Pu management in Gen IV reactors: the new European project PUMMA

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Introduction: The PuMMA project

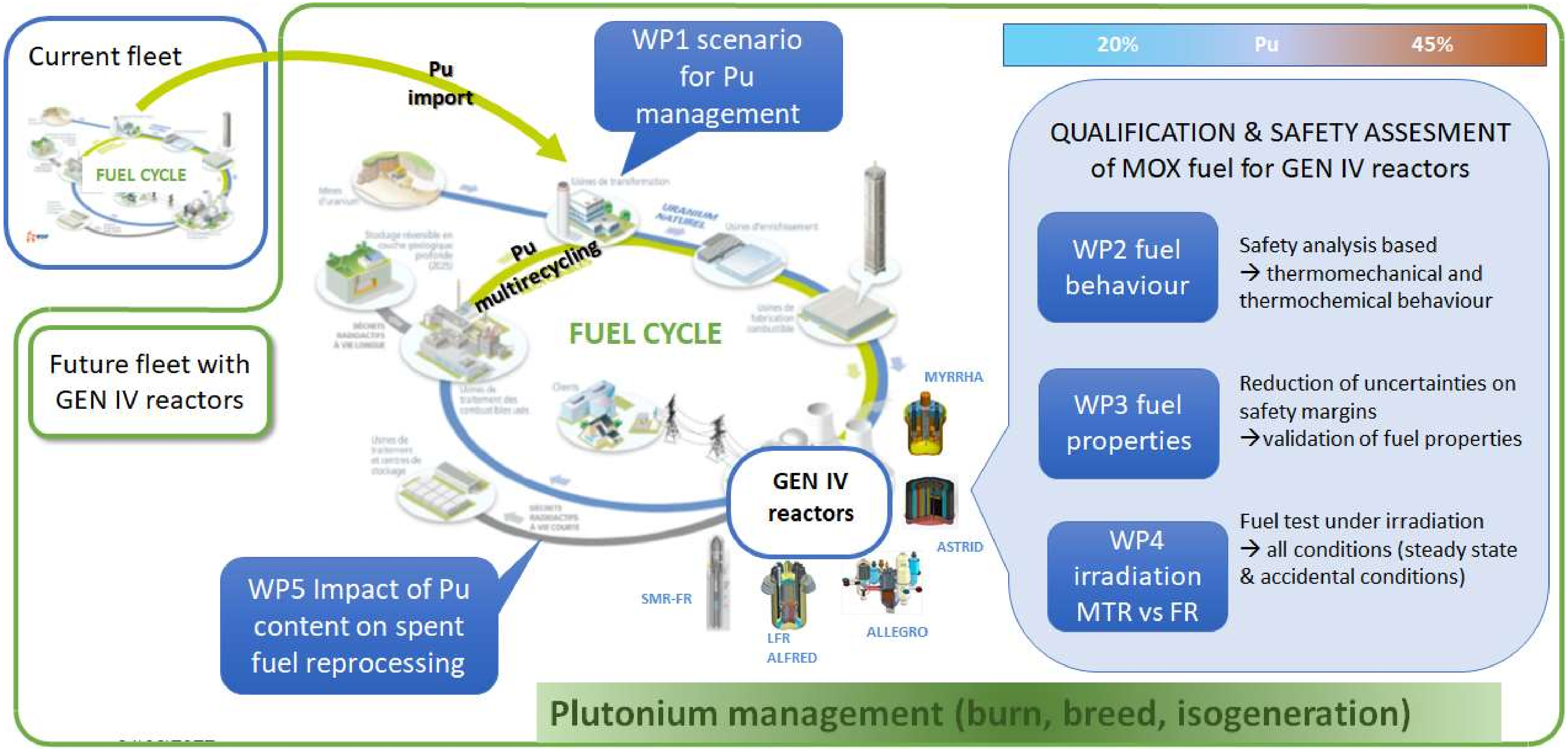
20 partners involved: BME, CEA, CIEMAT, EDF, ENEA, EPFL, FRAMATOME, JACOBS, JRC, KIT, LGI, NRG, MTA-EK, NNL, POLIMI, PSI, SCK-CEN, UJV, VTT, VUJE

