LESSONS LEARNED IN FARO DISMANTLING PROCESS II

LESSONS LEARNED REPORT

KP-JRC-002

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Foreword

In 2021, the European Commission (EC) adopted a new proposal for a Council Regulation[1] establishing a dedicated financial programme for decommissioning nuclear facilities and managing radioactive waste. This instrument covers the co-funding of the decommissioning programmes of Bulgaria, Slovakia, and the decommissioning of the Joint Research Centre (JRC). A separate Council Regulation[2] was adopted for the decommissioning programme of Lithuania.

The EC JRC is mandated to foster the spread of decommissioning knowledge across all the European Union Member States and facilitate knowledge sharing arising from implementing the abovementioned decommissioning programmes, funded by the Nuclear Decommissioning Assistance Programme (NDAP).

The decommissioning operators from the NDAP (NDAP Operators) implemented and tested a knowledge management methodology in 2021 through Project ENER/D2/2020-273. Using this methodology, the NDAP Operators can develop Knowledge Products that are currently available to share with other European stakeholders. In addition, this methodology is under implementation in the JRC Nuclear Decommissioning and Waste Management Directorate (NDWMD), which becomes a knowledge generator extracting the knowledge from the ongoing decommissioning activities at the different sites (Geel, Ispra, Karlsruhe, and Petten).

The JRC NDWMD aims to become a Centre of Excellence in nuclear decommissioning knowledge management and develop a decommissioning knowledge platform which allows exchanging information and building on the best practices in the EU inside the multi-annual financial framework (2021 – 2027) strategy. The operational phase of the project is expected to start in 2024 to develop ties and exchanges among EU stakeholders and document explicit knowledge and make it available through multi-lateral knowledge transfers on decommissioning and waste management governance issues, managerial best practices, technological challenges, and decommissioning processes at both operational and organisational level, to develop potential EU synergies.

This is a Knowledge Product prepared by IDOM Consulting, Engineering, Architecture S.A.U. for the JRC NDWMD.

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[1] Council Regulation (Euratom) 2021/100 of 25 January 2021 establishing a dedicated financial programme for the decommissioning of nuclear facilities and the management of radioactive waste, and repealing Regulation (Euratom) No 1368/2013

[2] Council Regulation (EU) 2021/101 of 25 January 2021 establishing the nuclear decommissioning assistance programme of the Ignalina nuclear power plant in Lithuania and repealing Regulation (EU) No 1369/2013

PRODUCT DESCRIPTION

The NE.40.2220.SR.002. Lessons Learned Report was prepared by a team of experts from JRC Decommissioning & Rad Waste Organization at JRC-Ispra in Italy. The guidance and recommendations of this product are collected from the experience gained during the execution of the FARO dismantling process sponsored by the European Commission via the Nuclear Decommissioning Assistance Program (NDAP) between the years 2013-2015.

The lessons learned presented in this report aim **to assist personnel in nuclear decommissioning projects and propose new working methodologies**. This document comments on key aspects of dismantling procedures such as identification and segregation of potentially clearable material, definition of homogenous groups or clearance levels measurements. **The most important lesson presented suggests changing the moment destructive analyses are made** to improve the quality of the measurements and reduce delays and safety risks in the project.

This product was developed as part of an effort to disseminate and share with all EU State Members the knowledge acquired during the decommissioning and radioactive waste management activities performed by the JRC Directorate J.

ABSTRACT

This is the second knowledge product on lessons learned from the FARO dismantling project. FARO was the Fuel Assembly and Release Oven building inside JRC Ispra's facilities. The first one focused on lessons learned mainly from design, characterization, and dismantling preparedness with a view to material clearance and waste management optimization. These lessons were applied to the continuation of the FARO dismantling project as of 2013.

The current document, following the completion of the FARO dismantling project, analyses the whole clearance and waste management process and distils generic lessons learned applicable to any future dismantling project.

OBJECTIVE

This knowledge product aims to provide a possible approach to solving the main hurdles of a decommissioning clearance process and provide guidance to other organizations in Europe for future similar works based on the lessons learned on the FARO dismantling project.

APPROACH

The first application of the JRC-Ispra clearance process on a big industrial scale took place at the back end of the FARO Dismantling Project. FARO dismantling activities have been completed in 2014, however, due to several reasons connected to internal and external dependencies, the downstream waste objects management did not finish by the time these lessons learned were compiled (November 2016). This fact motivates a retrospective evaluation of the lessons learned during this project.

This document provides background information on the status and practice of the clearance process (see 0) and of radioactive waste management (see 1.2). This knowledge will be useful for a quick understanding of the lessons learned identified afterwards.

Informed readers can skip directly to Section **¡Error! No se encuentra el origen de la referencia.** which describes the lessons learned in the FARO clearance process (see 3) as well as radioactive waste management (see 3.2). Then, recommendations are made in 0 for future clearance processes.

RESULTS, FINDINGS, AND INSIGHTS

This document guides the establishment of lessons learned during the clearance process in the FARO dismantling project. The study evaluates **new ways to optimise costs and time and to ensure safety,** thanks to the lessons learned from the different steps during the procedure.

The main hurdles encountered in clearance processes appear to **originate from the planning of the work** to be done. This report will show how an incorrect approach to the identification of materials will cause unnecessary delays, costs, and safety risks.

The design of the clearance process determines key aspects of the project (i.e., when destructive analyses are to take place, or which kind of instrumentation may be used**).** These aspects make an impact on the **quality of the measurements**, **essential to ensure that every object released from the site meets the safety standards**.

TARGET USERS

The product targets a broad range of potential beneficiaries using this guidance. Technical profiles from the nuclear industry will not need long experience and knowledge in this sector to be able to benefit from the advice given in this document since it is project-oriented rather than technology-specific. Knowledge in this document can add immediate value to key agents in the field such as decommissioning operators in Europe.

APPLICATION, VALUE, AND USE

This report may be used in other clearance processes (activities of removal of materials from a certain site). **Its use can impact key aspects like safety and environmental protection (e.g., safety factors calculation) or managerial performance (e.g., time-saving measures).**

Lessons learned in this product are related to the specific procedures used in the FARO dismantling process and were subject to Italian regulation requirements; hence other team projects would need to customize these lessons depending on their specific context. Despite that, recommendations and references made in this report have a general application, making their integration into other organizations easier than usual.

