

30 May - 3 June 2022  
Lyon, France

## **PATRICIA, PASCAL (and ANSELMUS) Partitioning and Transmutation, contribution to an EU strategy of HLM management**



10<sup>th</sup> European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems  
30 May - 3 June 2022 | Lyon, France

### **Projects**

**PATRICIA**

Partitioning And  
Transmuter Research  
Initiative in a Collaborative  
Innovation Action

H2020 2020-2024  
8,9 M€  
6,5 M€ EU

912 pm

Grant N°945077

 **PASCAL**

Proof of Augmented  
Safety Conditions in  
Advanced Liquid-metal-  
cooled systems

H2020 2020-2024  
4,6 M€  
3,8 M€ EU

436,5 pm

Grant N°945341



**ANSELMUS**

Advanced Nuclear Safety  
Evaluation of Liquid Metal  
Using Systems

EURATOM2027 2022-2026  
4,8 M€  
3,5 M€ EU

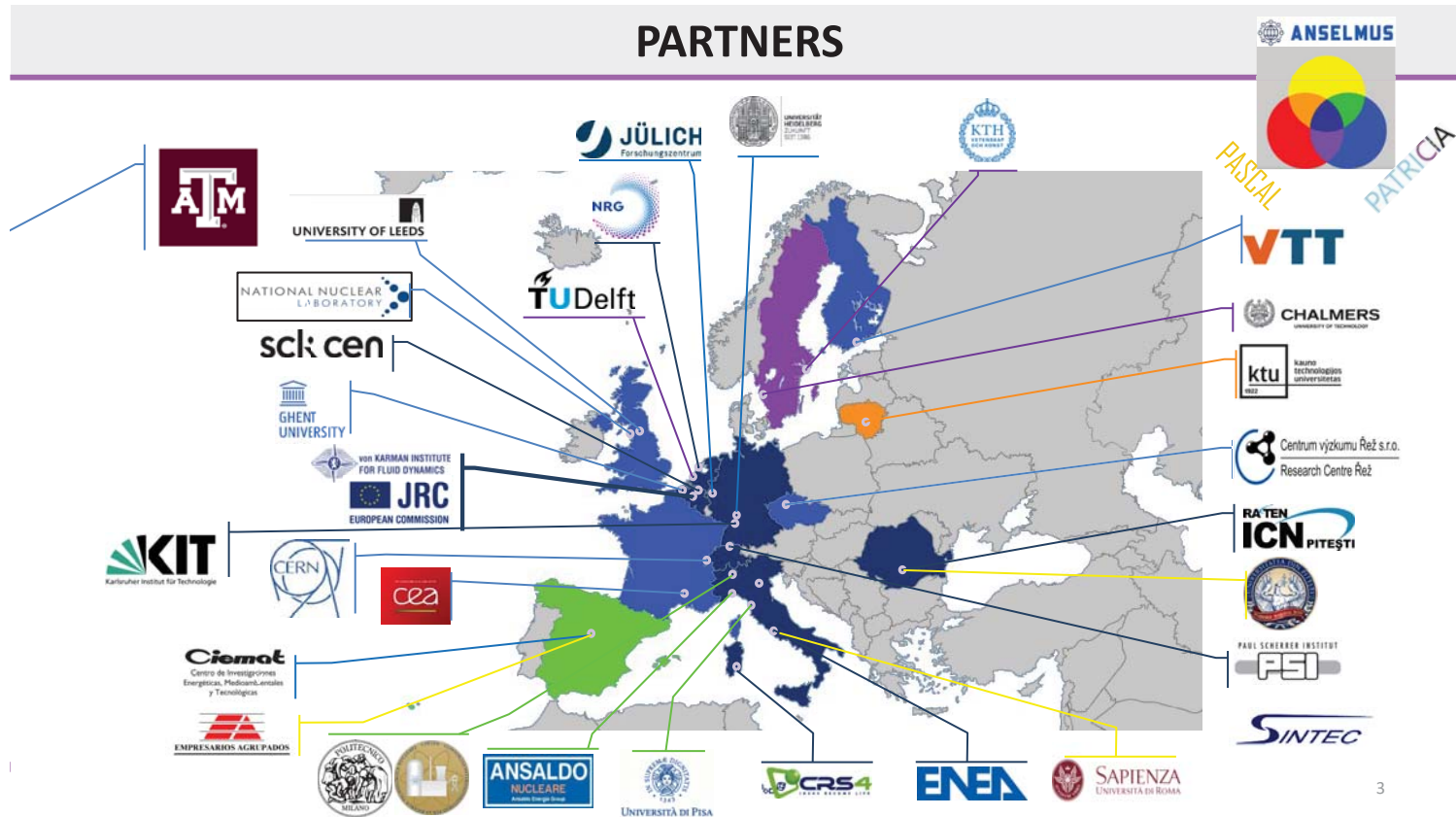
415,5 pm

Grant N°101061185



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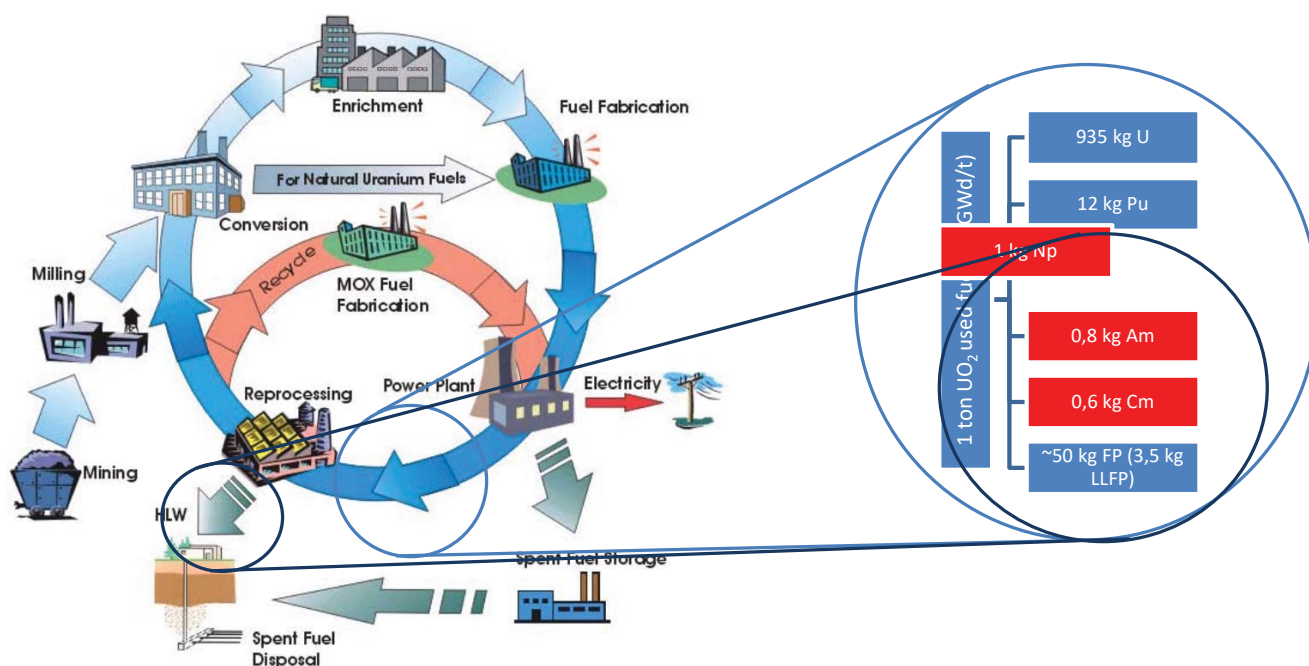
## PARTNERS



