

EURAD-2 Milestone 71 – Selection of specific use cases to test the developed NDT and methods in relevant industrial conditions



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Executive Summary

Milestone 71 (MS71) defines the **selection of specific industrial use cases** that will be used to validate and optimize innovative **Nondestructive Techniques (NDT)** developed within the **ICARUS (WP5)** work package of **EURAD-2**. Its objective is to support improved **radiological, physical, and chemical** characterization of large LLW/ILW waste volumes by identifying representative scenarios where NDT methods can be tested under realistic operational constraints.

This document is intended as a **working, living resource** and may be expanded through **future addenda** as WP5 develops new measurement capabilities, refines requirements, or integrates additional partner feedback.

The selected cases reflect recurring geometries, waste types, and radiological characteristics observed across Europe’s waste management organizations, including WP5 **partners and End Users**. They form the basis for evaluating the performance of the full suite of **NDT**, such as open and closed geometry gamma spectrometry, neutron-based methods, density and mass distribution measurements, and other physical and radiological NDT approaches.

Three representative use case categories were synthesized for MS71:

1. **Open geometry gamma spectrometry** for rapid activity assessment and hotspot detection in shallow containers.
2. **Closed geometry gamma spectrometry** for drums and large steel containers, enabling improved activity distribution mapping and WAC related checks.
3. **Neutron-based characterization** for fissile and fissionable material quantification and structural anomaly detection in heterogeneous waste packages.

These use cases will directly support **Task 3 (NDT Design)** and provide a structured basis for harmonizing and validating EURAD-2’s innovative NDT approaches in relevant industrial conditions, ultimately improving characterization accuracy and operational efficiency across predisposal waste management practices in Europe.

Keywords

EURAD-2, ICARUS, nondestructive techniques (NDT), radiological, physical, chemical, characterization, gamma spectrometry, open geometry, closed geometry, neutron-based characterization, hotspot detection, WAC compliance, fissile mass quantification, cylindrical drums, prismatic containers, machine vision, database processing

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1. Introduction

The selection of the three use cases presented in this milestone is the result of a synthesis of the common patterns identified across the EURAD2 WP5 dataset, which includes contributions from ENEA, NCSR, NTUA, CIEMAT, CSIC, SSTC NRS, FTMC, NRG Pallas, and SCK CEN, as well as from End User organizations such as SOGIN. These contributors provided a wide variety of geometries, radionuclide inventories, waste types and measurement setups, from which recurring and representative features could be extracted.

Milestone 71 (MS71) aims to define a set of specific test concepts —not techniques— for validating and optimizing the suite of NonDestructive Technique (NDT) developed in ICARUS (WP5) of EURAD2. These use cases serve as realistic and operationally relevant scenarios where innovative NDT methods can be deployed, compared, and progressively improved in the coming years. The focus is on physical, radiological and chemical NDT techniques, in alignment with the ICARUS objectives established within EURAD2.

This document is intended to be a working and evolving resource. As WP5 advances, new measurement capabilities, additional partner inputs, enhanced uncertainties analyses or new industrial requirements may emerge. Consequently, future addenda may be added over the project lifetime to refine or extend the selected use cases. This ensures flexibility while maintaining a clear, shared reference framework for all WP5 stakeholders.

The three consolidated use cases were selected because they represent robust test environments that cover the full spectrum of NDT application challenges encountered in industrial predisposal waste management. Rather than choosing partner specific configurations, the selection emphasizes generic measurement situations that stress different aspects of NDT performance— open vs. closed geometry, accessible vs. inaccessible measurement points, homogeneous vs. heterogeneous matrices, and radionuclide vectors ranging from simple gamma emitters to fissile materials. These use cases therefore provide a common ground for all WP5 subtasks (radiological, physical, chemical) to benchmark and coordinate their methodological developments.

Briefly, the three are representative use cases. For the purposes of this milestone, “open geometry” refers to measurement configurations in which the detector has direct or unobstructed access to the waste surface (e.g. shallow prismatic containers with the lid open or removed), allowing flexible detector placement and supporting measurements during filling. “Closed geometry” refers to configurations in which the waste is fully enclosed in a sealed container (drums, large prismatic packages) and the detector must characterize the content through the container walls, requiring dedicated efficiency calibration, attenuation correction, and typically a rotating or multi-point measurement protocol:

- **Open geometry gamma spectrometry:** ideal for shallow, prismatic or unsealed volumes where rapid activity determination and hotspot detection are required.
- **Closed geometry gamma spectrometry:** suited for drums and large steel containers, where WAC related compliance, internal activity distribution and attenuation effects must be managed.
- **Neutron based characterization:** essential for scenarios where verifying the presence or absence of fissile isotopes, or detecting shielding and structural anomalies, plays a critical role.

