

Fuel cycle development for MSR

Orano perspectives

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orano

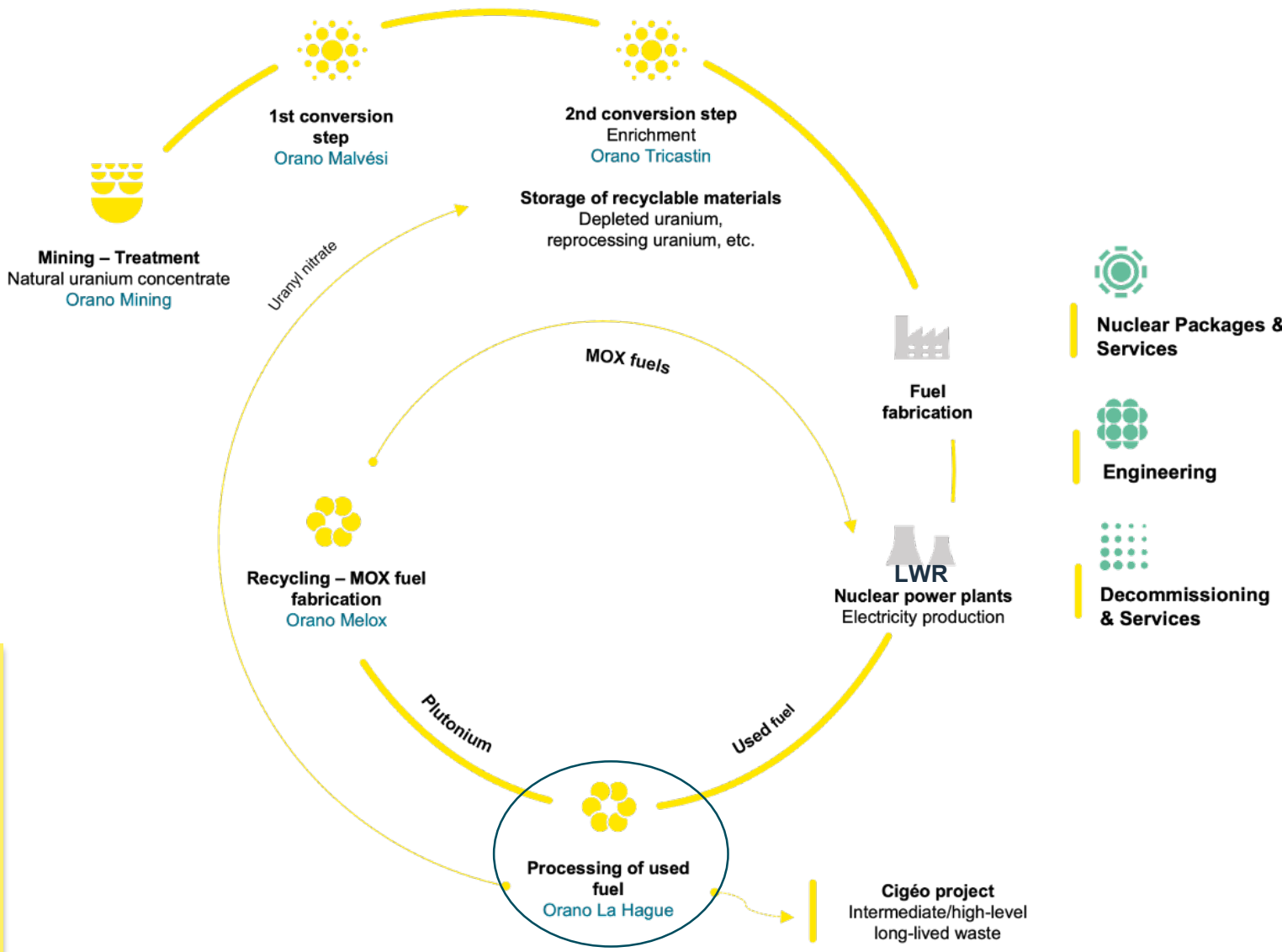
01 • Orano - World expert in the nuclear fuel cycle

The Orano Group offers its customers high-performing products and services, in mining, conversion, enrichment, recycling, logistics, engineering and decommissioning.

Orano is also a major force in nuclear medicine and targeted alpha therapy using ^{212}Pb , through its subsidiary Orano Med.