3

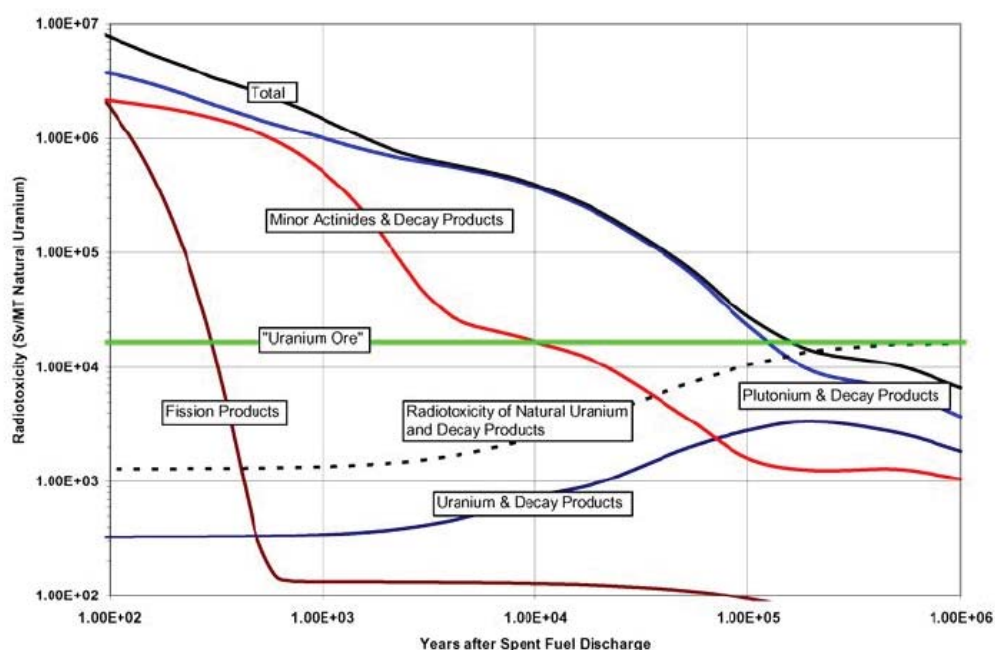
Figure: IAEA TECDOC-1613

## Fuel Cycle



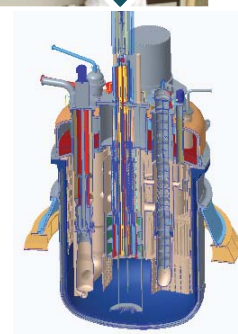
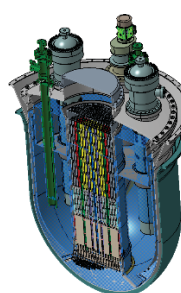
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## Radiotoxicity of spent fuel



## Partitioning and Transmutation building blocks

1. Advanced (multiple) reprocessing
  - Separate U, Pu, Am, Np, Cm, fission products
2. Transmuter fuel
  - Create MA bearing fuel
  - Understand behaviour
3. Transmuter
  - Build safe machine that can burn MA
  - Fast neutrons needed
    - Accelerator driven system
    - Fast critical reactor
4. Transmuter fuel reprocessing