Future decommissioning activities may run into inconveniences related to **an incorrect approach to the classification of materials.** A wrong characterization may lead to performing an insufficient number of measurements on an object or to choosing the wrong instrumentation. The second option will cause **time and economic inefficiencies** but the first one could mean that **contaminated material may be released.**

Suggestions made by the JRC Ispra site's team in this report will provide valuable insights (i.e. it is proposed a pre-compaction campaign that may **save 4% of the total waste management costs)** that will help future projects to solve these same problems that appeared during the FARO dismantling.

KEYWORDS

FARO, DISMANTLING, MATERIAL CLEARANCE, RADIOACTIVE WASTE MANAGEMENT.

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LIST OF ACRONYMS AND DEFINITIONS

ACRONYMS

AAP: SCO Activity Assessment Procedure for Surfaces-Contaminated Objects

CC: Clearance Container

CL: Clearance Level

DA: Destructive Analysis

DTM: Difficult-to-measure

ECO: Esperienza Critica Orgel (Experimental Critical Assembly)

EQ: Qualified Expert as per Art. 4.1.u) of [1]

***Esercente**:* Licence Holder as per Art. 10-ter of [1]

ETM: Easy-to-measure

FARO: Fuel Assemblies Melting and Release Oven

HG: Homogenous Group

ISOCS: In-Situ Object Counting System

ISPRA: *Istituto Superiore per la Protezione e la Ricerca Ambientale* (Institute for Protection and Research of Environment)

JRC: Joint Research Centre of European Commission

LMR: Site Laboratory

MCS: Material Clearance Station

MDA: Minimum Detectable Activity

NDA: Non-Destructive Analysis

STRRL: Liquid Effluents Treatment Station

UNI: *Ente Italiano di Normazione* (Italian Normalization Council)

WP26: External Work Package

DEFINITIONS

PCR: Plant Characterisation Report;

Terminology note: Two similar terms have been in use in the plant characterisation-related documents - Plant Characterisation Report and Project Characterisation Report. They are in principle both the same however, in an international context, Project Characterisation Report is not recognized. Nevertheless, this term was introduced in the JRC-Ispra site procedure [2] to distinguish the product of the past plant characterisation campaign belonging to the completed WBS projects I-04.##.03 from the follow-up iterations of the plant characterisation efforts. Thus Project Characterisation Reports are an evolution of Plant Characterisation Reports. In the meantime, JRC-Ispra decided to remove the confusion and therefore Project Characterisation Reports are renamed to Plant Characterisation Reports.

PPE: Personal Protective Equipment

RP: Radiation Protection

SGRR: Stazione di Gestione di Rifiuti Radioattivi

UMA: Unit of potentially clearable material (*Unità Materiale Allontanabile*)

WAC: Waste Acceptance Criteria

WP: 26 AMEC work pack managed by Decommissioning Sector, exploring effective approaches to industrial scale clearance process and based on international experience in the clearance of material arising from decommissioning

LIST OF FIGURES

1. GENERAL BACKGROUND INFORMATION

This is a brief description of clearance processes and their regulation, provided to facilitate understanding of the lessons learned presented in Section 3.

1.1. General Introduction to Clearance Process Requirements

This part of the report discusses the main characteristics of the FARO's clearance process at the JRC Ispra site. The content will board the context behind the **regulation, classification of materials, and the sequence of steps during the clearance process.**

1.1.1. Regulation

The process of clearance at the JRC Ispra site is governed by technical prescriptions [4] defining the table of clearance levels and JRC procedures in [3]. This complies with Italian law [1] and partially the Italian norm [4].

JRC clearance procedures are required to be submitted to the Safety Authority in line with the technical condition I.15.5 of the SGRR licence abovementioned.

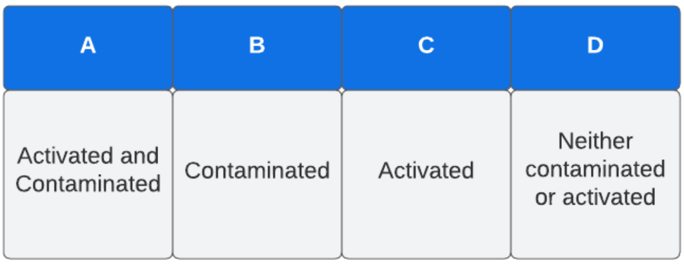
The FARO material clearance process was launched in a situation when the General Procedure for Clearance was in [5], which had been left without comments from the Safety Authority. Later into the progression of the FARO dismantling project**, the General Procedure was upgraded to Rev.1 to satisfy the operational needs of the project and allow buffer storage of potentially clearable material in the Supervised Area**.

1.1.2. Classification of Materials in the JRC

The underlying philosophy of the JRC clearance procedures, in line with the UNI norm [3], is a statistical approach. It means that **only a portion of material under clearance is measured and a non-parametric statistical test is applied** to conclude whether the whole material can be released. This approach is strongly based on the concept of a homogenous group. As this concept is crucial for further analysis, the following paragraphs discuss the definitions of homogenous groups and similar terms used in the documents relevant to the clearance topic.

The definition of the homogenous group mentioned in the JRC clearance procedure **is a "set of materials of matching material typology, radioactivity class, isotopic composition and activity concentration (by mass and by surface)".**

Returning to the description of the clearance process, four classes of materials by class of



radioactivity are distinguished in

Figure 1:

A	B	C	D
Activated and Contaminated	Contaminated	Activated	Neither contaminated or activated

Figure 1: Types of materials by radioactivity class

1.1.3. Key Steps of the Process

The key elements of the clearance sequence embedded in the clearance procedures [3] are:

- **Initial characterization of materials:** It enables to define homogenous groups. The initial characterization of material is based on the analysis of data and supplementary investigation set up by the contractor. This analysis results in an identification of the homogenous groups and the identification of the radionuclides excluded and those potentially present in each homogenous group. An initial nuclide vector is hypothesised based on historical information.

- **Destructive analyses:** Each of the homogenous groups must be characterized through a full range of destructive analyses. Destructive analyses are performed on samples of material taken before and/or during dismantling and sent to the site laboratory. The number of destructive analyses is equal to the number of UMAs (*Units of potentially clearable material*) in the homogenous group or 20, whichever is smaller. Therefore, the definition of the size of the homogenous groups can have a great impact on several destructive analyses and their costs and their duration (delay). For class D material, where no presence of artificial radioactivity is expected, hence destructive analysis results cannot possibly yield any sensible scaling factors between difficult-to-measure radionuclides and those easy to measure. It is sufficient to take only samples from a single representative portion of the material (often only one sample) to confirm the absence of the radionuclides that are difficult to measure.

