



**Milestone 50 – Identification of the most relevant
radionuclides and WAC for SF**

Work Package 5



Co-funded by the European Union under Grant Agreement n 101166718.

Document information

Project Acronym	EURAD-2
Project Title	European Partnership on Radioactive Waste Management-2
EC grant agreement No.	101166718
Work Package Title	Innovative characterisation techniques for large volumes
Milestone No.	MS50
Deliverable Title	<i>Identification of the most relevant radionuclides and WAC for SF</i>
Lead Beneficiary	ENRESA
Contractual Delivery Date	September 2025
Actual Delivery Date	September 2025
Dissemination level	PU
Authors	Artūras Plukis, Leon Kegel; Sandi Viršek; Luigi Lepore; Giada Gandolfo; Angela Pagano; Donatella Ferri;; Diego Espejo Hernando; Rita Plukienė; Valentine Ackermans; Elena Lagzdina; Grigorijus Duškesas; Javier Alonso; Sara Pérez; Katrin Ahlford ; Claes Johansson; Francesco Messi; Gergo Bator; Tibor Kovacs; Andras Bednar; Kateryna Fuzik; Yevheniia Kudriashova ; Oleksandr Soloviov; Steven Peetermans; Grégoire Augé; Rosa Lo Frano; Andrea Chierici; Salvatore Cancemi; Jose Luis Leganes Nieto

To be cited as:

Artūras Plukis, Leon Kegel; Sandi Viršek; Luigi Lepore; Giada Gandolfo; Angela Pagano; Donatella Ferri;; Diego Espejo Hernando; Rita Plukienė; Valentine Ackermans; Elena Lagzdina; Grigorijus Duškesas; Javier Alonso; Sara Pérez; Katrin Ahlford ; Claes Johansson; Francesco Messi; Gergo Bator; Tibor Kovacs; Andras Bednar; Kateryna Fuzik; Yevheniia Kudriashova ; Oleksandr Soloviov; Steven Peetermans; Grégoire Augé; Rosa Lo Frano; Andrea Chierici; Salvatore Cancemi; Jose Luis Leganes Nieto (2025): Identification of the most relevant radionuclides and WAC for SF M5.1 of the European Partnership EURAD-2. EC Grant agreement n°:101177718

Disclaimer

All information in this document is provided "as is" and no guarantee or warranty is given that the information is fit for any particular purpose. The user, therefore, uses the information at its sole risk and liability. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or European Atomic Energy Community. Neither the European Union nor the granting authority or the individual Colleges of EURAD-2 can be held responsible for them.

Acknowledgement

This document is a deliverable of the European Partnership on Radioactive Waste Management 2 (EURAD-2). EURAD-2 is co-funded by the European Union under Grant Agreement N° 101166718.

Status of deliverable		
	By	Date
Delivered (Lead Beneficiary)	ENRESA	30/06/2025
Verified (WP Leader)	POLIMI	21/08/2025
Reviewed (Reviewers)	Eros Mossini (POLIMI)	21/08/2025
Approved (PMO)	Peter Ormai (PURAM)	01/10/2025
Submitted to EC (Coordinator)	ANDRA	

Executive Summary

This document addresses Milestone 5.1 of the ICARUS project, which focuses on identifying the most relevant radionuclides for Scaling Factor (SF) methodologies and defining the associated Waste Acceptance Criteria (WAC). It aims to support the consistent and technically justified application of SFs by establishing a reference classification of radionuclides and proposing clear criteria for their use in waste characterization processes.

The classification of radionuclides is organized by their origin and measurement feasibility, with a distinction between Easy-to-Measure (ETM) radionuclides, which are directly detectable (e.g., Co-60, Cs-137), and Difficult-to-Measure (DTM) radionuclides, which require indirect estimation due to radiological or analytical constraints. DTMs include neutron activation products (e.g., C-14, Ni-63), fission products (e.g., Sr-90, Tc-99), transuranic elements (e.g., Pu-239/240, Am-241), tritium as a special case, and other long-lived or radiotoxic Hard-to-Measure (HTM) radionuclides.

