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New Dynamics of the Nuclear Energy in France: a Pillar to Reach Carbon Neutrality

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AESJ Annual Conference, Hitachi, Sept 9th 2022

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1. Current Situation of the Nuclear Energy in France

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V. Bessiron (Framatome)– V. Dufour (EDF) – JP Gros (Orano)
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The Nuclear Industry in France





 **3rd**
position for the nuclear sector in France,
after the aerospace and automotive sectors

 **2,600**
companies across the regions

 **200,000**
non-relocatable skilled jobs



 **400,000**
jobs induced and present in regions

 **€6 billion**
per year: contribution of the
nuclear sector to France's trade balance

€ 47.5 billion
revenues/year



Main Actors of the French Nuclear Industry



First electricity producer and provider in France. The exclusive operator of the nuclear power reactors
165 000 employees



Manufacturer of the reactors and of UO₂ nuclear fuel
15 000 employees



The industrial company covering the entire nuclear fuel cycle
17 000 employees



The national research center on nuclear and alternative energies
20 000 employees



The Nuclear Safety Authority
520 employees



The national agency for the management of radioactive waste
690 employees

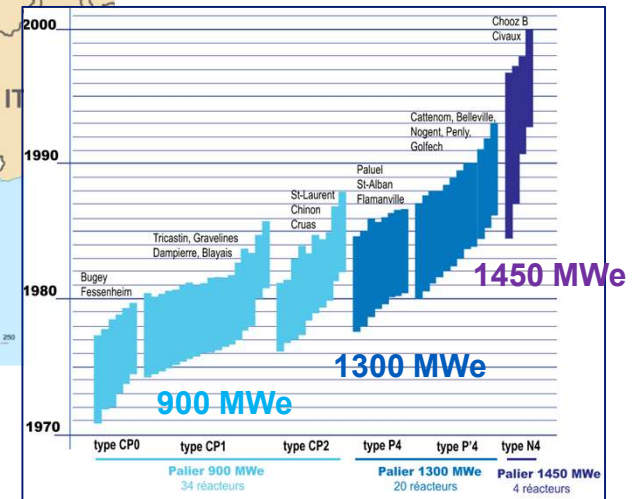
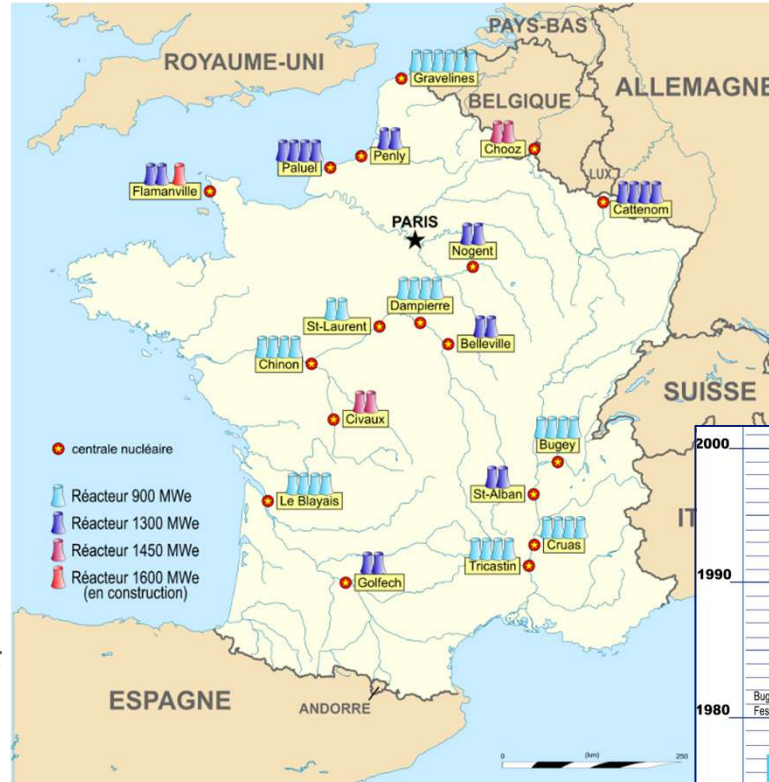


The Technical Support Organization of the safety authority
1700 employees



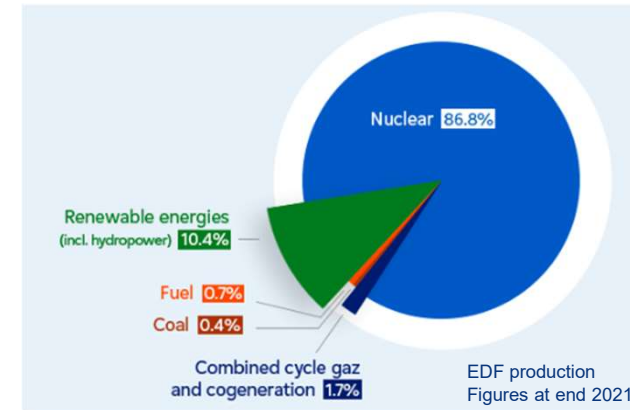
Fleet Overview

- 56 operating PWRs on 18 sites
- 61 GWe of installed capacity
 - 32 units of 900 MWe
 - 20 units of 1300 MWe
 - 4 units of 1450 MWe
- 1 EPR unit (1650 MWe) in pre-operation
- All reactors are operated by EDF