- **Definition of homogeneous groups**: The results of destructive analyses are used to confirm/determine the final nuclide vector, which will be then applied to recalculate the contributions of difficult-to-measure radionuclides based on the non-destructive analysis measurements using either total gamma counting provided by MCS (material clearance system) or gamma spectrometry by ISOCS (In-Situ Object Counting System).

- The secondary objective of the destructive analyses is to establish the number of required non-destructive analyses to be taken on the homogenous subgroup in a later stage. It was already mentioned that the clearance process in Italy [3] allows for less than 100% of material to be monitored when a statistically sufficient portion of measurements are compliant. The JRC procedures require that the size of this statistically sufficient portion is determined before the non-destructive analysis measurements based on "distance" from the clearance levels seen in the destructive analysis results or homogenous subgroups where average concentrations are found to be significantly below relevant clearance levels. The number of prescribed measurements can be as low as 10% of UMAs with a minimum of 14. When the average concentrations get nearer the clearance levels, a prescribed number of non-destructive analysis measurements is to be increased and can achieve measuring 100% of the UMAs.

- **Assignment of nuclide vector:** The results of destructive analyses must pass a statistical test of coherence (level of homogeneity/clearance level) of the group. If the test is passed, the homogenous group becomes a homogenous subgroup. In case of non-homogeneity, it is requested 10 supplementary destructive analyses, to fix the issues. However, if the homogeneity test is not passed even with 30 samples, the homogenous group must be divided into homogenous subgroups.

- **Non-Destructive Analyses:** The step of the highest importance is at the end of this process. Before the material is released from the Controlled Zone, it must be measured using bulk activity monitoring in an non-destructive analysis process. There are 2 options for non-destructive analysis measurements:

1	Material Clearance Station (**MCS**) System: A dedicated total gamma counting system located in Area 40, designed for high sensitivities, and operated by SGRR.
2	In-situ measurements with **ISOCS**, operated by LMR. This method is portable and allows deployment close to the dismantling site.

The sensitivity of ISOCS is lower than that of MCS, but ISOCS does have spectroscopic capability, allowing it to distinguish individual gamma emitters.

All the comprehensive activity concentrations in the UMAs subjected to non-destructive analyses are **compared with relevant clearance levels** and another statistical test is performed to see if the entire homogenous subgroup (including UMAs not measured) can be cleared or not.

For all steps mentioned in Section 1.1.3., it is also important to bear in mind that:

To ensure **no hot spots** (harmful concentrated activity localised in small area/volume), the limitation from UNI norm on measurement unit is 1000 kg or 1 m^3 or 1 m^2. Further limitation has been imposed by ISPRA for metallic material (400 kg).
The results of non-destructive analysis measurements must be multiplied by **a safety factor** compensating for non-homogeneities in UMAs. Then, the activities of difficult-to-measure radionuclides are obtained by the application of scaling factors from the knowledge of the nuclide vector.

FARO dismantling project could have been formally covered by the explained clearance procedure, so the questions of when to perform destructive analysis sampling and how much material needed to be fragmented into clearance containers for non-destructive analysis measurements had to be resolved. The fit of the clearance process with the dismantling is simplistically outlined in the figures below, separately for classes A, B or C (Figure 2) and for class D (Figure 3).

For classes A, B and C material, the number of UMAs to be subject to non-destructive analysis measurements is calculated from the results of the destructive analyses. For class D material, the proportion of UMAs selected for non-destructive analysis measurements is fixed at 10%.