Together, these use cases provide a structured, manageable starting point for WP5 Task 3 (NDT Design). They ensure that partners’ efforts converge on common test concepts that are both feasible with the available equipment and meaningful for long term EURAD2 objectives. Over the next years, these cases will act as the backbone for harmonizing and validating ICARUS NDT methods under realistic industrial conditions, supporting improved accuracy, reduced uncertainties, and more efficient predisposal waste management practices across Europe.

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2. Use Case 1 – Gamma Spectrometry in Open Geometry

This case reflects commonalities from METADEC-NCSR, FTMC, RUBICK-ENEA and similar setups, using open-geometry gamma spectrometry.

- Rectangular or shallow prismatic carbon-steel containers (0.1–1 m³)
- Metallic or mixed waste (metals, soil, cement, filters)
- Typical radionuclides: Co-60, Cs-137, Am-241, Ni-63, Ni-59, Fe-55, Eu-154
- Gamma spectrometry in open geometry using 2–4 detectors
- Goals: fast total activity determination (<30% uncertainty at 95% confidence level) of mixed VLLW/LLW waste, hotspot identification and localization with spatial resolution below 10 cm, and generation of 3D activity maps to support decision-making on further waste treatment. The innovative added value with respect to the state of the art lies in the multi-detector open-geometry approach combined with Machine Vision integration, enabling real-time monitoring during container filling and reducing measurement time by a factor of 2–4 compared to single-detector segmented scanning.
- Opportunities: direct visual access enables Machine Vision integration for surface mapping and physical characterization; measurements during container filling allow real-time activity tracking and reduce overall characterization time; synergy with database processing allows cross-referencing of measurement results with historical records and waste declaration forms.

3. Use Case 2 – Gamma Spectrometry in Closed Geometry (Large Containers)

This case aggregates characteristics from CIEMAT/CSIC, End User facilities (SOGIN), and SCK-CEN large-container systems.

- Cylindric drums (220–280 L) or prismatic 1000–1500 L containers in carbon steel. The smaller drums are representative of the most common operational packages; the larger prismatic containers represent the scale-up challenge with increased self-attenuation and heterogeneous source distributions that are directly within the WP5 scope.
- Waste types: cemented resins, rubble, metals, mixed dismantling waste
- Radionuclides: Cs-137, Co-60, Ni-63, Ni-59, Fe-55
- Closed-geometry gamma spectrometry using HPGe, LaBr₃, CeBr₃ detectors
- Goals: verification of compliance with Waste Acceptance Criteria (WAC — the set of radiological, physical and chemical requirements that a waste package must satisfy for acceptance at a disposal or storage facility); accurate reconstruction of the 3D internal activity distribution to account for self-attenuation and source heterogeneity; transport classification according to IAEA A2-value limits; and uncertainty quantification of the total package activity. The innovative contribution with respect to the state of the art is the combined use of HPGe, LaBr₃ and CeBr₃ detectors in a tomographic rotating configuration, enabling activity-distribution mapping beyond what is achievable with conventional single-point or single-detector systems.
- Opportunities: integration of advanced data management and tracking systems to correlate characterization results with historical records, operator declarations and prior measurements; use of Monte Carlo simulation codes (e.g., MCNP, GEANT4) for efficiency calibration without physical standards; potential synergy with Machine Vision for external package inspection and physical anomaly detection.



Fig.1 Example of a modular assembly to be treated as open or closed. [CIEMAT Year 1].

4. Use Case 3 – Neutron-Based Waste Characterization

This case synthesizes neutron-based analysis approaches from RUBICK-ENEA, CIEMAT neutron integrations, and legacy-waste work.

- Cubic or cylindric steel containers (50–200 L) or prismatic containers (1000–1500 L) in carbon steel, sometimes with internal compartments. The smaller containers (50–200 L) represent typical laboratory and experimental configurations where neutron interrogation is well established; the larger prismatic containers represent the industrially relevant scale where spatial mapping of fissile content and shielding anomaly detection under realistic attenuation conditions are critical, in full alignment with WP5 objectives.
- Mixed waste (metals, organics, cement, plastics)
- Passive neutron counting and active neutron interrogation
- Goals: Goals: determination of Pu-240 effective mass via passive neutron counting (with <15% uncertainty target) and U-235 effective mass via active neutron interrogation; detection of localized shielding anomalies (e.g., unintended dense inserts or voids) affecting neutron transport; and validation of Monte Carlo transport simulations against experimental data. The innovative value lies in combining passive and active neutron methods within a unified measurement protocol, enabling simultaneous quantification of both fissile and fissionable isotopes — a capability not routinely available in current industrial characterization systems.
- Opportunities: integration of Machine Vision for real-time monitoring of waste loading and physical anomaly detection; measurements during container filling to reduce post-conditioning uncertainty; data-management processing linking neutron measurement results with operator declarations and gamma spectrometry data for a comprehensive, multi-technique package characterization record.