~6.7 M€ (3.8 EU contribution), started in October 2020

Main objectives:

- Plutonium management in 4th generation reactors (SFR, GFR, LFR, ADS) -> impact on fuel behaviour, core safety, reprocessing and fuel cycle parameters.
- Experimental results & calculations during representative nominal conditions and during accidental conditions that lead to fuel melting and clad failure.
- Comparison of experimental irradiation in Material Testing Reactor (MTR) with the results of an irradiation in representative fast neutron reactor (SFR).

Introduction: The PuMMA project



Work Packages

- WP1. Study of plutonium management in connection with the fuel cycle
- WP2. Evaluation of Fuel Behavior with High Pu content: Nominal and Transient
- WP3. Fuel properties with High Pu content: measurements and modelling
- WP4. Comparison of irradiation test in fast spectrum vs thermal spectrum (MTR)
- WP5. Impact of high Pu content on reprocessing
- WP6. Education and training
- WP7. Project management

Work Package 1

Study of plutonium management in connection with the fuel cycle: scenario studies

11 partners involved

Main WP objectives:

- To highlight the flexibility of the Gen-IV reactors on the management of the plutonium (breeding, burning or iso-generation), given the many options foreseen in Europe such as fleet composition, installed nuclear capacity, increase in electrical demand. Uncertainty propagation.
- Different objectives with regard to plutonium: the stabilization of its inventory or the burning or the breeding.
- Impact on fuel composition, fuel cycle facilities and transportation.

WP1: Tasks

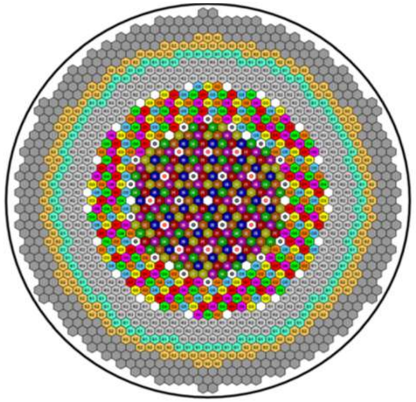
- **Task 1.1**: Reactors input data for scenario studies
- **Task 1.2**: Scenario calculations
- **Task 1.3**: Sensitivity studies with uncertainty propagation
- **Task 1.4**: Impact on fuel composition, fuel cycle facilities, transportation and economic criteria

WP1: Tasks 1.1/1.2

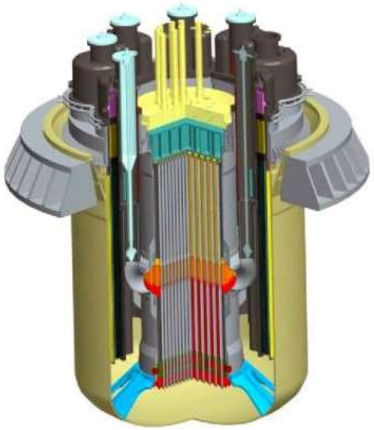
Reactors:

- Generic PWR
- Generic BWR
- VVER-1200
- EPR – Generation III
- ESFR-SMART – Sodium cooled fast reactor
- ALFRED – Lead cooled fast reactor
- ALLEGRO – Gas cooled fast reactor
- GFR2400 – Gas cooled fast reactor

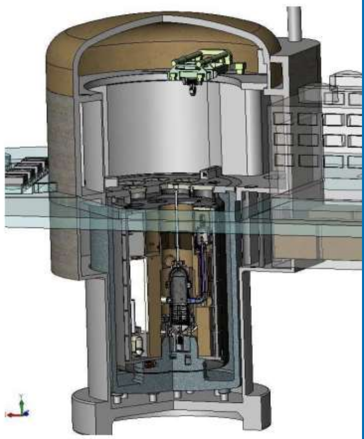
XY view of the ESFR-SMART core



ALFRED



ALLEGRO



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WP1: Task 1.1

Challenges:

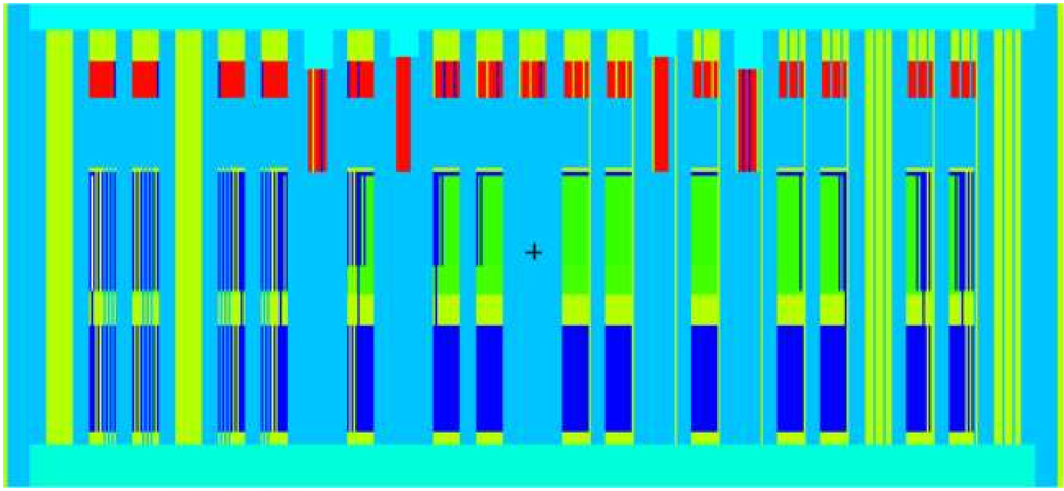
- New fuel require a new reactor design to explore its full potential.
- SMR designs are not easy to find. Differences between small and large versions of a reactors may exist. Reactors with small power are considered as SMR although they are not conceived as modular.
- MSR are not yet simulated in fuel cycle codes.

ESFR-2400 burner version

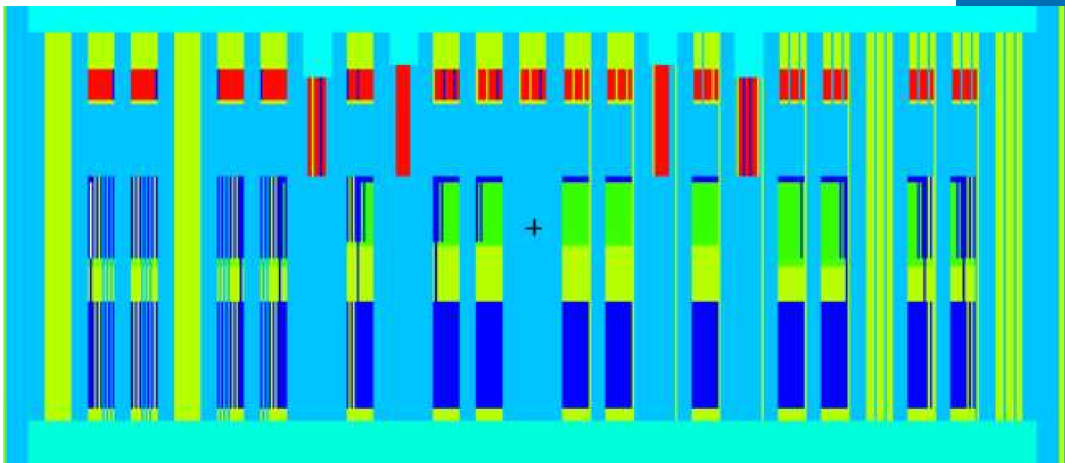
Inner fissile height reduced from 75 cm to 50 cm. Outer core height reduced from 95 cm to 65 cm.