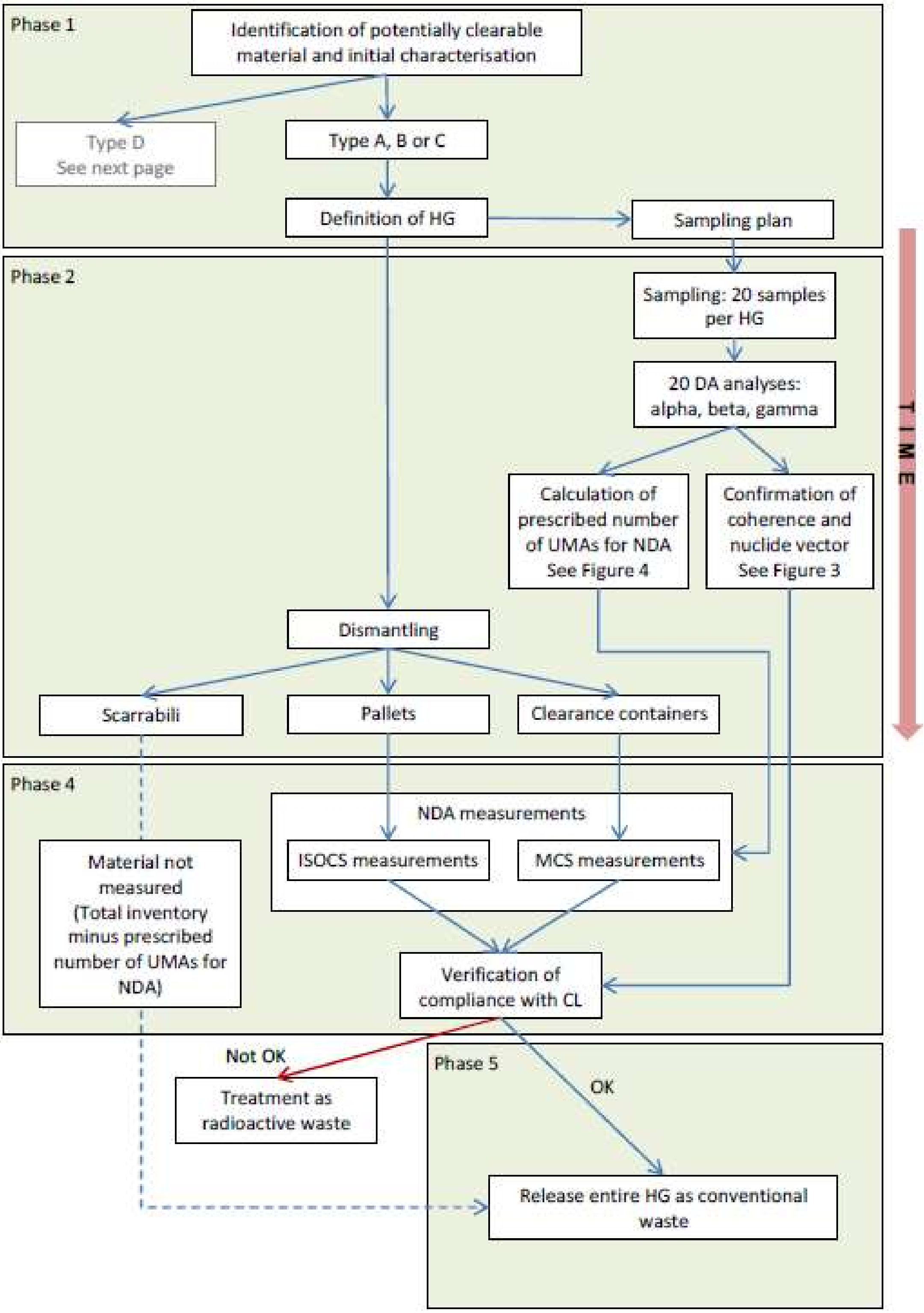
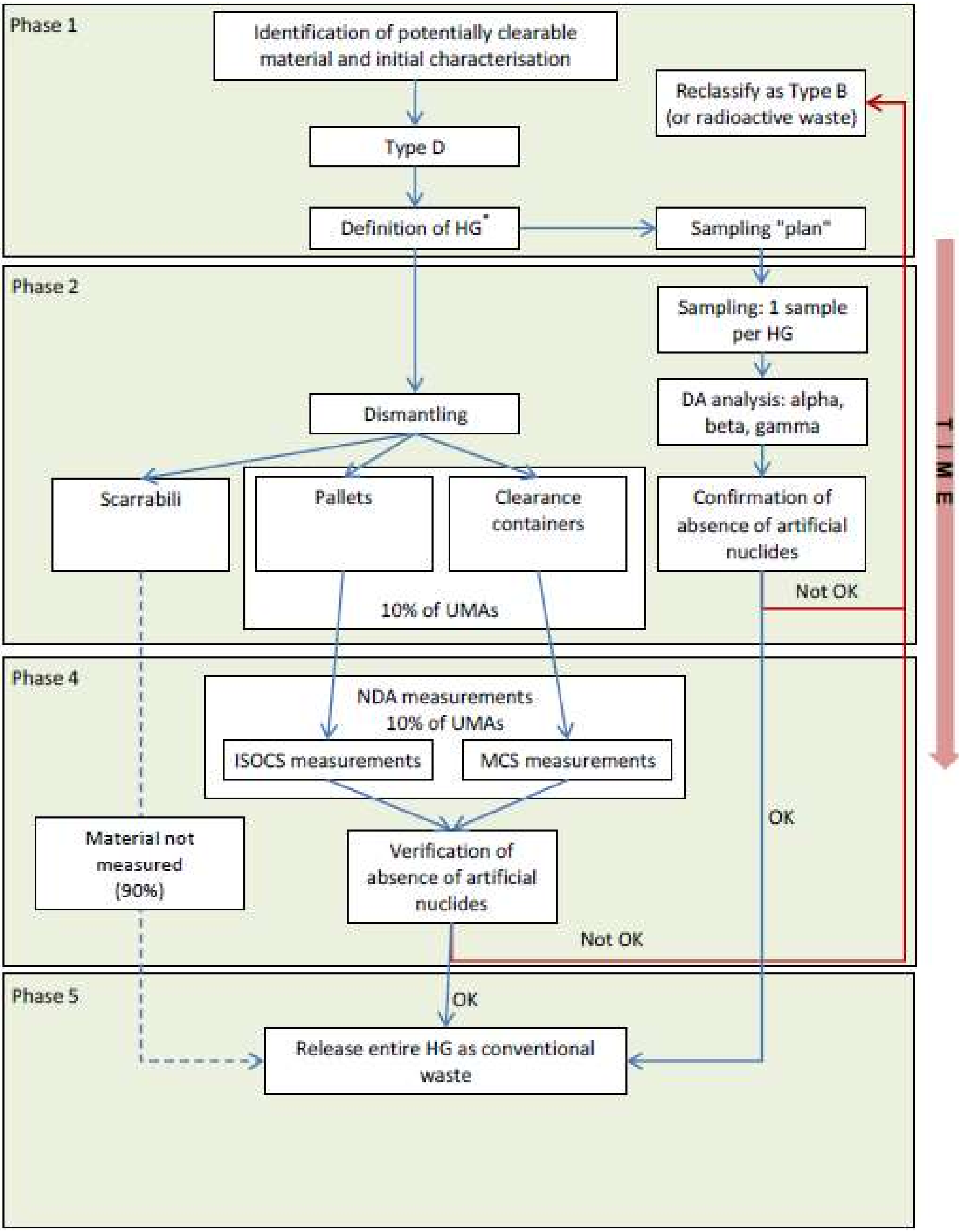


Figure 2: Graphical representation of the clearance process – Type A, B, and C material.



* In this case, a homogenous group does not imply any sorting. It is solely the term in line with the nomenclature of the procedures. Size of the homogenous

The group can be defined conveniently to cover for example all Type D material in the entire dismantling project.

Figure 3: Graphical representation of the clearance process – Type D material.

1.2. Radioactive Waste Management Requirements

Each dismantling project requires the development of a **Waste Management Plan** compliant with the requirements of the Decommissioning Plan / Detailed Design and Waste Acceptance Criteria of SGRR. This waste management plan must provide comprehensive information on **the nature and quantity of wastes** to be generated by the dismantling activities and identify the specific waste compliance documents from the WAC (Waste Acceptance Criteria) suite ([6] and the references therein) that the wastes will conform to.

Furthermore, a **Waste Characterisation Plan (WCP)** is also mandatory for each dismantling project which intends to confer radioactive waste to SGRR for downstream treatment and conditioning. The SGRR licence requires a WCP before the commencement of the characterisation, treatment, and conditioning of radioactive waste. More precisely, the technical prescription I.1.4 of [4] demands that a Safety Case (*Piano Operativo*) containing the Waste Characterisation Plan is submitted to the Safety Authority before starting the activities of characterisation, treatment, and conditioning of any homogenous batch under the SGRR's licence. The difference between a homogenous group and a homogenous batch is well illustrated in Figure 4 below.