Scaling Factors enable the estimation of DTMs based on the quantification of correlated ETMs. Their application supports efficient waste characterization, minimizes radiological exposure, and ensures regulatory compliance—particularly where direct measurement is unfeasible. However, for SFs to be valid and defensible, they must be developed and applied according to well-defined acceptance criteria.

The proposed criteria require that:

- SFs accurately represent the variability and characteristics of the target waste stream.
- Associated uncertainties and potential biases are quantified and transparently reported.
- Their use demonstrably supports the radiological classification and safety case for storage or disposal.

The document stresses that SFs are not generic constants but must be tailored to specific waste streams, drawing on inventory data, process knowledge, and safety assessment needs. The implementation of acceptance criteria within a quality assurance framework is essential to ensure technical soundness, traceability, and compliance.

In conclusion, the strategic use of SFs, underpinned by scientifically grounded criteria, allows for reliable indirect characterization of radioactive waste. This contributes to cost-effective, safe, and harmonized waste management practices across facilities and jurisdictions. The methodology outlined in this document provides a foundation for standardizing SF-based approaches while maintaining flexibility for waste-specific considerations.

Keywords

Scaling Factors, SF, Waste Acceptance Criteria, WAC, radioactive waste, waste characterization, radionuclides, Easy-to-Measure radionuclides, ETM, Difficult-to-Measure radionuclides, DTM, Hard-to-Measure radionuclides, HTM, neutron activation, fission products, transuranic elements, TRU, indirect measurement, radiological classification, uncertainty, bias, representativeness, quality assurance, regulatory compliance, gamma spectrometry, alpha/beta counting, long-lived radionuclides, radiotoxicity, waste streams, disposal safety, legacy waste, empirical correlation, safety assessment, radiological variability

Table of content

Executive Summary.....	4
Keywords.....	4
Table of content.....	5
List of figures.....	6
List of Tables.....	7
Glossary.....	8
Key Abbreviations.....	8
1. Purpose and Scope.....	10
2. Background and Regulatory Context.....	11
3. Classification of Typical Radionuclides for SF Applications.....	12
3.1 Typical ETM (Easy-to-Measure Radionuclides).....	12
3.2 Typical DTM from Neutron Activation.....	13
3.3 Typical DTM from Fission.....	13
3.4 Typical DTM: Transuranic Elements (TRU).....	13
3.5 Tritium (H-3) as a Special Case DTM.....	14
3.6 Additional HTM candidates (stream-dependent).....	14
4. Role of Scaling Factors in Waste Acceptance.....	16
4.1 Importance of Acceptance Criteria.....	16
4.2 Defined Acceptance Criteria for Scaling Factors.....	17
5. Conclusions and Recommendations.....	19
Appendix A. Past RD&D projects on waste characterisation.....	20
References.....	21

List of figures

Figure 1– Isotopes Analysis	12
Figure 2 - SF WAC Scheme	18

List of Tables

Table 1 - Classification of Radionuclides for Scaling Factor Applications	14
Table 2 - Proposed Acceptance Criteria for Scaling Factors (WAC Compliance)	17

Glossary

Scaling Factor (SF) – Ratio used to estimate the activity of difficult-to-measure radionuclides (DTMs) based on the measured activity of easy-to-measure radionuclides (ETMs).

Waste Acceptance Criteria (WAC) – A set of technical and radiological requirements that radioactive waste must meet to be accepted for storage or disposal at a given facility.

Easy-to-Measure Radionuclides (ETM) – Radionuclides that can be quantified with relative ease using standard non-destructive techniques, such as gamma spectrometry (e.g., Co-60, Cs-137).

Difficult-to-Measure Radionuclides (DTM) – Radionuclides that require complex, often destructive, or resource-intensive methods to be quantified (e.g., Sr-90, Pu-239).

Hard-to-Measure Radionuclides (HTM) – A subset of DTM that are particularly challenging to quantify due to low emission intensity, long half-life, or analytical complexity.

Transuranic Elements (TRU) – Actinide elements with atomic numbers greater than uranium ($Z > 92$), typically alpha emitters such as Pu, Am, and Cm, relevant for long-term safety assessments.

Neutron Activation Products – Radionuclides formed by the absorption of neutrons in non-radioactive materials, commonly found in reactor structural components (e.g., Ni-63, Nb-94).