ANNEX – Test Cases Survey Overview The full survey of use cases collected from WP5 partners and End Users is documented in the companion file EURAD-2_ICARUS_T03_UseCases_v1.xlsx (accessible to WP5 partners on the project SharePoint). The table below summarizes the key attributes of all ten use cases that informed the synthesis presented in this milestone.

Overview of the ten use cases collected from WP5 partners and End Users:

Case 1 – RUBICK (Italy, ENEA): Cubic metallic box (70 cm × 70 cm × 70 cm) subdivided into 8 sub-boxes of different matrix materials (wood, neoprene, paper, iron, heterogeneous mixtures). Techniques: gamma scanning (CAEN/ENEA) and active/passive neutron (ENEA, simulations). Goals: volumetric density distribution mapping and benchmark for all other WP5 techniques.

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Case 2 – Not-conditioned ILW (Italy, SOGIN – End User): Large prismatic carbon-steel container (10 m³, 170 × 340 × 170 cm), solid mixed dismantling waste, total activity 4.2 GBq. No measurement technique assigned at survey date; candidate for active neutron interrogation and closed-geometry gamma spectrometry.

Case 3 – Conditioned LLW (Italy, SOGIN – End User): Cylindric carbon-steel drum (550 L, 1097 × 800 mm), spent ion-exchange resins cemented in homogeneous matrix, 20 GBq total activity. Techniques: closed-geometry gamma spectrometry (Tractebel, simulations) and wireless passive monitoring system with LoRaWAN (UNUPI). Goals: uncertainty optimization for large volumes and real-time dose rate monitoring.

Case 4 – METADEC (Greece, NCSR D): Rectangular shallow prismatic carbon-steel container (120 × 120 × 30 cm, 100–300 kg), VLLW/LLW metallic or mixed waste on conveyor belt. Technique: open-geometry gamma spectrometry with 4 detectors. Goal: fast activity determination <30% uncertainty, 2 min per box, MDA 0.1 Bq/g.

Case 5 – VLLW/LLW drum (Greece, NCSR D/NTUA): Cylindric drum (280 L), metals or conditioned waste after super-compaction, up to 1000 kg. Technique: closed-geometry gamma spectrometry with 2–4 HPGe/BEGe detectors on rotating table. Goal: fast activity determination exploiting Compton scattering for activity localisation.

Case 6 – VLLW/LLW demonstrator (Spain, CIEMAT/CSIC): Prismatic carbon-steel container (1320 L), metallic debris, sand and mortar. Techniques: gamma spectrometry (Ge, LaBr₃, CeBr₃) plus neutron counters and ultrasound. Goals: WAC/clearance verification, Cm-244 evaluation via neutron detection, mass distribution mapping, and MC simulation benchmarking.

Case 7 – VLLW/LLW drums (Ukraine, SSTC NRS): Cylindric drum (200 L), historical waste from temporary storage facilities with highly variable inventory (sand, mortar, wood). Technique: open-geometry gamma spectrometry (1 detector). Goal: determination of activity, confirmation of absence of hot spots, WAC compliance, selection of further processing method.

Case 8 – LLW/ILW surface samples (Lithuania, FTMC/INPP): Flat carbon-steel samples (50 × 50 × 10 mm), no matrix filling, LLW/ILW surface contamination for laser decontamination support. Technique: open-geometry gamma spectrometry (1 detector). Goal: surface/volume activity determination before decontamination, selection of processing method.

Case 9 – Legacy raw waste drums (Netherlands, NRG Pallas): Small cylindric steel drums (25, 35 and 45 L; 29 cm diameter), 1356 drums with mixed LLW/ILW legacy waste including alpha-contaminated material and experiments wrapped in hot-cell cloths. Techniques: VINISH shielded rotating drum scanner with adjustable collimators; HIRARCHI hot-cell scanner for raw objects (80 × 40 cm); HPGe alpha hot-cell detector. Goals: LLW/ILW sorting by cobalt activity, fissile material identification, transport classification (A2 values).

Case 10 – LLW/ILW short-lived waste (Belgium, SCK CEN): Standard cylindric steel drum (220 L, φ 600 mm, H 885 mm) with dismantling waste (concrete, metals, mixed materials); R&D ongoing for scale-up to larger containers. Technique: closed-geometry gamma spectrometry using CsI detectors with real-time data acquisition during filling. Goals: evaluation of uncertainties due to inhomogeneous source distributions, reduction of radiological content uncertainty through real-time monitoring.