



**Combustibile nucleare
irraggiato:
dal “rifiuto” alla risorsa**
*La storia del nucleare italiano e
presupposti di ripartenza*

WEBINAR

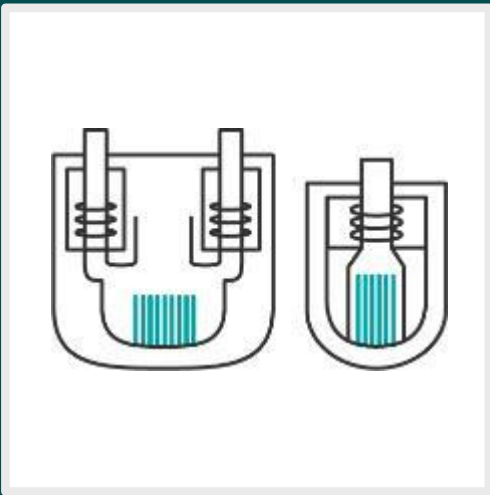
Commissione Ricerca e Reattori Innovativi
Ordine degli Ingegneri della Provincia di
Roma

Advanced Generation Reactors and the closed fuel cycle

newcleo's activities in the field of Pb Fast Reactors with MOX fuel

Andrea Barbensi, newcleo LFR Engineering Director

A new, innovative player in nuclear energy



REACTOR DESIGN:
Small Modular (SMR) + Lead-cooled Fast Reactors (LFR) = AMR

newcleo is working to design, build, and operate Gen-IV Advanced Modular Reactors (AMRs) cooled by liquid lead



FUEL MANUFACTURING:
Mixed Uranium Plutonium Oxide (MOX)

MOX and Fast Reactors allow the multi-recycling of nuclear waste into new fuel with no new mining for generations

INTRINSICALLY SAFE
power production

COMPETITIVE
energy cost

CIRCULAR
nuclear waste recycling

Presence across **EUROPE**

Launched in **SEPTEMBER 2021**

€537 million of private funds
~€50 million expected annual turnover

French **first licensing stage completed** for the first reactor and the fuel production facility

Selected by **France 2030** and the **European Industrial Alliance** on SMRs

1,000+ EMPLOYEES GLOBALLY

30+ YEARS OF R&D

22 PATENTS

Highly specialised EPCM capabilities

FUCINA ITALIA
A *newcleo* company

S.R.S.
A *newcleo* company

RUTSCHI
A *newcleo* company

ISO9001 and ISO19443 certification

Lead-cooled technology for *newcleo* reactors

SMRs improve economics and flexibility in nuclear

Small Modular Reactors (**SMRs**) are designed for enhanced safety, flexibility, and reduced environmental impact, with competitive energy costs, lower capital investments, shorter construction times, and suitability for remote deployment.

ECONOMIES OF SCALE

Large reactors > 1GWe

Serial production

Reduced costs and risks of overrun

- Learning curve and economies of series
- Centralised factory production to limit onsite costs
- Transportable on site and faster construction

Modularisation

Shorter construction time

- Modular construction
- Multi-module deployment enabling “chain” financing of one module to the next

Simplification

Enhanced safety

In the case of *newcleo*'s LFR: reduced complexity enhancing overall safety, while limiting costs (e.g., passive safety) and reducing local permitting requirements

Limited capital intensity

Better affordability

- Lower upfront capital costs
- Higher profitability due to faster construction
- Limited financing risk, with greater access to private capital

Smaller footprint

Greater site flexibility

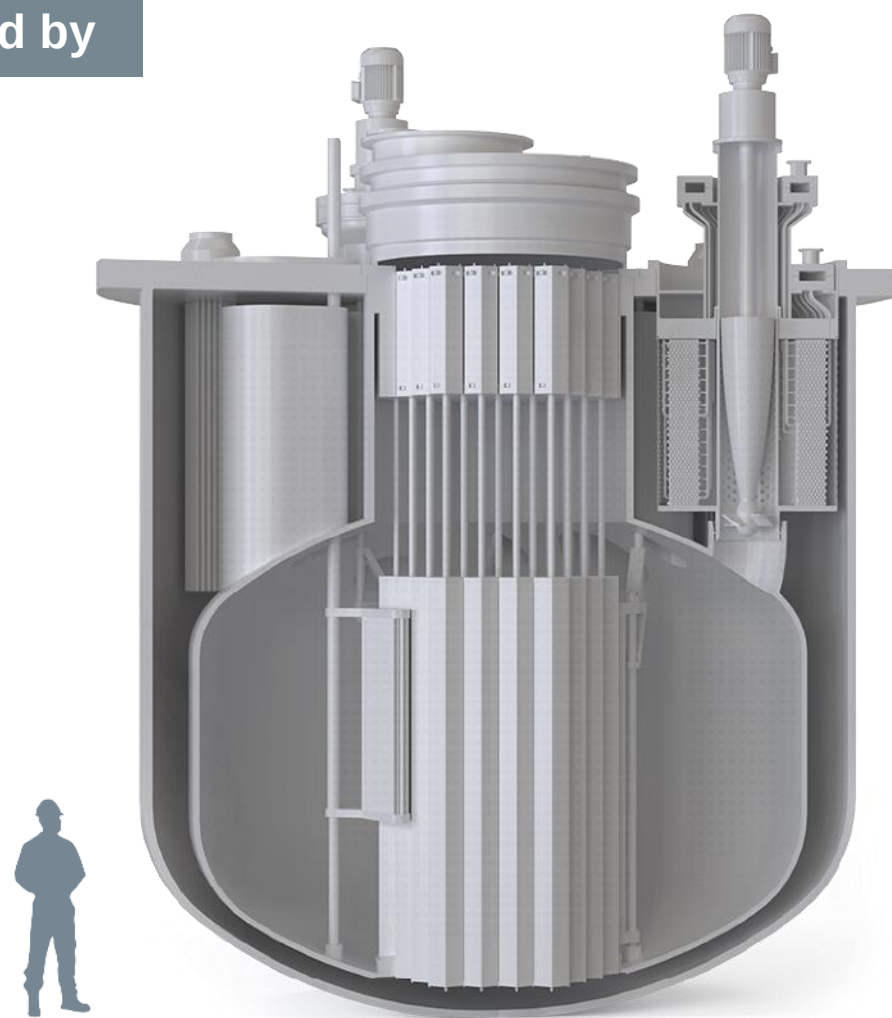
- Reduced site size
- Suitable to decarbonise industrial production or Data Centres
- In the case of *newcleo*'s LFR: reduced emergency planning zone

Flexible applications

Wider range of users

- Remote locations and small grids, suitable for fossil plant replacement
- Non-electrical applications (e.g. industrial heat, desalination)
- Marine based (floating, propulsion) applications and Data Centres

replaced by



ECONOMIES OF SERIES

Small, standardised designs < 300MWe

Advanced Modular Reactors: Generation IV (Gen-IV) can further improve economics and sustainability of nuclear

SMRs can use traditional technology (pressurised water and thermal neutrons) or can also be **Advanced Modular Reactors** (AMRs). Since 2000, an international forum coordinated by the Office of Nuclear Energy of the U.S. Department of Energy (DoE) has prioritised six **Generation IV** nuclear technology systems for development.

Why LFRs amongst the Gen-IV technologies?

- Only Fast Reactors (like the LFRs) allow closing the fuel cycle, a sustainable use of nuclear energy as it recycles the nuclear waste
- LFRs can enable intrinsic safety in accident scenarios
- Lead does not interact chemically with water or air unlike sodium, operates at atmospheric pressure. Lead is an excellent shield for gamma radiation. **LFRs can be simplified and made more cost competitive** compared to other Advanced Nuclear Reactor designs

Gen-IV categories:	
Sodium-cooled Fast Reactor (SFR)	
Lead-cooled Fast Reactor (LFR)	
Gas-cooled Fast Reactor (GFR)*	✗
Molten Salt (Fast or Thermal) Reactor (MSR)	
Super Critical Water-cooled Reactor (SCWR)*	✗
Very High Temperature (Thermal) Reactor (VHTR)	

*these two technologies are virtually abandoned

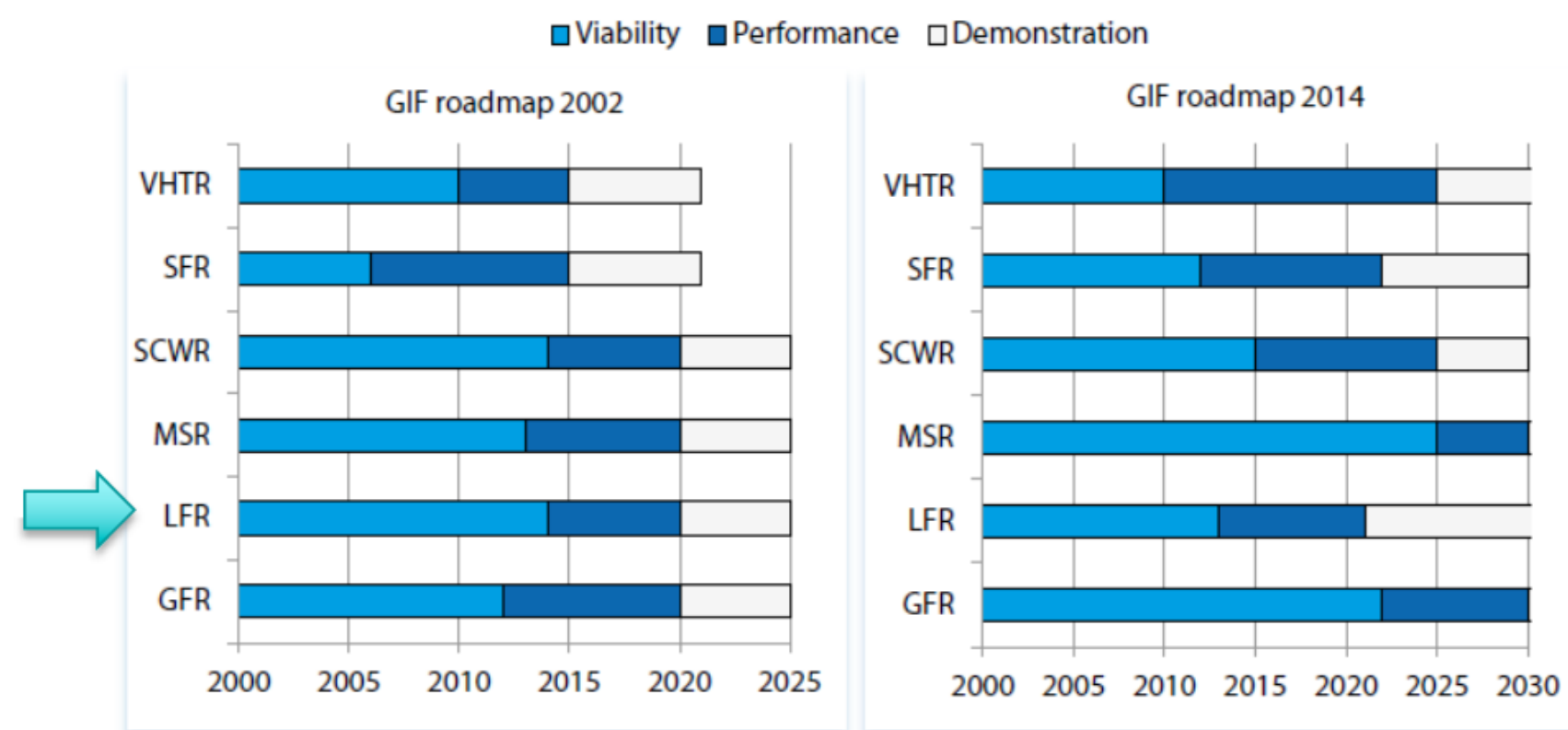
Technology Roadmap Update: *LFR the best Gen-IV technology*

Report available on GIF Web site – *public section*

[GIF Portal - Preparing the Future through Innovative Nuclear Technology new cover \(gen-4.org\)](http://gen-4.org)

2018 R&D Outlook report available at:

https://www.gen-4.org/gif/upload/docs/application/pdf/2019-06/7411_gif_r_and_d_outlook_update_web.pdf



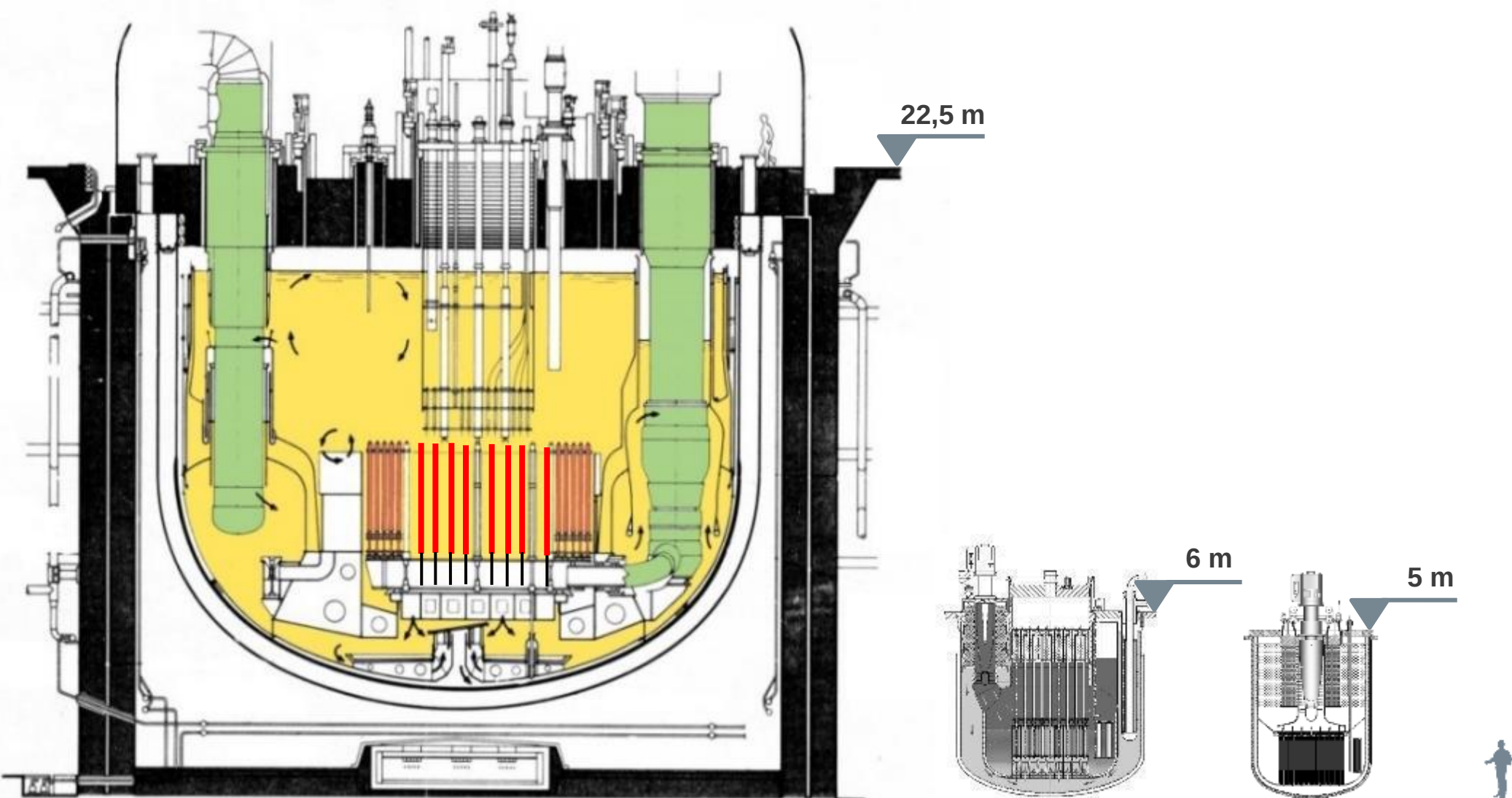
Expected development timelines for Generation IV concepts, by GIF

