste treatment system within the concrete section. This room is not interconnected with the remaining internal spaces, and access through this door is subject to a controlled regime. Door D4 leads to a staircase providing access to other rooms and, consequently, to the steel-clad section of H2. However, this door is currently sealed to ensure nuclear security and is not intended for use. Similarly, the door located on the south-eastern side of H2 (D5 in Figure 9) is also sealed for the same reason. In the south-western part of hangar H2, a separately constructed unit, designated as C2, is located. This unit, consisting of a steel structure clad with sheet metal, was originally used for the storage of equipment and materials, as well as for activities related to potential exemption from regulatory control. At present, it contains various radiation sources and radioactive waste.

2.1.2. RW and DSRS in H2 and the surrounding of the H2

Various types of disused sealed radioactive sources (DSRS) and radioactive waste (RW) are stored in hangar H2. The majority of the hangar’s space is occupied by RW of different origins and compositions, packaged in standard 200 L drums. According to the available data, hangar H2 was commissioned in 1982, and the first significant quantity of RW stored there originated from the remediation of an open landfill carried out in 1984.

By a decision of the competent state authority issued in 2006 (the so-called „zero license”), hangar H2 was used for the storage of limited quantities of RW (due to capacity constraints) until May 2012. A comprehensive overview of the radioactive waste (RW) inventory within hangar H2, including its spatial distribution (Figure 9), is presented in Table 2, based on available historical records ([5], [6]).

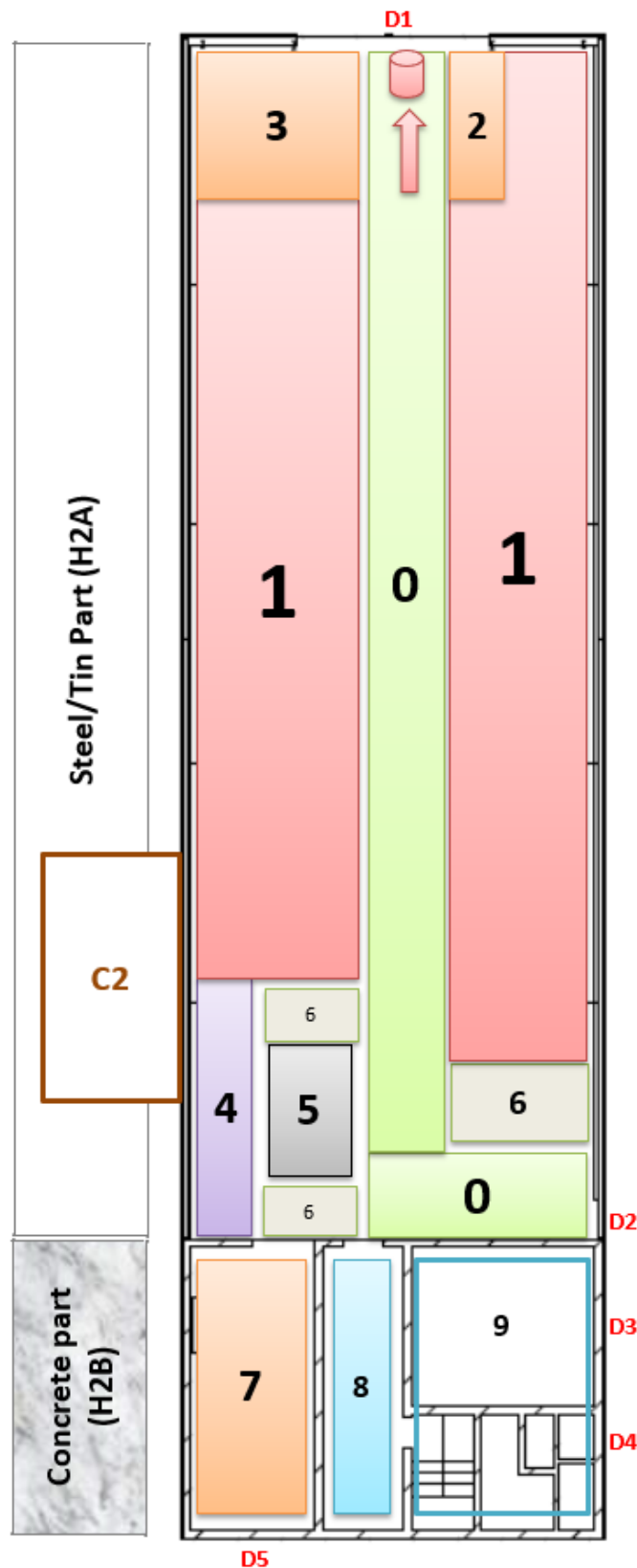


Figure 9: Assumed position of the RW and DSRS in the H2

Table 2: Inventory of the RW and DSRS in the H2 [5,6]

