Integration of MSRs in LW-SMR fleets to close their fuel cycle and/or manage waste

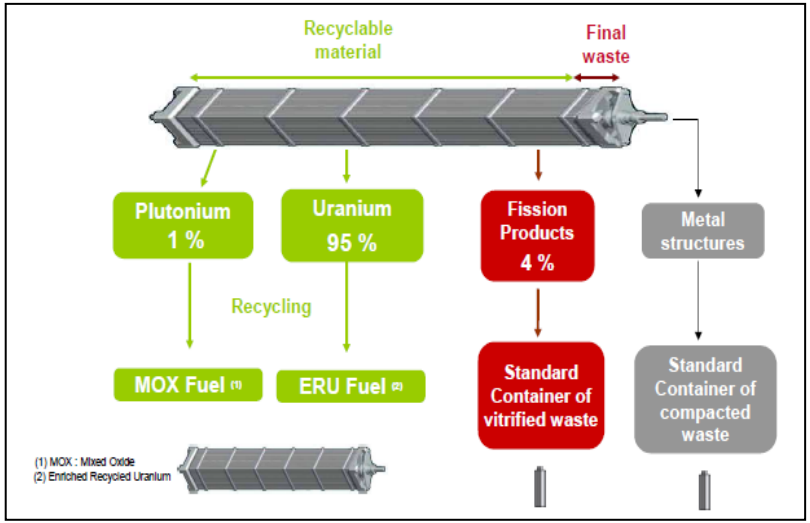
IAEA Technical Meeting

Orano La Hague reprocessing plant is a strategic asset addressing Back-End challenges for all LWRs spent fuels : 96% of spent fuel can be recovered, 4% conditioned and safely stored

A service that can be offered to LWR operators worldwide : reprocessing in La Hague + recycling of Pu into MOX fuel fabricated at Melox plant

- Savings in natural U
- waste are conditioned in Universal canisters (UC): a standardized waste form suitable for transport, storage and final disposal

French Nuclear Waste Act of June 28, 2006
*"**Importing foreign Spent Fuels for reprocessing is allowed provided that ultimate waste is to be sent back to the country of origin**"*



50 years of LWR fuel reprocessing experience

~27,000 tHM reprocessed for France
10,500 tHM reprocessed for 6 other countries

For LW-SMRs, the reprocessing and recycling processes developed from long date by Orano are directly applicable. Only if those SMRs use higher enrichment (HALEU), some parameters have to be slightly adapted for reprocessing.

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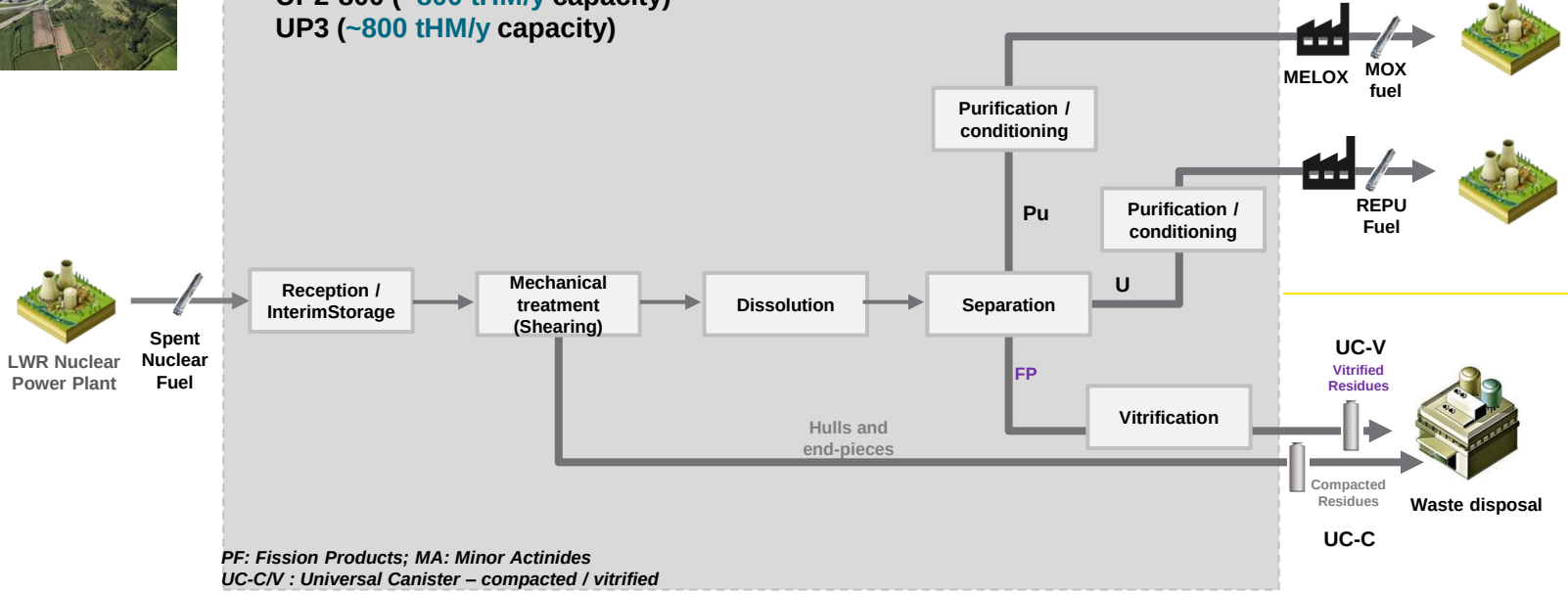
La Hague overall reprocessing process diagram – based on PUREX process (Pu and U Refining by Extraction)