## Previous projects context



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7

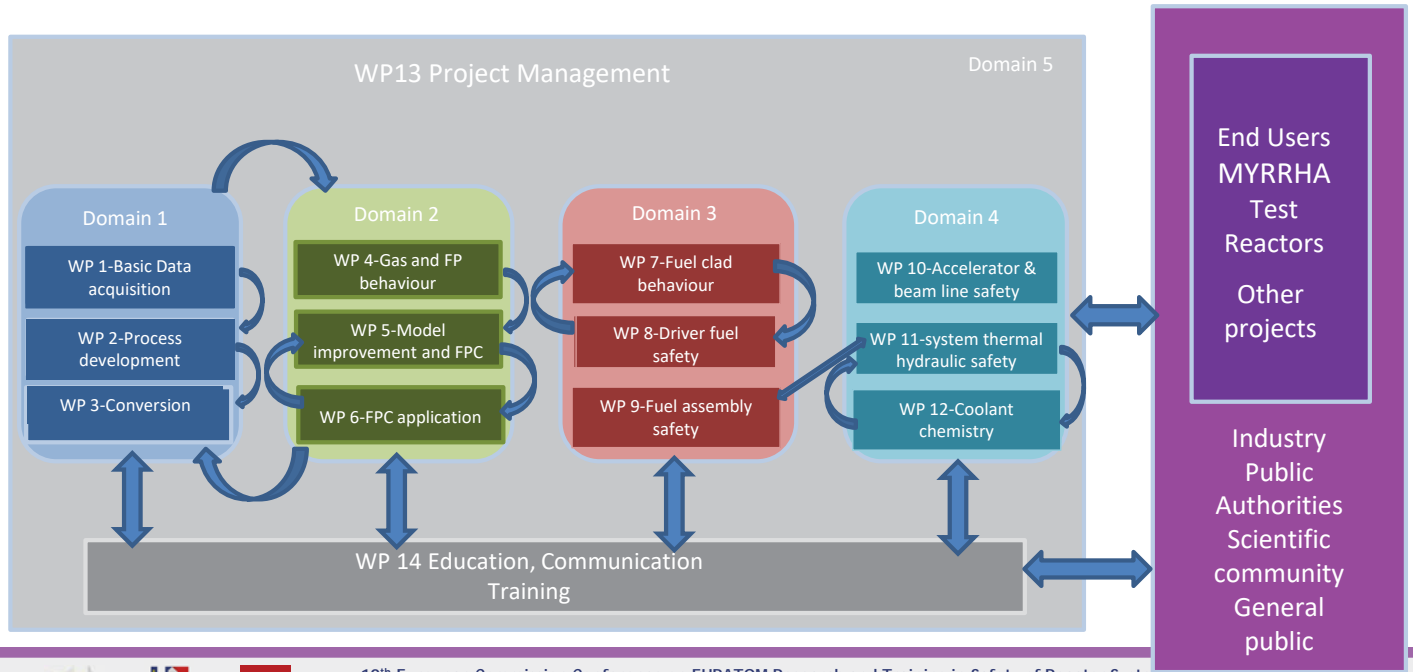
## PATRICIA Project

- Approach
  - Joint project between the Partitioning, Transmutation and Transmuter development communities
    - Fortify the international collaboration
    - Transmutation needs Partitioning and vice versa
- Methodology
  - Focus
    - Closing the fuel cycle
    - Building on existing experience
  - Covering
    - Advanced partitioning with focus on Am separation and conversion
    - Behaviour of MA (Am) bearing fuel under irradiation
    - Development of a dedicated transmuter demo following the MYRRHA track



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8



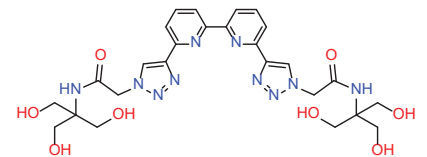
## DM1: Partitioning in PATRICIA

### – Focus

- separation of Am from the minor actinides
- conversion of the Am solution from the partitioning process to a material suitable for fuel fabrication

### – Topics

- WP1 Basic data acquisition on americium and fission products behaviour with the AMSEL chemical systems
- WP2 Process development
  - Development of simulation models
  - Flowsheet development (simulation & lab scale tests)
  - Process tests (with feed solution containing nominal Am concentration)
- WP3 Conversion to Am bearing fuel
  - Characteristics defined by DM2 (Cm & FP contamination & phys. properties)
  - Inert & actinide bearing matrix





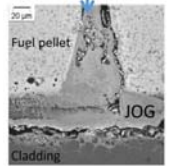
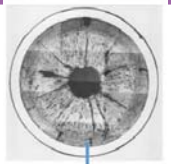
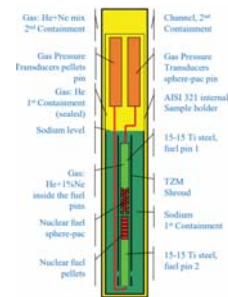
## DM2: Transmutation in PATRICIA

### – Focus

- Behaviour of Am containing fuel under irradiation
- Model development of Fuel performance codes

### – Topics

- WP4 Gas and fission products behaviour and thermo-chemical properties of Am bearing fuel: effects of irradiation
  - investigating, analysing and quantifying helium and fission gases and fission products production
  - behaviour during irradiation of Am-bearing fuels (PIE)
- WP5 Improved modelling and fuel performance codes
  - develop and improve modelling and simulation tools
    - » behaviour under irradiation of Am-bearing fuel itself
    - » interaction with the reactor environment
- WP6 Applications to simulations in normal conditions and off normal conditions
  - Design of future Am fuel test experiments



11

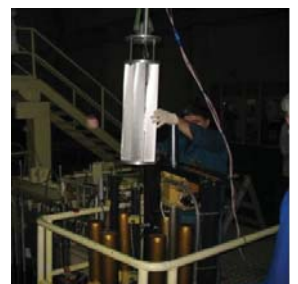
## DM3: Driver fuel and core safety in PATRICIA

### – Focus

- safety related studies of the MYRRHA core and driver fuel input for the PSAR of MYRRHA

### – Topics

- WP7 fuel clad integrity under exposure to the Lead-Bismuth Eutectic
  - Integrated corrosion-deposition experiment on a heated fuel bundle
  - Mechanical properties of exposed cladding
- WP8 fuel Safety
  - pin failure limits under transients
    - » Detailed PIE of segments tested in MAXSIMA
  - Fuel coolant (LBE) interaction at 1650°C



12

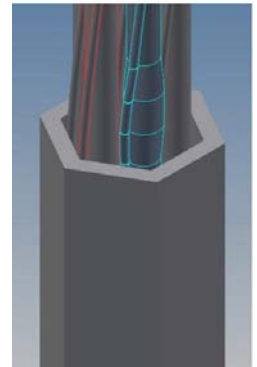
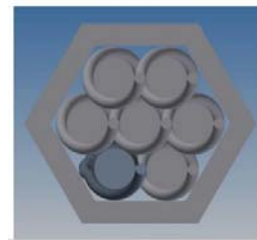
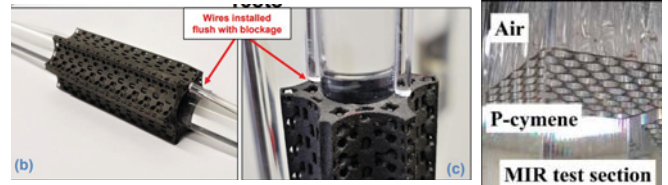
## DM3: Driver fuel and core safety PATRICIA