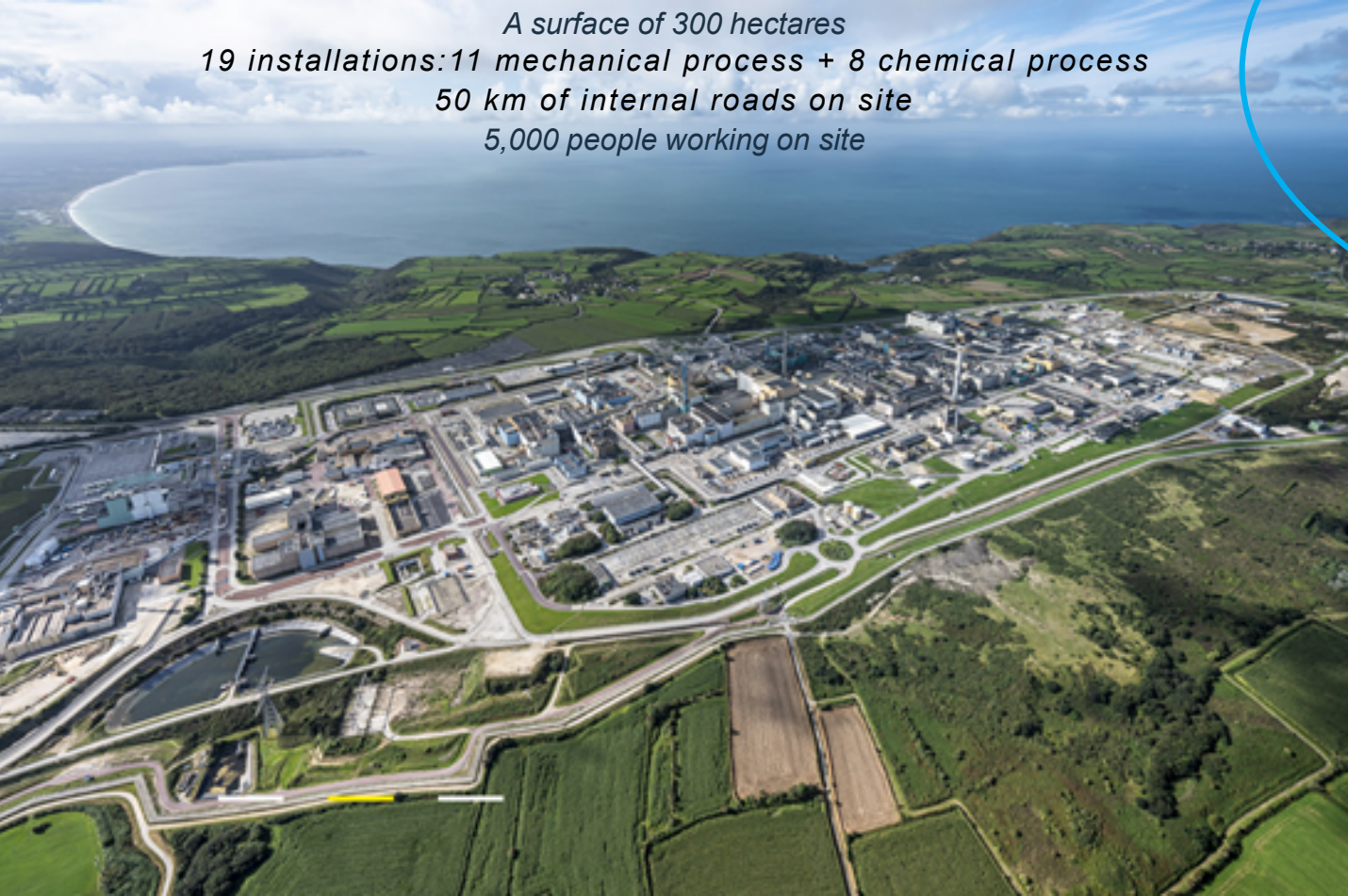
Its know-how across every stage of the fuel cycle and its ability to innovate are key success factors

Orano fundamental purpose:
To develop know-how in the transformation and control of nuclear materials, to protect the climate, health, and for a resource-efficient world now and tomorrow.

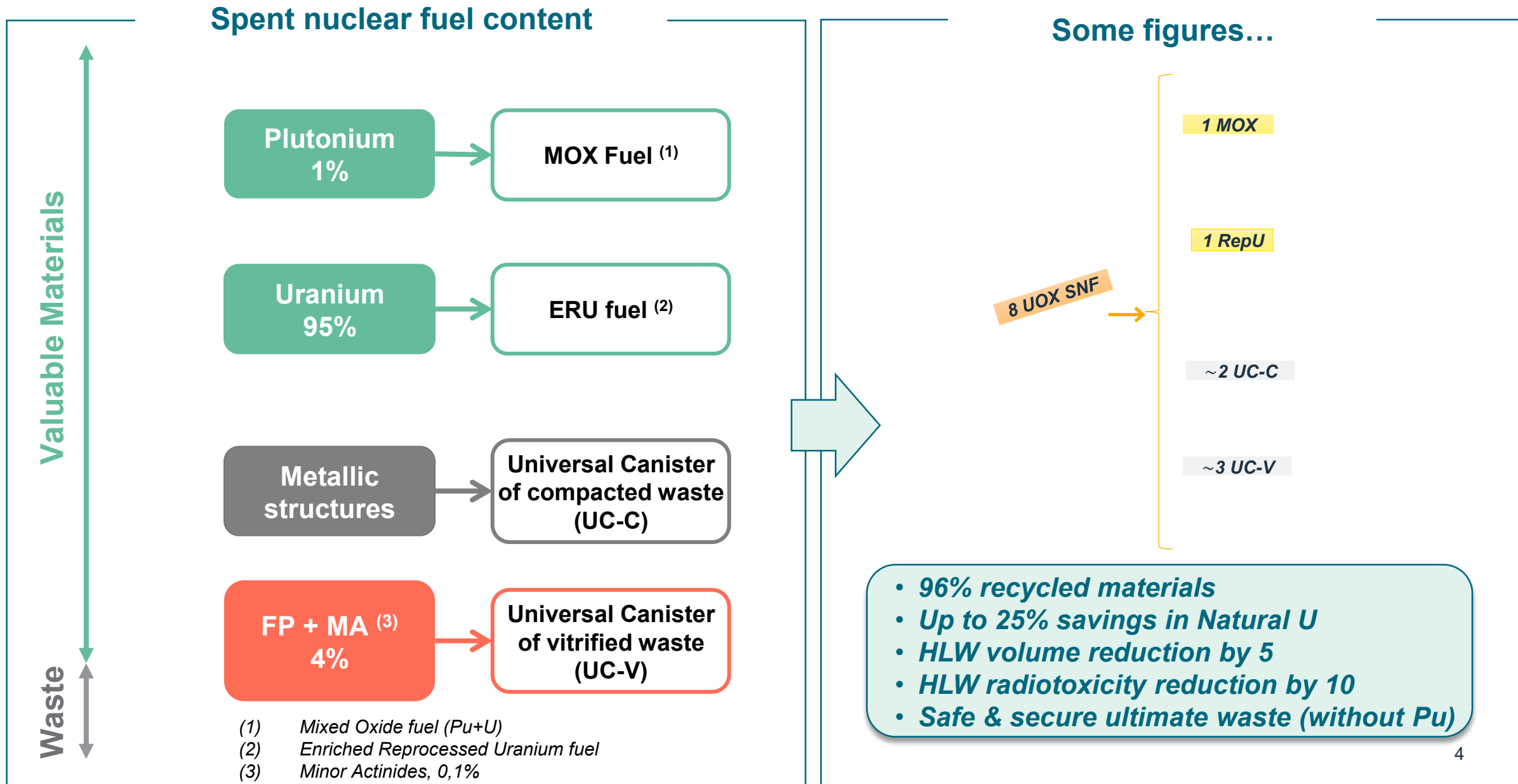


The La Hague plant is a strategic asset which has addressed Back-End challenges for LWRs spent nuclear fuels for 50 years

