9th R&D PLAN 2024-2028

GOBIERNO DE ESPAÑA

VICEPRESIDENCIA TERCERA DEL GOBIERNO

MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA Y EL RETO DEMOGRÁFICO

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Executive summary

The 9th R&D Plan 2024-2028 is designed to support Enresa's technological challenges and needs over the next five years. The reference scenario in which this plan is framed is that established in the 7th GRWP, approved by the Council of Ministers on 27 December 2023, which reflects the current strategy as regards radioactive waste management and the decommissioning of nuclear facilities.

In the coming years, the challenges facing Enresa and to which R&D should contribute are based, for the management of low- and intermediate-level waste (LILW) and very low-level waste (VLLW), on adapting the radiological and disposal capacity of El Cabril Disposal Centre to current needs, optimising its operation and improving LILW and VLLW characterisation technologies in order to address waste from decommissioning.

For the management of spent fuel (SF), high-level waste (HLW) and special waste (SW), temporary storage facilities will need to be implemented in the coming years at each of the nuclear power plants, with the capacity for recovery at cask level and, at some of these facilities, at spent fuel assembly level until the facility for their final disposal is available - the deep geological repository (DGR) - scheduled for the year 2073.

The recoverability capacity has been established in the Nuclear Safety Council's "Technical Instruction in relation to the medium- and long-term spent fuel recovery capacity". This latter need to have a facility for SF recoverability at a fuel assembly level when nuclear power plants are decommissioned makes it necessary to deepen knowledge for the development and operation of these facilities. R&D will have to provide the necessary knowledge for this purpose.

Furthermore, in relation to the final disposal of waste, R&D should contribute to compliance with the DGR Roadmap drawn up by Enresa in response to the recommendations of the IRRS/ARTEMIS international review mission in relation to the DGR programme, and to enhance knowledge of the behaviour of SF, HLW and SW in the long term for final disposal.

With regard to the decommissioning and closure of nuclear facilities, although Enresa is at the forefront thanks to the experience acquired through the decommissioning of José Cabrera and Vandellós I Nuclear Power Plants, the Protocol for the orderly closure of nuclear power plants signed in 2019 between Enresa and the owner companies, which establishes the schedule for the closure of the current Spanish nuclear power plants between 2027 and 2035, poses a dual challenge for Enresa in the coming years.

On the one hand, a planning and execution challenge, due to the large number of nuclear power plants that must be decommissioned in a limited period of time and simultaneously in some cases, and, on the other, a technological challenge, where R&D must provide solutions that improve the strategies and procedures for decommissioning and site reclamation and prepare the technical and human resources required to address the decommissioning plan established. To this should be added activities for the remediation of decommissioned sites, to which R&D should contribute developments in clearance and remediation techniques, to allow the sites to be released.

R&D should also serve other Enresa responsibilities such as logistics, and other activities commissioned to it (Protocol on the radiological surveillance of metallic materials, Megaport Protocol, etc.), which may require R&D activities to cover their needs.

Over the years, Enresa has acquired extensive operating experience, while developing the R&D necessary to meet its needs, applied R&D that has sought to solve specific problems and gain in-depth knowledge of issues relevant to the management of radioactive waste and the decommissioning of nuclear facilities.

The 9th R&D Plan identifies the R&D necessary to carry out the commissioned activities through an analysis of the current situation, which establishes the starting point, and the identification of those aspects that must be developed or improved in order to meet the aims established in the 7th GRWP.

The 9th R&D Plan is structured in eight chapters. After this executive summary and an introductory chapter, Chapter 2 sets out Enresa's functions and responsibilities; Chapter 3, the current situation and the knowledge acquired in each of its lines of action; and Chapter 4, the challenges and action plans for the coming years that will require R&D actions, in accordance with the 7th GRWP.

Chapter 5 explains how Enresa organises its R&D based around five main areas, each of which has its corresponding R&D lines: Area 1: Waste technology; Area 2: Treatment and conditioning technology and processes, and decommissioning; Area 3: Confinement materials and systems; Area 4: Evaluation of safety, radiation protection and associated modelling behaviour and the biosphere; and Area 5: Horizontal activities: support infrastructure, coordination, knowledge management.

The aforementioned Chapter 5 sets out the content and aims of the five areas and their corresponding lines and briefly describes the projects that have been active in the 8th R&D Plan 2019-2023, and the projects planned for the coming years based on the needs identified by the Enresa departments responsible for each of the areas.

The organisation of this 9th R&D Plan continues on from previous ones, since many projects respond to needs and requirements that are prolonged over time, and which need to be maintained throughout successive R&D plans.

Chapter 6 covers the economic and financial aspects of the 9th R&D Plan, in which an investment of approximately 31 million euros is planned. Since the start of Enresa's R&D Plans in 1987, the amount allocated to R&D has totalled almost 296 million euros.

The plan's control and monitoring tools are presented in Chapter 7, which highlights the importance of the Procedure drawn up in 2023 for the monitoring and control of Enresa's R&D. Chapter 8 deals with technological surveillance, R&D forums and international collaboration, on which R&D should be based, maintaining Enresa's participation in international R&D forums and sharing technological advances and harnessing the knowledge acquired by countries with more advanced DGR programmes.

In this regard, it is worth highlighting Enresa's participation in EURATOM projects, specifically those of EURAD (European Joint Programme on Radioactive Waste Management), a collaborative programme for the exchange of knowledge and technology between Member States, which seeks excellence in radioactive waste management. Enresa has had extensive participation in EURAD (2019-2024), which will be increased in EURAD-2 (2024-2028). This active participation in EURATOM programmes contributes to the improvement of R&D at Enresa.

The departments responsible for the areas involved have participated in drawing up this 9th R&D Plan, with contributions from the entire Enresa organisation. Furthermore, the collaboration and contribution of all the R&D agents (universities, research centres, companies, the EC, etc.) that have for decades been contributing their knowledge and experience to the management of radioactive waste and the decommissioning and closure of nuclear facilities in our country has been essential.

The State Plan for Scientific, Technical and Innovation Research 2024-2027 (PEICTI) includes radioactive waste in its strategic lines, within the grouping "Food, bioeconomy, natural resources, agriculture, climate and environment", in the strategic line "Environment, climate and air quality", in the area of intervention "Management of radioactive waste and radiologically contaminated areas", as the "National Radioactive Waste Plan" within plans and strategies.

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List of acronyms and abbreviations

AMS	Accelerator Mass Spectroscopy
Artemis	Integrated Review Service for Radioactive Waste and Spent Fuel Management, Decommissioning and Remediation
AT	Temporary Storage for waste from SF reprocessing and, where appropriate, SW from the decommissioning of Vandellós I NPP.
BWR	Boiling Water Reactor
CEIDEN	Nuclear Fission Energy Technology Platform
CIEMAT	Centre for Energy, Environmental and Technological Research
CRP	Coordinated Research Project
CSIC	National Higher Research Council
CSIC-ICTJA	CSIC Jaume Almera Earth Sciences Institute
CSIC-IETcc	CSIC Eduardo Torroja Construction Sciences Institute

CSIC-IFC	CSIC Corpuscular Physics Institute
CSN	Nuclear Safety Council
CTM	Manresa Technology Centre
CTS	Centralised Temporary Storage for spent fuel and high-level waste
D+C	Decommissioning and closure
DGPEM	Directorate-General of Energy Policy and Mines
DGR	Deep Geological Repository
DTS	Decentralised Temporary Storage for spent fuel and high-level waste
EC	European Commission
EIS	Environmental Impact Statement
El Cabril Disposal Centre	El Cabril Disposal Centre for very low, low and intermediate level waste
Enresa	Empresa Nacional de Residuos Radiactivos, S.A., S.M.E.
ENUSA	Empresa Nacional del Uranio, S.A., S.M.E.
EPRI	Electric Power Research Institute
EURAD	European Joint Programme on Radioactive Waste Management
EURATOM	Treaty establishing the European Atomic Energy Community
FEBEX	Full-scale Engineered Barrier Experiment in Crystalline Host Rock
FUA	Andújar Uranium Mill
GRWP	General Radioactive Waste Plan
GTS	Grimsel Test Site
HDPE	High density polyethylene
Hifrensa	Hispano-Francesa de Energía Nuclear S.A.
HLW	High-level waste
IAEA	International Atomic Energy Agency

ICRP	International Commission on Radiation protection
IGD-TP	Implementing Geological Disposal of Radioactive Waste Technology Platform
IGME	Spanish Institute of Geology and Mining
IGSC	NEA Integration Group for the Safety Case
INLA	International Nuclear Law Association
IRRS	Integrated Regulatory Review Service
ITS	Individualised Temporary Storage for spent fuel and high-level waste
JEN	Nuclear Energy Board
JRC-ITU	Joint Research Centre-Institute for Transuranium Elements
KoM	Kick-off meeting
LEN	Nuclear Energy Act 25/1964 of 29 April 1964
LID	Lower limit of detection
LILW	Low- and intermediate-level waste
LLILW	Long-lived intermediate-level waste
LLW	Low-level waste
MELODI	Multidisciplinary European Low Dose Initiative
MITECO	Ministry for the Ecological Transition and Demographic Challenge
NEA	Nuclear Energy Agency
NF	Nuclear facilities
NORM	Naturally Occurring Radioactive Material
NPP	Nuclear power plant
NPPs	Nuclear power plants
OECD-NEA	Organisation for Economic Co-operation and Development Nuclear Energy Agency

OPI	Public Research Agency
PDC JC	Plan for the Dismantling and Closure of the "José Cabrera" NPP
PDC SMG	Decommissioning and Closure Plan for Santa María de Garoña NPP
PEPRI	National Radiation Protection R&D Platform
PIMIC	Integrated Improvement Plan for CIEMAT Facilities
PRE	Site Remediation Plan
PWR	Pressurised Water Reactor
R&D	Research and Development
RF	Radioactive facilities
RILEM	Réunion Internationale des Laboratoires et Experts des Matériaux, systèmes de construction et ouvrages
RW	Radioactive waste
RWMC	NEA Radioactive Waste Management Committee
SEPI	Sociedad Estatal de Participaciones Industriales – State Industrial Holdings Company
SGEN	Sub-Directorate-General for Nuclear Energy
SKB	Svensk Kärnbränslehantering AB
SLW	Short-lived waste
SNE	Spanish Nuclear Society
SNETP	Sustainable Nuclear Energy Technology Platform
SW	Special waste
TFM	Thermo-fluid-mechanical
THM	Thermo-hydro-mechanical
THMC	Thermo-hydro-mechanical and chemical
TM	Thermo-mechanical

ToR	Terms of Reference
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
VLLW	Very low-level waste

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1. Introduction

This document identifies the approach to R&D activities for the five-year period 2024-2028. The document aims to respond, on the one hand, to the needs for continuous improvement in the management strategies implemented by Enresa and, on the other, to the development of those yet to be implemented, in accordance with the scientific and technical capacities previously developed.

The official document defining the Spanish policy and strategy in relation to radioactive waste management and the decommissioning and closure of nuclear facilities, including the associated R&D, is the General Radioactive Waste Plan (GRWP), with the 7th GRWP in force, approved on 27 December 2023. This document has provided the basis for drawing up this R&D Plan.

In addition, other documentation resulting from national and international developments has been taken into account, particularly Council Directive 2011/70/Euratom of 19 July 2011, which establishes a Community framework for the Responsible and Safe Management of Spent Fuel and Radioactive Waste, and Royal Decree 102/2014, which transposes it into Spanish law.

Chapter 2 of the 9th R&D Plan describes the Spanish system for radioactive waste management and the decommissioning and closure of nuclear facilities, while Chapter 3 describes the actions carried out by Enresa to date.

Considering the current and foreseeable medium-term framework conditions, Chapter 4 establishes a series of action plans for the coming years for the activities where potential R&D actions are identified.

Based on these strategic lines, the R&D Plan has been structured in specific areas of activity, indicating, for each one of them, the technological level reached and proposing a specific development for the period covered by this plan (Chapter 5), with an estimated financial allocation (Chapter 6).

Chapter 7 includes the tools proposed for the control and monitoring of the plan, while Chapter 8 includes aspects of technological monitoring and international R&D collaboration.

This 9th R&D Plan 2024-2028 has been drafted by the International Cooperation and R&D Department, with contributions from the entire Enresa organisation.

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2. The management of radioactive waste and the decommissioning and closure of nuclear facilities in Spain

Spain is a country that has had nuclear and radioactive facilities for more than 50 years. The presence of radioactive materials is more common than society is aware of. There are medical, industrial, food and research facilities that use radioactive materials; there is also uranium mining, as well as the natural presence of this mineral in certain geographical areas.

The best known use of radioactive materials is the use of uranium-based fuel in electricity generation activities, where both the fuel assembly factory and uranium concentrate plants and nuclear power plants are or have been involved, with varying degrees of specific weight. There are also facilities in use and planned for the temporary and final disposal of radioactive materials with no planned use.

Accordingly, a regulated system for the use of radioactive materials is organised in order to protect society, including the natural environment, from ionising radiation.

This chapter describes the organisation of the Spanish radioactive materials management system, the role of the company in charge of radioactive waste management and the decommissioning and closure of nuclear facilities (Enresa), the relevant regulatory framework, and an outline of radioactive waste producers.

2.1. National system established for radioactive waste management and decommissioning and closure of facilities

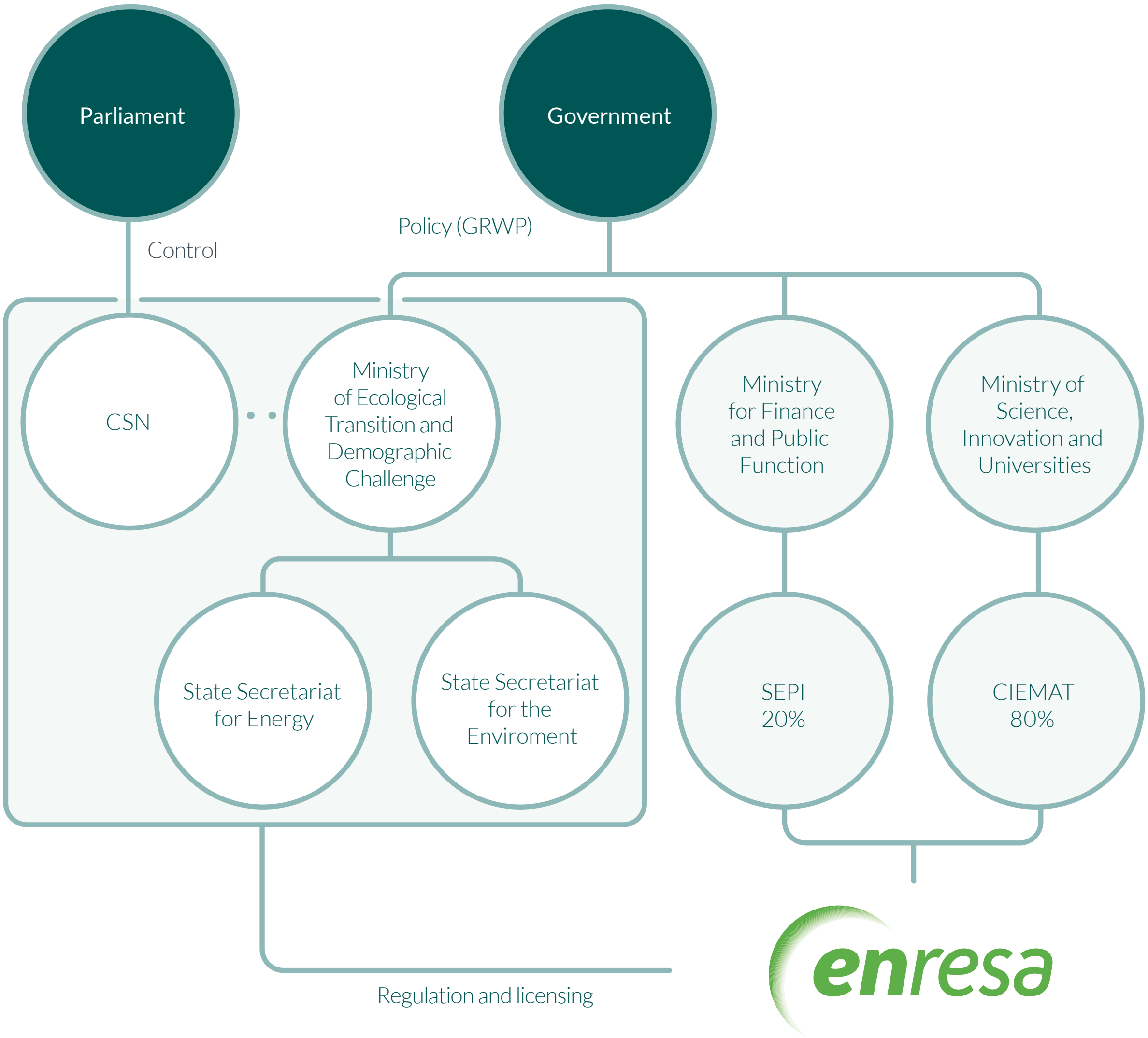


Figure 2-1: *Organisational chart of institutional control (Source: 7th GRWP)*

The national framework for the management of radioactive waste and the decommissioning and closure of nuclear facilities is integrated within the general framework regulating nuclear energy in Spain, which is a wide-ranging framework developed in keeping with the evolution of international regulatory requirements. Within this framework, the responsibilities of the different stakeholders are established, along with the distribution of functions among the competent authorities in each area, which act in a coordinated manner (Figure 2-1).

The Spanish Government is responsible for establishing energy policy and regulating the different sectors and activities, including nuclear and radioactive waste. With respect to the latter, the Government also defines the policy for the management of radioactive waste, including spent fuel, and the decommissioning and closure of nuclear facilities, through the approval of the General Radioactive Waste Plan (GRWP).

The Ministry for the Ecological Transition and Demographic Challenge (MITECO) is the ministerial department of the General State Administration with powers and functions within the Spanish regulatory system in relation to energy and, in particular, nuclear energy. The State Secretariat for Energy is the highest body responsible for energy and, within this Secretariat, the Directorate-General for Energy Planning and Coordination (DGPCE) is the executive body. Within the Directorate-General for Energy Planning and Coordination, the Sub-Directorate-General for Nuclear Energy (SGEN) is responsible for the practical execution of these functions.

MITECO has the following powers and functions in relation to radioactive waste:

- It defines radioactive waste management policy, submitting the General Radioactive Waste Plan to the Government for approval.
- In addition, MITECO controls Enresa's implementation of the General Radioactive Waste Plan. Enresa is supervised by MITECO, through the State Secretariat for Energy, which carries out the strategic management and surveillance and control of its actions and plans, both technical and economic.
- The Sub-Directorate-General for Environmental Assessment issues the Strategic Environmental Statement for plans and programmes, such as the GRWP, and the Environmental Impact Statements required for certain projects.
- It contributes to the definition of R&D policy, in coordination with the Ministry of Science, Innovation and Universities.

The **Nuclear Safety Council** (CSN) is the competent State body in relation to nuclear safety and radiation protection, and is a public body independent from the General State Administration, reporting to Parliament on the performance of its activities. Its main functions are established in Article 2 of Law 15/1980, of 22 April, on the creation of the Nuclear Safety Council.

Empresa Nacional de Residuos Radiactivos, S.A., S.M.E. (Enresa) is, in accordance with the Nuclear Energy Act 25/1964, of 29 April (LEN), the company responsible for the management of spent fuel and radioactive waste and the decommissioning and closure of nuclear facilities, which is considered an essential public service. It is a public company created by Royal Decree 1522/1984, 80% owned by the Centre for Energy, Environmental and Technological Research (CIEMAT), a public research organisation attached to the Ministry of Science, Innovation and Universities, and the remaining 20% by the State Industrial Holdings Company (SEPI), a public law entity attached to the Ministry of Finance and Public Administration.

In addition to MITECO, other ministerial departments are involved in certain procedures, such as the **Ministry of the Interior**, which is involved in physical protection and civil protection and emergencies.

2.2. Enresa's functions

For the purposes of the service it is commissioned with, Enresa is constituted as an essential public service, performing the functions entrusted to it by the Government and, particularly, those established in point 3 of Article 9 of Royal Decree 102/2014, of 21 February, for the Responsible and Safe Management of Spent Fuel and Radioactive Waste. The functions are listed below:

a. Treat and condition spent fuel and radioactive waste, without prejudice to the responsibilities of the generators of such waste or the Licensees entrusted with this responsibility.

b. Search for sites, design, construct and operate facilities for storage and disposal of spent fuel and radioactive waste.

c. Establish systems to ensure the safe management of spent fuel and radioactive waste in their facilities for storage and disposal.

d. Establish systems for the collection, transfer and transport of spent fuel and radioactive waste.

e. Draw up and manage the National Inventory of Spent fuel and Radioactive Waste. This inventory will continue to include the disposal of spent fuel and radioactive waste, following the closure of the facility at which they are deposited.

f. Adopt safety measures for the transport of spent fuel and radioactive waste, in accordance with the provisions of the specific regulations on the transport of dangerous goods and the determinations of the competent authorities and organisations.

g. Manage operations relating to the decommissioning and closure of nuclear facilities and, where appropriate, radioactive facilities.

h. Act, in the event of nuclear or radiological emergencies, in the manner and under the circumstances required by the competent bodies and authorities.

i. Establish training plans and research and development plans within the framework of the State Plan for Scientific and Technical Research and Innovation, covering the needs of the General Radioactive Waste Plan and making it possible to acquire, maintain and further develop the necessary knowledge and skills.

j. Carry out the necessary technical and economic/financial studies, taking into account the deferred costs arising from its tasks in order to establish the corresponding economic needs.

k. Manage the Fund for Financing the Activities of the General Radioactive Waste Plan.

l. Any other activity necessary for the performance of the above tasks.

In addition, Enresa must submit a revision of the General Radioactive Waste Plan every four years or when required by the supervising ministry (currently MITECO).

2.3. Nuclear and radioactive facilities in Spain

In terms of volume and radiological impact, nuclear power plants are the largest producers of radioactive waste. They produce waste during operation, as well as during decommissioning, including land remediation at the end of their service life. Other nuclear and radioactive facilities generating radioactive waste to be considered in the waste inventories are the Juzbado Fuel Assembly Factory (Salamanca) and various research centres, universities, hospitals and certain industrial activities. Radioactive waste producers are fully identified.

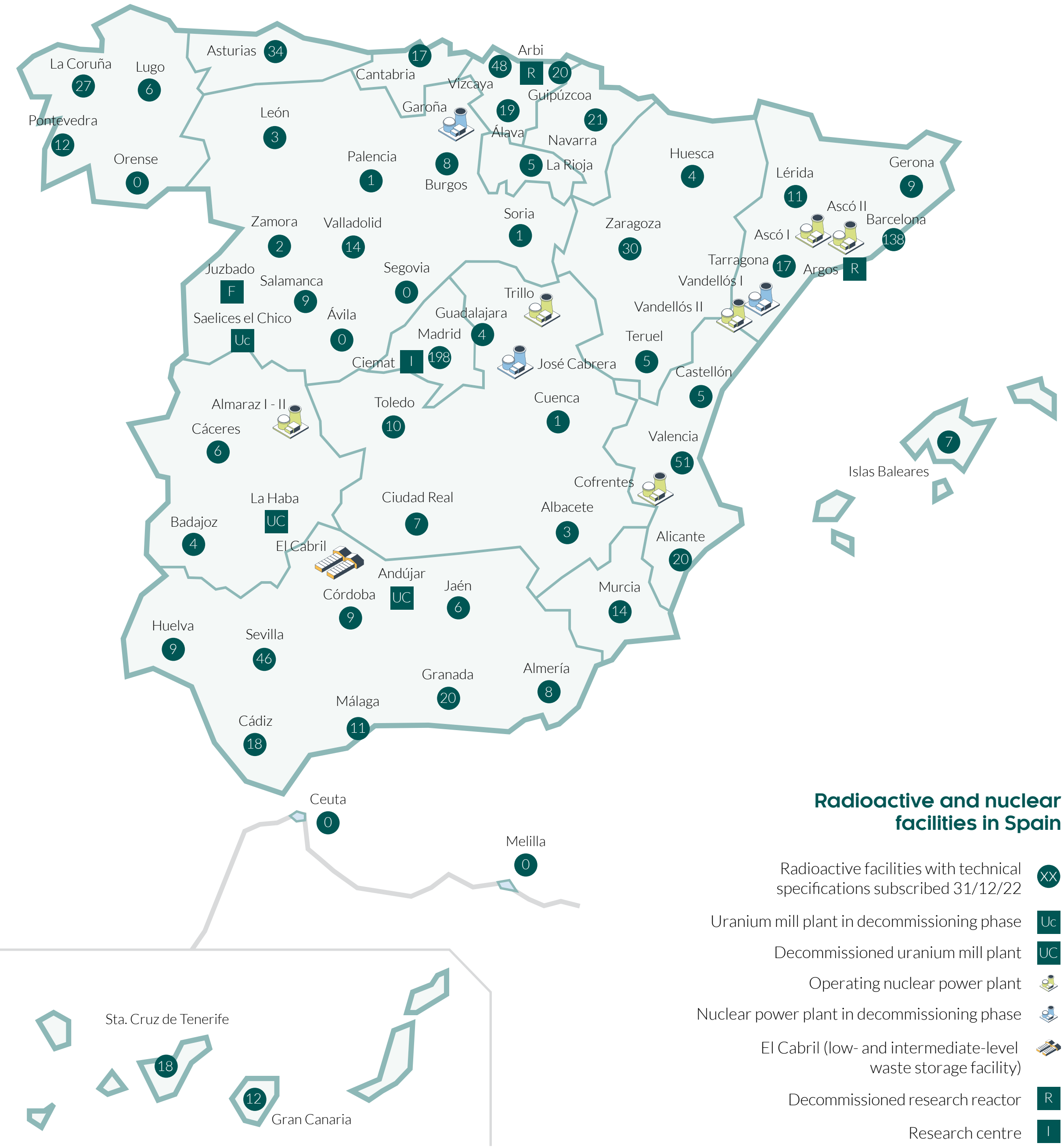


Figure 2-2: *Map of Spanish facilities generating radioactive waste (Source: 7th GRWP)*

There are currently seven reactors in operation at five sites in Spain. The Vandellós I, José Cabrera and Santa María de Garoña NPPs are shut down. The former ceased operation in October 1989 and is currently in a dormant phase following its partial decommissioning and is therefore awaiting total decommissioning. José Cabrera NPP ceased operation in April 2006 and is currently in the final phase of total decommissioning. Santa María de Garoña NPP definitively ceased operation in August 2017, and by Order TED/796/2023, of 13 July 2023, the transfer of ownership from the company Nuclenor, S.A. to Enresa was authorised and Phase one of decommissioning was authorised.

The Juzbado Fuel Assembly Factory, located in the province of Salamanca, started operating in 1985, manufacturing uranium oxide fuel assemblies for PWR (pressurised water reactor), BWR (boiling water reactor) and VVER (water-water energy reactor).

The Centre for Energy, Environmental and Technological Research (CIEMAT) is located in Madrid and includes a set of operational radioactive facilities and another set of nuclear and radioactive facilities that have been definitively shut down, which have been decommissioned under the PIMIC Project (Integrated Improvement Plan for CIEMAT Facilities).

Radioactive facilities use radioactive isotopes and are therefore subject to control by the regulatory body. Enresa currently has a radioactive waste collection contract with more than 900 radioactive facilities for the management of its radioactive waste.

Enresa also manages orphan sources, radioactive waste from conventional facilities or companies, mainly belonging to the iron and steel and metal recovery industries, in which radioactive materials are detected mixed in the metallic scrap they process, as well as radioactive waste resulting from incidents to which the existence of these materials may give rise.

The El Cabril Disposal Centre for very low-level waste (VLLW), and for low- and intermediate-level waste (LILW) generates radioactive waste in its operation, which is managed in a similar way to the external waste it receives for treatment, conditioning and storage from radioactive facilities and other producers.

In order to complete the National Inventory of Radioactive Waste, waste from the reprocessing of spent fuel that was sent to other countries and is to be returned to Spain in the coming years should be included, depending on the contractual clauses and the availability of facilities in Spain allowing for their subsequent management. At present, there is only Spanish radioactive waste in La Hague (France), generated as a result of the past reprocessing of the spent fuel from Vandellós I NPP at the Marcoule facilities (France).

As regards spent fuel, it is necessary to manage the SF produced by all the Spanish nuclear power plants, both those in operation and those that have ceased operation, with the exception of the SF produced at Vandellós I NPP.

Finally, waste materials from the first part of the nuclear fuel cycle, mining operations and uranium concentrate plants have to be taken into account. These waste materials require specific management which, following international practice, is based on on-site stabilisation.

2.4. Reference scenario

The reference scenario envisaged in the 7th GRWP, for planning and calculation purposes, can be summarised in the following points:

- Cessation of nuclear power plant operation in line with the National Integrated Energy and Climate Plan 2021-2030 (PNIEC) and the Protocol for the Orderly Cessation of Nuclear Power Plant Operation signed between Enresa and the owners in March 2019.
- Open fuel cycle, i.e. no SF reprocessing option is envisaged.
- Maintenance of the operating capacities of El Cabril Disposal Centre for LILW and VLLW from the operation and decommissioning of all nuclear facilities.
- Maintenance of SF, HLW and SW management capacity at nuclear power plants, through ITS.
- Start-up of a Decentralised Temporary Storage Facility (DTS) for SF, HLW and SW at each nuclear power plant with SF (Almaraz, Ascó, Cofrentes, Santa María de Garoña, José Cabrera, Trillo and Vandellós II). The DTS of each plant will consist of its ITS plus a new complementary facility or additional measures allowing maintenance and repair operations to be carried out on its casks, in order to guarantee the cask level recoverability function. The DTSs, including their complementary facilities, will be operational prior to the dismantling of their fuel pool. At José Cabrera NPP, in the final phase of decommissioning, the planned measures on cask-level recoverability will be implemented between 2024 and 2029. The DTSs will remain operational until the transfer of the entire SF to the DGR.
- In 2031, the means will be available at the site of one of the plants to guarantee the recoverability function at the fuel assembly level throughout the lifetime of the DTSs, until the SF, HLW and SW are transferred to the DGR. This facility will have a hot handling vault for SF and radioactive waste, and storage capacity for casks allowing potential contingencies to be dealt with in the DTSs throughout their operating lifetime, as well as a laboratory equipped with the necessary means to be able to verify and inspect the state of the fuel and waste, where appropriate.
- Start-up in 2027 of a temporary storage facility at Vandellós I NPP site to house the radioactive waste from the reprocessing of SF and, where appropriate, the SW from the decommissioning of the plant. It will remain operational until all the radioactive waste has been transferred to the DGR.
- Start-up of the DGR for SF, HLW and SW in 2073.
- Immediate full decommissioning of light water nuclear power plants. Preliminary work will begin between three or, preferably, five years prior to the date of definitive cessation, so that the transfer of ownership and initiation of the decommissioning works may be carried out within a period of no more than three years after definitive cessation. During these years, the activities of emptying the pools, the preparatory tasks for decommissioning and the obtaining of the authorisation for decommissioning and transfer of ownership to Enresa will be carried out. Once this authorisation has been obtained, decommissioning works will begin, with an estimated duration of ten years. In the case of Vandellós I NPP, the last phase of decommissioning will be carried out as from 2030, with an estimated duration of 15 years. The surveillance period, once the works have been completed, is estimated at a maximum of ten years, prior to the declaration of decommissioning.

3

3. Actions carried out

Since the outset, Enresa has carried out different activities in order to respond to the tasks entrusted to it. This chapter presents the main activities in which R&D has been considered necessary:

- Inventory of radioactive waste as a function of time.
- Management of very low-level waste (VLLW) and low- and intermediate-level waste (LILW): El Cabril Disposal Centre.
- Temporary management of spent fuel (SF), high level radioactive waste (HLW) and special waste (SW).
- Final management of spent fuel (SF) and high level radioactive waste (HLW).
- Decommissioning and closure of facilities.
- Other actions.

3.1. Inventory of radioactive waste as a function of time

In order to comply with the provisions of Royal Decree 102/2014 regarding inventories, Enresa launched an internal action plan to prepare a new National Inventory of Spent Fuel and Radioactive Waste with a closing date of 31 December 2015 to replace the method of determination previously used. The current Inventory is based on a series of partial reports that study in detail not only the origin of the waste and SF, but also the hypotheses necessary to reach a predicted value of conditioned waste now and in the future, and to quantify the uncertainties in the final values.

The criteria for the categorisation of radioactive waste in Spain are based on the final management envisaged (in accordance with RD 102/2014), taking into account volume, radiological inventory and pre-set limits of specific activity concentrations for the radionuclides present. The classification established in Spain is based on that of the International Atomic Energy Agency (IAEA) and is indicated in Figure 3-1, and is explained in more detail in Table 3-1.

The National Inventory is revised every three years; nevertheless, in the event of modification of any of the scenarios or hypotheses considered, or due to any other requirement, it may be revised in advance. Furthermore, in the first half of each year a report is issued on the closure of the inventory of waste generated as of December 31 of the previous year, including the quantities of waste disposed of at El Cabril Disposal Centre.

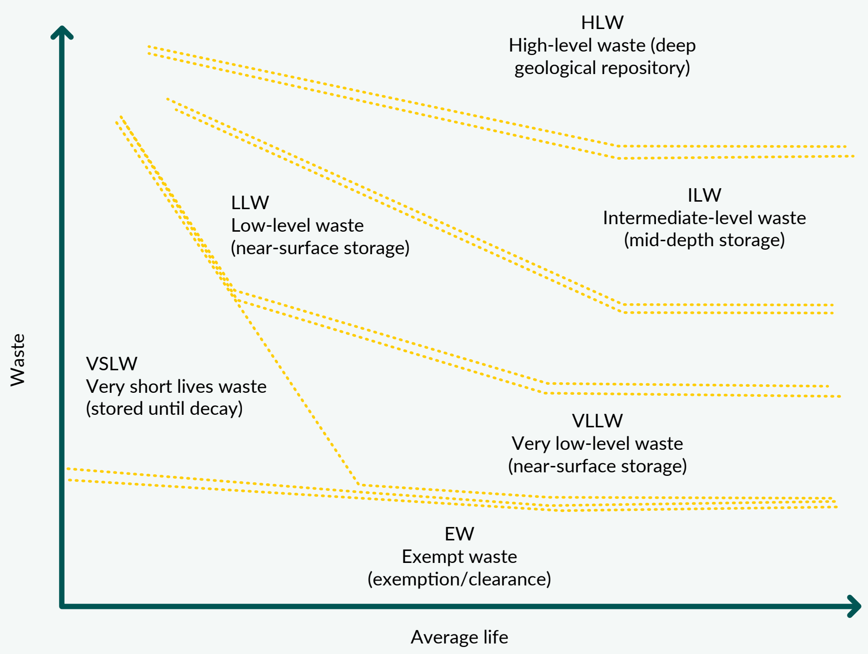


Figure 3-1: *International classification of radioactive waste according to IAEA*

Table 3-1: *Categories of radioactive waste considered in Spain according to final management*

Categories of radioactive waste considered in Spain according to final management	
Low- and Intermediate-Level Waste (LILW)	Waste that is mainly due to the presence of beta- or gamma-emitting radionuclides with a short or medium half-life (less than 30 years) and whose content of long-lived radionuclides is very low and limited. This group includes waste that is treated, conditioned and disposed of at El Cabril Disposal Centre (Cordoba).
Very Low-level Waste (VLLW)	This is a subgroup of the previous group, where only waste concentrations in the order of 10 to 1,000 Bq/g are reached, In Spain, since 2008, differentiated management has been established by means of disposal systems appropriate to the radiological risk involved, which are managed and disposed of at El Cabril Disposal Centre (Cordoba).
Special Waste (SW)	This includes additions for nuclear fuel, neutron sources, incore instrumentation used or replaced components from the reactor vessel system and reactor internals, generally of a metallic nature, with a high radiation rate due to neutron activation and other waste that, due to its radiological characteristics, is not suitable for management at El Cabril Disposal Centre, Its management is associated with that of HLW.
High-Level Waste (HLW)	Waste that contains appreciable concentrations of long-lived alpha- and beta-gamma emitters, and generates significant heat, This category includes SF discharged from nuclear reactors (PWR and BWR type) and vitrified waste produced in the reprocessing carried out in the past for certain quantities, For temporary management, storage is considered to be at the ITS/DTS of each nuclear power plant, and for final management it is considered to be disposed of in a DGR.

3.2. Very low- and low- and intermediate-level radioactive waste management (VLLW and LILW): El Cabril Disposal Centre

Figure 3-2: *Aerial view of El Cabril Disposal Centre*

El Cabril Disposal Centre, as an essential part of the national system, is the infrastructure used for the disposal of the VLLW and LILW generated in Spain in solid form. It is located in the province of Cordoba and belongs to the type of engineered barrier surface disposal facility.

El Cabril Disposal Centre has various technological capabilities, including treatment and conditioning facilities for the processing of radioactive and other waste removed from non-regulated installations. The treatment systems at the facility include a compactor and an organic waste incinerator. The facility carries out final conditioning whereby the conditioned LILW is placed in reinforced concrete casks forming the storage units, which are then placed in the North and South Platform vaults (Figure 3-3) (Figure 3-4).

El Cabril Disposal Centre also has laboratories for the verification of the quality and characterisation of radioactive waste, which are the basis for acceptance of the different types of waste and for verifying their characteristics. Finally, the facility has temporary storage capacities, workshops, laboratories and the auxiliary systems required for its operation.

El Cabril protected area has a total surface area of 35 ha. The buildings and the LILW storage area occupy 20 ha, while the rest is occupied by the VLLW vaults. El Cabril estate has a total surface area of 1,150 ha.

There are two platforms for the final disposal of LILW, the North Platform has 16 storage vaults and the South Platform has 12. Of the 28 storage vaults constructed, 22 have been completed as of 31 December 2023.

In October 2008, the operation of a new complementary disposal facility for VLLW (VLLW vaults) based on clay and high density polyethylene (HDPE) barriers and the use of different types of storage units (Figure 3-4) and (Figure 3-5) began.

The complementary VLLW facility is licensed for four vaults, which are being built as required. Currently, section 1 of Vault 29 has been completed, and section 1 of Vault 30 and section 2 of Vault 29 are in operation.

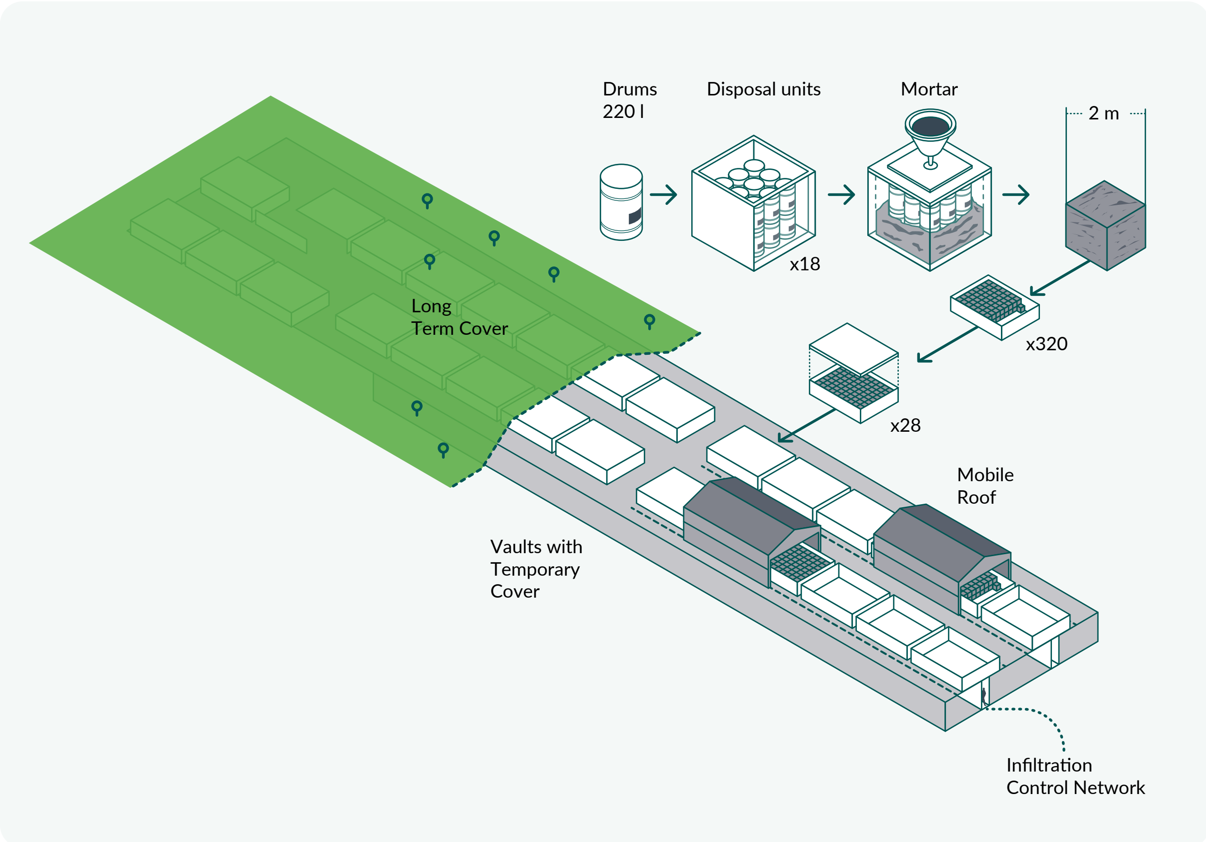


Figure 3-3: *El Cabril LILW disposal concept*

Figure 3-4: *LILW storage unit in preparation (left) and examples of different types of storage units for LILW (right)*

The storage of all LILW requires the construction of new vaults already envisaged in the 6th GRWP, which are necessary in any nuclear power plant operating scenario. Accordingly, it is considered strategic to optimise the management of this type of waste.

From the analysis of the capacity of the 28 LILW vaults currently existing and the planned inventory, it is concluded that new vaults are required by 2028 in order not to affect the operation and decommissioning planning of the nuclear power plants and to be able to continue with the normal storage of this waste. Accordingly, the project for the construction of the first LILW vaults has been submitted.

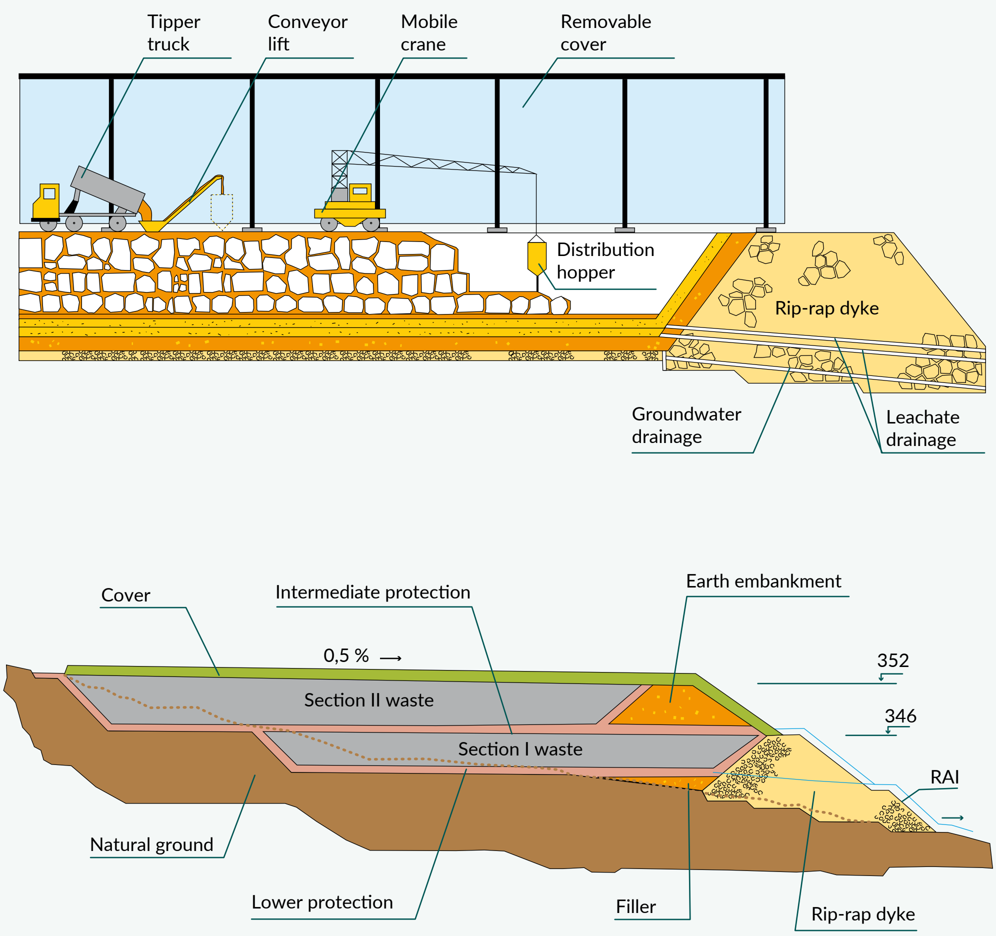


Figure 3-5: *Longitudinal section of a storage vault for VLLW. Top, operating vault; bottom, closed vault*

The construction of the new vaults will be undertaken in phases, with the first phase including the construction of 12 vaults and, subsequently, additional vaults (initially 15) that will be built as they are needed, in accordance with the development of the decommissioning of the nuclear power plants.

3.3. Temporary management of spent fuel (SF), high-level waste (HLW) and special waste (SW)

In Spain, it was initially decided to reprocess the SF from Vandellós I, José Cabrera and Santa María de Garoña NPPs at facilities in France and the United Kingdom. This practice was discontinued in 1982, except for the first of these nuclear power plants, which ceased operating in 1989 and whose SF, of a different type to that of the light water nuclear power plants, had to be entirely reprocessed for technical reasons. As a result of these activities, reprocessing waste was obtained, which, according to contractual requirements, had to be returned to Spain or not. At present, waste from the reprocessing of SF from Vandellós I NPP, which remains in France, has yet to be returned to Spain.

As regards HLW and SW (components associated with the operation of fuel assemblies such as control rods, BWR channels, primary and secondary sources, etc.), the final management of which is not envisaged at El Cabril Disposal Centre facilities, they are temporarily stored in the pools. Due to the fact that some nuclear power plants are accumulating a significant quantity of this type of waste, occupying positions in the pool, and in order to provide additional space for SF and optimise waste management, specific characterisation, segmentation and conditioning projects are being developed to separate the most activated parts, which will be kept in the pools, from the less activated parts that can be managed at El Cabril Disposal Centre, according to their acceptance criteria.

Since 1982, all the SF from the light water nuclear power plants generated in the Spanish nuclear power system has been stored in the pools of the corresponding nuclear power plants (Figure 3-6). In view of the saturation forecasts of the capacity of these pools, throughout the 1990s different projects were carried out for the progressive replacement of the original racks with other more compact and larger capacity ones. In most cases, this allowed the need to provide the Spanish system with additional SF storage capacity to that of the pools themselves to be significantly deferred over time, thereby ensuring the continued operation of the nuclear power plants. Furthermore, in 2020, the second phase of changing the racks in the Vandellós II NPP pool was carried out, thereby concluding the pool capacity optimisation activities at the nuclear power plants, as there were no viable alternative technical options.

Figure 3-6: *SF storage pool*

Despite having carried out the aforementioned actions to replace the racks, it has been necessary to develop other types of action to provide the nuclear power plants with additional storage capacity to that of the pools themselves, in this case in dry storage, at the site of the corresponding nuclear power plant, by means of an ITS (Individualised Temporary Storage).

There are currently operational ITSs at Trillo, José Cabrera, Ascó, Santa María de Garoña, Almaraz and Cofrentes NPPs. Given that some ITSs do not have sufficient capacity to continue operating until the scheduled date of cessation and for the complete emptying of the pools, Enresa has programmed the project for the construction of new ITSs, complementary to the current ones at these plants, along with the design and licensing of the SF storage casks for these ITSs. These ITSs, so-called Total ITSs, will store the total inventory of SF in the pools at these plants, with operation scheduled to begin in 2026. Also included in this same project is the construction of a Total ITS for the entire SF inventory, with operation scheduled to begin in 2026 at Vandellós II NPP, which is the only plant that does not currently have a dry storage facility.

The following is a brief description of the ITSs in operation in Spain:

- Trillo NPP. In 2002, an ITS was put into operation, consisting of a reinforced concrete building that allows the storage of up to 80 dual-purpose (storage and transport) metal casks.

Figure 3-7: *Trillo NPP ITS*

- José Cabrera NPP. This plant definitively ceased operation in April 2006 and, in order to allow it to be decommissioned, an ITS was brought into operation in 2009 in which all the SF (12 casks) and the SW (4 casks) of this plant are currently stored. This ITS consists of a reinforced concrete slab with 16 storage positions, all of them occupied by welded metallic capsule systems with concrete enclosure.

Figure 3-8: *José Cabrera NPP ITS*

- Ascó I and Ascó II NPPs. In 2013, an ITS was brought into operation to serve both units, consisting of two independent slabs for 18 casks each. A storage system based on welded metallic capsules with a concrete enclosure, similar to that used at José Cabrera NPP, was selected for this plant.

Figure 3-9: *Ascó NPP ITS*

- Santa María de Garoña NPP. This plant, which was provisionally shut down in 2012 and definitively shut down in August 2017, is currently in Phase 1 of decommissioning. Despite this, and under the initial hypothesis of continued operation of the plant, an ITS was licensed and built, which obtained authorisation for start-up in 2018. This ITS consists of two reinforced concrete slabs, was initially authorised for 10 casks and authorisation is currently being processed for the entire SF of the plant. The storage system selected for this plant consists of dual-purpose metal casks.

Figure 3-10: *Santa María de Garoña NPP ITS*

- Almaraz I and II NPPs. In 2018, authorisation was obtained for the start-up of an ITS, based on two reinforced concrete slabs with a capacity for 20 casks (10 casks in each slab). This ITS serves the two units of this plant, for which a storage system based on dual-purpose metallic casks has been selected.

Figure 3-11: *Almaraz NPP ITS*

- Cofrentes NPP. An ITS has been built for this plant, which was started-up and where the first casks were stored in 2021. This ITS consists of two slabs with a capacity to hold up to 12 positions each, with a total storage capacity for 24 casks. A dual-purpose metal cask has been selected for this plant.

Figure 3-12: *Cofrentes NPP ITS*

For the new ITSs programmed at Ascó, Almaraz, Cofrentes and Vandellós II NPPs, a storage system based on welded metallic capsules with a concrete enclosure has been selected, similar to the current ITSs at Ascó and José Cabrera NPPs, currently in the design and licensing process.