Two production *lines*

UP2-800 (~800 tHM/y capacity)
UP3 (~800 tHM/y capacity)



PF: Fission Products; MA: Minor Actinides
UC-C/V : Universal Canister – compacted / vitrified

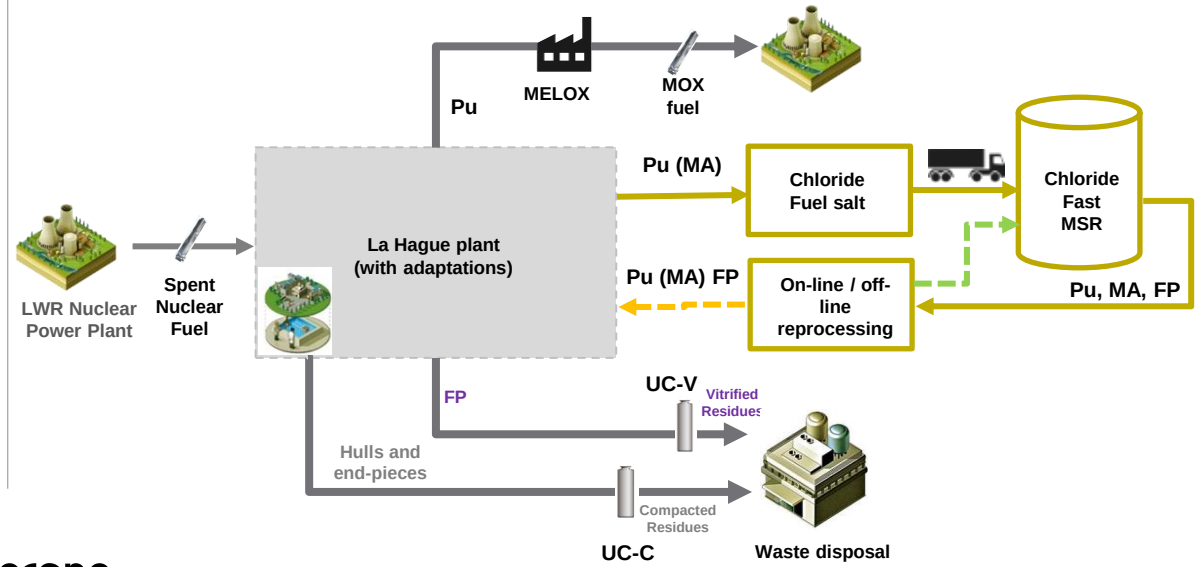
Coupling the La Hague plant with fast MSRs converting actinides into Fission Products would add value to the standard LWR spent fuel reprocessing service