- **Viability:** Basic concepts tested under relevant conditions and all potential technical show-stoppers are identified and resolved
- **Performance:** Engineering-scale processes, phenomena and materials capabilities are verified and optimised under prototypical conditions
- **Demonstration:** Detailed design is completed and licensing, construction and operation of the system are carried out, with the aim of bringing it to the commercial deployment stage

LFR is considered the most mature technology by the GIF (Generation IV International Forum)

Evolution of Fast Reactors

From old-generation SFRs to a new generation of small, modular LFRs



200 MWe

30 MWe

Superphénix (1974, 1240 MWe)

newcleo LFRs

The development of Sodium Fast Reactors (SFRs) particularly amongst other Fast Reactors has been an area of huge investment in recent years, but there has been limited deployment. Sodium is chemically reactive with both water and air; safety issues required complications to design which made SFRs **expensive**.

Learning from the past

Fortunately, the **experience** acquired with SFRs can be almost entirely used for the development of LFRs. They use a similar fuel, behave in a similar way functionally, present similar thermal-hydraulic and mechanical aspects. **LFRs are much more promising in terms of cost and safety.**

Lead has unique properties for developing a fast reactor

Atomic mass	Absorption cross-section	Boiling Point (°C)	Chemical Reactivity (w/Air and Water)	Risk of Hydrogen formation	Heat transfer properties	Retention of fission products	Density (kg/m³) @400°C	Density (kg/m³) @400°C	Melting Point (°C)	Opacity	Compatibility with structural materials
207	Low	1737	Inert	No	Good	High	10580	10580	327	Yes	Corrosive
Fast neutron spectrum	Large fuel pin lattice Low core pressure loss	Primary system at atmospheric pressure	No intermediate loop Possible use of low-cost water or air loops for DHR	Reduced risk of plant damage	Reduced risk of fuel cladding overheating	Reduced source term during postulated accidents	No risk of core compaction Core supported by lead	But it also has properties that have discouraged some designers			

newcleo has identified technical solutions to minimise the impact of the unfavourable characteristics of lead and in some cases has also drawn design advantages

Significant advantages of Lead-cooled Fast Reactors



Lead properties enable design simplification (hence **economic benefits**) and a high degree of inherent safety:

- Operating at atmospheric pressure, hence **thick forging not needed** as in traditional Pressurised Water Reactors (PWRs)
- No significant energy release in case of vessel failure, hence **high pressure-resistant containment not needed**
- Favourable chemical properties, hence **extra safety provisions can be avoided, no intermediate loop, possible use of low-cost water or air loops for Decay Heat Removal (DHR)**
- Coolant boiling practically eliminated, hence **safety injection systems not needed**
- Significant thermal inertia in case of a loss of cooling helps the reactor to switch off naturally with no damage
- Lead fission product retention capability, gamma radiation shielding
- **High plant energy conversion efficiency (40-50%)**
- **High operating temperature enables non-electrical uses**

Unique properties for fast reactors design

Absorption cross-section	Boiling Point	Heat transfer properties	Density @400°C
Low	1737 °C	Good	10580 kg/m3
Large fuel pin lattice, low core pressure losses	No loss of core cooling	Reduced risk of fuel cladding overheating	No risk of core compaction

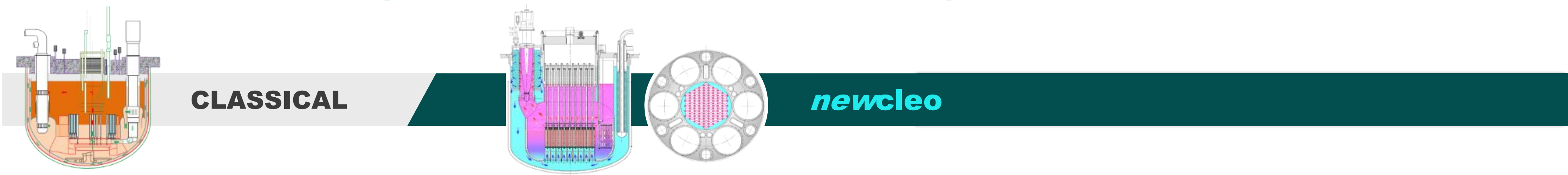
Critical properties that discouraged some designers were solved by *newcleo*

Density @400°C	Melting Point	Opacity	Compatibility with structural materials
10580 kg/m³	327 °C	Yes	Corrosive at high temperature
Significant weight in earthquakes	Risk of freezing	Difficult operations inside	Need of new materials

80 effective reactor-years of Lead Bismuth Eutectic reactors

- Russia has operated 15 reactors across land-based facilities and submarines since the 1950s
- Russia also began construction of a new LFR in Jun-2021

newcleo's design: simplification is key



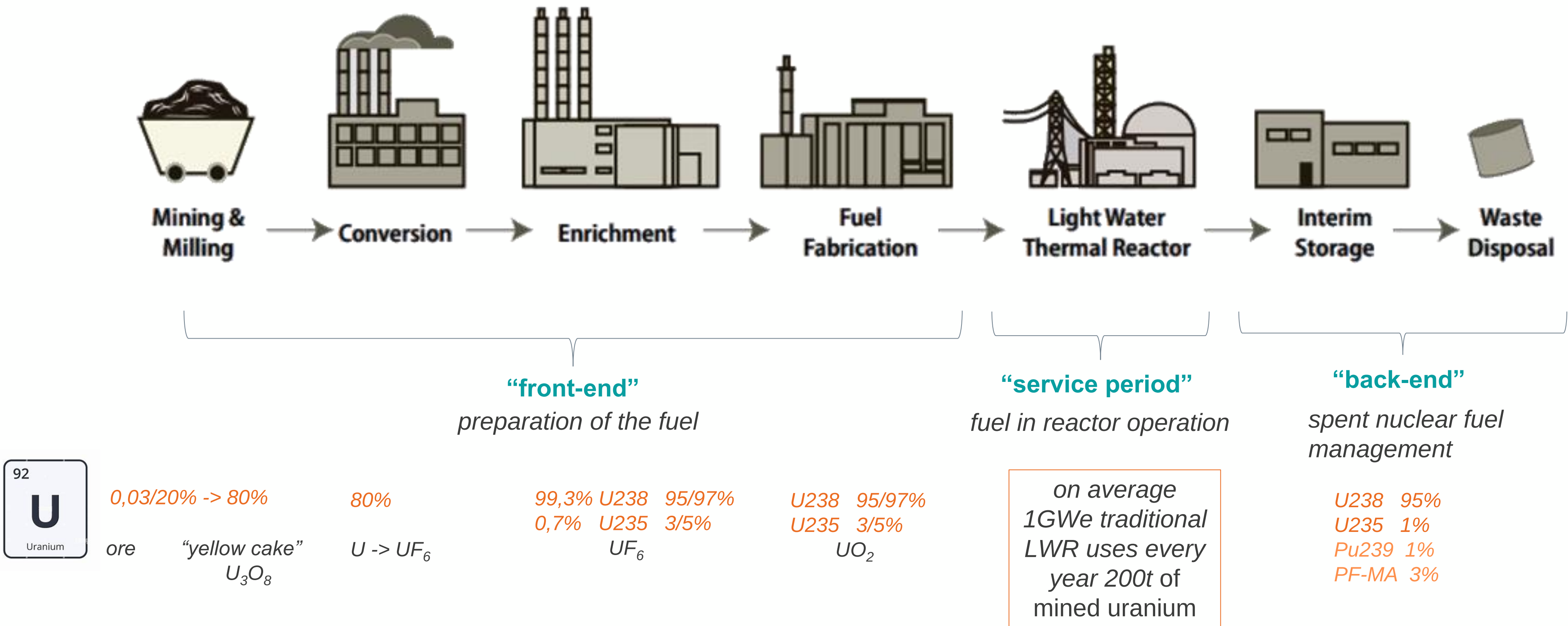
Pump in the cold	hot collector
Primary fluid inlet in the upper	lower part of the heat exchanger
Vertical	Radial flow of the primary coolant in the steam generator
Fuel element fully immersed in	with heads out of the primary coolant
Fuel element fixed at the bottom	top
Primary pumps between	inside the steam generators
Inner vessel larger at the top	bottom

INNOVATIVE COMPONENTS/SYSTEM		
STEAM GENERATOR, REFUELLING SYSTEM, DHR SYSTEM, CONTROL RODS, FUEL ELEMENT		
Compact and dense primary system		
~4x less than Superphénix		Short reactor vessel: only 6.2 m
Compact reactor building		
No intermediate loops	Compact primary system	No risk of LOCA

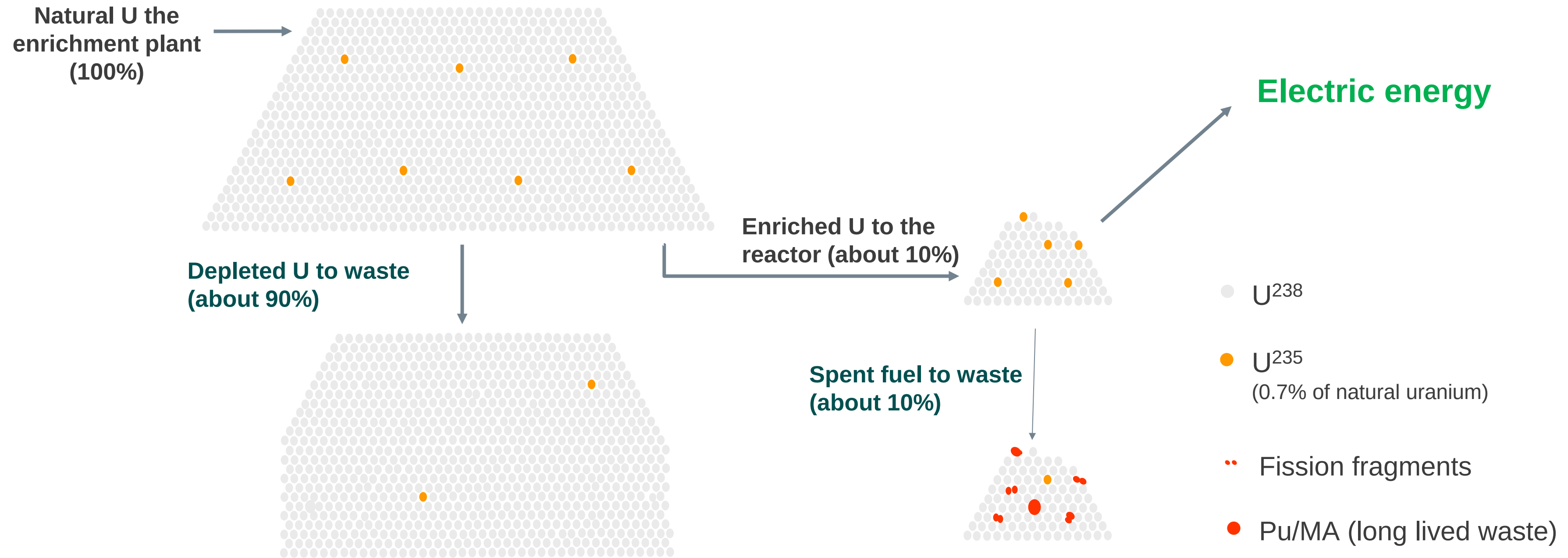
newcleo identified technical solutions to minimise the impact of lead's unfavourable characteristics and in some cases has also drawn design advantages. We innovate by reimagining the classical solution, resulting also in the elimination of several components no longer needed

Closing the fuel cycle

The nuclear fuel cycle – open type (LWR)

