THE CHANCE, MICADO AND PREDIS DEVELOPMENTS AND EXPERIENCES ON RADIOACTIVE WASTE CHARACTERIZATION

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The items

- Intro
- The CHANCE, MICADO & PREDIS projects
- GAP analysis on the nuclear waste characterization
- Waste types and categories considered by the projects
- The technologies under development
- Possible further ideas and Conclusion

Waste characterization in EU

Characterization is a key element when dealing with materials and waste streams that are produced during the operational, decommissioning and dismantling phases of nuclear installations.

The goal is to improve the characterization process and reduce the uncertainty levels that allow us to better distinguish between materials, well separate categories and decide the appropriate management and storage procedures.

- *Better knowing the package content ensure the regulatory control entities to work with safe, controlled and stable waste forms.*
- *A deep knowledge of the waste package content is also needed during the predisposal stages of radioactive waste management to show compliance with waste acceptance criteria of the facilities.*

This is the only way to treat, manage and store the Radioactive Waste Packages in the proper way and ensure safety, security and improve the impact on the social level.

The Projects

CHANCE
Characterization of Conditioned Nuclear Waste for its Safe Disposal in Europe

- **Call**: NFRP 7-2016-2017 topic "Research and innovation on the overall management of radioactive waste other than geological disposal" of the H2020 Euratom Work Programme 2016-2017.
- **Total budget**: 4.25 M€ (3.98 M€ EC contribution)
- **Consortium**: 11 partners from 7 EU countries
- **Grant agreement**: 755371
- **Duration**: 58 months (2017 – 2022)

https://www.chance-h2020.eu

micado

- **Call**: NFRP-2018/NFRP-2018 topic "Encouraging innovation in nuclear safety for the benefit of European citizen"
- **Total Budget**: 4.99 M€ (4.44M€ EC contribution)
- **Consortium**: 9 Partners from 5 countries
- **Grant agreement**: 847641
- **Duration**: 42 months (2019-2022)

https://www.micado-project.eu/

PREDIS

- **Call**: NFRP-2019-2020-10 topic "Developing pre-disposal activities identified in the scope of the European Joint Programme in Radioactive Waste Management"
- **Total budget**: 23.77 M€ (14 M€ EC contribution)
- **Consortium**: 46 Partners from 17 countries
- **Grant agreement**: 945098
- **Duration**: 48 months

https://predis-h2020.eu

The CHANCE project

The project aimed to address the specific issue of the characterization of conditioned radioactive waste with its specific needs addressable by non-destructive techniques and methodologies.

Characterization issues encompass both physical-chemical characterization and radiological characterization.

The experimental focus within **CHANCE** is radioactive waste held in large volume compounds, spent fuel held in large volume storage containers, problematic and legacy waste, specific waste arising from repair or maintenance, decommissioning/dismantling waste and radioactive waste destined for geological disposal.

1. **The first objective** was to establish at the European level a comprehensive understanding of current conditioned radioactive waste characterization and quality control schemes across the variety of different national radioactive waste management programmes.
2. **The second objective** was to develop, test and validate techniques to improve the characterization of conditioned radioactive waste, especially those that cannot easily be dealt with using conventional methods.

The 3 projects

The MICADO project proposes a cost-effective solution for non-destructing (NDA) characterization of nuclear waste, implementing a digitization to facilitate and harmonize the methodology used for the in-field Waste Management and Dismantling & Decommissioning operations.

The D&D process of nuclear infrastructures demands methods for a full traceability of waste material to improve quality management and operational safety.

The Digi-Waste solution proposed in the **MICADO** project will result in a proven modular solution offering an opportunity to proactively develop a unified and standardized Waste NDA Characterization Procedure and Method that could become an international reference allowing all Nuclear Operators – Research Laboratories & Safety Authorities to facilitate their exchanges.

What **MICADO** will prepare is a Platform of:

- Precise procedures of the data and measurement handlings providing twofold benefits: the optimization of costs, associated with D&D, and the minimization of the dose exposure to operators and personnel
- A toolbox of detection technologies for the NDA waste characterization: technologies cover different type of waste packages and matrixes providing a coverage of a wide range of waste types
- RFID Tags for and unique ID of the waste package inside the database and for logistics and tracking ID
- Software platform with a core database, a user GUI to display and access measurement data and report and block-chained data test provided
- Technologies for the long monitoring of the waste considered

The PREDIS project

The PREDIS project targets the development and implementation of activities for pre-disposal treatment of radioactive waste streams other than nuclear fuel and high-level radioactive waste.

