

SAEXFUEL
SAFETY OF EXTENDED DRY STORAGE OF NUCLEAR SPENT FUEL
Proposal EURATOM
Call of Section B fission WP 2016/2017
topic NFRP7

J. Cobos (CIEMAT), *F. J. Fernández (ENRESA)*, *V. Metz (KIT)*, *M. Ferreira (VTT)*,
J. De Mer (EDF) , *J. Desquines (IRSN)*, *M. Stuke (GRS)*

Context: EU and IGD-TP advices

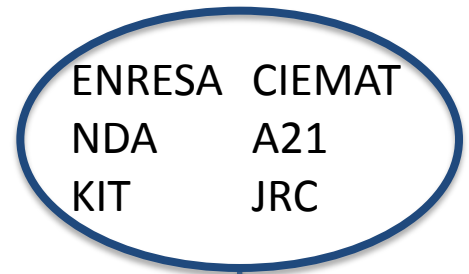
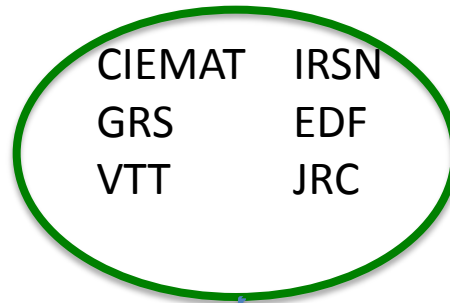
This proposal responds the call of Section B of the EURATOM fission WP 2016/2017 topic NFRP 7: “Research and innovation on the overall management of radioactive waste other than geological disposal”.

Specific Challenge: Deep geological disposal has been the subject of research for many decades, including in the Euratom Framework Programmes. However, the interim storage of waste destined for geological disposal, as well as the management and disposal of other, especially non-standard, radioactive waste types and forms present specific challenges.

Predisposal Activities

Interim storage

Background



SAEXFUEL

Integrating R&D predisposal activities with the plans of the nuclear waste management organizations and the corresponding European Technological Platforms.

Nature of the SAEXFUEL project

1. Develop cooperative research on interim storage of spent fuel and high level wastes focusing on its storage during extended periods.
2. Member States need optimization and safety validation on the behaviour of spent fuel stored for extended periods, requiring R&D effort.
3. Member States with nuclear parks have to design safe predisposal actions for a safe solution to SF & HLW until disposal.
4. Coordination of R&D will help optimum use of resources and sharing the technologies and safety concepts. A number of initiatives in different countries, i.e, Spain has committed national actions plan for interim centralized SF &HLW storage.

Scope of the SAEXFUEL project

1. Focus on the stability and safety of SNF storage for timescales over 100 years and the impact of the potential necessity of storing high burnup fuels at long term.
2. Take into account specific features of various nuclear fuels (e.g. PWRs, BWRs, VVERs, CANDU).
3. Approach covering safety aspects of fuel, cladding, assembly and storage system.
4. Include surveillance and monitoring aspects.
5. Consider further specific predisposal issues.

Why at European Level ?

The project will contribute to the scope for cooperation between Member States, by contributing the knowledge of radioactive waste storage to achieve:

1. SAEXFUEL represents an integrated European effort to foster predisposal activities focused on how to respond to a potential extension on the lifetime of an interim dry storage.
2. EU's recommendation on nuclear safety (PINC, COMMUNICATION FROM THE COMMISSION Nuclear Illustrative Programme COM(2016) 177 final).
3. COUNCIL DIRECTIVE 2011/70/EURATOM of 19 July 2011, establishing a Community framework for the responsible and safe management of SNF and radioactive waste .