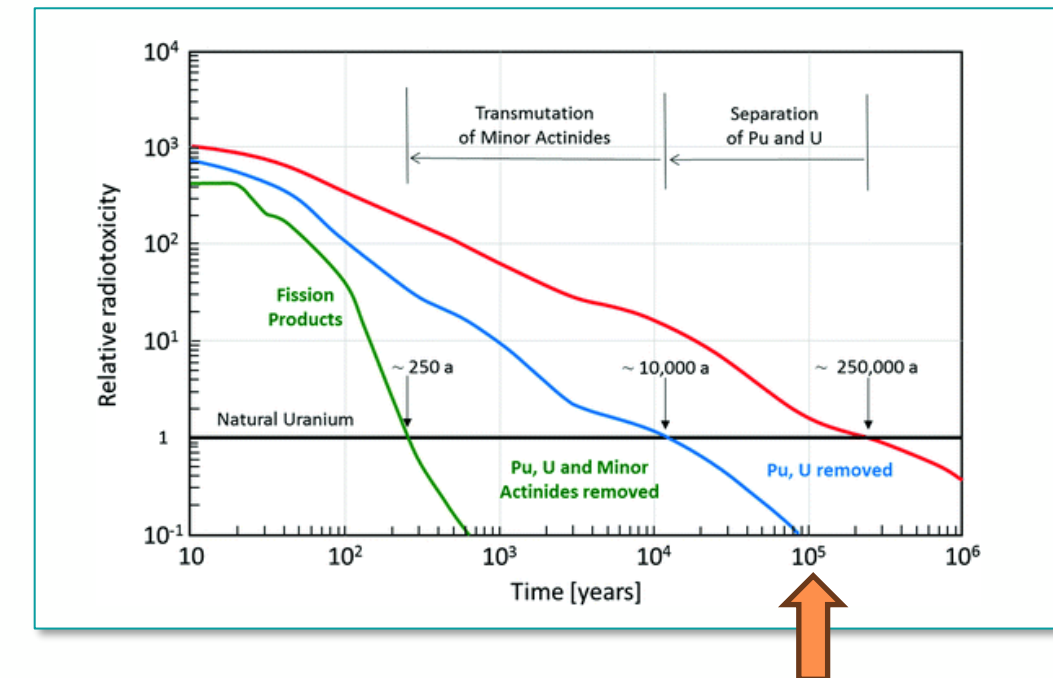
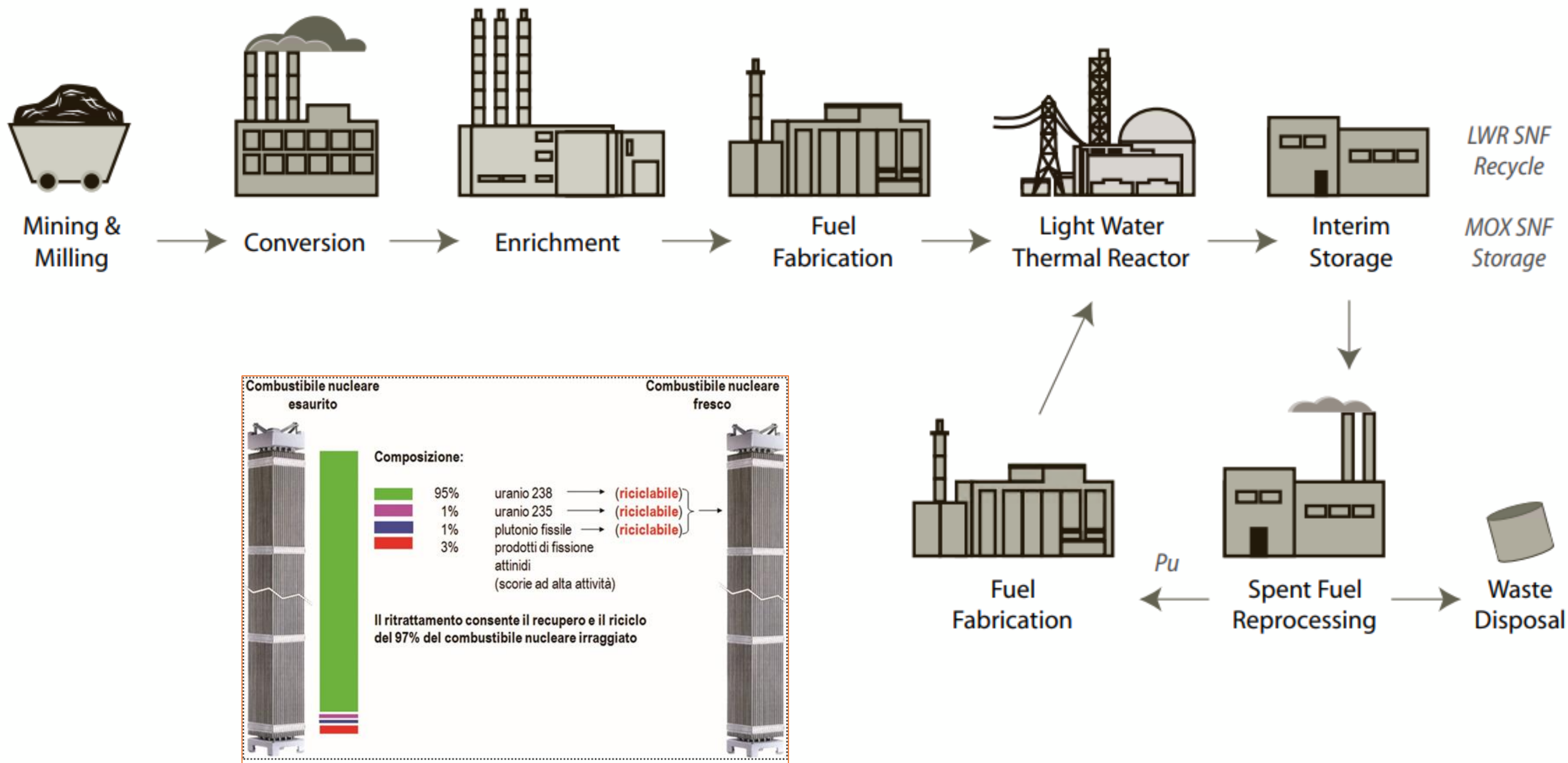


The LWRs fissions only 0.5% of the natural uranium and produce long-lived waste



In an open fuel cycle, natural uranium is transformed in waste, but only its 0.5% has contributed to the production of energy!

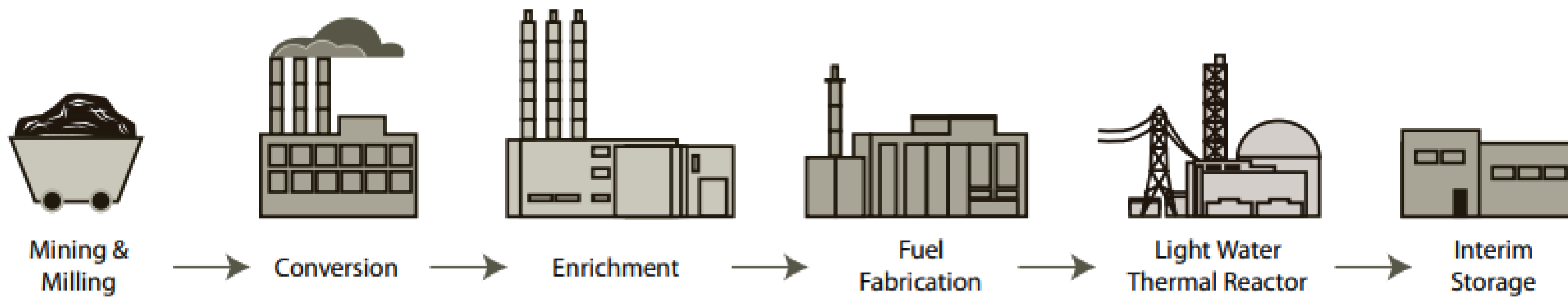
The nuclear fuel cycle – «partially» closed type (LWR)



Feasible recycling up to SNF with still 80% of U238

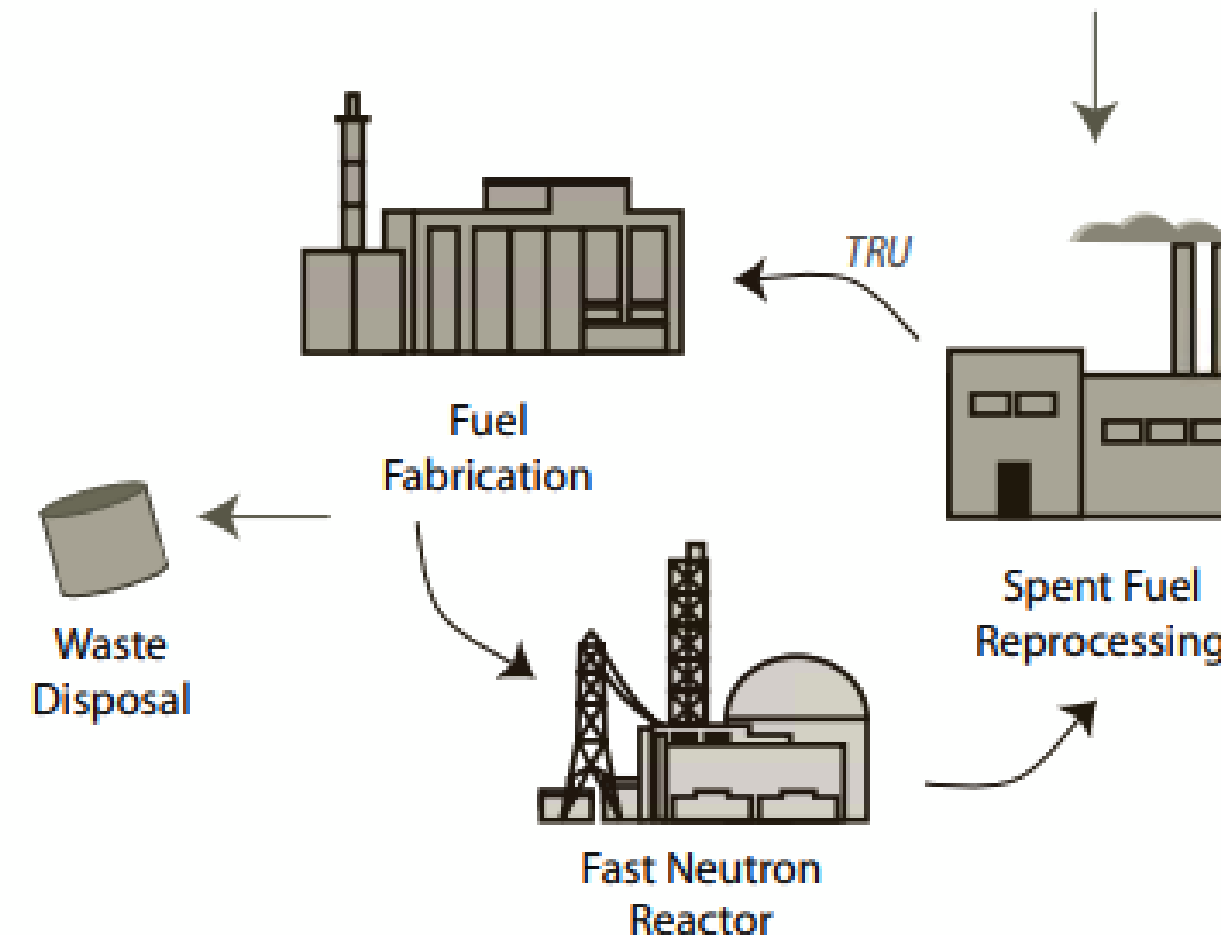
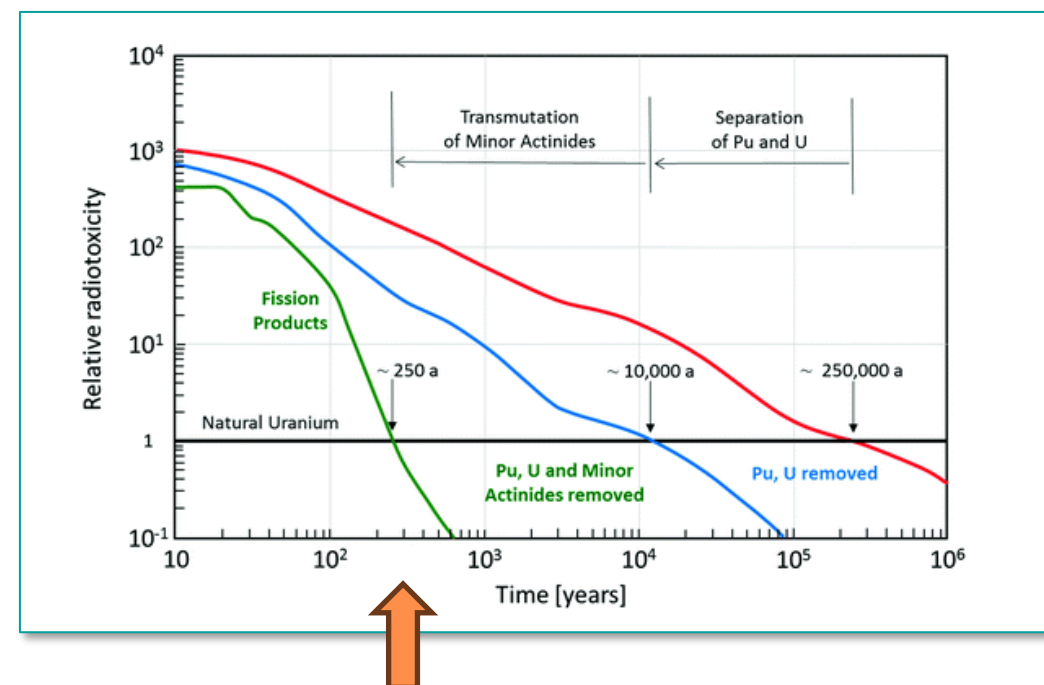
In a closed fuel cycle with LWR, the 97% of spent nuclear fuel (SNF) can be «only partially» reused to the production of energy.