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



Orano's technologies allow 96% of spent nuclear fuel to be recycled. The 4% of final waste is conditioned to make it safe and stable

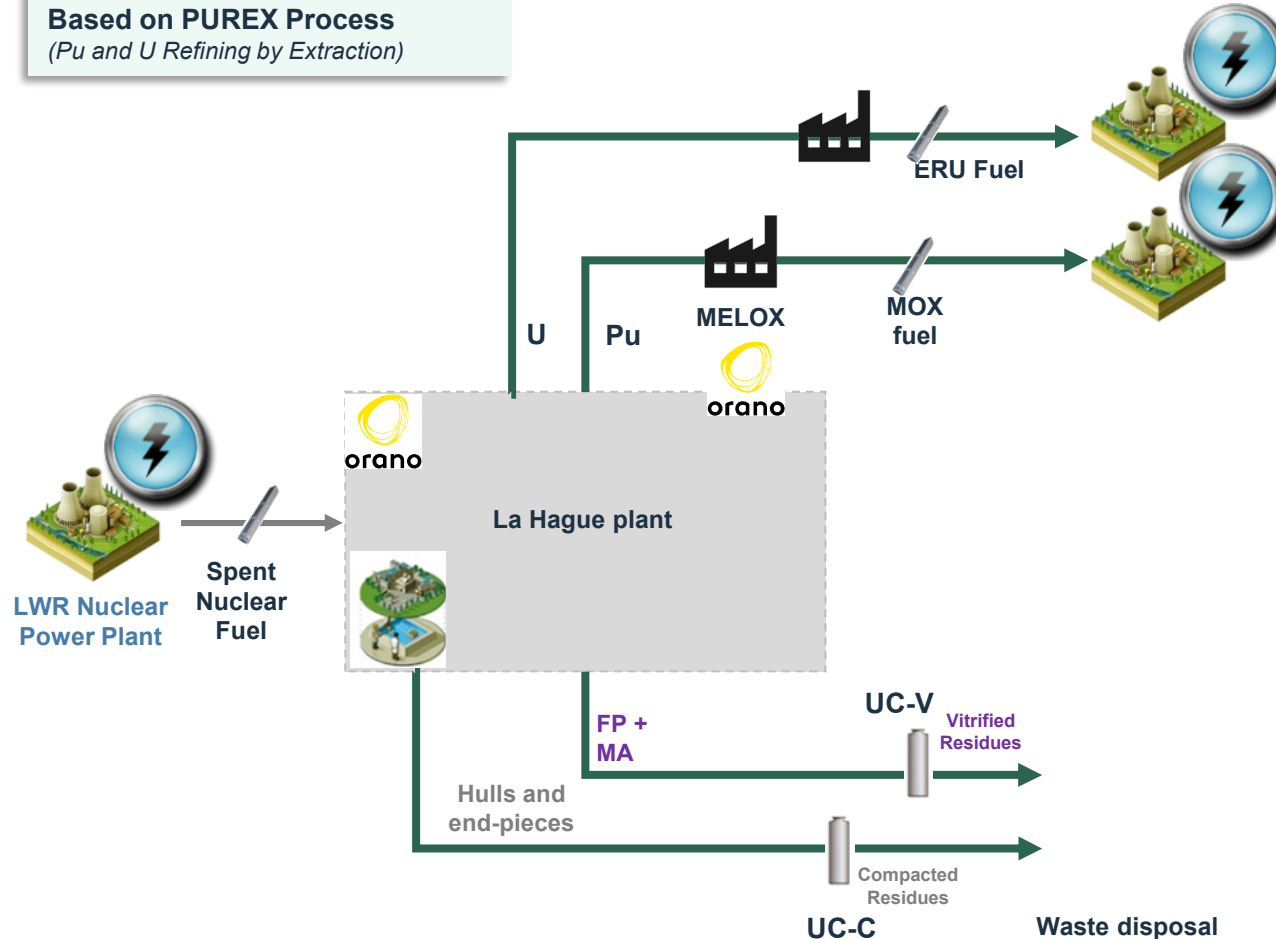


La Hague plant : A first-of-a-kind nuclear mechanical and chemical plant with complex process to operate by remote

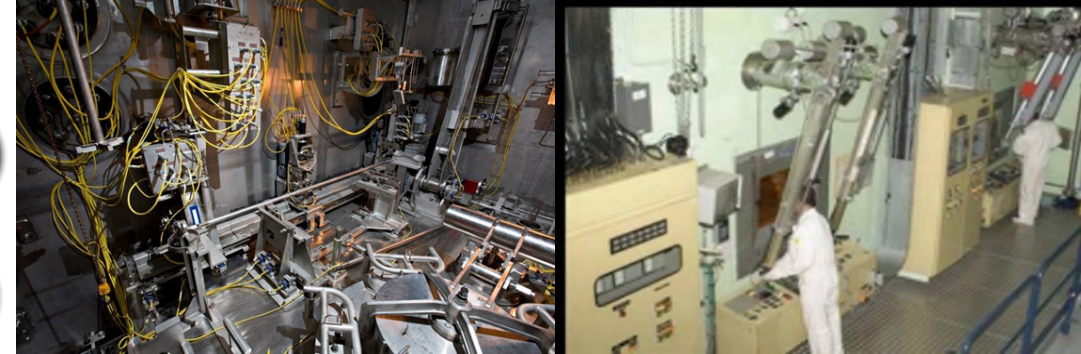
Two production lines

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

Based on PUREX Process
(Pu and U Refining by Extraction)



A fault tolerant design



Maintenance by design, a key pillar of the engineering process applied to La Hague



