Presentation of the fuel cycle related activities in the new European project PUMMA

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TWoFCS Workshop

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PuMMA
Plutonium Management for More Agility

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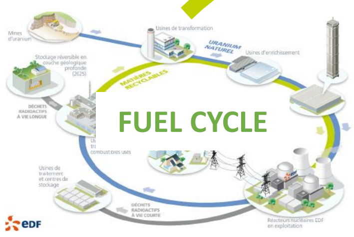
Introduction: The PuMMA project

PuMMA

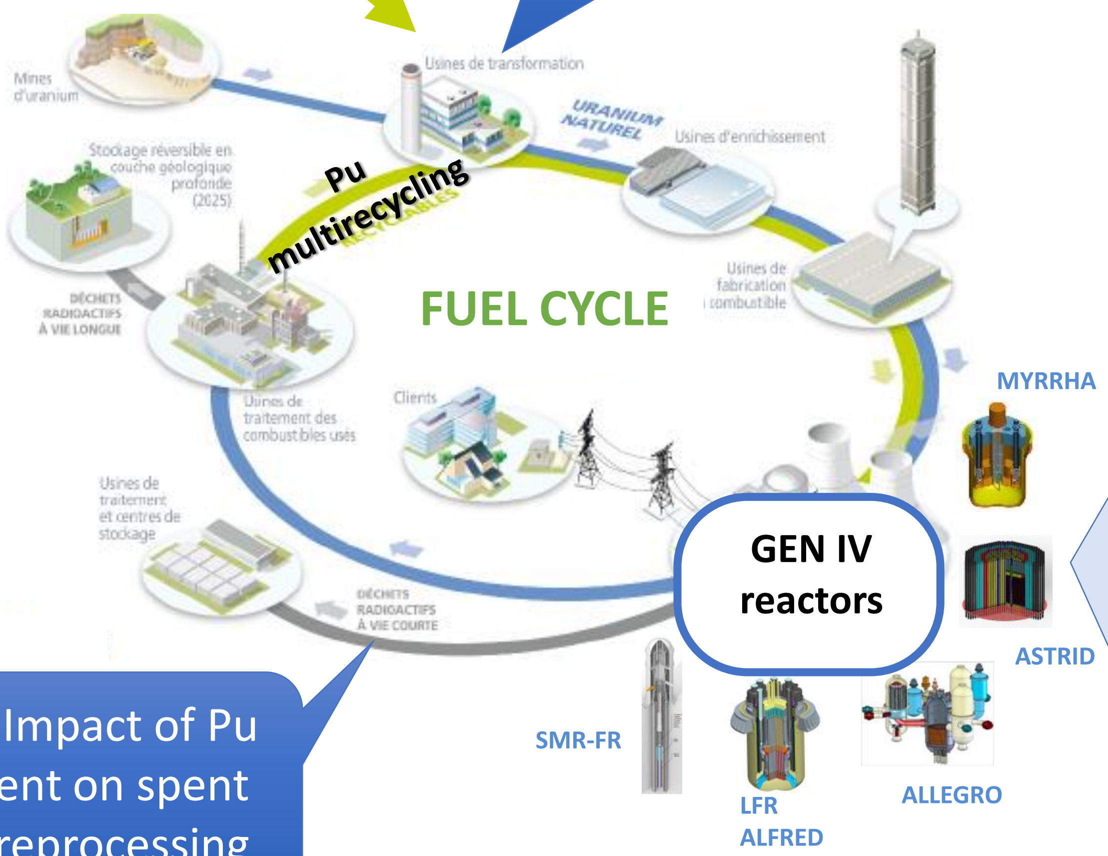
Current fleet



Pu import

Future fleet with GEN IV reactors

WP1 scenario for Pu management



WP5 Impact of Pu content on spent fuel reprocessing

20% Pu 45%

QUALIFICATION & SAFETY ASSESMENT of MOX fuel for GEN IV reactors

WP2 fuel behaviour	Safety analysis based → thermomechanical and thermochemical behaviour
WP3 fuel properties	Reduction of uncertainties on safety margins →validation of fuel properties
WP4 irradiation MTR vs FR	Fuel test under irradiation → all conditions (steady state & accidental conditions)