Fission Products – Radionuclides created by the splitting of heavy atomic nuclei such as uranium or plutonium (e.g., Sr-90, Tc-99, I-129).

Empirical Correlation – A statistically derived relationship between two or more variables, used here to relate the activity of ETMs and DTMs.

Representativeness – The extent to which sampled data or derived SFs reflect the characteristics and variability of the entire waste stream.

SF Uncertainty – A quantitative expression of the doubt about the exact value of a measurement or SF, influenced by sampling, modeling, and analytical limitations.

Bias – Systematic deviation of a result from the true value, which may lead to over- or underestimation of radionuclide activity.

Radiological Classification – The categorization of radioactive waste based on its radiological properties (e.g., activity level, half-life), determining its management route.

Quality Assurance (QA) – A systematic process to ensure accuracy, traceability, and compliance in waste characterization and SF application.

Safety Assessment – A formal evaluation of the potential radiological risks posed by waste streams during storage, transport, or disposal, used to support licensing and regulatory decisions.

Waste Stream – A group of waste items with similar physical, chemical, and radiological characteristics, often sharing a common origin or treatment process.

Legacy Waste – Radioactive waste generated in the past for which complete historical data or characterization may be lacking.

Key Abbreviations

SF – Scaling Factor

WAC – Waste Acceptance Criteria

ETM – Easy-to-Measure Radionuclide

DTM – Difficult-to-Measure Radionuclide

EURAD-2 Milestone 50 – *Identification of the most relevant radionuclides and WAC for SF*

HTM – Hard-to-Measure Radionuclide

TRU – Transuranic Element

QA – Quality Assurance

ALARA – As Low As Reasonably Achievable

IAEA – International Atomic Energy Agency

ISO – International Organization for Standardization

GSG – General Safety Guide (IAEA)

EURAD – European Joint Programme on Radioactive Waste Management

PREDIS – Pre-Disposal Management of Radioactive Waste (EURAD project)

LILW – Low- and Intermediate-Level Waste

ILW – Intermediate-Level Waste

LLW – Low-Level Waste

VLLW – Very Low-Level Waste

QA/QC – Quality Assurance / Quality Control

NPP – Nuclear Power Plant

1. Purpose and Scope

As the title itself suggests, this document serves two main purposes: first, to describe the typical radionuclides commonly encountered in the context of Scaling Factors (SF), and second, to propose a set of acceptance criteria that can be applied to SF.

Initially, it presents a reference classification of typical radionuclides used in the context of SF, organized by their origin and measurement feasibility. It is intended to support waste characterization practices where indirect methods are employed to estimate the activity of radionuclides that are difficult to measure directly (DTMs), based on the quantification of easy-to-measure radionuclides (ETMs).

The classification includes activation products, fission products, transuranics (TRUs), and other long-lived radionuclides, and provides a basis for developing or validating radionuclide vectors across waste streams. It supports the implementation of SF methods aligned with Waste Acceptance Criteria (WAC), regulatory expectations, and safety assessments for storage and disposal.

Second, it defines the acceptance criteria that SF must meet in order to be considered valid and applicable for the radiological characterization of radioactive waste. These criteria serve as part of a broader framework for ensuring compliance with WAC, with particular focus on waste classification for interim storage or final disposal.

The purpose of these criteria is to guarantee that the use of SFs contributes to the overall reliability, traceability, and safety of the waste inventory assessment process. The scope encompasses all types of waste streams where indirect methods based on SFs are used to estimate the activity of DTMs.

In this document, HTM is defined strictly as a measurement category (a subset of DTM). The set of radionuclides to be considered in SF models and to demonstrate compliance with WAC is waste-stream specific, based on inventory knowledge, process understanding, and the needs of the safety assessment. There is no “primary” HTM group; any examples listed are indicative only.

The radionuclide list provided in this milestone is indicative and intended to support a common terminology and initial planning. At subsequent stages, a stream-specific radionuclide list may be selected for detailed study and WAC demonstrations, driven by the safety case, detectability/analytical feasibility (ETM/DTM/HTM), and regulatory agreement.