SAEXFUEL Participants

	Participant organisation	Country
1	CENTRO DE INVESTIGACIONES ENERGÉTICAS, MEDIOAMBIENTALES Y TECNOLÓGICAS (CIEMAT)	ES
2	GESELLSCHAFT FÜR ANLAGEN UND REAKTORSICHERHEIT (GRS) MBH	DE
3	EMPRESA NACIONAL DE RESIDUOS RADIATIVOS S.A. (ENRESA)	ES
4	JRC-JOINT RESEARCH CENTRE – EUROPEAN COMMISSION (JRC-ITU)	BE
5	COMMISSARIAT À L'ÉNERGIE ATOMIQUE ET AUX ÉNERGIES ALTERNATIVES (CEA)	FR
6	INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE (IRSN)	FR
7	KARLSRUHER INSTITUTS FÜR TECHNOLOGIE (KIT)	DE
8	LIETUVOS ENERGETIKOS INSTITUTAS (LEI)	LT
9	REGIA AUTONOMA TEHNOLOGII PENTRU ENERGIA NUCLEARA (RATEN)	RO
10	STATE SCIENTIFIC AND TECHNICAL CENTER FOR NUCLEAR AND RADIATION SAFETY (SSTC)	UKR
11	TEKNOLOGIAN TUTKIMUSKESKUS VTT OY (VTT)	FI
12	ÉLECTRICITÉ DE FRANCE (EDF)	FR
13	BUNDESANSTALT FÜR MATERIALFORSCHUNG UND -PRÜFUNG (BAM)	DE
14	TECHNISCHE UNIVERSITÄTE MUENCHEN (TUM)	DE
15	PAUL SCHERRER INSTITUTE (PSI)	SW
16	AMPHOS 21 CONSULTING SL (A21)	ES

INSTITUTION	COUNTRY	RESPONSIBLE
ANDRA	France	Christelle Martin
CSN	Spain	Carlos Castelao
NDA	United Kingdom	Rick Short
SURAO	Czech Republic	Antonin Vokal
BfE	Germany	Ingo Reiche
ENRESA	Spain	Francisco Javier Fernandez
BAM	Germany	Konrad Linnemann

7 Institutions as End user

16 SAEXFUEL Partners: 9 EU Countries

- (i) European Nuclear Research Laboratory: JRC,
- (ii) National Nuclear Research laboratories: CEA, CIEMAT, KIT-INE, PSI, LEI, RATEN, VTT, BAM
- (iii) Universities: TUM
- (iv) Technical Safety Organisations: IRSN, SSTC, GRS, ENRESA
- (v) Nuclear Industrial Companies: EDF, A21.

Work plan: Work packages (4 years)

WP0 Management, dissemination, stakeholder engagement and training

(WP Leader: Joaquin Cobos (CIEMAT))

WP1 European Approach to the dry storage

(WP Leader: Francisco Javier Fernández (ENRESA))

WP2 - Alteration mechanisms of spent nuclear fuel

(WP Leader: Volker Metz (KIT))

WP3 - Safety assessment and ageing studies on casks and infrastructure during the extended dry storage

(WP Leader: Miguel Ferreira (VTT))

WP4 - Predisposal activities

(WP Leader: Joel De Mer (EDF))

WP5 - Accident Scenarios

(WP Leader: Jean Desquines (IRSN))

WP6 - Analytical capabilities to model the behaviour of SF under dry storage conditions

(WP Leader: Maik Stuke (GRS))

WP1 European Approach to the dry storage

WP1 European Approach to the dry storage (WP Leader: Francisco Javier Fernández (ENRESA))

Task 1.1: European approach

- Provide knowledge based on previous R&D EC projects (RED-IMPACT), IAEA coordinated research projects (BEFAST, SPAR, TRANSSC, WASSC, CRP T13014), and national nuclear programs, including international projects (FIP, Dry Cask Storage Characterization Project - NRC, ESCP - EPRI) and OCDE-NEA activities and operational experiences with dry spent fuel storage.
- Specific criteria associated to different type of nuclear fuels (PWRs, BWRs; VVERs; AGR).
- Consideration aspects related to dry storage: safety, transportation, costs, international policies.
- Identify knowledge gaps and uncertainties that must be tackled in order to properly go into detail.
- Evaluation of the impact of the temporary dry storage concepts of different fuel types on the long term waste management options, including the scenarios with the transmutation of HLW in fast reactors and accelerator driven systems.

Task 1.2: Regulatory framework

- Social aspects (e. g. public confidence and political commitment)
- Critical review of the existing regulations (European and international) particularly on dry storage of SF.
- Addressing issues to regulatory requirements, licensing and surveillance.
- Time limitation of operational licenses, requirements for systematic ageing management, periodic safety review, demonstration and approval of transportability of spent fuel casks for the whole storage period and beyond.
- Observation of the principle of not burdening unsolved problems of disposal to future generations.