Plutonium management (burn, breed, isogeneration)

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 behavior, 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).*

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.*
- *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: Task 1.1

Reactors input data for scenario studies

Partners: *BME, CEA, CIEMAT, KIT*

Objectives:

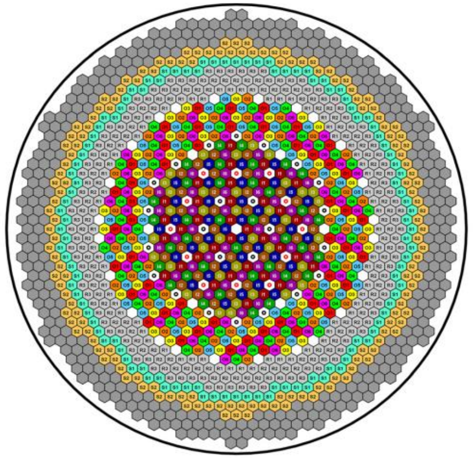
- *Definition of the input data regarding the reactors for the scenario studies*
- *Bibliographic search*
- *Supply of data for Task 1.2*

WP1: Task 1.1

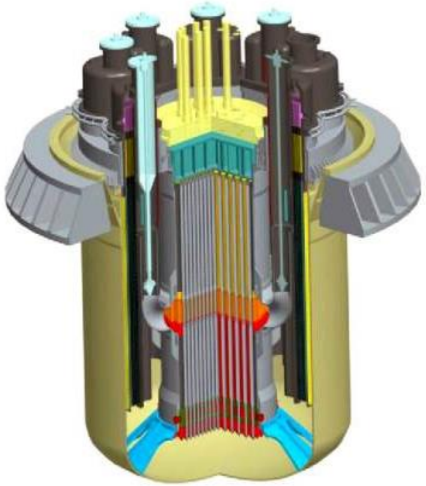
Reactors

- 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

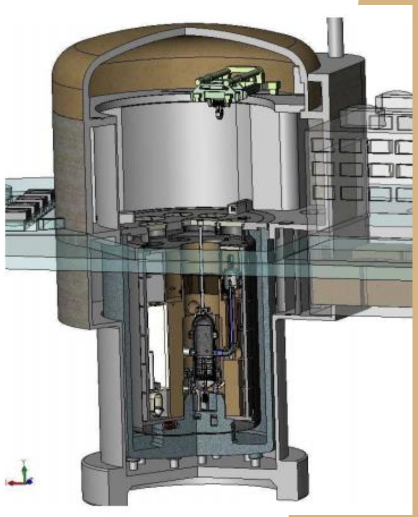
XY view of the ESFR-SMART core



ALFRED



ALLEGRO



WP1: Task 1.1

Reactor information

- Geometry description
- Power
- Fuel mass
- Cycle length
- Burn-up
- Fractional reloading
- Thermal efficiency
- Load factor

WP1: Task 1.2

Scenario calculations

Partners: *CEA, FRAMATOME, BME, CIEMAT, JACOBS, MTA EK, NNL, VTT, VUJE*

Objectives:

- *Scenario calculations for breeding, burning and isogeneration concepts*
- *Set of assumptions to be defined*
- *Set of output indicators to calculate*

WP1: Task 1.2

A non-exhaustive list of input data to be defined contains:

- *Date of technology introduction*
- *Technology deployment duration*
- *Reprocessing capacity*
- *Reprocessing losses*
- *Reprocessing strategy*
- *Energy production*
- *Share between reactor fleets*
- *Cooling time before reprocessing*
- *Fabrication time*
- *Enrichment tails*