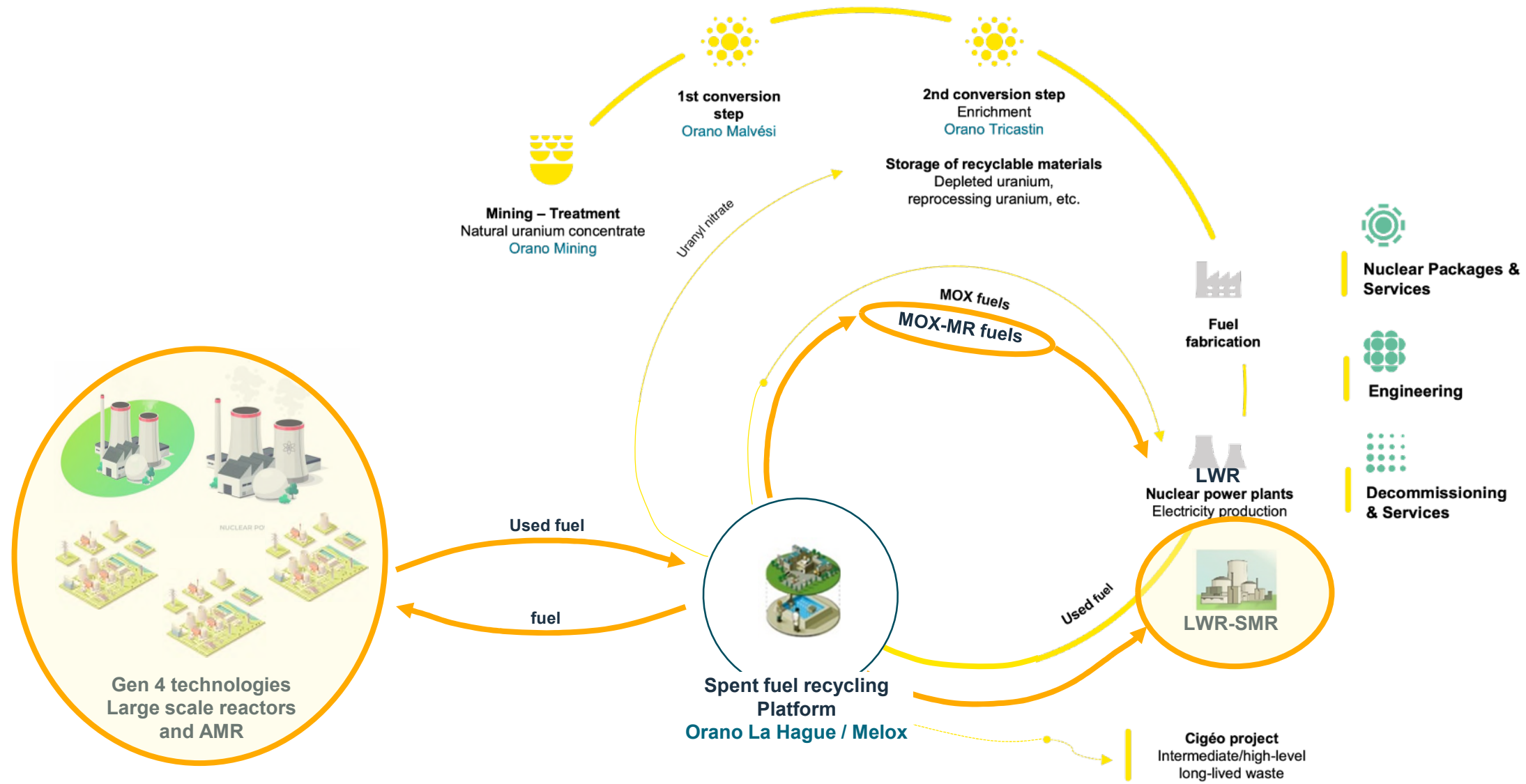
A complete maintenance organization and processes, taking into account

- **Scheduled operation**
- **Unscheduled operation**



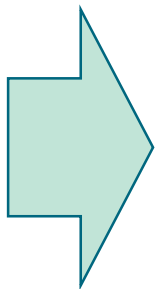
Hardened and proven technologies for remote maintenance, as well as skilled operators

02 • Orano recycling platform : A modular and flexible industrial plan, adaptable to the deployment of new reactors



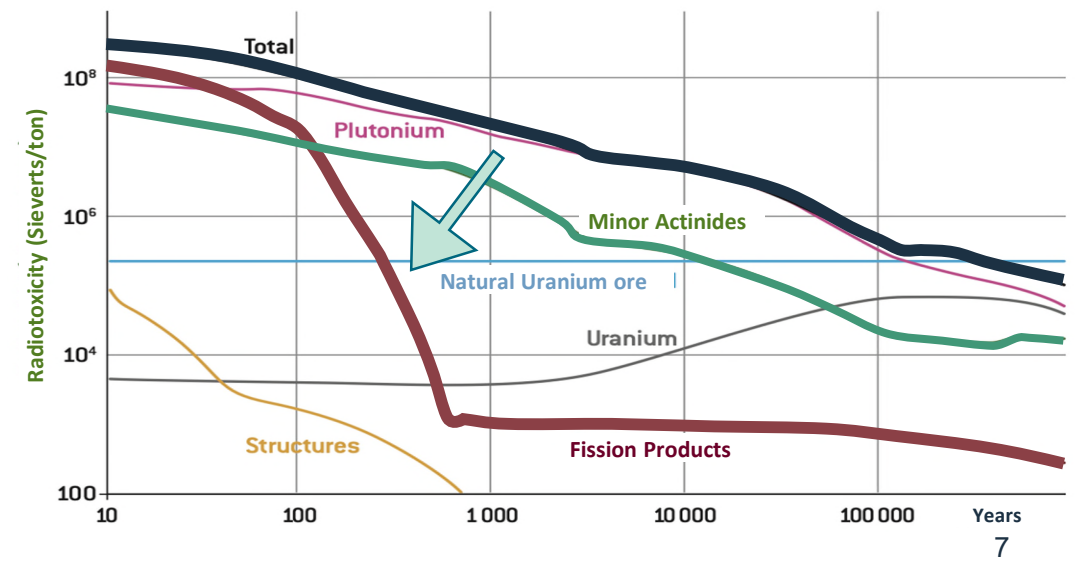
03 • Why is Orano interested in MSR ?