WP2 - Alteration mechanisms of spent nuclear fuel

WP2 - Alteration mechanisms of spent nuclear fuel (WP Leader: Volker Metz (KIT))

Analyse the integrity of SNF rods under dry storage conditions for timescales over 100 years. Provision of new experimental data on fuel behaviour (coupled with cladding) will improve the knowledge of the effect of corrosion resistance on SNF-cladding behaviour.

- Task 2.1: Oxidation extent of nuclear fuel under dry storage conditions:
Evolution of the SNF matrix (UO₂ and MOX) in contact with oxygen as a function of temperature.
- Task 2.2: Physicochemical properties of cladding and clad fuel rods under dry storage conditions:
Insitu measurement of hydrogen re-distribution in non-irradiated Zircaloy-4 clad samples depending on external mechanical loading at temperatures between 100 and 500 ° C.
Evaluation of material embrittlement induced by a spent high burn-up (HBU) and MOX fuel rod segment, crack depth and the hoop stress at crack nucleation.
Assessing the integrity of claddings and examining radiation protection issues at time of re-conditioning of fuel elements (Ukraine)
- Task 2.3 Studies on pellet-cladding interaction (PCI) due to irradiation damage and radionuclides inventory.
Analysis of pellet/cladding interactions (PCI) of two UO₂ and MOX fuel rod segments. Fission product precipitates on the inner surface of the studied Zy-4 cladding.
Identification of sources of crack formation in Zy-4 clads-UO₂ SF rodlet (annealed at 200 ° C/air 18M). 3D focused ion beam (FIB) reconstruction of SNF volumes at grain boundaries grain boundaries studies, TEM phase analysis at grain boundaries (U3O8).

WP3 - Safety assessment and ageing studies on casks and infrastructure during the extended dry storage

WP3 - Safety assessment and ageing studies on casks and infrastructure during the extended dry storage (WP Leader: Miguel Ferreira (VTT)). Take into account the service life extension of dry casks for SNF, including cask and structural materials considering the long term effect of thermal performance, radiation exposure, and ageing of materials.

- Task 3.1: Isotopic evolution/transport and decay heat
Simulation of heat transfer in dry storage cask for defined geometry and the surrounding environment.
Determine assessment of radiation field in long term perspective cask.
Performance assessment studies in dry cask based on CANDU fuel design.
- Task 3.2: Integrity of cask seals considering long-term ageing
In order to predict the failure point in the future will test the properties of elastomeric sealing compression set, tensile properties and hardness.
- Task 3.3: Concrete performance subject to prolonged thermal and radiation exposure.
Characterization of concrete that was subjected to a thermal and irradiation (γ , n) fields.
The behaviour of a concrete at high working temperatures depends on thermal, mechanical, and deformation properties.
- Task 3.4: Structural integrity modelling considering extended service conditions.
Structural integrity analysis of the cask (metallic/reinforced concrete) using finite element method.
The influence of high temperatures, drying, radiation, chemical reactions (ageing), and mechanical constraints will be included explicitly in the numerical models.
Thermo-mechanical analysis for the assessment CANDU fuel, material properties (concrete, stainless steel, Zircaloy).

WP4 - Predisposal activities

WP4 - Predisposal activities (Work Package Leader: Joel De Mer (EDF)) : This work package aims at establishing the potential damage of the radioactive waste from its generation up to disposal, including processing (pre-treatment, treatment and conditioning), storage and transport. This will lead to an evaluation of the technological strategies available and the associated costs. Spent fuel assembly dried, encapsulation (inert gas fill and pressurization of casks), transportation to be finally stored in vaults using the same or not cask container than in transportation.