RW stream [1]	DESCRIPTION	Estimated amount	Estimated activity	Position in Fig. 12
E14	Compacted and repacked RW from the former open „repository” (parts of metal and soil)	about 1000 drums	unknown	1
E15	Filters collected after the Chernobyl accident	about 300 drums of 200L (60m ³)	Very low-level waste (VLLW)	1, 8
E16	RW from different users	about 450 drums of 200L(90m ³)	unknown	1
E17	Solidified sludge from the SNF pool	100 drums of 200L (8m ³)	average 165MBq per drum	1
E18	Disused Sealed Radioactive Sources from Lightning Rods	Three drums of 200L 625 pieces ^{152,154} Eu	1 TBq	3
E19	Depleted uranium	3 metal boxes with 300 bullets, two metal boxes with aluminium casing, 100 drums of 200L with contaminated soil (12m ³)	1100MBq (300 × 3.5MBq)	1, 8
E20	Contaminated metal pipes	Metal pipes contaminated with alfa emitters, length 2m, diameter 250 mm (0.2 m ³)	unknown	1
E21	Contaminated scrap metal	8 drums of 200L (1.6m ³)	unknown	1
E22	Compressible operational RW	about 400 drums of 200L (80 m ³)	Low-level waste (LLW) ¹³⁷ Cs	1
E23	Contaminated scrap metal	about 110 drums of 200L (22 m ³)	Low-level waste (LLW) ¹³⁷ Cs	1
E24	Contaminated soil	about 120 drums of 200L (24 m ³)	Low-level waste (LLW) ¹³⁷ Cs	1
E25	Smoke Detectors (SD)	100 000 pieces	about 5GBq (100 000 × 50kBq)	4 and 6
E26	Industrial and other Disused Sealed Radioactive Sources	300 pieces ¹³⁷ Cs 300 pieces ⁶⁰ Co 200 pieces of other DSRS	/	2, 3, 5, 6, 7 and C2
E27	RW from repackaging of spent fuel elements	30 Al containers packed in 25 320 L drums	unknown	5

Hangar H2 is in better overall condition than hangar H1, both in structural integrity and load-bearing capacity, with no significant structural degradation observed. Radioactive waste (RW) in hangar H2 is predominantly segregated and stored in standard 200 L drums with known contents. Disused sealed radioactive sources (DSRS) are generally well organized, maintained in their original working containers, and arranged on appropriate wooden pallets, while radioactive smoke detectors (SD) are stored in a plastic box, also well organised, as shown in Figure 10.



Figure 10: Industrial sources (DSRS) and SD stored in hangar H2

2.3 Operational radioactive waste storage H3, SS and under licensing process WPF

Operational radioactive waste storage facilities are located at the Vinča site and are operated by the „Nuklearni objekti Srbije” LLC, as illustrated in Figures 11 and 12. The operational infrastructure comprises hangar H3 (hangar No. 3), designated for the acceptance of institutional and legacy radioactive waste (RW), the Secure Storage (SS) facility, intended for the storage of high-activity sealed sources, and the Waste Processing Facility (WPF) for the treatment of RW and DSRS.



Figure 11: Operational radioactive waste management facilities H3, SS, DG and WPF



Figure 12: Photos of the interior of hangar H3 and SS

Both facilities (H3 and SS) were constructed following a Government decision adopted in 2010 and subsequently became operational upon receipt of the relevant regulatory licenses in 2012. Hangar H3 has a total storage capacity of 1.260 m³ (26 m × 48 m × 8 m). In accordance with the established waste acceptance criteria (WAC), the facility is designed to accommodate standardised 200 L and 320 L drums, HL–HH ISO containers, as well as conventional ISO containers.

Capacity of DSRS in Secure Storage (SS) is 435 m³ (dimensions 16.1 m × 26.0 m × 4.5 m), and it can accommodate over 6000 of disused sealed radioactive sources (DSRS) of category 1-5, and over 100 000 smoke detectors of category 5.

The Radioactive Waste Processing Facility (WPF), originally designed as a laboratory for the production of transuranic elements—commonly referred to as “Latransa”—was repurposed in 2015 into its current function as the WPF. The facility encompasses an area of approximately 800 m², including 407 m² on the ground floor and 329 m² on the lower ground (main) floor, along with an additional 84 m² of covered space (designated as area NP15 at the level of the lower ground floor).

A license for the trial operation of the WPF was issued by the Regulatory Authority in 2022. The first phase of the trial operation, conducted without radioactive and nuclear materials (the cold phase), commenced in 2022. The second phase of the trial operation, involving radioactive and nuclear materials (the hot phase), commenced in early 2025 and was successfully completed within the same year. Following the completion and subsequent approval of the trial operation, the documentation required for obtaining the operational nuclear license was submitted in December 2025.

2.4 Waste Processing Facility WPF

Within the technological process of the Radioactive Waste Processing Facility (WPF), several auxiliary installations are located in its immediate vicinity, providing support to operational and safety-related functions. These installations include:

- a diesel generator (DG), which ensures the provision of backup power supply;
- an auxiliary chimney facility (P16), which serves ventilation and exhaust functions;
- temporary storage units designated as containers P14 and P15; and
- a mobile unit (P17), as illustrated in Figure 11.