WP1: Task 1.2

A non-exhaustive list of output indicators to be defined contains:

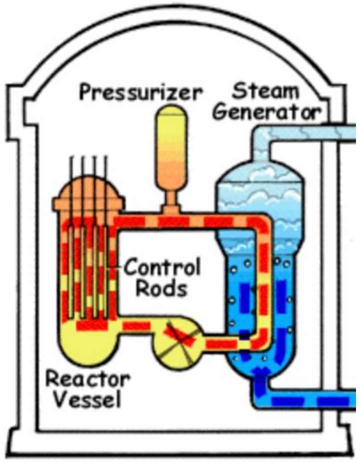
- *Natural U resources needed.*
- *Inventory of U, Pu and MA in each facility.*
- *Irradiated fuel stock and separated Pu stock.*
- *Capacities of fuel plants (reprocessing, manufacturing).*
- *Waste production.*

WP1: Task 1.2

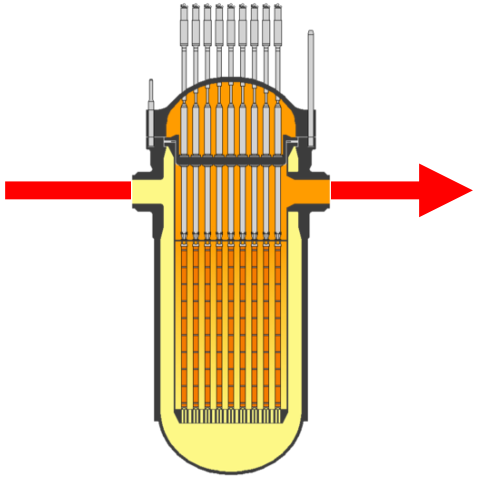
Scenario design

- *Transition from LWR (PWR, BWR, VVER) to FR*
- *Transition from LWR to FR + ADS*
- *Transition involving EPR*

LWR



EPR



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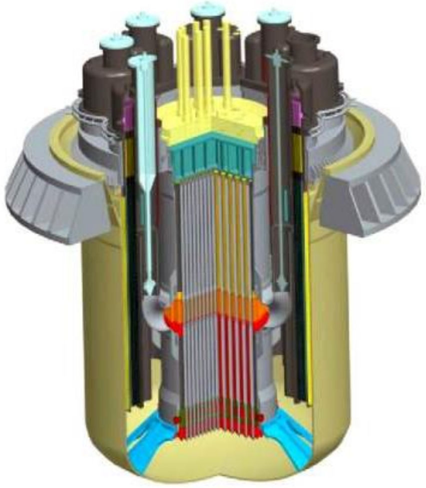
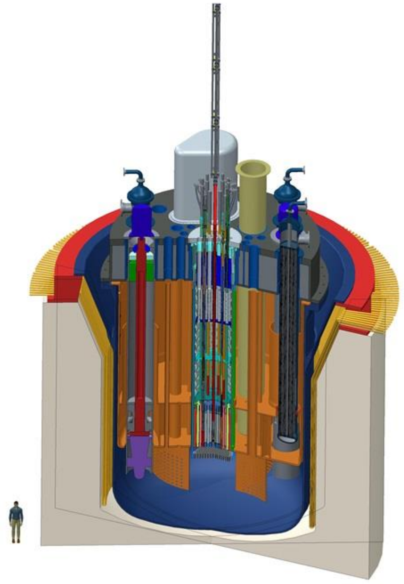


ADS



WP1: Task 1.2

Scenario strategy

- *Burning Pu*
- *Equilibrium*
- *Pu generation*
- *Mixture strategy, first burning and then equilibrium*
- *Different levels of installed power when the transition occurs*
- *ADS for MA minimization*