The nuclear fuel cycle – closed type (FNR)



Energy production per 1Kg U

1x open type (LWR)
25x «partially» closed type (LWR)
50x complete closed type (FNR)

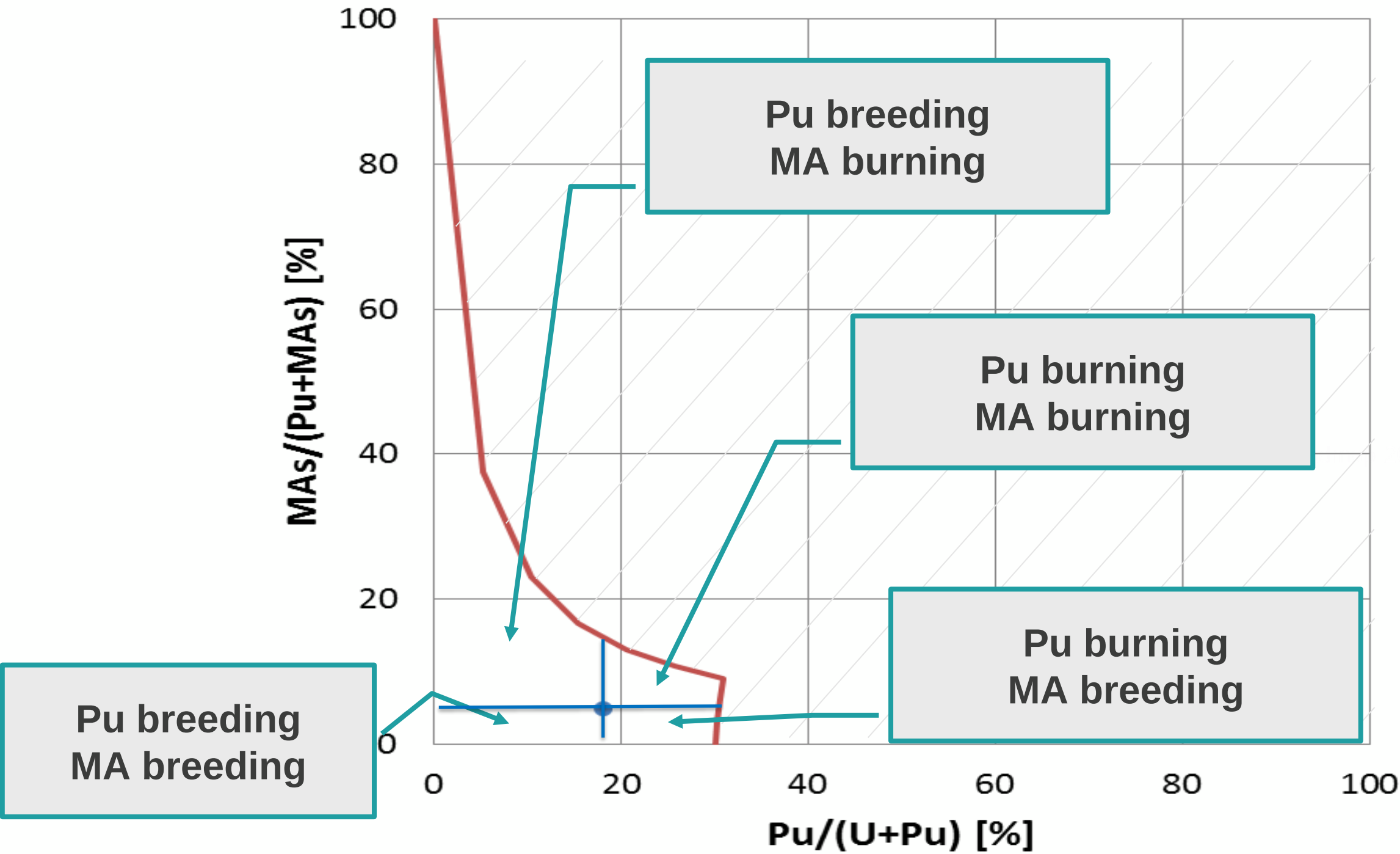


*on average
1GWe FNR uses
every year 4t of
Uranium only*

In a closed fuel cycle with FNR, the 99% of spent nuclear fuel (SNF) can be completely reused to the production of energy.

Fuel cycle potential of LFR

A LFR can effectively act as:
Pu breeders or burners
MA breeders or burners



Transuranic masses at equilibrium
for an **adiabatic** ELSY (600MWe LFR)
(Artioli et al., 2010)

- **Only natural or depleted Uranium** as make-up fuel;
- **Only fission fragments** as nuclear waste

Element	Composition (%)
Uranium	81.94
Plutonium	17.18
Neptunium	0.08
Americium	0.64
Curium	0.16

Pu balance for the self-sustaining and the burner cores

newcleo LFR 200 MWe can be used with a core in mode "plutonium burner" or "almost self-sufficient in Pu" (with higher power it can be "self-sufficient in Pu" or it can even be "breeder reactor")

	Core nearly self-sustaining		Core burner	
	U (kg)	Pu (kg)	U (kg)	Pu (kg)
Initial inventory	9139	2148	3900	1651
Final inventory	8063	2028	3606	1412
Balance	-1076	-120	-294	-239

MOX: the sustainable future fuel of Europe

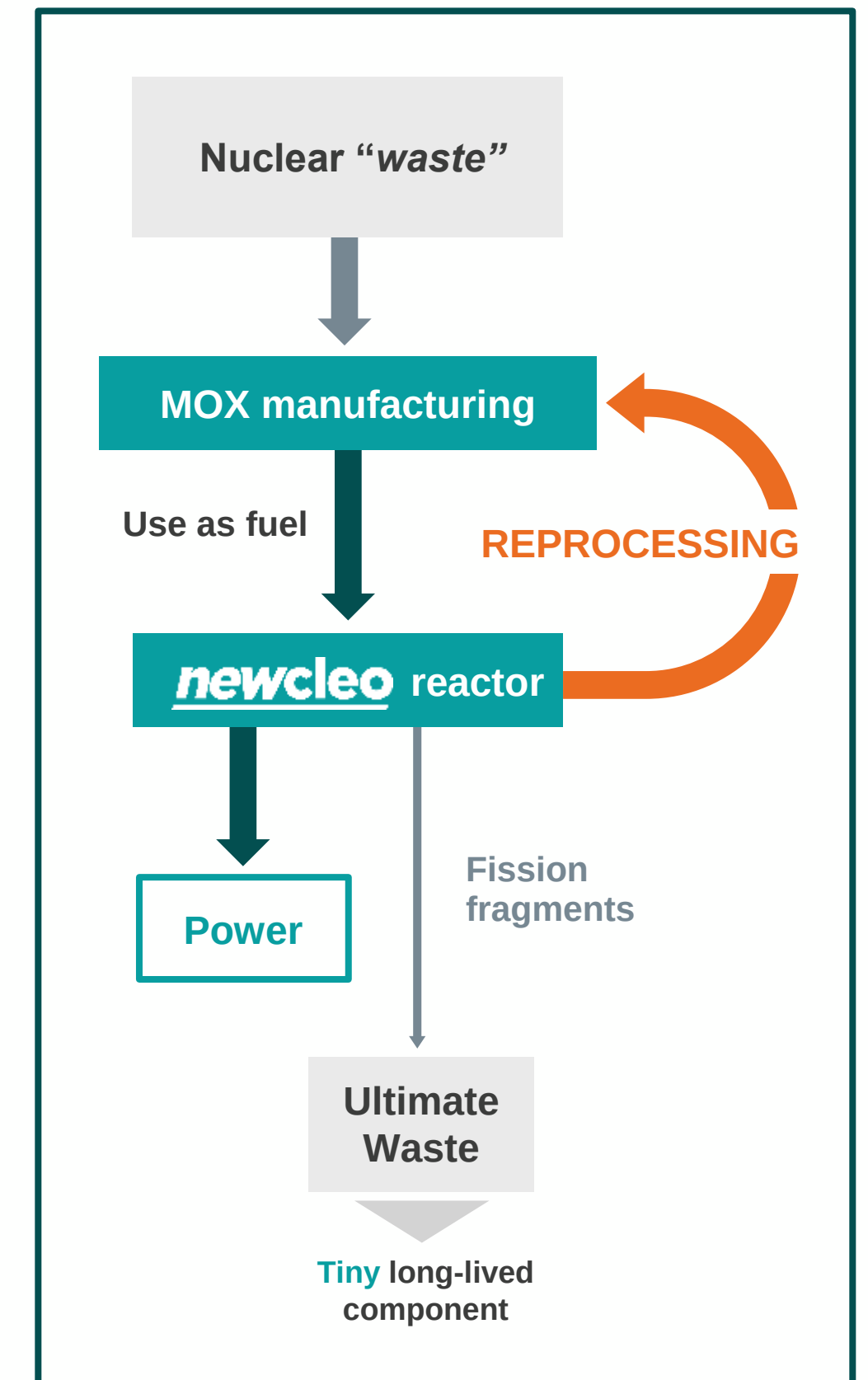
newcleo is working to design, build, and operate Gen-IV Small Modular Reactors (AMRs) fuelled with MOX: **M**ixed Uranium-Plutonium **O**Xides

newcleo's fuel cycle programme aims at establishing a MOX fuel fabrication plant in France to feed the LFR fleet

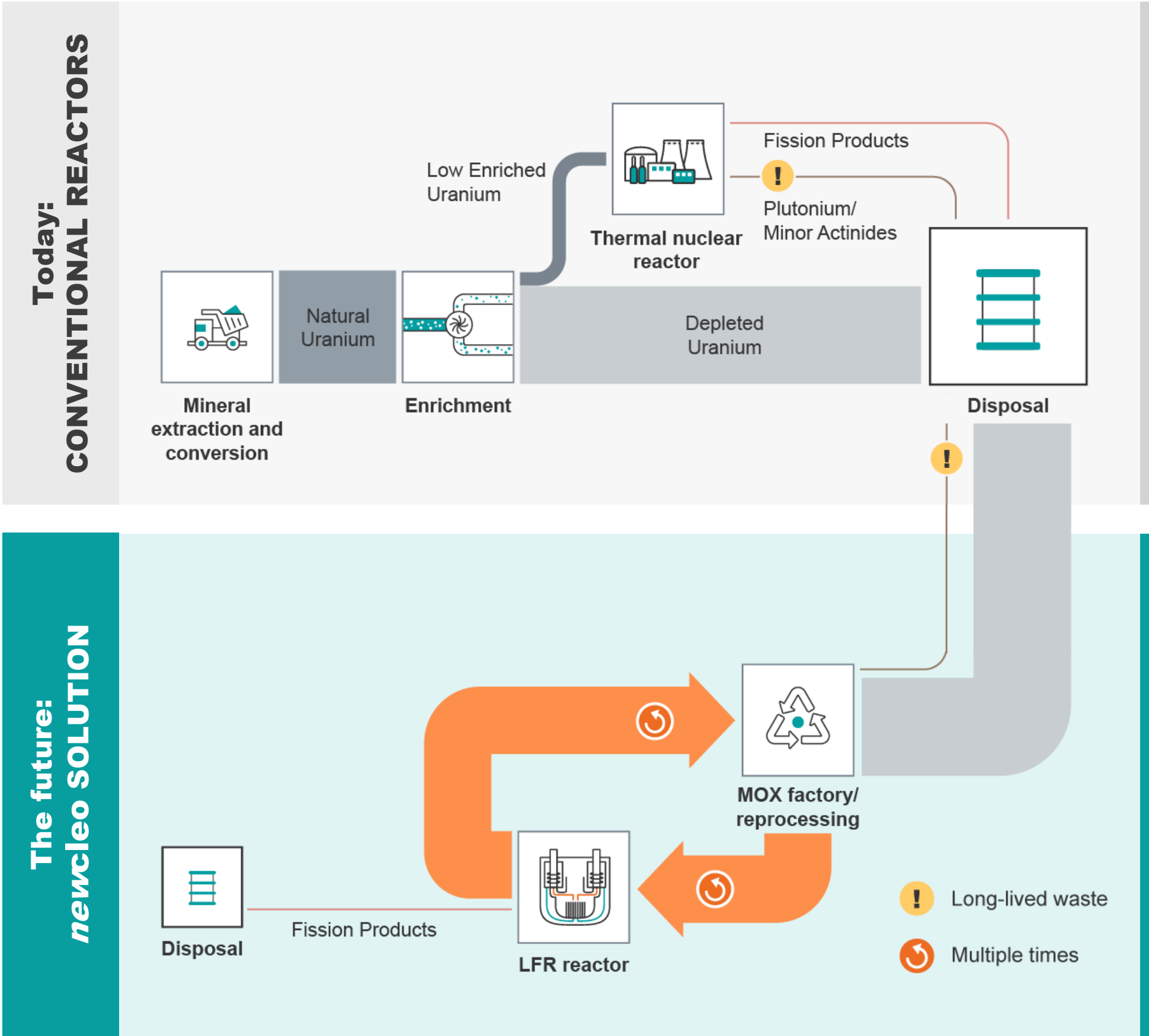
Ultimately, *newcleo* aims to close the fuel cycle by recovering material from the reprocessing of spent MOX_{LFR} fuel or other reactor fuels

MOX_{LFR} fuel is manufactured by using existing nuclear materials: depleted uranium, reprocessed uranium and plutonium from various origins (including reprocessed UOx fuels, reprocessed MOX_{LWR} fuels and MOX scraps). Currently, recoverable nuclear materials are not separated from waste, leading to very costly waste storage for many countries

newcleo aims to produce MOX to supply its fast reactors, allowing for the multi-recycling of nuclear materials into new fuel with no need of mining for generations

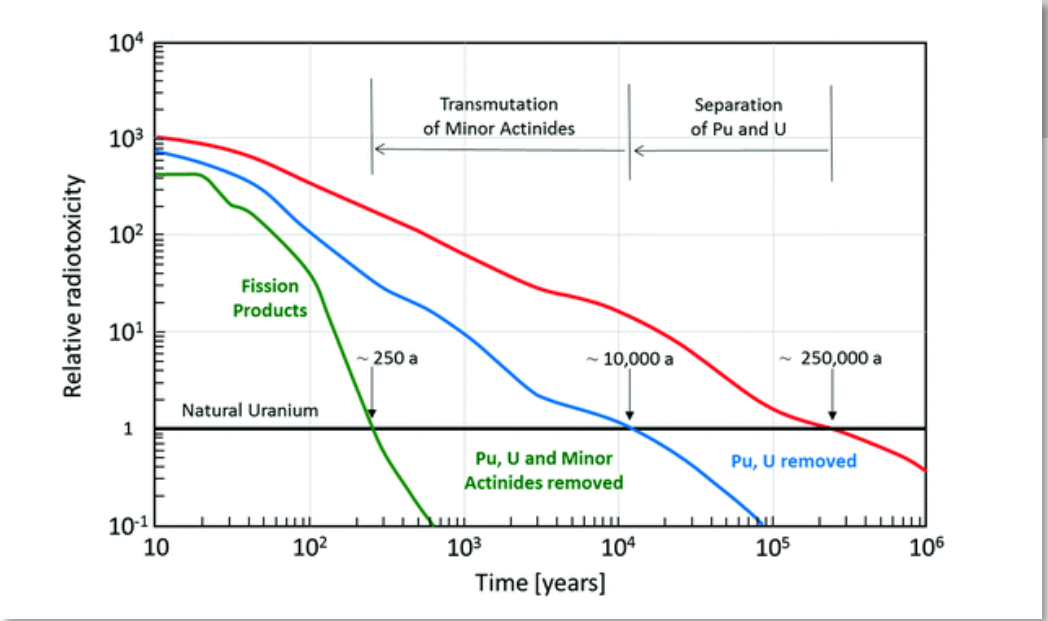


Closing the fuel cycle: MOX



Traditional thermal reactors use a very small portion of the extracted uranium: on average 1GWe traditional LWR uses every year 200t of mined uranium of which less than 1t is fissioned and generates the only waste we cannot avoid: Fission Products. The rest is not used and spent fuel becomes long lived waste (~250,000 y).