### – Focus

- safety related studies of the MYRRHA core and driver fuel as input for the PSAR of MYRRHA

### – Topics

- WP9 fuel assembly safety
  - Blocked wire spaced fuel assembly
    - » Investigation of Porous blocking
    - » Self heating blocking (fuel fragments)
  - Deformed wire spaced fuel assembly
    - » Reference experiments on defined geometries
    - » Numerical code validation



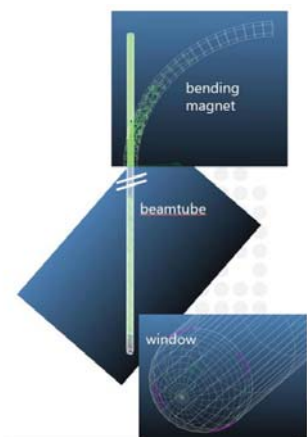
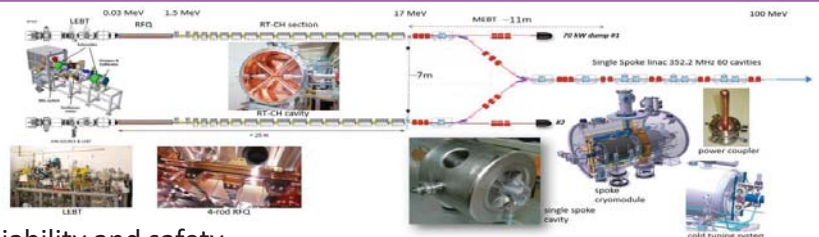
## DM4: ADS System safety in PATRICIA

### – Focus

- safety of the ADS system
- input for PSAR of MYRRHA

### – Topics

- WP10 Accelerator and beam line reliability and safety
  - Development of fault tolerance methodology
    - » Elaborate reliability model of driver linac
    - » Application to RF module and MINERVA linac
  - Beam window failure detection
    - » Po transport in vacuum
    - » Experiments with vapourised Hg and LBE with small leak



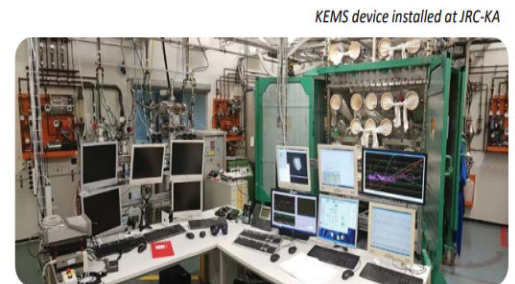
## DM4: ADS System safety in PATRICIA

### – Focus

- safety of the ADS system
- input for PSAR of MYRRHA

### – Topics

- **WP11 Thermal hydraulic system safety**
  - Stability of natural convection cooling in accident conditions
    - » Experiments CIRCE & ESCAPE
    - » Modelling (CFD & CFD+STH)
  - Heat transfer modelling in pool configuration
    - » “Engineering” heat transfer model development using AHFM
      - Implementation in Open Foam
    - » Use existing data & DNS simulations
- **WP12 Chemistry control experiments and modelling**
  - Development and validation of coupled thermal-hydraulic-chemistry simulation tool
    - » code coupling
    - » Validation tests on existing experimental data
  - Radiological release
    - » Release and retention of Po, Cs, I and Te in LBE



KEMS device installed at JRC-KA



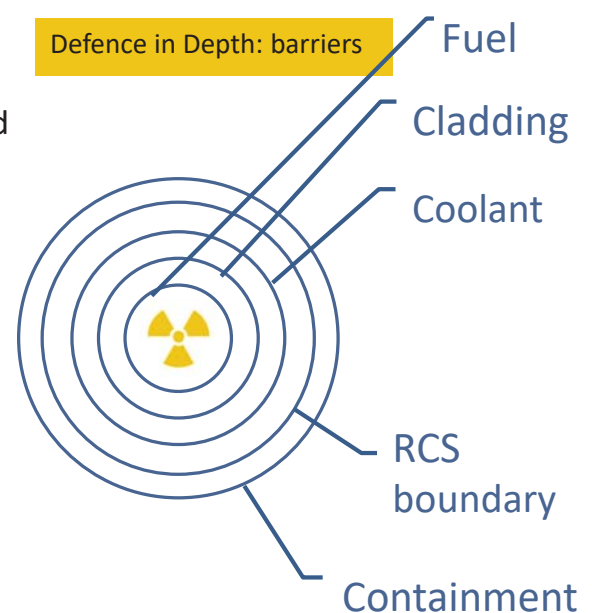
## PASCAL Project

### • Approach

- Support ALFRED and MYRRHA pre licensing
- Exploiting the inherent features of HLM cooling, and adding passive provisions, the possibility exists to exclude need for off-site emergency response planning