- High temperature operating window (600-800°C) allows for higher efficiency electricity production and industrial heat applications
- Enhanced safety
 - High boiling point and excellent cooling properties of molten salt
 - Low pressure operation
 - Passive safety features
- **Reduction of long-lived waste products**
- Capable of response to load changes
- Operational experience with 2 molten salt reactors at ORNL (U.S.)



Chloride fast MSRs are particularly promising for use as actinide (Pu and MA) converters

- The neutronic spectrum can be hardened (in Chloride salt)
- **No fabrication of solid fuel** (complex at industrial scale with MA, need of costly shielded chains)
- **No cladding limitation to burn up**, so the actinides remain in the core until they fission and are thus totally "burned"
- **Operation in Pu or Pu+MA cycle, i.e., without Uranium** → maximized consumption of Pu/MA
- **No degradation by MA of counter-reaction factors** → possibility to increase the MA content in the core (vs. LMFR with solid fuels)
- Chloride salts enable synergies with La Hague plants, which fluoride salts cannot do

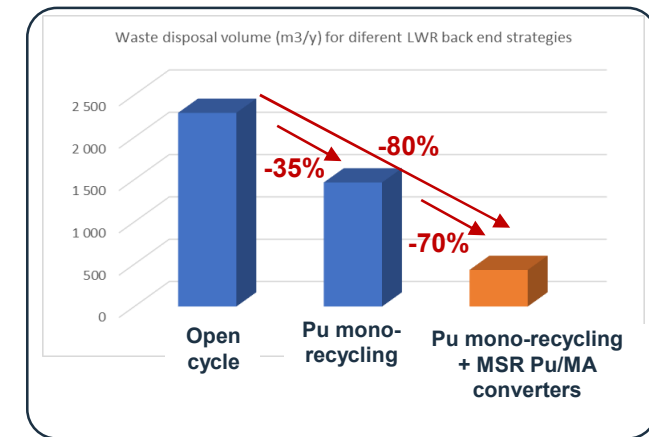
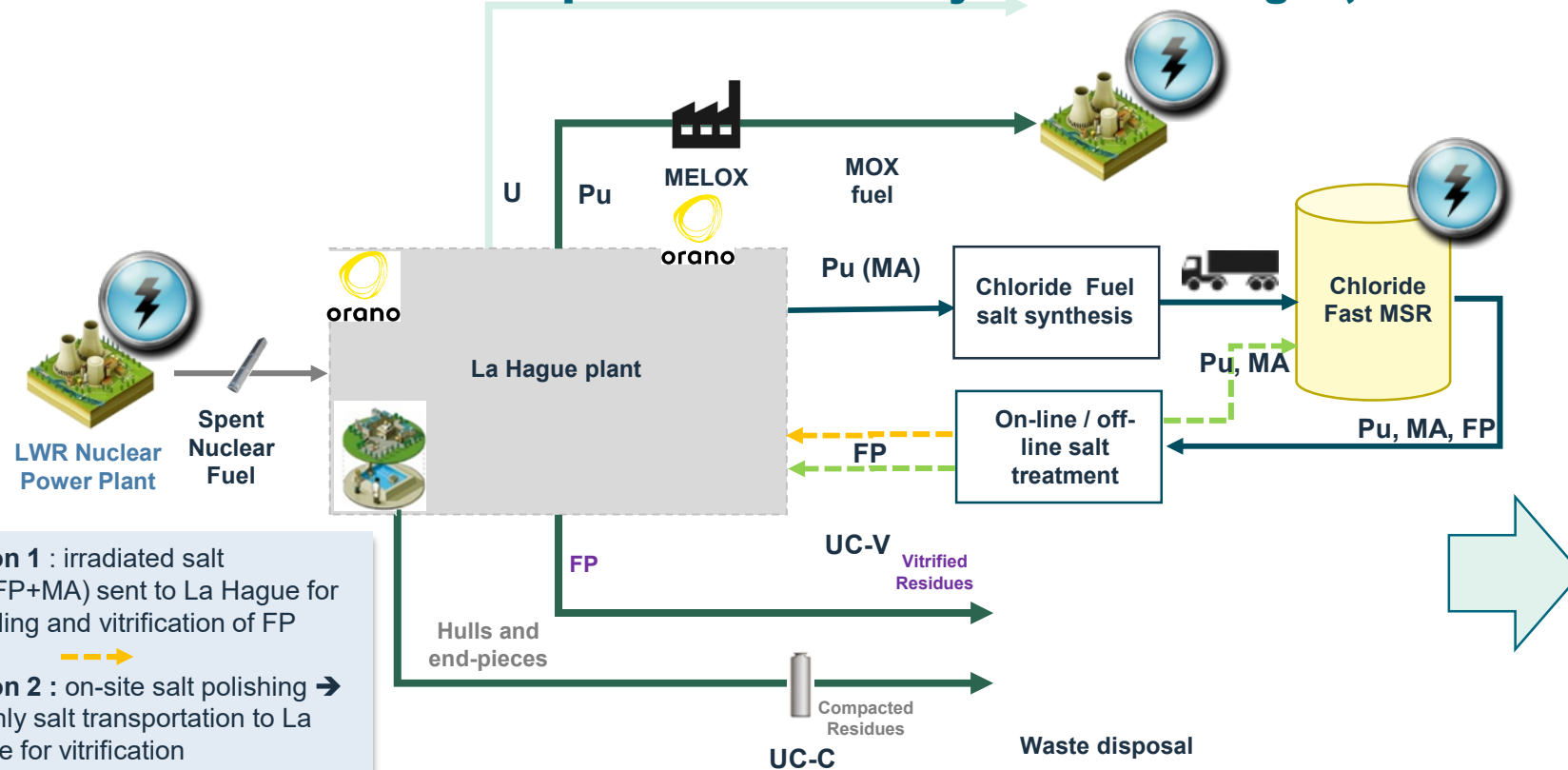