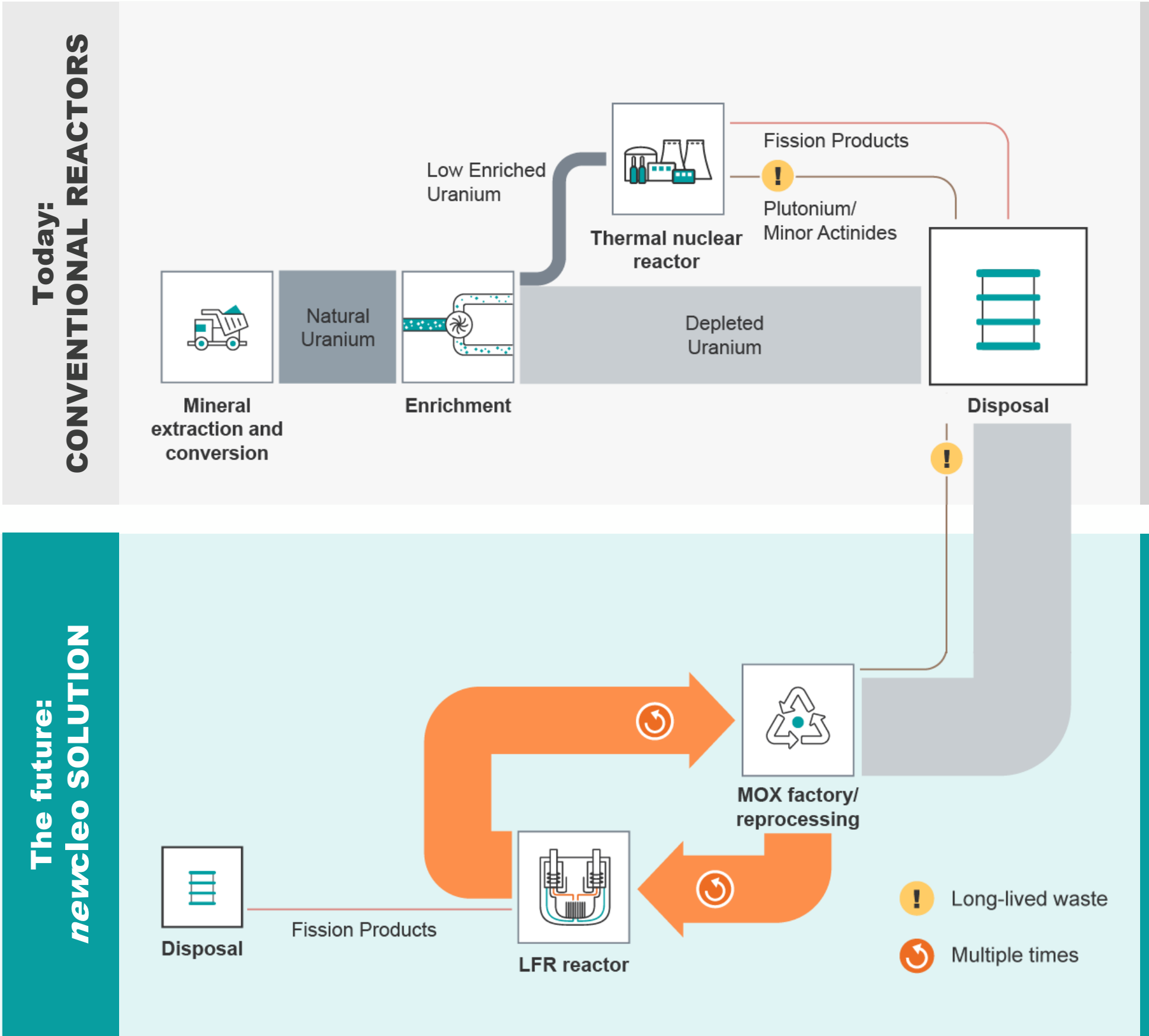
High-level waste has become an expensive liability



Reuse of Pu allows a significant reduction of the life of waste, but if other Actinides (elements heavier than the Uranium) are removed and burnt (transmuted), the only byproducts are less than **1t of fission fragments** per GWe of installed power per year: the waste from the consumption of a city like Rome becomes less than a cubic meter per year! And this material remains radioactive for only 250y. **This is the approach and the goal of newcleo.**

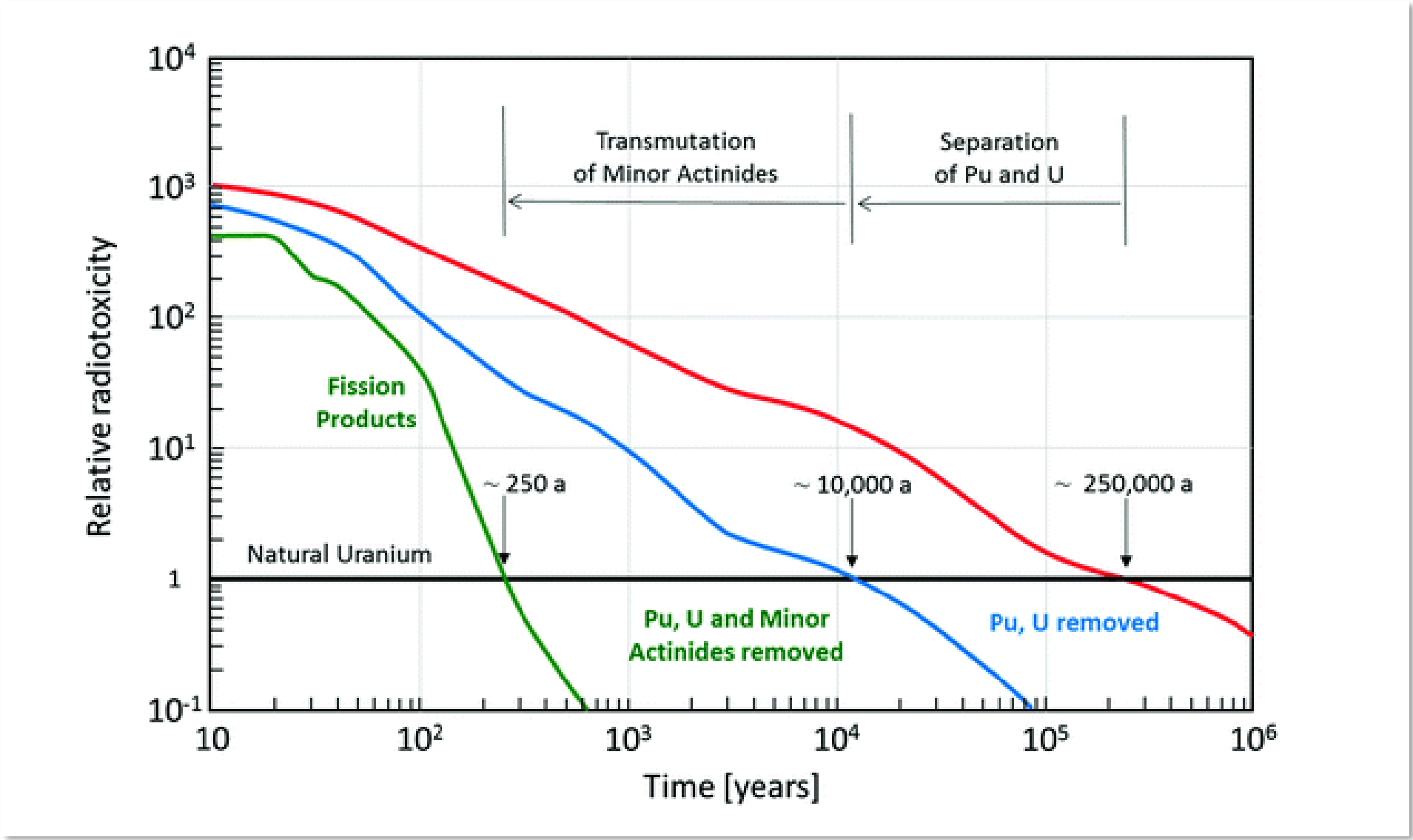
All artificial radioactivity created by reactors is virtually gone with newcleo's circular approach to nuclear waste

Closing the fuel cycle: MOX



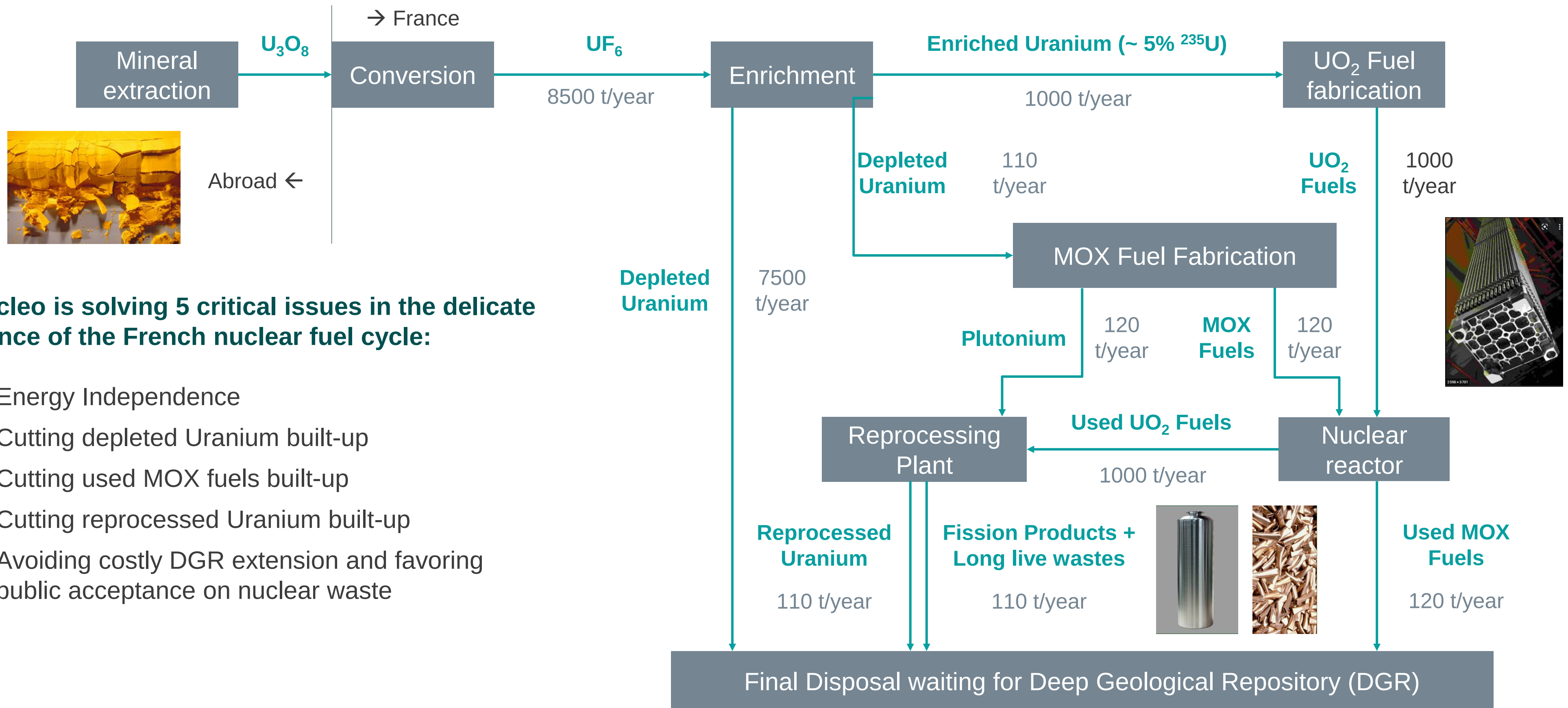
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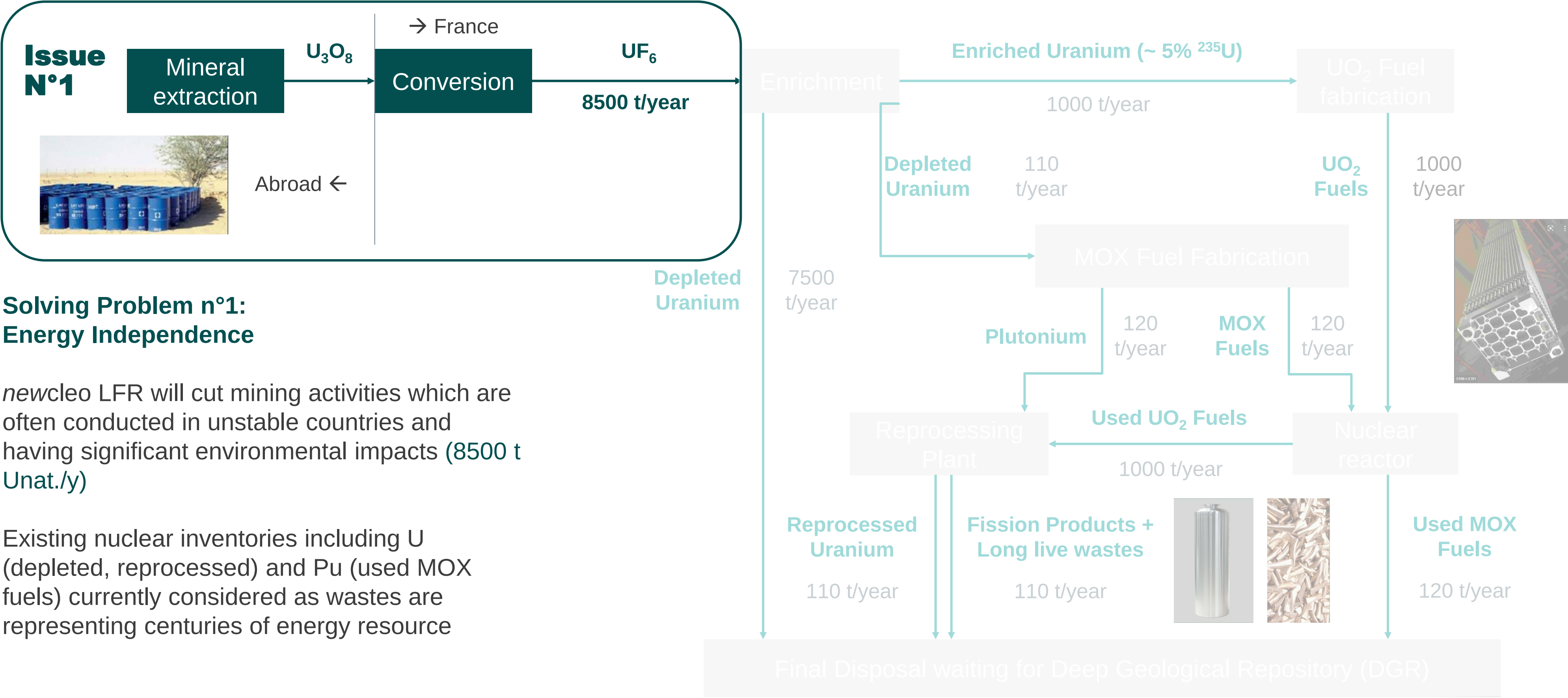
Simplified version of the French Nuclear Fuel Cycle



newcleo is solving 5 critical issues in the delicate balance of the French nuclear fuel cycle:

1. Energy Independence
2. Cutting depleted Uranium built-up
3. Cutting used MOX fuels built-up
4. Cutting reprocessed Uranium built-up
5. Avoiding costly DGR extension and favoring public acceptance on nuclear waste

Solving Energy Independence issues

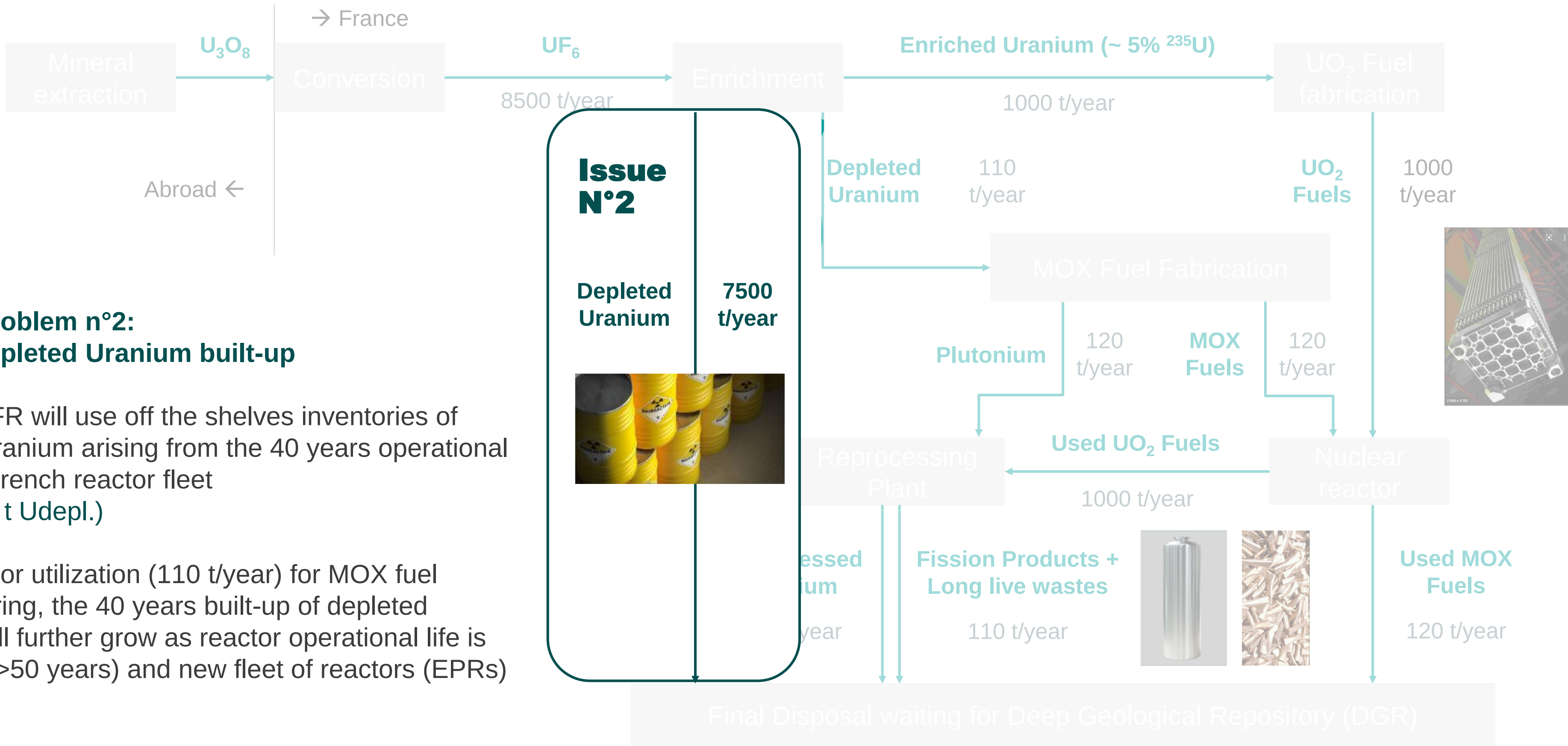


Solving large depleted uranium built-up issue

Solving Problem n°2: Cutting depleted Uranium built-up

newcleo LFR will use off the shelves inventories of depleted uranium arising from the 40 years operational life of the French reactor fleet (> 300,000 t Udepl.)

Except minor utilization (110 t/year) for MOX fuel manufacturing, the 40 years built-up of depleted uranium will further grow as reactor operational life is extended (>50 years) and new fleet of reactors (EPRs) is built.

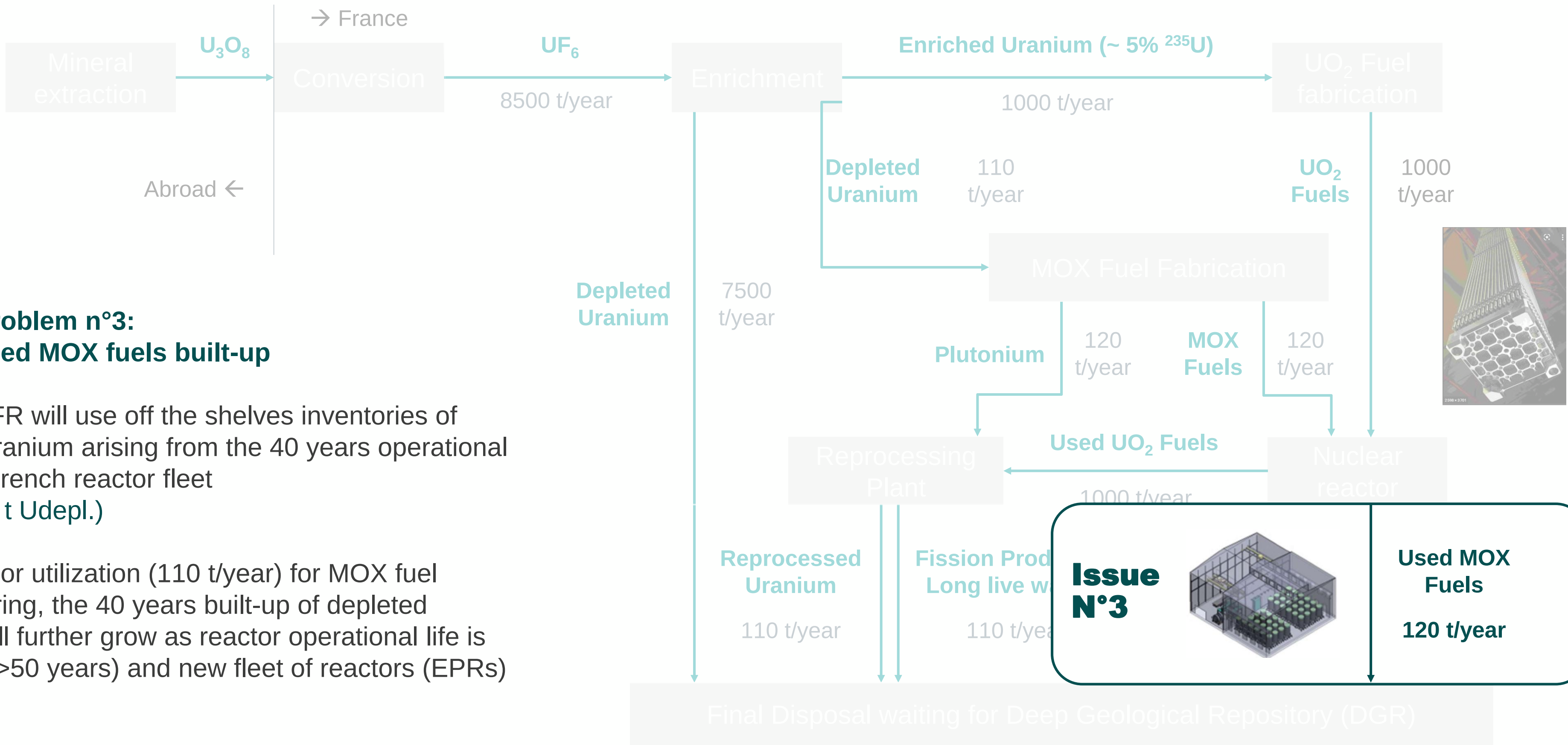


Solving large built-up of unrecycled used MOX fuels

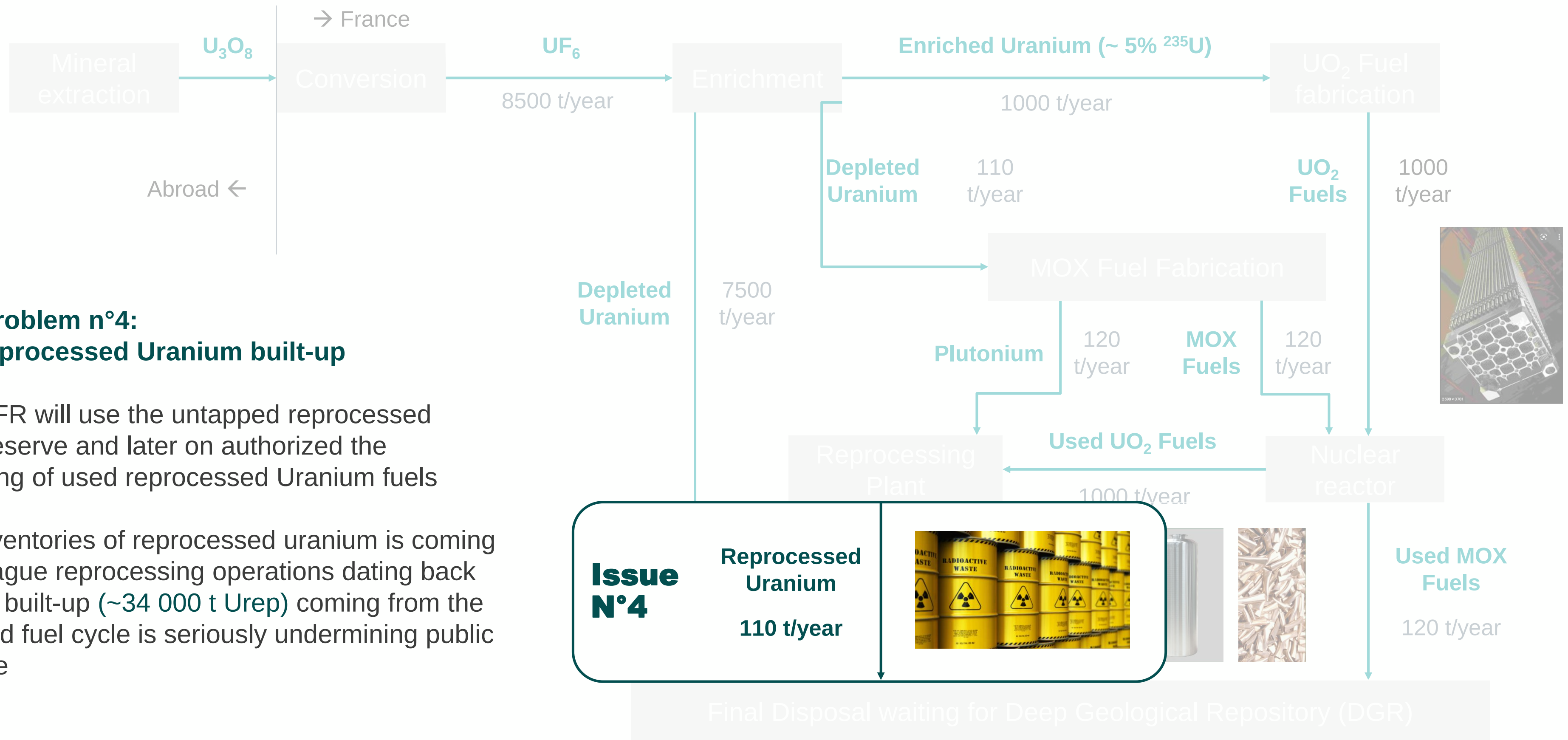
Solving Problem n°3: Cutting used MOX fuels built-up

newcleo LFR will use off the shelves inventories of depleted uranium arising from the 40 years operational life of the French reactor fleet (> 300,000 t Udepl.)

Except minor utilization (110 t/year) for MOX fuel manufacturing, the 40 years built-up of depleted uranium will further grow as reactor operational life is extended (>50 years) and new fleet of reactors (EPRs) is built.