The Waste Processing Facility (WPF) is intended for the treatment of radioactive waste (RW) currently stored in existing storage facilities (H0, H1 and H2), as well as disused sealed radioactive sources originating from lightning protection systems, industrial applications, radioactive smoke detectors and other similar sources. In addition, the facility will process radioactive waste generated during the decommissioning of the RA research reactor, together with other newly generated radioactive waste originating within the Republic of Serbia. The primary objective of waste processing is to condition the waste in a manner that ensures its safe and secure interim storage in facilities such as H3 and the Secure Storage (SS), while also meeting the requirements established

for its eventual disposal. The Waste Processing Facility (WPF) is designed to process solid very low-level waste (VLLW), low-level waste (LLW) and low and intermediate level waste (LILW), in accordance with the established waste acceptance criteria (WAC) applicable to the WPF.

Disused sealed radioactive sources of Categories I and II, as well as leaking sources, will not be accepted at the WPF. The conditioning of such sources will be carried out in the hot cells of the RA nuclear reactor.

The inventory of radioactive waste (RW) currently stored in existing storage facilities H0, H1 and H2, together with the waste that will be generated during the decommissioning of the RA research reactor, as well as the projected radioactive waste expected to arise in the future within the Republic of Serbia, taking into account the currently adopted radioactive waste processing technology as defined in the technological design [7], has led to the identification of three primary RW streams, as follows:

- **Stream T1:** Solid radioactive waste of very low, low and intermediate activity levels, delivered to the Waste Processing Facility (WPF) in standard packaging (most commonly 200 L metal drums), in temporary packaging suitable for transport, or unpackaged in cases where no non-fixed contamination is present and/or where the waste is otherwise conditioned or handled in a manner that prevents the spread of contamination.
- **Stream T2:** Disused sealed radioactive sources (DSRS), delivered to the WPF either in their original housings or in transport containers. Within this stream, the following output sub-streams are defined:
 - o Sub-stream 2.1: Consolidated capsules containing sources that are not welded;
 - o Sub-stream 2.2: Consolidated capsules containing sources that are welded within the mobile unit (room P17).
- **Stream T3:** Radioactive smoke detectors (SD), delivered to the WPF in plastic boxes, standard drums or other transport-suitable packaging. Within Stream T3, the following sub-streams are defined:
 - o Sub-stream 3.1: SD containing ^{226}Ra ;
 - o Sub-stream 3.2: SD containing ^{241}Am .

The radioactive waste RW processing technology applied in the Waste Processing Facility (WPF) comprises the stages of pretreatment, treatment and conditioning of radioactive waste. This includes the characterization, sorting and segregation of RW, decontamination, volume reduction by compaction, as well as processing activities involving the conditioning of disused sealed radioactive sources (DSRS) and dismantling radioactive smoke detectors (SD).

The complete technological process for the treatment of radioactive waste (RW) will be carried out at the ground floor level- main floor of the Waste Processing Facility (Figure 13) as follows:

1. Radiological characterization of RW and DSRS in room P13;
2. Sorting, segregation and classification of RW, compaction of RW in drums, and compaction of empty drums in room P6;
3. Conditioning of DSRS of Categories 3 and 4 in room P11;
4. Welding of a collection stainless steel capsule containing sources in the mobile unit located in room P17; and
5. Dismantling and disassembly of smoke detectors (SD) in room P10.

The balance between minimizing the total volume of radioactive waste (RW) to the extent reasonably achievable and the resources required to do so forms the basis for assessing individual operations or the overall processing of a specific waste type or stream, in accordance with the ALARA optimization principle. The proposed technical solutions presented in the technological design [7], together with internationally recognized good practice applied in similar radioactive waste processing facilities worldwide, and taking into account the limitations of the available space within the facility (including the size and layout of rooms distributed over two levels), have defined the feasible framework for the implementation of activities related to the treatment of RW and the conditioning of radioactive sources.