For Vandellós I NPP, in order to house the waste from SF reprocessing and, where appropriate, the SW from the decommissioning of the plant, activities have begun for the start-up of an ITS on the site of the plant in 2027.

The strategy considered in in the 7th GRWP consists of the storage of SF, HLW and non-manageable SW at El Cabril Disposal Centre, in Decentralised Temporary Storage (DTS) at the sites of the plants that generate them, until they are transferred to a disposal facility - a deep geological repository (DGR).

Figure 3-13: *Capsule with vitrified waste from reprocessing*

3.4. Final management of spent fuel (SF) and high-level radioactive waste (HLW)

There is international consensus that the option for the final management of HLW is its disposal in a deep geological repository (DGR). The 7th GRWP considers that the DGR would come into operation as from 2073.

Since 1985, Enresa has been working on the disposal option in four basic directions:

1. The Site Search Plan (PBE), which was halted in 1996 and from which sufficient information has been compiled to ensure that there are abundant granite, clayey and, to a lesser extent, saline formations in the subsoil of the Spanish geography that could house a disposal facility, with a wide geographical distribution.

2. Carrying out conceptual designs of a disposal facility for each of the lithologies indicated, looking for as many common points between them as possible.

3. Development of the Safety Assessment exercises of the conceptual designs (granite and clay), in which the knowledge attained in the work and projects of the successive R&D Plans carried out has been integrated, and which show that the geological repositories allow the safety and quality criteria applicable to this type of facility to be met.

4. Development of successive R&D Plans, which have evolved and adapted to the SF and HLW management programme in Spain. These plans have enabled the acquisition of know-how and the formation of national work teams, participating in national/international research projects and in demonstration projects in foreign underground laboratories.

Over the last few years, a major effort has also been made in research on separation and transmutation technologies in their different versions, although the scale of these programmes makes participation in the international context essential. Most of the work carried out is of a preliminary nature, obtaining basic data and analysing feasibility, with a predominantly theoretical content.

As a result of the work carried out between 1986 and 1996, in which an analysis of the geological formations favourable to host the DGR site was carried out, an Inventory of Favourable Formations is available in our country.

The generic design and associated safety assessment of the basic and conceptual designs of the aforementioned facility, adapted to a granite-type and clay-type host medium (Figure 3-14), was also carried out.

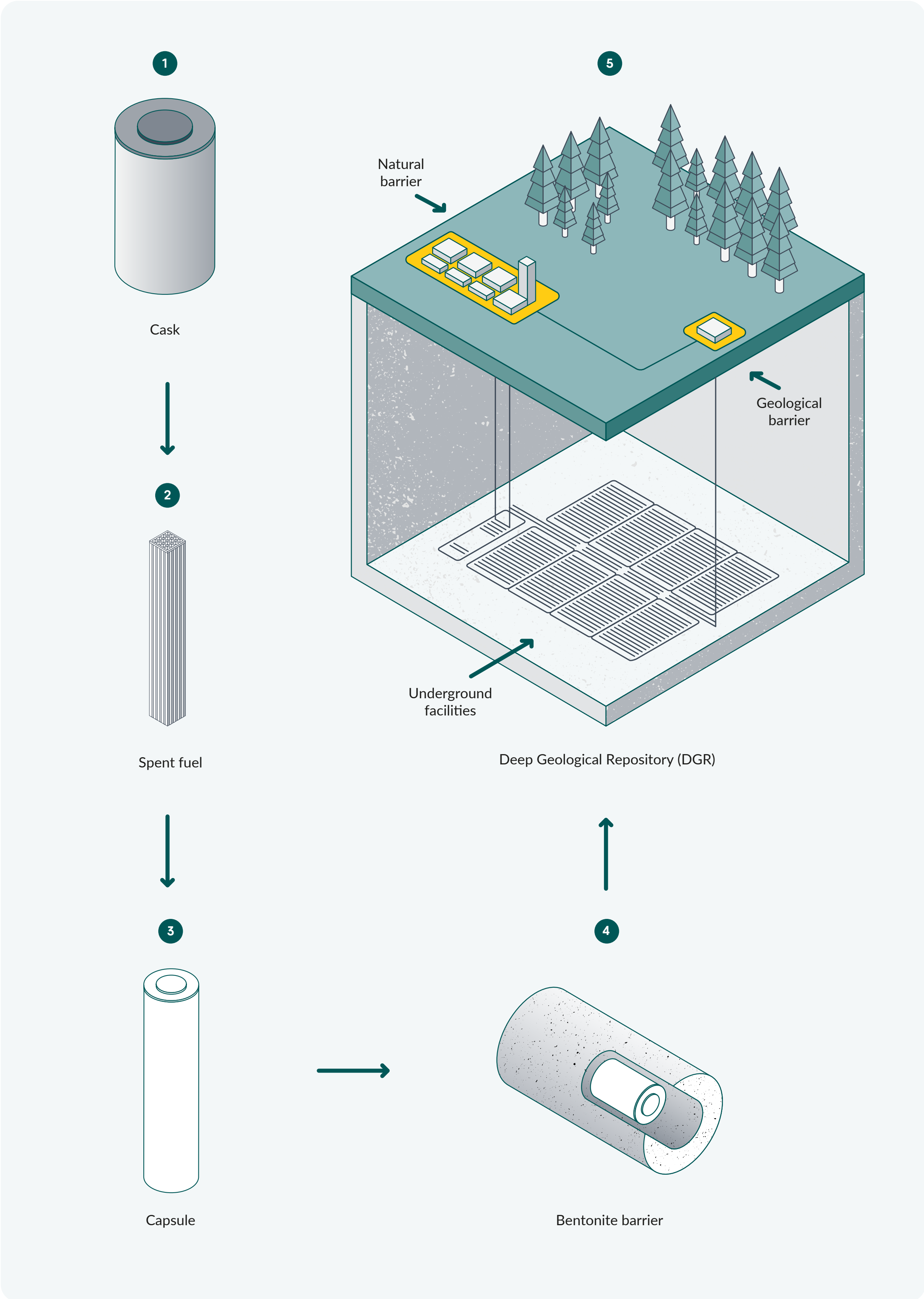


Figure 3-14: *Conceptual schematic of a DGR*

Based on the results obtained, as set out in the 6th GRWP, the following reports were submitted to the former Ministry of Industry, Energy and Tourism in 2013:

- SF and HLW management options. This report describes the characteristics, constraints and requirements for SF management, as well as a set of technically-feasible solutions in accordance with national and international safety principles. It analyses the advantages and disadvantages of these solutions, considering the opinions of international reference bodies, as well as the associated economic and socio-political aspects.
- Feasibility of new technologies: separation and transmutation. This report describes the main international and European projects in the field of radionuclide separation and transmutation systems. On the basis of this information, it identifies the main issues to be addressed for the industrial application of these technologies and indicates the associated technological and economic needs.
- Generic basic projects:
    - Disposal in clay formations
    - Disposal in granite formations

  Both projects describe and integrate the results obtained by Enresa up to 2004 in relation to "Site Selection", "Generic Repository Designs" and "Associated Safety Assessments" as fundamental elements in the final management of SF. The documents also indicate the results of the R&D developed in support of the above three activities. These basic projects describe the cases of disposal in granite formations and disposal in clay formations, which were considered feasible from a technical, safety and cost point of view.
- Experiences of SF and HLW management decision-making in some OECD countries. This analyses the most relevant or common characteristics of the decision-making processes for site allocation in ten OECD countries, as well as in the European Union and the NEA, with the aim of being able to infer useful decision-making mechanisms for future initiatives by the Spanish authorities.

These four documents complete the gathering of knowledge, technologies and experience related to the final management of SF committed to in the 6th GRWP. They form the basis for launching the next steps for site selection and implementation of the DGR.

Spain, in compliance with Article 14.3 of Council Directive 2011/70/Euratom of 19 July 2011, carried out, in 2018, an international peer review (IRRS/ARTEMIS mission) in relation to the regulatory infrastructure and the country's radioactive waste management and SF programme, which recognised that the establishment of an operational DGR is an iterative and lengthy process that requires careful and detailed planning, and considers it important to initiate the step-by-step development of the DGR as soon as possible. A specific legislative and procedural framework was thus considered necessary to cover, at an early stage, the site selection process, to facilitate the operator-regulator dialogue at the different stages of the project, and to provide for the necessary public participation.

In June 2019, Enresa drew up a first version of the "Roadmap for responding to the recommendations of the IRRS/ARTEMIS international review mission in relation to the DGR programme" which, among other aspects, established an action programme based on presenting the programme of activities for the technical development of the DGR with the main milestones and activities to be undertaken in order to comply with the mission's recommendation.

As a result of another of the mission's recommendations, a Tripartite Working Group (MITECO, CSN, Enresa) was formally constituted through the drafting of the Terms of Reference (ToR) and the holding of a kick-off meeting on 18 May 2020 (KoM), with the aim of studying and developing a proposal for a legislative, regulatory and procedural framework to support a DGR programme in Spain.

In 2022, the CSN and Enresa organised an international workshop on the DGR, which analysed international experiences in site selection, analysed the legislation and regulatory development of the Spanish regulatory framework and R&D activities relating to this facility, as well as the technical developments carried out within the national programme, and the information and public participation required for the start-up of a facility of this type.

Currently, Enresa continues to work in compliance with the "DGR Roadmap" and in close collaboration with the Tripartite Working Group (MITECO-CSN-Enresa) to define the proposed legislative framework for the DGR project.

3.5. Decommissioning and closure of nuclear facilities

Over the last few years, considerable experience has been accumulated in Spain in this field, including the following projects:

- Decommissioning of existing facilities and remediation of the site of the Andújar Uranium Mill (FUA).
- Environmental remediation of areas affected by uranium mining exploration and exploitation at various sites.
- Decommissioning and environmental remediation of the uranium ore processing facilities at La Haba and the existing facilities at Saelices el Chico, which include mining and large-scale production of uranium concentrates.
- Partial decommissioning of Vandellós I NPP (460 MWe), of graphite-gas.
- Closure of research reactors in the university sector (Argos and Arbi).
- Decommissioning and remediation of obsolete CIEMAT facilities (PIMIC Project).
- Decommissioning of José Cabrera NPP (160 MWe), with PWR (pressurised water reactor) technology, currently under way and nearing completion.

Particularly significant among the aforementioned projects, due to their scope and importance, are the partial decommissioning carried out at Vandellós I NPP and the total decommissioning of José Cabrera NPP, under way since 2010, which have allowed Spain to join the group of countries with comprehensive experience in this field. This experience has allowed a set of different types of capacities to be developed, and generic and specific tools for the planning, organisation, management and optimisation of decommissioning activities are now fully available.

The experience accumulated in the Vandellós I and José Cabrera NPP projects, both in organisational and documentary aspects and in interactions with the CSN and other authorities involved, is key to the planning and performance of the rest of the decommissioning projects and, particularly, to the decommissioning of Santa María de Garoña NPP, Phase 1 of the decommissioning of which began in July 2023.

Furthermore, the experience acquired in the integration of decommissioning activities and waste management, in the technologies applied for the dismantling of large components and in the volume reduction practices implemented will be highly relevant in the planning and execution of future decommissioning projects.

Figure 3-15: *Different phases in the decommissioning of José Cabrera NPP*

The current status of decommissioning and closure of nuclear facilities and facilities related to the mining and production of uranium concentrates is presented in Table 3-2 and Table 3-3 respectively.

Table 3-2: *Current status of decommissioning and closure of nuclear facilities*

Current status of decommissioning and closure of nuclear facilities			
Name of facility	Location (province)	Current status	Decommissioning and closure milestones
Vandellós I NPP	Tarragona	Partial decommissioning completed in 2003 Latency Phase since 2005	**1990.** End of the operating permit for the natural uranium-graphite-gas type nuclear power plant after 17 years of operation **1994.** Submission of the Decommissioning and Closure Plan **1998.** Decommissioning authorisation **2003.** Completion of partial decommissioning works **2005.** Latency authorisation
Argos research reactor	Barcelona	Decommissioned in 2002	**1977.** Final shutdown **1992.** Fuel withdrawal **1998.** Ministerial Order authorising decommissioning **2003.** Declaration of closure
Arbi research reactor	Bilbao	Decommissioned in 2004	**1972.** Final shutdown **1992.** Fuel withdrawal **2002.** Ministerial Order authorising decommissioning **2005.** Declaration of closure
CIEMAT Facilities	Madrid	In the process of being finalised	**2001.** Approval of the Master Plan for the Improvement of CIEMAT Facilities **2002.** Submission of the Decommissioning Plan to MINECO, CSN, Submission of the Environmental Impact Study to the corresponding ministry, Application to Madrid City Council for a construction permit **2005.** Decommissioning authorisation **2006-2012.** Execution of decommissioning works **2013-2015.** Contaminated soil removal and management **2017-2022.** Removal and shipment of radioactive waste **2023-...** Discontinuation PIMIC-West Area
José Cabrera NPP	Guadalajara	In the process of being finalised	**2006.** Final shutdown **2009.** Spent fuel in the ITS **2010.** Decommissioning authorisation **2010-2020.** Execution of the works **2013.** Special waste in the ITS **2022.** Favourable appraisal of Site Remediation Plan
Santa Mª de Garoña NPP	Burgos	Phase 1 of decommissioning under way	**2019.** Start of preparatory decommissioning activities **2023.** Authorisation of Phase 1 of decommissioning and transfer of ownership

Table 3-3: *Current status of decommissioning and closure activities of uranium concentrate mining and production facilities*

Current status of decommissioning and closure activities of uranium concentrate mining and production facilities			
Uranium mining and uranium concentrate facilities	Location (province)	Current status	Milestones in the process
Andújar Uranium Mill (FUA)	Jaén	Surveillance and maintenance phase	Decommissioning and remediation works were completed in 1994 In 1995, a surveillance period began
19 former uranium mines	Extremadura and Andalucía	Remediated	Remediation work began in 1997 and was completed in 2000
Lobo-G Plant (La Haba)	Badajoz	Long-term surveillance phase	Decommissioning and remediation work completed In 2004, a declaration of closure was obtained
Elefante Plant (Saelices el Chico)	Salamanca	Surveillance and maintenance phase	The decommissioning and remediation work was carried out between 2001 and 2004 In 2005, a surveillance period began
Saelices el Chico (mining expl.)	Salamanca	Surveillance and maintenance phase	The final remediation works were carried out between 2004 and 2009 Currently in the phase of improving and reducing the treatment of acidic water, for which an R&D project began in 2017
Quercus plant (Saelices el Chico)	Salamanca	Final shutdown	The CSN is currently in the process of evaluating the documentation for the request for authorisation of the Phase 1 of decommissioning
Former uranium mines	Salamanca	Surveillance and maintenance phase	The remediation work was carried out between 2006 and 2007

3.6. Other actions

- **Protocol on the radiological surveillance of metallic materials**. In order to attempt to prevent the occurrence of incidents at industrial facilities for the recovery or processing of metallic materials and to control the radioactive waste that might be produced in the event of such incidents occurring, a "Protocol for collaboration on the radiological surveillance of metallic materials" was signed in 1999 by the ministerial departments involved in the issue, the CSN, Enresa, the industrial associations involved in the recovery and manufacturing of metals and the most representative trade unions.
- **Megaport Protocol**. This is a protocol for action in the event of the detection of inadvertent movement or illicit trafficking of radioactive materials in ports of general interest that was signed in 2010, within the framework of their collaboration in the fight against terrorism. Since its entry into force, there have been a minimum number of detections, none of a criminal nature, which have been resolved on the basis of the mechanisms established.

- **Support for emergency response**. This involves providing support to the authorities where Enresa operates, always at the request of the competent authorities in the manner indicated by them. In addition, Enresa cooperates in training activities on radiation protection and radioactive waste management for the State Law Enforcement Agencies and other institutional groups, whose participation in this type of situation is almost always unavoidable.
- **Management of radioactive lightning preventers**. Royal Decree 1428/1986, of 13 June 1986, on radioactive lightning preventers, required the existence of this type of apparatus to be formalised in accordance with the regulations governing radioactive facilities, or their removal by Enresa as radioactive waste. Enresa has been removing and managing the radioactive lightning preventers and the sources they contained by exporting them for recycling in the case of Am-241 and by exporting them for disposal in the case of Ra-226. The process was formally terminated for all formal purposes in spring 2004. However, such devices continue to appear on a regular basis, in the order of dozens annually, making it necessary to maintain a sufficient removal capacity.
- **Other radioactive materials appearing outside the regulatory system**. The national system has two basic mechanisms in place for the safe removal and management of any radioactive materials that might appear outside regulatory control. The authorities set these mechanisms in motion by issuing "Intervention Orders" or "Transfer Resolutions", involving Enresa as appropriate in each case. The type of radioactive sources and materials removed by these mechanisms is varied and the volumes are generally not significant.
- **Management of naturally occurring radioactive material (NORM).** Some industries (fertilisers, etc.) use raw materials with low natural radioactivity content and generate waste materials containing radionuclides. There are European and Spanish standards that require a certain degree of control over these by-products. Enresa occasionally removes this type of waste for management at the request of the ministerial department in the event of certain activity concentration values.

4

4. Action plan for the coming years

Based on the actions carried out to date, described in the previous chapter, and in order to comply with the action plan for the coming years established in the 7th GRWP, the need to undertake R&D activities in the following areas has been identified:

- National Inventory of Radioactive Waste.
- Durability studies at El Cabril Disposal Centre, and life management of the temporary dry storage facilities for spent fuel, high-level waste and special waste.
- Action plan for the management of very low-level, and low- and intermediate-level radioactive waste.
- Action plan for the management of spent fuel, high-level waste and special waste.
- Action plan for the decommissioning and closure of facilities.
- Logistics action plan.
- Other actions.
- Knowledge management.

4.1. National Inventory of Radioactive Waste

Since its creation in 1984, Enresa has drawn up and maintained an inventory of radioactive waste in Spain based on data received from producers. As indicated above, in order to comply with the requirements of Royal Decree 102/2014, of 21 February, for the Responsible and Safe Management of Spent Fuel and Radioactive Waste, at the end of 2014 Enresa launched an internal action plan to have a new National Inventory of Spent Fuel and Radioactive Waste with a closing date of 31 December 2015.

The National Inventory of Spent Fuel and Radioactive Waste gives the expected value of each of the waste categories considered in Spain, both in terms of the quantities already generated and of those expected. This National Inventory is revised in depth, re-evaluating the hypotheses of future generation every three years, unless there is some need to recalculate it, for example, in the event of a significant variation with respect to the initial hypotheses.

Accordingly, a new revision of the National Inventory will be published in 2025 with a closing date of 31 December 2024, and so on every three years thereafter. In between these complete revisions to the National Inventory, the data on waste generated at the end of each year are revised annually as they are needed for various national and international reports.

Enresa participates in international forums and working groups focused on the preparation of national inventories, in which it not only shares experiences but also seeks opportunities for improvement in calculation methods, starting hypotheses and the reduction of uncertainties.

Enresa is currently working on improving the range of uncertainties in the quantification of certain streams such as waste from NORM industries. Another area of action that has been worked on in the past, but to which work should continue and to which R&D should contribute, is the improvement of possible treatments or techniques minimising the quantities of waste to be managed by Enresa, applicable both to waste from the operation and decommissioning of nuclear facilities and NORM waste.

4.2. Durability studies at El Cabril Disposal Centre, and life management of temporary dry storage facilities for spent fuel, high-level waste and special waste

In storage or disposal facilities for radioactive waste, it is essential to study and understand the degradation and ageing mechanisms of engineered barriers, structures, systems and components that are important for safety purposes, specifying their possible consequences, as well as to determine their expected lifetime and the activities necessary to maintain their operability and reliability.

The aim of durability studies and life management plans is to analyse the long-term behaviour of the waste in storage and of the structures, systems, equipment and components that ensure the maintenance of the safety functions of the facility during its lifetime. To this end, it is necessary to study the evolution of the physical, mechanical and chemical properties over time, as well as the degradation mechanisms of the materials subjected to specific environmental conditions at the site in question, under certain temperature and irradiation conditions, depending on the type of waste in question.

4.2.1. Durability studies at El Cabril Disposal Centre

El Cabril Disposal Centre is a LILW storage facility with engineered barriers in which the waste is conditioned in solid matrices, which in turn are arranged in concrete barriers, and which will be protected by cover layers for their closure. These engineered barriers are the basis for the safe isolation of waste.

At El Cabril Disposal Centre, VLLW is also stored through the interposition of natural and high density polyethylene barriers (HDPE) and the use of different types of storage units.

The following life stages are established for this type of above-ground waste storage:

- Operational phase, during which the waste is introduced into storage.
- Surveillance and control phase, which lasts as long as the dissemination of the stored material could present a radiological risk. During this phase, only maintenance or repair work is carried out.
- Post-surveillance phase, where no surveillance and control activities are required.

The surveillance and control phase, in accordance with the waste activity, should not exceed the estimated period of time for the engineered barriers to maintain their properties, a duration that for El Cabril Disposal Centre is considered to be at least 300 years for LILW and 60 years for VLLW after closure and introduction of the final cover.

In this way, it is essential to maintain the quality and durability objectives of the conditioning matrices and concrete used in the construction of the storage vaults and in the manufacture of the casks that make up the storage units. In addition, it is necessary to be aware of the scientific/technical progress in the area of cement, concrete and cement-based product manufacture, as well as the applicable regulations.

In view of the indications in the preceding paragraphs, it is considered necessary to study the following aspects during the operating period of the facility:

- The behaviour of the waste conditioning matrix.
- Compatibility between waste matrices and backfill mortar.
- The behaviour and parameters controlling the ageing of concrete structures under conditions as close as possible to those of storage, so as to allow more accurate extrapolations on the evolution of the behaviour of concrete structures.
- The behaviour of the different materials that will make up the cover layers.

Figure 4-1: *Installation of sensors in Vault 21 at El Cabril Disposal Centre*

Consequently, knowledge in the following areas is essential:

- Mechanical, thermal, physico-chemical and chemical properties of mortar and concrete, as well as the methodologies applicable for their determination.
- Evolution of the properties, previously indicated, over time under storage conditions.
- Durability of mortar and concrete against aggressive processes that can cause their degradation, as well as the mechanisms involved in these processes.
- Characterisation of the materials of the cover layers and their behaviour over time in the environmental conditions of the site.
- Methods for monitoring concrete barriers and cover layers.

4.2.2. Life management of temporary dry storage facilities for spent fuel, high-level waste and special waste

Individual Temporary Storage (ITS) comprises SF and HLW storage facilities of different types and with the same safety requirements, where containers with SF and HLW are stored in buildings or on slabs in the open. Both the systems and the facility itself are subject to specific licensing processes, where the safety characteristics of both are assessed.

Some ITSs also consider the storage of casks with SW containing the most active components from the dismantling of reactor internals and fuel operating equipment. Such systems do not require specific licensing, but are evaluated within the framework of the facility where they are stored.

As has been commented above, the strategy considered in the 7th GRWP is the storage of SF, HLW and non-manageable SW at El Cabril Disposal Centre in Decentralised Temporary Storage Facilities (DTS). The DTS of each plant will be made up of its ITS plus a new complementary facility allowing for the maintenance and repair of its casks, guaranteeing the safety function of cask level recoverability, in accordance with Enresa's assessment based on the "Technical Instruction in relation to the medium- and long-term SF recovery capacity" (CSN/IT/SG/ENRESA/22/01) issued by the CSN.

In this type of waste storage, the fundamental phase in which the life management programmes or plans is applied is the operation or storage phase during which the waste is loaded into the casks and systems which, in turn, are deposited on the storage slabs and environmental conditions begin to be applied. In addition, the fact that the availability of a final solution for the management of this type of waste is planned for 2073 implies the need for extended storage times.

To this end, regulations have been developed by the regulator which, from the design phase and in the successive licence renewal processes, assess the continuity of the application of the safety aspects applied during the initial licences, establishing a system life management programme or plan which, in turn, is framed within the facility where these aspects are developed, both at the level of analysis and of the establishment of specific inspection and maintenance programmes focused on the equipment, systems and components that are important for safety, apart from the usual maintenance of a general nature that applies outside these programmes.

In the case of these facilities, potential work is presented that affects the design and operation in terms of efficiency and safety, with in-depth knowledge of the following aspects:

- Behaviour of stored waste (addressed in the SF, SW and HLW action plan).
- Behaviour and degradation mechanisms of materials and components that are part of the system and facility, in particular for equipment, systems and components that are important for safety. Improvement in the inspection and maintenance processes of already loaded systems and casks.
- Comprehensive long-term modelling of the facility, taking into account the phenomena likely to occur simultaneously in the waste and in the system/container and facility materials.

It is important to study the structural elements and metallic barriers, analysing their **rheological behaviour** under certain stress and conditions of pressure and temperature (deformations, fatigue phenomena, creep tests, plasticisation, breakage, etc.) throughout the useful life of the facility. It is also necessary to study the behaviour of large equipment and components involved in the waste management and storage process.

Figure 4-2: *ITS casks at José Cabrera NPP*

Thus, in relation to the concrete of the ITS slab, the study of the evolution of phenomena such as carbonation, the aggregate-alkali reaction, fracture strength and toughness, water transport capacity and water loss, shrinkage cracking, etc. are of particular importance. This study does not apply to the concrete of the module in capsule-based storage systems, as it is enclosed in a steel structure.

In relation to stainless steel, from which the welded capsules are manufactured, it is known that the main degradation mechanism in these components during the storage is stress corrosion cracking, which exists in the weld zone, mainly induced by chloride ions. In the case of bolted metal casks, carbon steel is used, for which the study of mechanisms such as pitting or galvanic corrosion is relevant.

In addition to steel, other materials for which the effect of ageing must be analysed are used for the structures, systems and components of storage and transport casks. Among them, aluminium and its alloys used in the rack are noteworthy, whose most significant ageing mechanisms are twofold: due to their exposure to high temperatures: thermal creep which could lead to excessive deformation of the material, affecting the dimensions of the rack's vault and, ultimately, conditioning the recoverability of the fuel in subsequent management phases; and thermal ageing which, if present, could affect the thermal properties of the material and, thus, the heat dissipation function of the rack.

4.3. Action plan in relation to the management of very low-level, and low- and intermediate-level waste

The experience acquired in Spain in the management of VLLW and LILW has made it possible to identify areas for improvement and to define the ideal actions to optimise them, acting on those elements of the system that are most necessary at present.

From the estimates made regarding the generation of VLLW and LILW, taking into account the uncertainties inherent to the methodology used, the following may be identified as the basic areas for improvement actions in the management of these types of radioactive waste:

- Coordination of efforts with the producers of radioactive waste to minimise the generation of radioactive waste and its volume, both during the operation and during the decommissioning of nuclear facilities, which makes it advisable to carry out joint projects to undertake volume reduction.
- Ongoing analysis of the evolution of radioactive waste generation and the consequent adaptation of El Cabril Disposal Centre to potential future needs, optimising the occupation of the vaults, taking into account types of radioactive waste and new types of casks and vaults.
- Monitoring and participation in projects to optimise the management, waste treatment and conditioning of graphite waste, with a view to its final management.
- The evaluation of the design of new LILW vaults, and studies on the optimisation of the vault design for VLLW.
- The possibility of implementing treatment and volume reduction systems at El Cabril Disposal Centre.
- The evaluation of cover layer tests for the subsequent sealing of disposal areas.

- Continuous improvement in the knowledge of radioactive waste and in the methods and techniques for understanding the behaviour of the disposal system (engineered barriers) and assessing its safety.
- The improvement of available technological capabilities in order to optimise the above processes, as well as for the preparation of means to address future situations, both those already envisaged and other possible ones.
- The improvement of the methodology to be followed for classification in waste areas with the definition of the management pathways of the radioactive or conventional waste generated, so that:
  - Waste from conventional waste areas is managed in conventional ways, promoting reuse, recycling and recovery.
  - Waste generated in radioactive waste areas is managed in specific ways, taking into account its potential radioactive content. Its management will be associated with appropriate radiological checks and, in the case of radioactive contents, with the assessment of the radiological impact in the framework of specific procedures or authorisations (e.g. clearance).
  - Updating of the radiological capacity of El Cabril Disposal Centre, in order to determine the inventory actually disposed of and to respond to future disposal needs, as far as its activity is concerned.

R&D in the management of LILW and VLLW will be based on optimisation of the disposal capacity of El Cabril Disposal Centre, this being a strategic and priority objective in the management of this type of waste, and on updating the radiological capacity of the facility. Furthermore, activities to improve the efficiency and safety of the operation of El Cabril Disposal Centre will continue to be promoted.

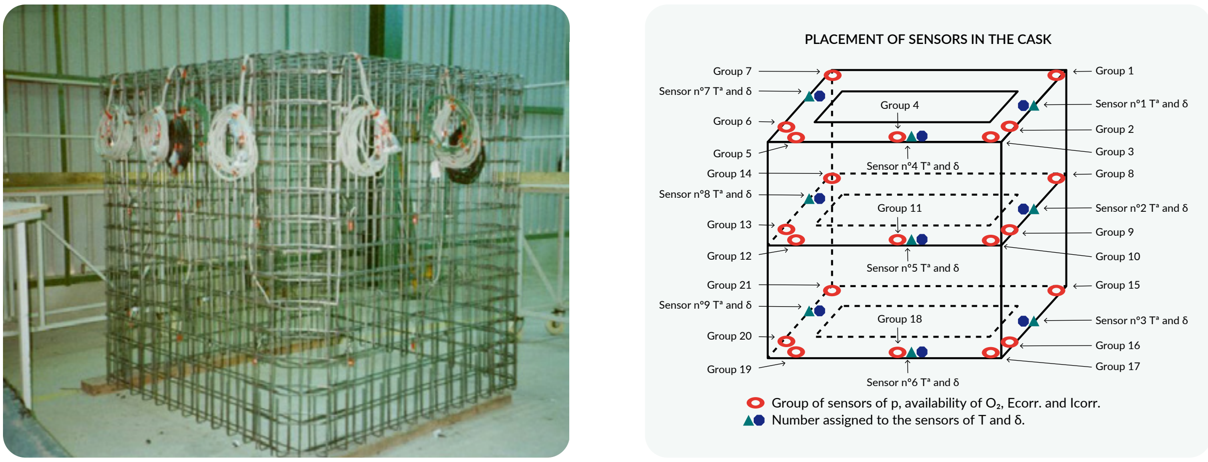


Figure 4-3: *Reinforcement of the instrumented cask for LILW at El Cabril Disposal Centre, and sensor wiring. Schematic with the distribution of sensors in the cask*

The actions planned in this regard are grouped into the following three areas:

a. Improvements in the management of VLLW and LILW.

- Support for activities to adapt and optimise the disposal capacity of El Cabril Disposal Centre (existing and future).
- Enhancement of volume reduction activities and conditioning of new flows.
- Improvement in waste characterisation processes to optimise waste classification (VLLW/LILW).
- Maintenance of R&D applied to safety improvement: better understanding of radionuclide/barrier interaction and containment materials.
- Technological improvement of site characterisation and monitoring, as well as their visual representation.
- Radiation protection and environmental remediation: analysis, verification and selection of technologies suitable for application in land remediation.
- Improvement of knowledge and technologies applicable to the management of waste from the decommissioning of nuclear power plants.

b. Improvement of the operation of El Cabril Disposal Centre.

- General process optimisation through the application of more advanced technologies that simplify the operation without compromising safety.
- Improved knowledge of the characteristics of the bulk inventory through the application of increasingly accurate analytical techniques.
- Optimisation and improvement of environmental control technologies.

c. Management of irradiated graphite.

- Continuation of treatment, conditioning and management activities.
- Participation in international collaboration projects related to the management of irradiated graphite.
- Study of other actions on graphite, such as its conditioning in geopolymers and its use in mortar and concrete.

4.4. Action plan on spent fuel, high-level waste and special waste management

As a continuation of the actions already carried out, the SF storage capacity at the ITSs of the nuclear power plants will be expanded to allow for their operation and decommissioning, depending on the needs of each plant. At Vandellós II NPP, an ITS will be built to house all the SF generated as a result of plant operation, while at Ascó, Cofrentes and Almaraz NPPs, additional ITSs will be built in addition to those already existing for the same purpose. In addition, at Vandellós I NPP, a storage facility will be built to house the HLW and SF from the reprocessing of SF in France and, where appropriate, from the decommissioning of the plant.

As has been explained in previous chapters, the strategy considered in the 7th GRWP is the storage of SF, HLW and non-manageable SW at El Cabril Disposal Centre, at DTSs at the sites of the plants that generate them, until they are transferred to the DGR.

In line with the staggered cessation of operation of the nuclear power plants, coordination and cooperation between the operating agents (Licensees and Enresa) will be maintained in order to optimise the SF management of the last groups to cease operation, in relation to the type of casks and characteristics of the SF.

The DTSs will provide an adequate timeframe to develop the disposal solution, allowing sufficient time to design, license, build and operate the future DGR.

The seven SF sites (Almaraz, Ascó, Cofrentes, Santa María de Garoña, José Cabrera, Trillo and Vandellós II) will have a DTS with sufficient storage capacity to house all the SF, HLW and SW generated during the operation and decommissioning of each plant, as well as the resources required for their operation until their transfer to the DGR.

The DTS of each plant shall consist of its ITS plus a new complementary facility (called support facility), or additional measures that allow, at any event, the maintenance and repair operations of its casks to be performed, ensuring the safety function of cask level recoverability. A site shall be equipped with recoverability at fuel assembly level.

Therefore, the needs identified in this area are based on improving the knowledge of the recoverability function at cask and fuel assembly level.

4.4.1. Action plan for the study of waste

This is internally called the **Fuel Programme**, and applies to each of the successive stages considered in the management strategy, both at a Spanish and international level. A SF and HLW (including SW and encapsulated sources) characterisation programme is necessary for various purposes, ranging from defining the criteria for acceptance of such waste, without hindering or rendering their future management unfeasible, to providing information for the design of casks, capsules and the facility itself, and even contributing data for the models used in safety assessments for both storage and disposal facilities.

It is considered necessary to have detailed knowledge of the characteristics and condition of the fuel to be managed, its evolution in dry storage stages, and when the integrity of the DGR casks has been lost, a better understanding of the mechanisms of dissolution and release of radionuclides from the fuel pellets.

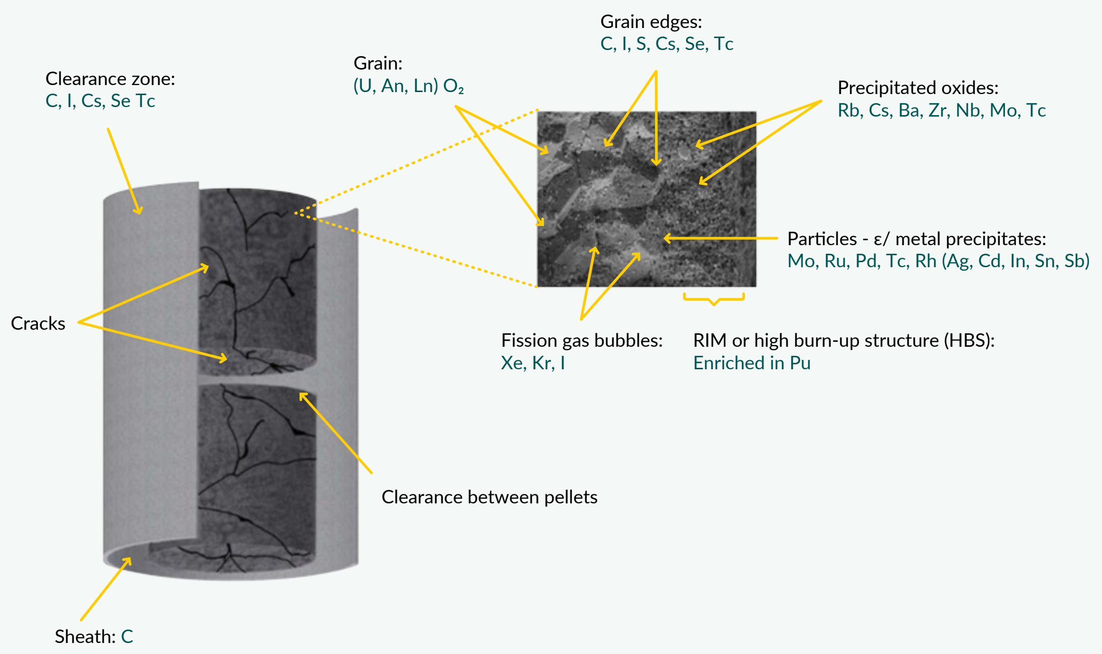


Figure 4-4: *Isotope localisation in the different zones of spent fuel*

The following are areas of R&D interest:

- The characterisation of irradiated fuel, both at source and in storage facilities. Consideration is given to all types of fuel used at the Spanish plants and to studies on the isotopic inventory of the waste, not only including pellets but also fuel assemblies and other activated parts.
- Studies and technical support for the establishment of criteria for the acceptance of fuel from nuclear power plants for management at Enresa facilities.
- Development of technologies and procedures for conditioning, transport and verification of damaged fuel.

- Studies of fuel behaviour during extended storage and subsequent transport, in particular for high burnup SF.
- Study on the dissolution and release of radionuclides from pellets and other parts of fuel assemblies (cladding, structural materials). Study of the mechanisms in a repository that control the release.
- Evolution of SF as a result of radioactive decay.
- Studies on waste from reprocessing to be returned to Spain both with respect to its stage in storage and subsequently disposal in the DGR.
- Follow-up of studies on assessments of potential criticality in the conditions of a DGR.

On the other hand, once the waste has been received at the Enresa facilities, it is necessary to carry out certain inspection tasks to confirm the condition of the fuel assemblies or waste to be stored during the unloading process. Given that these inspection tasks are usually performed in pools, it might be necessary to develop new technologies that allow dry activities to be performed. Based on the above, it is considered necessary to make progress in the study of the development of technologies for the repair of a damaged storage or transport system, source or fuel assemblies in storage facilities. These facilities need to be designed to deal with certain unforeseen exceptional situations, such as the reception of a cask with degraded safety functions, the loss of containment of a waste storage cask or source, etc.

4.4.2. Action plan for the optimisation of dry temporary storage facilities for spent fuel, high-level waste and special waste

As regards temporary storage, the Action Plan will be geared towards programmes for the improvement of knowledge of the engineered barriers (fundamentally metallic casks) and their monitoring; programmes geared towards the life management of facilities and the storage systems and the waste stored therein, through improved knowledge of behaviour during extended dry storage and subsequent transport of these systems and of the fuel they contain; support programmes for SF characterisation, conditioning, acceptance, etc.; programmes associated with the verification and acceptance of components, systems and materials; analysis of the impact on the disposal programme, in order to take into account the additional cooling time and the storage conditions from the point of view of safety, operability and costs; integral monitoring programme for the facility and its surroundings; and finally, modelling and assessment of the safety of the facility on an on-going basis, incorporating the improvements developed.

R&D should contribute in the short term with activities that support and underpin the temporary management of the SF, HLW and SW and their facilities (site, engineered barriers, monitoring and support of safety and environmental studies), through specific projects.

Planned R&D actions in the field of temporary storage will focus on:

- Programmes aimed at improving knowledge of engineered barriers (mainly metal capsules and casks) and their monitoring.

- Programmes aimed at the life management of storage facilities (mainly concrete).
- Programmes aimed at life management and improving the understanding of behaviour during long-term dry storage of fuel and the systems containing it, as well as their impact on subsequent transport, as mentioned above (Section 4.2.2).
- Analysis of the impact on the disposal programme to take into account additional cooling time and storage conditions from a safety, operational and cost point of view.
- Comprehensive monitoring programme for the facility and the environment.
- Modelling and evaluation of the safety of the facility on a continuous basis, incorporating the improvements developed.
- Support for the development of support facilities at DTSs to ensure recoverability at cask and fuel assembly level.

Figure 4-5: *General view of the ITS at José Cabrera NPP*

4.4.3. Action plan for the final management of spent fuel, high-level waste and special waste

As indicated above, the preferred option for the final management of the SF, HLW and SW is considered be a disposal facility in a deep geological repository (DGR) that would come into operation as from 2073, in accordance with the 7th GRWP.

The following are the main strategic lines of action on the basis of which the indicative programme for the development of a SF and HLW disposal facility will be drawn up:

- Updating of knowledge and technologies, based on information available and developments in international R&D programmes.
- Establishment of a legal framework and the necessary procedures to support the launch of a DGR development programme.
- Preparation of the basic documentation for decision-making in site selection.
- Development of generic documentation of the facility, as well as of the performance assessment methodology.

The DGR project development programme, in addition to taking into account the interdependencies with the temporary management of the SF, should be based on the following principles for its implementation and development: flexibility, systematic learning, evaluability, transparency and auditability.

The indicative programme envisages the stages shown in Figure 4-6:

ACTIVITIES		MILESTONES
Phase 1: Updating of knowledge	2025	Report on available capacities, proposal for site designation process and baseline information
Phase 2: Adoption of legislative and procedural framework	2028	Government evaluation and recommendations
Phase 3: Site selection process	2032	Procedure for choice of site. Inventory of possible sites
Phase 4: Analysis of the sites and selection of the definitive candidate	2039	Selection of the definitive site
Phase 5: Characterisation and verification of suitability and start of licensing	2059	Design of the repository and detailed characterisation. Licensing: request for prior authorisation and environmental impact study and construction application
Phase 6: Construction and authorisation of operation	2071	Construction of the facility
Phase 7: Initial operation	2073	Test period. Operation begins in 2073

Figure 4-6: *DGR development programme*

Planned R&D actions in this area will focus on:

- Review and analysis of the information generated by R&D associated with long-term management: assessment, selection and management of knowledge, technologies, applicable models, etc.
- Continuation of R&D projects associated with fuel behaviour under long-term storage conditions. Monitoring of international programmes.
- Continuation of R&D projects associated with the development of containment systems and site characterisation related to the safety assessment of long-term storage facilities. Monitoring of international programmes, applications, etc.

- Contribution to the development of the R&D programme associated with underground research laboratories.
- Continued monitoring of European activities in the field of transmutation and associated separation.

Plans for the period after the operational life of the DGR

Once the SF and all the waste housed therein have been conditioned at the DGR, Enresa will have to prepare the documentation to apply for the corresponding authorisation to decommission the surface facilities and closure of the DGR. To this end, Enresa will have to prepare a post-decommissioning safety analysis prior to construction of the DGR itself.

In order to preserve long-term knowledge of the facility, appropriate records will be developed to keep track of the development and characteristics of the facility as well as the inventory of stored waste.

4.5. Action plan for decommissioning and closure of facilities

As regards the nuclear power plants, the strategy established consists of total and immediate decommissioning, and with respect to Vandellós I NPP, which did not follow this strategy, the plan for the dismantling of the reactor box and management of the existing irradiated graphite is yet to be developed.

In addition, R&D is to provide support to the PIMIC Project, FUA and other facilities in the first part of the nuclear fuel cycle.

4.5.1. Nuclear power plants

The optimisation of decommissioning is based on an analysis of the lessons learned from the projects implemented to date, and in particular at José Cabrera NPP and the needs for improvement identified there.

Accordingly, the planned actions are as follows:

- Digitalisation of decommissioning through the development of tools based on 3D models of the facilities to be decommissioned, facilitating their planning, the management of both physical and radiological information, the definition of strategies and radioactive waste management plans. Furthermore, during the execution phase, these tools will facilitate the monitoring and supervision of the work.
- Analyse the plans and techniques for the dismantling and management of large nuclear power plant components, with a view to using advanced technologies to reduce costs and timescales and optimise the volumes of conditioned waste.
- Analyse improvements that facilitate the decontamination of surfaces with new technologies that replace manual processes and increase productivity, especially on high surfaces.
- Analysis of the improvement and extension to future decommissioning sites of the decontamination and volume reduction processes applied to both materials and land. These volume reduction activities for the waste generated at decommissioning sites consider, among other things, segregation, compacting and melting, as well as the use of new casks for large parts and those that maximise the quantity of waste incorporated per unit volume.
- Analyse improvements in the on-site characterisation processes for radioactive material and waste streams allowing for the optimisation of segregation in the different categories, as well as the reduction of subsequent rejections in both the VLLW characterisation and clearance processes.
- Analyse improvements that facilitate the processes to clear materials and surfaces with measurement techniques that replace manual processes, which require a large amount of human resources and time, with more advanced techniques, such as low background measurement equipment, use of drones and automation of measurement processes in the case of large surfaces, etc., that increase productivity.
- Continue to improve and automate measurement technologies for the remediation of contaminated soils to facilitate final site characterisation.

Figure 4-7: *Situation of José Cabrera NPP in November 2023*

R&D should focus on systems and technologies for the reduction of the volume of decommissioning waste, both in relation to waste directly associated with the materials of the facility itself and to those produced in actions aimed at the release of the land. This should include the improvement of characterisation technologies facilitating the clearance of materials, surfaces and soils.

The R&D actions envisaged in this area will focus on:

- Development and implementation of technologies to reduce the volume of waste generated.
- Development of specific land treatment and decontamination techniques to minimise waste generation.
- Application of advanced techniques for characterisation and clearance.
- Improvement of decontamination techniques for the different materials to be decommissioned.
- Improvement of material control and management techniques.
- Design and verification of storage and transport casks for the different types of waste generated.
- Improvement and fine-tuning of methods for planning and monitoring of nuclear facility decommissioning processes.
- Participation in projects of the European Framework Programme (EURATOM) and Horizon Europe.

4.5.2. PIMIC

Enresa continues to support CIEMAT in the final phase of the Integrated Improvement Plan for CIEMAT's Facilities (PIMIC Project), currently being carried out for the discontinuation of the PIMIC-West area. R&D activities will be considered if necessary.

4.5.3. Andújar Uranium Mill

On completion of the decommissioning and remediation works at the site of the former Andújar Uranium Mill (FUA) in June 1994, Enresa, as the Licensee of the facility, submitted the first Surveillance and Maintenance Plan (PVM) to the former Ministry of Industry and Energy for evaluation and approval by the CSN. The scope of the PVM has been modified over the years in order to adapt it to the needs and new developments in surveillance systems, the evolution of the facility and its surroundings and to adapt it to the instructions received from the CSN.

This Plan, and subsequent revisions approved by the CSN, have established the activities to be performed during the so-called Compliance Period in which the facility currently finds itself, since receipt of the Resolution of the Directorate-General for Energy on 17 March 1995. The objective of the Plan throughout the Compliance Period is verification of compliance with the decommissioning and remediation design objectives and criteria, in order for the facility to be considered definitively decommissioned.

R&D activities will be continued according to identified needs.

4.5.4. Uranium concentrate mining facilities and mills

Figure 4-8: *Aerial view of the Andújar Uranium Mill, before (left) and after (right) Enresa's actions*

Successive agreements between Enresa and Enusa regulate a series of activities affecting sites or facilities for the mining and production of uranium concentrates currently owned by Enusa and operated prior to July 4 1984 (R.D. 1522/1984, authorising the incorporation of Enresa), to which end there is shared technical/economic responsibility between the two organisations. The sites under consideration are grouped into three projects:

- La Haba site (Badajoz): Long-term surveillance and control programme for the site of the former Lobo-G plant at La Haba.
- Sites of former uranium mines in Castile and Leon: Surveillance and maintenance programme for the Casillas de Flores and Valdemascaño mines.
- Location of the Saelices el Chico Centre (Salamanca): Surveillance and control programme for the Elefante Plant and surveillance and maintenance programme for mining operations.

Since the completion of the final remediation works at the Saelices el Chico mining operations in Salamanca in 2009, acidic water continues to be generated and requires appropriate treatment. In order to minimise the annual volume of water that still requires treatment prior to discharge and to reduce the costs derived from this activity, hydraulic corrective actions have been taken at the site. In addition, an R&D project was launched in 2017 with the aim of applying combinations of soils made from organic and inorganic waste (technosols) in order to avoid the generation of acidic water and eliminate the current costly treatments. Depending on the results of this project, the application of technosols is planned for the entire site.

The surveillance and maintenance activities, with the scope and duration required by the CSN, at all those restored uranium concentrate mining/manufacturing sites in the compliance phase (Elefante Plant and restored mining operations at Saelices el Chico, Castile and Leon mines) or in long-term surveillance following the declaration of decommissioning (Lobo-G Plant), are mainly aimed at verifying compliance with the environmental and radiological objectives of the Remediation Project. Responsibility for actions at the sites of these facilities corresponds to the Licensees, with Enresa in charge of technical supervision and the corresponding financing, as established in the agreements entered into with the said Licensees.

4.6. Logistics for radioactive waste and spent fuel management

R&D will serve the needs that may arise regarding transport equipment for any type of radioactive waste, as well as the development of auxiliary tools, maintenance, transport casks, life management, optimisation of procedures, etc.

Figure 4-9: *CMT isoB3 type transport cask*

4.7. Other actions

Under "Other actions", which are the responsibility of Enresa, the content of which is described in the previous chapter, R&D activities will be carried out as required.

4.8. Knowledge management

Knowledge management is a cross-cutting action that affects all Enresa's activities. The great importance of an adequate knowledge management system in activities related to the proper management of radioactive waste has been recognised. International organisations such as the OECD-NEA, the IAEA and the European Commission, as well as national R&D platforms in nuclear fission energy (CEIDEN) and radiation protection (PEPRI), have included this issue among their lines of action.

One of the characteristics of R&D in waste management is the generation of knowledge and technologies that will be used over long time scales. The safety studies that allow facilities to be licensed are subject to continuous review, which means that knowledge must be systematically updated.

The knowledge generated should therefore:

- Be adequately conserved for long periods of time.
- Be easily identifiable and accessible at all times for use.
- Be supported by a system that guarantees their transmission.

With regard to the conservation of knowledge, one of the most relevant challenges in the short term is related to the evolution of computer mediums and the need to regularly update electronic documentation. In this regard, it is also considered necessary to make a selection of information and documents to be conserved in the medium and long term, given the large volume of documents that can be generated, several hundred thousand over the course of a project, as is the case at El Cabril Disposal Centre.

Knowledge transfer is essential for the continued efficient management of radioactive waste. It is most evident when there is a generational handover of those responsible for radioactive waste management, for example, in the case of El Cabril Disposal Centre, this may occur up to 25 times during the lifetime of the facility (operation and surveillance). Also important is the understandable transfer outside the management organisations directly involved; at a European level, this concept is applied to the transfer of acquired knowledge to countries with an initial management programme.

Enresa participates in initiatives and working groups of the NEA, the IAEA and the different national and international R&D platforms related to radioactive waste management in order to study and incorporate best practices.