An additional service to LWR operators to close the fuel cycle and reduce HLW

- For some LWR operators who can't / don't want to recycle Pu in their LWR fleet : Reprocessing of spent fuel with no return of Pu
- For all, in addition to mono/multi-recycling in LWR : Transmutation of MA ➔ less ultimate waste, with reduced long-term radiotoxicity

Salt management Services for MSRs (salt synthesis, logistics, used salt recycling)

- Pu and MA are converted in Fission Products ➔ conditioned in UC-V



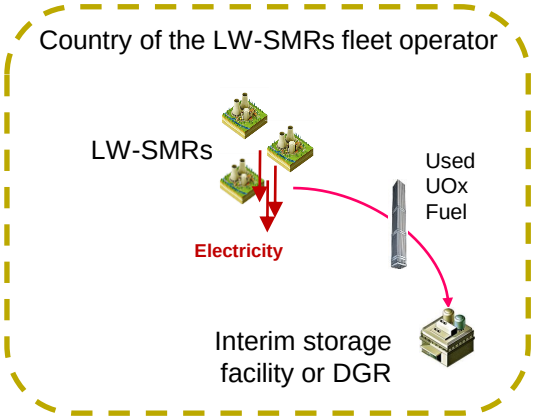
Synergies with La Hague plant where the molten salt can be produced and recycled

- **Step 1** : Production of a Pu chloride salt and off-site used salt recycling ➔ FP+Pu+MA salt transportation to La Hague ➔ waste (FP+MA) vitrification
- **Step 2 :** Production of a Pu+MA chloride salt and on-line used salt recycling ➔ FP-only salt transportation to La Hague for vitrification
  ➔ *Needs additional functions for MA management in La Hague*

Fuel Back End management options for a fleet of LW-SMRs

Direct disposal

Used UOx fuel is stored in an interim storage facility pending to be stored in a Deep Geological Repository (DGR)



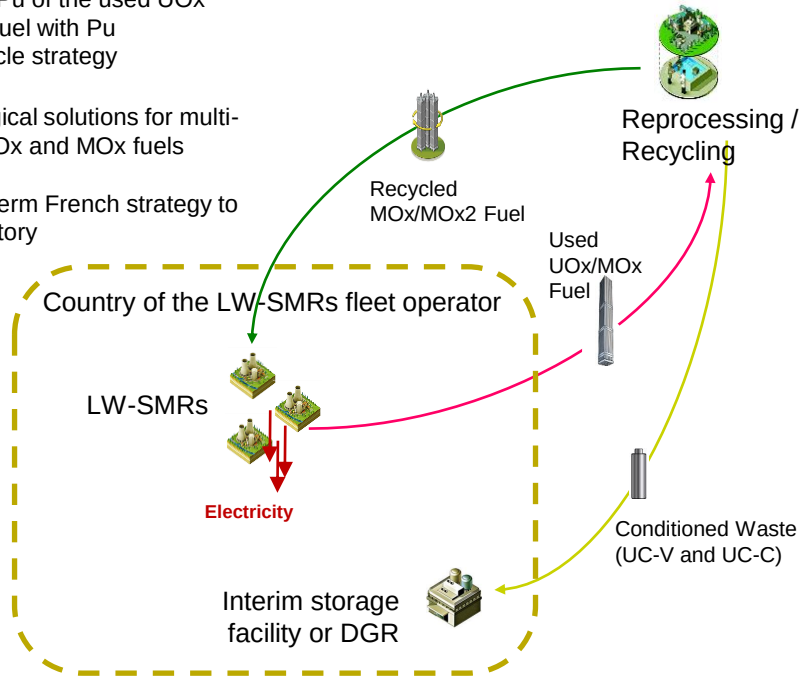
Recycling of Pu

Mono-recycling

- Recovering of U and Pu of the used UOx fuel, producing MOx fuel with Pu
- Actual French fuel cycle strategy

Multi-recycling

- Developing technological solutions for multi-recycling the Pu of UOx and MOx fuels through a MOx2 fuel
- Could be the middle term French strategy to stabilize the Pu inventory