Power reduced from 3600 MWth to 2400 MWth.

Reference model



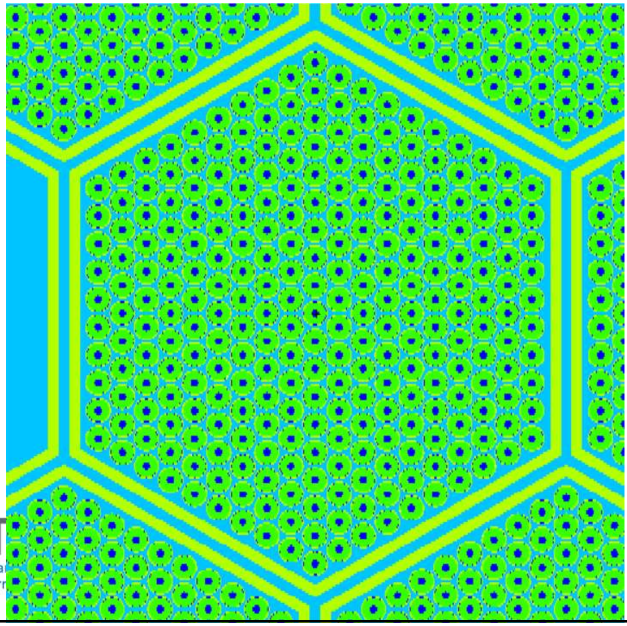
Burner version



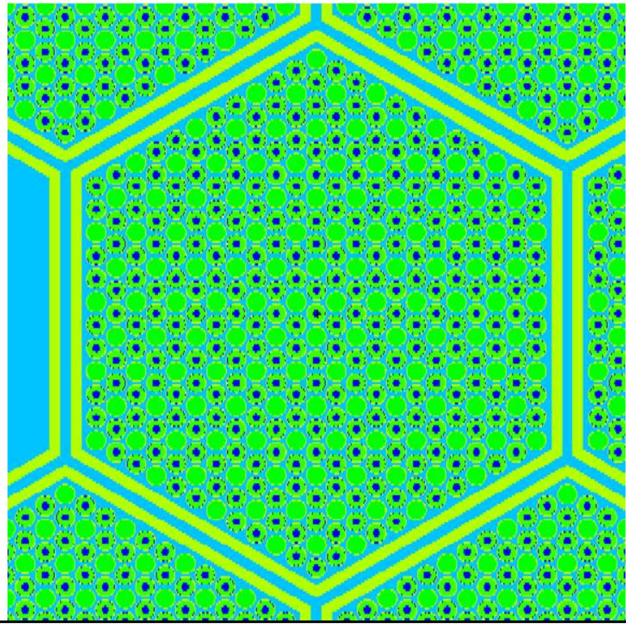
ESFR model: XY view

CAPRA concept. Total of 265 fuel pins per assembly (instead of 271 as in reference). 12 rings of smaller rods. 132 Mo rods. Additional B_4C required in Mo rods to reduce reactivity.

Reference model



Burner version



ESFR burner model

- This research opens a possibility for future collaboration.
- ESFR burner model with MOX fuel would need a detailed multiphysics analysis.
- Core safety measures. Possibly system safety measures.
- Bibliographic research.
- Experiments to increase the TRL would be needed.