The aims are:

- To analyse criteria, parameters and specifications for materials and packages with associated waste acceptance criteria for pre- and disposal activities, supporting homogenisation of waste management processes across EU
- to develops and increases the TRL of treatment and conditioning methodologies for wastes for which no adequate or industrially mature solutions are currently available, improving safety during next waste management steps
- To develop innovations in cemented waste handling and pre-disposal storage by testing and evaluating techniques
- To improve existing solutions with safer, cheaper or more effective alternative processes and methodologies
- To organize training sessions and mobility training schemes to enhance sharing and transfer of knowledge and competences as part of knowledge management activities.

CHANCE GAP analysis outputs –I

Leader: ANDRA

CHANCE WP2- METHODOLOGY aimed at identifying current methodologies and shortcomings of current characterization and metrology of CRW in Europe
Important R&D challenges identified in WP2

D2.3 R&D requests in the field of conditioned radioactive characterization

https://www.chance-h2020.eu/public-deliverables

- High energy and Dual energy X-ray for the characterization of physico-chemical and structure of large and dense waste packages
- ***Active photon interrogation*** with high energy X-rays to measure and identify nuclear materials in large and dense packages
- ***Neutron coincidence counting*** also based on alternatives to 3He detectors
- ***Active neutron interrogation*** to measure the fissile mass in high-level waste
- Neutron activation analysis for the characterization of chemical elements or the long – lived isotopes that are difficult to measure by gamma spectroscopy

Calorimetry, Muon spectroscopy And Cavity Ring-Down Spectroscopy already considered in the CHANCE proj.

CHANCE GAP analysis outputs - II

Leader: ANDRA

CHANCE WP2- METHODOLOGY aimed at identifying current methodologies and shortcomings of current characterization and metrology of CRW in Europe
Important R&D challenges identified in WP2

End Users Group (EUG) questionnaire

D2.2 Synthesis of commonly used methodology for conditioned radioactive characterization

https://www.chance-h2020.eu/public-deliverables

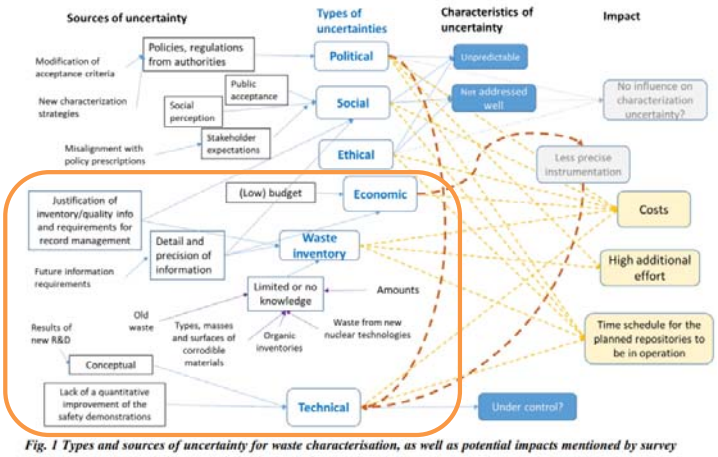


Fig. 1 Types and sources of uncertainty for waste characterisation, as well as potential impacts mentioned by survey respondents. An arrow indicates a relation between the two elements.

Which do you anticipate with regard to waste characterisation for safe disposal?

The uncertainties addressed by this question may relate to changes in the final disposal concept, regulation and/or policy, divisions of responsibilities, limits of knowledge, amounts of waste, societal incentives or pressures, financial constraints, safety/security protocols, among others.

PREDIS Gap analysis

A Gap Analysis was conducted to evaluate industry and stakeholder needs for R&D and demonstration in predisposal waste management technologies
Information was gathered by quantitative and qualitative surveys, live polling, interviews with end-users, webinar presentations, discussion groups and literature reviews.
The output is the Deliverable 2.2 – The GAP analysis

https://predis-h2020.eu/wp-content/uploads/2021/06/PREDIS-D2.2-Gap-Analysis_Final_2021-05-31.pdf

From the live polling:

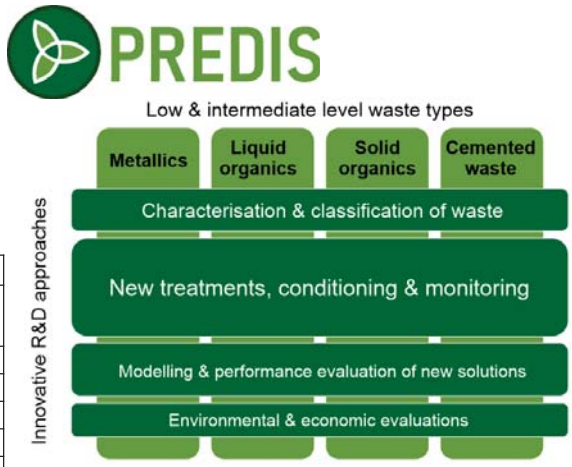
1. The greatest challenge in ***waste pre-treatment*** is the Waste classification and characterization (22%) and the waste processing (21%)
2. The waste types to focus on ***for near-term next R&D on treatment technologies*** are: Liquid organic waste- (oil, chemical etc.) (29%) and Metallic waste (18%)
3. The greatest challenge in ***waste pre-disposal management*** are the waste processing (27%) and the waste classification and characterization (25%)
4. The waste types to focus on for the ***near-term R&D on treatment technologies*** are liquid organic waste (41%), metallic waste (17%) and graphite waste (17%)

Again… the classification and characterization are main requirements

Waste types overview

Characterization of fully or partly conditioned radioactive waste. The characterization difficulties are several, the main ones can be summarized:

- conditioned waste may no longer be in its initial form
- conditioned waste is typically embedded or surrounded by a matrix



- MICADO covers Vol. up to m^3
- It may cover larger volumes with minor design changes

	Matrix					
	Glass	Concrete	Bitumen	Epoxy resin	Mortar	No matrix
Legacy W	X	X	X	X	X	X
VLLW						X
LLW-LHL		X				X
LLW-SHL		X	X	X	X	X
ILW-SHL		X	X	X	X	X
ILW-LHL	X	X	X			X
HLA	X	X				
VSHL						X
Exempt W						

VVL= Very Low Level Waste
LLW = Low Level Waste
ILW = Intermediate Level Waste
HLA = High Level Waste

LHL = Long Half Life
SHL = Short half Life
VSHL = Very Short Half Life

Exempt waste, large volumes metallic containers, free release and toxic element characterization (i.e. B, Hg, Cd, Gd, Cl, As) and the presence of neutron moderators or absorbers can be addressed in future projects

Waste forms projects coverage

Following the IAEA classification of the radioactive waste, the main families covered by the three projects are the following ones:

	CHANCE	MICADO	PREDIS
Legacy W	X	X	X
VLLW	X	X	
LLW	X	X	X
ILW	X	X	X
HLW	X		
VSLW		X	
Exempt W			

https://www.iaea.org/publications/8154/classification-of-radioactive-waste

Leader: orano

MICADO use case identified and analyzed within the project

- **Case1**: N. 5 Bags of wet decontaminated wipes (C3H6)
- **Case2**: N.1valve at the bottom with Pu retention + N.50 pipes
- **Case3**: N.6 compacted waste discs in a concrete matrix (N.2 metallic, N.3 technological waste, N.1 PVC waste)

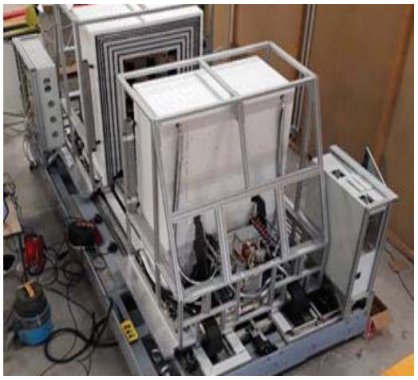
The characterization technologies table

Method/Technology/Sensor		Lead Institute	Purpose	Project
Calorimetry		KEP	Quantification of the alpha emitters or low energy emissions	CHANCE
Cavity ring-down spectroscopy (CRDS)		VTT	Characterization of radioactive waste outgassing	CHANCE
Gamma Station	Gamma camera	ORANO, ENEA	Hot spot search and identification	MICADO
	Gamma dose rate and spectroscopy & RFID	CAEN	gamma dose at contact and fast open geometry measurement for survey application	MICADO
	Gamma spectrometry	ENEA	Quantification of gamma emitters (open geometry, angular scanning, tomography)	MICADO
Neutron station	Neutron Active measurements	CEA	Quantification of nuclear materials (Pu, U) in not cemented packages	MICADO
	Neutron passive measurement	CEA	Quantification of nuclear materials (Pu, U) in not cemented packages	MICADO
Photofission station	Photofission measurements	CEA	Quantification of fissile materials in cemented packages	MICADO
Long term monitoring grid	SciFi technology	INFN	Gamma dose rate monitoring for storage or repository sites	PREDIS / MICADO
	SILIF technology	INFN	Neutron monitoring for storage or repository sites	PREDIS / MICADO
	Timepix network	CTU		MICADO
Data assessment	Uncertainties analysis	SCK-CEN	Monte Carlo error propagation, including pre- and post-processing of measurement data and results, tailored to radiological characterisation	MICADO
Muon tomography		UNIBRIS / INFN	Internal structure of drum	PREDIS / CHANCE
Ultrasonic echo (high frequency, metal)		BAM	Container Wall: thikness, internal, corrosion, cracks	PREDIS
Ultrasonic echo (low frequency, concrete)		BAM	Container fill: Structure, objects, cracks	PREDIS
Ultrasonic monitoring		BAM	Changes in concrete fill, crack development, stiffness	PREDIS
Acoustic emission analysis (AE)		BAM	Changes in concrete fill, crack development, stiffness	PREDIS