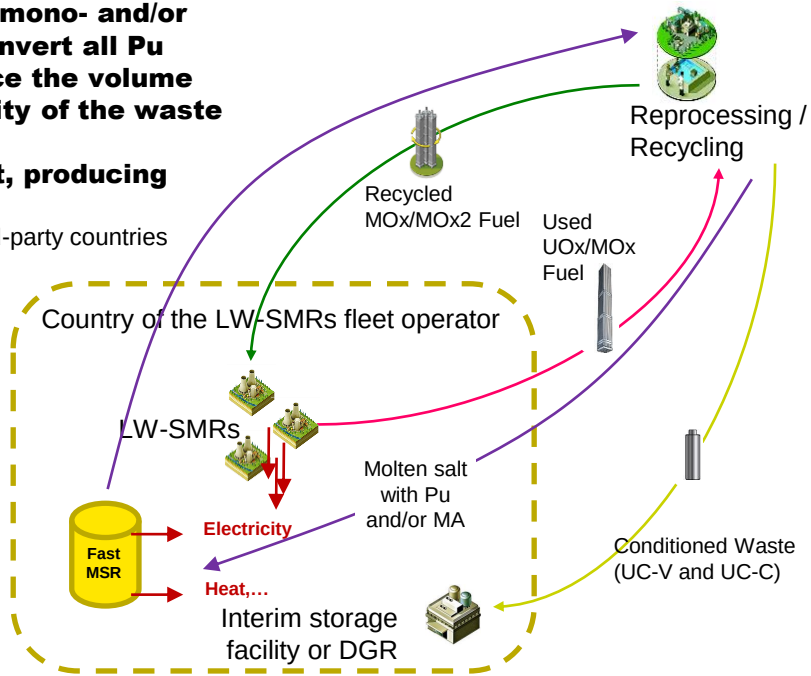
Fuel Back End management options for a fleet of LW-SMRs

Conversion of Pu and/or MA in Fast chloride MSRs

A complementary service to mono- and/or multi-recycling options to convert all Pu isotopes and/or MAs to reduce the volume and the long-term radiotoxicity of the waste

MSRs can be part of the fleet, producing also heat/electricity

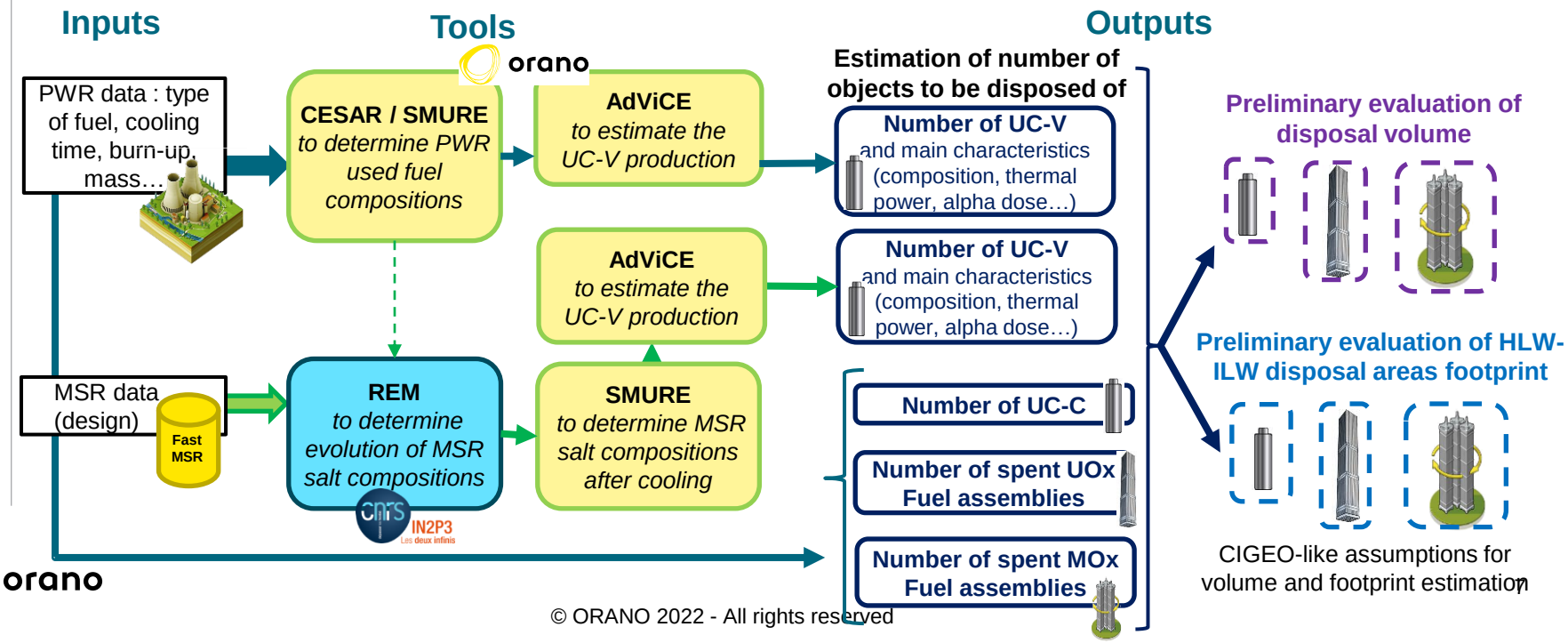
- Alternative : MSRs operated by third-party countries