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Other WP1 tasks

- Economics: Lack of a reliable database of unit costs.
- Uncertainties propagation: Difficult to evaluate jointly the different uncertainty sources.
- Optimization: Huge amount of calculations, more if uncertainties are considered.
- Transportation, impact of facilities…

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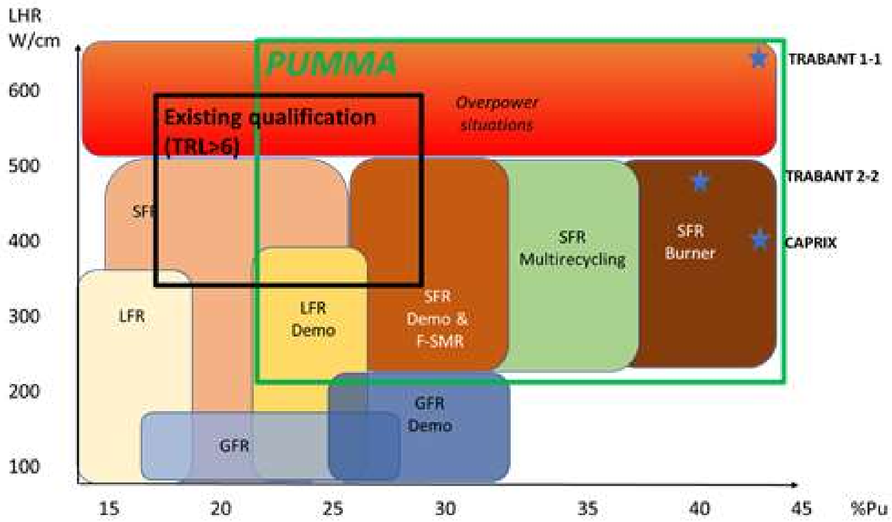
Work Package 2

Qualification of MOX fuel behavior for Gen IV systems

17 partners involved

Main WP objectives:

- Evaluation of the impact of high Pu content on fuel behavior: calculations with fuel performance codes and post irradiation examinations on several experimental irradiations.
- Extension of validation domain of Fuel Performance Codes.
- To compare the irradiation results of the same fuel in irradiated in MTR and in SFR.
- To have results of the same fuel irradiated in nominal conditions and submitted to over power.
- Methodology for safety analysis of fuel pins with high plutonium content – set of standards confidence.



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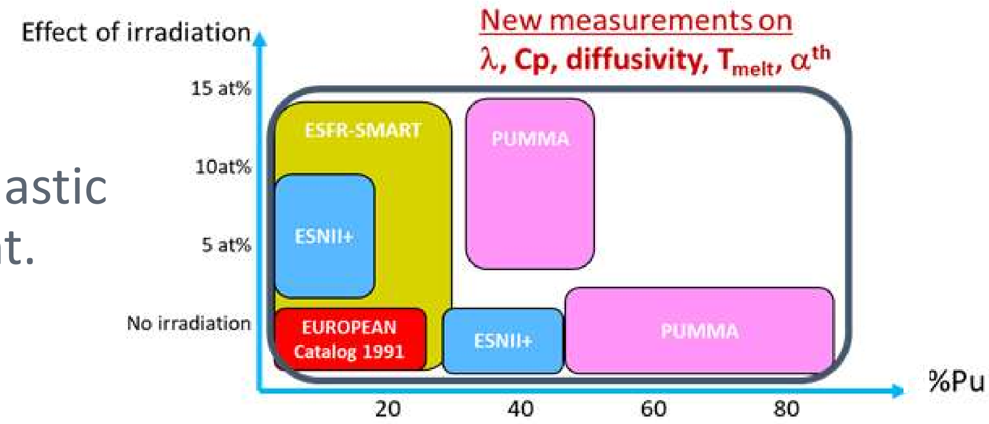
Work Package 3

Fuel properties with high Pu content: Measurements and modelling

7 partners involved

Main WP objectives:

- Reduce uncertainty in safety evaluation by reducing uncertainties on fuel properties.
- Measurements on MOX properties as a function of parameters such as density, Pu content, O/M and burn-up on non-irradiated and irradiated fuels.
- Monte Carlo calculations to determine properties of MOX fuel with high content on fresh and irradiated fuel with parameter dependency.
- Thermodynamic modelling in support thermal properties evaluation (melting temperature).
- Recommendation on mechanical properties: elastic and non elastic under steady state and accident.