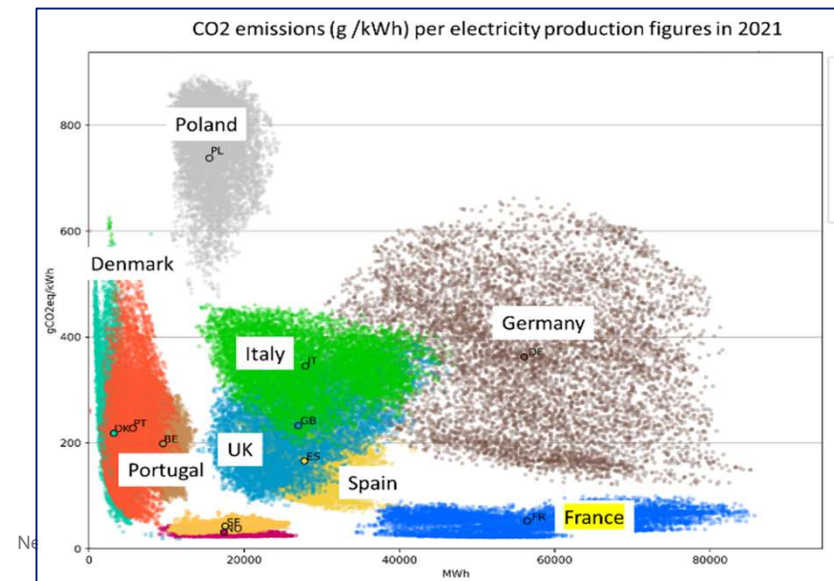
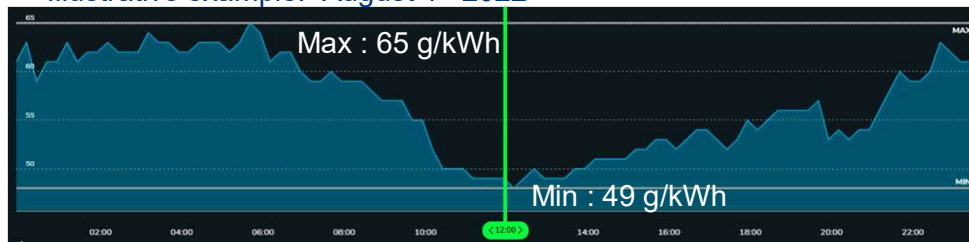


The French Energy Mix

- The energy mix in France is mostly based on **nuclear and renewables**
 - Nuclear: 87% of EDF production
 - 70% of total electricity in France
- 97% of EDF's electricity is CO2 free in France (2021)
- The **CO2 emissions** of EDF for electricity production in continental France are **~14 times lower than the average in Europe**