WP1: Task 1.3

Sensitivity studies with uncertainty propagation

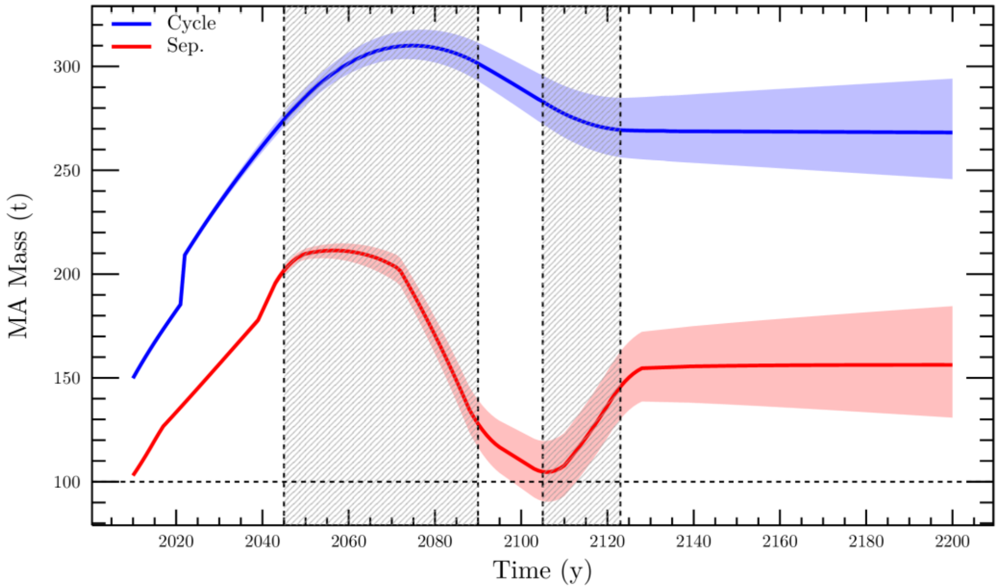
Partners: *CIEMAT, CEA, FRAMATOME, BME*

Objectives:

- *Propagation of uncertainties in the input parameters to the output indicators*
- *Set of representative scenarios assessed in Task 1.2*
- *Impact of uncertainties in facilities, waste, objectives, etc.*

WP1: Task 1.3, Methodologies

Sobol variance decomposition for the minimization of minor actinides inventory



$$S_i \coloneqq \frac{\mathrm{Var}_{X_i}\left(E_{\mathbf{X}_{\sim i}}(Y|X_i)\right)}{\mathrm{Var}(Y)}$$

$$ST_i \coloneqq \frac{E_{\mathbf{X}_{\sim i}}\left(\mathrm{Var}_{X_i}(Y|\mathbf{X}_{\sim i})\right)}{\mathrm{Var}(Y)}$$

	Parameter	S_i	ST_i	$ST_i - S_i$
MA pool	Pu_{ADS}	0,30	0,30	0,00
	E_{PWR}	0,27	0,27	0,01
	ε_{ADS}	0,20	0,20	0,00
	ε_{UOX}	0,08	0,08	0,00

Skarbeli, A. V. and Álvarez-Velarde, F. "Uncertainty quantification on advanced fuel cycle scenario simulations applying local and global methods". In: Annals of Nuclear Energy 124 (Feb. 2019), pp. 349–356. doi: 10.1016/j.anucene.2018.10.018

WP1: Task 1.3, Methodologies

Evaluation of uncertainties effects

- *Selection of one or several reference scenarios from Task 1.2*
- *Selection of uncertainties/sensitivities to evaluate*
- *Building of neural network metamodels*
- *Calculation with COSI code coupled with URANIE (CEA tool for uncertainty analysis)*
- *Evaluation of uncertainties effects on reference scenarios*

WP1: Task 1.3, Methodologies

Uncertainties about irradiation matrices

- *COSAC is the scenario code developed by Framatome*
- *In COSAC, the fuel depletion under reactor flux is modelled by an Irradition Matrix (M):*

$$M = S_{ref} \times E_{ref}^{-1}$$

where E_{ref} must be square, with a dimension equal to the number of initial isotopes in the fresh fuel