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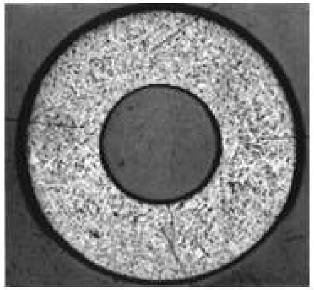
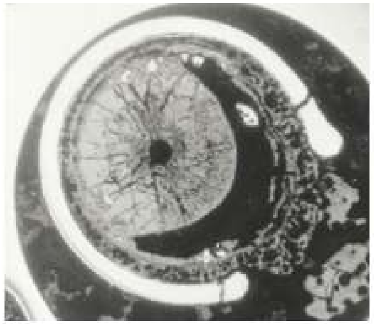
Work Package 4

Comparison of irradiation results in fast spectrum vs thermal spectrum (MTR)

7 partners involved

Main WP objectives:

- Interpretation of irradiation results in MTR and SFR
- Analysis of the advantages / disadvantages of SFRs / MTRs for future programs
- Contribution of MTR and SFR irradiations to the fuel qualification with different irradiation devices

FRESH FUEL	Irradiation in MTR – nominal conditions	Irradiation in MTR – fuel melting + clad failure	Irradiation in FAST REACTOR
			

Work Package 5

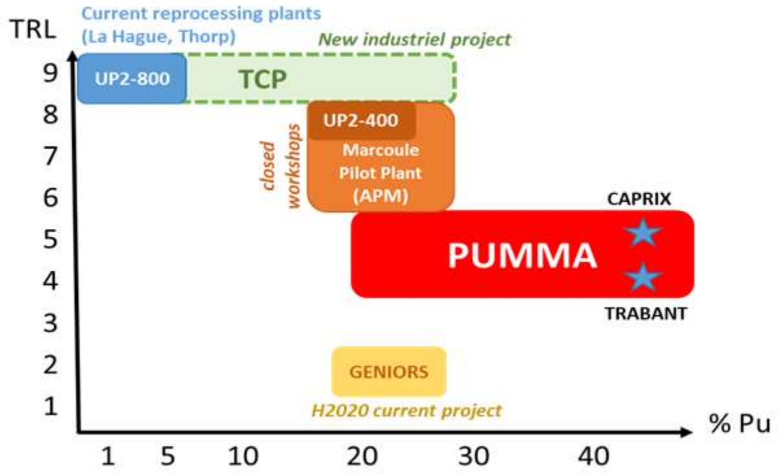
Qualification of MOX fuel dissolution

3 partners involved

Main WP objectives:

The dissolution of spent MOX fuel is fully qualified (TRL 8-9) for a standard MOX up to 30%Pu. For higher Pu content, the PUREX process was not tested and the PUMMA project will provide results to reach a qualification level of around TRL-4.

- Dissolution test at a lab scale with irradiated CAPRIX/TRABANT fuels in order to evaluate the impact of high Pu content (>30%) on U/Pu separation on Pu dissolution rate and FP distribution in solid residues
- Impact of irradiation in SFR on Pu dissolution behavior
- Dose evaluation of extractant molecule



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Work Package 6

Education and Training, dissemination and communication

14 partners involved

Main WP objectives:

- to encourage mobility of PhD students, post-doc...
- to organize workshops for PhD students, post-docs, researchers, designers, stakeholders, etc.
- to improve educational tools and learning methodologies
- to disseminate the outcomes of the project to a larger audience

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Work Package 7

Project management

3 partners involved

Main WP objectives:

- Quality management
- Project secretariat and internal project meetings organization
- Contractual & Financial management
- Management of Scientific Advisory Committee and stakeholders/end-users group
- Management of transports and mitigation of associated risks
- Interaction with International organizations and other European projects

Conclusions

- The study of plutonium management in connection with the fuel cycle is an essential part of the PUMMA project
- The impact of increasing the Pu content in the fuel is being studied
- The research has led to the design of a burner version of ESFR with MOX fuel with high Pu content.

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