Since 2019 Orano has been exploring the potential of fast Chloride MSR to use Pu / MA as fuel and to provide La Hague customers a global solution where they are left with FP waste only (in UC-V)

Beyond U/Pu recycling in their own LWR, this would be an additional service to LWR operators to close the fuel cycle and reduce High Level Waste (HLW)

- Treatment of spent nuclear fuel with no return of Pu
- Transmutation of MA → less ultimate waste, reduced long term radiotoxicity

The molten salts could be produced and recycled in La Hague, and FP vitrified in La Hague

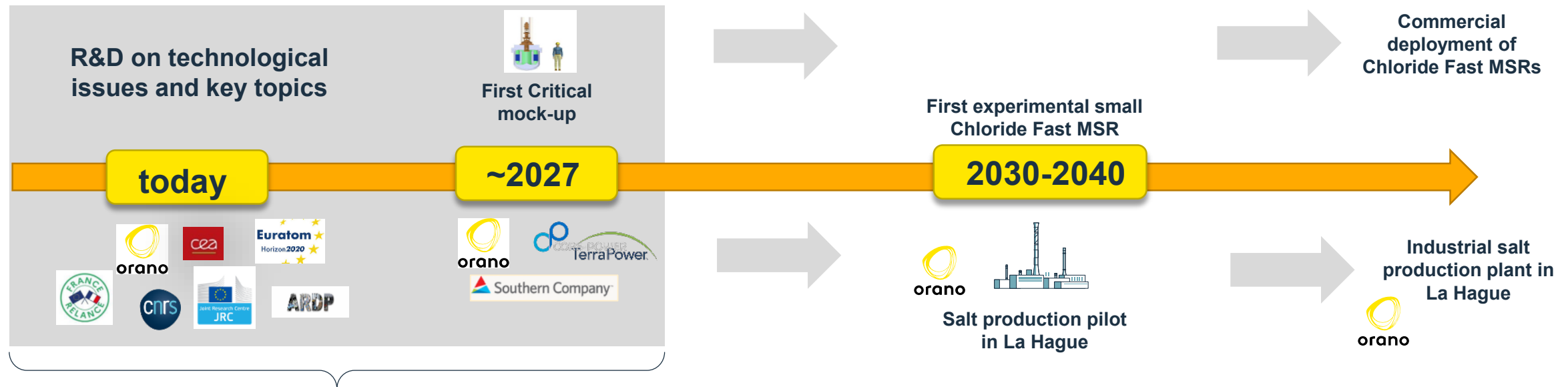


No MA in UC-V → strong reduction of both thermal impact and requirements for the Geological Repository

Orano's strategy is to enable the emergence of Chloride Fast MSR concepts, with a first demonstrator of CI Fast MSR in the 2030'

Orano has two ambitions :

- To contribute to the realization, with partners developing MSR concepts, of a **first operational demonstrator** of Chloride Fast MSR in the 2030s'
- To be able to produce **PuCl₃-based salt** to supply the first Chloride Fast MSRs in the 30's.

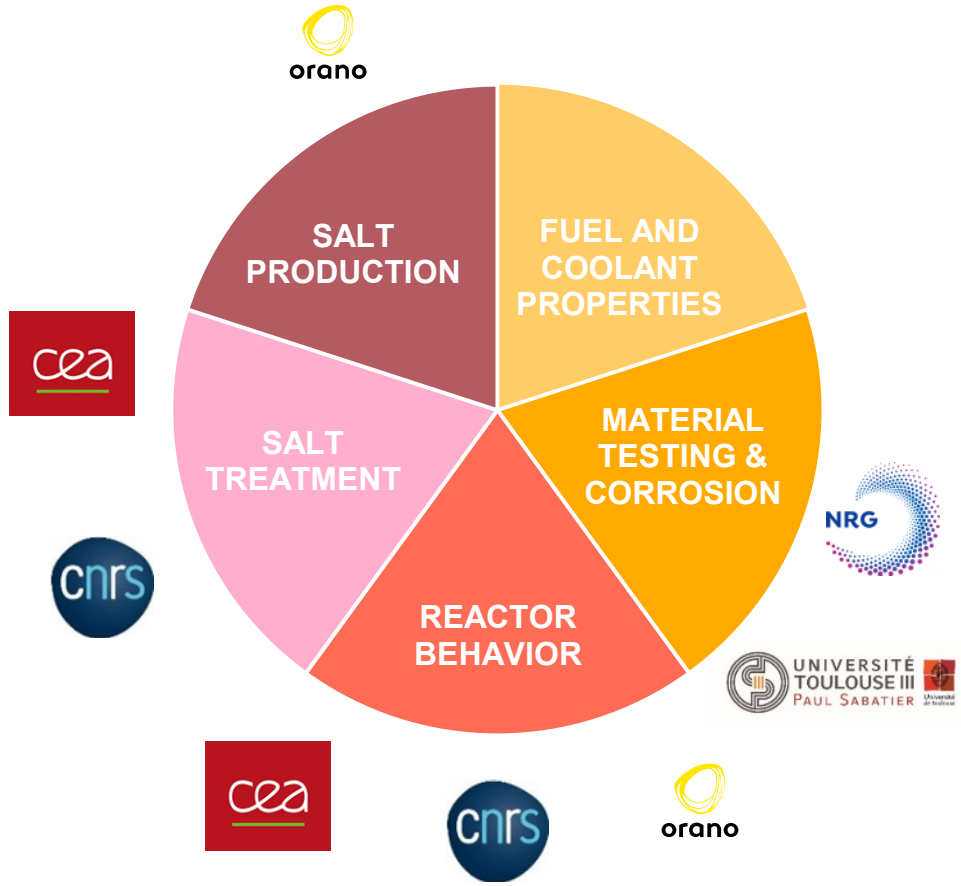


International cooperation is vital to succeed in the R&D programs leading to commercial CI MSRs

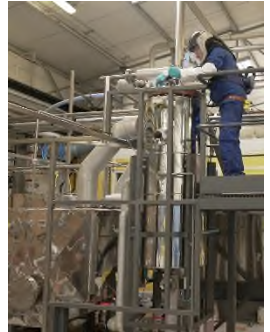
04 • Orano's R&D program main objective : to facilitate the pathway to a MSR Demo

An extensive R&D program has been initiated on various aspects of the MSR fuel cycle to accelerate technological development.