The coordination of R&D activities at Enresa has facilitated the achievement of objectives, the adjustment of costs and obtaining homogeneous and balanced results between the different areas of activity and management needs. The immediate transfer of R&D results to radioactive waste management has also been a coordination objective.

These activities have been reinforced in recent years in order to update and review the significant volume of assets generated by R&D associated with the long-term management of HLW and which, together with other previous design considerations, form an important starting point for the long-term management plan for HLW.

A fundamental idea within knowledge management is to ensure its transfer to the new generations of technicians joining Enresa, given the long periods of management, development, operation and surveillance after decommissioning of the different management options used.

To this end, the following activities are considered:

- Analysis and update of R&D assets for consideration in the long-term storage programme. Completion of the review, update and reordering of the assets generated in each of the plans, in order to subsequently integrate them into a single database.
- Technology surveillance, with the aim of acquiring precise information on the capacities and knowledge existing in areas even outside the field of radioactive waste management and potentially applicable. Monitoring of the results of external programmes and of the technology platforms IGD-TP (mainly focused on DGR), SNE-TP (related to nuclear energy) and those performing equivalent tasks in radiation protection issues included in the European joint programme. Of particular note since 2019 is the first European Joint Programme on Radioactive Waste Management (EURAD) in radioactive waste management, which emerged as a product of the Horizon 2020 JOPRAD project. This programme has very ambitious activities in the areas of management and transfer of knowledge and training. It will continue in the EURAD-2 programme, which coincides with the time horizon of this 9th R&D Plan.

5

5. Organisation of the R&D Plan

5.1. Organisation of the R&D Plan by areas and lines of action

5.1.1. Introduction

According to Article 9.3.i) of Royal Decree 102/2014, of 21 February, for the Responsible and Safe Management of Spent Fuel and Radioactive Waste, Enresa's functions include "establishing training plans and research and development plans ... that cover the needs of the General Radioactive Waste Plan and make it possible to acquire, maintain and further develop the necessary knowledge and skills".

Article 6 states that the General Radioactive Waste Plan shall include the specification of "the research, development and demonstration (RD&D) activities needed to implement solutions for the management of spent fuel and radioactive waste, as well as for the decommissioning and closure of nuclear facilities".

Article 7 states that the financing of the activities of the General Radioactive Waste Plan, including research and development, will be carried out through the Fund for the Financing of Activities of the General Radioactive Waste Plan.

Accordingly, this Plan is in line with the regulatory provisions and compliance with the functions of Enresa, as the manager of an essential public service, as defined in the Nuclear Energy Act 25/1964, of 29 April.

This R&D Plan spans five years, like the previous ones, and aims to respond to the R&D needs identified in the previous chapter, in accordance with the Enresa Action Plan for the coming years established in the 7th GRWP, taking into account the experience acquired and future needs.

Given that Enresa does not have its own research and development resources, the materialisation of the projects envisaged in this plan is carried out through different types of collaboration instruments, fundamentally with CIEMAT, CSIC and universities.

5.1.2. Structure

The 9th R&D Plan, which will cover the period 2024-2028, is structured in areas of activity, indicating, for each one of them, the technological level reached and proposing specific development for the period covered by the Plan.

This Plan retains the same project classification structure used in the two previous plans, as this structure allows the main aspects of management to be addressed in a systematic way and with great flexibility. The table below lists the areas and lines of research in this R&D Plan.

Table 5-1: *Organisation of the R&D Plan*

Organisation of the R&D Plan	
Area 1.	**Waste technology**
Line 1.1	Fuel and high-level waste
Line 1.2	Very low-level and low- and intermediate-level waste
Line 1.3	Basic properties of radionuclides
Area 2.	**Treatment and conditioning technology and processes, and decommissioning**
Line 2.1	Treatment
Line 2.2	Decontamination, optimisation
Line 2.3	Decommissioning
Line 2.4	Immobilisation
Line 2.5	Auxiliary technologies
Line 2.6	Separation
Line 2.7	Transmutation
Area 3.	**Containment materials and systems**
Line 3.1	Characterisation and behaviour of materials
Line 3.2	Behaviour of containment systems
Line 3.3	Storage technologies and systems
Line 3.4	Monitoring of containment materials and systems
Area 4.	**Evaluation of safety, radiation protection and associated modelling behaviour**
Line 4.1	Evaluation methods and models
Line 4.2	Process and system modelling
Line 4.3	Environmental remediation
Line 4.4	Radiation protection and the biosphere
Line 4.5	Climate and soils
Area 5.	**Infrastructure and coordination**
Line 5.1	Infrastructure support
Line 5.2	Coordination
Line 5.3	Asset management

The following sections include the R&D activities carried out in the context of the 8th R&D Plan 2019-2023, both Enresa's own activities and participation in international projects, as well as R&D activities planned for the future.

With regard to the activities carried out, these include projects from the 8th R&D Plan and other projects from previous plans that have continued to be active in the period covered by the 8th R&D Plan 2019-2023. It should be noted that the criterion is that a project belongs to the R&D Plan in force on its start date.

The reference that appears in each of the projects listed as activities carried out (memory cards a. b. c.) corresponds to the classification number used in the memory cards, Enresa's R&D monitoring and control tool, the purpose and content of which is detailed and explained in Section 5.1.7.3 , where "a" is the R&D area to which the project belongs, "b" the R&D line, and "c" the correlative project number.

The list of memory cards can be found Table 10-1 in Annex 1.

5.1.3. Area 1. Waste technology

The projects included in this group aim to extend current knowledge of the physico-chemical properties of radioactive waste, as well as to determine its possible evolution over time under storage conditions, which, in the case of high-level waste, considers both dry storage and disposal, where water may be in contact with the waste after a considerable amount of time has elapsed. This applies to all types of radioactive waste.

For research purposes, two main groups are considered, high-level waste (including special waste) on the one hand, and very low-level waste and low- and intermediate-level waste on the other hand. Studies and research in this area are ongoing, both because of their i) scientific and technical complexity, ii) variation in the properties of SF, due, for example, to changes in the degree of burnup of nuclear fuels, iii) increasingly stringent safety requirements, and iv) technological advances available to researchers, which allow more ambitious goals to be achieved.

This area also includes R&D activities aimed at improving knowledge of the intrinsic properties of radionuclides present in waste.

The three lines of research into which the R&D activities in this area are grouped are:

- Line 1.1. Fuel and high-level waste.
- Line 1.2. Very low-level and low- and intermediate-level waste.
- Line 1.3. Basic properties of radionuclides.

The following sections list the main R&D activities carried out in the 2019-2023 Plan and those planned for the following period, 2024-2028.

5.1.3.1. Line 1.1. Fuel and high-level waste

Spent fuel and high-level waste have been studied in each R&D plan. Early plans focused on the study of disposal conditions, i.e. long-term and geological repository conditions. Later plans have focused on the study of dry storage conditions, lasting several decades.

Activities carried out

Projects under Line 1.1 with activities in the horizon of the 8th Plan 2019-2023 are described below:

- **Spent Fuel Research Based on JRC/ITU (Karlsruhe) Hot Vault Trials, August 2015-January 2027 (Memory card 1.1.04c.)**

The aim of the project, which started in 2005 and has been developed since previous R&D plans, is to contribute effectively to the understanding and resolution of scientific issues in the field of irradiated fuel research and to ensure that the results are applied in the best possible way to benefit society, by obtaining scientific data needed to better understand the behaviour of high burnup SF under geological repository conditions, including matrix corrosion, collaboration in the experimental and modelling field of real or simulated fuel, and enhancing understanding of the scientific, economic and society-based issues related to the instantaneous release and behaviour of key radionuclides.

Knowledge of the medium- and long-term behaviour of SF in different storage conditions (dry, wet, etc.), under a wide range of factors such as the physical state of the fuel, irradiation parameters to which it has been subjected, degree of burned fuel, type of fuel, etc. is necessary to establish medium-term systems that guarantee the efficient and safe management of irradiated fuel and other HLW.

It will also contribute to the development of concepts and design of storage facilities and, above all, to the understanding and correct description of the evolution of fuel properties under disposal conditions in shifting environments over time.

Figure 5-1: *Irradiated fuel samples containing pellets and cladding*

This area of study can be approached with different strategies, which are complementary. One of them, proposed in this project, is to work with real nuclear fuel that has been irradiated in a reactor, either experimental or commercial, or as an experimental sample in a commercial reactor. It is necessary to have irradiated fuel that can be tested and to have high-level laboratories equipped with hot vaults where such tests can be performed. Since it is necessary to handle irradiated fuel, which is highly radioactive, these vaults constitute a sophisticated nuclear research facility, which does not exist in our country.

The European Commission's Joint Research Centre (JRC) has a complex of multiple hot vaults at its facilities in Karlsruhe in which to test irradiated nuclear material. The current project aims to develop experimentation with real fuel at the JRC/Karlsruhe facilities, a centre with which Enresa has signed a collaboration agreement for the joint development of a research programme with spent fuel.

This project is a collaboration agreement between Enresa, the Manresa Technology Centre (CTM) and the European Atomic Energy Community, represented by the ITU-JRC, reflected in "Collaboration Agreement No 33924".

- **Participation in "Modern Spent Fuel Dissolution and Chemistry in Failed Container Conditions" (DisCo, H2020), June 2017-November 2021 (EURATOM) (Memory card 1.1.19.)**

The development of robust safety cases for deep geological repositories (DGR) for the disposal of SF requires a solid understanding of the dissolution of SF over very long time scales (up to one million years). This dissolution constitutes the main source term for the release of radionuclides under DGR conditions, and will control the release of radioactivity in the environment of the engineered barriers (the near-field) of the DGR, once the engineered barrier system has degraded and groundwater comes into contact with the SF.

The DisCo project represents a natural continuation of previous EURATOM projects (SFS, NF-PRO, MICADO, REDUPP and FIRST-Nuclides) which focused on the dissolution and release of radionuclides from conventional UO2 spent fuel. This project has studied the dissolution of spent fuel from new fuel types (Cr-doped and MOX) (Figure 5-2).

The specific aims of DisCo have been:

- To improve the understanding of the dissolution of the SF matrix under representative conditions of defective casks in reducing repository conditions;
- Assess whether new fuel types (MOX, doped) behave like conventional fuels.

- **Participation in Spent Fuel Performance Assessment and Research (SPAR IV), June 2026-until agreement of the parties (IAEA) (Memory card 1.1.18.)**

This project studied the integrity of SF stored for long periods of time, with the aim of further developing a technical knowledge base on the long-term behaviour of SF and storage system materials by assessing the operational experience and research of the participating Member States.

DisCo
Modern Spent Fuel Dissolution and
Chemistry in Failed Container Conditions

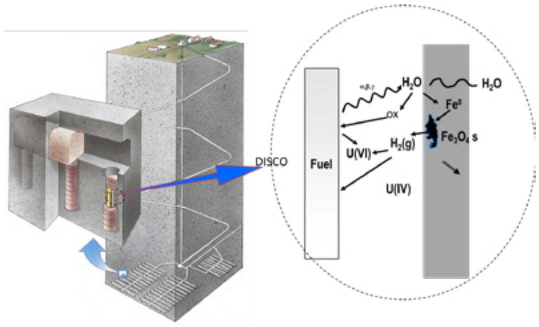


Figure 5-2: *Project logo and Overview of dissolution of spent fuel in a repository environment*

The specific aims of this research were to:

- Assess the behaviour of fuel and materials in wet and dry storage, and the impact of storage on the handling and transport of SF;
- Develop capacities to assess the impact of possible deterioration mechanisms;
- Collect and exchange relevant experiences in participating countries;
- Surveillance and monitoring programmes for SF storage facilities;
- Exploit synergies between participating Member States' research projects;
- Facilitate knowledge transfer;
- Extrapolate predictions of SF behaviour over long periods of time.

This project is expected to continue in a new project called SFERA (described on the following pages).

- **Participation in the H2020 EURAD WP8 Project "Spent Fuel Characterisation and Evolution Until Disposal" (SFC), June 2021- May 2024 (EURATOM) (Memory card 1.1.20.)**

This project is a work package (WP) of the European EURAD programme, specifically WP8, which aims, on the one hand, to reduce uncertainties in the properties of SF and, on the other hand, to carry out analyses and tests on the mechanical behaviour of fuel. Both cases are focused on the phase prior to disposal or pre-disposal.

The project sought to develop and experimentally verify a procedure to accurately determine the SF source term and to develop characterisation techniques to better understand the physico-chemical evolution of SF (pellets/chips and pods) in normal and credible accident scenarios after reactor discharge (i.e. during provisional storage (wet and dry), transport and its placement in a DGR).

Enresa's participation In WP8 occurred in Task 8.2, relating to the estimation of the waste heat of fuel assemblies, a parameter that greatly conditions their disposal. In particular, the codes available for the estimation of waste heat and their validation with experimental measurements were analysed, either of the heat of the assembly itself using different experimental techniques or on the basis of the isotopic composition of the fuel.

This last point was the focus of Enresa's participation, with the collaboration of Enusa, which provided the WP with isotopic concentration measurements of BWR (boiling water reactor) samples, a type of fuel for which there has been very little information to date, along with the manufacturing and irradiation details of the fuel from which the samples were taken. In this way, several organisations have been able to model the isotopic content of this fuel and assess how good the predictions are relative to experimental values.

It should be noted that of the experimental techniques used to measure isotopic concentration, radiochemical analysis, although more expensive, has yielded more reliable values than the second technique used - laser ablation - which needs to be better adapted to measure the isotopes relevant to waste heat.

- **Unirradiated Uranium Dioxide (UO_2) Oxidation Tests and Associated Analyses (OCATS), January 2020-March 2024 (Memory card 1.1.21.)**

The overall aim of OCATS, a project carried out jointly with CIEMAT, is the performance of non-irradiated uranium dioxide (UO_2) oxidation tests and the associated analyses for their interpretation. To this end, a UO_2 substrate was selected with physicochemical parameters (specific surface area, particle size and surface morphology) similar to those of the UO_2 of a fuel pellet.

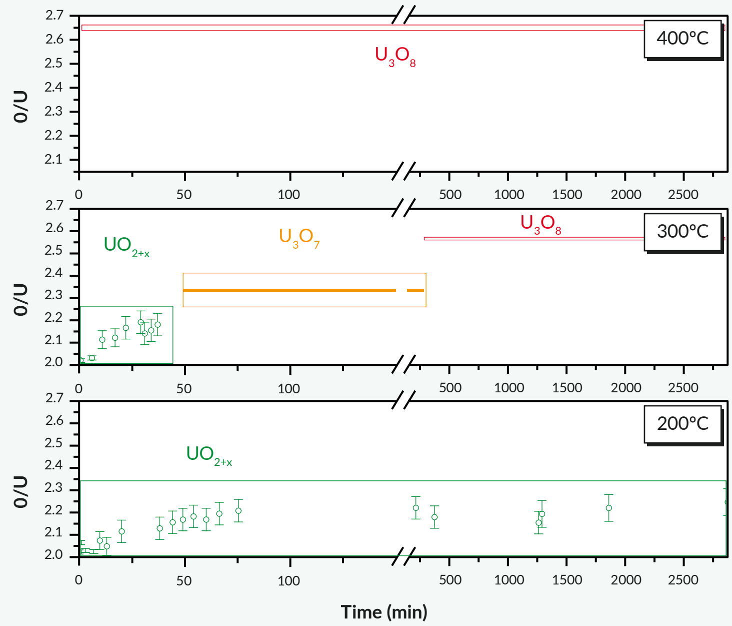


Figure 5-3: *O/U ratio calculated from the acquisition of Raman spectra in Linkam vs. reaction time at 21% O_2 and the three temperatures of interest, at 200, 300 and 400°C*

The experimental framework focuses on the development of UO_2 oxidation tests using *in-situ* and *ex-situ* techniques. These systems are complemented to obtain all the information on variables of interest during the oxidation process, such as the degree of oxidation of the sample or the formation times of the different uranium oxide phases - U_4O_9 and U_3O_8 - under different test conditions, which are temperature and the presence of varying concentrations of oxygen (gas).

In-situ test methods include thermogravimetry (TGA) and Raman spectroscopy, thanks to the coupling of the Linkam Stage high-pressure, high-temperature chamber (hereafter referred to as Linkam-Raman). *Ex-situ* tests are carried out using stainless steel reactors that are heated in an isothermal block, thus allowing the use of a larger sample, extending the experimental time, as well as measuring other properties of the materials tested thanks to the possibility of using additional analytical techniques that require a larger sample and that reveal important parameters for oxidation (Figure 5-3).

As a result of these tests, a series of experimental variables of interest are determined, among which the incubation time for the formation of the oxidised U phases, for each temperature and % of $O_{(2)}$, i.e. the fundamental result of the experiment is to establish the kinetics of the oxidation of UO_2 and its dependence on the most important environmental parameters, temperature and presence of oxygen.

The results obtained to date have shown that the oxidation of UO2 is a very temperature-dependent process, occurring above a certain temperature even for very low oxygen concentrations.

- **Long-term Stability of Irradiated Fuel, July 2020-December 2024 (Memory card 1.1.22.)**

The aim of this project was to carry out experimental work on the characterisation and study of the alteration of chemical analogues of irradiated fuel under different conditions representative of disposal, both chemically reducing and partially oxidising.

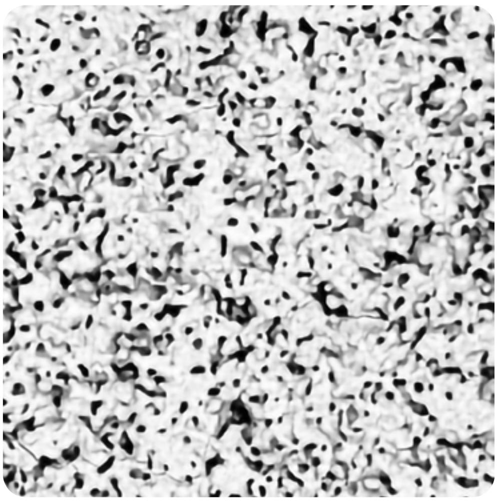
These analogues have been synthesised and doped in UPC laboratories, for subsequent analysis according to the programme described in the technical specification and in accordance with the aims of the EU project "Modern Spent Fuel Dissolution and Chemistry in Failed Container Conditions" (DisCo). The processes observed were also modelled and compared with results from real fuel samples from other laboratories, all with a view to ascertaining their long-term stability (Figure 5-4).

This project started a new phase in January 2023, with the aim of investigating the evolution of nuclear fuel behaviour under simulated underground storage conditions, under chemically reducing and oxidising conditions, and for different degrees of burn-up of the same fuel rod.

The aim was to study the importance of the formation of oxidised and secondary phases in the retention of radionuclides. Access to the experiments carried out with irradiated fuel samples in hot vaults will put the results of these experiments with non-irradiated samples into perspective and contribute to their interpretation, as they have been carried out under the same conditions as the first experiments.

Research activities consisted of modelling of spent fuel experiments, studies of UO2 matrix alteration, behaviour of fission products in spent fuel, and study of oxidised/secondary phases in SF.

a)



b)

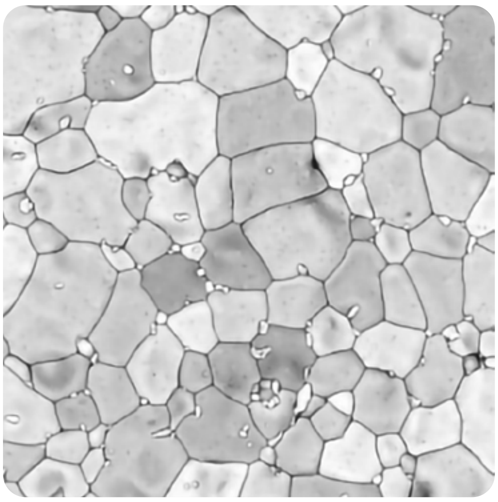


Figure 5-4: *UO_2 samples doped with 10% Gd_2O_3, a) porous sample; b) non-porous sample*

- **Post-Closure Criticality Safety (IGD-TP) (Memory card 1.1.23.)**

The Post-Closure Criticality Safety project is a collaboration project between waste management agencies from different countries to exchange information, approaches and best practices in relation to criticality safety following the closure of geological disposal facilities for radioactive waste.

This project addresses the possibility of a critical system formed in a deep geological repository (DGR) from fissile material consigned after facility closure, which has significant implications for the safety of the disposal system. The very long timescales over which safety must be ensured and the unique circumstances of waste evolution in a deep geological repository context make this a highly specialised field with a number of common challenges and issues.

- **Spent Fuel Research and Assessment (SFERA), November 2021-December 2025 (Memory card 1.1.24.)**

The completed SPAR IV Project included the study of storage system materials through the evaluation of operational experience and research in the participating Member States. The ongoing SFERA project is its continuation, fully dedicated to the behaviour of SF as waste.

The programme includes proposals from several Member States to address issues of major concern to the industry in recent years: fuel behaviour after a long period of storage and subsequent transport, failure mechanisms that can remain active in the long term, advanced fuels, management of damaged fuel, etc.

- **Study of the Oxidation of Spent Fuel in Non-inert Atmospheres at High Temperatures, August 2021-July 2024 (Memory card 1.1.28.)**

The aim of this project was to study the oxidation of SF in non-inert atmospheres at high temperatures and to carry out the associated analyses for its interpretation, i.e. it has a very similar experimental scope to that of the previous Section 1.1.21 but on irradiated material from nuclear fuel from Spanish nuclear power plants.

This material is in the Studsvik hot vault, which, under the direction of Enusa, carries out the experimental part, while Enusa performs the corresponding analyses. As the experimentation is on irradiated material in a hot vault, there are technical and volume restrictions on the sample available for testing, which entails a limited number of tests. Accordingly, the experimentation on non-irradiated material explained above completes and supports more robustly the conclusions of the analyses obtained.

The aim is to determine, with the uncertainties explained above, the "incubation time" as a function of temperature, for different degrees of fuel burn-up, and by analysing the influence of the oxygen concentration in the atmosphere. The "incubation time" is defined as the time below which any defective fuel exposed to a non-inert atmosphere would not experience a significant oxidation problem, and it can be guaranteed that the original defect would not evolve into a more significant defect.

The results obtained will be analysed in order to draw meaningful conclusions for the safety analyses associated with the fuel discharge vaults, which will be implemented in Spain (DGR encapsulation plant) (Figure 5-5).

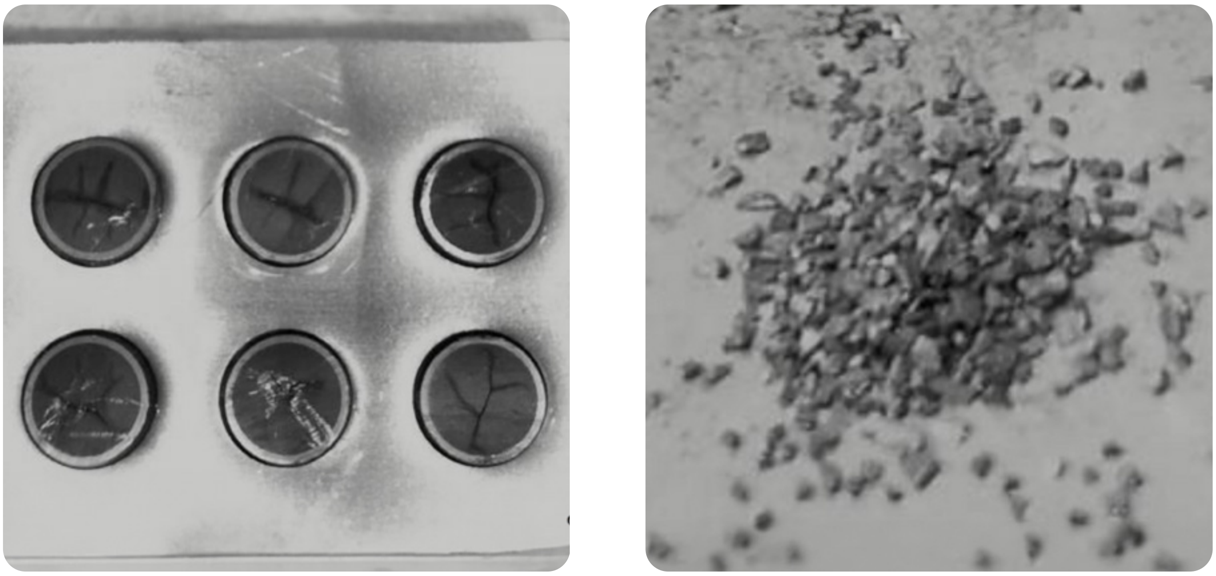


Figure 5-5: *Photos of the cut pieces of segment 09-VUD2, and after drilling, hammering and sieving operations*

- Chemical Composition Analysis of Fresh Fuel Assemblies and Core Components, May 2020-January 2023 (Memory card 1.1.29.)

The aim of this project has been to provide a detailed description of the chemical elements that are part of the source material and in the form of impurities in nuclear fuel pellets, cladding, fuel assembly structural components and other core-insertable components which, when irradiated during reactor operation, are precursors of the radiological inventory of the SF.

In this regard, the design basis fuel considered in the generic design of the DGR was a 17x17 AEF type PWR fuel, with zircaloy-4 cladding, whereby conservative assumptions of the composition were considered. However, various fuel types, both PWR and BWR, will have to be stored in the DGR, including other materials: fuel pellets with gadolinium, different alloys of steel and Inconel as structural materials, and other sheath materials than zircaloy-4, such as zircaloy-2, with nickel in the alloy, or Zirlo, which includes niobium. Insertable PWR components (control rod beams, neutron sources, consumable poisons and plugging devices) and BWR operating components, relevant for the presence of radionuclides such as indium, cadmium, etc., were not considered.

It is thus of particular importance for Enresa's activities related to the long-term management of SF at the DGR to know in greater detail the chemical composition of the fresh fuel and other core components, including the maximum concentrations of impurities and the area in which irradiation takes place, since the neutron flux varies significantly axially, affecting the resulting radionuclide inventory.

The main activities of this project were to:

- Determine the chemical composition and impurity concentration of selected chemical elements relevant for future DGR safety analyses.

- Determine the weight content for each element and for each material type, distinguishing steels, Inconel, Zircaloy and fuel (UO_2 and UO_2+Gd_2O_3) for each of the above PWR, BWR, fuel designs and PWR attachments (neutron sources, Ag-In-Cd control rods, capping devices and consumable poisons).

The values collected included the maximums of the raw material specifications or other reference documentation applicable to each fuel design, to allow their use and reference in the safety analyses necessary for the design, licensing, construction and operation of the future DGR.

For each chemical element, its majority location in the length of the fuel assemblies has been included, and in particular whether it is located outside or inside the active length (of importance for the proper characterisation of the waste).

- Participation in "Spent Fuel Characterisation" (IAEA), August 2020-December 2024 (Memory card 1.1.30)

This programme addresses all aspects related to the characterisation of SF required for the different management stages. It includes aspects such as basic research on characterisation methods and equipment for destructive or non-destructive determination of parameters of interest in SF; validation of models to facilitate the analysis of fuel behaviour and characteristics; databases; use of these data to support the design of SF management systems (storage, transport, deep disposal), in particular to determine its status, classification and optimise its management.

Each Member State makes proposals of interest and shares information with the other participants. Enresa participates with a proposal based on the GECYRE database, which is used as a repository for all the information on SF used at Spanish nuclear power plants, in collaboration with their Operators. This database also includes aspects relating to the characterisation of the fuel and its preliminary classification status for use in the systems provided by Enresa to the nuclear power plants.

- Investigation of the Mechanical Behaviour of Spent Fuel Cladding with Incipient Defects in a Drop Accident, September 2023-September 2026 (Memory card 1.1.31.)

This programme investigates the potential effect of incipient defects on the behaviour of SF cladding during the postulated drop accident in the transport of SF in casks.

To this end, the scope of the experimental work of the project consists of performing ring compression and 3-point bending tests, simulating the conditions of cask drop accidents, at different temperatures, on samples of zirconium-based alloy fuel tube with artificially created defects. The geometry of these defects is characteristic of the classification of SF, "hairline-crack" and "pinhole" type according to the ISG-1 guide of the USNRC applicable in Spain. In addition, the tube samples are pre-hydrated and undergo radial hydride reorientation treatment when tested under ring compression so that they have a hydride condition enclosure similar to that of fuel cladding.

The results will provide an insight into whether these incipient defects in SF, following a drop accident, can lead to a loss of fuel integrity, hindering its recoverability or, conversely, the defect does not propagate and the cladding essentially maintains its geometry. It may also allow characterisation of the modes of propagation of cracks in the cask during drops and contribute to a better distinction between damaged fuel and fuel debris, both of which are concepts used in the classification and loading of casks.

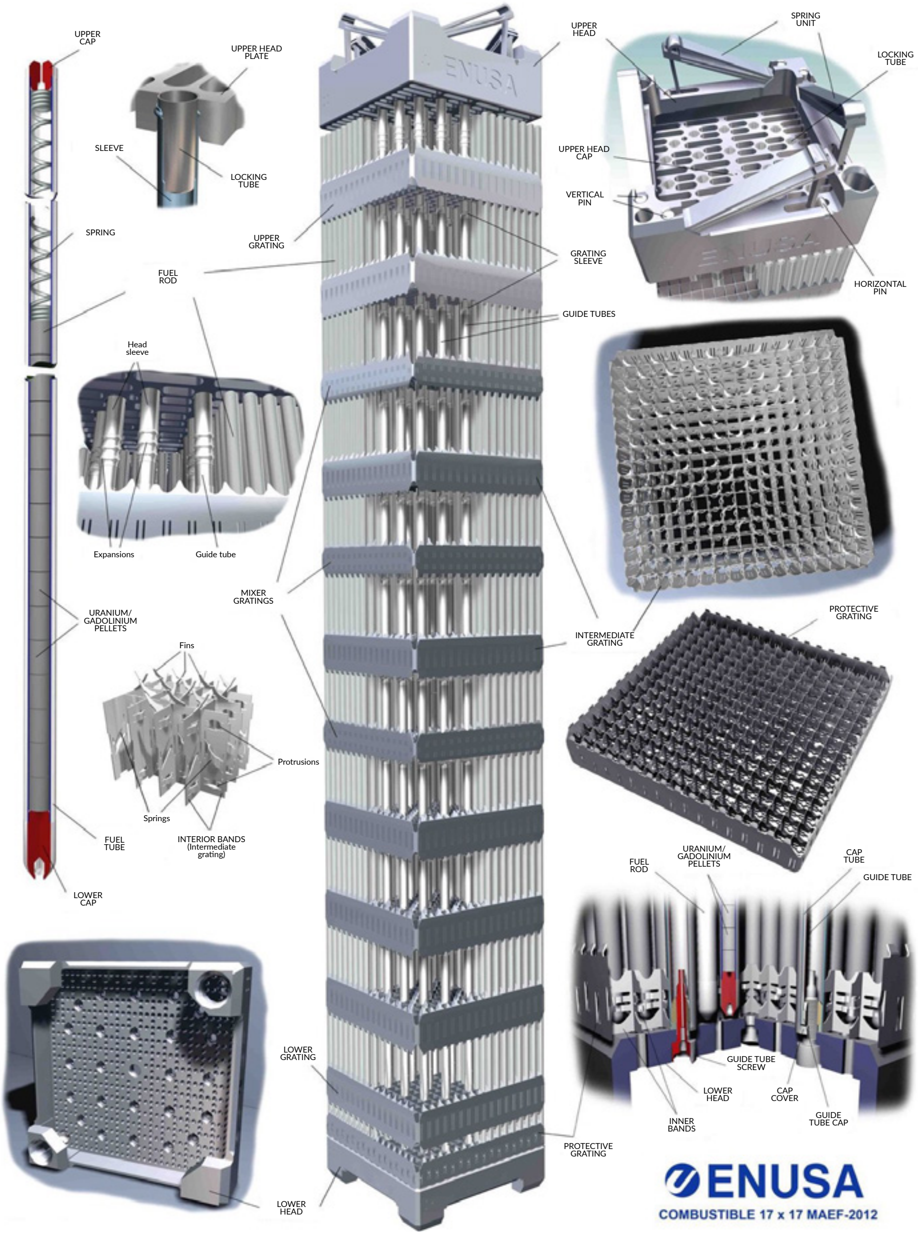


Figure 5-6: *Structure of a pressurised water reactor (PWR) fuel assembly manufactured by the Spanish company @enusa_sa*

Planned activities

The 9th R&D Plan considers activities focused on all the stages that SF has to undergo, including encapsulation, transport, temporary dry storage, transfer to the DGR and final disposal, also considering the period during which the capsule loses its integrity. Projects will address the fuel pellet, the cladding, other structural elements, the element and the complete assembly that makes up a capsule. The Plan also includes isotopic studies on irradiated samples and special waste studies.

The following projects have been initially identified as being of interest under Line 1.1 of the 9th R&D Plan:

- **Fuel Integrity Analysis in Extended Temporary Storage and Transport**

The continuation of the multi-year project for extended temporary storage and transport activities is considered, given the longer timescales to be considered than initially envisaged.

- **Participation in international projects associated with the NEA**

The continuation of collaborations in support of the CSN for activities in the NEA-SCIP V, or for the use of Halden samples in Studsvik (SPARE), as a contribution from the Spanish side to projects, is envisaged.

In particular, SCIP V, which began in June 2024 and will last for five years, will give access to important experimental data, since these tests will be performed in the Studsvik hot cells and with some of the samples to be tested coming from irradiated fuel at Spanish nuclear power plants. This Phase V of the SCIP has a test and analysis module focused on SF management, with new experimentation complementary to other programmes such as the Sisters Rods programme (as part of the DOE-sponsored programmes at ESCP) or even new programmes, such as creep tests on sheath samples with pellets inside.

- **Long-term Stability of Irradiated Fuel**

This project will continue to carry out studies related to fuel stability and, in part, to support the collaboration with the JRC/Karlsruhe within the Framework Collaboration Agreement with this centre.

- **Experimentation with Real Fuel in Hot Vaults. JRC_Karlsruhe-CTM-Enresa collaboration**

The Framework Agreement with the JRC-Karlsruhe has a long-term vision of continuity. The collaboration has proven to be successful and satisfactory for all parties involved, so this line of activity will continue to be developed in the future. The need to bring irradiated fuel rods or samples from Spanish nuclear power plants may be proposed.

- **Estudios sobre la influencia de la radiólisis en la evolución del combustible gastado en un almacén subterráneo**

This is a project to study and simulate the influence of radiolysis on the behaviour of SF in a DGR. The development of a 1D reactive transport model of SF dissolution, used in projects such as DisCo, which has already allowed modelling of experimental data from Studsvik of irradiated UO_2 type fuel and from CIEMAT of Cr and Al doped UO_2 pellet dissolution, will be continued. New processes are expected to be incorporated: i) effect of chloride on the generation of species by radiolysis, ii) understanding and implementation of the effect of different concentrations of epsilon particles and iii) inclusion in the model of certain fission products that make up the IRF. The model is implemented in the reactive transport tool iCP (**C**omsol-**P**hreeqC **i**nterface) (Figure 5-7).

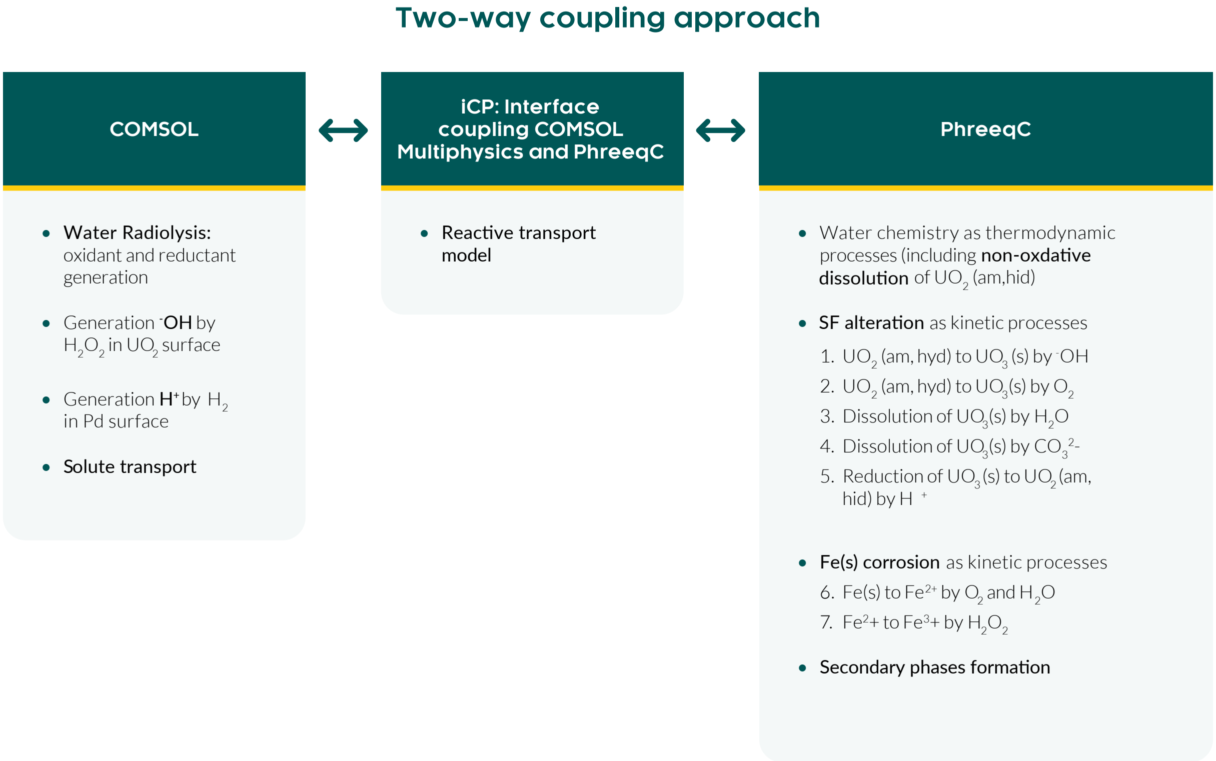


Figure 5-7: *Processes implemented in iCP involved in the alteration of spent fuel*

- Participation in EURAD-2 Work Package (WP) 8: "Release of Safety Relevant Radionuclides from Spent Fuel under Deep Disposal Conditions" (SAREC)

Enresa is participating in this work package, which will begin at the end of 2024, as an End User. It is aimed at investigating the response of SF under disposal conditions in deep geological formations. More specifically, it aims to improve the quantification and mechanistic understanding of the release of safety-relevant radionuclides, covering the most representative types of SF and the evolution of the fuel, before and after contact with groundwater, in order to better estimate the radionuclide source term for the assessment of the post-decommissioning behaviour and safety of a DGR.

5.1.3.2. Line 1.2 Low- and intermediate-level and very low-level waste

Low and intermediate-level and very low-level waste have required R&D projects for their improved management, in accordance with the Spanish strategy. Among the aspects of ongoing improvement at El Cabril Disposal Centre, the following are considered: optimisation of resources, storage capacity and radiological capacity, improvements in operation and a continuous increase in radiological and operational safety. These considerations, added to the need to know how to suitably manage the new waste streams each time a new decommissioning operation is undertaken, maintain the need for R&D projects.

Activities carried out

Projects under Line 1.2 with activities within the horizon of the 8th R&D Plan 2019-2023 are described below:

- **Accelerator Mass Spectrometry (AMS): Development of Methodologies for Cl-36 and Ca-41, Consolidation of Techniques for U-234, U-235, U-236, U-238, Np-237 and Am-243, and Development of Measurement of C-14 in Liquids, February 2020-May 2024 (Memory card 1.2.05.)**

The general aim of this project (Figure 5-8) has been the development of the methodology for the determination of the activity of large half-life radioisotopes in low- and intermediate-level waste by Accelerator Mass Spectrometry (AMS). The specific objectives refer to the different radioisotopes of interest for the project:

- Detection of Cl-36
- Detection of Am-243
- Detection of Ca-41
- Uranium isotopes (U-234, U-235, U-236, U-238)
- Measurements of Np-237
- Measurement of C-14 in liquid samples

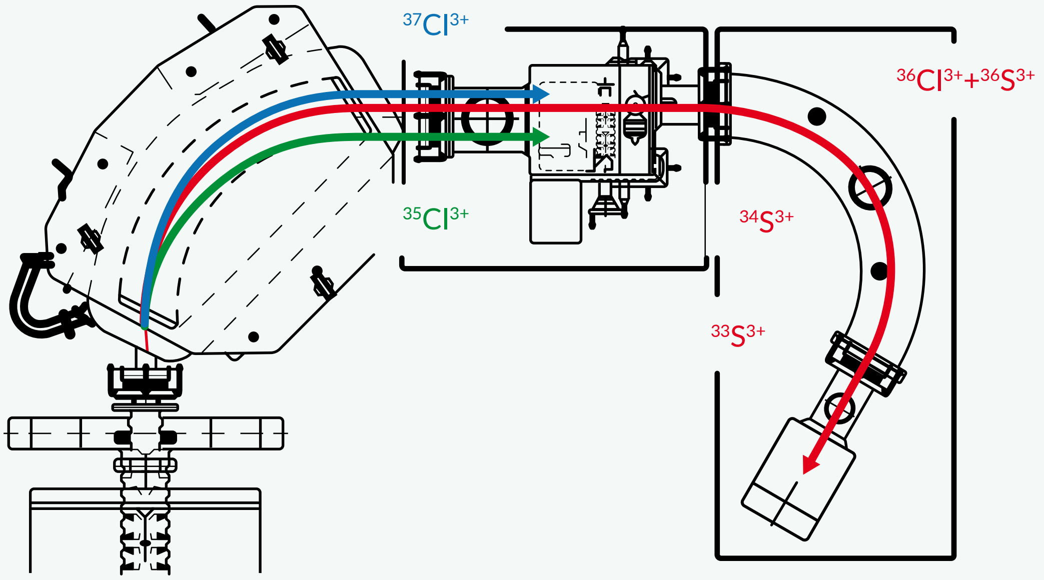


Figure 5-8: *Schematic used in the experiment for the detection of S and Cl isotopes by AMS*

- **Further Software Development of GUALI I and II Devices to Build a Passive Gamma Radiation Tomographic System for the Measurement of Radioactive Waste, November 2020-July 2028 (Memory card 1.2.07.b and Memory card 1.2.14.)**

The aim of the project is to investigate the identification, quantification and distribution of the activity of gamma emitters present in radioactive waste from nuclear power plants, both in operation and decommissioning.

In general, the usual gamma spectrometry measurements consider radiological homogeneity in the measured object, which is a rather crude approximation in waste of a heterogeneous nature, and cannot thus detect the heterogeneities intrinsic to this nature and optimise the characterisation of this type of waste.

The aim of the first phase of the project was further development of the software of the GUALI I and II devices to build a passive gamma radiation tomographic system for the measurement of radioactive waste by means of:

- Specific implementation of software in GUALI I and II equipment that allows spatial reconstruction of the distribution of activity in the radioactive waste casks.
- Periodic on-site measurements with real radioactive waste.
- Hardware adaptations to optimise the process.

A second phase of this project was launched in 2023, which will incorporate detectors with larger fields into gamma cameras to improve debris identification using low spatial resolution and high energy resolution detectors, and incorporate it into reconstruction algorithms.

In this second phase of the project, the aim is to:

- Enhance the capabilities of gamma cameras created in previous projects.
- Incorporate the gamma devices normally used by Enresa in the measurement sequence together with the gamma cameras.
- Create a new Pin-Hole Gamma camera unit with new capabilities.
- Optimise the processing of images obtained by the Compton camera using a new algorithm without spherical aberrations.

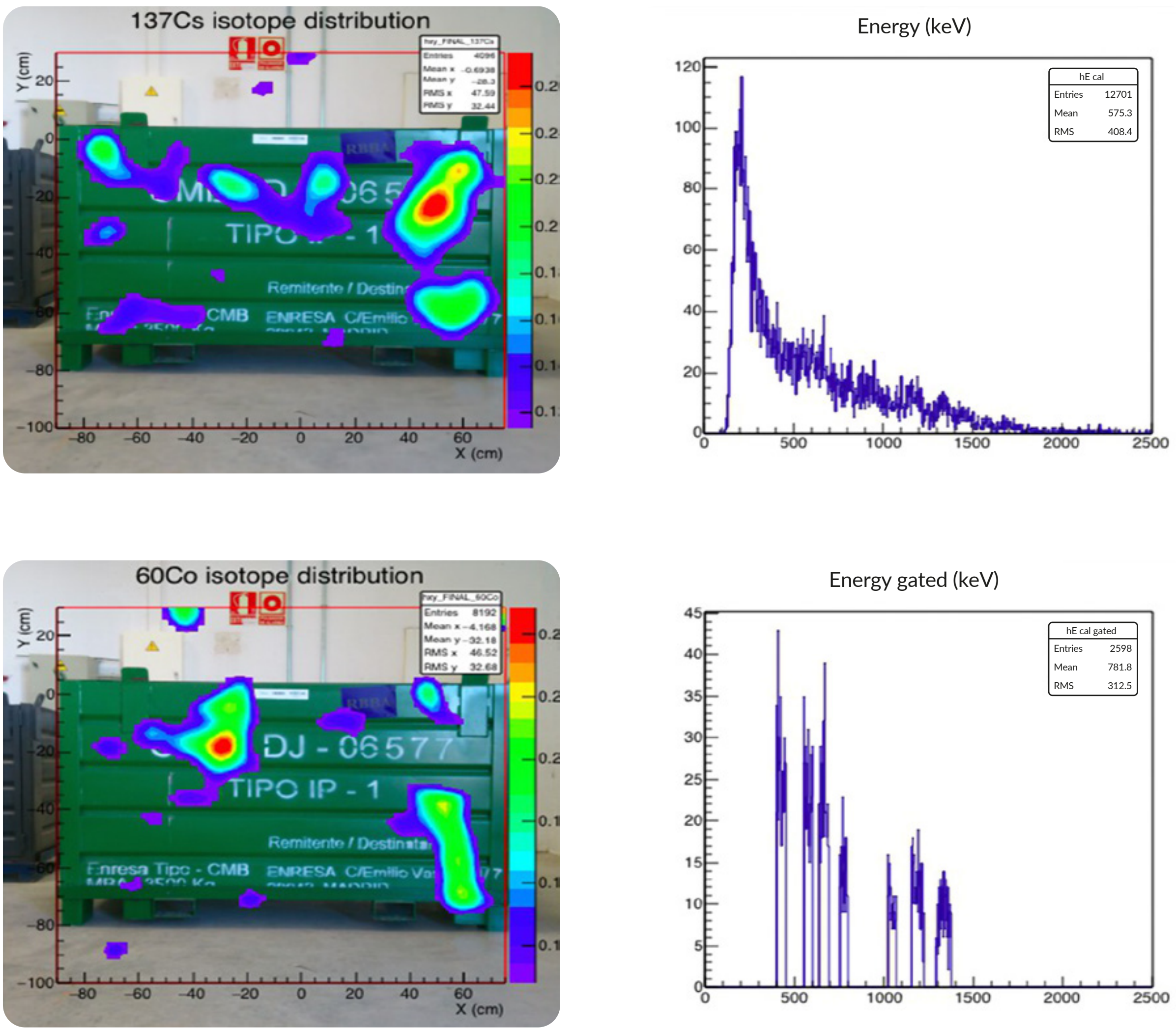


Figure 5-9: *Gamma radiation measurement tests in a cask at José Cabrera NPP*

- **Participation in "Characterisation of Nuclear Compounds for their Safe (Final) Disposal in Europe" (CHANCE, H2020), June 2017-March 2022 (EURATOM) (Memory card 1.2.09)**

The CHANCE project addressed the characterisation of conditioned radioactive waste. Its characterisation is more complex than that of unconditioned waste and requires specific non-destructive techniques and methodologies (Figure 5-9).

This is because conditioned waste is not in its initial form, but is usually embedded or surrounded by a matrix and may contain waste from different primary sources and therefore the radiological spectrum may be more complex.

The characterisation included both physico-chemical and radiological characterisation. The experimental focus was on radioactive waste from high volume components that may contain additional unanticipated structural components, SF stored in high volume casks, problematic and legacy waste, specific waste arising from repairs or maintenance, decommissioning waste and waste destined for the DGR.

The first aim was to establish a comprehensive compilation of current characterisation and quality control schemes for conditioned radioactive waste at a European level. CHANCE focused on the following waste forms according to the IAEA classification: Very low-level waste (VLLW); Low-level waste (LLW); Intermediate-level waste (ILW); High-level waste (HLW).

The second aim was to increase the degree of development, including testing and validation, of currently identified techniques, which can improve the characterisation of conditioned radioactive waste, i.e. waste that cannot be easily treated by conventional methods (Figure 5-10).

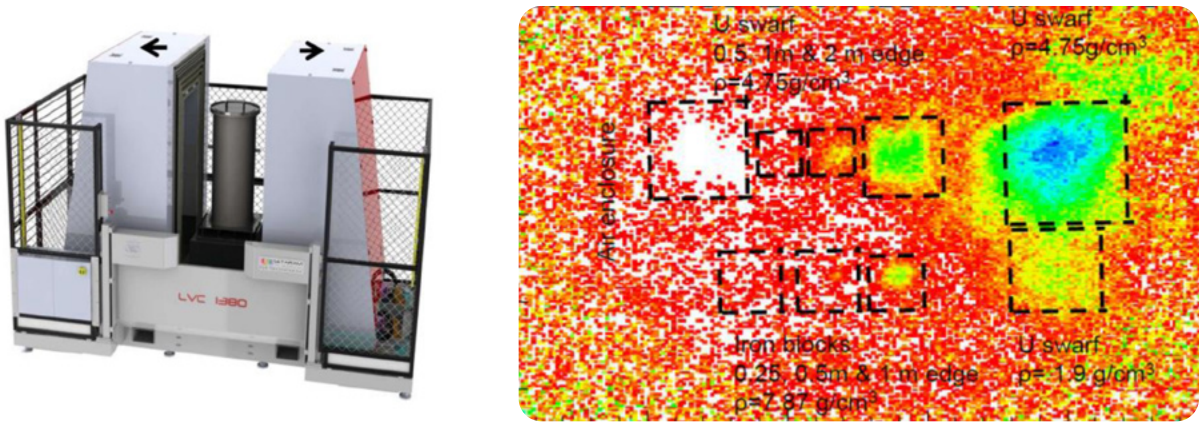


Figure 5-10: *Development of a 200-litre drum calorimeter and associated detector and muon tomography imaging studies*

- **Radiological Measurement of Materials with Activities in the Natural Background Range (Low Radioactive Content), December 2019-May 2022 (Memory card 1.2.10.)**

This project has had two main aims. On the one hand, to work towards determining the final management route for Low Radiological Content waste materials generated during the execution of the PIMIC Project on the remediation of the land at El Montecillo (CIEMAT).