2. Background and Regulatory Context

In radioactive waste management, especially within complex or heterogeneous waste streams, direct measurement of all relevant radionuclides is often impractical. DTMs may require destructive analysis, involve high radiological risk, or demand resources that are incompatible with routine operations.

To overcome these limitations, Scaling Factors are established based on empirical correlations between DTMs and ETMs, often derived from gamma-emitting isotopes. This practice is recognized and recommended in multiple international standards and technical guidance documents, including:

- IAEA Safety Guide GSG-1: Classification of Radioactive Waste
- ISO 21238: Scaling factor method to determine the radioactivity of low- and intermediate-level radioactive waste packages
- EURAD–PREDIS Deliverable 4.6 Report on gamma spectrometry and sampling procedure.

The validation and acceptance of these SFs require more than the establishment of numerical ratios: they must be supported by a structured evaluation that includes the uncertainty, bias, statistical robustness, and representativeness of the data from which they are derived.

It is important to emphasize that the selection of radionuclides to be included in SF models must be technically justified, stream-specific, and supportive of long-term safety demonstrations.

This selection must consider:

- The nuclear origin of radionuclides (e.g., activation, fission, TRU),
- Their radiological relevance for classification or safety,
- Their chemical mobility or long-term behavior,
- Their detectability, using standard gamma spectrometry or alpha/beta counting.

The radionuclide list in this document is established by the radiological criterion applicable to interim storage or final disposal (predisposal). Other radiological frameworks (e.g., clearance, transport, or waste-treatment criteria) are out of scope here; accordingly, short-lived DTM nuclides are typically excluded. Even under the same criterion, the list may vary case by case. Therefore, the lists provided are indicative, not prescriptive, and may be adapted as justified.

3. Classification of Typical Radionuclides for SF Applications

The following categorization represents a rational grouping of radionuclides based on operational experience, scientific relevance, and alignment with international best practice.

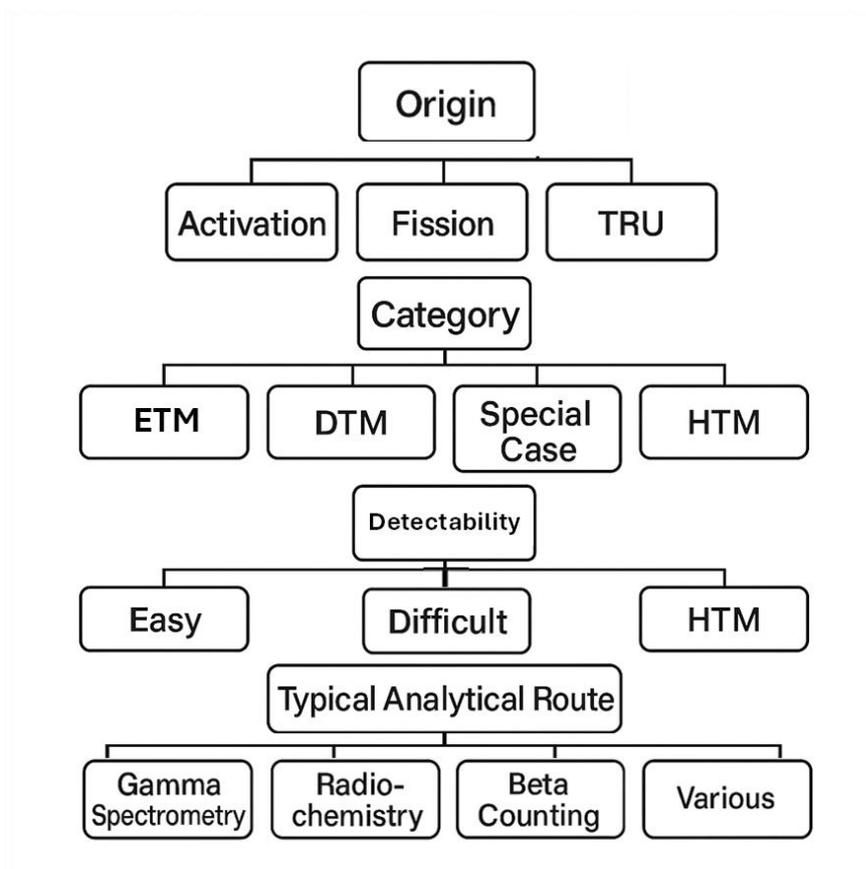


Figure 1– Isotopes Analysis

3.1 Typical ETM (Easy-to-Measure Radionuclides)

These are radionuclides measurable via **gamma spectrometry** with high sensitivity and minimal sample preparation. They are commonly used as predictors in SF relationships.