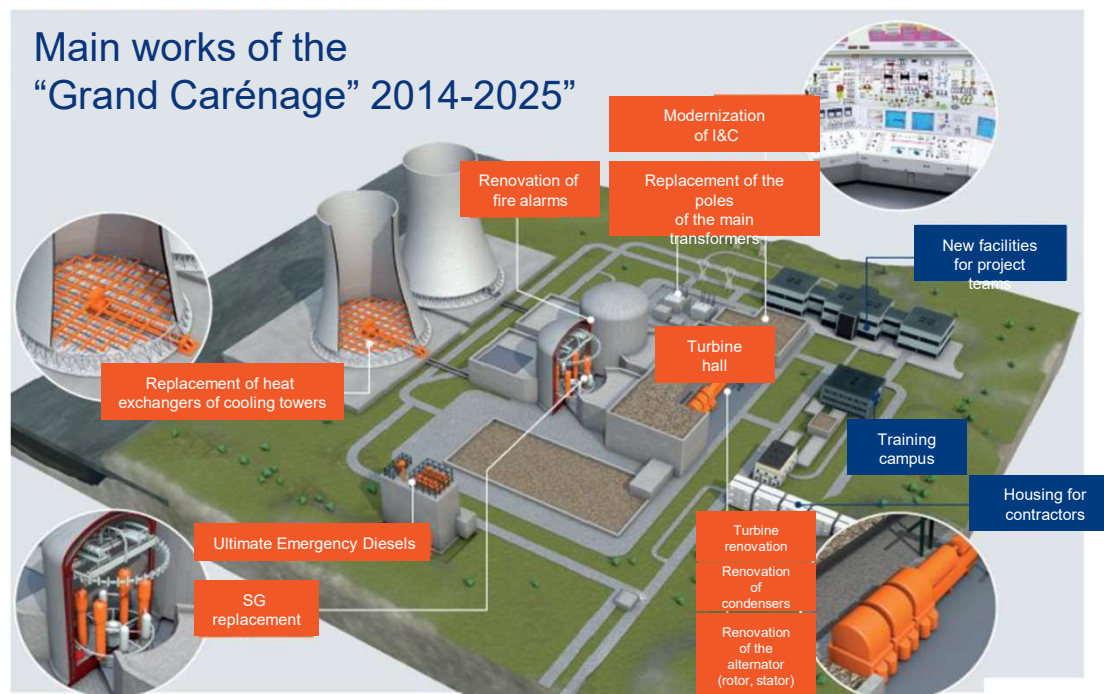


Illustrative example: August 4th 2022



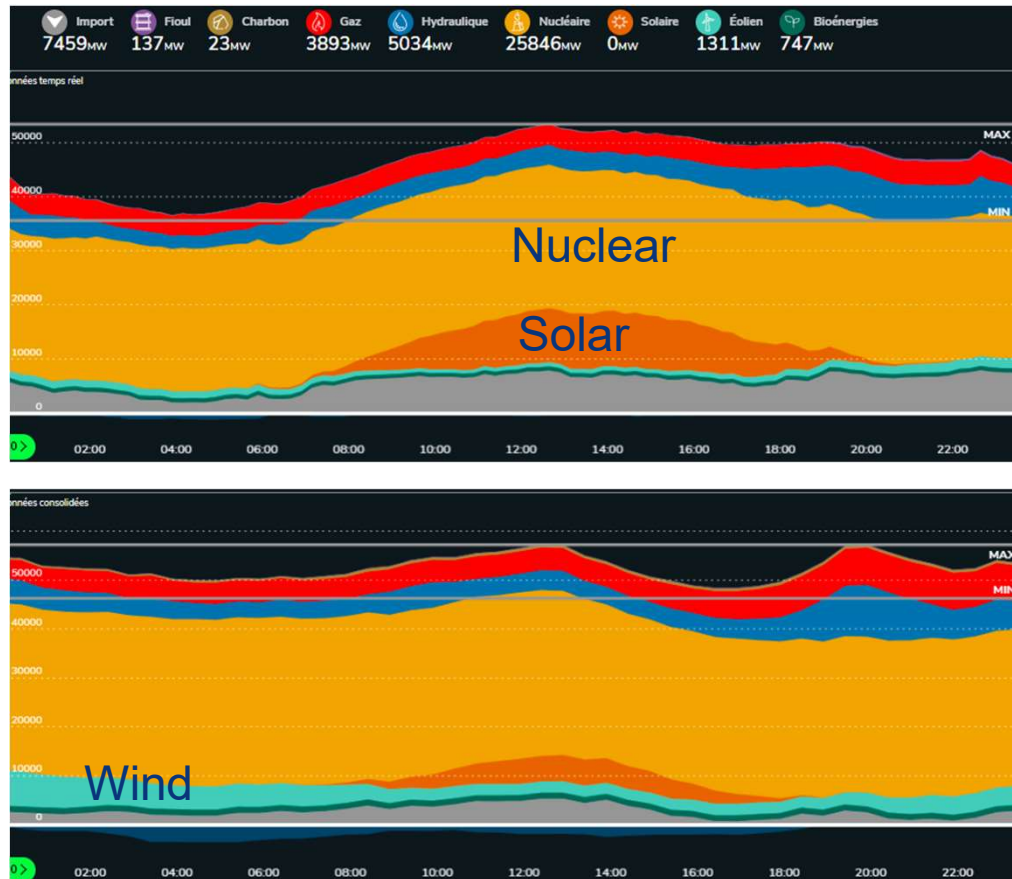
The periodical safety assessment / Life Time Extension

- The nuclear power reactors
 - are **initially licensed for 40 years** of operation
 - mandatorily undergo a thorough **safety reassessment every 10 years**
 - have to be retrofitted to account for the **lessons learned from the Fukushima accident**



➔ The Programme “Grand Carénage” aims at extending the Life Time of the Plants beyond 40 years while simultaneously retrofitting with post-Fukushima measures. It is deployed during the periodical safety assessment of the reactors.

Coexistence of nuclear and renewables: Flexible Operation (1/2)



Two illustrative days in France

August 3rd 2022: high solar production at noon ; low wind production

March 20th 2022: limited solar production, wind production significant but decreasing in the morning

→ **The nuclear fleet adjusts its production to the variations of renewable energy**

Coexistence of Nuclear and Renewables: Flexible Operation (2/2)

- Framatome has developed solutions allowing the reactors to modulate the power of the PWRs

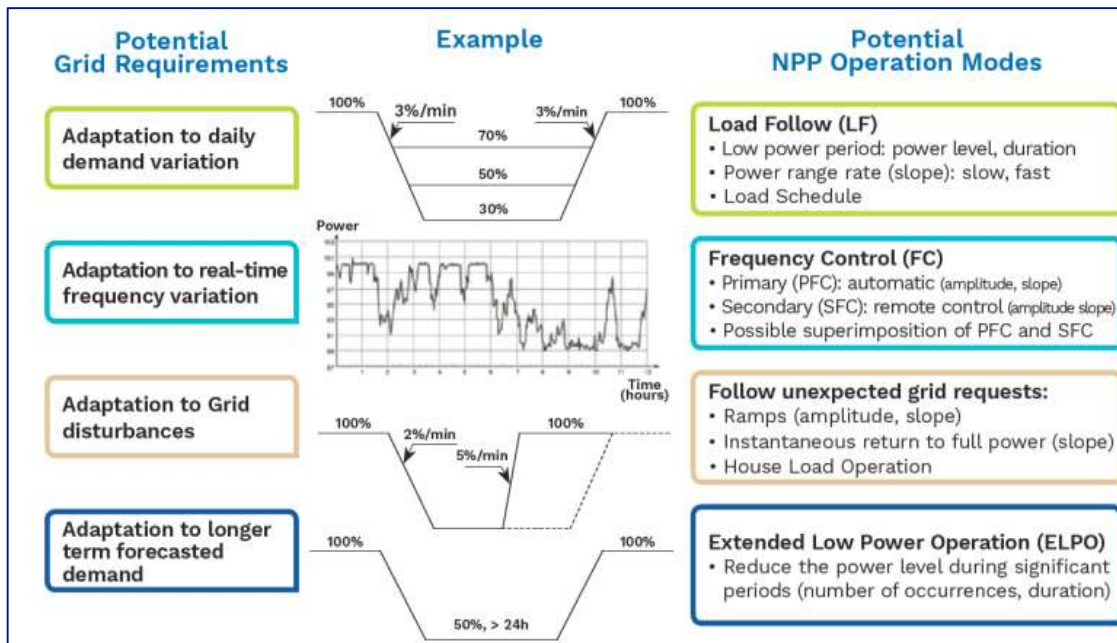


Illustration on 1300 MWe reactors

+ / - 900 MW in 30 minutes

2. A New Program of EPR2 Reactors

The Scenarios for Electricity Mix in France

- The French national grid operator (RTE) has studied the future evolution of the electricity mix by 2050