To this end, the waste collected in 0.5m3 big bags in the SuperMUM prototype, located at the CIEMAT facilities as part of the EMPIR Project 'MetroDecom II', has been characterised.

Work has also been carried out in parallel to condition 850 1m^3 Big Bags into new 0.5m^3 packages so that the material contained in them can be subjected to a declassification process.

- **Participation in "Improved Nuclear Site Characterisation for Waste Minimisation in Decommissioning and Dismantling Operations under Constrained EnviRonment" (INSIDER, H2020), June 2017-November 2021 (EURATOM) (Memory card 1.2.11)**

The INSIDER project was designed to develop and validate a new and improved integrated characterisation methodology and strategy during decommissioning and dismantling operations of nuclear power plants, post-accident site remediation and nuclear facilities in restricted environments.

Depending on their stage of operation, certain nuclear facilities (or some of their components) contain highly active or contaminated materials that require new methodologies for their decommissioning and closure. The characterisation phase is becoming increasingly important, in particular in restricted environments. Several measurement systems exist and new developments are in progress; however, not all have the same state of maturity.

New methodologies were considered necessary for an accurate initial estimation of contaminated materials, of the resulting waste volumes and for timely planning. Accordingly, a common approach was developed based on advanced statistics and modelling, innovative methods of analysis and measurement, and the results of three case studies.

The result of the project has been to achieve, with the required accuracy, a representation of the radiological status of the facilities or their components, in order to make appropriate decisions regarding the different options for decommissioning and closure scenarios (Figure 5-11).

Figure 5-11: *The three case studies of the INSIDER project: decommissioning of hot cells, decommissioning of a nuclear power plant and decontamination of land after an accident (http://insider-h2020.eu/case-studies/)*

- **Participation in "PRE-DISposal Management of Radioactive Waste" (PREDIS, H2020), September 2020-August 2024 (EURATOM) (Memory card 1.2.12)**

The PREDIS project aimed to develop and implement activities for the pre-disposal treatment of radioactive waste streams other than nuclear fuel and HLW.

Consideration has been given to developing and increasing the level of technological readiness for waste treatment and conditioning methodologies for which no suitable or industrially mature solutions are currently available, such as metallic material (WP4), liquid organic waste (WP5) and solid organic waste (WP6), and by testing and evaluating cemented waste innovations (WP7). In addition, PREDIS has sought to produce tools to guide decision-making on the added value of the technologies developed and their impact on the design, safety and economics of waste management and disposal (WP2).

PREDIS has also liaised with EURAD to provide complementarity in areas including the adaptation and updating of the EJP reference founding documents (vision, roadmap, governance and implementation mechanisms) (WP2), and the organisation of training courses and mobility training schemes to enhance knowledge and competence sharing and transfer as part of knowledge management activities (WP3).

The PREDIS consortium has 47 partners from 18 Member States, and its EUG, aimed at Radioactive Waste Producers as a separate group. Enresa has contributed with research into the interaction mechanisms of aluminium in basic media and the parameters related to the disposal of low-and Intermediate-level waste.

Planned activities

The following projects of interest have been initially identified under Line 1.2 of the 9th R&D Plan:

- Continuation of the Accelerator Mass Spectrometry (AMS) Project: Development of Methodologies for Cl-36 and Ca-41, Consolidation of Techniques for U-234, U-235, U 236, U-238, Np-237 and Am-243, and Development of the Measurement of C-14 in Liquids

In this case, separate detection of Cm-243/Cm-244 will be added in order to be able to determine this fraction at each nuclear power plant, with a view to the measurement of Cm-244by non-destructive methods.

- Passive Detection of Mass Distribution by Ultrasound

The Torres Quevedo Institute of Physical and Information Technologies will seek to develop mass distribution techniques in waste casks using ultrasound.

- Development of New Radiochemical Methodologies for the Detection of Isotopes that are very Hard to Measure and Detailed Elemental Analysis of Active and Inactive Materials

CIEMAT will develop new radiochemical separation techniques for isotopes that are very hard to measure, for which no technique is currently available, in order to detect them using mass spectrometry.

- Development of New Techniques for the Passive Detection of Pure Alpha and Beta Emitters

The aim is to detect Cm-244 by measuring spontaneous fission neutrons, using neutron detectors that measure the entire package. This avoids the sampling used so far in the determination of Alpha emitters. Once Cm-244 has been detected in a package, its good correlation with the rest of the Alpha emitters allows their quantification.

- Participation in EURAD-2 Work Package (WP) 5: Innovative ChARacterisation techniques for large volUmeS (ICARUS)

This European project will try to develop new characterisation techniques using non-destructive methods (gamma spectrometry, neutronics, etc.), destructive methods (radiochemistry) and finally an analysis of the Scale Factors to reduce their uncertainty.

- **Development of New Advanced Gamma Spectrometric Techniques**

The aim is to make progress in the passive determination of the activity distribution. Collaboration will continue with the Institute of Corpuscular Physics, IFIC, attached to the CSIC, with the aim of combining different types of detectors and the advanced use of Gamma and Compton cameras.

5.1.3.3. Line 1.3 Basic properties of radionuclides

This line includes activities aimed at obtaining supporting data for calculations and evaluation models, where the physico-chemical parameters of actinides and fission products are the basis for such calculations. These calculations are applied in a wide range of management areas.

The development of these activities has been approached through participation in the projects promoted by the OECD-NEA and in which numerous representatives of management agencies similar to Enresa participate.

During the 8th R&D Plan, no project was carried out under this line.

Planned activities

The following projects have been initially identified as being of interest under Line 1.3 of the 9th R&D Plan:

- **Joint R&D Thermochemical Database Project TDB (coordinated by the NEA)**

This is intended to be incorporated into the ongoing NEA project updating the thermodynamic database of chemical elements in waste.

- **Tests for Determination of Chemical Speciation in LILW and VLLW**

The aim is to carry out laboratory tests on waste conditioned in different conditioning matrices (mortar, etc.) and to determine the chemical speciation of the most significant isotopes present in the waste.

- **Compilation Study of Transport/Adsorption/Speciation Parameters of LILW and VLLW**

The aim is to carry out an updated study of transport, adsorption (kds) and speciation parameters for use in waste characterisation, waste acceptance and radiological impact assessment.

- **Development of Transport (TR) and Adsorption (ADS) Parameter Databases for LILW/VLLW Radionuclides**

An attempt will be made to determine the diffusion and distribution coefficients for H-3 and Cs-137 of Cabril type mortars, but with different ashes and plasticisers used in their composition. The concrete used in El Cabril Disposal Centre with the new plasticiser will also be analysed. Finally, the clays of the cover layers will be analysed for radionuclide transport.

Another identified topic of interest is:

- **Identification of Chemical Speciation for LILW and VLLW as a Function of pH and Redox Conditions**

5.1.4. Area 2. Treatment and conditioning technology and processes, and decommissioning

The projects classified in this group seek to improve the degree of knowledge and technological capabilities of the actions that Enresa and/or the producers need to take with regard to radioactive waste prior to disposal.

5.1.4.1. Line 2.1. Treatment

Treatment means those activities that result in the waste being contained in matrices or having characteristics that meet the acceptance requirements of the destination storage facility.

Activities carried out

Projects under Line 2.1 with activities in the horizon of the 2019-2023 Plan are described below:

- Waterproofing of Irradiated Graphite and Optimisation of Heat Treatment, September 2016-March 2019 (Memory card 1.2.08.)

The current LILW Acceptance Criteria prevent graphite from being stored at El Cabril Disposal Centre due to the activity of C-14, which exceeds the total inventory limit for this radionuclide. Other criteria, such as leaching, exothermic reaction and mortar-graphite phase compatibility need to be met in the near future to apply for storage at this facility, once the C-14 has been reduced.

Two new innovative methods and routes were therefore investigated to create a new management option for irradiated graphite waste:

- The first method consisted of special heat treatment of the irradiated graphite that will allow the separation of the C-14 without affecting the rest of the graphite.
- The second method was based on the conversion of graphite into an impermeable material (IGM) using a long-lasting stable inorganic binder. The use of the stable inorganic binder causes the resulting material to be homogeneous with virtually no porosity, preventing mechanical damage from re-opening the porous system (Figure 5-12).

The main application of these methods has already been demonstrated at laboratory scale. The applicability with irradiated graphite must be performed on a laboratory scale before being performed on an industrial scale.

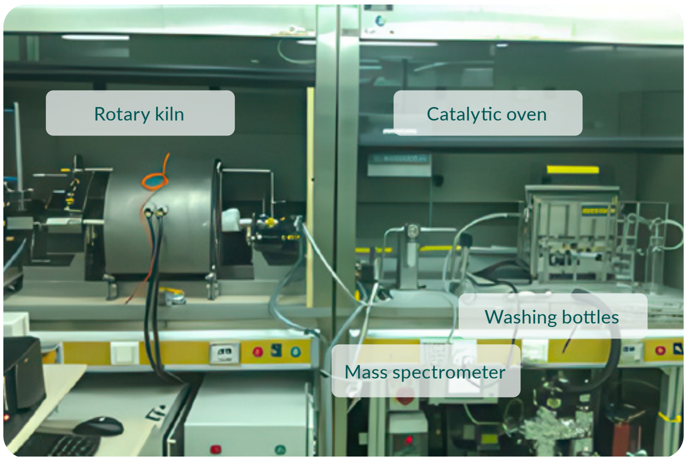


Figure 5-12: *Impermeable graphite (IGM) (left) and heat treatment plant schematic (right)*

- Tests on Conditioning and Treatment of Irradiated Graphite for Storage in Vaults at El Cabril Disposal Centre, January 2020-April 2024 (Memory card 2.1.07.)

The characterisation and acceptance processes required for the management and subsequent disposal in vaults of radioactive waste from all Spanish nuclear and radioactive facilities require determination of compliance with the Acceptance Criteria for each of the packages to be disposed of at El Cabril Disposal Centre. At present, the irradiated graphite from Vandellós I NPP from the liners has a Level 3 management mode, with no acceptance in the vaults, fundamentally due to the high C-14 content.

In order to move to a Level 2 management mode, with defined management, it is necessary to analyse compliance with the Acceptance Criteria specific to El Cabril Disposal Centre. The result of this analysis is as follows:

- Radiological inventory of C-14: the inventory of C-14 is exceeded and possible ways of selective decontamination have to be analysed.
- Exothermic release of energy: the energy produced by irradiation of the graphite has already been released, as temperatures of 400°C have been reached in the Vandellós I NPP operating phase.
- Leaching of H-3 and C-14: a readily leachable amount of both H-3 and C-14 has been observed. The labile fraction of these isotopes in the Vandellós I graphite is unknown; it will be necessary to study this aspect.
- Mechanical properties: the graphite blocks in the stack meet the required mechanical properties and can be stored in different shapes. This criterion does not apply to the graphite in the liners, as it is crushed.
- Volume optimisation: The 220 casks with the crushed graphite liners have a bulk density of 0.7 g/cm^3, while the density of graphite is 1.8 g/cm^3, so there is room for improvement in waste volume optimisation. The graphite in the stack has its own hollows where the liners used to be, so there is also room for improvement.

Based on these results, in order for the irradiated graphite from Vandellós I to pass to a Level 2 management mode, it is necessary to treat it with the following aims:

- Inventory reduction (mainly C-14).
- Volume optimisation.
- Reduction of the release rate of the labile fraction of graphite.

To this end, it is necessary to carry out tests aimed at making the management of irradiated graphite viable at El Cabril Disposal Centre, treatment tests to try to selectively decontaminate the graphite and conditioning tests compatible with the acceptance criteria in force (Figure 5-13).

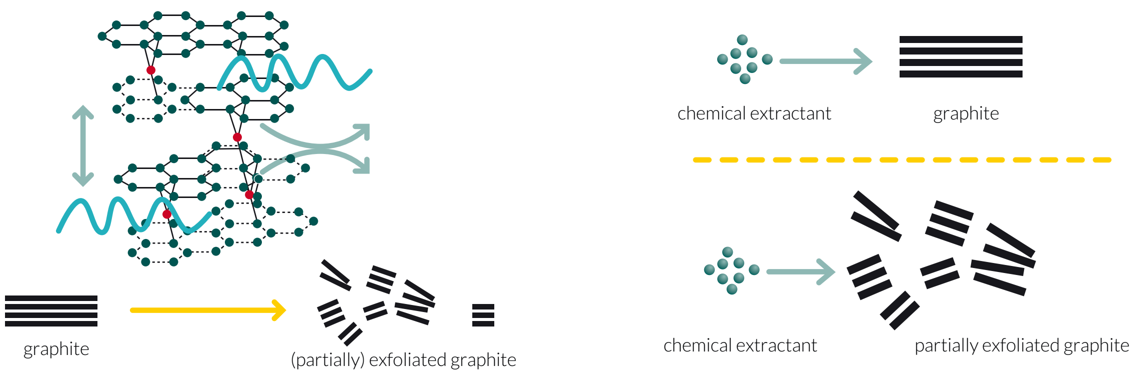


Figure 5-13: *Irradiated graphite treatment*

Planned activities

The following Line 2.1 projects of interest have been initially identified within the horizon of the 9th R&D Plan:

- **Waterproofing of Irradiated Graphite and Optimisation of Heat Treatment**

Previous projects will be completed and complemented by a new project to develop the characterisation methodologies for H-3 and C-14.

- **Continuation of Irradiated Graphite Conditioning and Treatment Trials for Storage in El Cabril Disposal Centre vaults**

The behaviour of concretes whose aggregates are crushed graphite will be analysed, particularly the mechanical and leaching properties. In addition, the incorporation of graphite in geopolymers will be studied, also from the mechanical and radionuclide release point of view. Finally, scaling up to a larger scale than that of the laboratory will be analysed with a view to its industrial implementation in Phase 3 of the decommissioning of Vandellós I NPP.

- **Study of New Materials for the Elimination of the Organic Component by means of their Immobilisation with Ion Exchange Resins, with Geopolymers, Analysis of Mechanical Properties, Leaching and Durability**

5.1.4.2. Line 2.2. Decontamination (optimisation)

This Plan includes as decontamination activities those that allow the radiotoxicity of radioactive waste to be declassified or reduced. This has the effect of optimising resources, since it generally implies a reduction in the volume of higher level waste.

The decontamination of land has been included in this Plan under Area 4.

Within the horizon of the 8th R&D Plan, no Line 2.2 projects have been carried out.

Planned activities

The following Line 2.2 project of interest has been initially identified within the horizon of the 9th R&D Plan:

- Development of New Technologies for Dry Capsule Decontamination

The aim of this project is to study technological advances in the decontamination of metal surfaces for application to dry storage capsules. Although, a priori, it is considered that the levels of environmental contamination in a dry storage facility should not require the surface decontamination of a capsule at depth, and dry wipe cleaning could be used, the study of alternative technologies for more intense decontamination could be of interest.

5.1.4.3. Line 2.3. Decommissioning

The experience of decommissioning Vandellós I NPP gave rise to numerous R&D projects, the aims of which were to develop better working methods, consolidate the knowledge acquired and study processes as yet unresolved, such as the management of irradiated graphite or the decontamination of soils. The Mestral Technology Centre set up by Enresa at Vandellós I NPP was the point of discussion and forging of new projects. The results of these projects have been applied at PIMIC and José Cabrera NPP, and will be applied in the future decommissioning of nuclear facilities.

Activities carried out

Projects under Line 2.3 with activities within the horizon of the 8th R&D Plan 2019-2023 are described below:

- Study of the Corrosivity and Airtightness of the Atmosphere of the Vandellós I Caisson, November 2002-July 2025 (Memory card 2.3.13.)

The aim of this project was to carry out a study of the corrosivity of the internal atmosphere of the Vandellós I NPP caisson during the latent period. The study was initiated in 2002 with the installation of experimental devices in three pits to monitor corrosivity using gravimetric and electrical resistance methods. The sensors have been renewed several times and there has been a partial renewal of metallic specimens. The next removal of probes will take place in 2025 and 2030 and new ones will be installed in 2025 (Figure 5-14).

Figure 5-14: *Specimens for the study of corrosivity inside the Vandellós I caisson; specimen exposed to corrosion for five years increased 2,500 times*

- **Participation in "Stakeholder-based Analysis of Research Needed for Decommissioning" (SHARE Project), June 2019-March 2022 (EURATOM) (Memory card 2.3.26.)**

As a precursor to the establishment of a framework for collaborative research activities related to decommissioning, the SHARE consortium has provided a roadmap for a joint research approach to decommissioning in the near future. It has been developed by stakeholders, in order to improve safety, reduce costs and minimise environmental impact in decommissioning nuclear facilities.

The objectives have been:

- Objective 1: Develop a methodology to define and prioritise possible collaboration activities required in the field of decommissioning research through an inclusive process involving all relevant stakeholders.
- Objective 2: Identify research needs for decommissioning based on the analysis of information gathered from stakeholders.
- Objective 3: Identify existing and emerging innovative decommissioning techniques and solutions used throughout the nuclear industry to meet current and future needs.
- Objective 4: Propose a roadmap, and instruments for its implementation, for strategic R&I activities aimed at improving safety, minimising environmental impact and reducing costs of decommissioning projects.
- Objective 5: Conduct dissemination and communication activities to present the results of the roadmap to the global community.

- **Participation in "PLatform based on Emerging and Interoperable Applications for enhanced Decommissioning processES" (PLEIADES Project), October 2020-November 2023 (EURATOM) (Memory card 2.3.27)**

This project stems from the growing number of nuclear power plants and other types of nuclear facilities reaching or approaching the decommissioning phase, which makes decommissioning and remediation actions a challenge and an international priority.

There are three general related issues:

- Protection of workers through dose limitation,
- environmental protection and,
- financial management, combining cost-effectiveness with respect for regulations and strict safety requirements.

To address these three issues, innovative solutions based on emerging technologies can provide efficient tools to improve R&D planning, safety of operations and protection of workers (Figure 5-15).

PLEIADES has had the following aims:

- Develop a new platform based on a BIM approach for:
    - designing scenarios, enhancing safety, minimising radiation exposure, optimising costs and planning, communicating,
    - "multidimensional modelling", including 3D modelling, time, dosage, feasibility studies, waste and costs,
    - 11 emerging softwares provided by the consortium (TRL 5-7), able to exchange data (interoperability),
    - implementation in real cases.
- Develop an associated methodology and impose it as a standard to establish a standardised process to organise the data collected throughout the project into data sets (codebooks, instructions, naming conventions...).
- Prepare the commercial exploitation of the PLEAIDES platform.

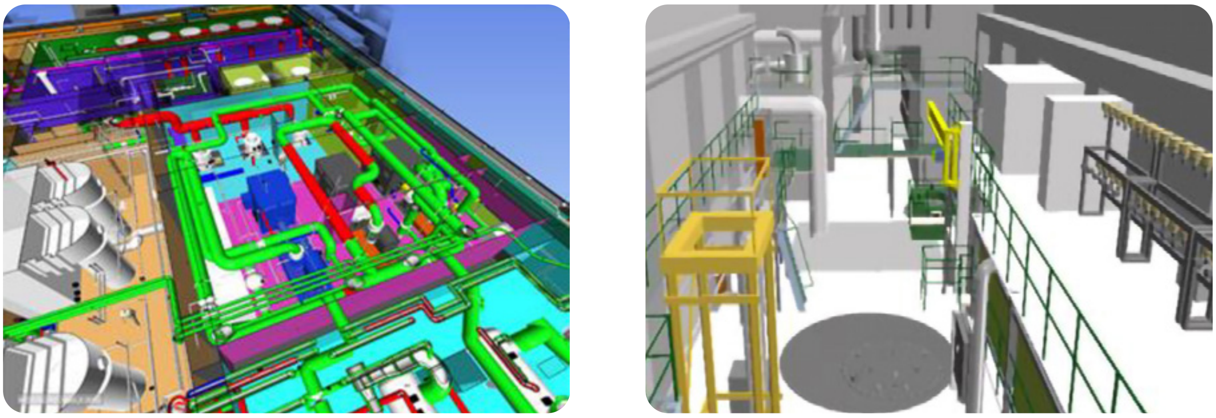


Figure 5-15: *Model based on the Garoña turbine building and Halden research reactor model*

- **Participation in "INNOvative tools FOR dismantling of GRAPHite moderated nuclear reactors", Inno4Graph, September 2020-October 2023 (EURATOM) (Memory card 2.3.28.)**

The EU-funded Inno4graph project has developed a set of tools and methods for the decommissioning operations of graphite reactors, both before the actual decommissioning operations (for decision-making and graphite characterisation) and during decommissioning (for optimal graphite removal). The project's tools and methods have been tested in an industrial demonstrator for the decommissioning of the graphite reactors in Chinon (France), inaugurated in 2022, which will facilitate their adoption and further development. The participation of Europe's leading graphite reactor operators in the consortium will launch an era of excellence in the field of decommissioning of graphite reactors (Figure 5-16).

The five scientific and technical objectives were as follows:

- OB1: Develop a multi-criteria network analysis tool that considers the needs of decommissioners and regulatory requirements, which supports the choice of different decommissioning scenarios.
- OB2: Develop and test digital and physical tools and models to characterise the properties of irradiated graphite and predict its behaviour during decommissioning operations.
- OB3: Develop and test tools for the extraction of graphite bricks during decommissioning (recovery, handling, conditioning...).
- OB4: Develop a set of tools to assess, optimise and qualify the operational decommissioning tools and the final scenario.
- OB5: Generate new 3D models to evaluate different scenarios for the decommissioning of the graphite reactors in terms of cost and safety.

Planned activities

The following projects have been initially identified as being of interest under Line 2.3 of the 9th R&D Plan:

- **Corrosivity Studies of the Interior of the Vandellós I Caisson**

The corrosivity of the atmosphere inside the reactor box will continue to be monitored, in compliance with the Vandellós I NPP Surveillance Plan.

Figure 5-16: *3D model of the Vandellós I reactor caisson and models of the graphite stack in the industrial demonstrator*

- **Participation in the European Commission's Inno4graph 2 European project for the period 2024-2027**

Inno4graph 2 will further develop:

- New tools for the extraction of graphite from the stack.
- Implementation of Artificial Intelligence, machine learning, augmented reality for training and decommissioning processes.
- Conditioning of graphite and its management for storage and disposal.
- Analysis of management pathways, specific acceptance criteria for graphite.

5.1.4.4. Line 2.4. Immobilisation

No R&D projects in this line have been developed under the 8th R&D Plan.

Planned activities

The following projects have been initially identified as being of interest under Line 2.4 within the horizon of the 9th R&D Plan:

- **Participation in EURAD-2 Work Package (WP) 6 "Sustainable Treatment and Immobilisation of Challenging Waste" (STREAM)**

The aim of the project is to study:

- New matrix conditioning processes.
- New materials to replace cement, such as geopolymers or binders activated in alkaline media.

- Low carbon footprint cements.
- Analysis of acceptance criteria.
- Analysis of the economic and environmental cost, carbon footprint.

- Development of new matrices for LILW and VLLW waste conditioning

This will consist of design for conditioning and its validation by testing (verification of compliance with acceptance criteria).

- Participation in EURAD-2 Work Package (WP) 7: "Long-term Performance of Waste Matrices" (L'OPERA)

The aim of the project is to study:

- Long-term performance of the new matrices developed in STREAM.
- Parameters influencing durability.
- Leaching studies of new matrices.

Another identified topic of interest is:

- Study of New Materials for the Immobilisation of Resins

5.1.4.5. Line 2.5. Auxiliary technologies

No activities have been carried out or are planned.

5.1.4.6. Monitoring of other technologies: Lines 2.6 Separation and 2.7 Transmutation

Separation (2.6) and transmutation (2.7) activities are two lines that have been taken into account in Enresa's last four R&D Plans.

Separation activities are prior to and essential for the transmutation of HLW. Enresa has undertaken R&D projects directly associated with transmutation work in order to obtain information on the real scope of new separation technologies, both hydrometallurgical and pyrometallurgical.

As for transmutation, although it is not a SF management option, especially for existing fuels, its industrial feasibility would give rise to the need for SF management with very different characteristics from at present and for which management systems would have to be put in place.

R&D activities in these two fields are aimed at providing research teams to support Enresa in the management of waste that may be generated as a result of these technologies. In Spain, CIEMAT systematically participates actively in separation and transmutation activities, including participation in European research programme projects.

Activities carried out

Projects under Lines 2.6 and 2.7 with activities in the horizon of the 8th R&D Plan 2019-2023 are described below:

- **Study and Assessment of the Sustainability of Hydrometallurgical Separation Processes for Long-lived Radionuclides, October 2016-October 2020 (Memory card 2.6.02)**

The aim of the project was to study and evaluate the feasibility of the implementation of extraction systems known as r-SANEX, i-SANEX and GANEX, based directly or indirectly on a series of specific molecules for separation called DGAs, from the point of view of their resistance to strongly acidic media and radiation (Figure 5-17). The critical factors determining the sustainability of separation processes considered were:

- Occurrence of undesirable behaviour in the system, associated with hydrolytic and radiolytic degradation (poor phase separation, formation of third phase or precipitates, decreased selectivity).
- Extrapolation of volumes.
- Long-term evaluation of the operation.
- Safety of continuous radionuclide extraction processes.

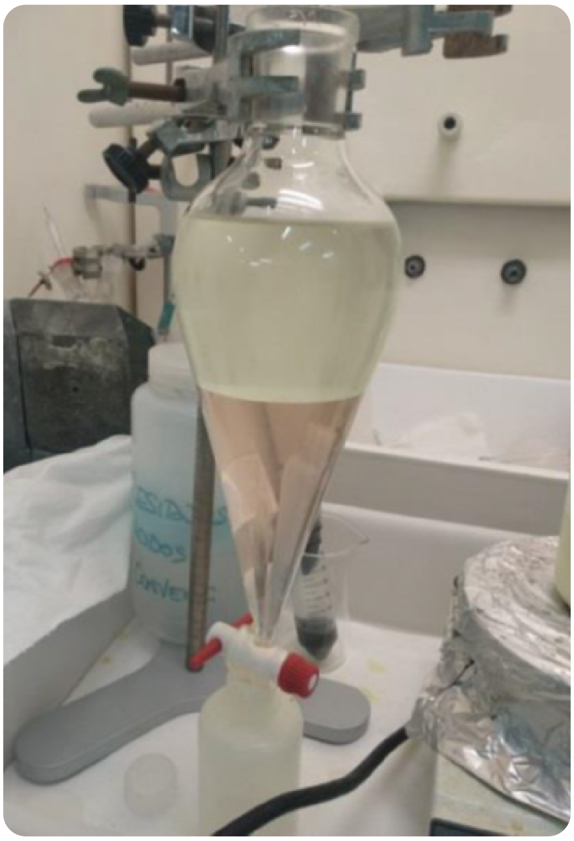


Figure 5-17: *Separation of $UO_2(NO_3)_2 6{*}H_2O$ by decantation. Colour change of the phases as a function of the amount of uranium remaining in them*

- **Advanced Studies for the Development of Separation, Retention and Conversion Processes (ESASERC), May 2023-May 2027 (Memory card 2.6.03)**

In May 2023, a new project called "Advanced Studies for the Development of Separation, Retention and Conversion Processes" (ESASERC) was formalised, which follows the same line of previous projects.

Within the context of international collaboration for the demonstration of different reprocessing scenarios, the most important current challenges are: the joint separation of the actinide group (Pu, Am, Cm, Np), the separation of Am and Cm; the separation/retention of medium/long-lived fission products (FPs) (Cs, Tc, Sr, I, etc.); the long-term prediction of the viability of the designed extraction systems; the study of the gases generated and secondary waste.

The technical demonstration of these processes implies the implementation of increasingly advanced study methodologies that allow an in-depth understanding of the processes that take place and their limitations. In this regard, this project seeks to study in depth the optimisation and validation studies of the most relevant wet separation processes of minority actinides (MA) in the current European framework; new separation strategies for those medium/long-lived FPs that may pose additional problems throughout the cycle; and studies of the compatibility of these separation processes with technologies for conversion into new fuels or transmutation targets.

- **Transmutation of Long-lived Radionuclides to Support the Management of High-level Radioactive Waste, December 2016-December 2019 (Memory card 2.7.03)**

This transmutation project included the following sub-lines of activity:

  - Assessment and optimisation of advanced nuclear fuel cycles that may affect waste management, with particular attention to those involving the separation and transmutation of long-lived radionuclides.
  - Improvement and validation of advanced fuel cycle simulation codes and nuclear systems dedicated to transmutation.
  - Participation in measurement experiments and evaluation of nuclear data for transmutation, both for the transmutation system and for the fuel cycle.
  - Participation in experiments on nuclear systems, to study the feasibility of transmutation systems and how their physics and engineering influence waste management.
  - Participation in International Forums (IAEA, OECD-NEA, EU Framework Programmes, ISTC etc.) where possible separation and transmutation strategies are discussed.
  - Coordination of the collaboration of other national research groups, selected by mutual agreement, for the development of the above objectives.

- **Technologies available for the Transmutation of Long-lived Radionuclides, May 2023-May 2027 (Memory card 2.7.04.)**

In May 2023, a new R&D project entitled "Technologies available for the Transmutation of Long-lived Radionuclides" was formalised with CIEMAT as a continuation of the previous transmutation projects.

The aim of this project is to develop a research project on potentially available technologies for the transmutation of long-lived radionuclides, in order to assess their applicability in support of the advanced management of high-level radioactive waste.

Planned activities

The following projects of interest have been initially identified under Lines 2.6 and 2.7 of the 9th R&D Plan:

- **Continuation of the long-lived radionuclide separation processes. Industrial feasibility (IHLW)**

Separation project, continuation of the current project.

- **Continuation of transmutation studies applied to HLW management (IHLW)**

Transmutation project, continuation of the current project.

5.1.5. Area 3. Containment materials and systems

The group of projects included in this area deals with the properties and behaviour of the constituent elements of the engineered barriers between the radioactive waste and the biosphere. The aim is to increase and improve the knowledge and associated technology considering each element of the engineered barriers, both individually and as a whole (Figure 5-18, Figure 5-19). Monitoring is included in this group.

The following lines of action are considered:

- Line 3.1. Characterisation and behaviour of materials.
- Line 3.2. Behaviour of containment systems.
- Line 3.3. Storage technologies and systems.
- Line 3.4. Monitoring of containment materials and systems.

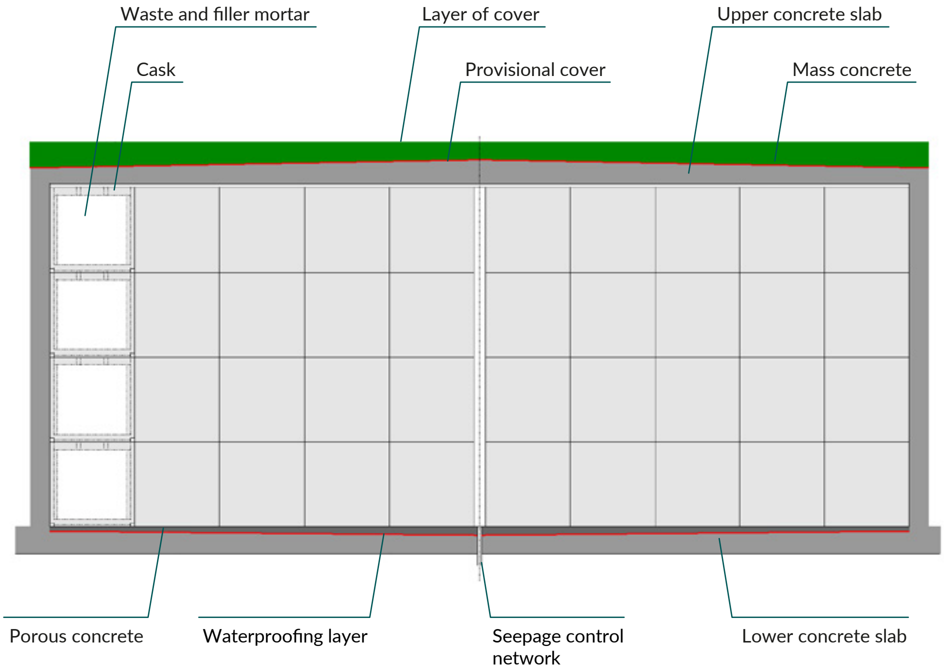


Figure 5-18: *Engineered barriers at El Cabril Disposal Centre*

5.1.5.1. Line 3.1. Characterisation and behaviour of barrier materials

R&D activities in the area of material characterisation and behaviour are very relevant. These have focused on concrete-based materials, metals, clays and constitute a fundamental line of knowledge and technology generation directly applicable to all types of storage.

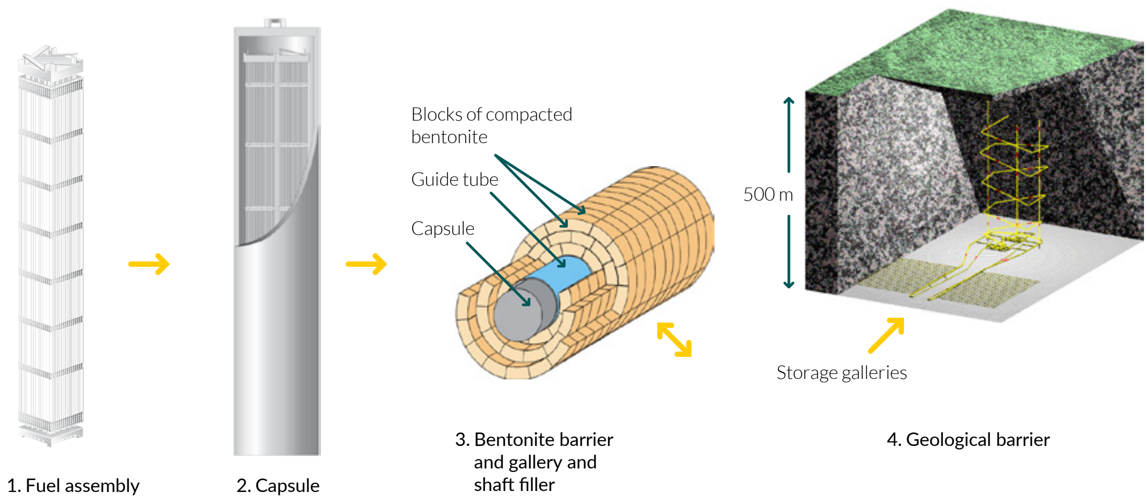


Figure 5-19: *Engineered barriers in a DGR built on a granitic massif*

Activities carried out

The projects aimed at studying natural or processed clays and other natural materials present at Enresa's sites within the scope of the 8th R&D Plan 2019-2023 were as follows:

- Participation in "Clay Club: IGSC Working Group on the Characterisation, the Understanding and the Performance of Argillaceous Rocks as Repository Host Formations", January 2012-ongoing, (NEA) (Memory card 3.1.17.)

Since, on the one hand, a large group of NEA countries consider clay formations for safe disposal of radioactive waste, both above ground (LILW) and below ground (HLW), and, on the other hand, clays are also an important part of engineered barriers, the NEA established a working group on clay media called the "Clay Club" in 1990. These materials have very favourable generic properties: homogeneity, low groundwater flow, chemical buffering capacity, propensity for plastic deformation and self-sealing of fractures, and finally a high capacity to retard the physical and chemical migration of radionuclides. In the working group, all the reference clays from the various participating countries are considered for study, and characterisation and modelling work is carried out. Enresa participates in this group.

- Thermo-hydro-mechanical and Geochemical Characterisation of Materials used in Radioactive Waste Repositories, December 2015-December 2020 (Memory card 3.1.20)

The aim of the project has been to investigate the characterisation and evolution of the thermal, mechanical, hydraulic and geochemical properties of materials used as an engineered barrier or as a geological substrate for facilities related to the disposal of both low- and high-level radioactive waste.

The work programme aimed to enhance the understanding of the processes occurring in the natural and engineered barriers of radioactive waste disposal systems and to characterise the evolution of these materials (bentonite, concrete and argillite). The geological substrate of waste disposal facilities was also studied, determining the parameters required to model their behaviour and response to radionuclide migration.

The work plan consisted of the thermo-hydro-mechanical and geochemical characterisation of the geological substrate of the potential site of the Centralised Temporary Storage (CTS) at Villar de Cañas (Figure 5-20), already discarded; the study of the processes taking place at the concrete/bentonite interface, including work related to the CEBAMA project carried out in the framework of the EU's H2020; the study in laboratory tests of the long-term behaviour of bentonite under storage conditions, in the context of EU-funded projects; and work on argillite used as storage rock (Opalinus, Ypresian) in different European underground laboratories (Figure 5-20).

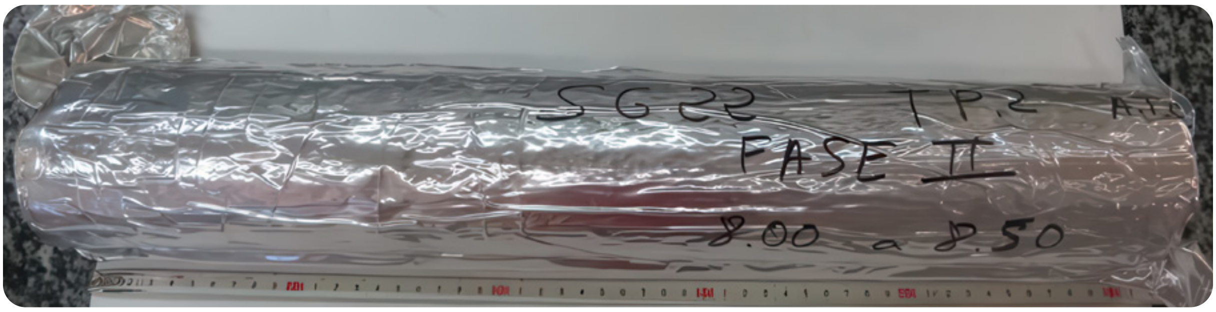


Figure 5-20: *Core samples from boreholes drilled at Villar de Cañas prepared for submission to the laboratory*

- **Characterisation and Durability Study of Engineered Barriers in LILW Storage Facilities, February 2020-February 2025 (Memory card 3.1.21.)**

The aim of the project is to characterise and study the durability of engineered barriers in low- and intermediate-level waste (LILW) storage facilities.

To this end, the aim is to describe the activities to be carried out by the service specialising in corrosion in reinforcement and structural safety for the characterisation and durability study of engineered barriers in radioactive waste storage facilities.

The work plan consists of the development of durability studies of concretes, mortars and their components, study of the corrosion of reinforcements, and improvements and characterisation of concretes and mortars.

- **Experimental Study for the Analysis of the Technological Behaviour of Single Concrete Elements, May 2019-May 2022 (Memory card 3.1.23.)**

In this project, a theoretical-experimental study was proposed in order to achieve the following general aims:

- Development of construction procedures for the most technologically and structurally significant concrete elements.
- Development of systems for inspection and control of the conformity of the execution of concrete construction elements for nuclear facilities.
- Analysis of the structural behaviour, especially at early ages, of concretes for potential use in nuclear facilities in order to minimise the probability of cracking.

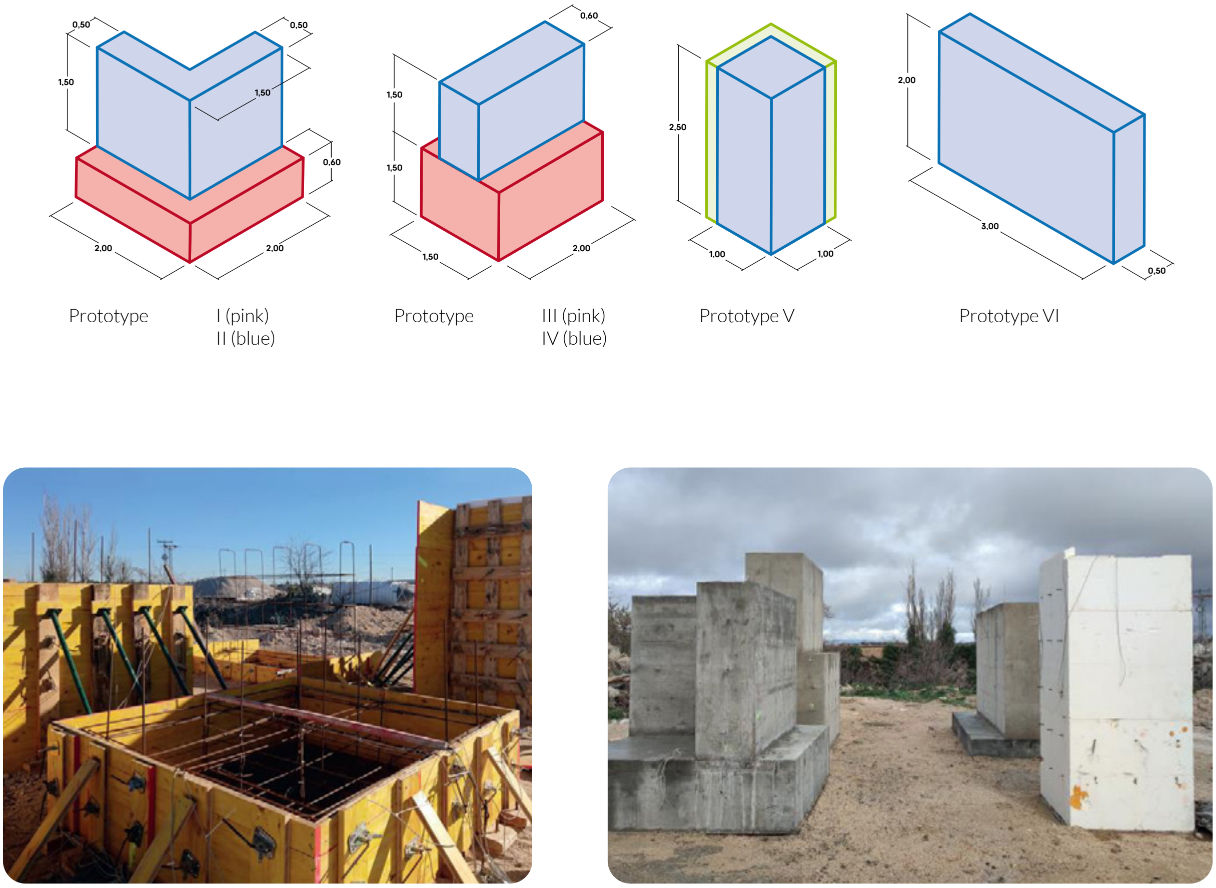


Figure 5-21: *Most characteristic structural elements studied*

In summary, the studies undertaken (Figure 5-21) provided results on:

- Behaviour at an early age.
    - Different concrete dosages were validated.
    - A procedure whereby early cracking control was identified and experimentally and numerically tested.
    - Different construction procedures were studied for the most characteristic elements of the facilities studied.
- Service conditions due to imposed deformations, rheological and temperature and gravitational actions.
    - It became clear that, in design, the study of service conditions cannot be approached with a linear analysis.
    - It was shown that there are important phenomena that cannot be neglected (beam growth, de-rigidisation of structural elements due to cracking, etc.).
    - Non-linear calculations were shown that allow for such phenomena to be considered.

- **Design Study of Self-levelling and Self-compacting Concretes for El Cabril Disposal Centre, November 2020-October 2023 (Memory card 3.1.24)**

The aim of this project was to study the design of self-levelling and self-compacting concretes, manufactured with limestone aggregates and specific mineral additions, for application at El Cabril Disposal Centre.

The scope of the work to be carried out includes the following study phases: Study of the characterisation and mechanical behaviour of limestone aggregates for their application in self-compacting and self-levelling concretes (SCC and SLC); Study of the suitability of different thermal fly ashes and silica fume powder for the manufacture of SCC and SLC; and Study of dosages and properties of self-compacting concretes (SCC) and self-levelling concretes (SLC), manufactured with CEM I and additions of fly ash and silica fume, in which the limestone aggregates selected from those previously studied will be used.

- **Thermo-hydro-mechanical and Geochemical Characterisation of Containment Materials used in Radioactive Waste Repositories (CAMBAR II), July 2022-July 2026 (Memory card 3.1.26.)**

The aim of this research project is to study the characterisation and evolution of the thermal, mechanical, hydraulic and geochemical properties of materials used as engineered barriers in facilities related to the geological disposal of HLW.

In particular, the aim is to assess how its functioning will be affected in the long term, analysing in a coupled way the processes that take place in the barrier (thermal, mechanical, hydraulic and geochemical), considering the interactions between the different materials that constitute a DGR.

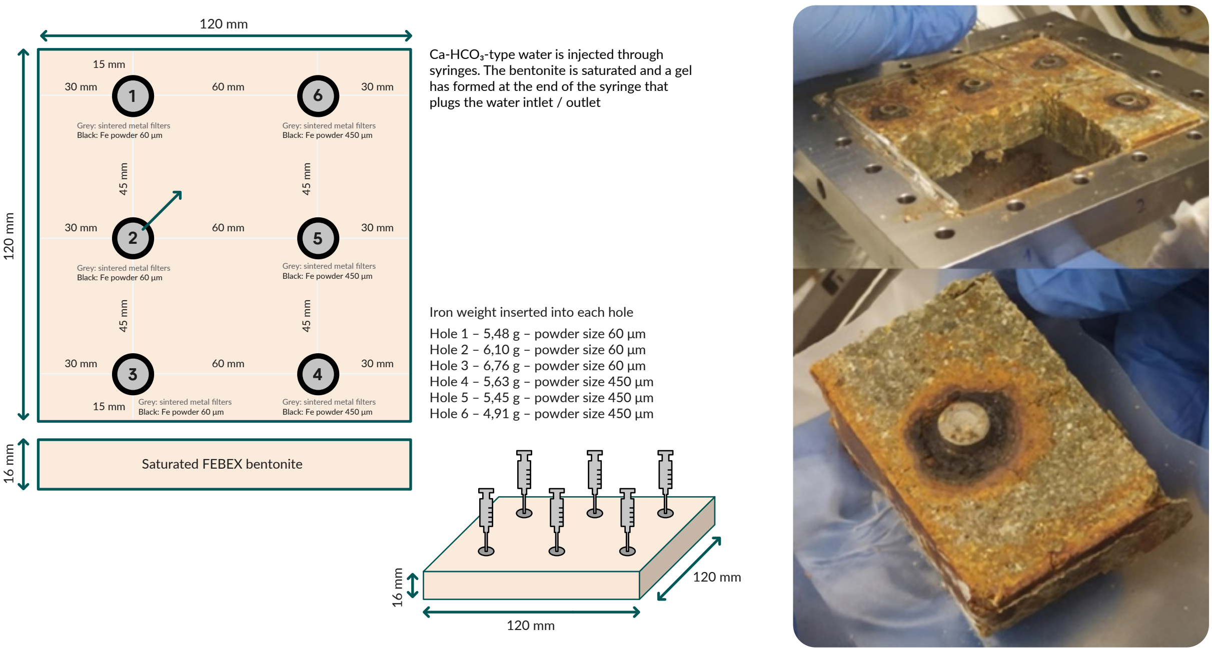


Figure 5-22: *Schematic of the configuration and dimensions of the FeMo vault (left) and photos of the dismantled vault (right)*

The work programme aims to enhance the understanding of the processes taking place in engineered radioactive waste storage barriers and to characterise the evolution of these materials.

Participation will continue in the HE-E (heating to 140°C) and SW-A (sealing of a well) tests at the Mont Terri Underground Laboratory (Switzerland) and in the HotBENT test at the Grimsel Underground Laboratory (Switzerland). In addition, the EURAD-2 project will participate in ANCHORS, dedicated to the study of the aforementioned processes in bentonite.

- **Characterisation of Barrier Materials (CARMA), October 2023-October 2027 (Memory card 3.1.27.)**

The aim of this project is the characterisation of barrier materials used in storage systems for low- and intermediate-level and very low-level waste. These barrier materials refer both to mortars and concretes and their components, as well as to clays (Figure 5-23).

Given their importance as constituent elements of the barriers between the radioactive waste and the biosphere, and therefore human beings, it is necessary to enhance our knowledge of the mineralogical and physicochemical characterisation and of the transport and retention properties, which are decisive for ensuring the confinement of radionuclides or contaminants under the conditions and for the period established for the achievement of the safety objectives of a radioactive waste storage/disposal facility.

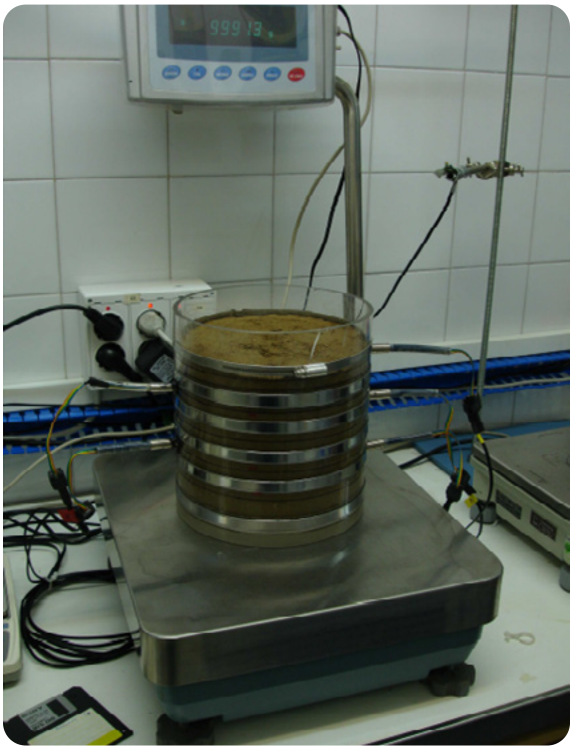


Figure 5-23: *Preparation of the material for the ground test and final appearance of the assembly*

Planned activities

The following Line 3.1 projects of interest have been initially identified within the horizon of the 9th R&D Plan:

- **Estimate of Temperature in Concrete from Environmental Data**

Development of activities to estimate the maximum temperature reached in concrete due to solar radiation at two sites, one with an oceanic climate, typical of northern Spain and, specifically, of Santa María de Garoña NPP in Burgos; and the other with a Mediterranean climate, typical of eastern Spain and characteristic of Vandellós I NPP in Tarragona.

- **Long-term Durability Study and Behaviour of Concrete subjected to High Temperatures**

Analysis of the behaviour of concrete subjected to high temperatures, for the study of its long-term behaviour.