- **Co-60**
- **Cs-137**

Other γ -emitters used as ETMs include:

- **Sb-125**
- **Ce-144**
- **Ba-133**
- **Eu-152**
- **Eu-154**

Notes.

- Ce-144 and Sb-125 can be useful during NPP operation, but their short half-lives make them unsuitable for the decommissioning phase.

- Eu-152 and Eu-154 are good key nuclides for bioshield concrete.
- Ba-133 can serve as an ETM for barite concrete, but beware that the Pb-214 γ line at 352 keV lies close to the Ba-133 line at 356 keV; adequate spectral resolution and background correction are required.

3.2 Typical DTM from Neutron Activation

These radionuclides originate mainly from neutron activation of structural materials, concrete, graphite, or process equipment.

- **C-14**
- **Cl-36**
- **Ca-41**
- **Ni-63**
- **Nb-94**

Although Nb-94 is a gamma emitter and thus nominally an ETM, in most practical cases its specific activity is low and the Compton continuum from co-present high-activity gamma emitters (e.g., Co-60) renders direct gamma spectrometry ineffective unless niobium is first isolated. Consequently, Nb-94 should be treated as context-dependent DTM: radiochemical separation is generally required prior to gamma spectrometry to obtain defensible results.

3.3 Typical DTM from Fission

These are fission products commonly found in irradiated fuel residues or materials exposed to neutron flux.

- **Sr-90**
- **Tc-99**
- **I-129**

3.4 Typical DTM: Transuranic Elements (TRU)

These alpha-emitting actinides are relevant for long-term safety and require radiochemical analysis. They are generally estimated via SF relationships in legacy waste or conditioned packages.

- **Pu-238**
- **Pu-239/240**
- **Pu-241**
- **Am-241**
- **Cm-243/244**

3.5 Tritium (H-3) as a Special Case DTM

Tritium is often treated separately due to its mobility and measurement challenges. Its estimation is critical in materials such as graphite, water-bearing waste, and structural components.

- **H-3**

3.6 Additional HTM candidates (stream-dependent)

The following radionuclides are HTM candidates for analytical reasons; their actual inclusion depends on the specific waste stream and the acceptance approach adopted.

- **Be-10**
- **Ni-59**
- **Se-79**
- **Zr-93**
- **Mo-93**
- **Pd-107**
- **Cs-135**
- **Sm-151**

The inclusion of a given radionuclide in SF models depends on its presence in the waste stream, its detectability, and its relevance for classification or disposal. The final set for detailed study may differ and will be selected stream-by-stream based on safety relevance, detectability, and regulatory alignment.

Table 1 - Classification of Radionuclides for Scaling Factor Applications

Radionuclide Type	Radionuclide(s)	Primary Origin	Measurement Category
ETM (Easy-to-Measure)	Co-60, Cs-137	Activation / Fission	Easy-to-Measure
DTM (Activation Products)	C-14, Cl-36, Ca-41, Ni-63, Nb-94	Neutron Activation	Difficult-to-Measure
DTM (Fission Products)	Sr-90, Tc-99, I-129	Fission	Difficult-to-Measure
DTM (TRU)	Pu-238, Pu-239/240, Pu-241, Am-241, Cm-243/244	Transuranic Elements	Difficult-to-Measure
DTM (Special Case)	H-3 (Tritium)	Activation, water-bearing materials	Difficult-to-Measure
HTM (Hard-to-Measure)	Be-10, Ni-59, Se-79, Zr-93, Mo-93, Pd-107, Cs-135, Sm-151	Various (long-lived, low emission)	Hard-to-Measure

HTM ≡ DTM with reinforced measurement difficulty. Whether a radionuclide is required for WAC is case-dependent (inventory, mobility, radiotoxic significance) and not determined by the HTM label per se.