- Task 4.1 : Assessment of requirements associated with activities from the reactor to interim storage: Inspection and characterization methods shall be established. Classification procedures. Finally, acceptance criteria considering prior steps in relation to spent fuel management systems.
- Task 4.2 : Assessment of requirements associated with activities from storage to final disposal: Scenarios where the spent fuel assemblies are sent to final disposal are the responsibility. Scenarios where there is a treatment of spent fuel to vitrify radioactive waste. Define interdependences and the impact of each step for establishing acceptance criteria.
- Task 4.3: Development of inspection and characterization methodologies
- Task 4.4: Define interdependences and the impact of each step for establishing acceptance criteria

WP5 - Accident Scenarios

WP5 - Accident Scenarios (Work Package Leader: Jean Desquines (IRSN)): The main goal of this work package is to study the SNF behaviour when it is exposed to an accidental scenario which may lead to a potential loss of confinement during dry storage, even to a rupture of the cask containment. Perform criticality safety analysis for credible transport accident scenarios after long term storage including significant fuel rod failure and in-cask fuel distribution, and determine the accumulated doses in materials relevant for moderation and/or shielding e.g. polyethylene (PE) rods or plates.

- Task 5.1: Alteration of the spent fuel and cladding under accident conditions:
 - Loose of internal pressure in the storage cask galvanic corrosion of metallic outer lid seals on multiple storage cask lids, between the aluminium seal and the stainless steel cask body loose of cask lid bolts.
 - Mechanical failure of the load cell may have been caused by different factor (less than adequate safety factor, a material defect, cyclic loading (horizontal and vertical)) or a combination of them.
- Task 5.2: Criticality safety analysis
 - Criticality safety analysis for different loading schemes of transport/storage casks, loaded with UO₂ and MOX fuel with different burnups, from slightly irradiated fuel up to 65 GWd assembly averaged. Consider different transport accident scenarios including partial fuel rod failure of varying extent. Consider moderator (PE) degradation and impact on shielding properties. Considered calculation tools: SCALE package, MCNP, GRS home-built DORTABLE (shielding only).
 - The re-criticality of the irradiated fuel will be evaluated in the case of accident conditions. First, the geometric configurations of several scenarios provided by the other WP6 will be modelled. Then, detailed MCNP calculations will be performed to evaluate the possible re-criticality level of these configurations.
- Task 5.3: Description and analyses of accident scenarios.
 - Evaluation of accident scenarios for drop, erroneous loading, cooling failure and fire.
 - Analyses of vibrations induced by impact of object, crash of airplanes (or other items), earthquake, flooding.

WP6 - Analytical capabilities to model the behaviour of SF under dry storage conditions

WP6 - Analytical capabilities to model the behaviour of SF under dry storage conditions (WP Leader: Maik Stuke (GRS)). Developing necessary analytical capabilities to model the behaviour of fuel and cladding of spent fuel during dry storage under normal conditions.

- Task 6.1: Initial and Boundary Conditions for the Modelling of Fuel and Cladding Behaviour:
Rod internal pressure, which is the main contributor to the cladding stress in dry storage and will be the driver of degrading mechanisms. Cladding resistance to failure, depending on a set of variables e.g. oxide thickness, hydrogen content and irradiation hardening. Potential hydrides redistribution will be dependent of the ductile-to-brittle transition of the cladding material.
Analysis on thermal fuel rod evolution by the isotopic composition of the spent fuel and the thermo-fluid dynamics of the storage system
- Task 6.2: Degradation mechanisms
Modelling of the main degradation mechanisms (hydrogen distribution across the cladding, precipitated fraction, cladding deformation due to creep, which might evolve in failure) and the determination of the impact on mechanical properties will be conducted.
- Task 6.3: Verification and Validation strategies