- **Study of the Performance of New Materials for DGR Capsules and Barriers**

In recent years, waste management agencies have incorporated the study of coating materials in DGR capsules to improve their performance under repository conditions. This interest has been translated into specific work packages in the EURATOM-EURAD and EURAD-2 projects (ConCorD, InCoManD, respectively). A materials project is proposed to analyse improvements in the behaviour of Enresa's DGR capsule, fundamentally taking into account the repository environment, both the host rock and its interaction with bentonite. Specifically, a project is proposed to increase the level of knowledge of copper and the techniques for its application as a coating for the disposal capsules (DGR), which will consider aspects relating to the selection of the most suitable copper alloys, their coating applicability methods and their performance under the service conditions envisaged.

- **Characterisation and Durability Study of Engineered Barriers in Radioactive Waste Storage Facilities**

Characterisation and durability of LILW/VLLW engineered barrier materials.

- **Investigation of Indicators of Potential Reactivity of Aggregates to Alkalis**

The aim is to investigate indicators of the potential reactivity of aggregates to alkalis for application at El Cabril Disposal Centre. The scope includes the collection of aggregates and materials, laboratory tests, specific tests using instrumental analysis techniques and the creation of a model and an analysis protocol to be used by Enresa as a tool for predicting the behaviour of the aggregates.

- **Definition of Formulation of Cabril-type Concretes that are Self-levelling and Self-compacting**

A continuation of the design study of self-levelling and self-compacting concretes, for application at El Cabril Disposal Centre.

- **Durability of Concrete subjected to Irradiation and High Temperatures. Development of New Mortars and Concretes for Engineered Barriers. Development of Very High Strength Concretes**

The scope of the work to be carried out includes the following study phases which are explained below:

1. Study of the characterisation and mechanical behaviour of limestone aggregates for their application in self-compacting and self-levelling concretes (SCC and SLC).
2. Study of the suitability of different fly ashes from thermal power plants and silica fume dust for the manufacture of SCC and SLC.
3. Study of dosages and properties of self-compacting concretes (SCC) and self-levelling concretes (SLC), manufactured with CEM I and additions of fly ash and silica fume, in which the limestone aggregates selected from those previously studied will be used.

- **Characterisation Tests on Irradiated Concrete**

Durability of concrete subjected to irradiation and high temperatures.

- **Materials Testing: Soils, Clays and Water of Cover Layers**

Laboratory tests shall be carried out for the chemical, physical, mechanical, hydraulic and thermal characterisation of the materials that make up the cover layers, such as soil, sand, coarse aggregates, clay, water in contact with these materials, etc.

Among the parameters of interest are the granulometry, thermal conductivity and heat capacity, as well as the suction and permeability curves of these materials. The data obtained will be used to feed the numerical models of the hydraulic behaviour of the cover, as well as to see the physico-chemical conditions of the materials and to be able to predict their stability over time and in contact with water or other materials.

- **Characterisation of Vegetation Cover in Layers**

The aim is to characterise the vegetation cover in layers and in the future in the provisional cover in order to see the type of vegetation that has proliferated on it and to be able to make a better adjustment of the water balance of the cover (evapotranspiration, runoff rate and infiltration).

- **Participation in the OECD-NEA "Clay Club" 2024-2028 Working Group**

Participation in this group, of which Enresa has been a member since its creation in 1990, will continue.

- **Thermo-hydro-mechanical and Geochemical Characterisation of Materials used in Radioactive Waste Disposal (CAMBAR 2)**

As mentioned above (Memory card 3.1.26), participation will continue in the HE-E (heating to 140°C) and SW-A (sealing of a well) tests at the Mont Terri Underground Laboratory (Switzerland) and in the HotBENT test at the Grimsel Underground Laboratory (Switzerland). In addition, the EURAD-2 project will participate in ANCHORS, engaged in the study of THMC processes in bentonite, which is described below.

- **Participation in EURAD-2 Work Package (WP) 12: "hydrAulic mechaNical CHemical evolution of bentOnite for barrieRs optimiSation" (ANCHORS)**

The aim of this WP is to increase the optimisation potential of bentonite barrier systems: buffer, filler and seals, and the resilience of the Safety Case:

- by qualification of the hydromechanical (HM) behaviour of various bentonite types, grades and blends through a laboratory experimental programme focused on the evaluation of heterogeneity, chemical effects and friction at different scales, and
- by improving the numerical tools necessary to carry out the evaluation of THMC behaviour of bentonite barriers in a repository environment.

5.1.5.2. Line 3.2. Behaviour of containment systems

This line includes R&D activities related to the design and verification of engineered barriers as they consist of a combination of different materials/individual barriers. Geochemical barriers applicable in storage systems or contaminated area remediation systems are also the subject of this R&D line.

The projects in which Enresa has been involved have been related to international collaboration projects involving underground laboratories (generally Mont Terri and Grimsel, both in Switzerland) and to H2020 and Horizon Europe Framework Programme and IAEA projects.

At a national level, work has been carried out on the development of artificial materials for the construction of geochemical barriers for the retention of certain radionuclides.

Activities carried out

Projects under Line 3.2 with activities within the horizon of the 8th R&D Plan 2019-2023 are described below:

- **Enresa's Participation in the Mont Terri Project, 2016-ongoing (Memory card 3.2.09.)**

The Mont Terri Project, promoted in the context of an OECD-NEA working group, is a forum for the coordinated promotion, discussion, planning and implementation of international R&D activities and projects related to the use of geological clay formations for the management of HLW, in accordance with the needs and interests of the consortium members (Figure 5-24).

The consortium consists of 21 partners from nine countries under the direction and management of Swisstopo (Swiss Federal Office of Surveying), which negotiates with the local authorities for the relevant permits, carries out the recruitment of the various international research groups and invoices the consortium partners for the participation costs.

Through its participation in the consortium, Enresa has developed experience and technology in the characterisation of clay media, which initially supported the development of the generic design and safety assessment of the HLW clay repository, and subsequently applied part of the methods and technologies developed at El Cabril Disposal Centre.

Participation in this consortium is therefore of great strategic importance for Enresa, as it will not only be applied to its current projects, but will also be of great use in the future for the characterisation of the DGR.

Enresa has access to all technical reports and data generated in the Mont Terri Project to date, and attends an Annual Technical Meeting where the most important results are presented.

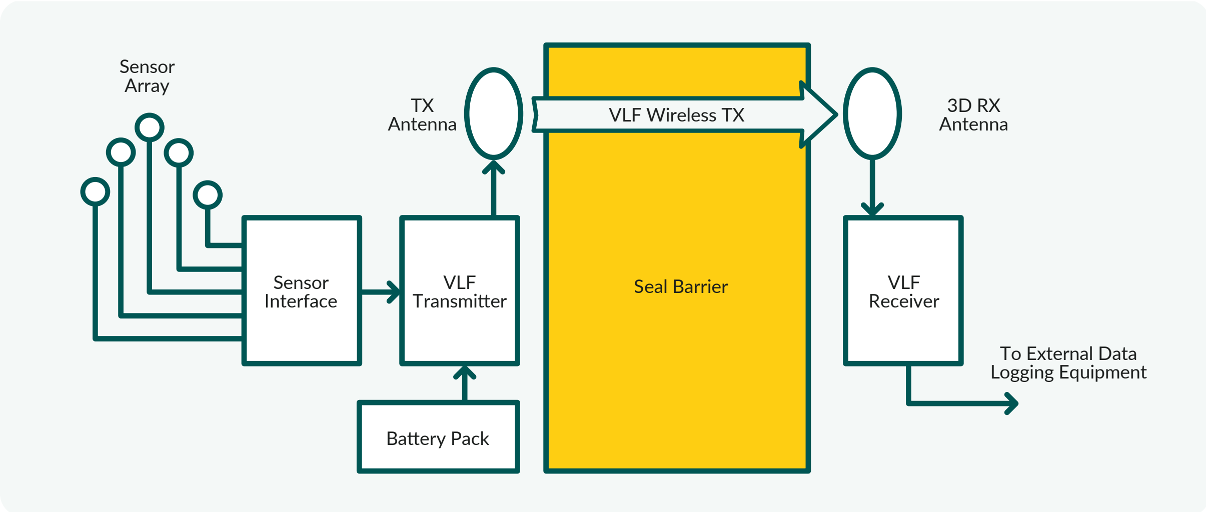


Figure 5-24: *Schematic of the "Wireless transmission" (WT) project, under the framework of the Mont Terri Project*

- Participation in the "Bentonite Mechanical Evolution" Project, BEACON (EURATOM H2020, June 2017-May 2021 (Euratom) (Memory card 3.2.11.)

The assessment of the long-term safety of a geological repository must be based on a robust model that takes into account the spatial and temporal distribution of safety-relevant bentonite properties. Accordingly, the development of predictive capabilities of the mechanical behaviour of bentonite barriers, plugs and gallery backfill material is a common need for all radioactive waste management programmes that use bentonite in one or several components of the engineered barrier system.

The project sought to develop an understanding of the fundamental processes leading to the homogenisation of the material and to improve numerical modelling capabilities. In previous assessments of the long-term behaviour of the bentonite of an engineered barrier, the mechanical evolution of the installed bentonite was neglected and an "ideal" end state was optimistically assumed. Now that several European national programmes are moving towards the licensing, construction and operation of repositories, this assumption is no longer sufficient (Figure 5-25).

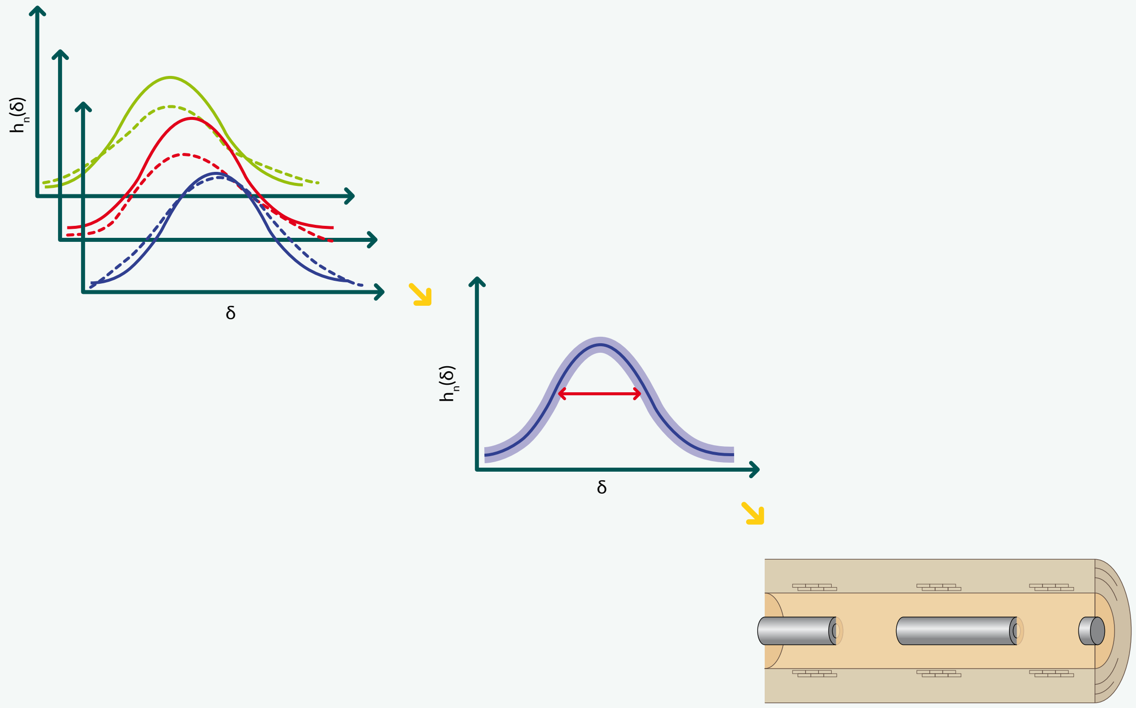


Figure 5-25: *BEACON Project concept, creation of a "variability term" of properties to be used in modelling (Nagra)*

A database of bentonite experiments was developed that compiled the available experimental information. It was designed and completed as a collaborative effort, composed of experiments at various scales (from laboratory experiments to large-scale field experiments), some of which were specifically designed for bentonite homogenisation studies.

A number of constitutive models were developed to address areas of deficiency in modelling the mechanical evolution of bentonite. The models cover a wide range of approaches and can address a broad combination of simulation conditions that allow key features of the behaviour underlying the homogenisation processes to be reproduced.

A series of laboratory experiments were carried out to provide input data and parameters for model development and validation and to reduce uncertainties about the conditions and phenomena influencing bentonite homogenisation. The homogenisation of an initially inhomogeneous bentonite system and the persistence or development of inhomogeneities in a bentonite system under various mechanical and hydraulic conditions were investigated.

In addition to laboratory work, natural analogues were studied to draw conclusions about the long-term evolution of bentonite systems. The findings showed that unsaturated and inhomogeneous bentonite systems tend to evolve into more homogeneous systems. Hydration rate was identified as a key parameter affecting homogenisation.

The models developed were tested and verified against different evaluation cases at different scales. Three large experiments were selected in the underground laboratory to be studied based on the criteria of being relevant to the disposal concepts of the project partners, highlighting the role of heterogeneities in bentonite disposal concepts, which were well described and detailed. The experiments selected were:

- EB: Enresa's bentonite Engineered Barrier emplacement experiment, carried out on clay rock in Mont Terri (Switzerland).
- FEBEX: Enresa's large-scale engineered barrier experiment in crystalline rock in Grimsel (Switzerland).
- CRT: SKB's cask recovery test, conducted on crystalline rock in Äspö (Sweden).

Large-scale tests demonstrated the progress made during the project with the developed tools able to approach the final state of the experiments despite adopting a diverse set of approaches. Aspects of the modelling were identified for further work.

- **Participation in "Ageing Management Programmes for Spent Fuel Dry Storage Systems", October 2017-October 2021 (IAEA) (Memory card 3.2.13.)**

The aim of this CRP was to develop a technical and methodological basis to guide Member States on how to generate a life management programme for dry storage facilities. This work was translated into a technical document (TecDoc).

The project was organised to develop the following main themes:

- Methodologies for developing a life management plan;
- Lessons learned in dry storage of SF/AMP development;
- Techniques for the monitoring and inspection of dry storage systems;
- Methodologies for the identification of structures, systems and components;
- Methodologies to assess the impact of deviations from normal operating conditions on structures, systems and components;
- Mitigation/remediation techniques.

Using existing Life Management Plans as a reference, guidance was established on how to develop, generate and maintain ageing management programmes for temporary dry storage of SF in the most efficient manner.

Different technologies available for the temporary dry storage of SF have been studied. A distinction was made between casks and storage structures and the materials they are made of (metals and/or concrete) were also considered.

- **Participation in the "High Temperature Effects on Bentonite Buffers" Project (HotBENT) March 2019-March 2024 (NAGRA) (Memory card 3.2.14.)**

*(Information taken from the Grimsel Test Site website, **https://www.grimsel.com/gts-phase-vi/hotbent-hightemperature-effects-on-bentonite-buffers/hotbent-introduction**)*

HotBENT provides information and data for repository optimisation with respect to design, space, siting strategies and costs. The experiment seeks to evaluate currently-accepted safety functions by investigating the effects of high temperatures (above 100°C) on bentonite-based barriers (blocks and pellets) and their safety functions.

The behaviour of bentonite barriers in the temperature range <100°C is supported by an extensive knowledge base built up in laboratory and large-scale in situ experiments. Characterisation of bentonite parameters above 100°C is scarcer (especially for granular materials), although up to about 150°C, no significant changes in safety-relevant properties are indicated. Such information is desirable for repository optimisation with respect to design, space and costs and to allow more options with regard to the required intermediate storage time periods. HotBENT corresponds to the initial period of highest thermal output of geological storage; the data may be used to evaluate strategies for the behavioural confirmation period (Figure 5-26).

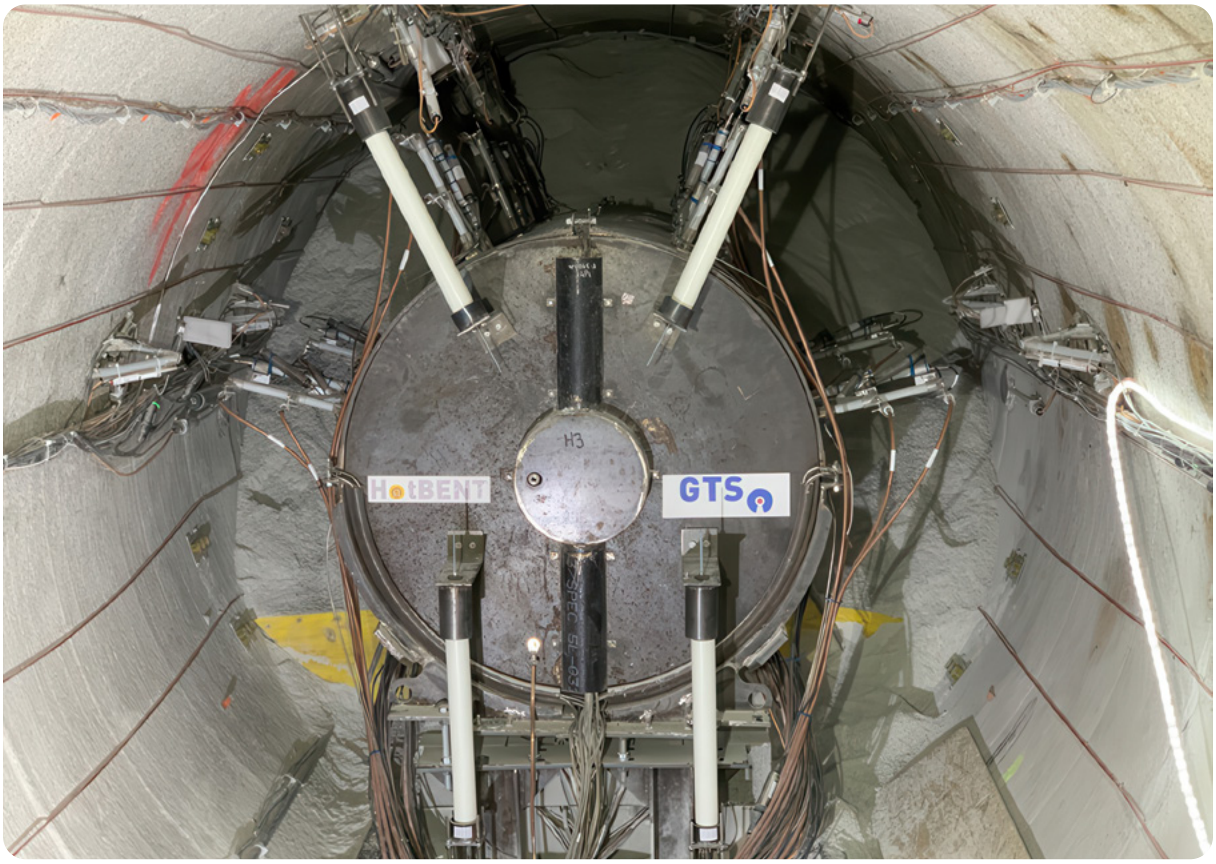


Figure 5-26: *Construction of the HotBENT test in the FEBEX gallery (Grimsel, Switzerland)*

- **Participation in the H2020 EURAD WP7 Project "Influence of Temperature on Clay-based Material Behaviour (HITEC)", June 2019-May 2024 (EURATOM) (Memory card 3.2.15.)**

WP7 sought to improve the degree of THM understanding of clay materials (host rock and engineered barriers) of a DGR exposed to high temperatures (> 100°C) for extended periods of time. The aim was to assess whether high temperature limits (100-150°C) are feasible and safe in various DGR concepts for heat-generating radioactive waste.

The study focused on clay formations (<120°C) and established the possible extent of damage, and its consequences, caused by high temperatures in the near and far field (e.g. by overpressure of interstitial water). In bentonite, the influence of temperature on swelling pressure, hydraulic conductivity, sorption and transport properties (i.e. whether the safety functions of the clay barrier were inhibited) was determined.

For most safety cases (considering DGR in clay) a temperature limit of 100°C is currently considered. Tolerance of higher temperatures, while ensuring an adequate safety standard, would have significant advantages (e.g. more efficient casks, fewer casks, fewer transport operations, DGR on smaller surfaces, etc.).

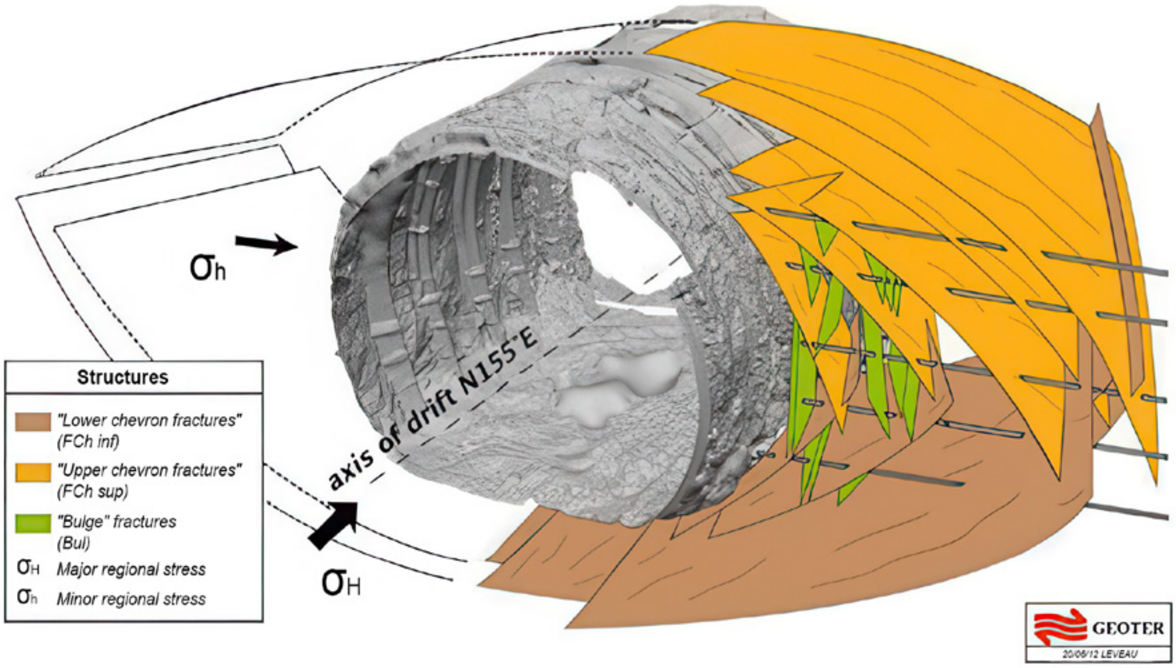


Figure 5-27: *Conceptual model of the excavation-induced fracture network in Callovo-Oxfordian clay (Meuse/Haute-Marne URL) (Andra)*

- Participation in "Performance Assessment of Storage Systems for Extended Durations" (PASSED), April 2022-September 2026 (Memory card 3.2.16.)

The overall aim of this CRP is to maintain and improve the technical knowledge base of IAEA Member States on the long-term performance of SF storage systems, inspection capabilities and monitoring technologies, through the exchange and dissemination of technical information, reporting on current research conducted by participating Member States and documentation of ongoing storage system performance and operations. To this end, the aim is to:

- Document experiences in the performance of the SF storage system (wet and dry storage).
- Collect and exchange relevant operational experience on SF storage system inspections.

- Collect experience from ongoing programmes and any new or novel techniques for monitoring storage systems.
- Exploit areas of synergy between participating Member States' research projects to achieve agreed approaches to research and evaluation of results.
- Facilitate knowledge transfer by documenting the technical basis for SF storage system performance assessment, focusing on critical components and materials.
- Enable predictions of the performance of SF storage systems over long periods of time and adequate inspection intervals.

Planned activities

The following projects have been initially identified as being of interest under Line 3.2 of the 9th R&D Plan:

- **Study of Condensate Generation Produced in the Recirculation of the Cooling System and in the Hydraulic Seals of a Discharge Vault, under the Effects of the HVAC System**

The aim of this project is to study the risk of water condensation inside an unloading vault. The HVAC system, the cooling system and the hydraulic confinement system in the cask coupling, among others, will be studied in order to estimate a volume of water inside the vault and to determine the consequences from a safety point of view.

- **Study of Radionuclide Retention Factors in Rooms with Significant Environmental Contamination of a Temporary Storage Facility**

Development of a methodology for the calculation of gaseous effluent releases to the exterior that allows radionuclide retention factors (LPF) to be deduced in those rooms of a temporary storage facility with significant environmental contamination under conditions of total loss of dynamic containment systems. It is of particular importance for all processes carried out in a SF discharge vault or in the hot cells of any research laboratory with irradiated fuel and other high-level waste.

- **Participation in R&D Projects in the Underground Laboratory in Grimsel (Switzerland), in Granite Rock**

It is planned to continue participation in the HotBENT project until the end of 2027, when the two outdoor heaters are scheduled to be decommissioned. At that time, the possibility of participating in the next phase, which is estimated to last 10 years until the decommissioning of the two indoor heaters, will be evaluated. In addition, it is planned to participate in the LSP project, related to the demonstration of the feasibility and effectiveness of a low pH shotcrete plug (Figure 5-28).

Figure 5-28: *Gallery of the Grimsel underground laboratory (Nagra)*

- **Participation in R&D Projects in the Mont Terri Underground Laboratory (Switzerland), in Clay Rock**

Participation in the HE-E (heating to 140°C) and SW-A (demonstration of a borehole sealing methodology) tests will continue in collaboration with other European and international partners. In addition, the WT project will culminate in the development of a wireless system for the transmission of geotechnical data in solid media using low-frequency digital magnetic induction technology called TTE (Through-the-Earth). A prototype of this system was developed in the Modern Project (Memory card 3.4.20.).

Leaching Study of Resins Conditioned in a Cement Matrix

The aim is to use the information from the leaching tests already available at Enresa, supplemented with information available in the literature, to generate behavioural models that allow the optimisation and improvement in the efficiency of resin conditioning by incorporation into the cement matrix and to complete the information available with additional experimental tests.

The following topics of interest have also been identified:

- Diffusion and adsorption tests on concrete and clays
- Application of IBA techniques to diffusion and adsorption
- Reactive transport in concrete (tests)

5.1.5.3. Line 3.3. Storage technologies and systems

This section includes R&D projects aimed at the design and verification of the performance of storage facilities.

Activities carried out

Projects under Line 3.3 with activities within the horizon of the 8th R&D Plan 2019-2023 are described below:

- Study of Capsules to be Managed at the CTS Facility and Associated Works, June 2018-January 2021 (Memory card 3.3.05.)

In the CTS, the temporary storage option for SF, discarded in the 7th GRWP, it was envisaged that the SF capsules would contain the fuel assemblies during the dry storage period in the vaults. These capsules would be designed in such a way that they would constitute the double confinement barrier during the entire storage period. The detailed design and the necessary regulatory documentation for these were carried out in this project. In addition, a feasibility study was also carried out for transportable capsules to be loaded at source (nuclear power plant fuel storage pools) in the corresponding transport casks. This would meet the SF acceptance criteria that were being developed. These capsules would allow the safe management of fuel classified as damaged and its storage under optimal conditions. In addition, the project also included the development of a technological feasibility study of an "additional Argon-assisted handling and venting system", which would be developed to ensure the maintenance of safety functions in situations of unloading of leaking fuel assemblies. This system would ensure the safe condition of no oxidation of the fuel assemblies until the welding, vacuum and helium inerting operations of the storage capsule have been completed. Finally, the safety criticality risk analysis of the dry wells for the transient storage of SF in the offloading vaults was included.

- Participation in "Schedule Project" (Steel Concrete High Efficiency Demonstration-eUropean coLLaborative Experience), October 2018-March 2023 (The Steel Consortium Institute) (Memory card 3.3.06.)

This pilot project aimed to quantify the efficiency of mixed steel and concrete modules by constructing a replica of a reinforced concrete building, which is a standard typology. The project addressed the challenges of the manufacturing, assembly, joining, transport, placement, concreting and subsequent dismantling of the modules.

The project was organised in several work packages dealing with performance, material and welding specifications, detailed design, module manufacturing, instrumentation, transport, site erection, concreting and partial dismantling. Also included was a work package dedicated to overall engineering coordination, including the development and maintenance of a Building Information Model (BIM).

The SCHEDULE Project has led to a better understanding of the construction technique of composite concrete and steel modules by demonstrating its efficiency and organisational advantages on a project scale. The project also allowed the main technical problems to be solved and appropriate construction methods to be developed.

Figure 5-29: *Transport of modules*

- **Final Cover of El Cabril Disposal Centre Storage, June 2021-June 2025 (Memory card 3.3.07.)**

There is a pilot test of casks at El Cabril Disposal Centre and several instrumented vaults for the acquisition of knowledge of construction aspects, the performance of materials and their characteristic parameters of the variables determining the design of a cask, with a view to compliance with the Operating Permit for El Cabril Disposal Centre as regards Conditions 6.5 and 7.7 on the closure of disposal vaults and on the studies, results, analyses and activities performed by Enresa in relation to aspects contributing to guaranteeing the long-term safety of the facility.

The aim of the project is to continue the ongoing work of the monitoring of storage structures and the pilot testing of the cover by studying the materials through laboratory-scale tests and the development of predictive models to simulate the behaviour of the cover, all of this to verify design parameters and guarantee the functionality and durability of the cover in the long term (300 years).

In addition, in order to verify the effect of the cover on the thermal-hydraulic performance of the LILW disposal vaults and, specifically, on the collection of water produced as a result of the condensation/evaporation processes that take place inside them, a project has been launched for the implementation of a provisional cover in one of the currently closed vaults of the North Platform, which will be executed once it has been favourably assessed by the Nuclear Safety Council (CSN). This cover will be constructed and instrumented and will be the object of study and monitoring, with periodic reporting to the CSN.

Planned activities

The following projects have been initially identified as being of interest under Line 3.3 of the 9th R&D Plan:

- **Development of Technologies for Shielding CCTV Cameras Subjected to a High Radiation Environment**

At present, vision in high radiation environments is based on specific high radiation tolerance cameras, which are very slow to incorporate the technological improvements of the standard CCTV camera market, with a high cost and a half-life of around two years, at which point they become waste to be managed.

In contrast, a wide and inexpensive range of camera vision options (optics, magnification, low-light, etc.) is available on the standard market and, given the rapid evolution of these technologies, these capabilities will improve greatly in the short, medium and long term.

The strategy for the vision system in a temporary SF storage facility is based on incorporating the wall penetrations necessary to ensure vision over 100 years in the design and construction, using permanent shielding systems and standard market chambers, allowing the incorporation of the capacities and technologies at any given moment, ensuring the useful life of the devices, and eliminating the radioactive waste to be managed.

In line with the above, the aim of this project is to work on the development of shields specifically designed to withstand high radiation fields, which allow the clean replacement of cameras and optics and do not obstruct or distort image quality, while maintaining a significantly lower cost than currently existing high radiation tolerance cameras.

- **Repair and Mitigation Techniques in Welded Capsules**

This involves defining the sequence of operations for the repair or mitigation of welded capsules in use at José Cabrera and Ascó NPPs and in the standardised system that have suffered damage during their storage, with a view to guaranteeing the recoverability of the normal operating conditions of the storage configuration.

- **Analysis of Technologies and Technological Developments in Welded Capsule Cask Inspection Equipment**

Study of the technological possibilities for the inspection of the various components of casks based on welded capsule systems in which high radiation conditions will be encountered.

- **Dry Inspection Equipment for the Identification of Leaking Fuel Assemblies**

Study of technological solutions applicable to dry SF storage facilities for the inspection of SF and detection of damaged leaking elements.

- **Compatibility Study of the Temporary Storage Capsule with Future Management in the DGR**

The aim is to develop compatibility studies and analysis of technological options that could allow the management of a storage capsule for use in the DGR without having to reopen it.

- **Development of Systems for the Coupling and Transfer of Bars in a Vertical Position, Applied to a Dry Discharge Vault**

Study of technological solutions to enable the transfer of SF rods into a hermetically sealed bundle or cask vertically coupled to an unloading vault.

- Final Cover for El Cabril Disposal Centre

Continuation of ongoing work on the monitoring of storage structures and pilot testing of the cover, study of materials through laboratory-scale testing and development of predictive models for simulating the behaviour of covers, all to verify the design parameters and ensure the functionality and durability of the cover in the long term (300 years).

The study and monitoring of water collection data will also continue. The water collection that occurs as a result of the condensation/evaporation processes that take place inside the LILW storage vaults.

- Construction of a Partial Cover for LILW Vaults at the North Platform

This consists of the construction of a cover on Vault 5 of the North Platform, with the aim of validating the final cover to be implemented on this platform. This cover will be instrumented with different types of sensors to evaluate its thermal, hydraulic and mechanical behaviour.

- Materials Study (Erosion/Infiltration/Evapotranspiration Laboratory Tests) and Sensor Data Management

The aim is to carry out laboratory scale tests to improve the knowledge of the behaviour of the provisional cover materials on a LILW vault at El Cabril Disposal Centre.

The experiments, which will partially reproduce the profile of such a cover, are divided into three types to allow the behaviour of different layers or combinations of layers to be analysed separately. The general aim is to improve the design of the temporary cover, by enhancing its effectiveness, through knowledge of the thermal-hydraulic behaviour of its layers. Specifically, the aim is to i) optimise the required behaviour, both individually and in combination with other materials, and ii) determine characteristic parameters that define the thermo-hydro-mechanical behaviour of the materials that make up the layers of the covers. To achieve this, a) infiltration, erosion and evapotranspiration rates will be measured for the calculation of mass balances, b) the evolution of different variables (water content, suction, temperature) will be recorded, and c) the behaviour obtained will be compared with materials of different hydraulic properties and/or different layer thicknesses.

- Concrete and Clay Tests with Sensors

This aims to design concrete and clay scale models that can be used for the development, testing and validation of sensors that can be used in the monitoring of confinement barriers.

5.1.5.4. Line 3.4. Monitoring of containment materials and systems

These R&D activities are related to Enresa's facilities, whether storage or temporary during decommissioning. The activities also focus on the elements of the engineered barriers used at each facility. The facilities monitored are El Cabril Disposal Centre, the sites corresponding to the nuclear power plants being decommissioned and even conceptual studies for a DGR.

Instrumented barriers are the cells on the El Cabril Disposal Centre platforms, a model of a CE-2a cask used in the LILW vaults, models of the vaults' cover layers, and a SF cask arranged in an ITS.

Activities carried out

Projects under Line 3.4 with activities within the horizon of the 8th R&D Plan 2019-2023 are described below:

- **Groundwater and Soil Characterisation of the Area of the Former SROA Construction Site at Vandellós I, 2010-March 2023 (Memory card 3.4.05b.)**

In the installations at Vandellós I NPP, decommissioned at level 2, there is an area affected by contamination, detected in 1992, located to the south of the site bordering the Mediterranean Sea.

The monitoring of the contamination of these soils, consisting of the radiological characterisation of these soils and their groundwater, has been carried out in two stages. The first stage was carried out by HIFRENSA in the period 1992-1997. The second stage has been carried out by Enresa since 1998, in accordance with the Surveillance Plan in force for the facility.

The purpose of this study is the radiological characterisation of the former SROA construction site of Vandellós I, and of its groundwater (Figure 5-30).

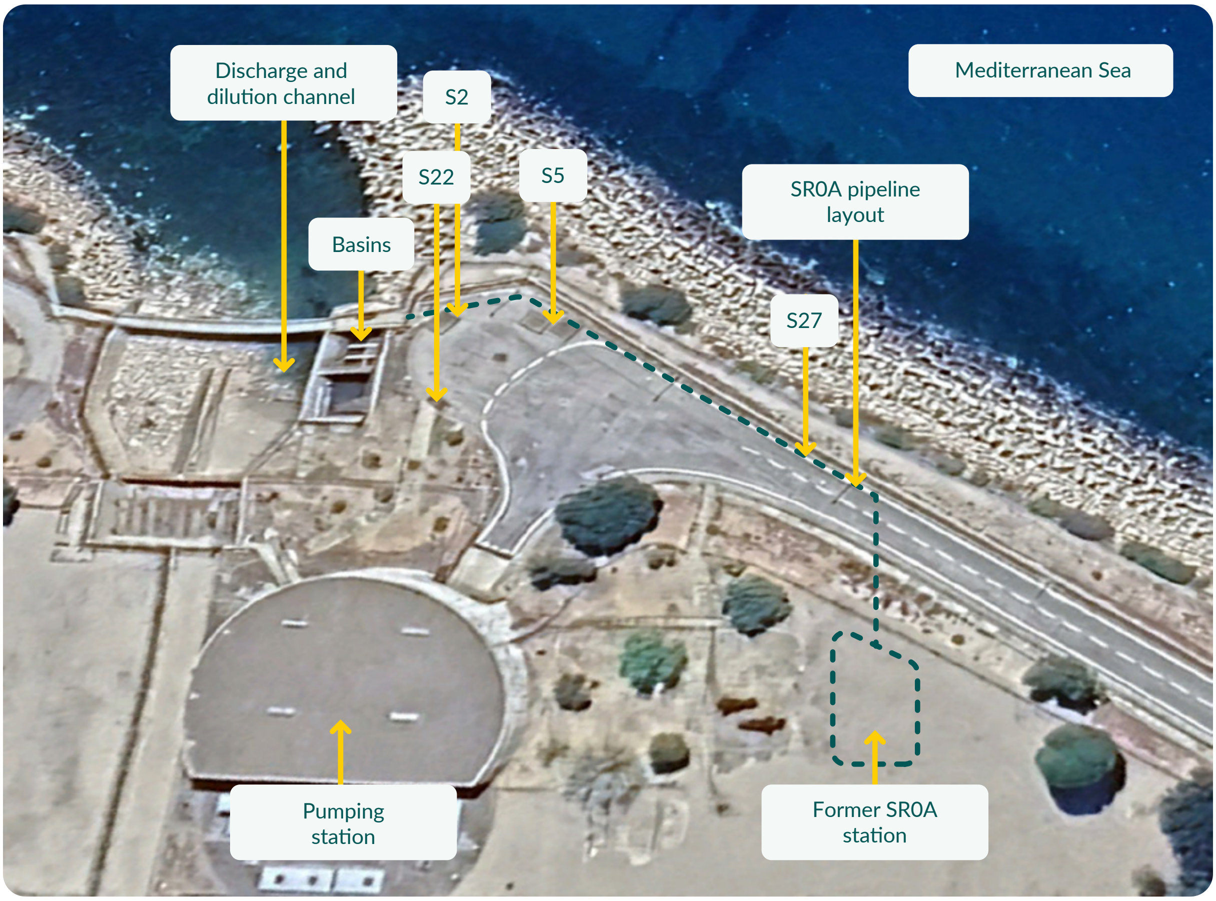


Figure 5-30: *View of the SROA area*

- **Electrochemical and Permeability Measurements in Storage Structure 22 of El Cabril Disposal Centre, 1994-2025 (Memory card 3.4.08.)**

As part of the durability programme for the engineered barriers of El Cabril Disposal Centre LILW, Enresa carries out two annual campaigns to measure the state of passivation/corrosion of the reinforcements of a LILW vault and to measure the permeability of the structural concrete.

The aim of this activity is to verify that certain durability parameters of engineered barriers, in this case, LILW storage structures, remain constant over time and that no concrete degradation processes are occurring.

The work plan consists of two annual campaigns (spring-summer and autumn-winter) to measure concrete resistivity, corrosion potential, corrosion intensity and air permeability at 18 points in Vault 22 using non-destructive methods. The data are also evaluated by CSIC-IETcc and Enresa.

- **Monitoring of the El Cabril Disposal Centre Storage Structures, October 2009-August 2024 (Memory card 3.4.10)**

Enresa, within its scope of action, carries out control, monitoring and modelling activities for engineered barriers, all within the LILW-VLLW engineered barrier durability programme.

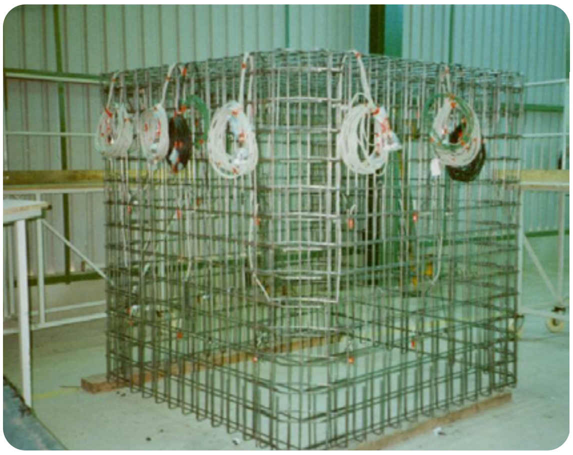
Figure 5-31: *Data acquisition system in the infiltration control network gallery of Vault 1; data acquisition system of Vault 16 during the assembly phase*

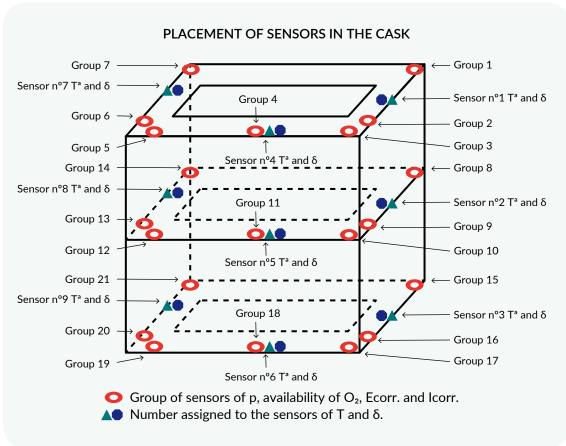
The aims of this project are to learn about the thermal-hydraulic behaviour of the LILW storage structures by obtaining in situ data, to obtain experimental information that allows the verification and validation of the thermal-hydraulic models developed, as well as the processes included in them, and to obtain information on the reliability of sensors.

The work plan consists of periodic downloading of data from installed instrumentation and data collection reports (Vaults 1, 16 and 5), the placement of new sensors in the infiltration control network with a dedicated data acquisition system, the installation of new sensors and data acquisition systems in Vaults 1 and 5 (exterior wall faces) and data analysis and evaluation (Figure 5-31).

- **CE-2a Type Cask Instrumented at El Cabril Disposal Centre, 1995-2025 (Memory card 3.4.11.)**

Since 1995, thermal, mechanical and electrochemical variables have been measured in a CE-2a cask with simulated waste inside it, instrumented with a set of sensors. The main aim of this project is to obtain variables related to the durability of the concrete used by Enresa in LILW engineered barriers, in this case the CE-2a casks (Figure 5-32).





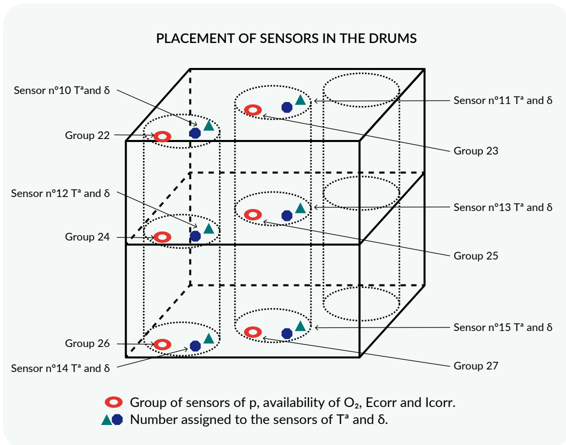


Figure 5-32: *Reinforcement of the instrumented cask and sensor wiring, schematic with distribution of sensors in the cask (top); distribution of instrumented drums inside the cask; schematic of sensors in the drums (bottom)*

- **Investigation of Dissolution/Precipitation Processes in the CTS and their Long-term Evolution, November 2015-November 2019 (Memory card 3.4.14b.)**

The processes of dissolution and precipitation of minerals and water-rock interaction that could take place at the CTS site in Villar de Cañas in the long term and the evolution of the hydrogeochemical system of the site were investigated, taking into account that surface water and groundwater are the main mobilising agent for pollutants.

Geochemical backgrounds were established for the main chemical and isotopic parameters affecting the chemical quality of surface and groundwater, taking into account that during the construction of the CTS numerous anthropogenic materials would be used that would react with the environment and a volume of water would be incorporated into the system. The infiltration of this water into the environment could produce anthropogenic effects that would distort the natural water conditions of the site.

These possible chemical and physico-chemical alterations had to be monitored immediately in order to assess where and when changes in the natural conditions of the chemical composition of the groundwater occur and to verify whether the effect could damage or alter the resistance, longevity and corrosion status of the different materials used in the construction.

This project continued the characterisation and improvement of the hydrogeochemical model based on water-rock interactions and hydrogeological studies of the site.

- Modelling the Hydrogeochemical Behaviour of Sites in Radioactive Waste Storage Systems, January 2015-December 2019 (Memory card 3.4.19.)

A research project was carried out on the modelling of water-rock interaction processes and the hydrogeochemical behaviour of radioactive waste storage systems.

The work plan consisted of the hydrogeochemical characterisation of the groundwater around the waste storage platforms at El Cabril Disposal Centre, the establishment of the geochemical background of the key groundwater parameters of the area where the future VLLW storage vaults will be installed, the support to the hydrogeological performance model by contributing to the identification of the preferred flow paths through the study and characterisation of the chemical and isotopic parameters related to the different origins and mixing processes of the waters.

The contribution of fundamental hydrogeochemical data to develop the numerical models of flow transport in the different sites selected was also studied, in order to understand the hydrogeochemical functioning model of the formations of the sites and especially the evolution and characteristics of the groundwater up to the depths necessary to establish the flow model, and to understand the mobile components of the solid and the mechanisms and conditions of mobilisation-retention of the pollutants.

- Participation in "Development and Demonstration of Monitoring Strategies and Technologies for Geological Disposal" (Modern2020, H2020), June 2015-May 2019 (Memory card 3.4.20)

The work was based on the research carried out under the MoDeRn project, where a solution for the wireless transmission of geotechnical data in solid media based on high frequency radio was developed. The technology was tested at El Cabril Disposal Centre and subsequently implemented by means of several prototypes installed in the underground laboratory in Grimsel (Switzerland). The results demonstrated the feasibility of this solution, but provided a relatively small range, a few centimetres or metres depending on the conditions of the medium.

The Modern2020 Project continued the work, studying different solutions based on significantly lower frequencies (from kHz to a few MHz). The research was structured along three lines:

- Solutions based on high or medium frequencies with ranges of a few metres,
- Low-frequency solutions with ranges of hundreds of metres,
- Combinations of both for a complete solution to send data from the deepest parts of the storage site to the surface.

The solution explored by Enresa-Amberg consisted of adapting a low-frequency digital magnetic induction technology, called TTE (Through-the-Earth), capable of penetrating rock, bentonite and concrete. The prototype was tested in a mine in the Bierzo region and then in a facility developed specifically for testing wireless equipment at the underground laboratory in Tournemire (France). The results obtained were better than expected, providing ranges far superior to those of units tested by other research groups. The maximum range obtained in both cases was 30 m (Figure 5-33).

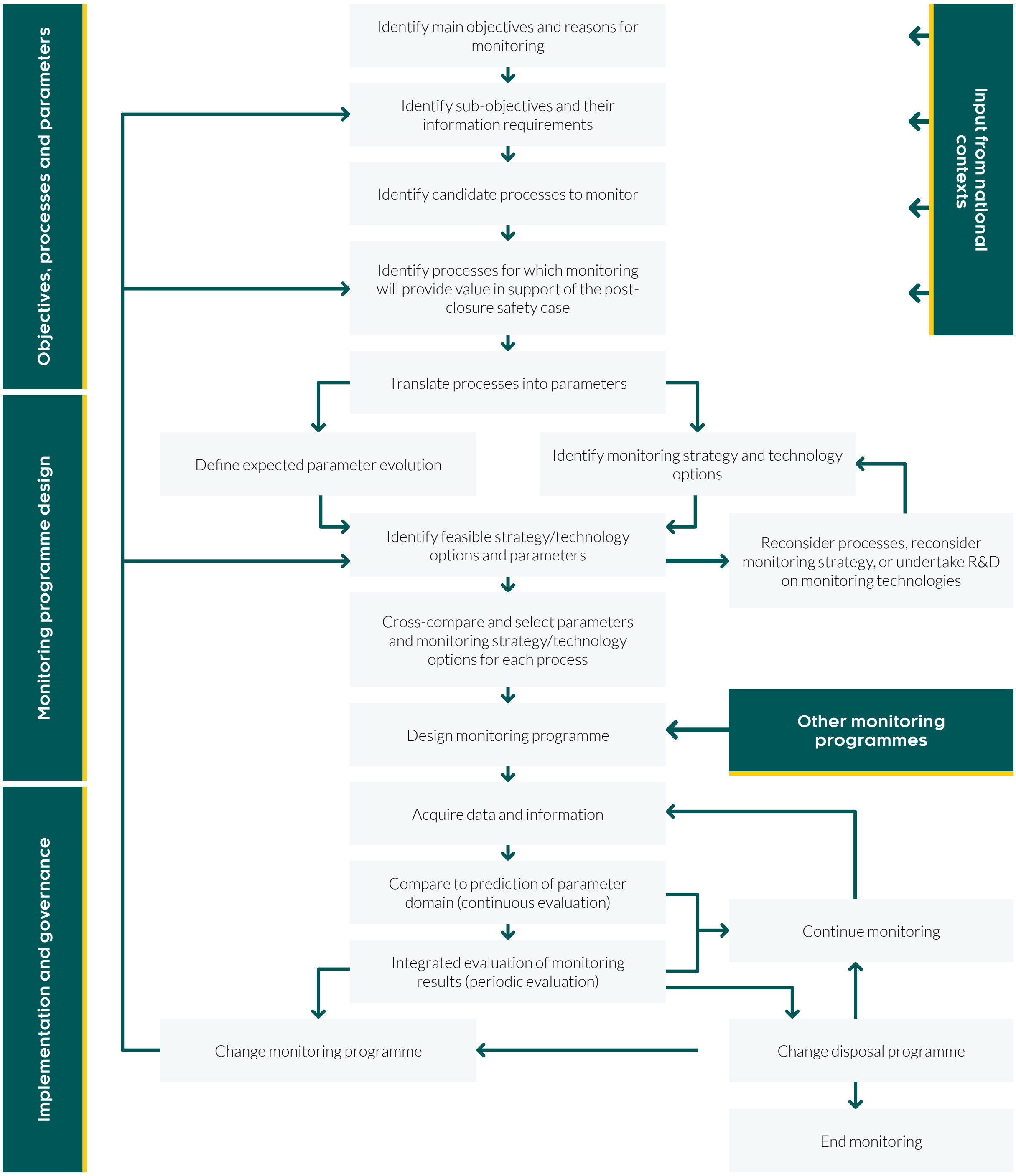


Figure 5-33: *The DGR monitoring work programme of the Modern2020 Project*

- **Instrumentation of Vault 21 of the South Platform at El Cabril Disposal Centre, August 2021-February 2024 (Memory card 3.4.22.)**

The aim of this project is the instrumentation of Vault 21 of the South Platform at El Cabril Disposal Centre to extend and provide continuity to the studies carried out on the thermohydraulic behaviour of the concrete and, in particular, to study the external and internal temperature and humidity differences in the walls and the interior of the vault.