4. Role of Scaling Factors in Waste Acceptance

Scaling Factors play a critical role in enabling:

- Efficient and safe waste characterization without full-spectrum radionuclide measurement.
- Consistency across waste packages, especially in legacy, operationally and decommissioning variable waste streams.
- Optimization of analytical efforts, focusing resources on representative sampling and minimizing exposure to workers.
- Regulatory compliance by demonstrating that all radionuclides relevant to radiological classification and safety assessments are duly accounted for.

However, the validity and defensibility of SFs depend on their transparent derivation and well-defined limits of applicability. This includes clearly articulating the theoretical/statistical basis, experimental evidence, and operational boundaries under which each SF can be applied.

The application of SF and the selection of radionuclides relevant for WAC are justified on a waste-stream basis, combining detectability (ETM/DTM/HTM) with safety relevance; therefore, HTM lists may vary within a single case as different streams are characterized.

4.1 Importance of Acceptance Criteria

Establishing explicit acceptance criteria is essential for:

- Ensuring that the SF remains applicable to the target waste stream and reflects its radiological variability.
- Quantifying uncertainty and potential bias, which are critical for conservative decision-making.
- Providing regulatory authorities and operators with a traceable methodology that can be audited and independently verified.
- Reducing misclassification risks, which could result in inappropriate waste routing, overconservatism, or non-compliance.

Moreover, these criteria are not fixed numerical thresholds, but qualitative and quantitative conditions that must be met or justified for each SF. Their implementation should be integrated into the Quality Assurance (QA) framework of the waste characterization process.

Finally, rather than prescribing a universal valid number of samples, this document prioritizes a robust, stream-specific SF model that improves as valid control samples accumulate. An initial, statistically justified sample size shall be used to establish the model with predefined performance objectives; thereafter, the model parameters are re-estimated on a rolling basis as additional qualified data are collected. This adaptive approach—combining ongoing verification with control/validation samples—typically yields better accuracy, sharper uncertainty bounds, and earlier detection of process changes than fixing a sample count *ex ante*. Accordingly, stakeholders should focus on model adequacy and continuous learning (data governance, QA/QC, and change control) rather than on a single “magic number” of samples.

4.2 Defined Acceptance Criteria for Scaling Factors

Below are the proposed acceptance criteria applicable to the SF:

- The SF must accurately represent the radiological characteristics of the associated waste stream, ensuring that its activity range encompasses that of the waste package to which it is applied.

This guarantees that the SF remains valid across the expected variability of the waste population, avoiding extrapolation beyond its domain of representativeness.

- The SF must have any potential bias clearly quantified, as well as its uncertainty, in view of its application to the waste packages belonging to the corresponding waste stream.

This allows for a conservative but realistic use of the SF, avoiding systematic under or over estimation of DTM activity.

- When applying the SF to a waste package, it must be ensured, with an appropriate level of confidence, that the activity of the DTM falls within the radiological classification of the waste, in accordance with the intended storage or disposal route.

This directly supports compliance with WAC and provides assurance that the SF supports the broader safety case of the facility.

Table 2 - Proposed Acceptance Criteria for Scaling Factors (WAC Compliance)

Criterion	Description
Representativeness of the SF	The SF must adequately reflect the radiological characteristics of the waste stream to which it is applied.
Statistical Validity and Application Range	The SF must cover the expected activity range of the target waste stream without extrapolation beyond its domain of representativeness.
Quantification of Uncertainty	The uncertainty associated with the SF must be evaluated, including statistical dispersion and systematic errors.
Quantification of Bias	Any systematic bias must be identified and either corrected or conservatively incorporated into the estimation.
Compliance with Radiological Classification	The SF must ensure, with an appropriate level of confidence, that the waste is correctly classified according to the intended management route.
Technical Justification of the SF	The SF must be supported by empirical data, process knowledge, validated correlations, and documented quality procedures.
Integration into the Quality Assurance System	Acceptance criteria must be embedded in the QA system of the characterization process, and be auditable and independently verifiable. Periodic verification of the Scale Factor (SF) shall be performed to detect potential changes and, where appropriate, to refine the current model.