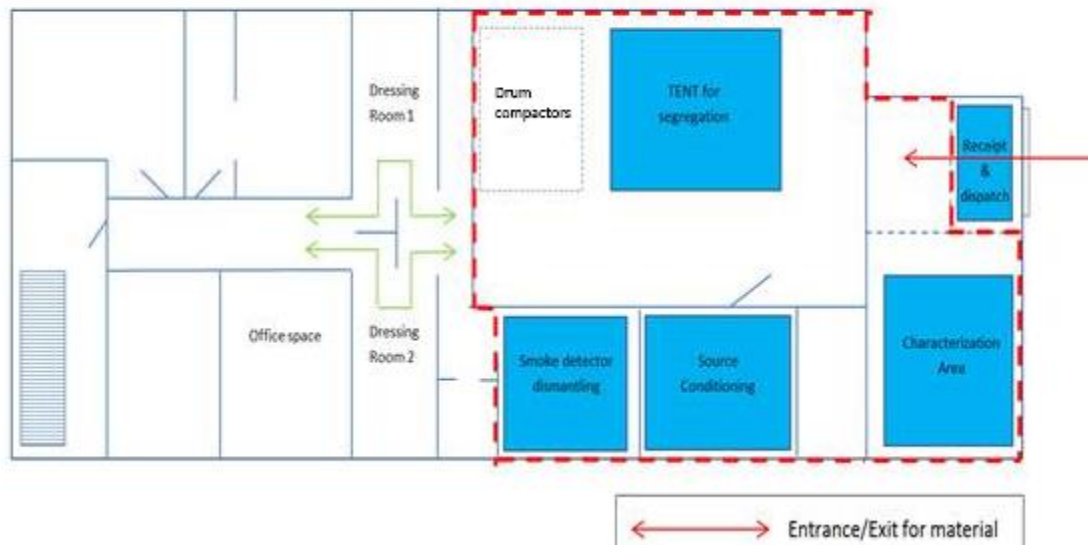


Figure 13: Main floor of the WPF for processing RW

2.4.1. Characterisation of RW

The delivery and receipt of radioactive waste (RW) and disused sealed radioactive sources (DSRS) are carried out within the designated receiving and dispatch area of the Waste Processing Facility (WPF), identified as area NP15. In this area, incoming RW packages are pre-sorted and grouped according to similar characteristics, thereby forming defined processing campaigns. From area NP15, RW packages are transported by forklift to the radiological characterization area (room P13), where both preliminary and final characterization activities are performed.



Figure 14: Equipment for non-destructive characterisation of RW with rotating stands

Room P13 is equipped with two in situ measurement systems for radionuclide identification and assessment of the ambient dose equivalent rate within the packages (Figure 14). These systems include a high-purity germanium (HPGe) detector (BE2825–Canberra) and a portable germanium-based detector (DetectiveX).

The determination of specific activity for a standard 200 L drum is performed across three or more measurement zones, applying a methodology for assessing the spatial distribution of radionuclides. A dedicated domestic software tool for numerical efficiency calculation is used to support the evaluation of radionuclide distribution within RW packages.

After completion of the treatment of radioactive waste (RW) and disused sealed radioactive sources (DSRS) in the Waste Processing Facility (WPF), and before storage in H3 or the Secure Storage (SS), final radiological characterization of the outgoing RW package is performed in the same room P13, together with verification of compliance with the acceptance criteria for storage in H3 or for safe storage in SS.

2.4.2. Sorting, classification and segregation of solid RW

After the preliminary radiological characterisation of the incoming radioactive waste (RW) package is completed, a standard 200 L drum is transferred to a ventilated enclosure maintained under negative pressure ($\Delta p \approx -25$ Pa) relative to the surrounding environment, i.e., the RW treatment room P6. A schematic representation of the ventilated enclosure, including the arrangement of key elements required for work organisation within this specially controlled area, is shown in Figures 15 and 16.

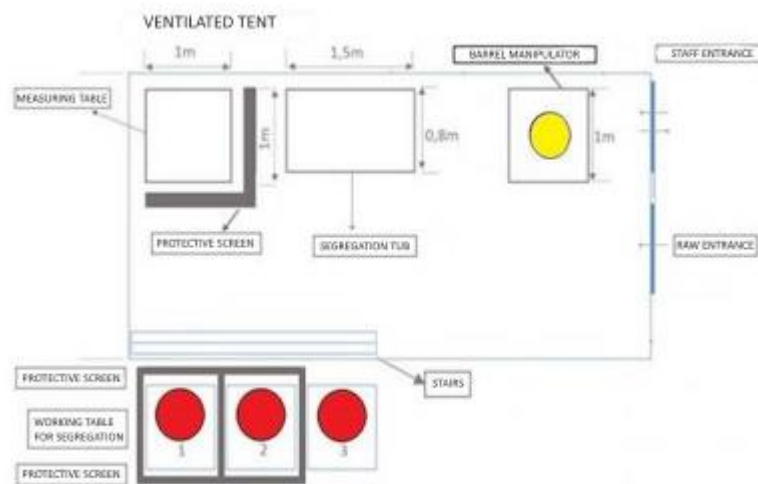


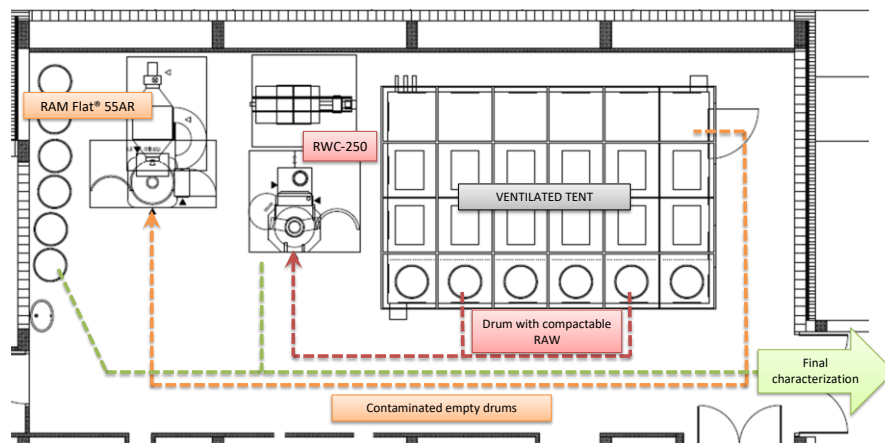
Figure 15: Workspace layout in a ventilated tent



Figure 16: Photos of the ventilation tent

The RW processing technology (flow T1) comprises the following principal operations:

- Opening of incoming RW packages;
- Pretreatment of RW: removal of individual waste items from the drum, sorting and segregation according to established criteria (compactible and non-compactible waste), cutting using hydraulic tools/shears, repackaging into plastic bags and new RW containers of up to 50 L, and formation of specific waste streams and output RW packages;
- Additional radiological characterization within the enclosure using a measurement system equipped with a NaI detector; based on the measurement results, further segregation of compactible waste into clean and radioactive fractions is performed, along with surface activity measurements of non-compactible waste (metal, wood, plastic, rubber) using GM probes;
- RW treatment: compaction of RW in drums (compactor RWC-250) and compaction of empty drums (compactor RAM Flat 55AR) (Figure 18), repackaging of compacted empty drums into an HL-HH ISO container, and formation of output RW packages in room P6;
- Transfer of output RW packages to the storage area for processed RW (room P14) and/or to room P13 for final radiological characterization;
- Final characterization of output RW packages, including in situ gamma spectrometric measurements and entry of data into a centralized RW package database (room P13);
- Transport of output RW packages to hangar H3.



Sketch of area for RAW compacting (room no. 6) in the WPF
 (Red - RAW flow for in drum compacting of compactable RAW after sorting in ventilated tent by RWC-250 compactor; Orange - RAW flow for crushing of the empty contaminated drums by RAM Flat 55AR compactor, Green - packages of RAW after compaction will be dispatched to the area for final characterization)

Figure 17: Disposition of equipment in the room for RW treatment



Figure 18: Compactors for RW in-drum compacting and compacting empty drums

2.4.3. Conditioning of disused sealed radioactive sources (DSRS)

The room designated for the conditioning of disused sealed radioactive sources (DSRS), room P11, is specifically designed and equipped for the repackaging of Category III and IV sealed sources - primarily industrial sources and lightning rod sources. These sources are transferred from their original housings, devices, or existing transport containers into specialized stainless steel collection capsules and shielded lead containers that meet the acceptance criteria for storage in the secure storage facility (SS). The conditioning of leaking sources, as well as Category I and II sources, is not performed in room P11.

To ensure safe handling, a dedicated „hot cell” has been installed within room P11. This system comprises an auxiliary workbench and a main workbench equipped with shielding screens, a lead brick wall, lead glass with hand access ports, and an additional barrier constructed from concrete blocks.

The shielding elements of the hot cell are designed to protect both the operator’s upper body and legs. In the upper section of the workbench, lead shielding is provided in the form of lead bricks and protective lead glass ($\rho = 5 \text{ g/cm}^3$), with dimensions of $400 \times 400 \times 140 \text{ mm}$. In the lower section, concrete blocks are used as a shielding barrier (Figure 19). The thickness of the lead shielding between the operator and the work area where source handling is performed is 10 cm, while the lead shielding thickness at the workbench where source removal takes place is 5 cm. The thickness of the concrete shielding barrier is 10 cm.

The height of the protective barrier is ergonomically optimized for an operator of average height ($185 \text{ cm} \pm 5 \text{ cm}$), enabling safe and efficient manipulation using manual tools such as manipulators, tongs, and long tweezers while maintaining an upright working posture. The structural components of the workbenches are made of steel, whereas the working surfaces are constructed from stainless steel to facilitate efficient and reliable decontamination.

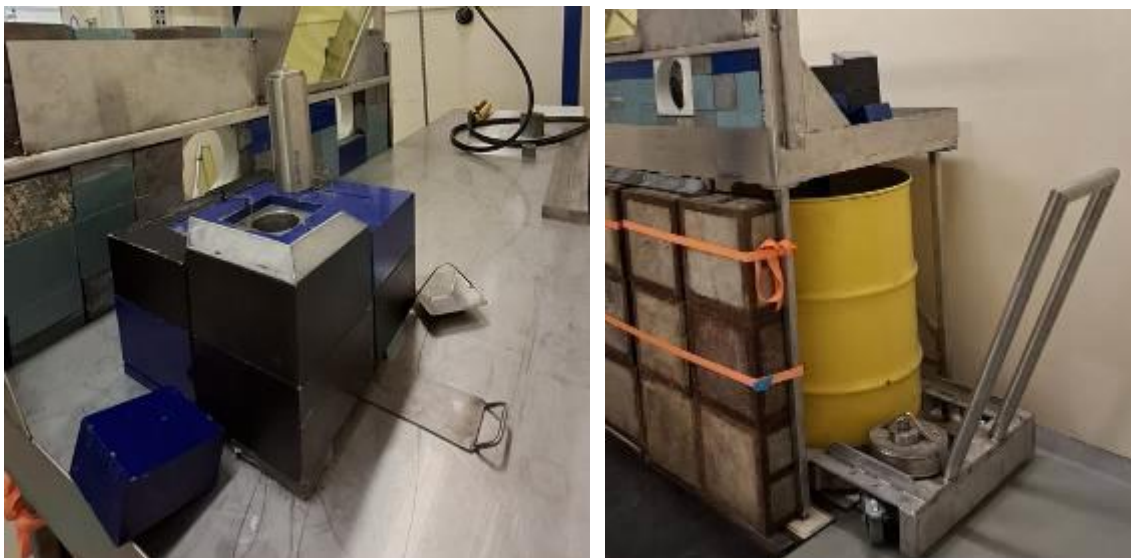


Figure 19: View of lead shielding around the collection capsule on the workbench and a barrel cart with concrete shielding

In room P11, equipment is installed for measuring the ambient dose equivalent rate of gamma radiation, including an FHZ-612 probe connected to an FH40G-X device, as well as a system for continuous air monitoring in the working environment.