To this end, the project covers the instrumentation of Vault 21 (thermocouples, thermohygrometers) and the systems for data acquisition and storage, protection and preparation, and programming for periodic data collection. In order to comply with the safety requirements for defined waste storage, certain requirements exist relating to the tracking of the performance of the storage structures, on which Enresa reports annually to the Nuclear Safety Council (CSN).

The parameters measured are temperature and humidity, at different positions on the walls of Vault 21, both inside and outside, and on the outer walls of the storage units inside the vault, as well as on the infiltration control network.

The instrumented walls are north, south, east and west. The storage units to be instrumented are those adjacent to the walls and towards the inside of the vault in positions close to the central crosshead.

Temperature is measured by thermocouples, humidity by capacitive thermohygrometers and/or digital humidity sensors.

The sensor element is in contact with the concrete and shall be adequately protected to minimise the risk of breakage during the insertion operation of the storage units.

The activities have been based on the periodic reading of the data collected by the sensors and their analysis to see the evolution over time and their seasonal variation.

- Modelling the Hydrogeochemical Behaviour of Waste Storage System Sites (MOCHESAR), December 2022-December 2026 (Memory card 3.4.25)

The aim of this project is to carry out research and development programmes in the field of radioactive waste, in particular the modelling of hydrogeochemical processes at sites hosting radioactive waste.

For Enresa, one of the priority lines is to understand the processes that take place in the surface and groundwaters of the different facilities, as well as to determine the elements of the geosphere in order to collect reliable field data and be able to establish a hydrogeochemical model as the final result, allowing it to be adjusted to the geological-structural and hydrogeological model of the site, predicting the chemical evolution of the groundwater, the geochemical processes of water-rock interaction and the possible impact on the safety of the storage facility.

The work plan is aimed at enhancing understanding of the processes of water-rock interaction at sites with nuclear facilities and characterisation of the evolution of the mobility of radionuclides or pollutants in their groundwaters. For this purpose, two sites were initially considered as the scope of work: El Cabril Disposal Centre (Figure 5-34) and the former Andújar Uranium Mill Plant (FUA). At El Cabril Disposal Centre, activities are being carried out for the hydrogeochemical characterisation of the groundwater and the determination of its interaction with the different storage infrastructures. At the FUA, a geochemical characterisation of the soils and groundwater in this sector is being carried out in order to establish a conceptual model of the hydrogeochemical behaviour of uranium compatible with the hydrogeological operating model of the area, in keeping with the real current scenario existing at the site and its surroundings.

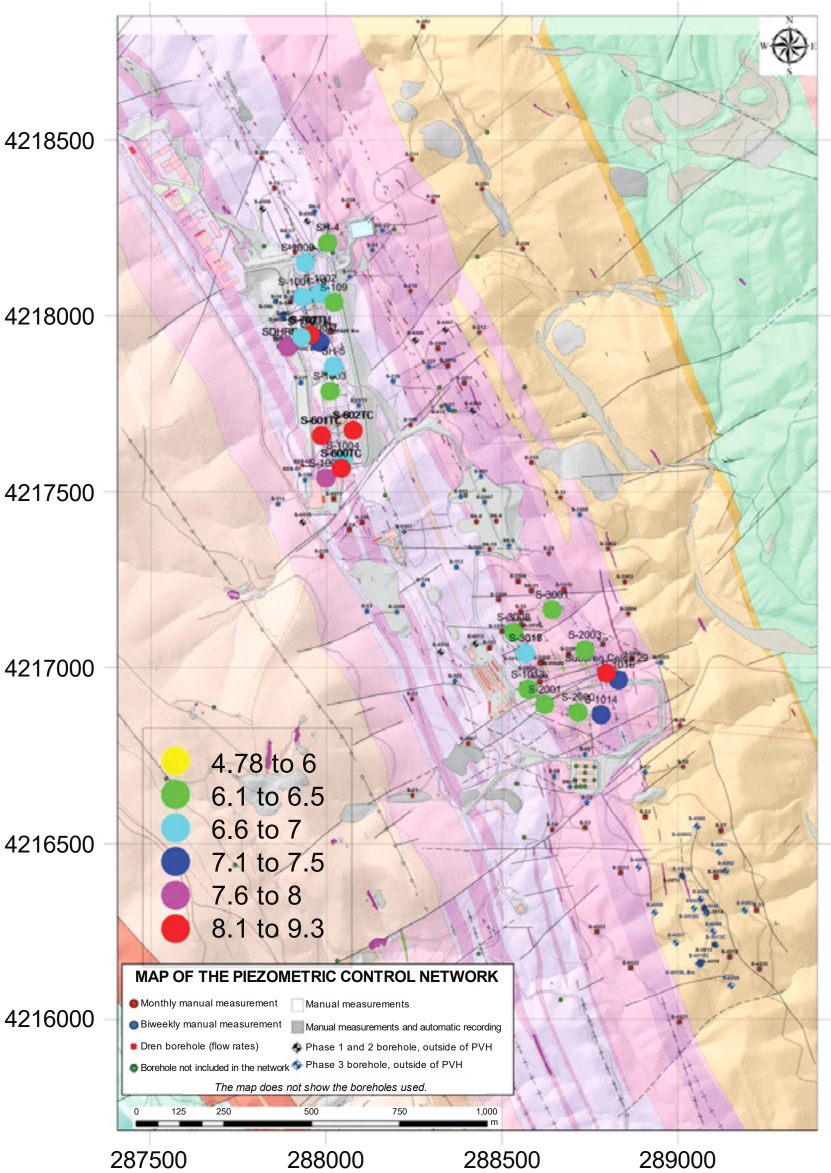


Figure 5-34: *Distribution of pH values in El Cabril Disposal Centre groundwater*

Planned activities

The following projects have been initially identified as being of interest under Line 3.4 of the 9th R&D Plan:

- Analysis of the Behaviour of Monitoring Systems against Temperature and Radiation

The aim is to study the useful life management of the elements that form part of any monitoring system (cables, sensors, etc.). The aim of this project is to study the degradation phenomena of these elements, subjected to conditions similar to those of a discharge vault. The results of the project will be used to minimise or slow down, as far as possible, this degradation phenomenon and to establish the maintenance and replacement tasks required by this system.

- Characterisation of Groundwater and Soils in the SROA Area of Vandellós I NPP

The monitoring of contaminated land in the SROA area will be maintained, consisting of the chemical and radiochemical characterisation of groundwater and the radiochemical characterisation of soils in compliance with the Vandellós I Surveillance Plan.

- Development of Inspection and/or Monitoring Equipment for Storage/Transport Systems. Validation Campaigns on Loaded Systems

In the interest of having equipment to monitor the behaviour of loaded systems in support of the Life Management Plan for HLW storage facilities, the development of equipment for monitoring and inspecting storage and/or transport systems is proposed, to provide data for their life management, and monitoring campaigns on loaded systems to validate them.

- Development of Monitoring and Inspection Systems for Civil Structures

Development of a system for in-situ monitoring of the condition of civil structures of a SF storage facility (temperature, water content, cracking, deformation, settlement, etc.).

- Supply, Installation and Start-up of H-3 and C-14 Gas Monitors in Vaults

Installation of equipment and measurements for the determination of H-3 and C-14 content inside the LILW and VLLW vaults, given their characteristics as volatile components and preferential migration towards the geological environment.

- Maintenance, Taking of Measurements and Interpretation of Data in the Instrumented Cask at El Cabril Disposal Centre

As has been done since 1995, thermal and mechanical measurements will continue to be taken, as well as electrochemical variables, in a CE-2a cask with simulated waste inside, instrumented with a set of sensors inside, to obtain variables relating to the durability of the concrete used by Enresa in the LILW engineered barriers, in this case of CE-2a casks.

- Electrochemical and Permeability Measurements in Storage Structure no. 22 of El Cabril Disposal Centre

The programme of the durability study of the engineered barriers of the LILW disposal facility will continue with two annual campaigns to measure the state of passivation/corrosion of the frames of an LILW vault, as well as permeability measurements of the structural concrete.

- Collection, Analysis and Evaluation of Instrumentation Data from Cover Layers

Monthly data will be taken from the instrumentation located in the provisional cover to check the effectiveness of the design of the cover and to study its thermal-hydraulic behaviour. The data measured will also be used to validate models that are being developed to predict the future behaviour of the cover (evaluating other weather conditions, etc.) and to obtain information on water and heat flows and unrecorded variables.

- **Repair, Maintenance, Collection, Analysis and Evaluation of LILW Engineered Barrier Instrumentation Data (Cover Test, Instrumented Cask, Vaults 1, 5, 16 and Infiltration Control Network and PS)**

Repair, maintenance and monthly data collection activities will continue on the instrumentation located in Vaults 1, 5 and 16, the instrumented cask, the infiltration control network, and the cover and PS test. The different types of data will be analysed to study the processes that take place in these structures (evaporation and condensation processes).

- **Sensor Definition, Installation and Data Management (Collection and Analysis) on the Partial Cover in LILW North Platform Vaults**

In order to study the operation and efficiency of the design of the partial cover in the LILW vault of the North Platform and to verify its effect on the thermo-hydraulic behaviour of the vault, and specifically, on the collection of water produced as a result of the condensation/ evaporation processes that take place inside the LILW vaults, this cover will be instrumented with an ad-hoc monitoring system.

The design of the instrumentation shall take into account the optimal location of the sensors within the enclosure and certain conditions for their installation, as well as the cabling and mounting of the data logging equipment so that the impact on the structure is minimised.

The instrumentation system of the temporary cover will monitor different thermo-hydraulic variables, including sensors to measure temperature, heat flow, volumetric water content, suction or matrix potential and relative humidity in porous mediums. In addition, as the location of the cover, partially supported on the vault, could cause ground settlement, the instrumentation will also include systems to measure deformation. Infiltrated flows in the different layers forming the cover, runoff and erosion caused by the cover will also be measured. In addition, the evolution of the roots of the vegetation on the surface of the cover will be studied and the outer walls of Vault 5 will be instrumented to measure relative humidity and temperature on all sides.

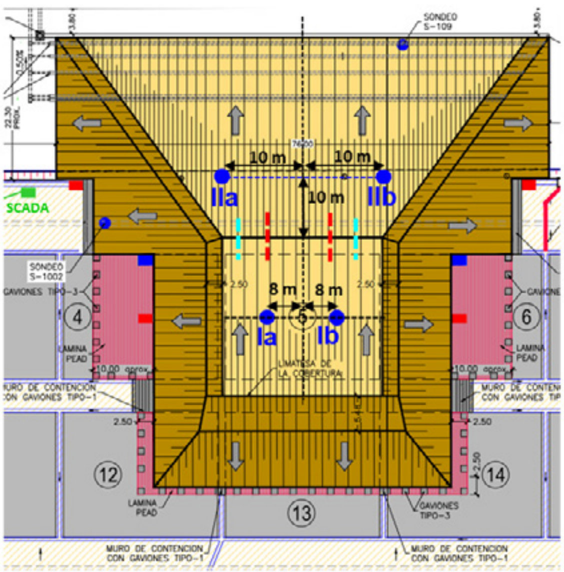


Figure 5-35: *Design of cover test*

- Installation of Data Acquisition and Remote Reading Systems

A remote communication system associated with the existing instrumentation system will be installed in Vaults 1, 5, 16 and 21, as well as in the cover test and provisional cover, in order to be able to take data from the existing instrumentation remotely and reliably, thereby facilitating both the monitoring of vaults and layers and the maintenance of said instrumentation, and thus see in advance any potential problems therewith.

In addition, the following topic of interest has been identified:

- Development of Equipment and Methodology for the Monitoring of H_2 and Noble Gases

5.1.6. Area 4. Evaluation of safety, radiation protection and associated modelling behaviour

This area refers to activities related to radiation protection and safety studies. The work ranges from the development and improvement of analysis tools, mainly numerical, to the definition and harmonisation of radiation and environmental protection criteria at an international level. It also includes studies necessary for the remediation of radiologically contaminated environments with specific problems. Experimental activities necessary for the validation of conceptual and numerical models under development are also included. Knowledge of the current environmental status of sites and their surroundings, as well as vulnerabilities and areas for improvement are also covered in this area.

5.1.6.1. Line 4.1. Evaluation methods and models

Activities carried out

Projects under Line 4.1 with activities within the horizon of the 8th R&D Plan 2019-2023 are described below:

- H2020 EURAD Project WP10. Uncertainty Management multi-Actor Network (UMAN), June 2019-May 2024) (Memory card 4.1.02.)

This work package (WP) of the EURAD programme focused on the management of uncertainties potentially relevant to the safety of different radioactive waste management stages and programmes. It included various activities, such as exchanges of views, uncertainty management practices and options and the review of existing strategies, approaches and tools. Interactions between different types of stakeholders, including civil society, were essential

These interactions were intended to fulfil the shared aim of fostering a mutual understanding of uncertainty management strategies, approaches and preferences.

Decisions associated with radioactive waste management programmes are made in the knowledge that irreducible and reducible uncertainties exist. Therefore some of the decisions in the early stages of a programme taken on the basis of limited information will have to be confirmed in later stages. At the end of the process, uncertainties will inevitably remain, but it must be demonstrated that these do not undermine the safety arguments. The management of uncertainties is therefore a key issue when developing and reviewing the safety case for waste management facilities and, in particular, in final repositories because of the long period of time during which the radiotoxicity of the waste remains significant.

Planned activities

The following Line 4.1 projects of interest have been initially identified within the horizon of the 9th R&D Plan:

- Optimisation of Measurement Methods for I-129 in Air

I129 is one of the isotopes under study as part of the Environmental Radiological Surveillance Plans of nuclear facilities. To date, it has not been possible to measure this isotope reliably in air, due to the absence of proven methodologies. Although it is known that a methodology has recently been developed that could be applied, it would be advisable to continue research into techniques for measuring this isotope in air for its future application to temporary SF storage facilities.

- Development of an Integrated Safety Analysis (ISA) Methodology and its Integration into a Safety Study

The aim is to study methodologies similar to the APSs carried out for nuclear power plants, applicable to a temporary SF storage facility. The fundamental aim of this line of research consists of developing an analysis methodology applicable to this type of project (temporary facilities) and a methodology for the integration of the results of the ISA in the Safety Analysis of the facility.

- Analysis of the Feasibility of Implementing a Graded Approach in the Safety Analysis of SF and HLW Dry Storage Facilities

In the international context, especially at the IAEA, work is being carried out in different groups for the development of an analysis methodology based on a graded approach to safety, which could be of particular interest in a newly constructed temporary SF storage facility. The aim of this project is to develop a study on the possibilities and ways of implementing a graded safety approach in the analysis of SF storage facilities.

5.1.6.2. Line 4.2. Process and system modelling

Activities carried out

Projects under Line 4.2 with activities within the horizon of the 8th R&D Plan 2019-2023 are described below:

- Modelling of the Behaviour of Reinforced Concrete Subjected to Blast and Penetration Taking into Account Reinforcement Bonding, February 2017-February 2019 (Memory card 4.2.09b.)

The project aimed to simulate the impact of aircraft and other large projectiles on reinforced concrete walls, taking into account the strength and the depletion of reinforcement anchorage at varying strain rates. The model was based on the M7R model, the most advanced microplane model formulated for variable strain rates, which respects the microstructure of the material and takes into account cracking and damage by explosions and impacts of fragments and projectiles (Figure 5-36).

The new numerical model was verified and calibrated using test data available in the literature simulating the pull-out of reinforcement bars from the encasing concrete at varying strain rates, oblique tensile failure of beams without transverse reinforcement at varying strain rates and punching shear failure of slabs without transverse reinforcement at varying strain rates.

In addition, the effects of concurrent explosions and penetration were simulated.

- Model of the Hydrogeochemical Evolution of the Andújar Uranium Mill (FUA), December 2013-July 2025 (Memory card 4.2.10.)

The mathematical model of uranium flow and transport in the area surrounding the Andujar Uranium Mill (FUA) is permanently contrasted and revised with the field data obtained regularly by Enresa. The results of these cross-checking and revision activities are taken into account in the Annual Reports and future reviews of the Site Surveillance and Maintenance Plan. The civil works carried out in the area surrounding the tailings dam that might affect the hydrogeological operation of the area are included in the model.

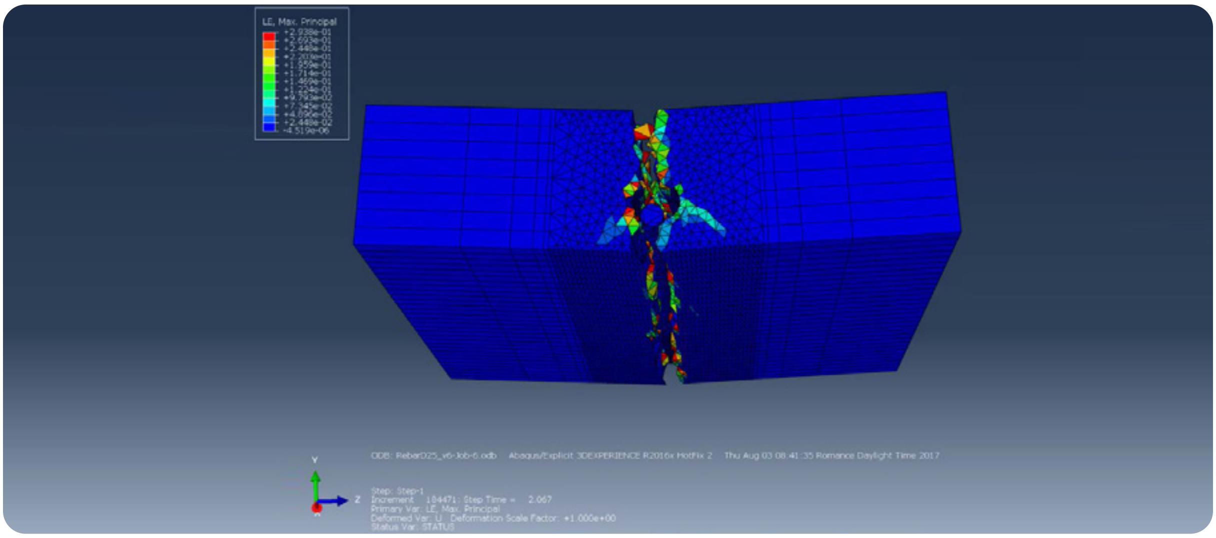


Figure 5-36: *The deformed shape of the rebar-concrete model at full bar pull-out*

- Modelling of Soil-structure Interaction in Specific Buildings of the CTS in Villar de Cañas, April 2017-April 2019 (Memory card 4.2.12.)

In this project, the soil-structure interaction in specific buildings was simulated by means of strategies that made it possible to evaluate the effect of environmental loading on their performance in service, from an energy and deformational point of view.

Thus, the analysis took into account the sensitivity to drainage and excavation strategies, as well as the type of foundation structure, using realistic models of geochemical and geomechanical soil behaviour.

These analyses make it possible to predict the evolution of the building's performance, determining the measures to be taken in the design to improve it.

These analyses are carried out using the M4B (Multiphysics for Buildings) model based on a numerical simulation module developed in a multiphysics programming environment.

- **Participation in the H2020 EURAD WP4 Project. Development and improvement Of NUmerical methods and Tools for modelling coupled processes (DONUT), June 2019-May 2023 (Memory card 4.2.14.)**

Understanding the multi-physical coupled thermal, hydraulic, mechanical and chemical (THMC) processes that occur in a DGR for radioactive waste is essential and is an ongoing issue to support the optimisation of its design and the preparation of safety cases.

Multi-physics predictive analyses of time periods and spatial scales larger than experiments are performed with numerical simulations. These require an integration, in a coherent framework, of increasing scientific knowledge acquired for each of the individual components of a DGR. This involves considering couplings of different, non-linear physical processes of a wide range of materials with different properties as a function of time and space in gradually larger systems.

It is also necessary to i) manage the uncertainties associated with the input data that feed the models and the representation of the processes, ii) assess the range of variability of the results and iii) identify the main parameters and processes that control the performance of the systems under study. The management of uncertainties in these complex systems requires the improvement and development of innovative, appropriate and efficient numerical methods.

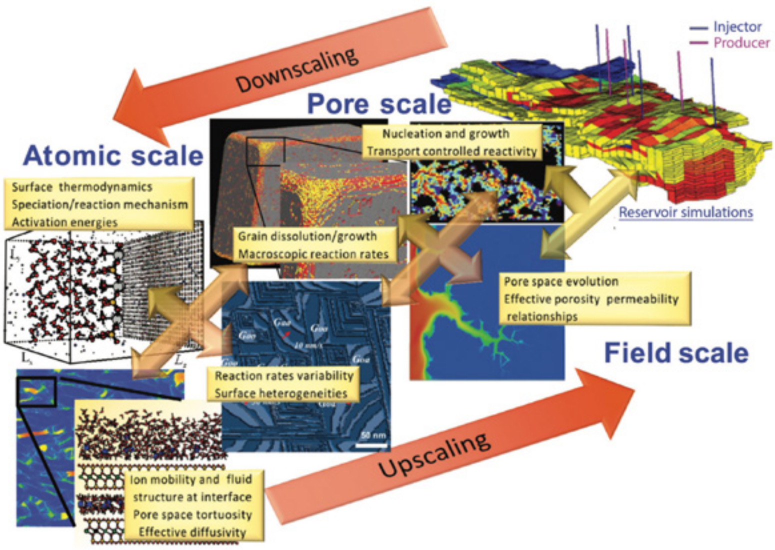


Figure 5-37: *The problem of scaling in modelling addressed in the DONUT project (Churakov & Prasianakis Am. J. Science, 318 (9) 921-948)*

The specific aims of this EURAD WP were the development of relevant, high-performance, state-of-the-art numerical methods that can be easily implemented in existing or new codes, in order to carry out high-performance numerical calculations to study strongly coupled processes in large-scale systems, the development of numerical scale transition schemes for coupled processes to support the study of specific couplings at multiple scales, the development of innovative numerical methods to perform uncertainty and sensitivity analyses, inter-comparison exercises, on representative test cases, to test the efficiency of the methods developed in relevant tools.

- **Participation in the H2020 EURAD WP2 Project "Assessment of Chemical Evolution of ILW and HLW Disposal Cells (ACED)", June 2019-May 2024 (Memory card 4.2.15.)**

This WP, EURAD's second, was proposed to improve the methodology to integrate knowledge about the geochemical processes occurring in, and between, the materials present in a vault of intermediate- and high-level radioactive waste (ILW and HLW) in a DGR. This knowledge will be applied for the assessment of the long-term evolution of a system that is highly complex. A multi-process and multi-scale modelling scheme will allow the assessment of chemical evolution at various material interfaces and thermal, hydraulic and/or chemical gradients, from the micro-scale up to the scale of the vault (ILW, HLW) in the near-field environment, and for larger time scales, the host rock mass.

Having understood the geochemical processes, this WP sought to discover at what detail and complexity these processes should be incorporated into models for different types of studies related to safety and performance assessment.

The study focused on HLW vaults, representative of European vaults, and the data obtained can then be used and adapted for national concept-specific vault designs.

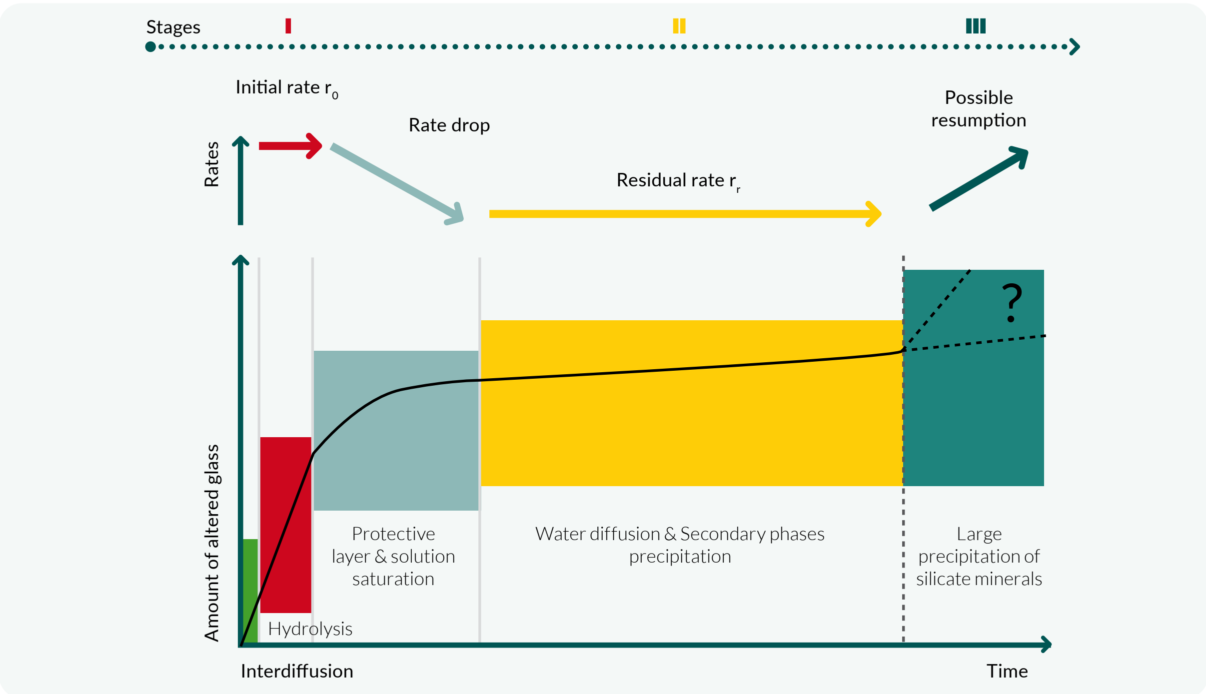


Figure 5-38: *ACED project: stages of vitrified waste corrosion and possible mechanisms conditioning the rate at which it occurs (Gin et al., 2013)*

- **Participation in the project "DEvelopment of COupled models and their VALidation against Experiments" (DECOVALEX), April 2020-March 2024 (Memory card 4.2.16.)**

The DECOVALEX project started in 1992 and has operated in three- or four-year phases since then, the latest phase being DECOVALEX-2019, which ended in April 2019.

The current phase of the project has been a continuation of the international multidisciplinary, interactive and cooperative research effort to analyse and model thermo-hydro-mechanical (THM) processes in various geological formations and backfill and sealing materials of interest for the design and safety analysis of radioactive waste repositories.

There are several reasons for international cooperation in this area, including the joint improvement from multiple perspectives of the basic understanding of processes of importance for radionuclide release and transport, and the opportunity for international peer review of the mathematical models employed. This cooperation will also provide the exchange of extensive and valuable laboratory and field databases for validation purposes, and will improve the state of the science on issues related to coupled THM processes.

Enresa has participated in two phases of the DECOVALEX Project, 1995-1999 and 2000-2003, together with the modelling groups of the UPC and the UPV. The second period was financed by the European Union (EURATOM).

Planned activities

The following projects have been initially identified as being of interest under Line 4.2 of the 9th R&D Plan:

- **Improved Modelling and Assessment Methodology for Extreme Cases arising from Terrain Characteristics**

To give continuity to the projects carried out on soil-structure interaction (SSI) in specific buildings.

- **Development of Methodologies for the Calculation of Projected doses in Design Extension scenarios**

The aim is to develop methodologies for the analysis of projected doses deriving from various scenarios of radioactive material release, as a result of the scenarios proposed for the application to a SF temporary storage facility of Directive 2014/87/Euratom on design extension. Development of thermal-hydraulic and transport models for LILW/VLLW and chemicals.

The aim is to develop thermal-hydraulic and transport models, both conceptual and geometrical models, including barrier and conditioning materials, the identification and modelling of physical and physico-chemical processes, as well as the development of calculation methods.

- **Application of Thermohydraulic and Transport Models of Radioactive Components and Chemical Components in Enresa's storage facilities**

This consists of applying the models developed to the Enresa storage facilities in order to take into account the specific characteristics of each disposal site (geometry, geological environment, etc.).

- **Development of Thermal-hydraulic and Transport Models for LILW/VLLW Waste and Chemical Components in LILW and VLLW Storage**

The aim is to develop thermal-hydraulic and transport models, both conceptual and geometrical models, including barrier and conditioning materials, the identification and modelling of physical and physico-chemical processes, as well as the development of calculation methods.

- **Development and Application of Hydraulic, Thermo-hydraulic and Cover Layer Transport Models**

This consists of the development and application of the aforementioned models to the cover layers to be installed in the LILW and VLLW waste storage facilities.

The following conceptual and numerical models, predictive simulations and sensitivity analyses will be developed with the aim of evaluating the behaviour of the set of materials that make up a cover and its implications on the long-term flow of water, as well as its consequences on the safety of the facility:

- Development of a conceptual and numerical thermal-hydraulic and transport model for covers on VLLW vaults.
- Development of a conceptual and numerical thermal-hydraulic and transport model for the future cover to be built over one of the LILW vaults on the North Platform.
- Predictive simulations of the behaviour of the cover layers and of potential variations in their design based on the results obtained in the laboratory tests.
- Sensitivity analysis.
- Proposal of tests for model validation, if necessary.

- **Flow and Transport Modelling of Reactive Solutes in Radioactive Waste Repositories**

The continuation and continuous improvement of the mathematical model of uranium flow and transport in the area surrounding Andújar Uranium Mill (FUA) is planned, which allows for predictive simulations of uranium concentrations in the aquifer, as well as simulating potential corrective measures.

- **Enresa's Participation in the DECOVALEX Project (THMC Models)**

Participation in the next phase of the project that began in March 2024 (Decovalex 2027) is envisaged. Enresa will foreseeably participate in two case studies, one of them focused on the HM modelling of a well sealing system (SW project at the Mont Terri underground laboratory). The other case is the modelling of the flow and transport of radioactive solutes related to the natural analogue of Cigar Lake (Canada).

- **Modelling Hydrogeochemical Behaviour in Radioactive Waste Disposal Systems**

The updating of the reactive solute flow model will continue in order to complete the Surveillance and Maintenance Plan for the restored site of the former Andújar Uranium Mill (FUA), in compliance with Condition 21 of the Nuclear Safety and Radiation Protection Limits and Conditions of the facility's decommissioning plan.

5.1.6.3. Line 4.3. Environmental remediation

Activities carried out

The projects under Line 4.3 with activities in the horizon of the 8th R&D Plan 2019-2023 are described below:

- **Application of "Carbocal" Amendments in the Topsoil Layer of the Restored Site of Saelices El Chico (Salamanca), April 2012-December 2019 (Memory card 4.3.07)**

At the Saelices el Chico mine (Salamanca), intensive work has been carried out to reconfigure and restore the mine workings (dumps and mine pits). The whole of the remodelled area was subsequently covered with a multilayer of different materials, including a surface layer of about 30-50 cm of "raña" soil or arkose soil. Given that there is abundant pyrite in the rocks surrounding the site, oxidation of the pyrite in contact with runoff water and air leads to acidification of the surrounding water and leaching of heavy metals and metalloids, including uranium. It is therefore necessary to treat the surface soils to neutralise them. In this way, the risk of contamination of leachate and run-off water can be greatly reduced (Figure 5-39).

Figure 5-39: *Assisted Natural Recovery philosophy*

This project has studied the possibility of increasing the buffering capacity of the cover soil (raña or arkose) through the use of a "Carbocal" limestone amendment, a product supplied by the company AZUCARERA, SA. In this way, the aim was to reduce the acidity and concentration of metals and metalloids in the water around the Saelices el Chico mine.

Planned activities

The following project of interest under Line 4.3 has been initially identified within the horizon of the 9th R&D Plan:

- **Optimisation in the Management of NORM Waste Materials (OPTINORM)**

The main aim of this project is to investigate the possible alternatives for the safe management of waste materials generated by NORM industries from the point of view of radiation protection, and to study the possible future implementation of some of them in Spain, monitoring international developments in the management of NORM waste.

Another aim of the project is to update and improve the CROM calculation tool by developing a new calculation module, incorporating a dynamic soil-plant transfer model for natural radionuclides and groundwater modelling to allow the study of exposure scenarios related to residual NORM materials. The user interface will also be improved.

5.1.6.4. Line 4.4. Radiation protection

These relate to the monitoring of international projects on radiation protection, whether they are promoted by EURATOM, NEA, IAEA or the different European platforms or associations, and their results usually include the application of their developments to Spanish cases. Enresa has always counted on the collaboration of CIEMAT to increase its capabilities in radiation protection from an R&D perspective.

Activities carried out

The project of Line 4.4 with activities in the horizon of the 2019-2023 Plan is described below:

- Improved Knowledge of Factors that Strengthen Safety Culture, October 2023-October 2027 (Memory card 4.4.07.)

This is a project that seeks to improve the understanding of the factors that strengthen safety culture, in particular the improvement of safety conduct and attitudes of staff and the organisation. Research will be carried out on the levers that drive a strong safety culture, increasing knowledge of socio-technical concepts and their impact on the organisation. In particular, organisational intervention protocols will be developed to support the improvement of organisational culture and activities will be designed for the promotion and continuous improvement of the safety culture.

Planned activities

The following projects have been initially identified as being of interest under Line 4.4 of the 9th R&D Plan:

- Dynamic Analysis of the Performance of Spent Fuel Transport Casks in a Loss of Containment Accident Condition

Study of the migration of radionuclides from the cask to the atmosphere, in the event of any accident occurring which, during the process of unloading into a vault, would make it necessary to return the cask to the preparation area.

- Developments in the Methodology and Generic Model for Biosphere Security Assessment at El Cabril Disposal Centre (BIOMODES)

The aim of this Agreement is, on the one hand, to improve the biosphere safety assessment methodology used in Spain for environmental radiological impact assessment, which is part of the safety assessment studies in radioactive waste management, and, on the other hand, to develop specific models that improve the way of assessing the behaviour of pollutants in Spanish ecosystems, taking into account the assessment of doses in humans and biota.

Biosphere assessments estimate the potential radiological impact arising from the release and migration of radionuclides from a storage system and through engineered barriers and the geological environment, with the biosphere being where the effectiveness of a storage system is assessed, either in terms of radionuclide activity concentrations, effective dose to the representative individual or exposure levels to biota.

5.1.6.5. Line 4.5. Climate and soils

This line includes R&D activities related to site characterisation and environmental and paleoenvironmental studies to support the safety analysis. No projects have been carried out in this line in the 8th R&D Plan, nor are there any future projects planned.

5.1.7. Area 5. Horizontal activities: support infrastructure, coordination, knowledge management

This horizontal area includes activities related to support actions for the monitoring of R&D projects, management of technological assets and returns on experience, and actions aimed at the preservation of knowledge, records and memory in the short, medium and long term.

The work has been classified into the following three lines of action:

- Line 5.1, Infrastructure support
- Line 5.2, Coordination
- Line 5.3, Asset management

5.1.7.1. Line 5.1. Infrastructure support (Technology Centres)

No projects have been carried out under this line in the 8th R&D Plan (2019-2023).

Planned activities

The following projects have been initially identified as being of interest under Line 5.1 of the 9th R&D Plan:

- **Research on Cyber-security Technologies and their Application to Spent Fuel and Dry High-level Waste Storage Facilities**

Development of strategies and techniques for protection against intrusion and computer system failures, reducing the vulnerability of security systems in such facilities.

- **Study of Digital Capabilities for Monitoring Emergency and Accidental Situations in Spent Fuel and Dry High-level Waste Storage Facilities**

Study of innovative solutions for radiation surveillance and control of people, especially geared towards their use and application in accidental or emergency situations. The aim is to make progress in the study of strategies for the use of systems remotely in such situations (both for monitoring and information gathering). The model proposed in accidents is preferably analogue and cabled; however, this does not exclude the possibility of investigating digital capabilities as available alternatives once their robustness and security are known and proven. Thus, for example, the following applications will be studied:

- The use of conventional radiation meters on new equipment, cameras, drones, etc., allowing remote measurements to be taken.
- The use of personal smart bracelets incorporating location technologies, which can be used to keep track of presence, evacuation status, counts, etc.

This study would provide recommendations that could be applied in the preparation of the Interior Emergency Plan for facilities.

5.1.7.2. Line 5.2. Coordination

Activities aimed at facilitating plan coordination and technology surveillance are included in this line. This basically includes participation in R&D platforms, attendance at project coordination meetings, and exchanges of experience, etc. (described in Technology surveillance, R&D for).

The development of this line provides an updated view of R&D activities focused on radioactive waste management and radiation protection at an international level. It also includes syntheses and evaluations of its own results, as well as a synthesis of the results of its own R&D.

Activities carried out

The project of Line 5.2 with activities in the horizon of the 2019-2023 Plan is described below:

- **Participation in the European Technology Platform IGD-TP (Implementing Geological Disposal of Radioactive Waste Technology Platform), January 2012-December 2023 (Memory card 5.2.02)**

2040: Towards industrialisation of radioactive waste disposal in Europe

Safely operate	Optimise & industrialise	Tailor solutions
The first geological disposal facilities in Europe	Planning, construction and disposal operations	For disposal of the diverse waste inventories in Europe

Figure 5-40: *Vision defined for the platform stage from 2020 onwards*

The Technology Platform for the Implementation of Geological Disposal of Radioactive Waste (IGD-TP) is focused on launching and implementing strategic European initiatives to facilitate the gradual implementation of the safe deep geological disposal of SF, HLW and other long-lived radioactive waste. It aims to address pending scientific, technological and society-based challenges and to support European waste management programmes.

The IGD-TP was launched on 12 November 2009 at the initiative of the European Commission and waste management organisations. Currently funded exclusively by waste management organisations, the group welcomes all stakeholders (industry, research and academia, research centres, technical safety organisations, non-governmental organisations, associations, SMEs, ...) that support the vision of the IGD-TP and are willing to contribute positively and constructively to the aims of the group, such as the establishment and implementation of the Strategic Research Agenda and participation in information exchange and knowledge transfer.

At present, practically all the European Agencies participate in the platform. The platform's structure is made up of an Executive Group, which is the platform's decision-making and management body, of which Enresa is a member, assisted by a Secretariat and an Exchange Forum for the exchange of information and discussion of R&D needs and results.

A vision document, a strategic research agenda and an implementation plan have been published for the R&D activities identified in order of their importance and assigned priorities.

Planned activities

The following project of interest under Line 5.2 has been initially identified within the horizon of the 9th R&D Plan:

- **Participation in the European Technology Platform IGD-TP (Implementing Geological Disposal of Radioactive Waste Technology Platform)**

We will continue to participate in the European IGD-TP platform, as a member of the Executive Group.

5.1.7.3. Line 5.3. Asset management

This line includes R&D activities relating to the management of the products generated by R&D and their transfer to management. In recent years, at least in relation to radioactive waste management, society has become aware of the importance of knowledge due to its high level and the great specificity of the issues dealt with. This concern has made the aspects of **management and conservation of knowledge**, of documentation, of transmission via the media or otherwise, to future generations, to be perceived at a general European level as essential. This is based on the following circumstances:

- The management of radioactive waste spans very long periods of time, from at least 15 generations (more than 375 years since the conception of El Cabril Disposal Centre) to hundreds of generations in the case of a DGR. The temporary management of SF and HLW will last no less than 80 years, or four generations.
- Few or very few companies/organisations are involved, either nationally or internationally.
- Today, most of the people who started these activities are already or are about to leave the active world of work.
- There is generally little interest among the younger generation in radioactivity-related activities, throughout the whole cycle, from generation to disposal.

At Enresa, one tool for managing its R&D assets is the " Memory card ", which is an instrument that concisely summarises an R&D project or activity, and which can be used for information purposes (Figure 5-41). In addition to the summary, the list of documents that have been produced in the project is included.

Figure 5-41. *Sample "R&D Memory card"*

Planned activities

The following projects have been initially identified as being of interest under Line 5.3 of the 9th R&D Plan:

- **Support for NEA Activities related to Radioactive Waste Management (SF and HLW, LILW, VLLW)**

Contribution to databases, R&D projects, etc. in support of NEA activities related to radioactive waste management.

- **Collaboration in the Knowledge Management Activities of EURATOM Projects (EURAD-2, Inno4graph 2, Others)**

Contribution to activities related to the conservation and transmission of knowledge.

- **Study of Operational Experience in High-risk Industrial Sectors**

Development of models for SF temporary storage facilities based on operating experience, through the use and application of international models, new methods and tools to support this type of analysis. The aim is to investigate the nuclear sector and other high-risk sectors, such as the petrochemical or aeronautical sectors, for their transfer to temporary SF storage facilities.

- Study of the Influence of Socio-technical Systems on Nuclear Safety

The aim is to investigate the influence of the technology-personal-organisational set-up on the safety of SF temporary storage facilities. To study the impact of organisational changes on nuclear safety and to analyse human reliability, through research in the nuclear sector and in other high-risk sectors (e.g. petrochemical and aeronautical), to study the probability of failure of human action in maintenance and operation tasks, so that the consequences of such failure can be assessed and, therefore, the influence of such failure on the technological context.

- Study of Project and Site Management Techniques in the Nuclear World

The aim is to learn from experience in the management and construction of projects at other benchmark nuclear facilities, in order to take on lessons learned that can be applied to the project for the construction of a temporary storage facility for SF. Both the organisation and the methods, tools and standards applied in the management of large projects and works, in particular those developed in the nuclear field, will be studied.

- Analysis of the Capabilities Offered by Digital Engineering, Applicable to Education and Training Programmes

The aim is to investigate the influence of the technology-personal-organisational set-up on the safety of SF temporary storage facilities. To study the impact of organisational changes on nuclear safety and to analyse human reliability, through research in the nuclear sector and in other high-risk sectors (e.g. petrochemical and aeronautical), to study the probability of failure of human action in maintenance and operation tasks, so that the consequences of such failure can be assessed and, therefore, the influence of such failure on the technological context.

6

6. Budget and financing

R&D activities in radioactive waste management and the decommissioning of nuclear facilities form part of the tasks commissioned to Enresa, in accordance with Royal Decree 102/2014, of 21 February, for the Responsible and Safe Management of Spent Fuel and Radioactive Waste, and are financed from the Fund for the Financing of the Activities included in the General Radioactive Waste Plan. Table 6-1 shows the amount budgeted and awarded, as well as the percentage of execution for the performance of R&D activities in each of the R&D plans.

For budgetary and organisational purposes, a project is considered to belong to the R&D Plan to which the time horizon of its starting year corresponds.

Table 6-1: *Amounts budgeted and awarded in each of Enresa's R&D Plans*

R&D Plan	Budgeted in the plan (€)	Awarded	% execution
1 (1987-1991)	32.1	9.2	28.7%
2 (1991-1995)	43.3	37.0	85.5%
3 (1995-1999)	50.4	42.1	83.5%
4 (1999-2003)	29.7	35.1	118.2%
5 (2004-2009)	28.3	22.4	79.2%
6 (2009-2013)	22.3	17.8	79.8%
7 (2014-2018)	27.0	17.8	66.02%
8 (2019-2023)	31.7	14.1	44.56%
9 (2024-2028)	31		

The distribution of the amounts awarded each year by Areas of the 8th R&D Plan for the period 2019-2023 is indicated in Table 6-2. The R&D projects awarded in any given year are those considered to relate to said year.

Given that several projects are, or have been, cost-shared with other organisations, especially those related to participation in the European Framework Programmes (EURATOM), the value of the information and knowledge generated by the R&D is higher than indicated.

The new Plan also envisages the development of important projects involving the participation of several organisations, both nationally and internationally (EURAD-2), sharing costs and equipment, so that the value of the information to be generated, for the same investment by Enresa, will be much greater.

Table 6-2: *Annual amounts awarded by R&D Plan Areas (2019-2023)*

	2019	2020	2021	2022	2023	Total
1. Waste technology	328,326	2,943,199	843,151	139,239	1,477,394	**5,731,309**
2. Treatment and conditioning technology and processes, and decommissioning		588,471			2,258,170	**2,846,641**
3. Containment materials and systems	1,329,467	588,879	1,526,164	799,750		**4,244,260**
4. Evaluation of safety, radiation protection and associated modelling behaviour	211,251	333,613		109,980	395,217	**1,050,061**
5. Infrastructure and coordination	62,100					**62,100**
	1,923,144	**4,454,162**	**2,369,315**	**1,048,969**	**4,130,781**	**13,934,371**

In addition, the possibilities or opportunities promoted by the Ministry of Science and Innovation and Universities, through the corresponding calls for proposals, will be analysed with regard to public support to carry out R&D projects, within the framework of the State Plans for Scientific and Technical Research and Innovation.

Graphically, the information in Table 6-2 is shown in Figure 6-1 and Figure 6-2 for the amounts awarded under the 8th R&D Plan (2019-2023) per Area, in absolute values and in percentages.

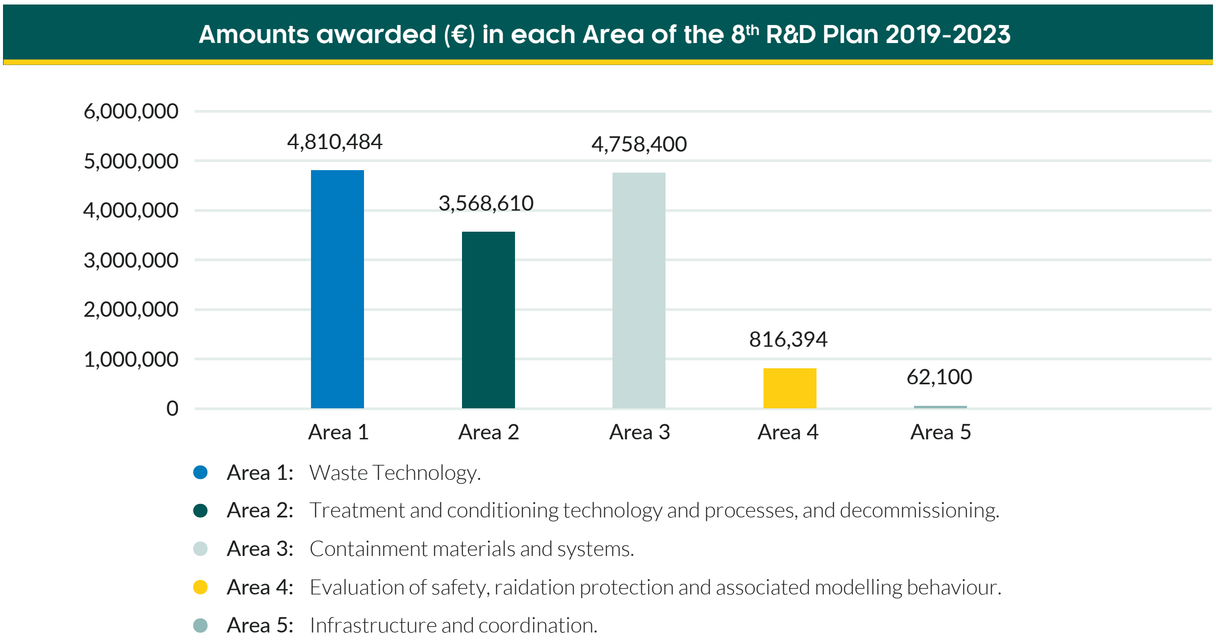


Figure 6-1: *Amounts awarded (€) in each Area of the 8th R&D Plan (2019-2023)*

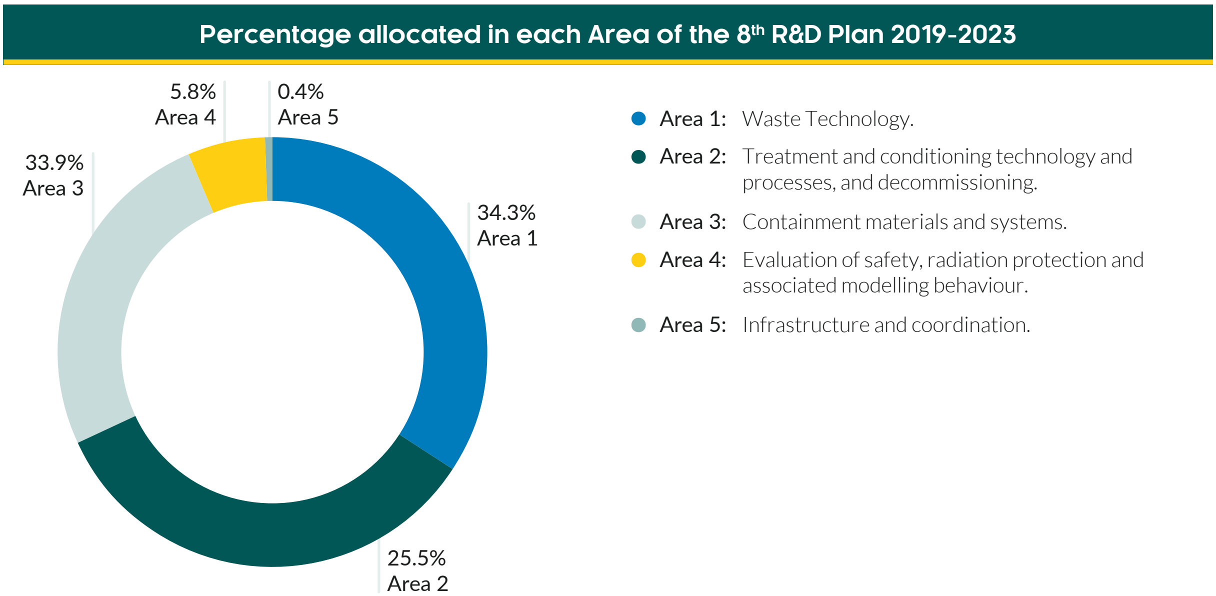


Figure 6-2: *Percentage allocated in each Area of the 8th R&D Plan (2019-2023)*

It is also interesting to note the number of projects per Area of the 8th R&D Plan in absolute values and in percentages (2019-2023), shown in Figure 6-3 and in Figure 6-4.