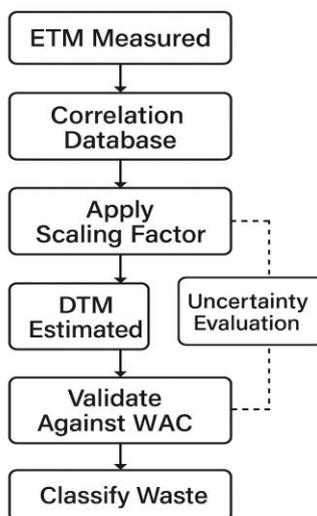


Figure 2 - SF WAC Scheme

5. Conclusions and Recommendations

The integration of Scaling Factors within a WAC-compliant waste acceptance system requires a balance between operational feasibility and scientific rigor. The acceptance criteria presented above are intended to formalize this balance and to offer a robust framework for the validation, application, and traceability of SFs used in radioactive waste characterization.

Their adoption supports multiple goals:

- Reducing the need for direct measurement of DTMs, lowering costs and radiological exposure,
- Enabling consistent waste classification across heterogeneous waste streams,
- Enhancing the defensibility of compliance claims during audits, licensing, and inspections,
- And supporting future harmonization of waste acceptance methodologies across different countries and disposal concepts.

Furthermore, by anchoring SF criteria in uncertainty and bias analysis, and requiring demonstration of representativeness across waste packages, the approach ensures that indirect estimation methods remain transparent, technically justified, and aligned with safety objectives.

The use of these criteria, in combination with documented validation datasets, quality assurance procedures, and regulatory oversight, will be essential to demonstrate that SFs are not merely empirical ratios, but part of a scientifically grounded, safety-driven system for radioactive waste management.

The categorization presented here is intended as a reference framework for developing and applying SF-based methods in radioactive waste characterization. It reflects both practical measurability constraints and the radiological importance of each radionuclide type.

Key conclusions:

- Co-60 and Cs-137 remain the primary ETMs due to their detectability and presence in most waste forms.
- Activation products (e.g., C-14, Ni-63, Nb-94) and TRUs (e.g., Pu, Am, Cm isotopes) constitute the most frequent DTMs in operational and legacy waste.
- H-3 deserves special treatment, particularly in porous matrices.
- Other HTMs, while not universally tracked, may be critical in advanced safety assessments and should not be neglected in generic SF libraries.
- The use of SFs must always be justified per waste stream, and the selection of radionuclides should be linked to historical inventory data, process knowledge, and the disposal facility's safety case.

A robust SF methodology does not require measuring every radionuclide in each package, but it must ensure that all relevant contributors to risk and classification are addressed, whether through measurement, correlation, or bounding assumptions.

Appendix A. Past RD&D projects on waste characterisation

- CHANCE project – Characterisation of conditioned radioactive waste, funding from Horizon 2020 Euratom Work Programme under grant agreement n° 755371, 2017–2021, <https://www.chance-h2020.eu/>.
- INSIDER project – Improved nuclear site characterisation for waste minimisation in decommissioning and dismantling operations under constrained environment, funding from the Euratom Research and Training Programme under grant agreement n° 755554, 2017-2021, <https://insiderh2020.eu/>.
- MICADO project – Measurement and instrumentation for cleaning and decommissioning operations, funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement n° 847641, 2019-2023, <https://www.micado-project.eu/>.
- PLEIADES – Platform based on Emerging and Interoperable Applications for enhanced Decommissioning processES, funding from Horizon 2020 Euratom Work Programme under grant agreement n° 899990, 2020-2023, <https://cordis.europa.eu/project/id/899990>.
- CLEANDEM project – Cyber physical equipment for unmanned nuclear decommissioning measurements, funding from Horizon 2020 Euratom Work Programme under grant agreement n° 945335, 2021-2024, <https://cordis.europa.eu/project/id/945335>.
- SHARE project – Creating a strategic plan for the research focused on enhancing safety, reducing environmental impact, and cutting costs in the decommissioning process, funding from European Union’s Horizon 2020 Research and Innovation Programme under grant agreement n° 847626, 2019-2022, <https://share-h2020.eu/>.
- PREDIS project – the development and implementation of activities for pre-disposal treatment of radioactive waste streams other than nuclear fuel and high-level radioactive waste, funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 945098 (2020-2024) <https://predis-h2020.eu/>