- Electricity demand in France: **+35% in a reference assumption** even with efficiency and energy savings
+15% in a high sobriety case / +60% in a massive electric reindustrialization case

- Several mix electricity-scenarios have been analyzed, ranging from

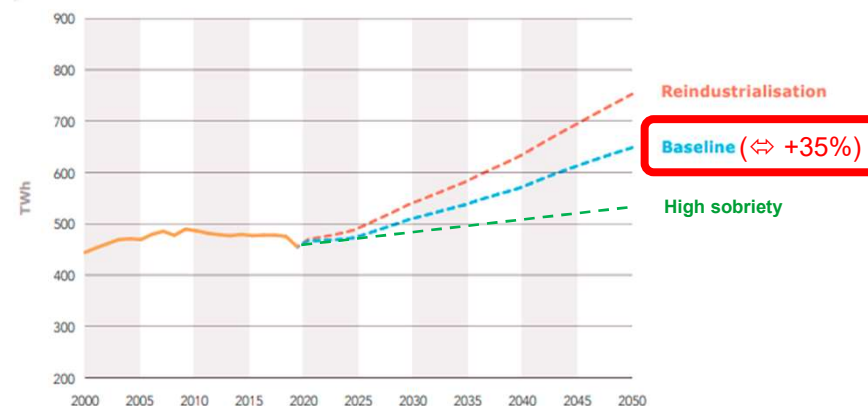
100% renewables

→ ie phase out of nuclear by 2050

to

50% renewables, 50% nuclear power

→ ie extension of current reactor lifetime beyond 60 years and construction of 14 new EPRs



- From all the scenarios investigated, **the scenario 50% renewables and 50% nuclear is the most optimized on both CO2 emission reduction and cost of electricity.**

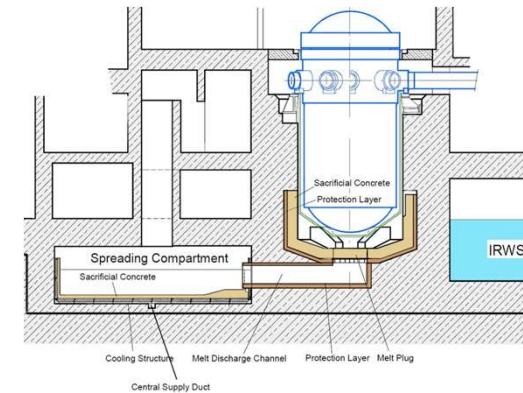
The New Program of EPR2s

- In February 2022 the French President Emmanuel MACRON announced
 - that **6 EPR2s will be built in France** and that studies will be initiated for the construction of **8 additional units**
 - that no **operating reactor will be decommissioned** if it still has the capacity to produce electricity efficiently, as long as the highest standards of safety are ensured



The EPR2 Reactor

- **EPR2 is an optimized version of Framatome's EPR**
 - 3 EPRs units are in operation, 1 EPR is in pre-operation stage
- **Common features**
 - Same output of 1670 MWe, same components
 - Among the highest safety standards in the world (core catcher...)
 - Enhanced environmental performance
- **Differences**
 - Simplified design for easier construction
 - Construction by pair (2 units) to benefit from serial gains
 - Rationalized options based on plat operation experience



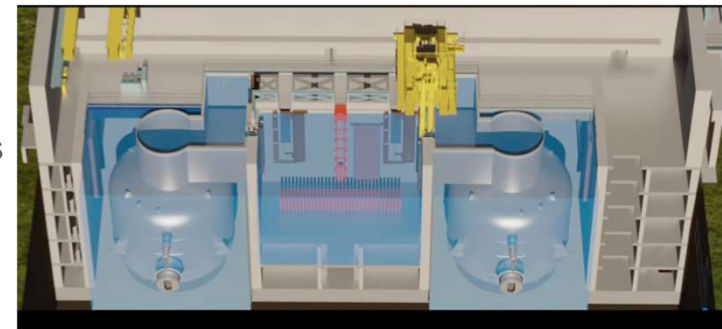
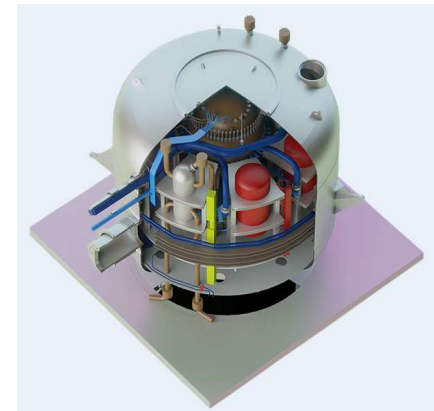
Framatome and EDF are deploying the industrial roadmap for a commissioning of the 1st unit around 2035

3. An Innovative Nuclear Industry

The Nuward™ Small Modular Reactor

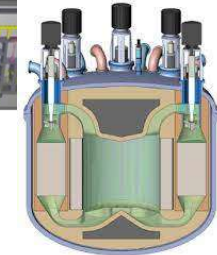
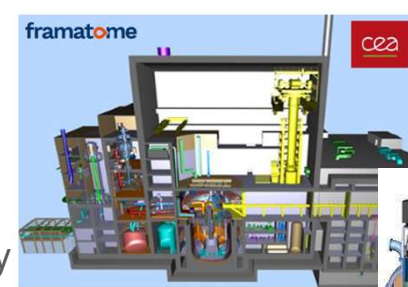
nuward