- Salt production
- Salt thermo-physical properties measurement
- Material testing and corrosion mitigation
- Actinides conversion performance
- Salt treatment, fission products treatment and conditioning
- Compatibility of salts with La Hague plant



HRB
Development & qualification of process and equipment (inactive)

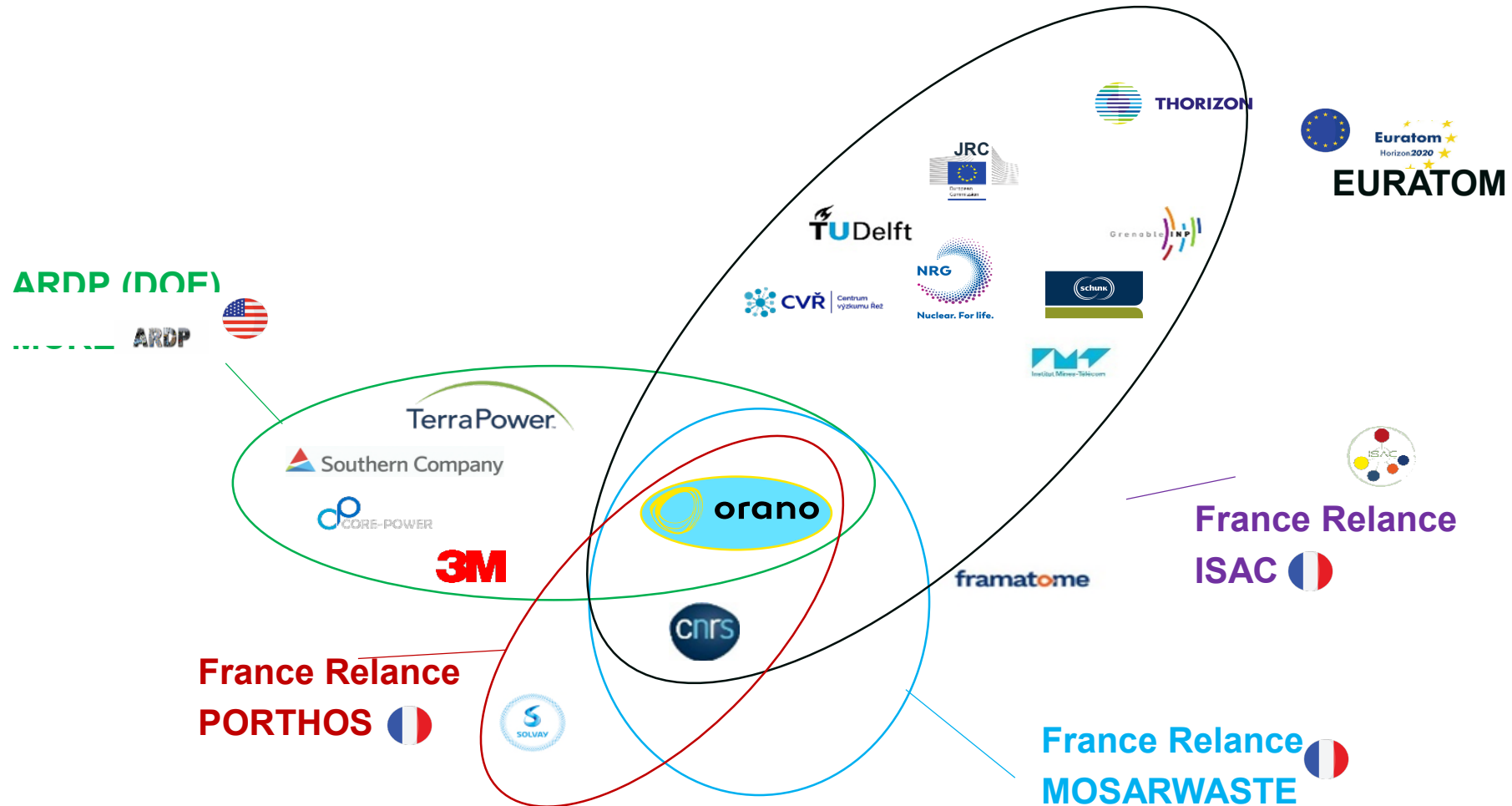


CIME
Lab & Large pilot units, inactive or using U, Th

HRB (Hall de Recherche de Beaumont) for development of fission gas treatment solutions and maintenance solutions
 CIME (Centre d'Innovation en Métallurgie Extractive) for large scale salt synthesis and loop tests

We believe that international cooperation is vital to succeed in the R&D programs leading to commercial Chloride Fast MSR

In parallel to the Orano's R&D program, several French and International collaborative R&D projects in which Orano is involved are running today.

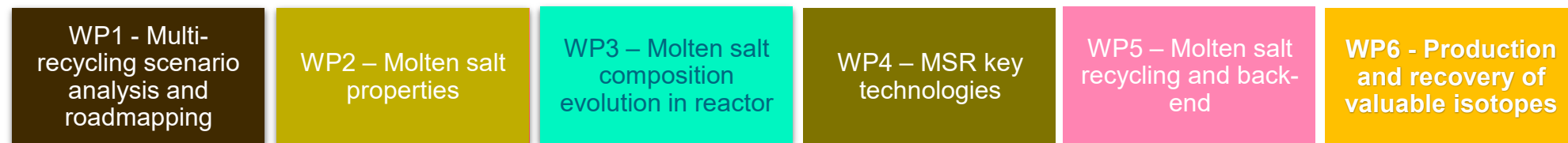


- MCRE** : Molten Chloride Reactor Experiment
- ISAC** : Innovative System for Actinides Conversion
- PORTHOS** : PrOcéde de valoRisation du THORium en Sels fondus
- MOSARWASTE** : MOlten SAIt Reactor WASTE management
- MIMOSA** : Multi-recycling strategies of LWR SNF focusing on MOlten SAIt technology