Work plan: Efforts in person-month, Deliverables

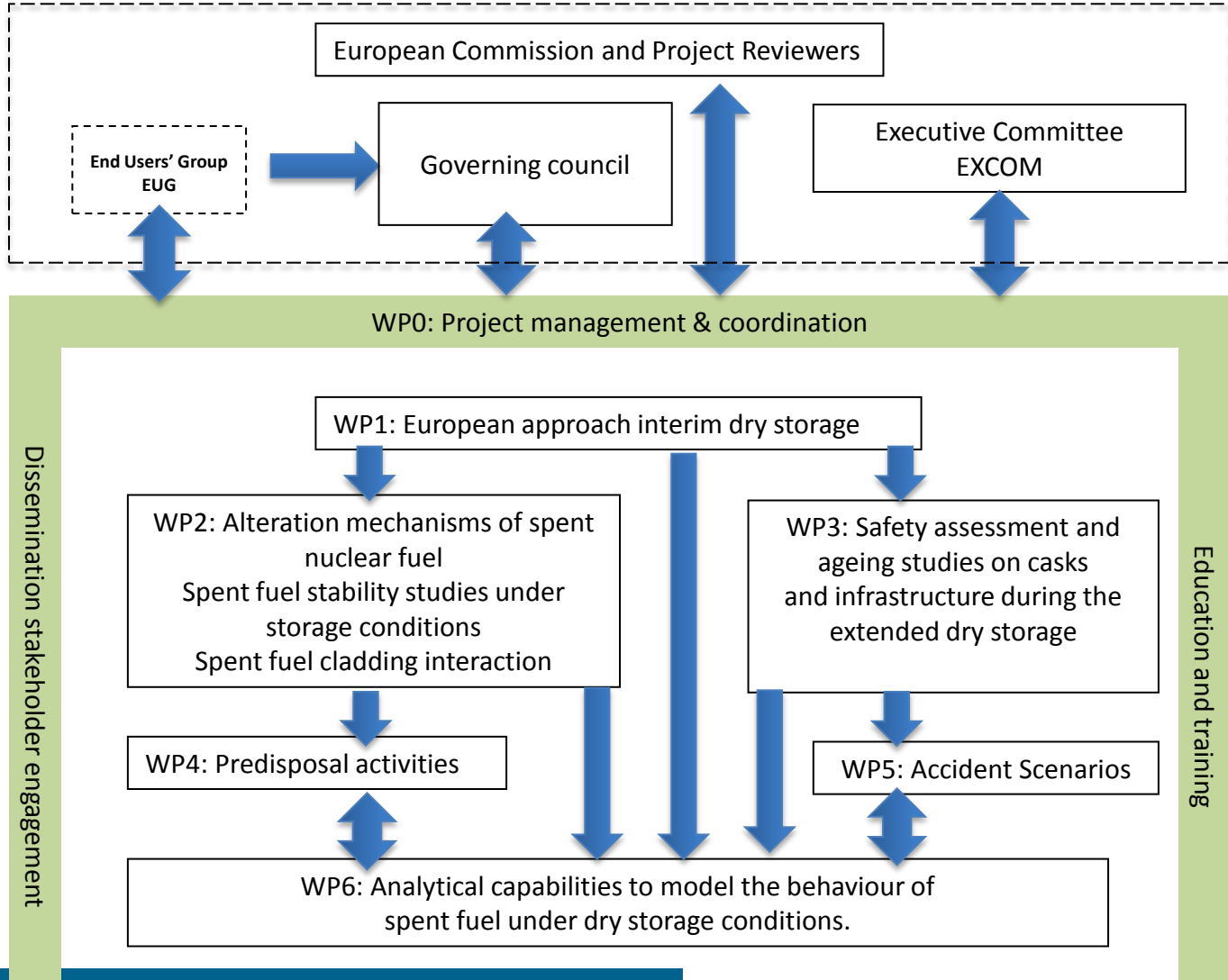
	WP0	WP1	WP2	WP3	WP4	WP5	WP6	Total Person-Months per Participant
1-CIEMAT	20	16	40	0	10	6	48	140
2-GRS	4	2	0	0	0	14	21	41
3-ENRESA	0	2	0	6	4	6	0	18
4-JRC-ITU	0	0	20	0	0	0	0	20
5-CEA	0	0	31.08	0	0	0	0	34
6-IRSN	0	0	19	0	0	4	6	29
7-KIT	0	0	13.5	0	0	0	0	14
8-LEI	0	0	0	11	0	14	22	47
9-RATEN	0	0	0	8	0	0	8	16
10-SSTC	0	5	2	0	2	4	0	13
11-VTT	0	0	12	14	0	0	14	40
14-EDF	0	0	0	6	4	5	7	22
15-BAM	0	0	0	18	0	0	0	18
16-TUM	3	0	0	0	0	0	11	14
17-PSI	0	0	0	0	0	0	10	10
18-A21	7	8	0	7	8	0	0	30
total PM	31	31	137.5	70	28	53	160	511