In addition, systems for recording and monitoring conditioning activities involving radioactive sources have been implemented. Three cameras are installed, one of which is equipped with high resolution and zoom capability, along with a monitor positioned to provide the operator with clear and convenient visual access.

On the workbench equipped with lead shielding screens and protective lead glass, the container/housing is opened, and the source holder and/or the source is removed. The source is then positioned for the measurement of the ambient dose equivalent rate of gamma radiation. In this position, the identification of the source and its activity are verified, photographs are taken, and relevant data are recorded. Also, the serial number of the source is recorded visually and its dimensions are recorded using a camera. Following the procedure, the source is transferred using manual tools (tongs, long tweezers), depending on its size and physical form, into appropriate collection capsules made of stainless-steel type 316L.

Filling of the stainless-steel collection capsule is performed using a suitable funnel. The dimensions of the collection capsules are provided in Table 3. The appearance of different capsule types is shown in Figure 20. The number of capsules and their arrangement within the collection container are defined before the conditioning campaign for a specific type of DSRS. Only sources containing the same radionuclide are intended to be packaged within a single capsule.

Table 3: Dimensions of collection capsules for conditioned DSRS

	Type of collection capsules for conditioned sources			
	SCC-S2	SCC-S3	SCC-S4	IAEA SCC-R L2
Outer diameter D (mm)	21,3	33,7	42,4	65
Inner diameter d (mm)	17,3	29,7	38,4	55
Col	1/2 ”	1 ”	5/4 ”	/
DN	15	25	32	/
Total height / height without lid (mm)	170/160			195/185



Figure 20: Stainless-steel capsules for conditioned sources showing the packaging of SCC-S2/S3/S4 capsules into an IAEA SCC-R L2 capsule

If the source being conditioned has dimensions that do not fit the predefined capsules, as is the case with ⁶⁰Co sources originating from radioactive lightning rods, it is packaged directly into the collection container.

The stainless-steel collection capsule, into which sources are placed, is positioned on the workbench within a steel support frame and surrounded on all four sides by lead shielding with a thickness of 15 cm / 10 cm. A 5 cm thick lead brick is placed over the stainless-steel collection capsule after each addition of a source (Figure 19).

When the target ambient dose equivalent rate of gamma radiation is reached within the collection capsule, the capsule is closed by fastening the lid using a cordless angle screwdriver. Depending on requirements, SCC-S2/S3/S4 capsules may be further packaged into an SCC-R L2 capsule, manufactured in accordance with IAEA recommendations and suitable for placement in a so-called disposal container for DSRS in boreholes. The SCC-R L2 capsule is also made of 316L stainless steel.

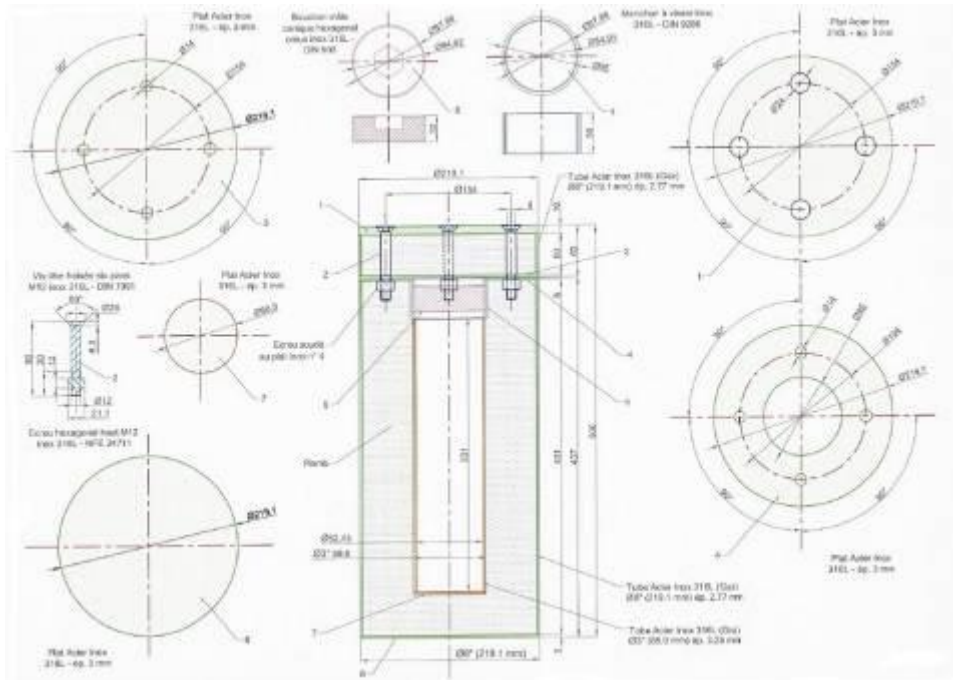


Figure 21: The technical drawing of the protective lead container for the collection capsule with conditioned sources

Beneath the conditioning workbench, a 200 L concrete-shielded drum is placed on a special trolley. The drum contains 623.3 mm of lead and 173 mm of concrete shielding, within which a protective lead container is located (Figure 19). The technical drawing of the protective lead container is shown in Figure 21. A transfer channel is used for moving the filled stainless steel collection capsule into the protective lead container. This transfer is performed for DSRS whose collection capsules are not welded closed. Once the stainless-steel collection capsule containing the sources is placed inside the protective lead container and the concrete-shielded drum, the drum is removed from below the workbench and transported to the secure storage facility (SS).