- EDF, Naval Group, Technicatome and Framatome are developing the **SMR Nuward**
 - **340 MWe unit** in a single building comprising two 170 MWe compact reactors
 - An Innovative design with **simplification by modularization**
 - Integrating the **highest standards of safety**
 - Generation III+ reactors meeting post Fukushima requirements
 - Robust to accident scenarios with passive safety systems
 - **Flexible and continuous generation**, complementary with renewable intermittent production and large nuclear power plants to:
 - replace 300-400 MWe coal fired power plants
 - power remote municipalities and intensive industrial sites
 - supply networks not adapted to high/medium sized reactors



Development of Advanced Reactors

- The French nuclear industry is **developing advanced reactors**
 - Fast Neutron Reactors for optimized closed nuclear fuel cycle
 - High Temperature Gas Reactors for alternative use of nuclear energy (heat, hydrogen...)
 - Molten Salt reactors to burn actinides and reduce volume and radiotoxicity of waste

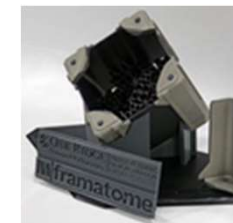


- Break-through innovation while ensuring industrial feasibility and performance during all stages

R&D and design



Manufacturing and construction



- Achieved through
 - **Standardization**
 - **Qualified technology bricks** (incl. cybersecurity) and **qualified licensed products** when relevant
 - The support of **technology centers** for testing, validation and qualification
 - The benefits of **nuclear-adapted advanced manufacturing methods**

Nuclear Innovation for Higher Safety

- Innovation is supporting the **safety** of the nuclear energy
- Illustration with **PROtect LWR nuclear fuel of Framatome** that brings improvement in the nuclear fuel behavior in accidental situations

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PROtect: The leading
Enhanced Accident
Tolerant Fuel Program



- Chromium coated cladding



- Chromium doped fuel pellets

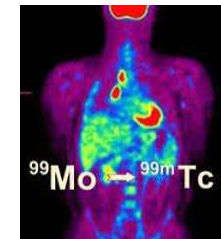


Nuclear Innovation for Health

- Innovation in nuclear energy provides **break-through progress in medical care**
 - Medical Imaging
 - Cancer treatments...

- Examples

- **Irradiation capsules in reactors** (research reactors and power reactors)