All actions considered to optimize and improve the waste characterization within the 3 projects

- ✓ **Radiation detection**
- ✓ **Software analysis**
- ✓ **Treatment of the waste**
- ✓ **Procedural management method**

Calorimetry & CRDS



The CHANCE calorimeter at SCK·CEN premise

Leader: KEP Nuclear

Calorimetry: based on the measurement of head flux emitted by nuclear material

- CHANCE calorimeter developed to measure 200 L with an optimized detection limit to host a 200L drum (10-3000mW range)
  - minimum detectable power: 5 to 15 mW under good conditions; 100 to 200 mW without baseline
- Combination of calorimetry with gamma spectrometry and neutron passive measurement can significantly reduce the uncertainty when characterizing the mass of plutonium of large, dense and heterogeneous waste packages, like concrete drums containing technological waste

Leader: VTT

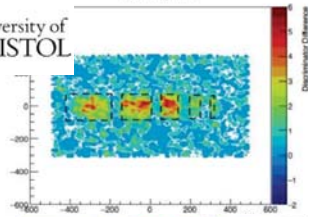
Cavity Ring-Down Spectroscopy (CRDS): development of a transportable instrument for in situ airborne radiocarbon detection based on mid-infrared cavity ring-down spectroscopy. The implementation of CRDS method in measuring outgassing of ^{14}C from graphite was demonstrated successfully in CHANCE with measurements that showed good repeatability and accuracy.

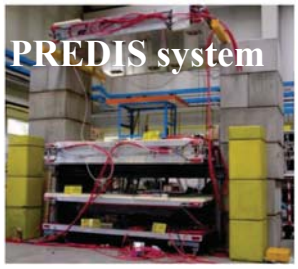
Muon tomography

NDA technique with a long exposure time (d/w) produces a full 3D image of a volume, allowing individual objects or bubbles inside the drum, as well as giving information on their atomic number Z and density.

- In the ***CHANCE*** project, a muon tomography system using drift chambers and resistive plate chambers was built. Unfortunately, several unforeseen challenges have led to a very small track sample; too small for detailed imaging. Many Monte Carlo studies were performed to prepare the expected experimental data and further the development of data analysis algorithms: development of new algorithms which have improved material identification, the detection of hydrogen bubbles in waste drums with a bitumen matrix and to detect anomalies in the contents of CASTOR drums.
- The ***PREDIS*** collaboration has a prototype made of 2 layers of *drift chambers* used to validate the properties of concrete waste packaging including density analysis. At this stage of the project a first test was obtained detecting iron content inside a concrete block.

Leader: University of BRISTOL





Leader: INFN

Gamma characterization and protocols

WC protocol to drive the characterization process of the different waste packages to minimize measurement time of each step and being more effective in the detection technologies to be used to optimize the NDA characterization.

Gamma characterization: MICADO has a station which integrates three technologies to determine the gamma radiological content.

- Identification phase based on **UHF-RFID tag** on the waste package providing a unique identifier of the waste
- **RadHAND:** scintillator sensor performing dosimetry measurements and automatic dosimetry and spectroscopic measurements in open geometry in parallel with
- The **Nanopix** gamma camera for the localization and identifications of hot spots

Results obtained from this part of the procedure determines the measurement type of the following and next steps

- **SRWGA:** tomographic, segmented and angular gamma scanner performing spectrometry measurements of the package

The main innovations comes from the procedural integration of the three techniques into four steps procedure: identification, screening, preliminary and characterization phases.

A&P neutron and photofission systems

Leader:

The neutron transportable station combines passive neutron coincidence counting and active neutron interrogation techniques to quantify the presence of fissile or fertile materials. **MICADO** includes Analysis based matrix effect correction using artificial intelligence with trained data to apply signal attenuation corrections

- it can be used for large metallic waste packages difficult to characterize by gamma spectroscopy and when gamma rays of fission or activation products mask the Pu gamma rays

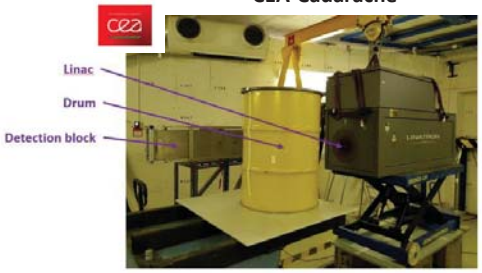
MICADO neutron station at CEA-Cadarache

The photofission station This techniques is important to address large volumes packages and conditioned waste with concrete or polyethylene matrices that are considered difficult to be characterized other techniques.