In cases where collection capsules containing DSRS (e.g., ^{226}Ra , ^{90}Sr , ^{241}Am , ^{137}Cs , and neutron sources such as Ra-Be, Am-Be, Pu-Be) are intended for welding, the stainless steel capsule is transferred into a lead-shielded container and moved to a mobile conditioning unit, where it is positioned for automatic welding under remote operation, ensuring operator safety at a distance. The mobile unit is a container with dimensions of 6058x2438x2590, the external appearance is shown in Figure 22. The mobile unit contains a workbench equipped with lead-shielded screens, lead glass, and manipulators, as well as sorting shelves with hand and power tools. It also includes a welding machine (Figure 22) with a wire feeder, an argon cylinder, a lead-shielded metal container, and equipment for testing the hermeticity of welded capsules (Figure 23).



Figure 22: Mobile unit for welding collection capsules, automatic capsule welding machine

After welding, the integrity of the weld is verified using a „bubble test“. Capsules with an acceptable weld are cleaned, briefly drained of glycerin oil, and returned to the protective lead container, while those with defective welds are sent back for re-welding with the addition of welding material. Finally, the shielded container is placed into a concrete-shielded drum and transported to the secure storage facility (SS).

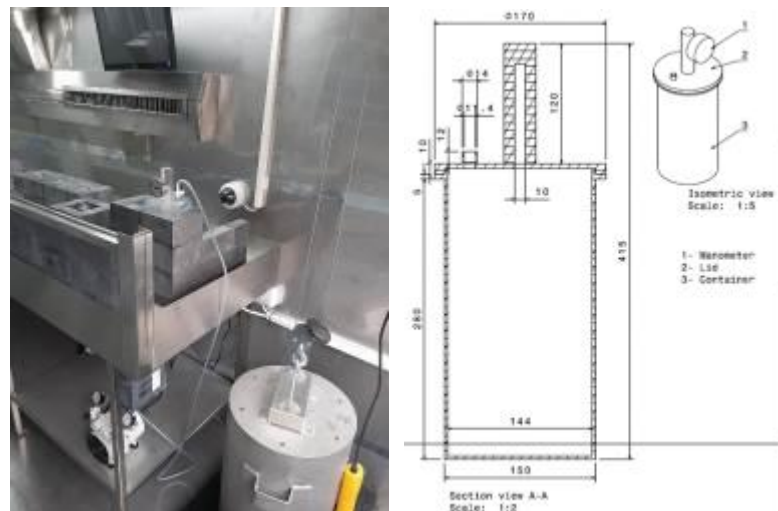


Figure 23: The technical drawing and photo of the equipment for testing the tightness of a welded stainless steel collection capsule „bubble test“

2.4.4. Conditioning of smoke detectors (SD)

For dismantling and disassembly of radioactive smoke detectors (SD), room P10 is equipped with four workbenches and one glove-box fume hood (Figure 24). SDs are delivered to the WPF facility in plastic boxes, standard drums, or other transport-appropriate packaging. In the radiological characterization room P13, accompanying documentation is checked and preliminary radiological characterization is performed. Using a Ge detector, the energy spectrum of photons from the plastic box is measured, enabling identification of radionuclides (^{226}Ra / ^{241}Am). Measurement results are recorded and entered into the database. After preliminary characterization, the box with SDs is transferred to the room P10.



Figure 24: Working area for the condition of Cat. 5 DSRS

If preliminary radiological characterization confirms a ^{226}Ra SD, the box is opened, and the SDs are repackaged directly into a stainless-steel collection capsule placed within a concrete-shielded drum, without dismantling or disassembly of the ^{226}Ra SD. The stainless-steel collection capsule has a diameter of 12 cm and a height of 39 cm and is positioned inside a concrete-shielded drum with a wall thickness of 12.5 cm. Once the capsule is filled with ^{226}Ra SDs, it is sealed, and the concrete-shielded drum is transported to the mobile unit for welding.