Number of projects per Area of the 8th R&D Plan 2019-2023

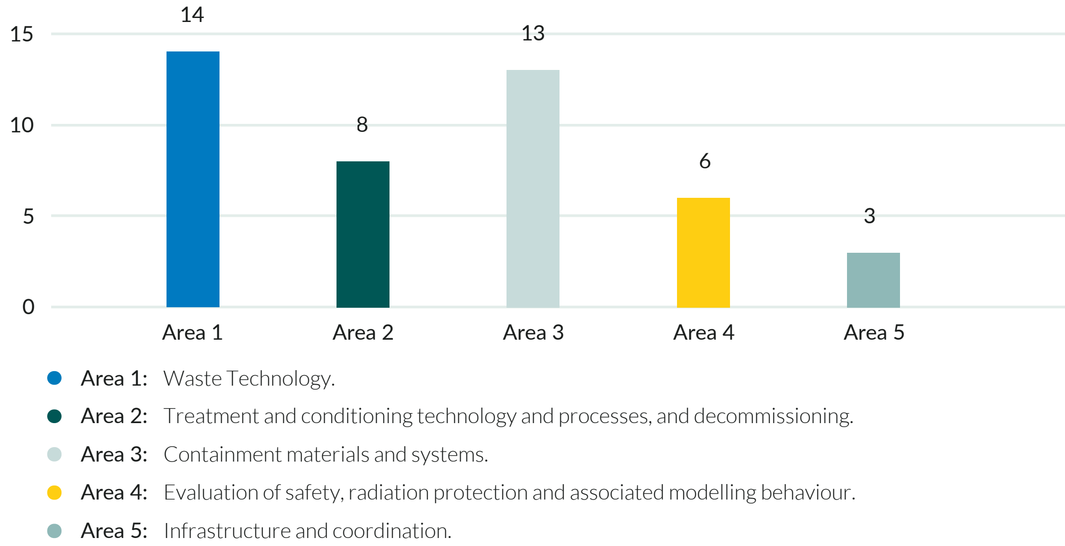


Figure 6-3: *Number of projects by Area of the 8th R&D Plan (2019-2023) in absolute values*

Number of projects (%) by Areas of the 8th R&D Plan 2019-2023

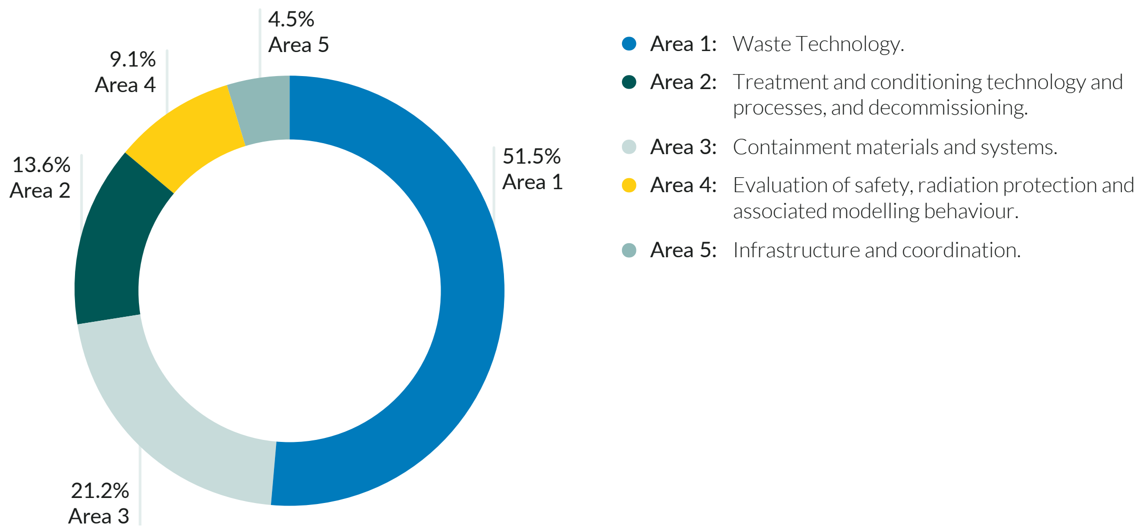


Figure 6-4: *Number of projects by Area of the 8th R&D Plan (2019-2023) in percentages*

Enresa collaborates with different entities (universities, companies, research centres, etc.) for the development of its R&D projects. Figure 6-5 shows the number of projects in the 8th R&D Plan (2019-2023) by participating entities.

Number of projects by entities of the 8th R&D Plan 2019-2023

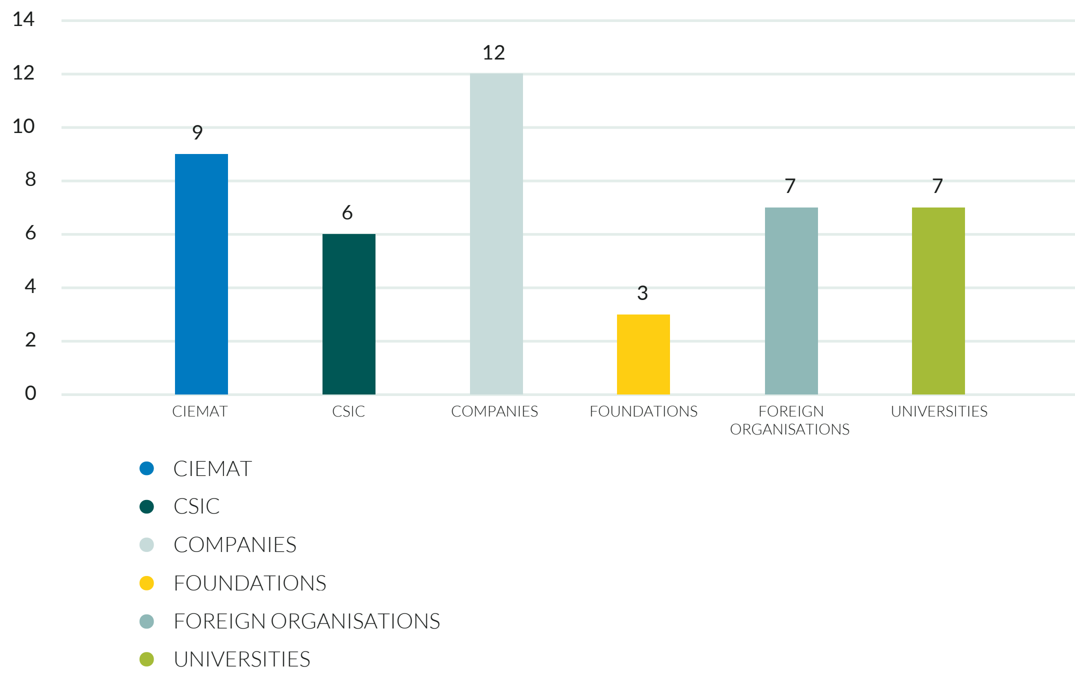


Figure 6-5: *Number of projects by entities of the 8th R&D Plan*

Based on the forecast of new projects for the 9th R&D Plan (2024-2028), the following figure shows the estimated number of new projects envisaged by Area for the period 2024-2028.

Number of projects foreseen per Area in the 9th R&D Plan 2024-2028

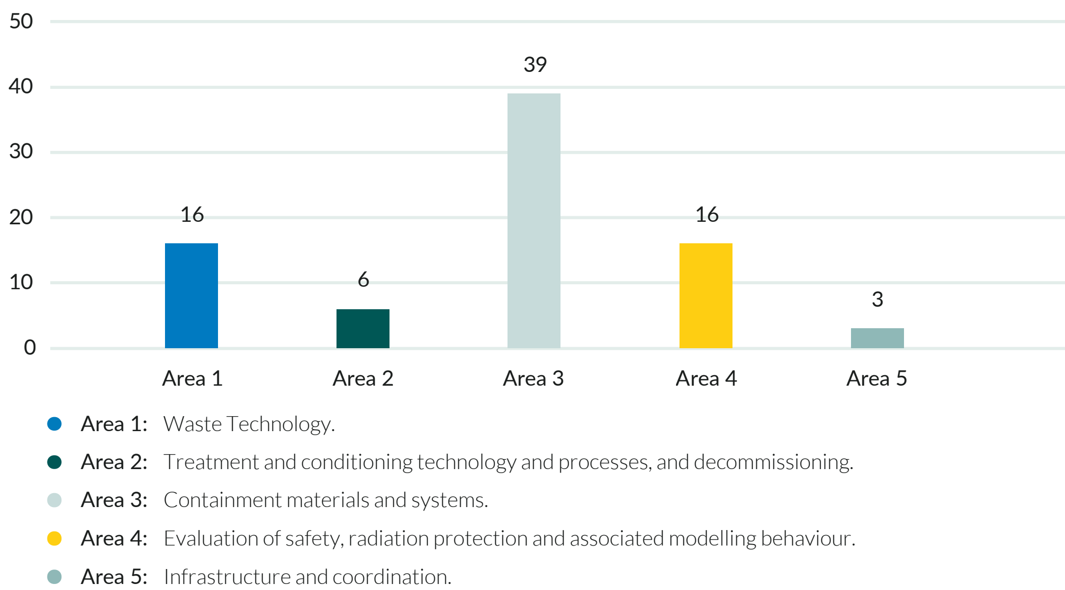
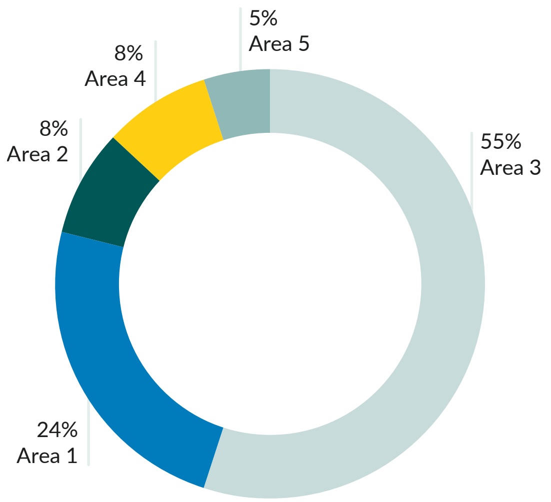


Figure 6-6: *Number of projects envisaged per Area in the 9th R&D Plan (2024-2028)*

The following is the estimated R&D investment forecast, in percentage, by Area for the period 2024-2028. (Figure 6-7)

Planned investment (%) by Area in the 9th R&D Plan 2024-2028



- **Area 1:** Waste Technology.
- **Area 2:** Treatment and conditioning technology and processes, and decommissioning.
- **Area 3:** Containment materials and systems.
- **Area 4:** Evaluation of safety, radiation protection and associated modelling behaviour.
- **Area 5:** Infrastructure and coordination.

Figure 6-7: *Estimated planned investment (%) by Area in the 9th R&D Plan (2024-2028)*

7. Monitoring of the plan

In 2023, Enresa's International Cooperation and R&D Department prepared a procedure for the coordination and monitoring of R&D projects, with the aim of regulating the establishment, definition and monitoring of R&D projects at Enresa, in accordance with the UNE 166002: 2021 standard. R&D&I management. R&D&I management system requirements.

Specifically, the purpose of the procedure is to establish and define Enresa's R&D projects in accordance with the R&D Plan in force at any given time, and to control and monitor these projects during their development and define their products, in order to apply their results to radioactive waste management.

7.1. Project proposals

In accordance with the Procedure for the coordination and monitoring of R&D projects (079-PC-CY-0001), it is up to the heads of department to propose new R&D projects, which will be approved by the Technical Director, as well as to designate the project leaders.

The subject matter and classification of R&D projects is determined by taking into account the degree of technological development achieved to date, national and international boundary conditions, and the radioactive waste management and nuclear facility decommissioning milestones to be addressed.

The established classification facilitates the technical and economic monitoring of projects. Any R&D project to be formalised must be assigned to one of the Areas and Lines of Enresa's R&D Plan. Each project must have aims that are in line with at least one of the lines indicated in the R&D Plan. A project may partially fit its aims into more than one line, in which case it will be included in one of them, at the discretion of the R&D coordination manager, taking into account the arguments of the proposing department or management and of the R&D coordination unit.

7.2. Control and monitoring tools

The control and monitoring of the R&D Plan, as a whole and of each project in particular, is part of the R&D management system. This is regulated in the aforementioned Procedure for the coordination and monitoring of R&D projects

Three levels of control of R&D activities are considered:

1. At project level. This level mainly involves the person responsible for project management and his or her department head.
2. At the R&D coordination level. The R&D coordination manager, the R&D coordination unit, the R&D project managers and their department heads are involved.
3. At management level. The managers of the Technical Directorate, the heads of department and the person in charge of R&D coordination are involved.

1. Control and monitoring at project level

The projects promoted and managed by Enresa will have a monitoring system so that the degree of progress and possible deviations with respect to the established schedule may be known, in order to anticipate the corrective actions deemed appropriate at any given moment. Different methods exist to carry out this task, the most common of which are listed below.

- Regular meetings. These meetings are scheduled from the start of the project and are usually held every six months, sometimes every three months. They are attended by at least the project leaders from each party. In some projects, usually those that take the form of collaboration agreements, a monitoring committee is formally established which must meet at least twice a year. Minutes must be drawn up of all these meetings, recording the agreements reached and the technical and economic monitoring of the project.
- *Ad hoc* meetings. These are convened to deal with specific topics stemming from the development of the project (pre-set milestones, decision points, unforeseen results, etc.).
- Technical monitoring reports. These are prepared every six months, although another frequency, such as quarterly or annually, may be decided on the basis of the expert judgement of the R&D coordinator and the head of the corresponding department, depending on the nature and duration of the work to be carried out.
- Documented evidence of the achievement of project milestones.

- Delivery of planned project products.
- Issue of the final project report.
- Issue of a poster proposal.
- Memory card, a tool for the management of R&D assets, which summarises very concisely an Enresa R&D project or activity, the content of which is described in Chapter 5, in the section Line 5.3. Asset management.

2. Control and monitoring at R&D coordination level

The R&D coordination manager must be aware of the status of Enresa's R&D activities in order to have reasonably up-to-date knowledge of the state of development of the R&D Plan, and of the projects under development, in the process of being formalised or planned for the future.

The result of this monitoring involves the following actions:

- Database of R&D projects and their products.
- Preparation of an Annual Report on R&D with the state of progress of the Plan.
- Preparation of the R&D Results Report at the end of each Plan.
- Input for annual budgets.
- Proposal for a new R&D Plan every five years.
- Coordination in the preparation of workshops to disseminate the R&D Plan (R&D days), if appropriate.

3. Control and monitoring at Enresa's management level

In the case of Enresa, this level of control corresponds to the Technical Director. The latter will monitor and control R&D projects and activities on the basis of the ad hoc documentation requested from the corresponding directorates (normally Engineering, El Cabril Disposal Centre, Operations) or from the R&D coordination manager.

Two specific monitoring tools exist:

- 1.- R&D Project Evaluation and Monitoring Committee. The fundamental mission of the committee is to enable Enresa's Technical Director to be aware of the evolution and status of R&D activities and, consequently, to make informed decisions. The Committee meetings will review the state of R&D, either as a whole, or particular aspects, or both, depending on the specific purpose of the meeting call made by the Technical Director (or whoever he/she delegates). This Committee shall meet in ordinary session once every six months. The Technical Director may convene as many extraordinary sessions as he/she deems appropriate in order to fulfil its objectives.
- 2.- Monitoring Committee for Framework Collaboration Agreements. This type of tool has been set up to monitor Enresa's R&D activities with other entities (CIEMAT, CSIC,

universities, etc.) with which framework collaboration agreements have been entered into. This committee normally involves the directors, heads of department and the R&D coordinator, as well as equivalent managers of the other organisations involved. The functions and operating mechanism are defined in the framework collaboration agreement between the parties involved in accordance with prevailing legislation.

The basic functions in relation to the monitoring and control of R&D projects of this committee are:

- Monitor the status of each of the R&D projects (usually defined with specific agreements), both in technical and economic aspects, and evaluate their development and completion.
- Assess joint R&D needs, and make, where appropriate, proposals for new projects to be developed jointly.
- Others to be defined in the framework agreement.

8

8. Technology surveillance, R&D forums, international collaboration

Enresa's R&D management includes, in order to be more effective, the development of *technology surveillance* and competitive intelligence processes, as suggested in the UNE 166006:2018 standard.

- The first concept, technology monitoring, refers to capturing, analysing, disseminating within the organisation and exploiting scientific, technical, legislative, regulatory, economic, market and social information useful to Enresa. This information is necessary for knowledge of the environment, whether national, European or global, related to radioactive waste management.
- Competitive intelligence refers to the analysis, interpretation and communication of information of a strategic nature that is transmitted within the organisation and thus influences decision-making.

Technology monitoring is mainly addressed at Enresa through participation in various forums in which information and experiences are exchanged, and which include the collaborative preparation and development of R&D activities. The aims of these forums, *R&D exchange forums* in this document, normally include communication within the community of members, the search for synergies and the promotion of new projects or joint R&D activities.

Competitive intelligence activities are developed internally in the company through the preparation of reports on participation in international meetings, which are widely distributed to the departments concerned. Furthermore, reports are issued on R&D activities with the developments made and experiences gained, which are discussed internally in the departments and directorates involved.

The most important forums in which Enresa participates are grouped as follows:

- EURATOM framework programmes.
- R&D platforms: CEIDEN, PEPRI, IGD-TP and monitoring is carried out with specific interactions both via the SNETP platform and in those corresponding to radiation protection.
- Technical Committees and subsidiary groups of the Nuclear Energy Agency of the OECD (OECD-NEA).
- Groups and projects, forums of the International Atomic Energy Agency (IAEA).
- Spanish Nuclear Society (SNE) and the Nuclear Forum.
- EDRAM, Agencies Club.
- Others (EPRI, HUG, ...)
- International collaboration between organisations, agencies.
- Underground laboratories.

8.1. EURATOM framework programmes

The two treaties establishing the European Economic Community (EEC) and the European Atomic Energy Community (EAEC and EURATOM) were signed on 25 March 1957. Both treaties established complementary framework programmes for research and development.

The Euratom Treaty, originally set up to coordinate Member States' research programmes for the peaceful use of nuclear energy, now contributes to the pooling of knowledge, infrastructure and financing of nuclear energy [EUR-Lex - xy0024 - ES - EUR-Lex (europa.eu)].

Horizon Europe is the European Union's (EU) 10th Framework Programme for Research (and Innovation) and spans the period 2021-2027. The overall aim of the programme is to achieve a scientific, technological, economic and society-based impact of EU investments in R&I, thereby strengthening its scientific and technological bases and fostering the competitiveness of all Member States. This is complemented by the EURATOM Research and Training Programme (2021-2025) covering nuclear research (and innovation) (https://op.europa.eu/en/publication-detail/-/publication/f358e7de-b2ca-11eb-8aca-01aa75ed71a1/language-en). As is customary, it will be extended by two additional years, until 2027, and thus remains in line with the EU programme.

The EURATOM programmes are developed in biannual plans, with the second Horizon Europe programme being the *Euratom Work Programme 2023-2025*, the first of these whose actions fall within the timeframe of Enresa's 9th R&D Plan.

As a result, project proposals have been prepared at a European level in 2023 that can be developed from 2024 onwards, if they continue without interruption. Among the activities that may be co-funded for Enresa is the "HORIZON-EURATOM-2023-NRT-01-07: Innovative technologies for safety and excellence in **decommissioning**, including robotics and artificial intelligence" line and the actions aimed at renewing the joint European programme, initiated with EURAD, in EURAD-2, known under this programme as "Co-funded **European partnership** on radioactive waste management".

Other co-fundable lines include nuclear material, partitioning and transmutation of minority actinides, nuclear data enhancement and radiation safety.

In EURAD-2, following the established rules of participation, Enresa and CIEMAT are the only Spanish actors benefiting from the partnership and are nominated for this purpose by their respective supervising ministries; they are the so-called "mandated actors". In addition to the mandated actors, other organisations may participate as affiliated entities of one of the mandated actors, provided that there is a prior and independent link for carrying out R&D activities under EURAD-2.

Enresa and CIEMAT, together with other participants from the rest of the EC member countries and other partners, have participated in the definition and scope of the activities to be addressed in EURAD-2.

As a historical summary, the following tables include the projects of the 5th Euratom framework programmes onwards in which Enresa has participated or participates. This participation may be direct, as part of the research teams, indirect, supporting the activities of third parties, or as advisors included in the group known as end users of the project results.

Table 8-1: *EURATOM projects in which Enresa has taken part since 1998*

EURATOM projects in which Enresa has taken part since 1998							
Enresa's direct participation	Project	Start date	End date	Total budget	Spanish participation budget	Awarded by Enresa to third parties	EC returns (Enresa and other Spanish groups)
5th Framework Programme							
No	ACTAF			1,626,837	219,987	219,987	109,998
No	ADOPT			426,711	15,384	15,384	15,384
Yes	BENCHPAR			1,474,062	174,269	174,269	87,134
Yes	BENIPA			1,528,430	433,631	55,217	183,859
Yes	BIOCLIM			1,587,115	232,490	232,490	116,244
No	BIOMOSA			1,041,768	130,300	n/a	65,150
No	BORIS			1,043,926	60,000	30,294	30,000
No	CALIXPART			2,261,657	174,015	174,015	118,806
Yes	CDD			282,733	28,601	0	28,601
Yes	COMPAS			472,361	23,958	0	23,958
Yes	Container corrosion			1,250,721	370,724	360,596	139,000
Yes	CROP			747,449	64,015	23,139	64,015
No	DACAPO			908,589	138,772	138,772	69,386
Yes	EB			1,577,185	606,976	556,893	250,073
Yes	ECOCLAY II			2,211,491	304,867	142,499	201,388
No	FASSET			2,586,252	213,028	80,930	106,514
Yes	FEBEX II			5,126,000	3,011,987	3,011,987	1,221,198
Yes	GASNET			259,000	17,269	0	17,269
Yes	HE			2,026,734	471,871	458,663	235,935
Yes	Interlab Analysis			873,572	222,379	222,379	111,190
Yes	MODEX-REP			1,427,218	144,001	117,162	72,000
No	MUSE			4,056,932	292,373	292,373	146,186
No	N_TOF_			6,520,905	646,220	646,220	374,009
Yes	NANET			309,896	9,400	0	9,400
Yes	NET-EXCEL			446,218	70,571	0	65,600
Yes	PADAMOT			1,237,000	265,266	751,265	132,633
No	PARTNEW			11,794,529	232,500	232,500	140,000
No	PDS-XADS			12,101,018	157,504	157,504	78,752
Yes	PROTOTYPE REPOSITORY			5,290,555	341,410	341,410	145,296
No	PYROREP			3,556,438	454,528	454,528	227,264
Yes	RETROCK			474,000	75,000	n/a	75,000
Yes	SFS			2,725,201	424,908	424,908	202,700
Yes	SPIN			1,361,275	203,538	0	101,769
No	KEY			6,061,890	504,400	240,081	252,200
Yes	TN on MONITORING			20327,084	38,740	0	38,740
Yes	TND			446,218	47,653	0	47,653
Yes	VE			1,623,855	577,018	467,154	288,508
	TOTAL			**89.072.825**	**11.399.553**	**10.022.619**	**5.592.812**

EURATOM projects in which Enresa has taken part since 1998							
Enresa's direct participation	Project	Start date	End date	Total budget	Spanish participation budget	Awarded by Enresa to third parties	EC returns (Enresa and other Spanish groups)
6th Framework Programme							
Yes	CARD			541,419	43,180	0	24,637
Yes	CND			749,991	63,586	0	63,586
No	ERICA			3,900,000	300,319	31,500	46,500
Yes	ESDRED			18,131,001	1,624,001	783,053	647,260
No	EUROPART			11,499,785	624,747	736,330	312,374
No	EUROTRANS			42,626,412	792,430	276,344	247,000
Yes	FUNMIG			15,006,980	3,130,080	1,622,000	1,490,080
Yes	MICADO			1,750,482	361,062	0	270,199
Yes	NF-PRO			16,837,330	3,580,700	1,780,200	1,555,500
Yes	OBRA			320,748	93,847	0	93,847
Yes	PAMINA			7,617,169	765,489	61,048	386,832
Yes	RED IMPACT			3,512,021	381,612	61,048	194,272
	TOTAL			**122,493,338**	**11,761,053**	**5,351,523**	**5,332,087**
7th Framework Programme							
End User	FIRST NUCLIDES	I-2012	XII-2014	4,741,261	Not available	--	n/a
End User	ReCoSy	IV-2008	III-2012	6,198,797	Not available	--	n/a
Yes	CARBOWASTE	IV-08	III-13	12,081,363	956,443	--	516,478
Yes	MODERN	V-09	IV-13	5,111,484	760,448	192,100	380,223
Yes	PEBS	III-10	II-14	6,539,009	2,598,043	529,673	1,372,190
Yes	PETRUS II	I-09	XII-11	1,913,356	240,000	--	88,260
Yes	PETRUS III	IX-13	VIII-16	2,116,531	327,902	--	153,000
Yes	CAST	X-13	III-18	14,701,467	327,867	--	147,540
	TOTAL			**53,403,268**	**5,210,703**	**721,773**	**2,657,691**
Horizon 2020 Programme							
Yes	BEACON	VI-2017	V-2021	4,051,777	466,315	--	466,315
Yes	MODERN2020	VI-2015	3V-2019	6,813,013	724,691	--	724,691
End User	CHANCE	VI-2017	III-2022	4,269,850	--	--	--
End User	DISCO	VI-2017	IX-2021	4,692,067	No access	--	
End User	INSIDER	VI-2017	IX-2021	4,173,870	No access	--	
End User	CEBAMA	VI-2015	V-2019	5,952,944	No access	--	
Collaboration	JOPRAD	2015	2017	1,785,944	--	--	--
Yes	EJP1: EURAD (I)	VI-2019	V-2024	61,786,887	5,505,991	681,764	3,028,290
Yes	SHARE	VI-2019	III-2022	1,525,925	69,418	--	69,418
Yes	Inno4Graph	IX-2020	X-2023	3,818,635	417,856	--	307,691
Si	PLEIADES	X-2020	XI-2023	3,571,016	81,167	--	81167
Yes	PREDIS	IX-2020	VIII-2024	23,433,613	1,970,229	311,000	1,155,450
	TOTAL			**125,875,541**			
Horizon Europe Programme							
Yes	EURAD-2	2024	5 years	In progress			
Yes	I4G 2	2024	3 years	In progress			

8.1.1. Strategic Research Agendas (SRAs) of EURATOM projects and programmes

During the implementation of the Horizon 2020 programme, three projects/programmes, SHARE, PREDIS and EURAD (described in Chapter 5) developed three Strategic Research Agendas (SRA) according to the theme of each project/programme. These public documents serve as a basis for the preparation of R&D and RD&D activities for the coming years.

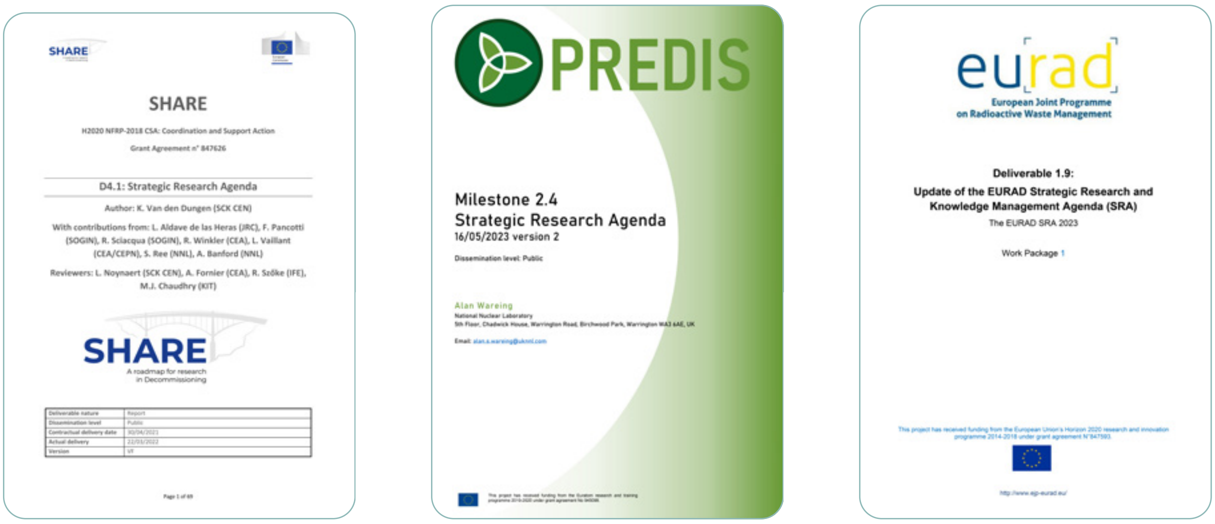


Figure 8-1: *Cover pages of the Strategic Research Agendas of the Horizon 2020 framework programme projects corresponding to the SHARE, PREDIS and EURAD projects*

These documents are the result of long and intensive collaborative work that has taken into account not only the indications of the project/programme participants (Enresa among others) but also suggestions from other institutions and experts worldwide invited to this end. They are as follows:

Strategic Agenda of the SHARE project *(StakeHolders-based Analysis of REsearch for Decommissioning)*. The document has identified knowledge gaps and defines and prioritises research topics based on a weighted survey analysis. In addition to innovation and technological challenges, it also addresses non-technological issues in the fields of planning, costing, knowledge management and exchange of best practices.

It is organised according to the following subject areas: 1, safety, radiation protection and resource management; 2, characterisation; 3, management of radioactive materials and waste from decommissioning; 4, site preparation, decommissioning, decontamination and demolition activities; 5, environmental remediation; 6, final survey and release from regulatory control.

Strategic Agenda of the PREDIS project *(PRE-DISposal management of radioactive waste)*. This SRA document was developed based on the needs of PREDIS and the End User Group (EUG), identified through consultations with project partners and the wider stakeholder community.

It was prepared considering seven key technical topics of interest, in descending order as follows: characterisation; waste acceptance criteria (WAC); conditioning and packaging; treatment and processing; inventory; technology selection; and optimisation. In addition, socio-economic aspects and legislation; knowledge management, and finally, stakeholder involvement have been included.

EURAD Strategic Agenda. The agenda, in its second version in 2023, presents identified needs of common interest that may require research, development and demonstration (RD&D), strategic studies (think tank) and/or knowledge management activities for the entire radioactive waste management chain, from cradle to grave.

In order to make the SRA more useful in the future definition of work packages, these needs have been categorised using a set of 'drivers'. This helps the SRA to focus more on the "what" can be done and the "why". The use of drivers replaces the ranking scheme of high, medium and low priority scores used in the 2019 version of the SRA.

The guiding factors that have been identified are: security of implementation; tailor-made solutions; scientific knowledge; innovation for optimisation; involvement of society and knowledge management.

This agenda categorises the identified needs into seven themes: 1: national programme management; 2: predisposal activities; 3: engineered barrier systems; 4: geosphere; 5: design; 6: siting and licensing; 7: safety case.

8.2. Nuclear Energy Agency (NEA)

The **Nuclear Energy Agency**, known by its acronym NEA, is a body of the Organisation for Economic Co-operation and Development (OECD), founded in 1958. It is an intergovernmental agency that facilitates cooperation between countries with advanced nuclear technology infrastructures in order to pursue excellence in nuclear safety, technology, science, environment and legislation.

The NEA's mission, as reflected in its strategic plan, is to assist its members in developing, through international co-operation, the scientific, technological and legal basis for the safe, environmentally-sound and economic use of nuclear energy for peaceful purposes, as well as to conduct assessments and promote a common understanding of key issues, in support of government decisions on nuclear energy policy and as an aid to broader OECD policy analysis in areas such as energy and sustainable development.

Currently, 33 countries from Europe, America and the Asia-Pacific region are members of the NEA: Argentina, Finland, Italy, Poland, Sweden, Australia, France, Japan, Portugal, Switzerland, Austria, Germany, South Korea, Romania, Türkiye, Belgium, Greece, Luxembourg, Russia, United Kingdom, Canada, Hungary, Mexico, Slovak Republic, United States, Czechia, Iceland, Netherlands, Slovenia, Denmark, Ireland, Norway and Spain.

The NEA is organised into six divisions, Nuclear Safety Technology and Regulation; Radioactive Waste Management and Decommissioning; Radiological Protection and Human Aspects of Nuclear Safety; Nuclear Science and Education; Nuclear Technology Development and Economics; and Nuclear Law. The NEA's work programme is developed and implemented through committees made up of highly qualified international experts from member countries assisted by a secretariat. Joint international projects are also developed on technical or scientific topics, as well as programmes of joint interest.

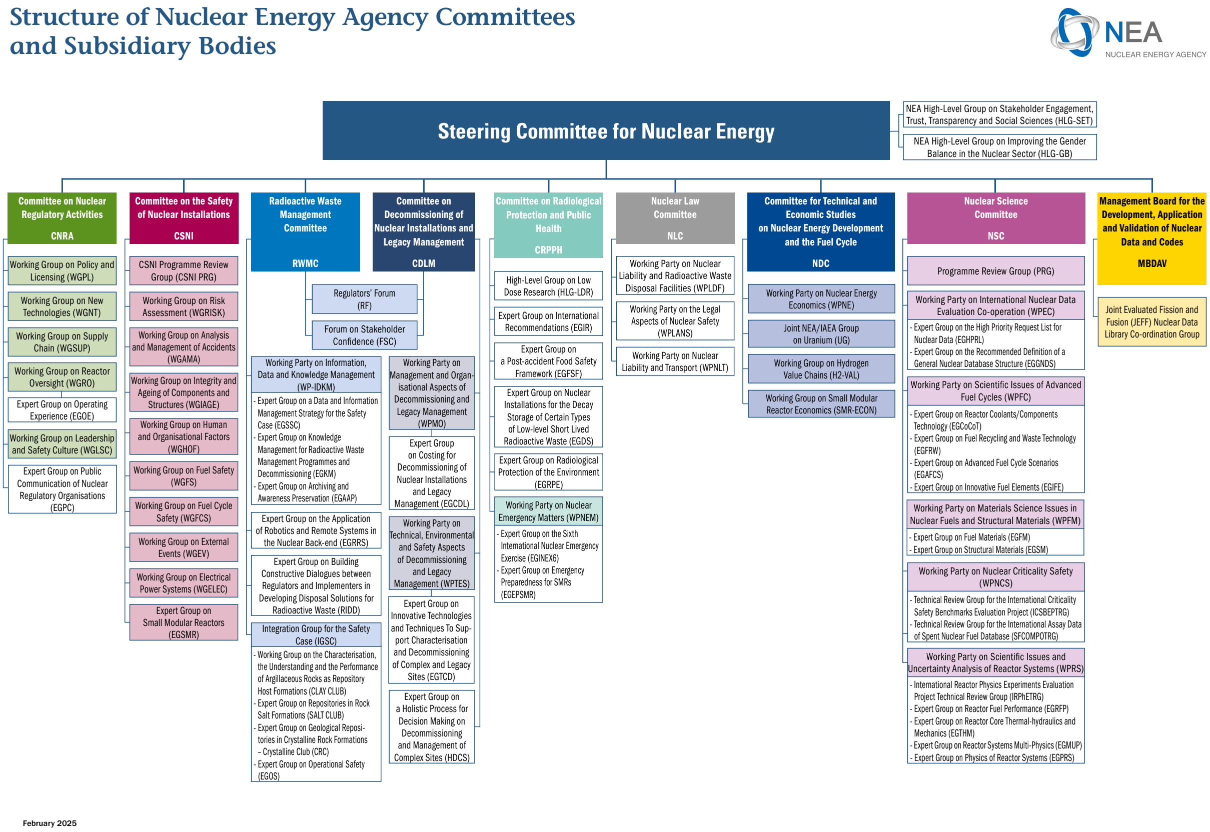


Figure 8-2: *Organisation of the Nuclear Energy Agency, OECD-NEA in technical committees and subsidiary groups (NEA, February 2025)*

Figure 8-2 shows the technical committees and their subsidiary groups as of May 2024. Participation in the following committees is on a regular basis, and depending on the activities covered, this list may be expanded or reduced:

- Radioactive Waste Management Committee (RWMC) and in its subordinate groups, entitled Forum on Stakeholder Confidence (FSC), Integration Group for the Safety Case (IGSC); Working Group on the Characterisation, the Understanding and the Performance of Argillaceous Rocks as Repository Host Formations (CLAY CLUB); occasionally in Working Party on Information, Data and Knowledge Management (WP-IDKM); Expert Group on Building Constructive Dialogues between Regulators and Implementers in Developing Disposal Solutions for Radioactive Waste (RIDD).
- Committee on Decommissioning of Nuclear Installations and Legacy Management (CDLM), and in its subordinate groups, which at present are the Working Party on Management and Organisational Aspects of Decommissioning and Legacy Management (WPMO); Expert Group on Costing for Decommissioning of Nuclear Installations and Legacy Management (EGCDL); Working Party on Technical, Environmental and Safety Aspects of Decommissioning and Legacy Management (WPTES); Expert Group on a Holistic Process for Decision Making on Decommissioning and Management of Complex Sites (HDCS).
- Nuclear Law Committee (NLC) and participation in subordinate working groups (Working Party on Nuclear Liability and Radioactive Waste Disposal Facilities (WPLDF)).

- Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC).
- Nuclear Science Committee (NSC).

Enresa participates in two international NEA projects:

- Joint Project Co-operative Programme for the Exchange of Scientific and Technical Information on Nuclear Installation Decommissioning Projects (CPD).
- International Joint Project on Socio-economic Assessment of Radioactive Waste Management (JPOSEA/RWM).

In addition, Enresa is present as assistants, speakers or members of coordination teams at workshops and conferences organised by the NEA.

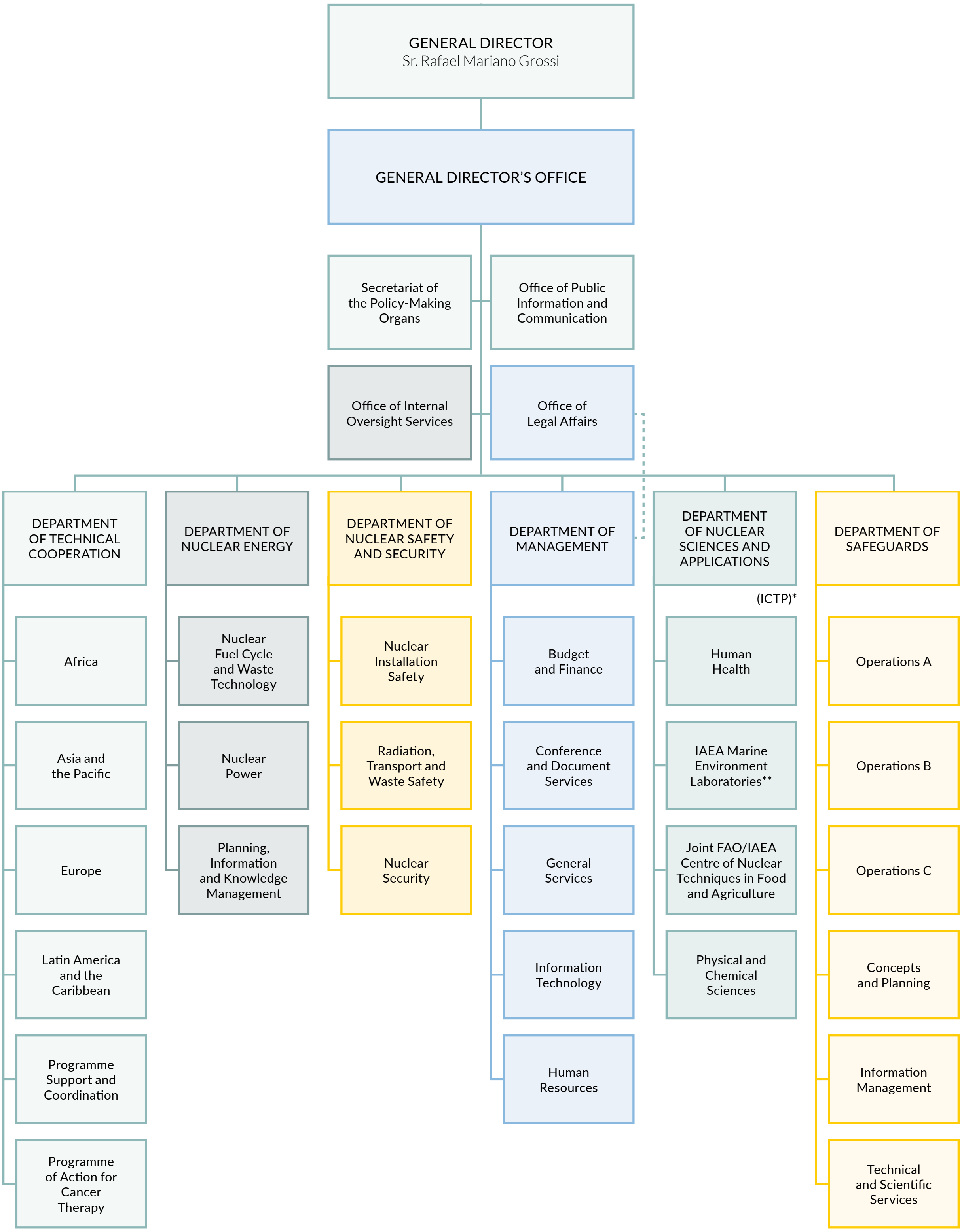
8.3. International Atomic Energy Agency (IAEA)

The International Atomic Energy Agency was set up in 1957 with the mission to work for the peaceful, safe and secure uses of nuclear science and technology, thereby contributing to international peace and security. It is the world's leading intergovernmental forum for scientific and technical cooperation in the nuclear field. All countries that are members of the United Nations are members of the Agency. As of April 2023, its membership stands at 177.

The services provided by the IAEA range from technical cooperation in support of the least developed countries in nuclear matters to coordinated research projects or the establishment of networks of excellence in various aspects of radioactive waste management.

As regards Enresa's own participation, it takes part in numerous activities, mainly organised by the *Nuclear Fuel Cycle and Waste Technology Department* and, to a lesser extent, by the *Nuclear Safety, Technology and Physics Department*. With respect to the networks, committees and working groups in which it participates, the following are noteworthy:

- Technical Working Group on Nuclear Fuel Cycle Options and Spent Fuel Management (TWG-NFCO).
- Forum on the Safety of Near Surface Disposal.
- IAEA International Low Level Waste Disposal Network (DISPONET).
- International Decommissioning Network (IDN).



* The Abdus Salam International Centre for Theoretical Physics (ICTP), legally referred to as the "International Centre forTheoretical Physics", is operated as a joint programme by UNESCO and the Agency. Administration is carried out by UNESCO on behalf of both organizations.

** With the participation of UNEP and IOC.

Figure 8-3: *IAEA Organisational Chart (from IAEA Annual Report 2023)*

- Coordinated Research Projects (CRP):
  - CRP on PERFORMANCE ASSESSMENT OF STORAGE SYSTEMS FOR EXTENDED DURATIONS (PASSED)
  - CRP on Spent Fuel Characterisation
  - CRP on Spent Fuel Research and Assessment (SFERA)
- Status and Trends in Spent Fuel and Radioactive Waste Management.
- International conferences of interest (decommissioning, radioactive waste management, etc.).

In addition, Enresa participates in technical and consultancy meetings on specific topics in order to prepare reports that can be published by the organisation and are of interest to Enresa: inventories, management of irradiated graphite, site selection criteria, management of sealed sources, etc.

8.4. Spanish platforms: CEIDEN and PEPRI

Figure 8-4: *Logos of the R&D platforms PEPRI, CEIDEN, IGD-TP and SNETP*

- CEIDEN

The Nuclear Fission Energy R&D Technological Platform, CEIDEN, defines itself in its Statutes as "a meeting forum for the most relevant representatives of R&D (Universities, Technology Centres, Industry, Public Administration, etc.) in Spain, to foster communication within the nuclear fission community through the promotion of expert meetings, working groups and the drawing up of documentation that may be useful to this community and to the managers of R&D Plans at all levels of the Public Administration". The platform was created in 1999, initially as the Strategic Nuclear R&D Commission, CEIDEN, at the request of the Ministry of Industry and Energy.

The general aim of CEIDEN is "to develop R&D&I activities aimed at the safe, reliable and economic operation of current nuclear facilities and the nuclear fuel cycle, and the development of potential new nuclear projects". The actions are based on working groups and meetings. CEIDEN has no legal entity, so the development of projects is carried out by the members of the consortium, historically in the form of collaboration agreements.

Technological challenges

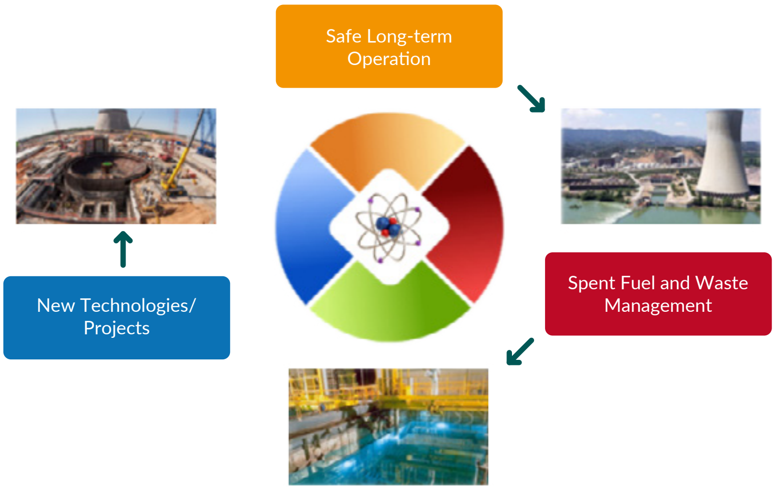


Figure 8-5: *Technological challenges defined in the CEIDEN platform (https://ceiden.com/)*

The platform is managed and coordinated, by delegation of the **General Assembly**, by a **Management Council** made up of 15 representatives of electricity utilities, fuel cycle companies (Enresa among others), R&D institutions, universities, engineering and construction companies, capital goods and services companies, and also includes representatives of the CSN, the Ministry of Economy and the ministry of Enresa's supervisory body (currently MITECO).

CEIDEN has, or has had, the following R&D activity programmes: Materials Group; SIREN Group: Nuclear Reactor Simulation; CAMP Programme - Spain; Socio-technical Research Working Group; KEEP+ Programme; ZIRP Project [Completed]; Jules Horowitz Reactor Project; Concretes; Harnessing of Materials from Zorita; Storage and Transport of SF; ES-NII Spain; Neutron Pattern Laboratories Users Group (CEIDEN-GUN); and Capacities of the Spanish Nuclear Industry. Enresa participates or has participated in several of them.

- PEPRI

The Spanish Society for Radiation Protection created the "National Platform for R&D in Radiation Protection" (PEPRI), in 2014 in order to "strengthen and structure the collaboration of all actors involved in Spanish R&D related to radiation protection" as stated in its Statutes. The general aim is defined in the aforementioned document as "promoting R&D activities aimed at protection against ionising radiation, as well as the knowledge and minimisation of its effects".

The functional structure of the platform is based on a **General Assembly**, which is the supreme governing body and is made up of all the members, which delegates the management and coordination of the platform's operation to a **Management Council**. The Management Council is made up of 18 representatives from the following sectors: hospitals; R&D institutions and universities; industry and energy (Enresa falls in this category); engineering and service companies; equipment manufacturers and commercialisation companies; the regulator (CSN) and other entities.

11 thematic working groups have been created to identify specific R&D lines and projects. 1. Planned exposure area; 2. Existing exposure area; 3. Emergency and physical safety area; 4.

Public and environment area; 5. Radioactive waste management area; 6. Non-ionising radiation area; 7. Medicine area; 8. Radiobiology and epidemiology area; 9. Detection and measurement area; 10. Enresa is the coordinator of Working Group 5. Radioactive waste management area.

As with CEIDEN, any actions that may arise are carried out directly by the members involved.

8.5. European R&D platforms

Enresa has been a member of the European **IGD-TP** platform (*Implementing Geological Disposal of Radioactive Waste Technology Platform, www.igdtp.eu*) since 2009, and is involved in the activities of **SNE-TP** (*Sustainable Nuclear Energy Technology Platform, www.snetp.eu*). There are others related to ionising radiation protection, of which it has been informed through other Spanish participants.

- IGD-TP (Implementing Geological Disposal of Radioactive Waste Technology Platform)

[Text from the platform's website https://igdtp.eu/about/].

The objective of the Implementing a Geological Disposal Technological Platform (IGD-TP) is to launch and implement strategic European initiatives to facilitate the gradual implementation of safe and secure deep geological disposal of SF, HLW and other long-lived radioactive waste. It also aims to address outstanding scientific, technological and society-based challenges and to support European waste management programmes.

The IGD-TP was launched on 12 November 2009 at the initiative of the European Commission and waste management organisations. Now exclusively funded by waste management organisations, the group welcomes all stakeholders (industry, research and academia, research centres, technical safety organisations, non-governmental organisations, associations, SMEs, ...) who support the IGD-TP Vision and are willing to contribute positively and constructively to the group's objectives, such as setting and implementing the Strategic Research Agenda and engaging in information exchange and knowledge transfer.

The IGD-TP Vision is the industrialisation of radioactive waste disposal in Europe by 2040, through three pillars: (1) safe operation of the first geological disposal facilities in Europe; (2) optimisation and industrialisation of planning, construction and disposal operations; and (3) development of tailor-made disposal solutions for the various waste inventories in Europe.

The IGD-TP's commitment is to build confidence in the safety of geological disposal solutions among European citizens and decision-makers; to encourage the establishment of waste management programmes that integrate geological disposal as the accepted option for the safe long-term management of long-lived and/or high-level waste; and to facilitate access to expertise and technology and maintain competence in the field of geological disposal for the benefit of European Member States....

The platform is **governed** by an Executive Group, which is the decision-making body that coordinates and manages the platform. It is assisted by a Secretariat and has made use of public Exchange Forums for information and discussion of R&D needs and results.

The core document of the platform is *Vision 2040-Strategic Research Agenda*, whose version 2 is dated September 2020. The preparation of the document involved the structuring of R&D needs considering the stages of a DGR programme (Figure 8-6).

Figure 8-6: *Main stages of the deep geological repository programme. The number of main stages and sub-stages may be subject to licensing according to national legal regulations [Vision 2040-Strategic Research Agenda, Fig. 3.1]*

In this document, the platform has identified 9 key R&D and RD&D (development and demonstration) themes, broken down into areas, which will inspire activities to achieve the 2040 vision:

- (Key Topic, KT 1): Post-closure Safety Case.
- KT 2: Waste forms and their behaviour.
- KT 3: Technical feasibility and long-term performance.
- KT 4: Implementation and optimisation.
- KT 5: Construction and operational safety.
- KT 6: Monitoring.
- KT 7: Methodologies for site characterisation.
- KT 8: Strategies for Repository Project Development.
- KT 9: Knowledge management.