Solving large built-up of reprocessed Uranium built-up



Solving Problem n°4: Cutting reprocessed Uranium built-up

newcleo LFR will use the untapped reprocessed Uranium reserve and later on authorized the reprocessing of used reprocessed Uranium fuels

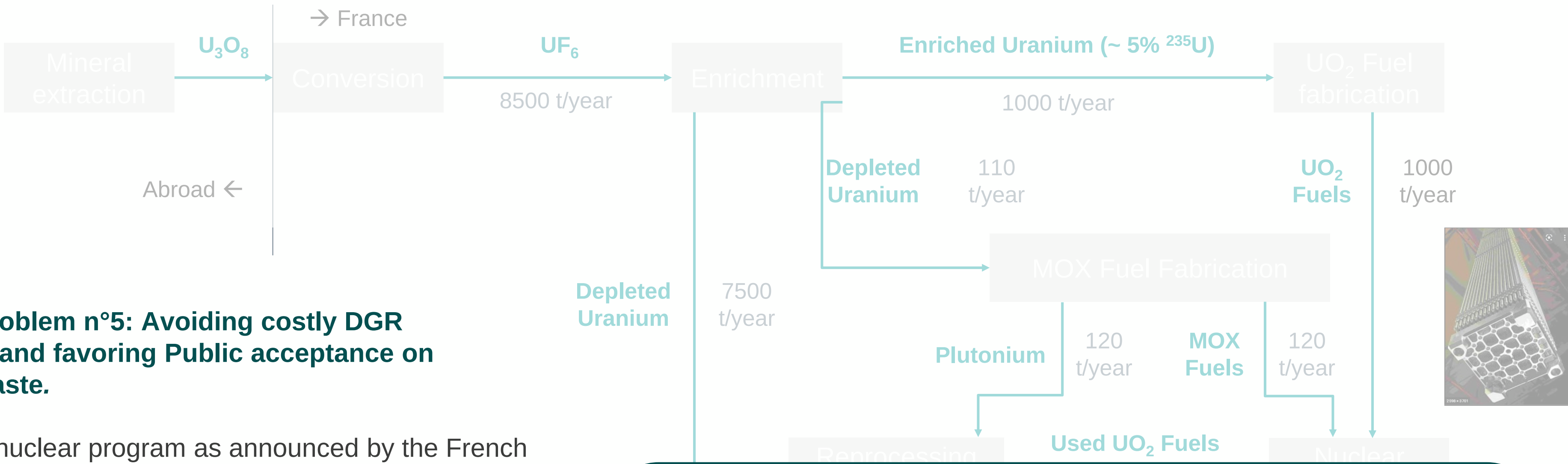
Current inventories of reprocessed uranium is coming from La Hague reprocessing operations dating back 1990. This built-up (~34 000 t Urep) coming from the semi-closed fuel cycle is seriously undermining public acceptance

Solving the current disposal project at Bure (CIGEO)

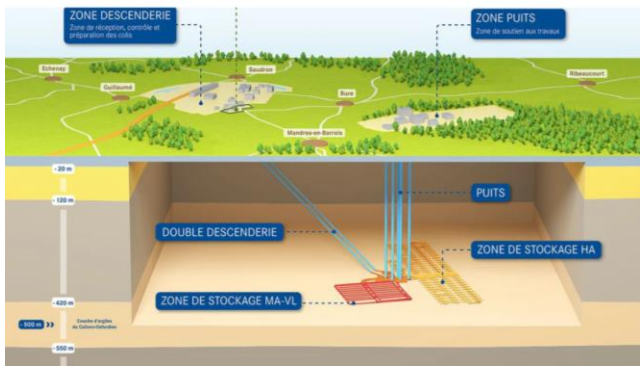
Solving Problem n°5: Avoiding costly DGR extension and favoring Public acceptance on nuclear waste.

Upon new nuclear program as announced by the French Government, large inventories (reference and reserve) of waste from existing and future reactors will grow

The most mature industrial Generation IV reactor like the *newcleo*'s LFR is able to cope with waste volume reduction (Burner) and promote multi-recycling solution therefore avoiding DGR extension and favoring public acceptance on nuclear activities



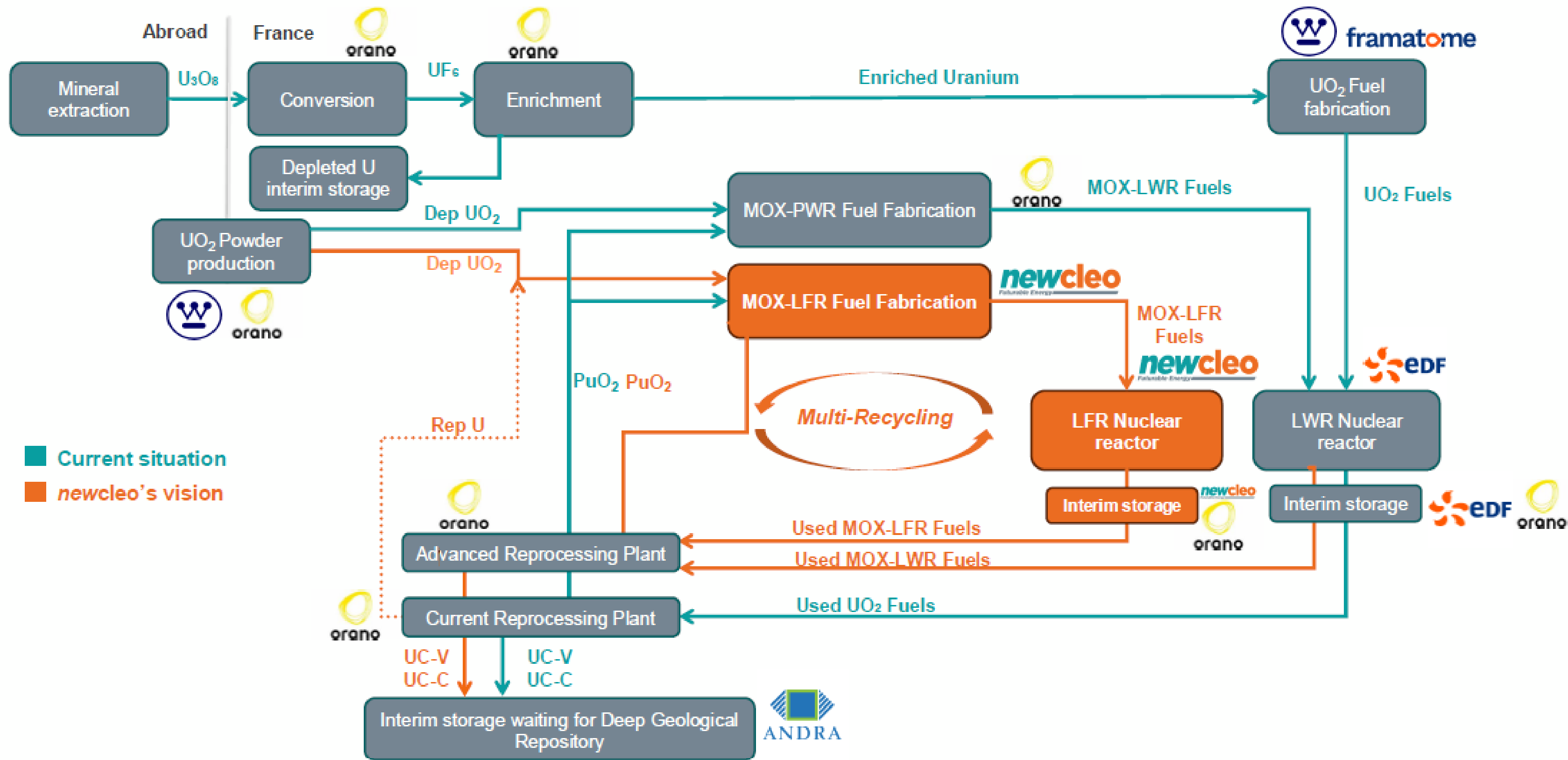
Issue N°5



Final Disposal waiting for Deep Geological Repository (DGR)

Closing the fuel cycle – French example

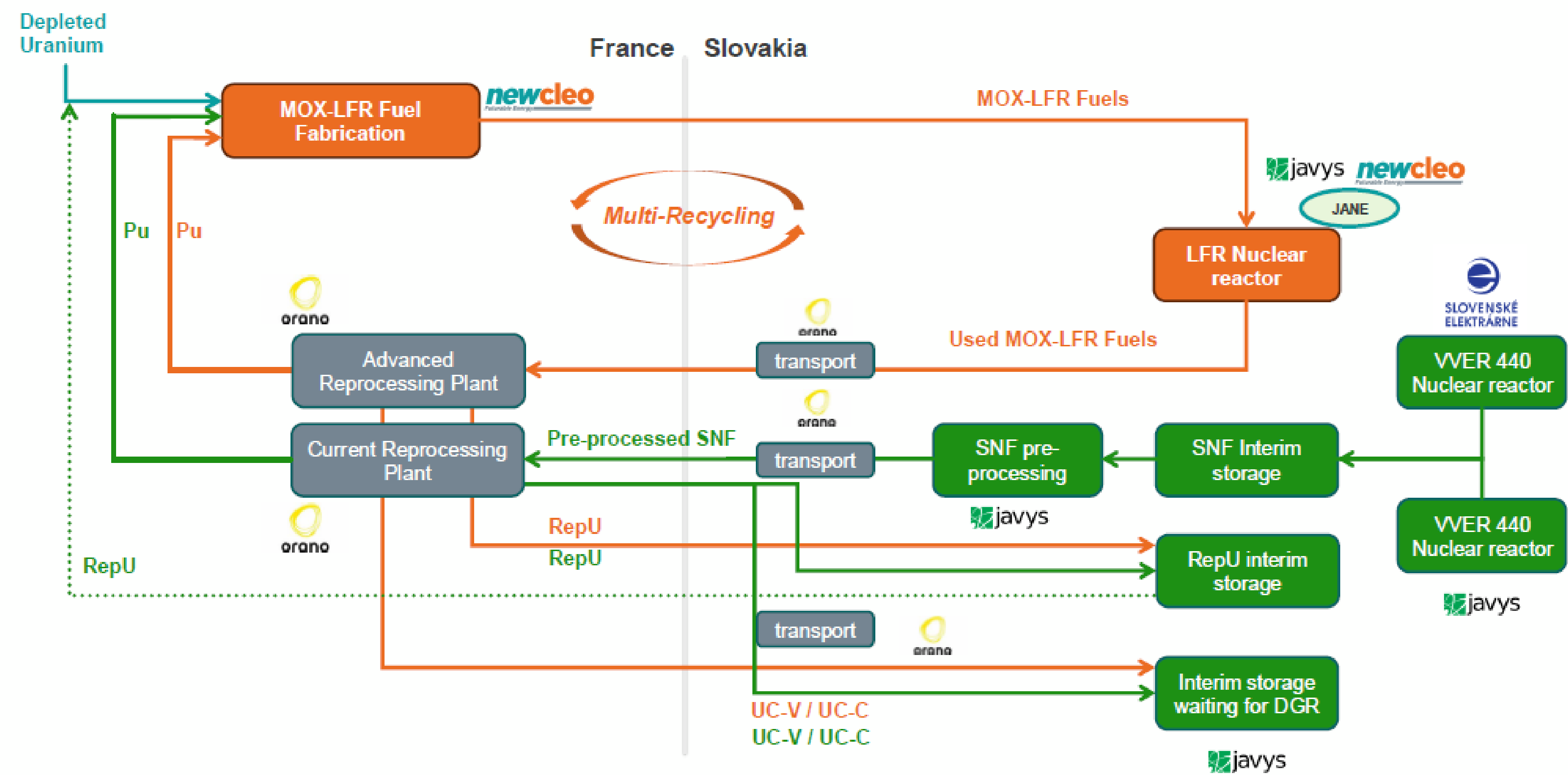
newcleo vision



Note : The use of company logos is for the sole purpose of a better understanding of the fuel cycle proposed by newcleo.

Closing the fuel cycle – Slovakia example

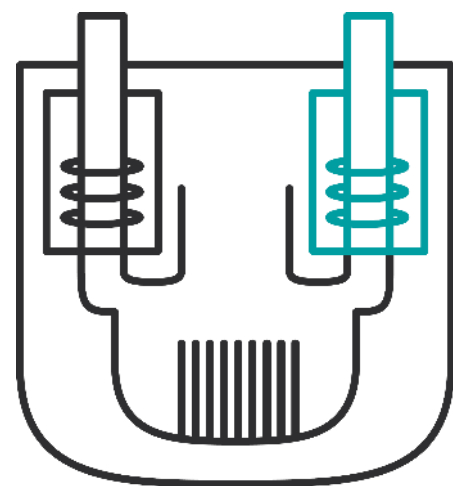
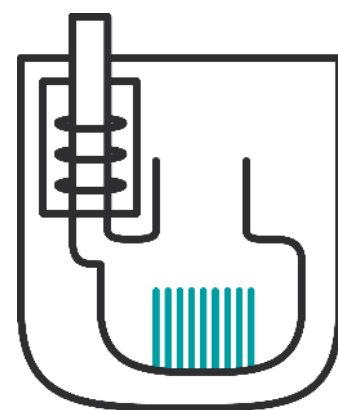
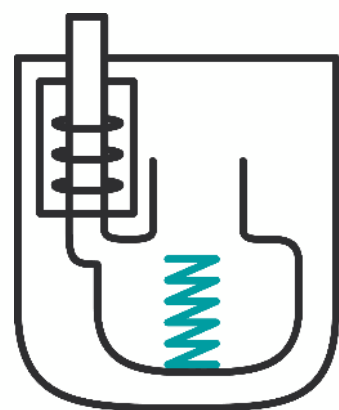
newcleo vision



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newcleo roadmap

newcleo's plan-to-market



R&D and Precursor

2026

Several R&D and qualification facilities, and a **10 MW non-nuclear reactor** with turbo-generator (Precursor) built in ENEA-Brasimone

Design, manufacturing and operation in progress

MOX production

2030

FR-MOX production facility, starting from available (separated) material in France