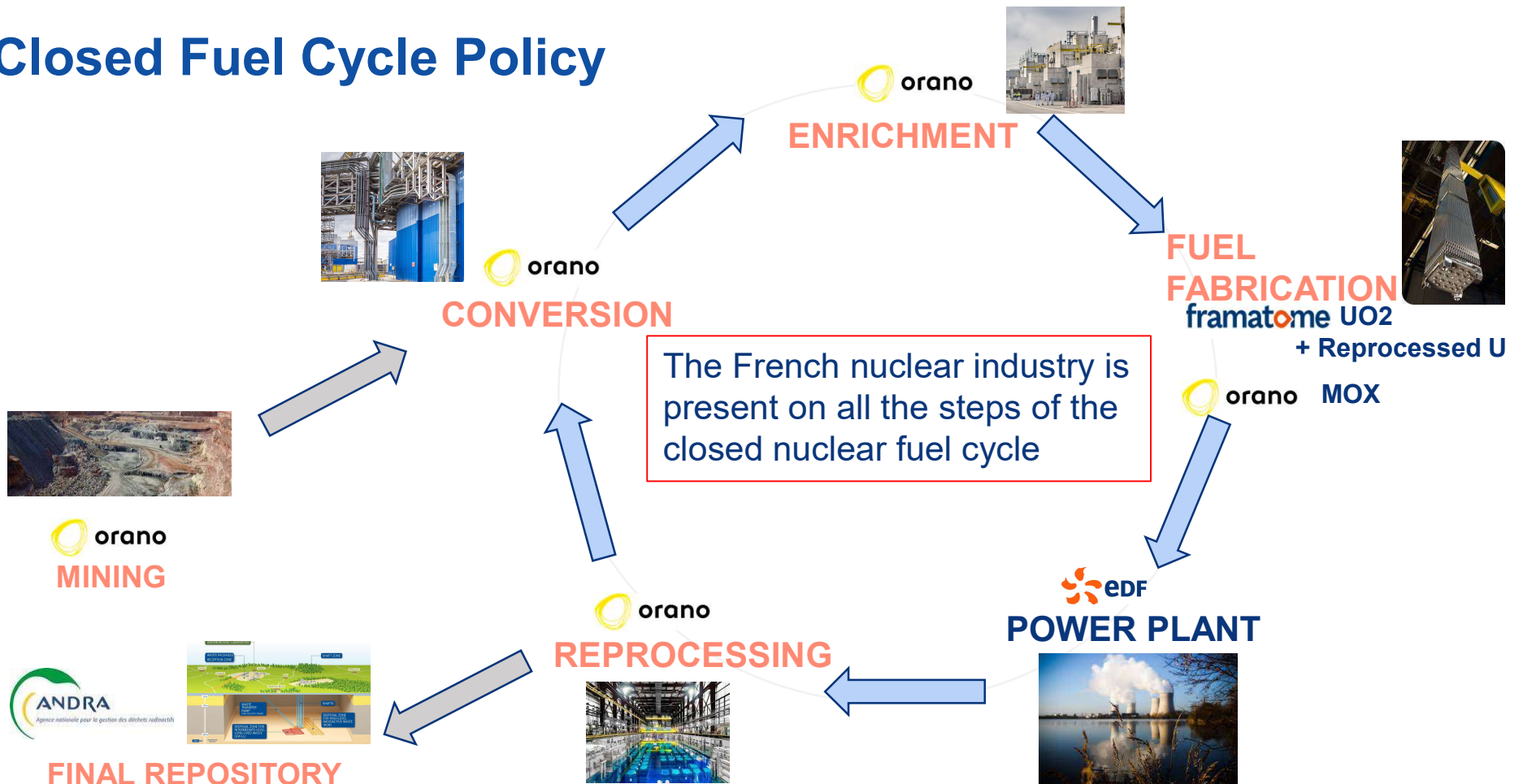


- **^{212}Pb targeted alpha therapy** from thorium



4. Closed Cycle and Dismantling: Nuclear Energy at the Forefront of the Circular Economy

Closed Fuel Cycle Policy

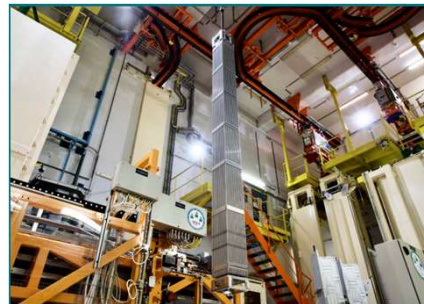


Benefits of the Closed Fuel Cycle: Recycling of the Fissile Material

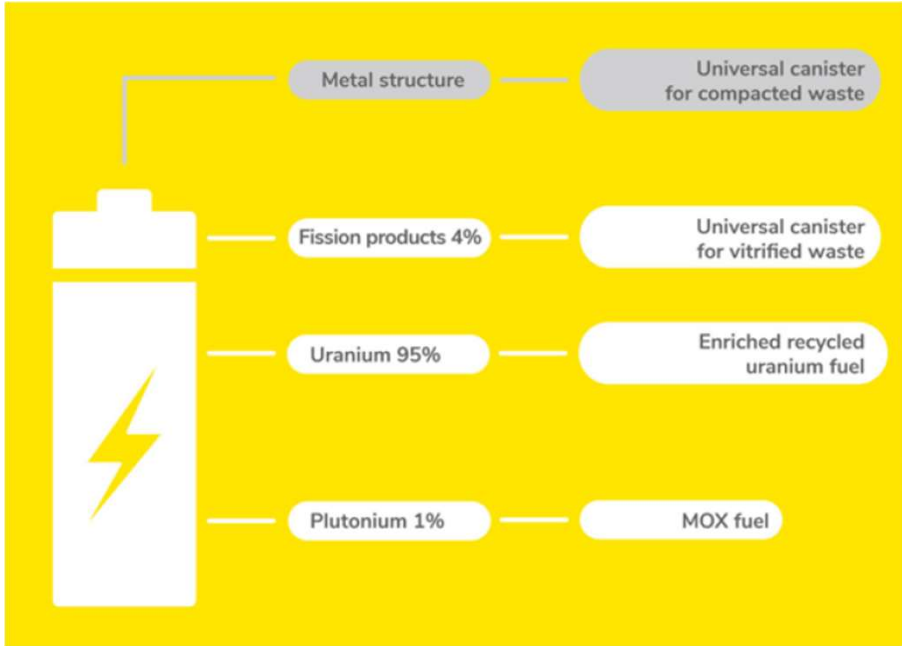
- Orano's reprocessing plant (La Hague)



- Orano's MOX fuel manufacturing (MELOX)



- 96% of the used fuel content is recyclable through new fresh fuel (MOX, reprocessed U fuel)**
- Up to 25% of uranium resources saved**
- 10% of electricity produced with MOX in France**

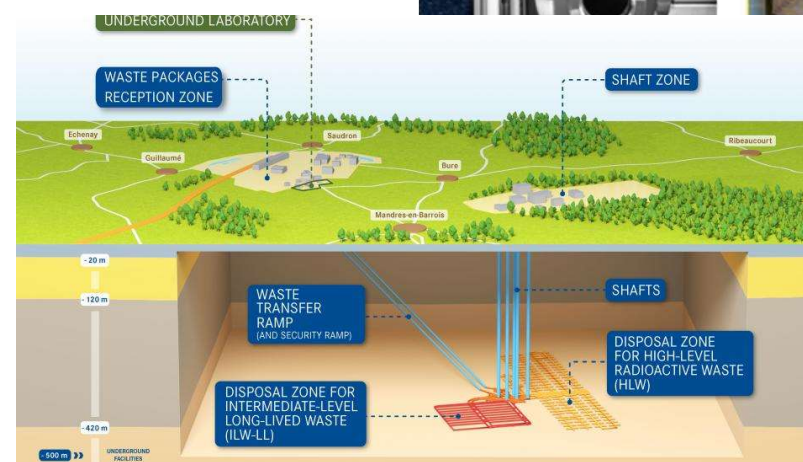
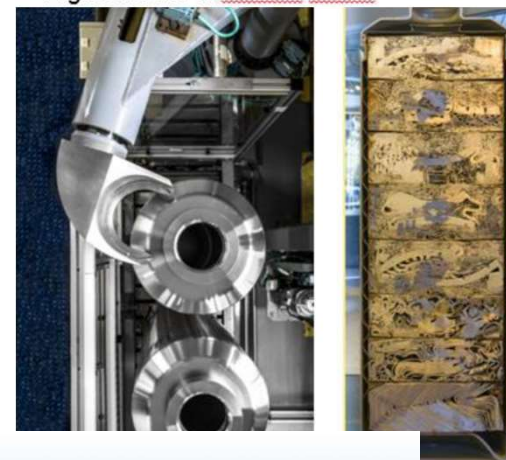


Composition of LWR fuel after unloading from the reactor

Benefits of the Closed Fuel Cycle: Reducing the Volume of Waste

- Long Term conditioning of Final Wastes
- What are final wastes ?
 - Final nuclear waste are fission products and metal structure **only 4% of spent fuel**)
 - In France, final nuclear waste represents only **5g/habitant /year**
- How to manage final waste ?
 - Reprocessing operation:
 - **radioactivity cut by 10**
 - **Volume cut by 5**
 - Final wastes are **vitrified and compacted**
 - **Deep geological repository** : CIGEO facility (from 2035)