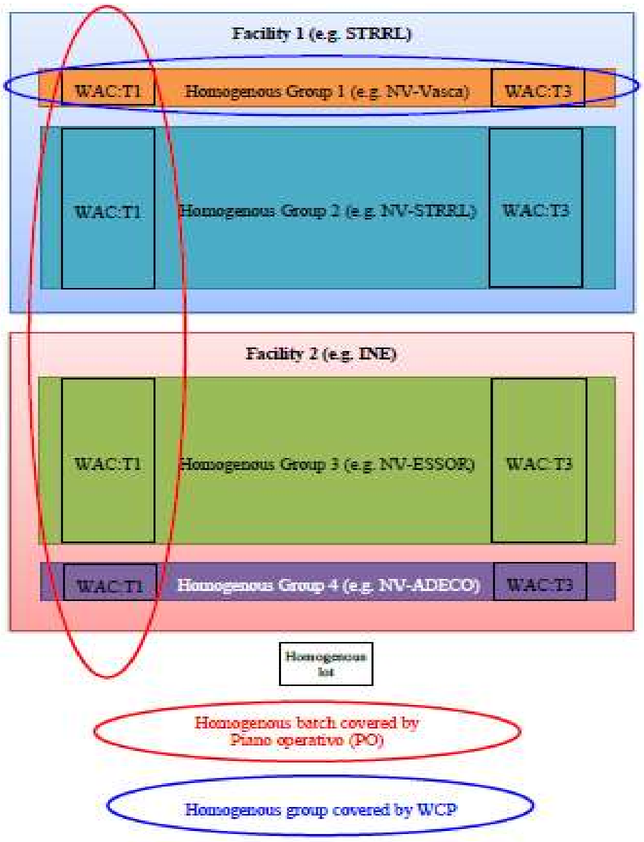


Figure 4: Illustration of the difference between homogenous batch and homogenous group

The Waste Acceptance Criteria recognize the following waste streams and associated WAC documents:

WAC: PT1	Abrasive Decontamination of Radioactive Metallic Waste
WAC: T1	Melting of Radioactive Metallic Waste
WAC: T2	Incineration of Combustible Radioactive Waste
WAC: T3	Supercompaction of Solid Radioactive Waste
WAC: T4	Treatment of Radioactive Effluent
WAC: BS1	Buffer Storage of Orphan Radioactive Waste
WAC: BS2	Buffer Storage of Radioactive Sludge
WAC: BS3	Buffer Storage of Category 3 Radioactive Waste
WAC: C1	Conditioning of Category 2 Solid Radioactive Waste
WAC: C2	Conditioning of Category 2 Mobile Radioactive Waste

2. SCOPE

This report analyses results related to clearance material management and radioactive waste management by looking back to the methods and organisation of work, identifying possible improvements for further continuation of the FARO waste management as well as capturing the lessons learned for future dismantling projects. For the sake of brevity, the specific lessons learned identified in [5] but applicable only to the second phase of the FARO dismantling project have been deleted from the scope of the current document.

3. LESSONS LEARNED

The experience obtained during FARO dismantling can provide advice to future similar projects regarding their **material clearance and radioactive waste management**. The majority of the inconveniences found in dismantling works appear to be related to **material characterization and destructive and non-destructive analysis sampling.**

3.1. Material Clearance

Type D reclassification

Some slight surface contamination was found on cables (presumed class D). The source of this contamination was traced to the event described in the Historical Site Assessment Report [7]: "On the 29th of July 1992, during a pressurization test of TERMOS tank (L-08 test), a structural failure of a connection pipe and a discharge of high-pressure steam (dozen of kilos) dragging uranium dioxide particles occurred".

Any site's history of experimental activity **will make it hard to justify the existence of type D material (neither contaminated nor activated).**

The absence of radioactivity levels in clearance procedures may be rarely achieved with available non-destructive analysis measurements. Moreover, measurements may not only hurt the cost efficiency of the process but also increase safety risks related to the handling of the samples.

There is one more argument against the identification of potentially clearable material of FARO as class D. It will be discussed later that depleted uranium is a challenging task for gamma-spectrometric non-destructive analysis measurements on UMAs. Although class D material necessitates fewer UMAs to be measured (10%), the Clearance Procedures specify that the measurements must confirm the "absence" of manmade radioactivity which is understood to be minimum detectable activity at least one order of magnitude below relevant clearance levels. Such levels were very rarely achieved in non-destructive analysis measurements of FARO material, hence measurements attached to this class of material were a **waste of time and money**. Furthermore, those type D UMAs that were not used as samples were cleared, **becoming a safety risk**

TIP: It may be interesting to reclassify class D material into class B material.

A different approach for this situation is presented later in Section 4.

Size of Homogenous Groups

Another important lesson learned in the identification of clearance waste of material at FARO relates to the size of homogenous groups. The entire FARO experimental rig is homogenous given its nuclide vector (all experiments had been carried out with depleted uranium). At the beginning of the FARO dismantling project, some components had been suspected to have also hereditary contamination from ECO critical assembly, but apart from these, the majority of waste was assigned depleted uranium nuclide vector from the beginning.

Nevertheless, even this waste of material with a unique nuclide vector had been initially divided into many (initially 37, but as additional inventory was discovered this number rose to 56) rather small homogenous groups. At the time of the development of the destructive analysis sampling plan, it was realised that there would be **excessive costs and delays associated with destructive analyses**. It was shown that when the same amount of waste was split into 37 homogenous groups, the number of destructive analyses was 155, while if it was 4 homogenous groups, the number of destructive analyses was 61.

Splitting waste into a large number of homogeneous groups can unnecessarily increase the number of **destructive analyses** and incur **excessive costs and delays.**

The number of destructive analyses to be made was reduced by 60% when the number of homogeneous groups decreased to 4 groups instead of 37.

As material had already been tagged with 56 different tags, the FARO project invented a concept of mini-groups – subsets of homogenous groups respecting the original fine division of waste. **The main benefit of the mini-groups was an easier split of homogenous groups into homogenous subgroups in case the coherence checks on destructive analysis results failed.**

The heaviest consequence of **155 destructive analyses** was associated **delay of 8 months** which would adversely impact dismantling operations. These considerations led to the **re-definition of the homogenous groups at FARO from 56 to 4.** Consequently, the open clearance dossiers were rearranged (fused) to leave only four of them.