References

- [1] **ISO 21238:2007** – The scaling factor method to determine the radioactivity of low- and intermediate-level radioactive waste packages. International Organization for Standardization.
- [2] **IAEA TECDOC-1537** – The Use of Scaling Factors for the Characterization of Low and Intermediate Level Radioactive Waste. IAEA, Vienna, 2007.
- [3] **IAEA Safety Guide GSG-1** – *Classification of Radioactive Waste*. International Atomic Energy Agency, Vienna, 2009.
- [4] **EURAD – PREDIS Project** – *Pre-Disposal Management of Radioactive Waste*. European Joint Programme on Radioactive Waste Management. Deliverable 4.6 Report on gamma spectrometry and sampling procedure
<https://www.ejp-eurad.eu/activities/predis>
- [5] ISO 11929-1, Determination of the detection limit and decision threshold for ionizing radiation measurements — Part 1: Fundamentals and application to counting measurements without the influence of sample treatment
- [6] ISO 11929-2, Determination of the detection limit and decision threshold for ionizing radiation measurements — Part 2: Fundamentals and application to counting measurements with the influence of sample treatment
- [7] ISO 11929-3, Determination of the detection limit and decision threshold for ionizing radiation measurements — Part 3: Fundamentals and application to measurements by use of linear-scale analogue ratemeters, without the influence of sample treatment
- [8] ISO 11929-4, Determination of the detection limit and decision threshold for ionizing radiation measurements — Part 4: Fundamentals and application to measurements by use of linear-scale analogue ratemeters, with the influence of sample treatment
- [9] ISO 14870, Nuclear energy — Waste management — Waste data sheet
- [10] ISO 16646, Nuclear energy — Design principles for post-closure safety of geological repositories
- [11] ISO 16760, Nuclear energy — Waste management — Waste characterization
- [12] INTERNATIONAL ATOMIC ENERGY AGENCY, *Characterization of Radioactive Waste Forms and Packages*, IAEA Technical Reports Series No. 376, IAEA, Vienna (1995).
- [13] INTERNATIONAL ATOMIC ENERGY AGENCY, *Guidebook on Radioactive Waste Disposal*, IAEA Technical Reports Series No. 222, IAEA, Vienna (1983).
- [14] INTERNATIONAL ATOMIC ENERGY AGENCY, *Predisposal Management of Radioactive Waste, including Decommissioning*, Safety Guide No. WS-G-2.1, IAEA, Vienna (2000).
- [15] INTERNATIONAL ATOMIC ENERGY AGENCY, *Disposal of Radioactive Waste*, Safety Guide No. WS-G-1.1, IAEA, Vienna (1999).
- [16] INTERNATIONAL ATOMIC ENERGY AGENCY, *Classification of Radioactive Waste*, Safety Guide No. GSG-1, IAEA, Vienna (2009).
- [17] INTERNATIONAL ATOMIC ENERGY AGENCY, *The Principles of Radioactive Waste Management*, Safety Series No. 111-F, IAEA, Vienna (1995).
- [18] INTERNATIONAL ATOMIC ENERGY AGENCY, *The Use of Scientific and Technical Results from Underground Research Laboratory Investigations for the Geological Disposal of Radioactive Waste*, IAEA TECDOC-1243, IAEA, Vienna (2001).
- [19] INTERNATIONAL ATOMIC ENERGY AGENCY, *Derivation of Activity Limits for the Disposal of Radioactive Waste in Near Surface Disposal Facilities*, Safety Reports Series No. 20, IAEA, Vienna (2002).
- [20] NUCLEAR ENERGY AGENCY OF THE OECD, *Radiological Characterisation for Decommissioning of Nuclear Installations*, NEA/RWM/WPDD(2004)8, OECD, Paris (2004).
- [21] US NUCLEAR REGULATORY COMMISSION, *Branch Technical Position on Concentration Averaging and Encapsulation*, USNRC, Washington, DC (1995).