  - *It consists of subvectors containing the reference compositions that form the basis for linear extrapolation*

and where S_{ref} is composed of subvectors of spent fuel compositions corresponding to the reference vectors in E. These spent fuel compositions should be given as a result of Task 1.1

- *In Task 1.3, the effect of a perturbation introduced in the Irradiation Matrix (M) onto the results of the scenario (especially onto the isotopic content of the interim storage of spent fuel) will be studied*

WP1: Task 1.3, Methodologies

Sensitivity and uncertainty analysis of fuel cycle parameters

- *Breeding ratio*
- *Transmutation rate*
- *Salvatores' D factor*
- *Based on Markov chain models of nuclear transmutation*
- *More details in*

https://doi.org/10.1016/j.anucene.2018.07.010

WP1: Task 1.4

Impact on fuel composition, fuel cycle facilities, transportation and economic criteria

Partners: *VTT, CEA, CIEMAT, LGI*

Objectives:

- *Economic assessments, waste management, impact on facilities*
- *Different approaches*

WP1: Task 1.4, Impact on facilities

- *Reactivity analysis in spent fuel pools, storage casks, etc. depending on availability of input data for the facilities*
- *Dose estimates*
- *Estimation of proliferation resistance of different processes and scenarios studied in task 1.2 based e.g. on the Charlton method[1]*
- *Calculation tools*
  - *Serpent 2*
  - *COSI6*

[1]W. S. Charlton, et.al., "Proliferation resistance assessment methodology for nuclear fuel cycles", Nuclear technology, 157 (2017) pp. 143-156.

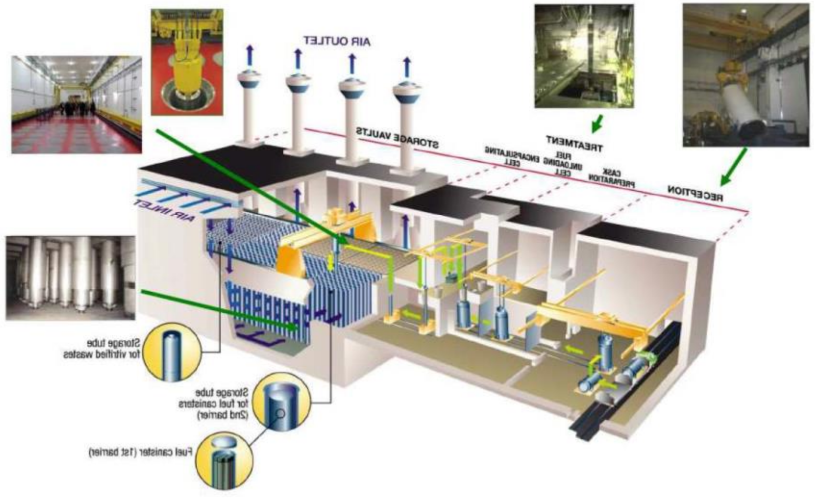
WP1: Task 1.4, Economic assessments

- *Selection of one or several reference scenarios from Task 1.2*
- *Selection of an open cost database (e.g NEA cost database)*
- *Update of missing or incomplete cost data*
- *COSI calculation to evaluate the cost of the fleet (e.g LCOE) using a dedicated module*

WP1: Task 1.4, Waste production

- *Selection of one or several reference scenarios from Task 1.2*
- *Evaluation of the amount of waste considering waste form*
- *Evaluation of derived quantities: decay heat, radiotoxicity, gallery length*

Centralized Interim Storage. Source: ENRESA



Conclusions

- *The study of plutonium management in connection with the fuel cycle is an essential part of the PUMMA project*
- *11 institutions are studying the impact of increasing the Pu content in the fuel*
- *Scenario calculations will be done, considering uncertainties, economics, transportation, facilities, waste production…*

Thank you!

Contact us for more information!

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