8 months of delay was associated with the unnecessary destructive analyses conducted in Ispra

TIP: It is advantageous to define the maximum possible size of homogenous groups as this reduces requirements on several destructive analyses and associated delays and costs in the process.

DA Sampling

JRC-Ispra procedures did not address the interface of clearance and dismantling (1.1.3). The same applies to the timing of destructive analysis sampling relative to dismantling. Initially, samples for destructive analyses had been taken in FARO as the first dismantling action in each room. Therefore, at the beginning of the FARO dismantling project, **cutting, and packaging had been performed without knowledge of the number of segregated UMAs** that will have to be made available for non-destructive analysis measurements. This fact was then recognised in the initial revision of this document as causing potentially **unnecessarily elevated cutting and fragmentation costs** and therefore destructive analysis sampling was brought forward and completed in all remaining rooms even though it meant some repeated erection of temporary protective containments.

The performance of cutting and packaging before knowing the number of segregated UMAs can give rise **to unnecessarily high costs related to repeated construction of containments.**

Consequently, when the dismantling started, the Project Leader did not have information on homogenous subgroups and final nuclide vectors. In order to **mitigate the potential impacts** of non-coherence discovered by destructive analysis sampling after some potentially clearable material had been already packaged**, the inventory of FARO was more finely divided into so-called homogenous mini-groups** which in principle respected division by technological systems, **but later became a problem** as it is mentioned in the section above.

The lesson learned identified already in [5] of this report on the timing of destructive analysis sampling is still valid. If the statistical approach philosophy is retained (and a portion of material can be released without measurement) or indeed if the necessity to sample potentially clearable material for destructive analyses is retained (see paragraphs below) in the clearance procedures, then destructive analysis sampling must be executed before dismantling and packaging.

TIP: Any destructive analysis sampling at the plant to be dismantled must be performed before the detailed design and waste management plan are produced, as the destructive analysis results are an indispensable input for the correct development of these documents.

<u>**Scaling Factors Calculation**</u>

FARO facility had been using depleted uranium to simulate a core melting accident. The Waste Characterisation Plan for Radioactive Waste [8] identified the scaling factor between activities concentrations of U-235 and U-238 SF(U-235/U-238) = 0.017. It means that even for samples termed "hot spots" where the **activity** concentration of U-238 is slightly (less than one order of magnitude) below its **relevant clearance levels** (in the interval between 0.1 Bq/g and 1 Bq/g), the **activity concentration of U-235** ranged from 0.0017 Bq/g to 0.017 Bq/g and such concentrations were on the **borderline of the minimum detectable activity**.

Indeed, out of 62 destructive analysis samples on FARO potentially clearable material, only three yielded positive pairs of U-235 and U-238 (both radionuclides' concentrations were higher than their MDAs (Minimum Detectable Activity Values). When the requirements of the procedure [3] were followed and relevant minimum detectable activity values were interpreted as true contaminations, the **resulting scaling factor indicated that FARO had been using enriched uranium**. It is an obvious error as no physical process in FARO experiments could have changed the level of enrichment/depletion. Such a scaling factor is the scaling factor between MDAs of the detection method of the two radionuclides and not between their concentrations.

Scaling factors may introduce errors in obtaining the activity concentration of U^{235}.

Only 4,8% of the samples had higher concentrations than their MDAs (Minimum Detectable Activity Values)

The experience gained by following the process prescribed by the JRC-Ispra procedure [3] showed that the **philosophy of having to confirm or establish scaling factors on the destructive analysis samples of the potentially clearable material is wrong**. Although the procedures explicitly prescribe that the samples are taken from presumed hot spots, these samples were still not sufficiently "hot" to enable the detection of all radionuclides – they are very mildly contaminated, being potentially clearable material.

TIP: Destructive analysis sampling of potentially clearable material may be unnecessary, or its **purpose should not be aimed at the establishment of scaling factors.**

NDA Measurements Using ISOCS

There were several motives why ISOCS measurements were explicitly named in the clearance procedure [3] issued ahead of the FARO dismantling project. It was added on the specific request of the FARO Project Leader because of **the envisaged complications of managing a high number of clearance measurements and associated transports** going forward and back from Area 40 and due to **storage issues** there (rather than because of temporary unavailability of the material clearance system station at the time).

Instrumentation needs to be robust. Clearance procedures imply a high number of measurements and transports between the study area and the controlled zone.

Indeed, the material clearance system was not meant for decommissioning scale measurements (bearing in mind the exclusion of material from decommissioning specified in the procedures – see 1.1.3).

TIP: **In-Situ Object Counting System measurement technique has more potential and flexibility** than a material clearance system, due to it being more fit for any dismantling project.

Measurement Difficulties

It transpired that **depleted uranium is difficult to measure using with sufficient sensitivity ISOCS equipment** because of the absence of typical radionuclides for other streams of radioactive waste (Co-60 and Cs-137) which show very easily in ISOCS spectra. To compensate for this, a measurement corner with a (relatively) low background was searched for and established in building 42 and metallic shielding was made to further decrease the background.

Despite these arrangements, the typical counting time had to be 60 000 s (overnight measurements) and in some cases had to extend to 300 000 s (weekend-long measurements). These spectra acquisition times allowed the minimum detectable activity to achieve desirable values below the clearance levels (but only just). It was noted that **if UMAs with low weight had been selected for measurements, their compliance with clearance levels could most probably not be demonstrated even with such long acquisition times** as the denominator in the fraction minimum detectable activity (Bq) / mass (g) would be too small. It is repeated that **for class D material such sensitivity as achieved in FARO would be insufficient**, as the JRC procedures require the activity value to be one order of magnitude below the clearance levels.

120 UMAs have been measured by ISOCS in such conditions. **None of the measurements revealed any positively detected activity of any radionuclide in the spectra; all results were below MDAs**.

The experiment demonstrates that ISOCS equipment for non-destructive analysis measurements is insufficient for successful clearance levels compliance verification in decommissioning projects.

In order to have indications for future decommissioning projects, **a notional experiment was made** using these FARO results. STRRL scaling factors have been applied to these 120 FARO results to see if this material which has no detected activity whatsoever can be proven to be compliant with clearance levels if it originated from other than a FARO facility (in this experiment from STRRL). The result has shown that **84 UMAs out of 120 would exceed clearance levels** with their minimum detectable activity values. In all cases, **the problematic radionuclide was Am-241.** Unfortunately, Am-241 and other transuranic elements related to Am-241 are present in the majority of JRC-Ispra facilities. **A potential approach for this situation is presented later in Section** ¡Error! No se encuentra el origen de la referencia..