MICADO

- is studying the possibility to work with a mobile photofission system based on “low energy” (6 MeV) X-rays to minimize the hazard and the safety shielding usually required by this technique giving the possibility to assemble a mobile system.
- Is also working on a prototype to work in laboratory conditions at 9 MeV

Leader:



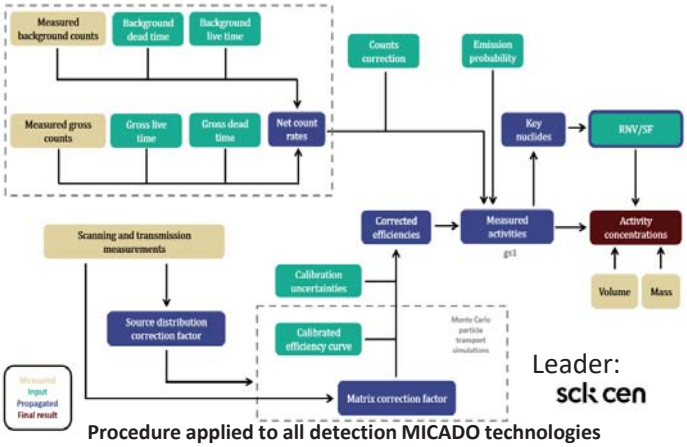
Experimental setup at the SAPHIR platform (CEA Paris-Saclay)

Software applications

Pipeline data assessment: the data analysis pipeline is a software infrastructure based on Monte Carlo particle transport simulations able to:

- propagate the uncertainties related to the individual detection techniques
- combine results of the individual techniques to ***reduce the global uncertainty on the final inventory***

Used in **MICADO** to validate the technique to better determine the levels of radioactivity optimizing the waste classification especially of packages closer to limits betwee surface storage or geological repository.



Leader: sck cen

Procedure applied to all detection MICADO technologies

The data digitalization: Software platform providing a database of all data provided by the **MICADO** detection technologies available and the visualization of the characterization process. All **MICADO** technologies, software, and hardware, provide data outputs that are saved in a common software framework. One of the key elements is the database from which the organized collection of stored data can be accessed to from several computers and by different operators and security stored using the blockchain technology to verify the data content reliability.

PREDIS waste package monitoring

PREDIS WP7 develops various tools to monitor integrity and evolution of the cemented RWP. This includes

- ***Wireless gamma and neutron monitoring*** with affordable sensors
- ***Embedded sensing*** techniques to monitor temperature, humidity, pressure,…

To complement this, various other methods are applied, such as:

- high frequency ***ultrasonic echo*** technique (thickness, corrosion, and cracks on the metallic container wall)
- ***low frequency ultrasonic echo*** (detection of voids, objects and cracks in the cemented matrix)
- **acoustic emission**: detection of crack events during hardening of the concrete, but also related to degradation of the cement matrix.

Results are used as input for a detailed simulation and predictions of the integrity and geochemical evolution of the RWP (***digital twin technology***)

https://www-pub.iaea.org/MTCD/publications/PDF/TRS390_scr.pdf

PREDIS WP7 Leader: BAM

See poster No 087 on PREDIS WP7

γ&n monitoring grid sensors

Low cost sensors for long term monitoring of gamma and neutron trends

- SciFi => Scintillating fibers for gamma detection
- SiLiF => Neutron sensors based on Litium
- TimePix3 R&D technology

These technologies were developed inside **MICADO** and a new miniaturized electronics for SciFi and SiLiF is under development in **PREDIS**

Leader: INFN

Leader: CTU

Conclusions

- The importance of waste characterization is fundamental for granting the quality and optimize the disposal phases
- The GAP analysis from **PREDIS** and **CHANCE** enlightened critical points to be addressed, in term of detection technologies and waste types and categories to be evaluated in the future
- The importance of cooperation is at the basis of this work. **CHANCE**, **MICADO** & **PREDIS** are complementary projects allowing to cover a big core of the waste types
- The coordination and the possibility to provide reliable and complete data to regulatory entities is the key for the future

Video MICADO

https://youtu.be/3xV6WtOUkRk

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