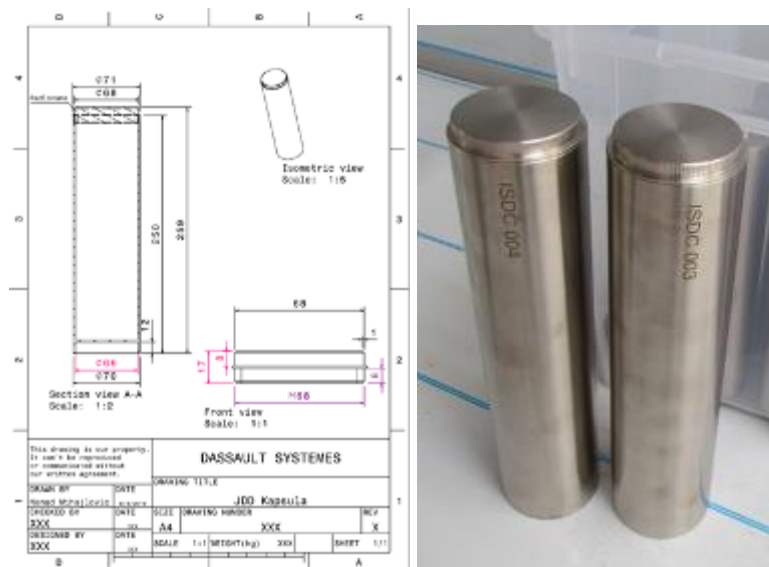


Figure 25: The technical drawing of a stainless-steel capsule (a type 316L) for SD, photo of a stainless-steel capsule for source from SD

If preliminary characterization confirms a ^{241}Am SD, the box is opened, and a representative dry (paper) smear is taken from the external surface of the SDs. The smears are measured using a spectrometer equipped with a thin NaI or ZnS probe. Based on the measured total alpha activity of ^{241}Am on the smear, the SD is transferred either to a workbench or to the glove box. Dismantling and disassembly of non-contaminated SDs are performed on the workbench, while contaminated SDs are transferred to the glove box, where dismantling and disassembly are also carried out.

In both cases, the radioactive components (wires or metal strips) are separated from the plastic housing and printed circuit board and placed in a Petri dish. At the end of the working day, the collected sources are transferred from the Petri dish into a 316L stainless steel collection capsule (Figure 25).

Once the collection capsule is filled, it is transported to the mobile unit, where automated welding is performed using a welding device integrated into the system. The welded capsule is then transferred using a manipulator into a “bubble test” vessel for weld integrity verification. If the weld is satisfactory, the capsule is moved to a tray to allow drainage of glycerin oil and subsequently placed into a concrete-shielded drum. The drum is then transported to the secure storage facility (SS). In the case of an unsatisfactory weld, the capsule is returned for re-welding with the addition of welding material.

Segregation of contaminated SD components is carried out to minimize radioactive waste generation, while ensuring an optimal level of disassembly from the original housing. Contaminated components are conditioned into radioactive waste packages (standard 200L drums), while components meeting clearance criteria are packaged separately in 200L drums intended for clearance. This waste is transferred to room P13 for final radiological characterization, where non-active components are verified for compliance with regulatory exemption criteria (clearance), in accordance with the decision of the regulatory authority. Measurement results are recorded in the centralized radioactive waste database.

Nuclear activities in the WPF facility are planned and carried out in campaign-based operations, meaning that for SD conditioning, tools for dismantling and disassembly are pre-selected and prepared in advance, depending on the type of SD to be processed. The equipment for continuous monitoring of air quality in the working environment operates continuously throughout the conditioning activities. The filter paper from the system is spectrometrically analyzed at the end of each day, and the measurement results are recorded.

3 CONCLUSION

Legacy radioactive waste management at the Vinča site is implemented by the „Nuklearni objekti Srbije” LLC, with a strong focus on the development and operation of the Radioactive Waste Processing Facility (WPF). This facility represents the central technological element of the ongoing VIND Programme and a key step toward establishing an integrated waste management system.

The legacy waste originates from the former Yugoslav nuclear programme and institutional activities and is mainly stored in hangars H1 and H2, as well as liquid waste tanks at the site. The WPF enables the safe characterization, processing, and conditioning of these waste and disused sealed radioactive sources, allowing their transfer to interim storage in hangar H3 or secure storage (SS), in accordance with defined waste acceptance criteria.

Ongoing activities focus on the removal and processing of waste from legacy facilities, supported by international cooperation and primarily national funding. The continued development and use of the WPF, together with the decommissioning of H1 and H2, are essential for resolving the legacy waste issue at the Vinča site and ensuring long-term nuclear safety and environmental protection in Serbia.

REFERENCES

- [1] The Law on Protection from Ionizing Radiation and Nuclear Safety („Official Gazette of the RS”, No. 36/2009)
- [2] INTERNATIONAL ATOMIC ENERGY AGENCY, The Management Wastes Produced by Radioisotope Users, IAEA Safety Series No. 12, 1965.

- [3] INTERNATIONAL ATOMIC ENERGY AGENCY, Radioactive Waste Disposal into the Ground, IAEA Safety Series No. 15, 1965.
- [4] INTERNATIONAL ATOMIC ENERGY AGENCY, The Management of Radioactive Wastes Produced by Radioisotope Users, - Technical Addendum, IAEA Safety Series No. 19, 1966.
- [5] Institute, Radioactive waste management strategy in the VINČA Institute, Serbia, QM.1.RAO.000.01, Rev. 1.0; October 12, 2006, and Rev. 4, 2008.
- [6] Statement of Work for implementation of radioactive waste processing and decommissioning activities at the Vinča site, Serbia”, IAEA-TC Revision 1.0 of 28.11.2013.
- [7] Detailed Design Project, Volume 7 – Process Technology Design, Faculty of Technology and Metallurgy, University of Belgrade, June 2019.