### • Methodology

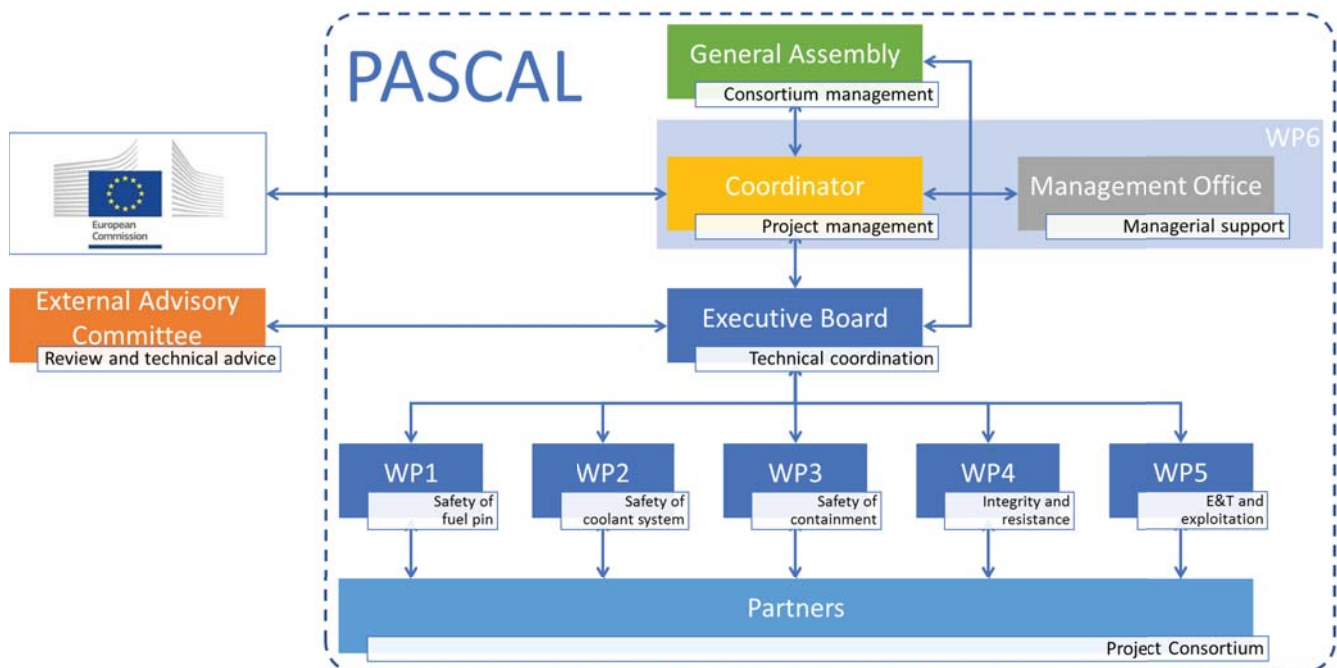
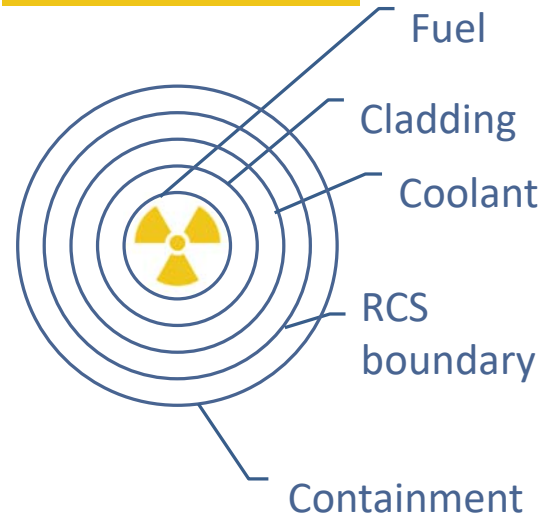
- Quality experimental results to support the claimed performances in front of the safety authorities
- Basic insights to enhance the mastering of less-known phenomena
- Separate and integral effects data to validate software models and codes





- Retention in fuel
  - New phenomena could be expected by interaction of the fuel (and matrices generated by the fuel) with HLMs
- Enclosure in cladding
  - Clad and FA integrity in HLM
- Retention in coolant
  - Assessment of very high fission products retention capabilities credited to HLMs.
- Enclosure in RCS boundary
- Confinement in building
  - Aerosols and volatile species from the coolant (in case of breach of the RCS boundary) characterize the anticipated conditions.