A preliminary study has been performed to assess the potential of Fast chloride MSRs in a symbiotic fleet of SMRs to “burn” Pu and MA from the LW-SMRs

The methodology is based on the use of several codes and tools for PWR and MSR modeling

- AdViCE (Advanced Vitrified Estimator) is an Orano simplified non-industrial tool
- SMURE package (CNRS) is a combination of SERPENT (VTT) and a depletion module
- CESAR (CEA, Orano) is a simplified depletion code developed for back-end purposes



The models and assumptions that are used for the calculation are simplified and will need to be refined or further developed in the future

By assumption, a fleet producing 10 TWhe/y is considered (equiv. to 12 LW-SMRs @ 100MWe), at equilibrium

- Steady state compositions are considered for both LW-SMRs and MSRs
- For the scenario with MSRs, the number of MSRs is determined to convert 100% of the quantity of Pu+MA produced by LW-SMRs

	LW-SMR 100 MWe (fictional model)
Mass of fuel in the core (tHM)	13
Burn-up (GW.d/t)	49,5
Power (MWe)	100

LW-SMR model

	MSR 135 MWe (fictional model)
Pu+MA Conversion rate per year (g/MWth)	~400
power density (150 MWth/m^3)	150
Power (MWe / MWth)	135 / 300

Fast chloride MSR model

Reprocessing and vitrification are performed in La Hague (LW-SMRs and MSRs spent fuels)

- Streams are separated per reactor type
- Cooling time 5 years before reprocessing
- Ideal U, Pu and MA extraction rates
- Reprocessed Uranium to be recycled in LWRs, not considered in the simulation

Conversion of Pu+MA in MSR will produce used salt with only FP

- U+TRU are reinjected in the MSR core (on-line ideal & instantaneous reprocessing)
- Ideal conversion rates for Pu and MA

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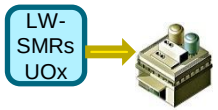
cnrs IN2P3 Les deux infinis

The comparison of 3 scenarios illustrates the potential of MSR in reducing the volume and radiotoxicity of High-Level Wastes (HLW)