More than 50 Deliverables

Facilities

Partner	Facility / Service	Use in the project
CEA	LECA facility at CADARACHE	This facility allows both destructive and non-destructive characterization of in-pile irradiated fuels. the available techniques for microstructural analysis are: SEM/FIB, EMPA, XRD, TEM, XRD
JRC	24 concrete and lead hot cells with a capacity of up to 106 Ci with shielded facilities in gloveboxes	Optical microscope, SEM-EDX, EPMA, Knudsen cell, SIMS, γ -spectrometers, gas-mass spectrometer for fission gas determinations
JRC	300 gloveboxes in 30 laboratories equipped with instruments relevant for transuranium element	Optical microscope, SEM-EDX, EPMA, Knudsen cell, SIMS, γ -spectrometers, gas-mass spectrometer for fission gas determinations
CIEMAT	NAYADE Alpha lab with all equipment	Gamma irradiation facility to perform irradiation experiments Laboratory work with larger amounts of lanthanides and actinides
CIEMAT	IR 30	Gamma spectrometer, alpha spectrometer, UV-Vis spectrophotometer, Potentiometric titrator, oscillating shaker and centrifuge, ICP-MS, HPLC-MS, potentiostat-galvanostat, multimeter-software.
CIEMAT	Others	HPLC-Diode, CG-MS, HPLC-MS, XRD, SEM-EDX
ENRESA	EI Cabril intermediate, low level and very low level waste repository	Hot cell and alpha Laboratory consistent of two installations: a radiochemical laboratory for the radioactive waste, and waste forms characterization; and a laboratory for the characterization of concrete and mortars. SEM, DRX and TG-DTA equipment
KIT	Hot cells	Four thermobalance-instruments with different temperature ranges (up to 1750°C) furnaces are connected with Bronkhorst mass and gas flow controllers off-gas compositions are measured by state-of-the-art mass spectrometers
KIT	Shielded box line for handling of highly radioactive material	HPLC-Diode, CG-MS, XRD, SEM-EDX SEM, XPS, DRX and TG-DTA equipment
IRSN	Alpha laboratories	INSTRON 5567 and another 5566 tensile test devices, Juwe ONH-mat 286, Keyence VHX-5000, numerical-optical microscope
VTT	Alpha laboratories	FEI Talos F200X scanning transmission electron microscope (STEM), equipped with a field-emission gun (FEG), energy dispersive X-ray spectrometer (EDS) and electron energy loss spectrometer (EELS)
VTT	Alpha laboratories	DSC, Differential scanning calorimetry; TGA,

SAEXFUEL project Management structure



SAEXFUEL Budget

Total eligible costs: 4.3 M€
funding: 3.8 M€

Total requested EC

1. SAEXFUEL addresses activities included in the IGD-TP, NUGENIA and SNE-TP and focus on their safety issues in order to prepare relevant and safe options to be further developed at an upper scale on sound technical and safety basis.
2. An important Training and Mobility program is proposed.
3. SAEXFUEL budget is far from being overestimated if we compare it with other budgets of national programmes addressing the same objectives and the same kind of activities.
4. Resources (Hotcells and glovebox with irradiated fuel activities) have been integrated within a coherent and well-balanced scheme in order to create synergisms and make the best use of allocated money.

Conclusions of the SAEXFUEL proposal

1. People: all the participants are renowned experts in their field, with a long-standing experience in waste management focused on spent fuel characterization studies under storage and disposal conditions. They are often accompanied by young researchers who are well educated and trained, thus preparing for future generations of scientists.

2. Devices/facilities: SAEXFUEL project will gather world-class nuclear laboratories (JRC-ITU, CEA, VTT, KIT, PSI, IRSN, SSTC, RATEN, LEI, EDF) with modern devices that proved to be operational and reliable. Other laboratories equipped with gloveboxes will complete this system, with sometimes more flexibility and fewer constraints (CIEMAT, ENRESA).

3. Budget: Strong efforts have been devoted to budget considerations. The budget has been optimized, well balanced according to the project priorities, and capped for each work package, consistently with these priorities. All the main Partners limited their EC contribution to 75% or even lower.

Thank you for your attention