Defence in Depth: barriers



— Focus

- Interaction of fission products and fuel with the coolant

— Topics

- Structural and thermodynamic study of interaction products for
  - JOG-Pb/LBE
  - Pb/LBE-(radionuclides with long term radiological impact)
- Interaction tests of
  - Pb/LBE-JOG/clad up to the clad melting temp
  - irradiated (U,Pu)O<sub>2</sub> and Pb/LBE
- Study of
  - phase equilibria in {PbI-BiI-CsI}
  - release equilibria and kinetics of major fission products from {Pb/LBE+JOG} and {Pb/LBE+irradiated MOX}

— Focus

- Thermal-hydraulics in off-normal conditions

— Topics

- Thermal-hydraulic study of asymmetric flow conditions in the pool
  - experimentally, in E-SCAPE
  - numerically, by CFD analysis
- Thermal-hydraulic study of heat exchange in a grid spaced fuel bundle with deformed pins
  - experimentally, in a new ad hoc water loop
  - numerically, by sub-channel and CFD analysis



— Focus

- Release of radionuclei from the coolant

— Topics

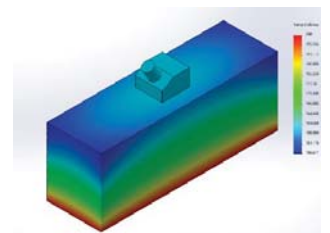
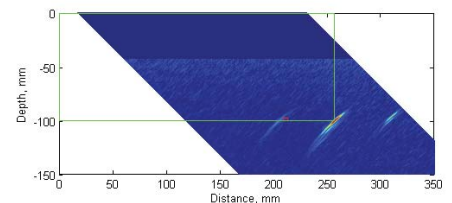
- Study of fission product release from HLM and deposition from the gas phase, relative to
  - Cesium and Iodine evaporation
  - Tellurium evaporation
  - evaporated fission products molecules with cover gas
- Study of Pb/LBE aerosol formation and transport
  - experimentally
  - numerically, extending the models integrated in the containment modules of severe accident codes