Left: empty container before vitrification
Right: model of vitrified waste

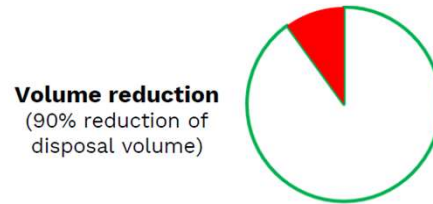
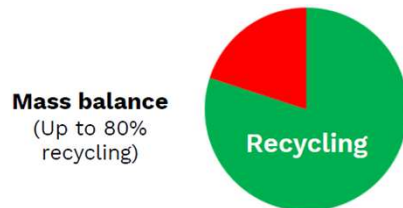
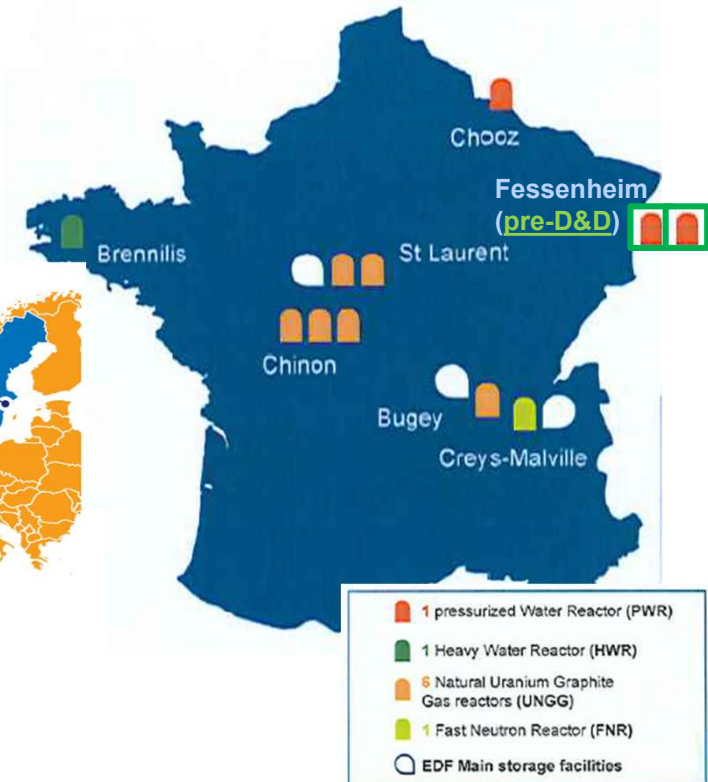


Decommissioning and Dismantling of EDF Reactors

- EDF is committed for the D&D of its shut-down reactors
- The strategy for D&D is based on **Waste-led approach**:
 → The definition and implementation of optimized waste routes, *before the starting of the dismantling* to improve the project schedule and cost effectiveness.

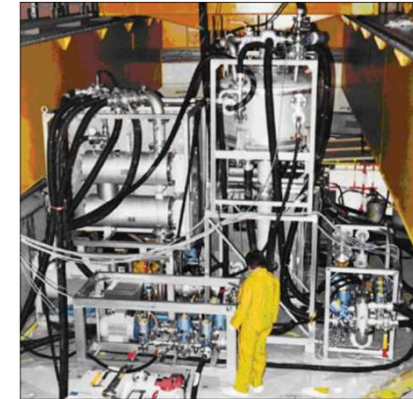
- EDF benefits from its dedicated waste treatment facilities

- The liberation of material under the clearance threshold allows to **reduce the volume and mass of waste of large equipment (Steam Generators ...)**



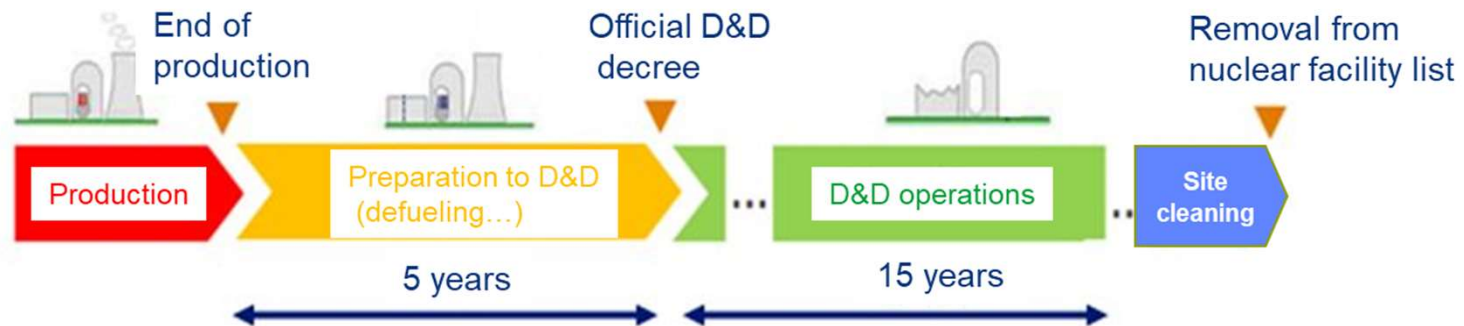
Decommissioning and Dismantling of EDF Reactors

- The decontamination of the Nuclear Steam Supply System from the early stage of D&D is essential to **reduce individual and collective dose** and to **globally optimize the D&D schedule**.