Impact on waste to be emplaced in a Deep Geological Repository

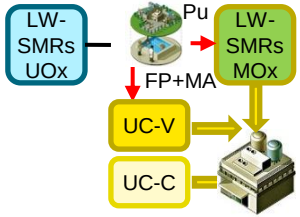
1 **Open cycle**



130 UOx fuel assemblies per year

2 **Mono-recycling of Pu in LW-SMRs (MOx)**

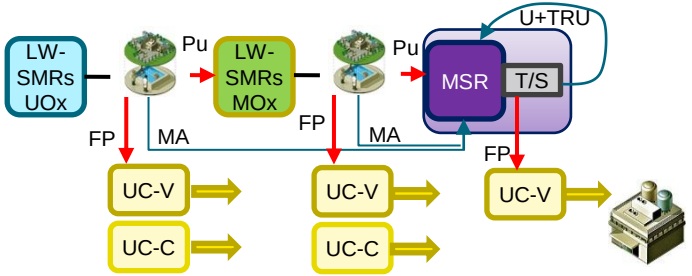
Pu stream balanced in MOx fuels



14 MOx fuel assemblies + 20 UC-V + 23 UC-C per year

3 **Mono-recycling of Pu in LW-SMRs (MOx) + MSR as Pu+MA convertors**

Pu ex-MOx & MA ex-UOx/MOx streams balanced in MSR



20 UC-V without MA + 21 UC-C per year

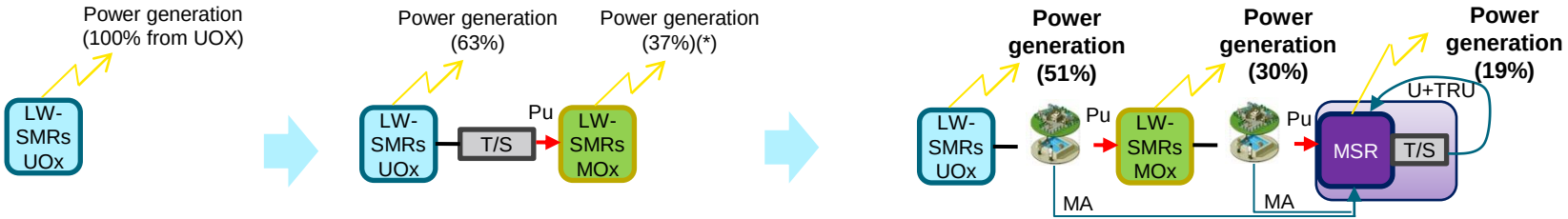
No MA in UC-V ➔ strong reduction of both thermal impact and of requirements for the DGR

T/S : on-line treatment / separation of salt

A “symbiotic fleet” of LW-SMRs and MSRs is achieved when actinide production in LW-SMRs equals actinide disappearance in MSRs – optimal for the closure of the fuel cycle and waste reduction

Based on the models and assumptions used for the estimation, a symbiotic fleet was obtained @ 81% LW-SMR / 19% MSR

- E.g., for 10 TWhe/y and the chosen power capacity of reactors: ~10 LW-SMRs /~2 MSRs
- A smaller proportion of MSRs (~6%) would be needed if Pu was multi-recycled in LW-SMR
- Scenarios could accommodate MSRs to be built at a latter stage (low maturity today) and/or in other countries



(*) SMRs loaded at 30% of MOx fuel

A unique value in terms of sustainability and public acceptance of nuclear energy in the future

As a conclusion…

A Pu+MA conversion solution can limit the needs in natural resources and reduce the production of waste in volume and long-term radiotoxicity : It is based on the coupling of a "symbiotic" fleet of LW-SMRs and MSRs, and a fuel treatment / separation processing plant

Most of these process steps are already available in La Hague at industrial scale with a long experience of services to French and foreign LWRs operators

Using synergies with the industrial capabilities of La Hague can accelerate the development and deployment of such Back-End solutions for any LWR - including LW-SMR - fuel

Preliminary evaluations (at steady state) show a promising potential in the reduction of volume and long-term radiotoxicity of ultimate waste using MSR as *Pu+MA convertors*, as a complementary service to Pu mono- and/or multi-recycling options.

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THANK YOU FOR YOUR ATTENTION

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[1] Tillard, L., et al. (2022), “Estimation of the vitrified canister production for PWR fleets integrating MSRs with different fuel cycle strategies”, Proceedings of GLOBAL 2022, Reims, France, July 2022

[2] Meridiano, Y., et al. (2022), “Analysis of value proposition and economic advantages of scenarios based on the use of MSRs as “waste burners”, Proceedings of GLOBAL 2022, Reims, France, July 2022

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