An EU funded project aiming at demonstrating multi-recycling strategies based on the use of molten salt reactors in European countries

The methodology is twofold : developing multi-recycling scenarios with MSRs, and advancing MSR technology beyond state of the art

- 1. MIMOSA develops and analyses** tangible strategies for multi-recycling of LWR Spent fuels in EU countries, with a special focus on the role that MSRs could play in such advanced nuclear energy systems (WP1)
- 2. In parallel, MIMOSA focusses on the demonstration of several key aspects of technical feasibility and performance of CI MSRs** simultaneously by calculations / simulations and experimental investigations

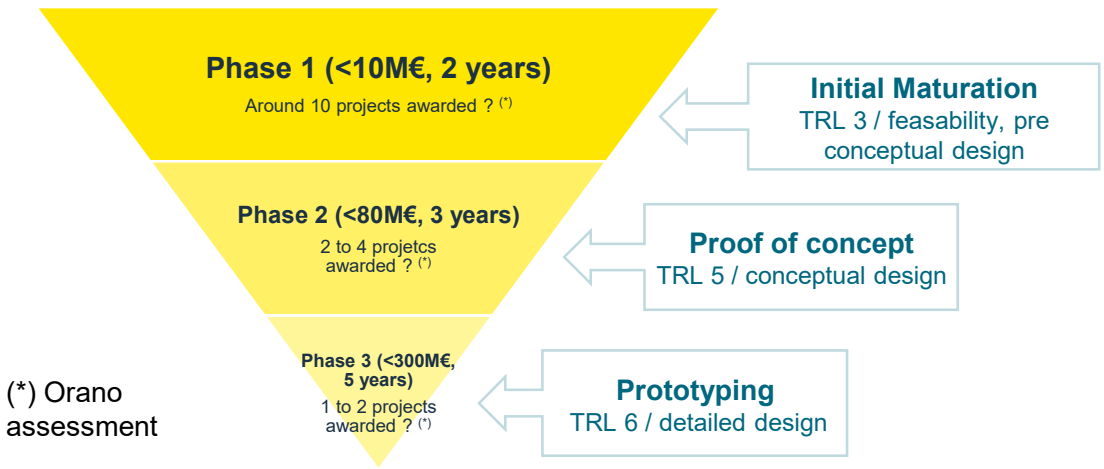


Globally, the MIMOSA project will raise the TRL of several CI MSR related technologies, processes and materials from 1 or 2 (initial status) to 3 or 4 (final status), depending on topics.

04 • France 2030 investment plan for advanced reactors development : an opportunity to develop the fuel cycle of chloride MSR

France 2030 “advanced reactors” Call For Projects (CFP) has a 500 M€ budget for 10 years in the 3 phases

- To foster French deep tech startups focused on innovative nuclear reactors development
- To accelerate prototype implementation



CFP phase 1 files submission is now complete :

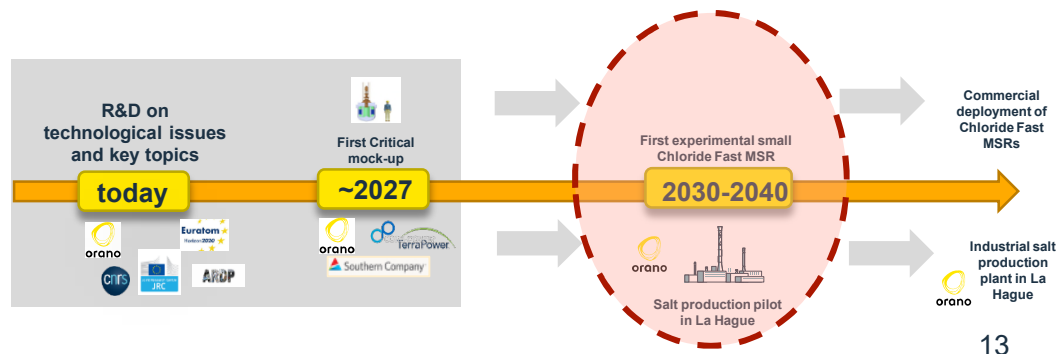
11 laureates, having received more or less 10 M€ of subvention each !

Orano partners with startups developing Chloride Fast MSR and gets funded for

- The development of the salt scope
- The exploration of the potential business models



Common WPs on Fuel Cycle :
PuCl₃ / UCl₃ / ThCl₄ pilot plants, transportation, conditioning and storage of salt



Take aways ...

Fast CI MSR are ideal candidates to close the fuel cycle and reduce Long-lived HLW



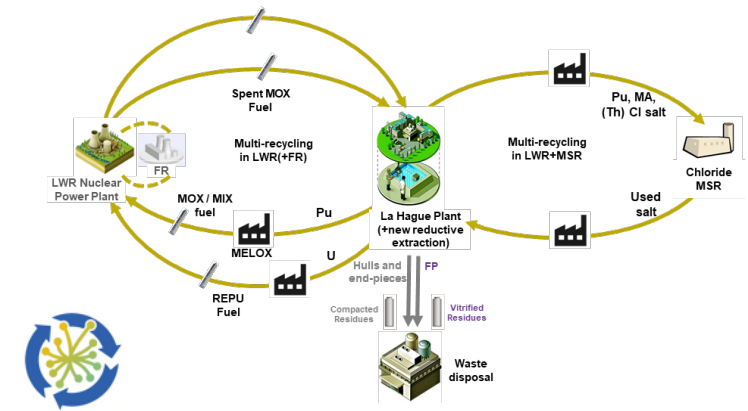
a unique value in terms of sustainability and public acceptance of nuclear energy in the future

Orano's strategy is to enable the emergence of Chloride Fast MSR concepts, with a first demonstrator of CI Fast MSR in the 2030'

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

International cooperation is vital to succeed in the R&D programs and demonstration steps leading to commercial CI MSRs

France 2030 is an opportunity to accelerate the technology development in Europe... may be followed by other European initiatives ?...



France 2030

European SMR Industrial Alliance



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Giving nuclear energy its full value