In addition, a needs classification and prioritisation exercise has been carried out according to the stage of implementation of the DGR. Figure 8-7 shows the summary table.

Stages of repository development					
	Generic studies and concept development	Selection of host rock and site	Technology development and repository design	Technology development and repository construction	Industrial-scale manufacturing and repository operation
Safety strategy and methodology	Development of safety assessment methodology	Application of methodology in safety case and improvement of methods	Application of methodology in safety case and improvement of methods	Application of methodology in safety case	Application of methodology in safety case
Long-term safety: Scientific and technical basis	Broad-based research	Research narrowed to deal with host rock-specific aspects and specific aspects associated with the selected EBS	In situ experiments and improvement of data bases and understanding	Scientific work sharply focused on small number of residual issues, large-scale in situ experiments and component tests	Confirmation studies on components under site conditions incl. monitoring
Facility and component design	Concept variant studies	Repository design concepts adapted to specific rock type	Component design and layout design Operational safety studies	Full-scale prototypes constructed Industrial scheme developed	Full-scale production and operation
Site-related characteristics	Surveys of potential host rocks and their characteristics based on available information	Host rock characterization and site-specific studies	Detailed site characterization Excavation	Construction of main underground facilities Confirmation of rock properties for final design	Construction, confirmation, monitoring

Figure 8-7: *Classification of activities to be carried out according to the degree of development of the DGR [IGD-TP (2011). Strategic Research Agenda. Implementing Geological Disposal of Radioactive Waste Technology Platform]*

- SNETP (Sustainable Nuclear Energy Technology Platform)

The *Sustainable Nuclear Energy Technology Platform* (SNETP), started its activities in 2007 to promote R&D activities. It was created, promoted by the European Commission, for the development of nuclear fission power generation technologies, including radioactive waste management. In 2019, it was established as an international non-profit association under Belgian law.

More than a dozen Spanish organisations, including CIEMAT, participate in this platform. Enresa's presence is not necessary for the time being, as information on potential R&D projects is received through various channels, including the Spanish platform CEIDEN and the IGD-TP.

The platform has prepared a strategic research and innovation agenda, the latest version of which is dated July 2021.

The general lines of its vision document include achieving sustainable energy production; improving economic performance; improving efficiency in the use of natural resources; continuously improving safety levels and minimising waste generation, among others. Enresa's focus is on R&D activities related to radioactive waste, and on improving safety levels.

8.6. Other forums

- Spanish Nuclear Society (SNE)

The Spanish Nuclear Society (SNE), which was founded in 1974, is a non-profit association declared to be of Public Utility. Its function is to promote knowledge and dissemination of nuclear science and technology. The SNE is made up of around 1,000 individual members (engineers, scientists, doctors, lawyers, economists and students) and more than 60 groups. An annual meeting is organised and Enresa is invited to participate in one of the sessions at which the results of activities, including R&D generally carried out in Spain, are presented.

(Information from www.sne.es)

- Nuclear Forum

The *Nuclear Forum* is a non-profit association set up in 1962. It brings together Spanish companies related to the peaceful uses of nuclear energy, ensuring the integration and coordination of their interests within the highest levels of safety and reliability in the operation of nuclear power plants.

The *Nuclear Forum* seeks to bring the activities of the nuclear industry closer to society, as it is a dynamic sector, an exporter of technology, products and services, with a firm commitment to R&D and a creator of wealth and employment.

(Information from www.foronuclear.org)

- Cask end-user group

Cask user groups (e.g. Holtec, ECAS, TNUG) seek to exchange experiences between users on findings, lessons learned, the detection and possible solutions of potential problems, etc. It also includes the drafting of analysis documents on various issues from the design of applications for users. In some of them, membership involves the payment of a fee.

- Themed associations

This type of association seeks the collaboration of internationally-renowned experts in scientific, technical or even legal matters related to Enresa's activities. The following are noteworthy:

  - RILEM (*Réunion Internationale des Laboratoires et Experts des Matériaux, systèmes de construction et ouvrages*), founded in 1947 with the aim of promoting scientific cooperation in the field of building materials and structures.
  - EPRI (Electric Power Research Institute), there are two Enresa-EPRI agreements, one on nuclear power plant decommissioning activities (since 2004) and a second more modern one on SF since 2021.
  - INLA (International Nuclear Law Association).

8.7. International collaboration

The management of radioactive waste and the decommissioning of nuclear facilities is an activity to be addressed by all countries. It is a relatively recent concern in human economic activity, since the mid-20th Century. In Europe, North America and countries in the Far East (Japan and South Korea) it is generally an activity of a single organisation per country, usually State-owned, or else heavily regulated. This has led to collaboration between these organisations to exchange experiences and knowledge, develop joint projects, etc. Accordingly, Enresa, as the Spanish State agency, has signed bilateral or multilateral partnership agreements with other European agencies (Andra, Ondraf-Niras, COVRA, Nagra, SKB, POSIVA, SOGIN), American agencies (USA, Canada, Argentina) and Asia-Oceania agencies (Japan, South Korea, Australia).

Bilateral and multilateral agreements allow for the exchange of information and sometimes lead to the development of R&D projects, the results of which have been applied to Enresa's management activities. Under these agreements, Enresa has received information, and over the years Enresa has become a supplier of knowledge.

This type of relationship has made it possible to incorporate knowledge and technologies from nuclear programmes that are more advanced than ours, at least in some aspects, as well as to take advantage of synergies stemming from sharing objectives, knowledge and human, technical and financial resources in joint R&D activities. The results of these collaborations have been used, for example, for the design of El Cabril, the FUA cover layers, and the design and safety studies of the Spanish conceptual DGR.

8.8. Underground research laboratories

Underground research laboratories **(URL)** are underground research and development facilities built to seek analogies with deep geological repositories (DGR). They are excavated in geological formations deemed suitable for repository implementation at depths ranging from several hundred to a thousand metres.

These are underground facilities in which the properties of the geological massif, the components of the engineered barriers and as the phenomena that may affect the safety of a DGR are tested and studied. They thus make an important contribution to resolving issues raised by safety studies, and help to confirm the feasibility of DGRs.

According to the OECD-NEA, the purpose of underground laboratories is to:

- Develop both technologies and methodologies required to conduct underground experimentation;
- Provide data to understand and evaluate the behaviour of the repository and the interactions between its systems;
- Demonstrate the robustness of the design and show potential areas for optimisation of components and engineering processes;
- Train personnel for the safe operation of a future repository;

- Build trust with stakeholders so that they understand the important processes that govern the repository's behaviour.

Two types of underground laboratories are considered according to their main purpose,

- Generic URLs. The purpose is to conduct generic research and testing at a site where no radioactive waste will be stored, but where the results will be useful for potential sites elsewhere.

- Site-specific URLs. These are built on a site that is considered potentially suitable to host a deep geological repository, to be a precursor or an initial phase of a DGR at that location.

Enresa participates in research in European underground laboratories, mainly of a generic nature, which do not exist in Spain. An example of one of these is the activities carried out at the "Grimsel Test Site" underground laboratory in Switzerland, which is included in an informative publication and fundamentally focuses on the following points:

- Geological and hydrogeological characterisation of geological formations likely to host a DGR.

- Properties and long-term behaviour of engineered barrier components.

- Retention and transport of radionuclides in engineered barriers and the surrounding geosphere.

- Verification of data and models used in safety studies.

- Development of tunnel excavation technologies and storage machinery.

- Provision of information to the general public, politicians and authorities.

- International collaboration and knowledge sharing.

Most of them are built in Europe, although there are other important ones in North America and in the Far East (Figure 8-8). European laboratories are systematically involved, through specific projects, in the different Euratom Framework Programmes, and can be considered as a very significant European R&D asset.

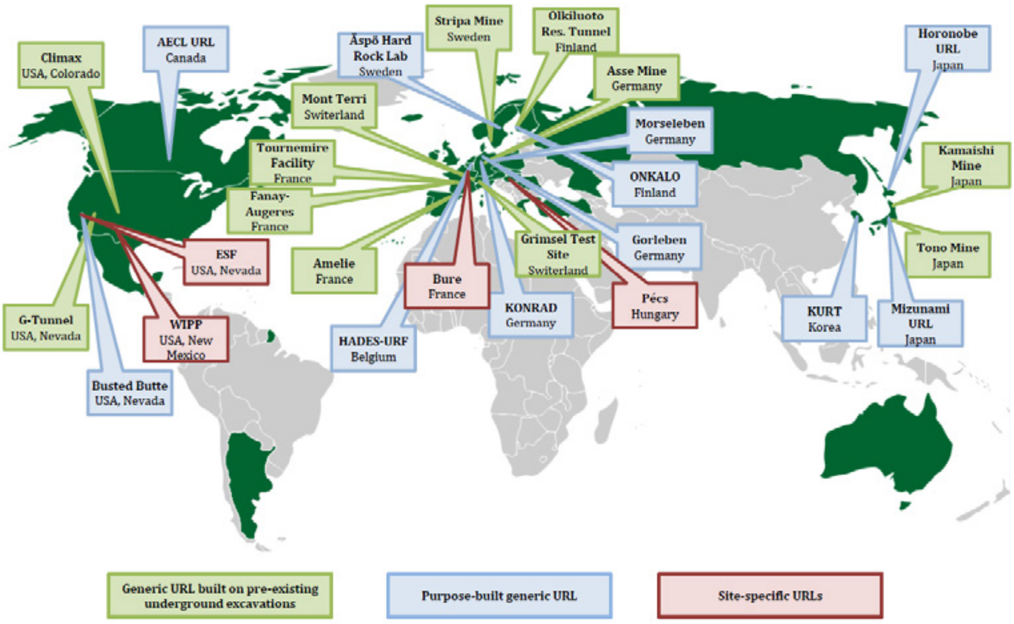


Figure 8-8: *Underground research laboratories in OECD countries [V. Lebedev]*

Enresa has participated in international projects developed at several of them. Of these, Mont Terri and Grimsel, both in Switzerland, are noteworthy due to the importance of the projects, although projects have also been carried out in Äspö, Hades, Tournemire, Bure and Asse. Enresa also belongs to the Executive Group of two of them, Mont Terri, in clayey material, and Grimsel, in granite. Table 8-2 shows the main R&D projects carried out with Enresa's participation in European URLs in granite and clays.

Table 8-2: *Selected projects and experiments carried out in underground laboratories with Enresa participation*

Laboratory	Projects (experiments)
Mont Terri (Ch) Clay formation	**WS-A, WS-B, WS-C, WS-D, WS-E** Groundwater sampling, porewater sampling, porewater chemistry, trace elements, porewater profile through Opalinus Clay (1996-1999) **FM-B, FM-C**, Flow mechanism (resin injection + tracer) (1996-2003) **FP** Fracture propagation (1997-2000) **ED-B** EDZ evolution around Ga 98 (1997-2001) **HE, HE-B, E** Heater experiment, In-situ heater test (1997-2005, 2010-) **Ongoing** **GM** Geochemical modelling (1998-2001) **RB** Horizontal raise boring (1998-2001) **DI-A**, DI-B Long-term diffusion (2000-2006) **EB**, Engineered Barriers (2000-2013) **VE** Ventilation test (2001-2008) **GD** Analysis of geochemical data (2006-2009, 2013-) **Ongoing** **SW-A** Large-scale Sandwich Seal Experiment (2016-) **Ongoing** **WT** Wireless Transmission of Geotechnical Data through Clay Rocks (2022-) **Ongoing**
Grimsel (Ch) Granite formation	**CRR** Colloid and Radionuclide Retardation Experiment (Andra, Enresa, FZK, JNC, Sandia, Nagra). Full-scale Engineered Barriers Experiment (**FEBEX I and II**), continued in NF-PRO, (Projects coordinated by Enresa) (AITEMIN, Andra, BRGM, CEG-CTU, Ciemat, Clay Technology, CSIC-Zaidin, EIG EURIDICE, EUROGEOMAT, G3S, GRS, INASMET, INPL, Nagra, Posiva, PSI, SKB, UAM, UDC, UPC-DIT, UPM, VBB VIAK, DM Iberia, Enresa). **GAM** Gas migration in shear zones (Andra Enresa CSIC UPC Sandia ETH). **HPF** Hyperalkaline Plume in Fractured Rocks (Andra Enresa SKB JNC Sandia). Near Field Processes (**NF-PRO componente 3**) (Enresa, AITEMIN, Cimne, POSIVA, VTT, Nagra, BGR, SKB,Niras/Ondraf, SCK·CEN, GRC, NERC (BGS), IfG, NRG, UTR). Test and Evaluation of Monitoring Systems (**TEM**) (**ESDRED + MoDeRn**) (Enresa, Nagra, POSIVA, SKB, CSIC-IETcc, AITEMIN, Andra, NDA, Solexperts). **FEBEX-DP** Full-scale Engineered Barrier Experiment – Dismantling Project (Ciemat, SKB, POSIVA, KAERI, Nagra, Obayashi, USDoE / LBNL, RWM, BGR, Andra, Surao, and Enresa as collaborator). **HotBent** High Temperature Effects on Bentonite Buffers (Nagra, RWM, NUMO, NWMO, SURAO, USDoE, BGE, BGR, Enresa, Obayashi, KORAD). **Ongoing**
Äspö URL (Se) Granite formation	**PROTOTYPE REPOSITORY** Full-Scale Testing of the KBS-3V Concept for the Geological Disposal of High-Level Radioactive Waste (SKB, Aitemin, AB-BBK, UWC, Clat Tech, Sweco VIAK, CIMNE, BGR, VTT, GU, Geodev,, GRS, JNC), (2000-2005). **TRUE Block Scale**, (Andra, Enresa, JNC, NIREX, POSIVA, SKB as funders). **BACKFILL AND PLUG TEST** (SKB, Enresa, CIMNE, AITEMIN). **ESDRED** Engineering Studies and Demonstrations of Repository Designs (Andra, Enresa, CSIC-IETcc, Aitemin, DBE Tech, EURIDICE GIE, GRS, NRG, ONDRAF, POSIVA; NIREX, SKB, NDA), (2004-2009).
Hades (Be) Clay formation	**RESEAL** A large scale *in situ* demonstration test for repository sealing in an argillaceous host rock (SCK·CEN, CEA, Andra, Ciemat, UPC). **ESDRED** Engineering Studies and Demonstrations of Repository Designs (Andra, Enresa, CSIC-IETcc, Aitemin, DBE Tech, EURIDICE GIE, GRS, NRG, ONDRAF, POSIVA; NIREX, SKB, NDA). **CLIPEX** Clay instrumentation programme for the extension of an underground research laboratory (EIG Euridice, Andra, G3S, Enresa, Geocontrol, UPM), 1997-2002.

The *Mont Terri underground laboratory* was opened in 1996 as an international research project, the “Mont Terri Project”. It was excavated in a clay formation (known as *Opalinus Clay*) located in the Canton of Jura in Switzerland. Currently (2023), 22 partners from nine countries are involved, plus the European Union as co-funder of some experiments. Each partner in the Mont Terri project, including Enresa, has a delegate on the Steering Committee, chaired by the Project Director. This committee analyses the experiment proposals made by the Principal Investigators and, if approved, secures the appropriate funding. The table (Table 8-2) shows the projects in which Enresa has participated and continues to participate in this laboratory.

The Grimsel Test Site (GTS) laboratory was opened in 1984 i n a granite massif in the Alps from the communication gallery with the outside of a hydroelectric power plant. Currently (2023), there are 21 partners, including Enresa, participating in R&D projects. The European Union and the Swiss Federal Administration are regular partial co-funders of some experiments. Enresa started participating in projects in 1996 with the FEBEX project. In addition to participating in projects, it attends International Steering Committee (ISCO) meetings where, in addition to presenting the results of ongoing projects, proposals for new activities are presented in response to the concerns of the participating countries and organisations. The table (Table 8-2) shows the projects in which Enresa has participated and continues to participate in this laboratory.

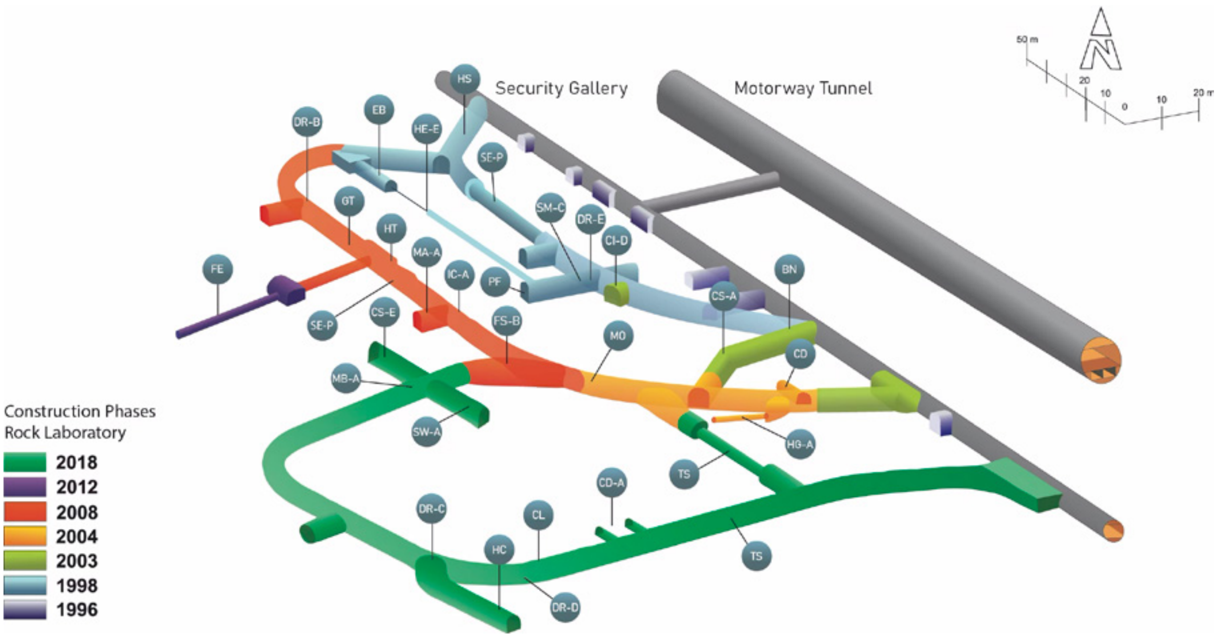


Figure 8-9: *Physical structure of the Mont Terri Underground Laboratory, Switzerland (Main Presentation 2023, from the Mont Terri Visitor Centre)*

The *Äspö underground* laboratory is built near Oskarshamn NPP and is run by the Swedish agency, SKB. The agency began preparatory work for its construction in 1985. It currently has experiments under way at different depths, from 250 to almost 500 metres. The table (Table 8-2) shows the projects in which Enresa has participated in this laboratory.

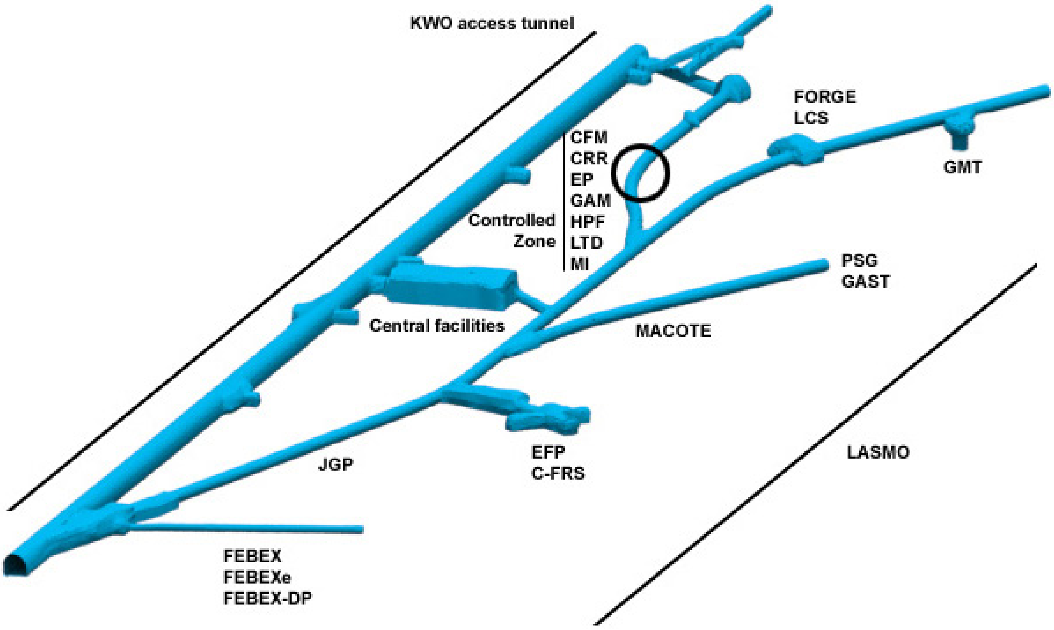


Figure 8-10: *Schematic of the underground laboratory in Grimsel, Switzerland, with the acronyms of the main projects [from www.grimsel.com/gts-information/about-the-gts/gts-location-a-visiting]*

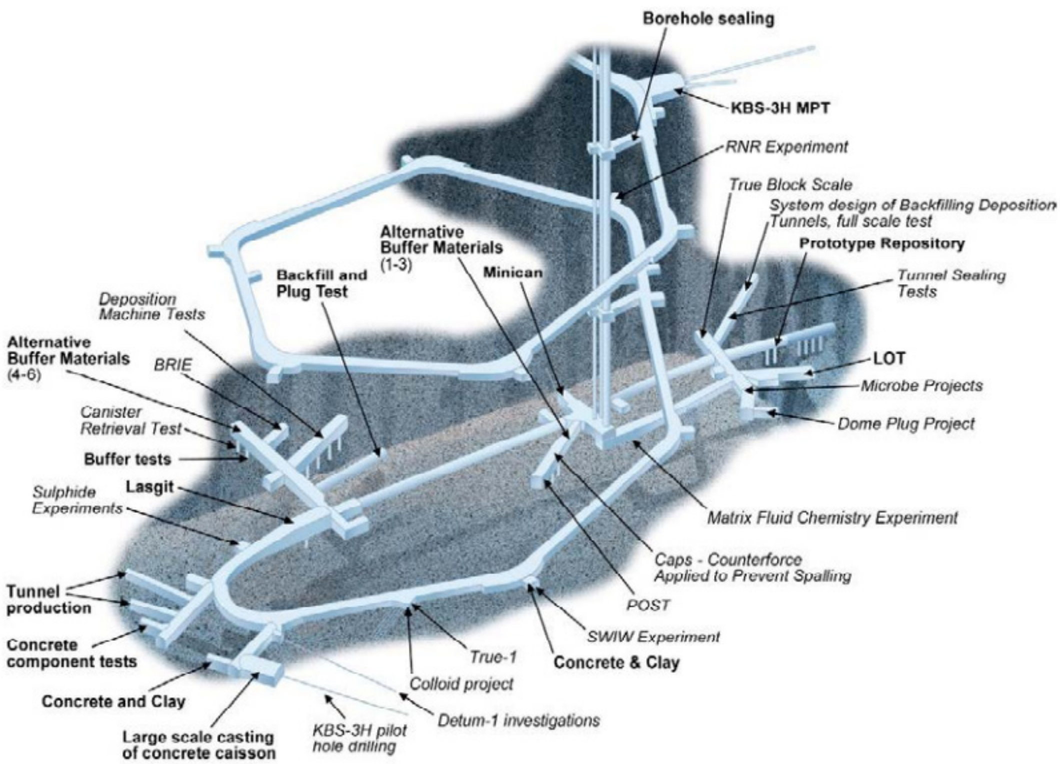


Figure 8-11: *Diagram of the Äspö Underground Laboratory, showing experiments between elevations -220 and -460. In bold, the current experiments [from: Äspö Hard Rock Laboratory. Annual Report 2019]*

Joint European Research Centre (JRC)

Figure 8-12: *Logos of the Joint Research Centre of the European Commission and of the Institute for Transuranium Elements in Karlsruhe*

The JRC, which stands for *Joint Research Centre*, is a Directorate-General of the European Commission responsible for providing scientific and technical advice in different areas of social and economic interest, including nuclear safety and security. Since its creation in 1958, it has contributed to the objectives of the Framework Programmes, the current one being Horizon Europe. The results of its research activities are shared with the Member States of the European Union, and a large number of scientists from different organisations collaborate with the JRC. The JRC manages scientific infrastructures and nuclear (research) facilities.

Its headquarters are located in Brussels, and it has five other offices in Karlsruhe (Germany), Ispra (Italy), Geel (Belgium), Petten (Netherlands) and Seville (Spain). It is organised into 11 directorates, of which the one corresponding to the decommissioning of nuclear facilities and radioactive waste management is of greatest interest to Enresa.

The Karlsruhe site, the *Institute for Transuranium Elements (ITU)*, is of particular importance to Enresa. This facility houses highly specialised equipment. It is geared towards contributing to the scientific basis for the protection of European citizens against the risks associated with the handling and storage of radioactive material, and provides scientific and technical support for the conception, development, implementation and monitoring of EU policies related to nuclear energy.

It is possible to experiment with samples of irradiated nuclear fuel here, as the institute houses facilities prepared to this end, the so-called hot cells. As there are no facilities of this type available for R&D in Spain, Enresa has had collaboration agreements in place with this centre for more than 20 years. The terms of the agreement are that the JRC provides the facility and test materials and Enresa provides one or two researchers who travel to Karlsruhe.

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10. Annex 1. List of Memory cards

The Memory card is an instrument that very concisely summarises an Enresa R&D project. Its purpose and content are defined in the section Line 5.3. Asset management

Table 10-1 shows the list of all the R&D projects, by R&D areas and lines, that have been carried out under Enresa's 7th and 8th R&D Plans, identifying their Memory card number.

Table 10-1: *List of "Memory cards under 7th and 8th R&D Plans"*

List of "Memory cards under 7th and 8th R&D Plans"			
Area / Line	Memory card	Title	Researcher
AREA 1: TECHNOLOGY			
Line 1.1		Fuel and high-level waste	
	1.1.01	Experimental study on the characterisation of the stability of spent fuel as a waste form under disposal conditions	UPC-DIQ, CTM
	1.1.02	Modelling of fuel behaviour in the fuel/cask system	Amphos 21
	1.1.03	Fuel behaviour during short-term storage, Passivation	CIEMAT
	1.1.04.a.b.c	Experimental studies with real fuel	JRC-ITU, CTM, UPC-DIQ
	1.1.05	Low velocity impact rupture in hydride embrittled nuclear fuel cladding	ENUSA, UPM, CSN
	1.1.06	Fuel integrity analysis in dry storage and transport (AICAST project)	CIEMAT
	1.1.07	Development of a thermal model of MPC32 capsule vault storage in the CTS	UP Vasco
	1.1.08	Development of a neutron metrology facility	CIEM CIEMAT AT
	1.1.09	First-Nuclides, Instant release of safety relevant radionuclides from spent fuel	EC
	1.1.10	Evaluation of experimental measurements of spent fuel isotopic composition	Enresa, CSN, SEA
	1.1.11	Application of characterisation techniques in the study of the stability of irradiated nuclear fuel under storage conditions (ACESCO)	CIEMAT
	1.1.12	Exfoliation fuel analysis (ENUSA)	ENUSA, UPM, CSN
	1.1.13	Fuel and its analogues: project stability Phase II	UPC-DIQ, CTM
	1.1.14	Technological research for dry storage and transport (ITAST) (CIEMAT)	CIEMAT
	1.1.15	Integrity of irradiated, severely hydrated sheath material under storage and transport conditions	ENUSA, UPM, CSN
	1.1.16	Fuel and fuel analogues: studies on the stability of irradiated fuel as a high-level waste form	UPC-DIQ
	1.1.17	Study on the applicability of research on the behaviour of spent fuel for final management (AICON)	Amphos 21
	1.1.18	Collaborative Research Project (CRP): "Spent Fuel Mechanical Behaviour During Long Term Storage and Transportation, SPAR IV"	IAEA
	1.1.19	H2020 DisCo project: "Modern Spent Fuel Dissolution and Chemistry in Failed Container Conditions"	EC
	1.1.20	H2020 EURAD Project WP8, Spent Fuel Characterisation and Evolution Until Disposal (SFC)	EC
	1.1.21	Unirradiated uranium dioxide (UO2) oxidation tests and associated analyses OCATS	CIEMAT
	1.1.22	Long-term stability of irradiated fuel	UPC

List of “Memory cards under 7th and 8th R&D Plans”			
Area / Line	Memory card	Title	Researcher
AREA 1: TECHNOLOGY			
	1.1.23	IGD-TP project, Post-closure criticality safety **PCCS**	Enusa
	1.1.24	CRP Spent Fuel Research and Assessment (**SFERA**)	IAEA
	1.1.25	BPA - Enresa-Enusa-Ensa-Sandia-PNNL collaboration agreement, Fuel element vibrations test	UPC
	1.1.26	**SPARE** project	F, Eurecat
	1.1.27	The OECD Nuclear Energy Agency (NEA) STUDSVIK Cladding Integrity Project (**SCIP IV**)	NEA
	1.1.28	Study of the oxidation of spent fuel in non-inert atmospheres at high temperatures	Enusa
	1.1.29	Analysis of the chemical composition of the fresh fuel element and core components	Enusa
	1.1.30	CRP Spent Fuel Characterization Database	IAEA
	1.1.31	Investigation of the mechanical behaviour of spent fuel cladding, with incipient defects, in a drop accident	Enusa
Line 1.2		**Very low-level and low- and intermediate-level waste**	
	1.2.01	Developments in low energy accelerator mass spectrometry (AMS) methodologies with application to radioactive waste problems	CNA
	1.2.02	Technological improvements of stability and bulk leaching studies	U, Cordoba
	1.2.04	Analysis and assessment of non-radioactive characteristics of VLLW and LILW	Westinghouse
	1.2.06	Behaviour and speciation of Carbon 14 in stainless steel and irradiated graphite, plus CAST project	EC, CIEMAT
	1.2.07	Development of a device for the identification, quantification and spatial distribution of gamma-emitting isotopes on a surface or in a material	CSIC-IFC
	1.2.08	Waterproofing of irradiated graphite and optimisation of heat treatment	CIEMAT
	1.2.09	H2020 CHANCE project: "Characterisation of Conditioned Nuclear Waste for its Safe Disposal in Europe"	EC
	1.2.11	H2020 INSIDER project: "Improved Nuclear Site characterisation for waste minimisation in Decommissioning and Dismantling operations under constrained EnviRonment	EC
	1.2.12	Mechanisms of interaction of aluminium in basic media and the parameters to be investigated related to LILW storage, PREDIS project, Includes: tests to determine the interaction mechanisms of aluminium in basic media and the parameters to be investigated related to the storage of low- and intermediate-level waste (LILW)	EC
Line 1.3		**Basic properties of radionuclides**	
	1.3.01	DDEP Workshop 2010: Training sessions of the Decay Data Evaluation Project	CIEMAT
	1.3.02	The NEA Thermochemical Data Base Project, TDB	OECD-NEA

List of “Memory cards under 7th and 8th R&D Plans”			
Area / Line	Memory card	Title	Researcher
AREA 2.	**TREATMENT AND CONDITIONING TECHNOLOGY AND PROCESSES, AND DECOMMISSIONING**		
Line 2.1		Treatment	
	2.1.01	Filling and function tests of control elements of a plasma reactor	TECNALIA, U, Cordoba
	2.1.02	Investigation of waste management options for irradiated graphite (GRAFEC), Phase 1	CIEMAT
	2.1.03	CARBOWASTE Project, Treatment and Disposal of Irradiated Graphite and Other Carbonaceous Waste (FP7 EURATOM)	EC, CIEMAT
	2.1.04	Collaborative Research Project (CRP): "Treatment of Irradiated Graphite to Meet Acceptance Criteria for Waste Disposal"	IAEA
	2.1.05	Detailed design documentation of a prototype waste treatment plant with a plasma reactor **CONFIDENTIAL**	TECNALIA
	2.1.06	GRAPA: International Project on Irradiated Graphite Processing Approaches	IAEA
	2.1.07	Tests on the conditioning and treatment of irradiated graphite for storage in vaults at El Cabril Disposal Centre, GRACO	CIEMAT
Line 2.3		Decommissioning	
	2.3.02	Use of magmolecules for the selective adsorption and concentration of 36Cl, 94Nb, 99Tc and 129I isotopes (doctoral thesis),	URV
	2.3.03	Magmolecule plant	URV
	2.3.04	Greg@l system installation and set-up at CIEMAT	URV
	2.3.05	Void filling with low density materials	URV
	2.3.06	Recycling of contaminated lead and optimisation of the sorbent/chelating agent ratio in the magmolecule system	URV,
	2.3.07	Adaptation and implementation of quality and environmental systems for small companies in the field of decommissioning	URV
	2.3.08	Study of the thermodynamic evolution of the inner atmosphere of the Vandellós I caisson, associated with operational and/or natural events	URV
	2.3.09	Study of the correlation between diffusion/leaching values and mechanical properties of waste packages	URV
	2.3.10	Technical basis for the implementation of in situ bioremediation programmes in uranium-contaminated aquifers	URV
	2.3.11	Durability of the confining structure of the Vandellós I caisson in relation to its corrosion integrity	URV
	2.3.12	Adaptation of the Greg@l system for the declassification of UDS with MARSSIM methodology	URV
	2.3.13	Study of the corrosivity and airtightness of the atmosphere of the Vandellós I caisson	CSIC-CENIM
	2.3.14	Determination of the degree of fullness of disposal units	URV
	2.3.15	Decontamination of graphite by micro-organisms	URV
	2.3.16	Pilot laboratory test for the decontamination of the José Cabrera Nuclear Power Plant site	UTE ENINGE
	2.3.18	Technical requirements for automatic determination of X, Y, X coordinates in characterisation measurements using conventional cameras	U-Las Palmas
	2.3.19	3D scanning system for large parts and modification of "form factor" software	UCO

List of "Memory cards under 7th and 8th R&D Plans"			
Area / Line	Memory card	Title	Researcher
AREA 2.	**TREATMENT AND CONDITIONING TECHNOLOGY AND PROCESSES, AND DECOMMISSIONING**		
	2.3.21	Study of the influence of graphite on the tendency to overpressure in the inner atmosphere of the Vandellós I caisson	URV
	2.3.22	Experimental decontamination of irradiated graphite from Vandellós I using fungi, Further search for new organisms	URV
	2.3.23	Cesium diffusion tests on El Cabril Disposal Centre mortar discs immersed in graphite powder	URV
	2.3.24	Study of the origin of CO_2 formation in the inner atmosphere of the Vandellós I caisson	URV
	2.3.26	Stakeholder-based analysis of research needed for decommissioning (SHARE Project)	EC
	2.3.27	Emerging and interoperable application-based platform for improved decommissioning (PLEIADES Project)	EC
	2.3.28	INNOvative tools FOR dismantling of GRAPHite moderated nuclear reactors, INNO4GRAPH	EC
Line 2.6		Separation	
	2.6.01	Processes for the separation of long-lived radionuclides	CIEMAT
	2.6.02	Study and evaluation of the sustainability of hydrometallurgical separation processes for long-lived radionuclides	CIEMAT
	2.6.03	Advanced studies for the development of separation, retention and conversion processes ESASERC	CIEMAT
Line 2.7		Transmutation	
	2.7.01	Transmutation applied to high-level radioactive waste management	CIEMAT
	2.7.02	Processes for the separation of long-lived radionuclides	CIEMAT
	2.7.03	Transmutation of long-lived radionuclides to support the management of high-level radioactive waste, Phase 1	CIEMAT
	2.7.04	Available technologies for the transmutation of long-lived radionuclides	CIEMAT

List of "Memory cards under 7th and 8th R&D Plans"			
Area / Line	Memory card	Title	Researcher
AREA 3.	**CONTAINMENT MATERIALS AND SYSTEMS**		
Line 3.1		Characterisation and behaviour of materials	
	3.1.01	pH measurement in special concretes for the collaborative project between SKB, POSIVA, NAGRA, NUMO, NDA and Enresa	CSIC-IETcc
	3.1.02	Development of new concretes and mortars, Characterisation and durability tests of concretes and mortars	CSIC-IETcc
	3.1.04	Durability of metallic materials	TECNALIA
	3.1.05	Characterisation of concrete/clay-based confinement materials	CIEMAT
	3.1.06	Application of recycled concrete aggregates in the manufacture of structural concretes	U, Cordoba
	3.1.07	Conducting diffusion tests on concretes and mortars with radioactive elements	CIEMAT
	3.1.08	Characterisation of actinide retention mechanisms in silicate materials	U, Seville
	3.1.09	Characterisation of the actinide retention mechanism in synthetic micas: application to Cs and I retention	U, Seville
	3.1.10	Development of self-compacting concretes for use at El Cabril Disposal Centre	U, Cordoba
	3.1.11	Study to evaluate the influence of K+ and NH4+ on the adsorption capacity of 137Cs on "Rojo Carboneros" clay,	CIEMAT
	3.1.12	Radionuclide migration parameters at the Villar de Cañas CTS site: THM and GQ response of the geological substrate and its impact on long-term safety	CIEMAT
	3.1.13	Identification and validation of geophysical methods for the detection and characterisation of discontinuities in recent sedimentary environments	CSIC-IJAct
	3.1.14	Development of concretes for centralised temporary storage (CTS)	CSIC-IETcc
	3.1.15	Study of the effects of ageing by irradiation and other factors on the concrete at José Cabrera Nuclear Power Plant	Enresa, CSN, ,,,
	3.1.16	LILW engineered barrier materials and their components: characterisation and durability	CSIC-IETcc
	3.1.17	Clay Club: IGSC Working Group on the Characterisation, the Understanding and the Performance of Argillaceous Rocks as Repository Host Formations	NEA
	3.1.18	Characterisation and environmental geochemical modelling of geological materials from El Hito lagoon and its surroundings	UPM ETSIMM
	3.1.19	Analysis and evolution of thermo-hydro-mechanical processes of the materials of the Centralised Temporary Storage Site at Villar de Cañas	UPC-DIT
	3.1.20	Thermo-hydro-mechanical and geochemical characterisation of materials used in radioactive waste repositories	CIEMAT
	3.1.21	Characterisation and durability study of engineered barriers in LILW radioactive waste repositories	CSIC-IETcc
	3.1.23	Experimental study for the analysis of the technological behaviour of single concrete elements	FHECOR
	3.1.24	Design study of self-levelling and self-compacting concretes for El Cabril Disposal Centre	UCO
	3.1.25.	CONtainer CORrosion under Disposal conditions (CONCORD)	EC
	3.1.26	Thermo-hydro-mechanical and geochemical characterisation of containment materials used in radioactive waste repositories (CAMBAR II)	CIEMAT
	3.1.27	Characterisation of LILW and VLLW barrier materials (CARMA)	CIEMAT
	3.1.28	IGD-TP project on Site Characterisation	IGD-TP

List of "Memory cards under 7th and 8th R&D Plans"			
Area / Line	Memory card	Title	Researcher
AREA 3.	**CONTAINMENT MATERIALS AND SYSTEMS**		
Line 3.2		Behaviour of containment systems	
	3.2.01	Boreholes for geological and hydrogeological monitoring in marshland systems	ByA
	3.2.02	Geochemical Barriers: hydraulic testing	AITEMIN
	3.2.03	Geochemical Barriers: piezometric monitoring	AITEMIN
	3.2.04	Geochemical Barriers (LRC): interpretation of characterisation information with the TRANSIN-RETRASO code, barrier design	UPC, CSIC
	3.2.05	Radiological scanning programme, Inert Recovery Facility CRI-09	GEOCISA
	3.2.06	FP7 EURATOM PEBS project: "Long-term performance of Engineered Barrier Systems (EBS)"	EC, UAM, UDC, Golder, AITEMIN, UPC-DIT, CIEMAT
	3.2.08	Comparative analysis of Cesium retention in sludge by reactive clay barriers: pre-pilot scale	U, Seville
	3.2.09	Enresa's participation in the Mont Terri Consortium	GI
	3.2.10	H2020 CEBAMA Project: "Cement-based materials, properties, evolution, barrier functions"	EC
	3.2.11	H2020 BEACON Project: "Bentonite Mechanical Evolution"	EC
	3.2.12	FEBEX-DP Project: "Full-scale Engineered Barrier Experiment - Dismantling Project"	Nagra
	3.2.13	Collaborative Research Project (CRP): "Ageing Management Programmes for Spent Fuel Dry Storage Systems"	IAEA
	3.2.14	High Temperature Effects on Bentonite (HotBent)	Nagra
	3.2.15	EURAD WP7, Influence of temperature on clay-based material behaviour (HITEC)	EC
	3.2.16	Performance Assessment of Storage Systems for Extended Durations (PASSED)	IAEA
Line 3.3		Storage technologies and systems	
	3.3.01	Development of an automated vault for the closure of casks, Alcón Project	AIMEN
	3.3.02	Optimising capsule and rack design for the CTS	ENSA, ENUSA
	3.3.03	Analysis and design of an automated hot vault weld inspection and repair system	AIMEN
	3.3.04	Integral system for welding, inspection and cutting of capsules in a high radiation environment	ENSA
	3.3.05	Feasibility study of transportable capsules, detail development and integration of nuclear fuel storage capsules in the CTS design and feasibility study of Argon inertisation of capsules and casks coupled to the SF and HLW unloading vault of the CTS	ENSA, ENUSA
	3.3.06	"Schedule Project" (Steel Concrete High Efficiency Demonstration - European Collaborative Experience	SCI
	3.3.07	Engineering for the design of the cover layers of the LILW vaults at El Cabril Disposal Centre	Amphos 21

List of “Memory cards under 7th and 8th R&D Plans”			
Area / Line	Memory card	Title	Researcher
AREA 3.	**CONTAINMENT MATERIALS AND SYSTEMS**		
Line 3.4		Monitoring of containment materials and systems	
	3.4.01	Hydrogeochemical monitoring of El Cabril Disposal Centre (update of analysis and interpretation methodologies and equipment)	CIEMAT
	3.4.02	Hydrogeochemical characterisation of El Cabril Disposal Centre	CIEMAT
	3.4.03	Hydrogeochemical characterisation of marsh systems	CIEMAT
	3.4.04	Support for hydrogeochemical characterisation at José Cabrera Nuclear Power Plant	CIEMAT
	3.4.05	Characterisation of groundwater and soils in the area of the former SROA construction site at Vandellós I	GEOCISA
	3.4.06	Study of the water supply to El Cabril Disposal Centre	CU, Cordoba
	3.4.07	Automatic measurement and monitoring system of El Cabril Disposal Centre	AITEMIN, others
	3.4.08	Electrochemical and permeability measurements in the storage structure no, 22 of El Cabril Disposal Centre	GEOCISA, CSIC-IETcc
	3.4.09	MoDeRn FP7 project: "Monitoring Developments for safe Repository operation and staged closure"	EC, AITEMIN
	3.4.10	Monitoring of El Cabril Disposal Centre storage structures	AITEMIN / OMP; Amberg
	3.4.11	CE-2a cask instrumented at El Cabril Disposal Centre	GEOCISA
	3.4.12	Development of a 3D vision system	U, Cordoba
	3.4.13	Elaboration of calibration procedure, calibration of flowmeters and repair of constructive elements in cover layer tests	AITEMIN, others
	3.4.14	Water-rock interaction studies at Villar de Cañas	CIEMAT
	3.4.16	Hydraulic tests on the El Cabril Disposal Centre 3000 Series	
	3.4.17	Diagnosis of the operation of the water treatment plant at El Cabril facilities, proposed within El Cabril Disposal Centre	U, Cordoba
	3.4.18	Design of a mobile unit to collect data for the hydrogeological, radiological and environmental monitoring programmes of El Cabril Disposal Centre	AITEMIN, others
	3.4.19	Modelling the hydrogeochemical behaviour of sites in radioactive waste disposal systems	CIEM CIEMAT AT
	3.4.20	H2020 MODERN2020 Project: "Development and Demonstration of monitoring strategies and technologies for geological disposal"	EC
	3.4.21	Development of a system with FBG fibre-optic sensors for continuous internal monitoring of environmental conditions and radiation in spent fuel casks at Zorita	ENSA
	3.4.22	Instrumentation Vault 21 South Platform of El Cabril Disposal Centre	Amberg
	3.4.23	Tritium and carbon-14 sampling at El Cabril Disposal Centre	Mirion
	3.4.25	Modelling of hydrogeochemical behaviour of sites in radioactive waste disposal systems (MOCHESAR)	CIEMAT

List of "Memory cards under 7th and 8th R&D Plans"			
Area / Line	Memory card	Title	Researcher
AREA 4.	**EVALUATION OF SAFETY, RADIATION PROTECTION AND ASSOCIATED MODELLING BEHAVIOUR**		
Line 4.1		Evaluation methods and models	
	4.1.01	THMQ modelling of the near field of the Villar de Cañas CTS	UCLM
	4.1.02	H2020 EURAD Project WP10, Uncertainty Management multi-Actor Network (UMAN)	EC
Line 4.2		Process and system modelling	
	4.2.03	Thermohydraulic and transport modelling of LILW and VLLW vaults	INITEC, Westinghouse
	4.2.04	Development of water flow and transport models in LILW vaults	UPC-GHS
	4.2.05	Development of cover layer models	UPC-GHS
	4.2.06	Hydrogeological model of El Cabril Disposal Centre	UPC-DIT
	4.2.07	José Cabrera Nuclear Power Plant decommissioning and closure plan, Annual Report on the groundwater monitoring plan, 2010	UPM-ETSIMM
	4.2.08	Prediction of blast effects in reinforced concrete structures	UPC
	4.2.09.a, b	Prediction of blast and impact effects in fibre-reinforced concrete structures; modelling of the behaviour of reinforced concrete under blast and penetration taking into account reinforcement bonding	UPC
	4.2.10	Model of the hydrogeochemical evolution of the FUA (2012-14)	SVP
	4.2.11	Hydrogeological characterisation and modelling of the surroundings of El Cabril Disposal Centre	UPC
	4.2.12	Analysis of soil-structure interaction in specific buildings, Advanced model of climate effect, drainage and excavation process for different types of cementation and soil models	UCLM
	4.2.13	Groundwater flow modelling of the CTS site	SVP
	4.2.14	EURAD, Development and improvement Of NUmerical methods and Tools for modelling coupled processes (DONUT)	EC
	4.2.15	H2020 EURAD Project WP2, Assessment of Chemical Evolution of ILW and HLW Disposal Cells (ACED)	EC
	4.2.16	DEvelopment of COupled models and their VALidation against EXperiments project (DECOVALEX)	LBL
Line 4.3		Environmental remediation	
	4.3.01	BIOCHAL Project: necessary developments for the treatment of the biosphere in radiological impact assessments	CIEMAT
	4.3.02	TRANSFER Project: data analysis, parameter derivation and modelling of radionuclide behaviour in the biosphere	CIEMAT
	4.3.03.a, b	Systems for the dynamic detection of radioactive material mixed with other materials, with fixed and mobile equipment; Characterisation of dynamic detection equipment at borders and critical points	UPM
	4.3.04	PROCORAD Project: Quality assurance in urine radionuclide determination methodologies through participation in the intercomparison exercise	TECNATOM
	4.3.05	MODAS Project: Developments for environmental radiological impact assessments in the management of radioactive materials and waste	CIEMAT
	4.3.06	Laboratory tests and field supervision of the application of soil amendments on the restored site of Saelices el Chico (Salamanca)	CSIC-IRNA

List of "Memory cards under 7th and 8th R&D Plans"			
Area / Line	Memory card	Title	Researcher
AREA 4.	**EVALUATION OF SAFETY, RADIATION PROTECTION AND ASSOCIATED MODELLING BEHAVIOUR**		
	4.3.07	Application of "Carbocal" amendments in the topsoil layer of the restored site of Saelices El Chico (Salamanca)	CSIC-IRNAS
Line 4.4		Radiation protection	
	4.4.01	APRA Project: Radiation protection support and university agreements	CIEMAT
	4.4.02	PROMEDIA Project: Radiation protection of the environment	CIEMAT
	4.4.03	Research on safety culture assessment developments and methodologies applied to radioactive waste management organisations	CIEMAT
	4.4.04	NORMIMA Project: NORM: Industries and Materials	CIEMAT
	4.4.05	PRCAU Project: radiation protection, support and recommendations	CIEMAT
	4.4.06	ERIBIO Project: Biota risk assessments due to ionising radiation exposure	CIEMAT
	4.4.07	Improved knowledge of factors that strengthen safety culture	CIEMAT
Line 4.5		Climate and soils	
	4.5.01	Study of the surface water balance of the El Cabril hydrological basin, measurements of hydrological components and parameters	U. Cordoba
	4.5.02	Ecology of El Cabril Disposal Centre	U. Seville
	4.5.03	Study of the surface water balance in the areas of influence of the El Cabril waste storage platforms	U. Cordoba

List of "Memory cards under 7th and 8th R&D Plans"			
Area / Line	Memory card	Title	Researcher
AREA 5.	**INFRASTRUCTURE AND COORDINATION**		
Line 5.2		Coordination	
	5.2.01	Summary and analysis of Enresa's participation in the 7th EURATOM Framework Programme R&D projects up to February 2011	AITEMIN
	5.2.02	Implementing Geological Disposal of Radioactive Waste Technology Platform	Various
	5.2.03	JOPRAD project: Towards a Joint Programming on Radioactive Waste Disposal	EC
	5.2.04	6th Enresa R&D Seminar and presentation of the 7th R&D Plan 2014-2018	Transedit, Expectagran
Line 5.3		Asset management	
	5.3.01	Technical publications/Internal reference documents	TRANSEDIT
	5.3.02	Review, analysis, updating, organisation and structuring of R&D results (1989-2005)	Enresa, TRANSEDIT
	5.3.03	Preservation of Records, Knowledge and Memory (RK&M) Across Generations	NEA
	5.3.04	6th Enresa R&D Conference and presentation of the 7th R&D Plan 2014-2018	Enresa, TRANSEDIT
	5.3.05	*NKM: Nuclear knowledge management organisational working group (ORWG-NKM)*	IGD-TP
	5.3.06	Projects FP7 Towards a European training market and professional qualification in Geological Disposal, Implementing sustainable E&T programmes in the field of Radioactive Waste Disposal (PETRUS II and III)	EC
	5.3.07	Technical information panels on R&D activities and projects at the El Cabril facility (El Cabril Posters)	EXPECTAGRAN
	5.3.08	Design and engineering of DGR (granite and clay respectively)	Amberg, Enresa

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