Not even a single UMA could exceed clearance levels in FARO.

70% of UMAs would exceed clearance levels if STRRL scaling factors had been used instead of the scaling factors obtained in FARO.

Considerations about non-destructive analysis Measurements of Homogenous Groups

A-posteriori considerations about the concept of the homogenous group/subgroup as defined in the clearance procedures [3] mentioned before led to **concerns that the unmeasured portion of the potentially clearable material in the homogenous subgroup could be contaminated** more than the relevant clearance levels because the homogenous subgroups of FARO material contain diverse, unconnected waste of material streams.

There is uncertainty about the level of contamination of unmeasured portions of material if the is statistical monitoring.

Statistical monitoring measurement techniques may introduce additional uncertainties in the characterization of the level of contamination of unmeasured portions of material

Statistical monitoring of UMAs in future projects will be defendable only on homogenous objects rather than homogenous groups. When applying the concept of the homogenous group as defined in the JRC-Ispra site procedure [2], only the coherence of the nuclide vector is relevant and the homogenous group can cover objects of varying contamination levels, from non-contaminated to highly contaminated. Therefore, in general, the **contamination level of one UMA does not correlate to another UMA**. However, for homogenous objects, such as big tanks, walls of a single room or for example ESSOR hermetic dome (the biggest homogenous object on the JRC-Ispra site), statistical monitoring makes perfect sense.

TIP: Full coverage (100%) measurements may work better than statistical monitoring for this type of waste

Nevertheless, the measurement plan for statistical monitoring ensured its maximum representativeness and lacking ISOCS measurements have been substituted by RP monitoring.

3.2. Radioactive Waste Management

It is worth reminding that FARO dismantling was the first industrial-scale implementation decommissioning project of the D&WM Programme. As such it also became a test case for relatively new Waste Acceptance Criteria of SGRR as well as the test case for the creation of object dossiers: Information packs that will any time in future provide comprehensive descriptions of the objects created in dismantling (and sufficient confidence that this description is correct).

Safety Case Submission

One can see from Figure 4 that it was **very difficult to fulfil requirement I.1.4** to [9] because the waste characterisation plans submitted before the characterisation cannot contain the knowledge of homogenous groups and their radiological inventories necessary for further development of *Piano Operativo* for waste treatment. After all, they had not been defined yet.

Waste Characterization Plans may not contain information about homogeneous groups which can complicate the submission of the Safety Case to the regulatory council.

This conflict can be addressed by the recently issued Homogenous Group Definition Procedure [2], which standardizes the process of establishing the homogenous groups of waste material and their nuclide vectors. **Future similar projects would benefit economically from this**, thanks to them being able to avoid the initial material characterization phase. In the case of dismantling projects, this process takes place before dismantling the intact facility.

TIP: Standardize the homogeneous groups' definition process or perform **destructive analyses before the design and WCP**, as mentioned in 3.1.

An alternative approach for this situation is presented later in 4.

Metal Melting Criterion

As to WAC, FARO dismantling gave feedback on the WAC: T1 for metal melting identifying that the **surface contamination upper limit was unreasonable and made the majority of dismantled metallic components non-compliant** with WAC: T1. Consequently, WAC: T1 application was updated [10] and became a permanent lesson learned. Higher limits are expected to be embedded in the next revision of this WAC.

WAC: T1 needs to be updated so there are metallic components that can be accepted by an external metal melting service provider**.** If that happens it will enable the project leader to **compare if that option is not more costly** than the local one performed by framework contractors.

Supper-Compaction Criterion

FARO dismantling project **produced 131 standard drums with soft technological waste**. These drums were compliant with WAC: T3 for super compaction, but their **average content was only 25 kg (per drum)**.

The number of drums may be too high compared with their average content. The space they occupy translates into unnecessary spending.

Seeing the **opportunity for the reduction of the number of drums to be characterised, transported to the service provider and super-compacted and reduction of associated costs**, JRC-Ispra Project Leader decided to launch a preliminary compaction campaign of these drums. The pre-compaction campaign managed to achieve an average volume reduction factor of 2 and decrease the number of technological waste drums to 65. A feedback report [11] has quantified that **the pre-compaction campaign saved 4% of the total waste management costs of this waste stream**.

The pre-compaction campaign saved up to 16 000 €

TIP: Pre-compaction campaigns can achieve higher savings, especially if they are carried out **during the technological waste drums creation** rather than afterwards.

Since the FARO dismantling project, the datasheets of the waste of material objects created in dismantling have been developing in continuous improvement. Anyway, it is fair to say that **FARO datasheets gave a very solid basis for modern waste object dossiers** and thus left a positive lesson learned.

4. RECOMMENDATIONS FOR OPERATORS IN THE EU

Although FARO Dismantling Project was included in JRC-Ispra the D&WM programme, it was formally carried out under a "Richiesta di Variante" authorization because of the non-existence of a standalone license for the FARO operation. Nevertheless, it bore all the practical aspects of a decommissioning project.

The material from FARO dismantling was formally classified as material arising from the Variante execution, enabling the application of the existing General Procedure [3], intended for material produced under a safe conservation regime. However, given the nature of the Variante and the scale of the intervention, the clearance process was a good test case for future decommissioning projects.

Valuable lessons were learned for the future evolution of the clearance procedures in their orientation towards decommissioning – see 3. Decommissioning Sector intended to capitalize on the gained knowledge and awarded an external work package to the Project Implementation Assistance Framework Contractor for the development of brand-new Clearance Procedures for Decommissioning. The resulting draft can be looked up in [12], [13], [14], [15] and [16].

Today, the development of a **unified clearance procedure** (not distinguishing between historical material, and material from pre-decommissioning and decommissioning) is under the responsibilities of the Clearance Coordinator.

The notion of the need for a standalone clearance procedure for decommissioning has been overcome and **JRC adopted the approach of a unique clearance process where it is not important by what activity the material is generated** (decommissioning, maintenance, or past decommissioning without prior characterisation).

Because of the complexity of these new procedures and their untested unfinished status**, they are not ready for use**. Nevertheless, they were handed over to the Clearance Coordinator as input into future updates of the site-wide clearance procedures.