— Focus

- Integrity of the barriers

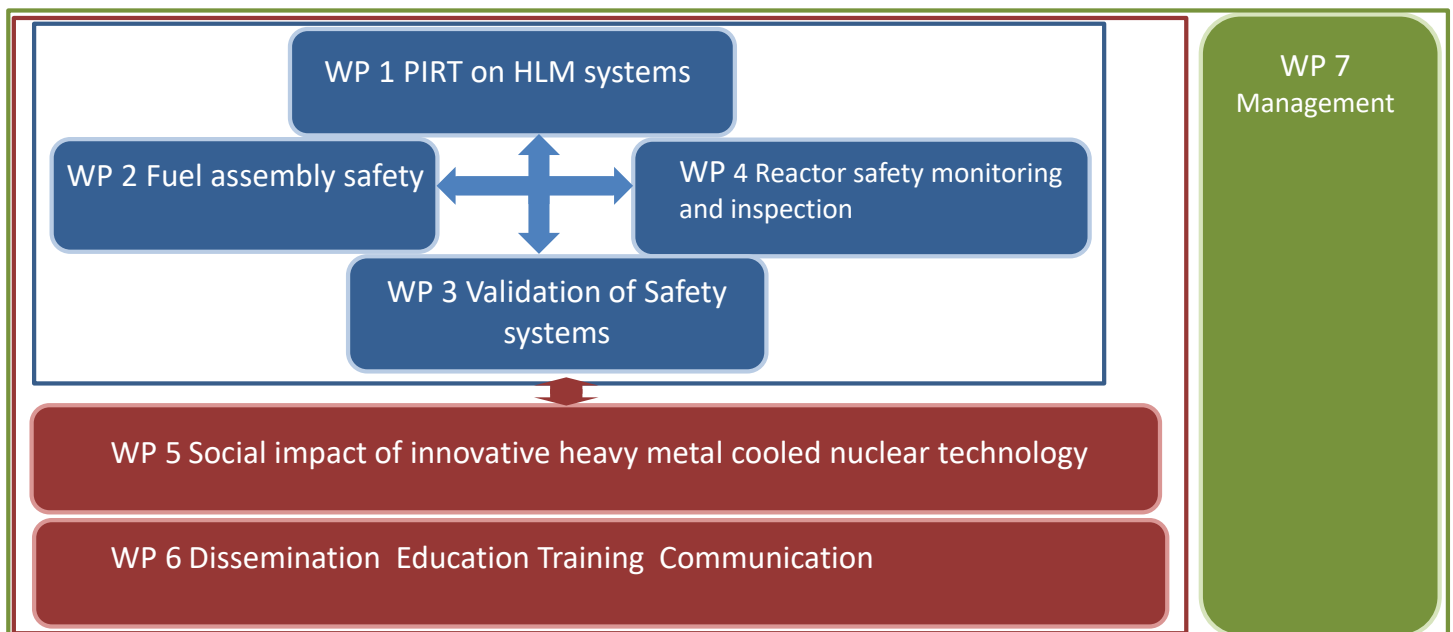
— Topics

- Study of flow-induced vibrations in grid-spaced fuel bundles
  - experimentally, in HELENA
  - numerically, by CFD analysis
- Study of sloshing effects in a pool
  - Experimentally, in SHAKESPEARE
  - numerically, by CFD analysis
- Development of under-HLM integrity inspection device, by
  - comparison of HLM impact on normed tests
  - calibration of detection through pre-cracked samples inspection in HLM





- Approach
  - Support ALFRED and MYRRHA pre licensing
  - Use maturity of design to take concrete steps towards PSAR
- Methodology
  - Use state of the art and design status to do thorough PIRT
  - Focus on key safety issues
  - Validation of safety related components and procedures
  - Outlook towards society







### — Focus

- Thorough PIRT analyses as starting point for safety evaluation

### — Topics

- PIRT methodology and development
- Reference design and initiating events
  - Selection for the reference designs of MYRRHA and ALFRED to be used
  - Selection of initiating event
- Numerical evaluation of selected scenarios
- R&D roadmap for V&V needs



### — Focus

- Safety related experiments for grid and wire spaced fuel assemblies

### — Topics

- Grid spaced fuel bundle heat transfer characterization in lead
  - Experiments in liquid Pb using the HELENA loop
  - Numerical modelling
- Wire spaced fuel bundle heat transfer
  - Generation of a database of experiments with wire spaced bundle
  - Measurements with a wire spaced fuel bundle in water representative of MYRRHA
    - » Use laser sheet to characterise velocity field
  - CFD modelling of the (NRG)
  - Assessment of CFD uncertainty and guidelines for CFD simulations

**— Focus**

- Validation or development of key Safety related systems

**— Topics**

- Safety rod validation (SCK CEN, CRS4)
  - POP tests of MYRRHA safety rods in flowing LBE using COMPILOT
  - Numerical simulations supporting the COMPILOT safety rod experiment
- Failed fuel pin detection
  - Analysis of noble gas inventory in MYRRHA
  - Noble gas transport tests in Pb and LBE
  - Tag gas mixture selection and capsule conceptual design for MYRRHA
  - Noble gas detection experiments using fission product Gas-jet Facility
- Validation of oxygen control systems
  - Oxygen control system in LBE selection and test in MEXICO facility
  - Oxygen control system in Pb selection and test in HELENA

**— Focus**

- Development of NDUS inspection for LFR up to 400°C

**— Topics**

- Inspection strategy
- NDT inspection at high temperatures
  - Selection of high temperature US sensors
  - NDT inspection tests in Pb
- Inspection tools
  - specifications of inspection tools in MYRRHA and ALFRED

## WP4 Social Impact of Innovative HLM cooled technology

### — Focus



- Assessment of the impact of HLM cooled systems on society

### — Topics

- Energy use
  - Identification of key parameters, modelling and components definition
  - Techno-economic analysis
  - Financing and business model
- Social and ethical considerations of advanced nuclear technology
  - Sociotechnical integration in research labs
  - Mapping societal values linked to the development of advanced nuclear technologies
  - Public views on advanced nuclear reactors



## EDUCATION AND TRAINING

- Data management plan for the FAIR approach
- Dissemination and exploitation of the results
- Education & Training
  - Education and training of researchers by summer schools and workshops

### — PATRICIA

- Large focus on PhD support with dedicated financing for PhD
- International workshop in conjunction with established conference
- High-School level booklet on nuclear waste and transmutation
- Meet the pupils days

### — PASCAL

- Hands on training of students and young researchers through mobility grants

### — ANSELMUS

- Stakeholder interaction
  - Communication to general public
  - Short films on the use of liquid metal –Youtube platform
  - Stakeholder workshop





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