Framatome's Full Decontamination System of to be applied for the D&D of 2 PWRs at Fessenheim
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- **Sequence of D&D**



D&D of Nuclear Cycle Facilities on Orano sites



LA HAGUE PLANT
 UP2-400 reprocessing facility :
 - Legacy waste retrieval
 - Dismantling

TRICASTIN PLANT
 - Dismantling of TU2-TU3, TE, laboratory, waste facility
 - Large dismantling projects
 • GB1 enrichment facility
 • CX1 conversion facility
 - Waste on site disposal (hills)
 - Dismantling of UF6 cylinders

More than 30 D&D projects on-going on the Orano sites



Mine sites rehabilitation



ANNECY & VEUREY SIGM PLANTS
 - Decommissioning of fuel fabrication sites
 - Completion of brown field



MALVESI PLANT
 - Dismantling of small facilities (roasting, magnesio-thermal units)
 - Preparation of CX1 conversion facility dismantling
 - ECRIN waste on site disposal

MIRAMAS PLANT
 Soil remediation



5. Renewing the Competencies to Ensure the Performance of the Nuclear Industry

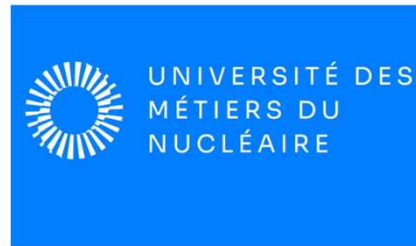
The Renewal of Competencies at the Core of Industrial Performance

- Recent difficulties in large nuclear projects worldwide have highlighted the need to
 - **Rebuild strong competencies**
 - **Strengthen the supply chain**
 - **Enhance the level of standardization** of processes and equipment (including licensing).

- The actors of the nuclear industry have coordinated their efforts through with the governmental support (“France relance” national program)
 - Within the EDF Group, the **EXCELL plan** structures the related action to increase performance
 - **Teaching & Training institutes** have been created



Recycling Campus (Orano)



University of Nuclear Jobs (EDF)



School of welding (Framatome)



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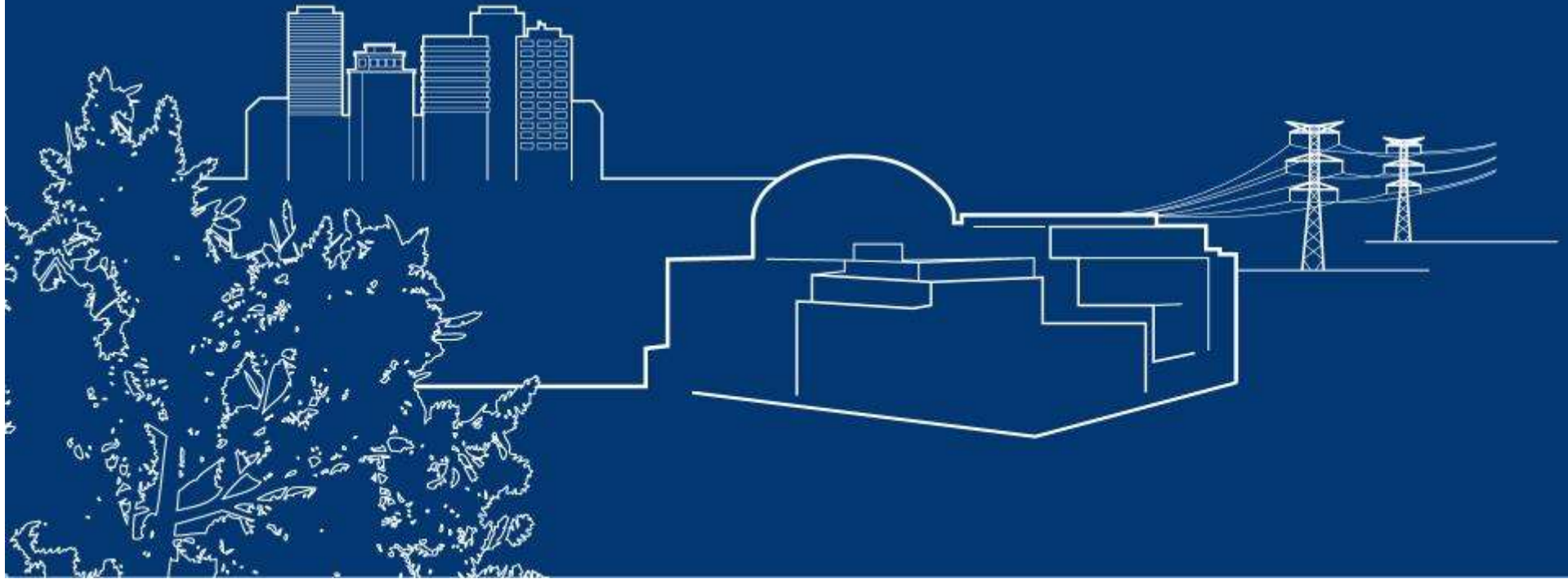
5. Conclusion

- **Japan and France are both major nuclear countries** with fleets of comparable size
- There are some differences between both countries (type of reactors, number of operators...) but **Japan and France share the same global approach:**
 - The **priority to nuclear safety** while accounting for the lessons learnt of the past accidents and incidents
 - **A closed fuel cycle policy**
 - A commitment **to manage waste and clean sites**
 - **Innovation** for enhanced and even safer use of the nuclear energy
- In both countries, nuclear energy will play a major role as regards
 - The objectives of **reduction of CO2 emissions**
 - The **stable supply of energy at affordable price**
- **France and Japan have established fruitful nuclear collaborations for many years**

The climate and energy supply challenges ahead make the collaborations on nuclear energy between France and Japan even more relevant today and in the future.

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