Therefore, **¡Error! No se encuentra el origen de la referencia.** illustrates the **proposed actions u ntil this moment** that have been suggested from the work done in FARO. These actions might **help to improve the overall performance of clearance processes in future dismantling projects.**

Area of Application	Hurdle to Overcome	Proposed Action/s
Type D classification	Cost Deficiencies Time Consumption Safety Risk	Reclassification to Type B Introduction of Type E material
Number of Homogeneous Groups	Cost Deficiencies Time Consumption	Define homogeneous groups with the maximum size possible
Destructive Analyses Timing	Cost Deficiencies Time Consumption	Perform destructive analyses as early as possible
Scaling Factors Calculation	Measurement Error	Avoid destructive analyses Do not calculate scaling factors via destructive analyses Calculate scaling factors from truly contaminated samples
Instrumentation	Time consumption	Use of ISOCS instead of material clearance system.
Measurement	Sensitivity Deficiencies	More instrumentation alternatives available
	Safety Risk	Full coverage measurement instead of statistical monitoring
Safety Case Submission	Lack of Information	Perform destructive analyses as early as possible Standardize the homogeneous group definition
Metal Melting Criterion Fulfillment	Cost Deficiencies	Update the criterion Perform surface contamination measurements directly Calculation of mass limits only from the conversion factor
Super-Compaction Criterion Fulfillment	Cost Deficiencies	Execute a pre-compaction campagin
Role Assigment	Time consumption	The role of the Clearance Coordinator is re-introduced as person managing and administrating the non-conformance process
Process Certification	Indecision	Requirement of only 1 signature per object, enabling immediate clearance after successful measurement.

Figure 5: Proposed action/s to face clearance processes' main hurdles

Out of all lessons learned in 3.1, there were a few hurdles whose solution may be found or reinforced by the suggestions made in **¡Error! No se encuentra el origen de la referencia.**:

Type D reclassification

Firstly, as is mentioned at the beginning of 3.1, due to a site's historical experimental activity, finding type D material would be hard to do. In addition, the use of depleted uranium makes it a challenging task to do gamma-spectrometric non-destructive analysis measurements on UMAs from this type of material. Therefore, even though type D material is thought to be the "cheapest" material to work on (class D material necessitates only 10% of UMAs to be measured), its required minimum detectable activity levels are very rarely achieved hence measurements attached to this class of material were a waste of time and money.

That's why **introducing type E material would reduce the range of possible type D material to be measured**. Consequently, measurements would be more certain of the origin of the sample**, improving the precision** of the measurement. This could also **reduce costs and delays** by working on a smaller portion (1% of UMAs).

Scaling Factors Calculation

The work package awarded by the Decommissioning Sector encourages determining **scaling factors from truly contaminated samples** (of radioactive waste). Before, they should have been tested in line with the new Homogenous Group Definition Procedure [2].

Measurement Difficulties

3.1 also exposes **the lack of sensitivity** in measurements if ISOCS is the alternative selected for the process. Despite this, **ISOCS is thought to be a better alternative** to the material clearance system due to its portability and ability to execute a high number of measurements.

A higher versatility in non-destructive analysis equipment can be achieved by introducing Berthold LB 124 and a substitute that would always work: "bulk destructive analyses".

This last method is based on a collection of statistically enough representative (point) destructive analyses samples from a single waste of material object under clearance (not to be confused with destructive analysis samples taken during plant characterization for nuclide vector determination). Later, there is an assessment of the results by application of the same non-parametric test.

Metal Melting Criterion

3.2 comments on the difficulty of fulfilling the criteria for melting radioactive metallic waste because the surface contamination upper limit was unreasonable and made the majority of dismantled metallic components non-compliant. Satisfying this criterion would enable the project leader to send metallic waste to an external melting service instead of being subject to the local contractor, which could be a cheaper option. This is why 3.2 proposes an **updating of the criterion**.

Instead, direct surface contamination determination is proposed as the primary check and calculation of mass limits only from the conversion factor. This new way of measuring would open the possibility of achieving the original limits instead of updating the criteria, **which could cause bureaucratic delays.**

5. CONCLUSIONS

5.1. Executive Summary

This report aims to help future dismantling projects avoid inefficiencies during their respective clearance processes. Thanks to the experience obtained during FARO dismantling, some suggestions to solve the problems encountered are made.

Every clearance process needs to follow an integral sequence of steps to avoid delays and unnecessary spending. If a phase is completed and there is no certainty about the results obtained, the following activities will carry a great risk that will grow as the project progresses.

A precise **characterization of materials** will be crucial for the project's success. There is a good chance that non-contaminated or activated material (type D) causes problems with its identification due to the site's historical experimental activity and a wrong selection of measurement equipment. In addition, it has been found that the wrong calculation of the scaling factor can aggravate this issue. If materials are classified incorrectly, contaminated objects might be released and create a **high safety risk**. **Possible steps towards this obstacle** might be:

- Introduction of a type E material to shorten the range of materials to identify
- Performance of destructive analyses before the design and planning of the clearance process
- Disposal of great versatility in instrumentation

On another note, the **definition of homogenous groups** could also bring more problems to projects. A high number of groups means a high number of measurements. This implies **excessive risks, delays, and the possibility of not measuring contaminated material.** To prevent it:

- The size of the homogeneous groups should be defined to a maximum
- The measurement of material should check 100% of its UMAs instead of performing statistical monitoring.

Finally, a pre-compaction campaign is proposed to reduce the number of drums that contain solid waste in half. It could mean the **cutting of 4% of the total waste management costs**.

5.2. Iimportance of Capturing These Practices

This technical report helps to share the experience obtained throughout the FARO dismantling project I-04-05-01 until June 2016. These activities include the characterization of materials, equipment selection, or sampling. Due to the lack of experience in this kind of project, the lessons learned in this report add great value to future JRC's decommissioning activities. This knowledge will also be beneficial to users such as operators, and regulators outside the JRC program.

Thanks to the knowledge provided by these lessons, clearance processes will be able to **solve economic deficiencies** in different ways. Changing the moment destructive analyses take place, updating waste management criteria or reducing the number of homogeneous groups are some of the solutions that have been brought up in this report. In addition, most of these measures will reduce some **accelerate the process** and **avoid possible delays**.

On another note, this document will help to **ensure safety** via some of the suggestions that are made, like the reclassification of type D material or the change of the measurement technique.

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