Basic Design in progress
Licensing in progress for both facilities

LFR-AS-30

2031

30 MWe nuclear irradiation reactor with core outlet at 440°C and later 530°C in France

LFR-AS-200

2033

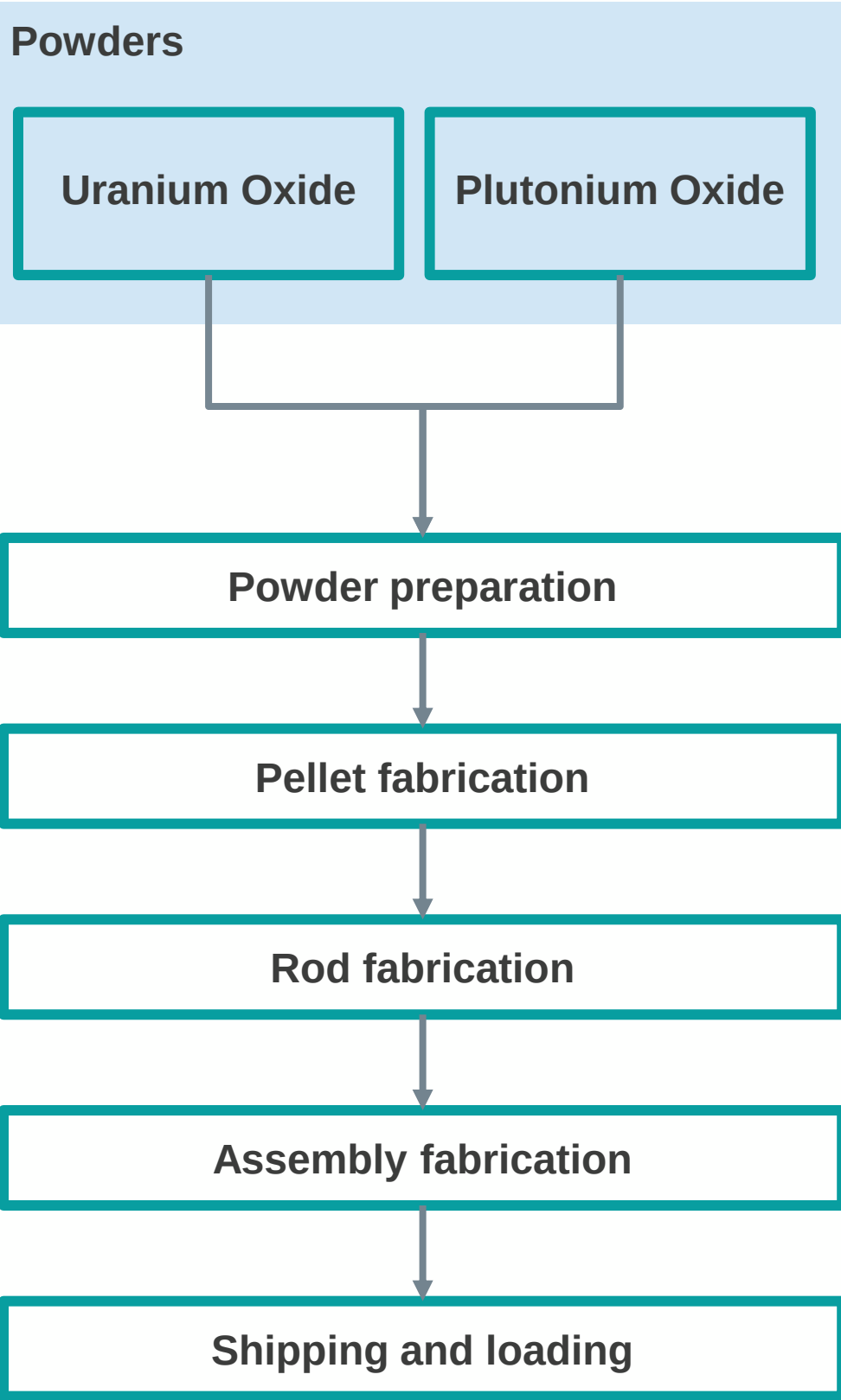
200 MWe FOAK, also for non-electrical uses (e.g. cogeneration and chemicals production)

Starting **Basic design**
UK Licensing started in 2024

Ongoing M&A Acquisition programme

Our fuel cycle programme

R&D and PRECURSOR	MOX PRODUCTION	LFR-AS-30	LFR-AS-200
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newcleo to manufacture MOX fuel

- from powders to assemblies to fuel our LFR demonstrator and fleet
- starting from already available (separated) material
- in synergy with the in-country environment, establishing deep industrial collaborations with the sector’s leading actors

Design and licensing in progress

An advanced and modular facility concept to gradually increase capacity: first production line of 20 t/year (rapidly increasing to 40 t/year), with the possibility to add other production lines up to 120t/year.

Licensing status: submitted our **Safety Options Dossier (DOS)** to **ASN**

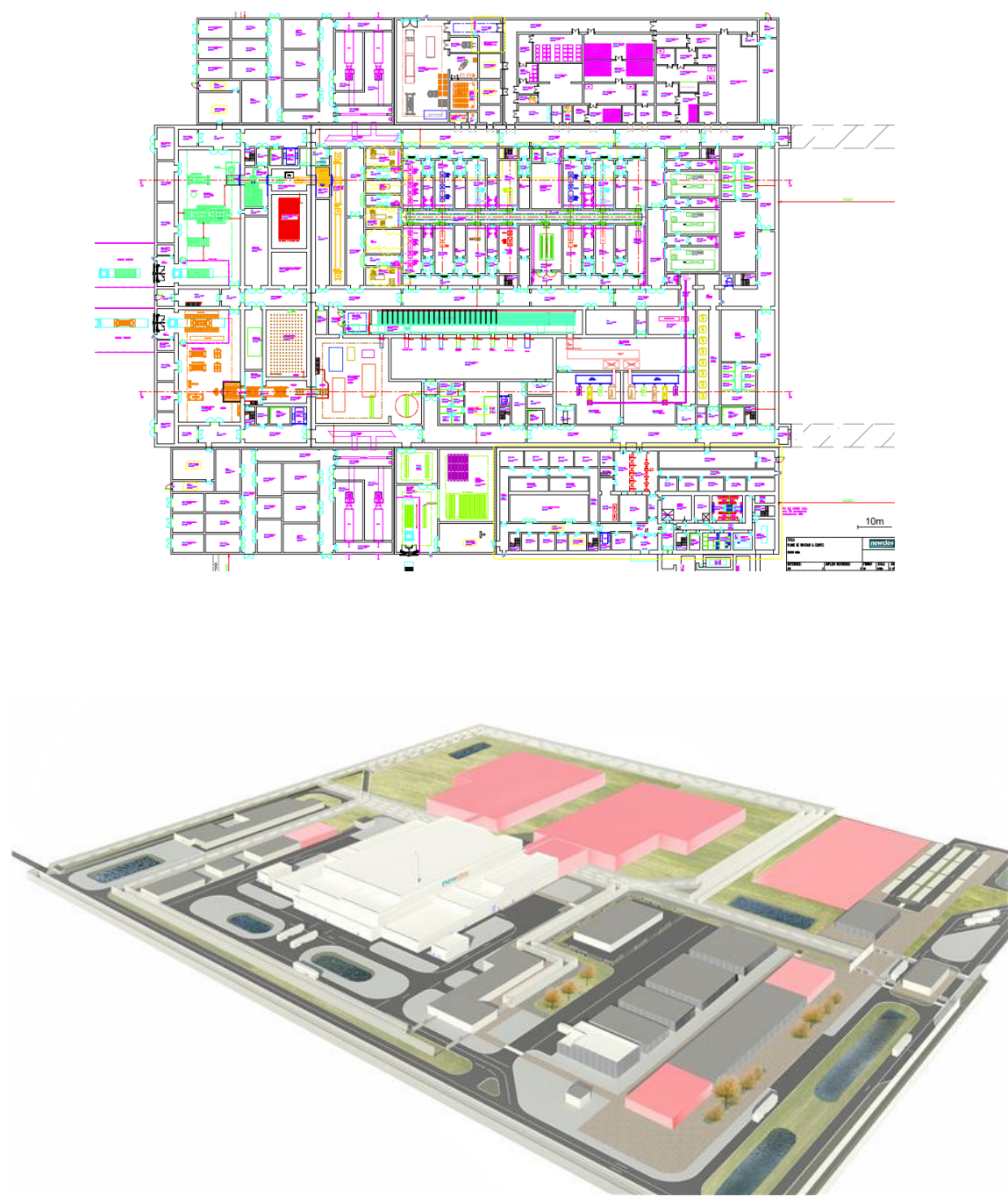
Progressive implementation of long-term fuel cycle programme

newcleo’s long-term fuel cycle programme will be realised one step at a time in an agile and flexible way: taking rapid steps to make progress in a way that will not preclude future options or a change of approach

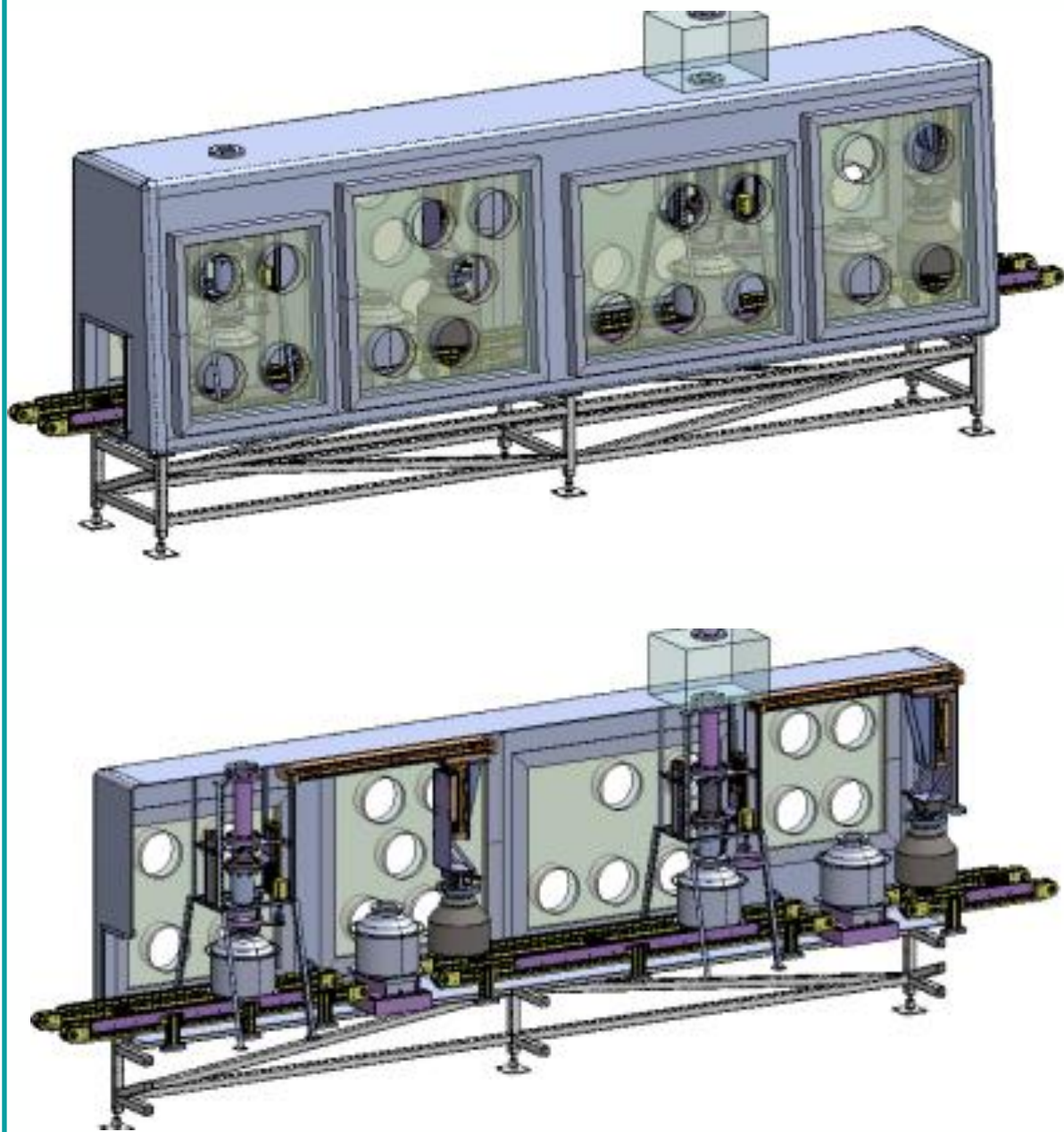
- Fuel newcleo’s demonstrator and first commercial unit
- Fuel newcleo’s fleet
- Exploit reprocessing
- Deliver services internationally
- Achieve fully sustainable nuclear

Fuel Manufacturing plant - MOX-LFR *newcleo*

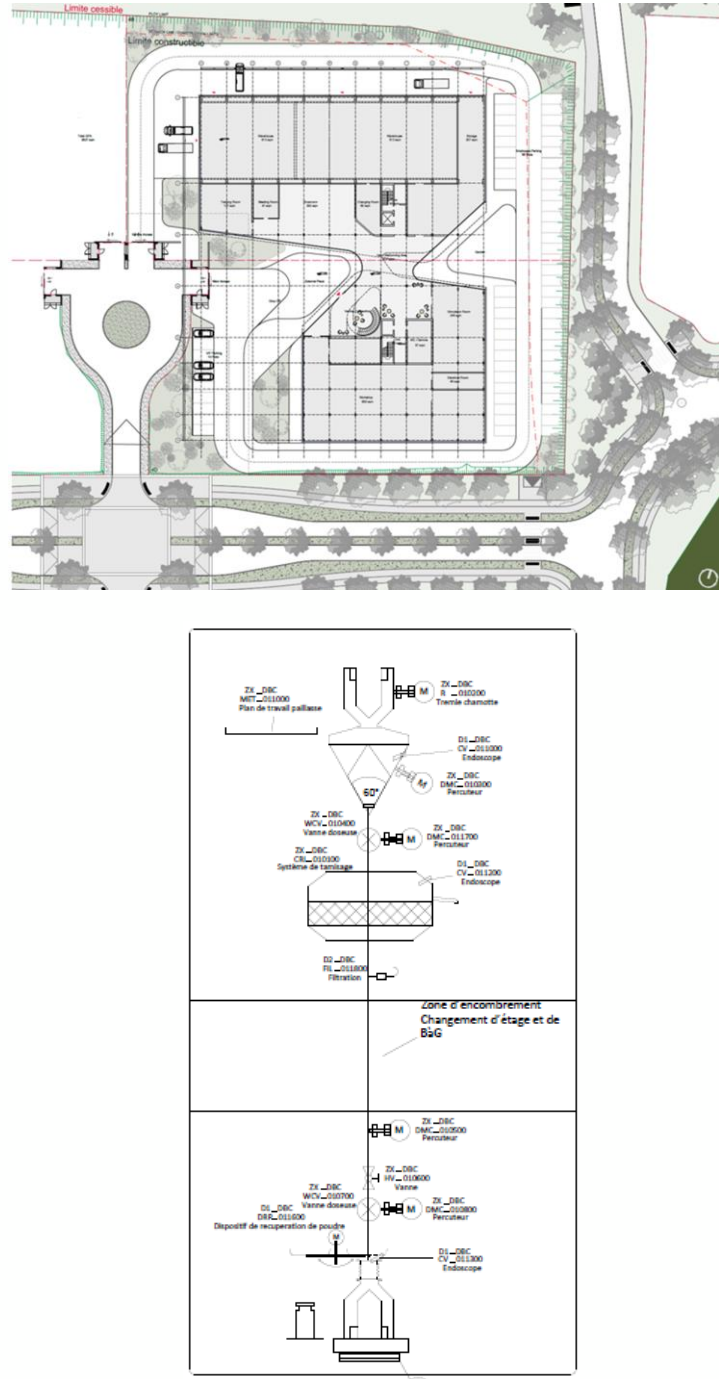
Layout and 3D model



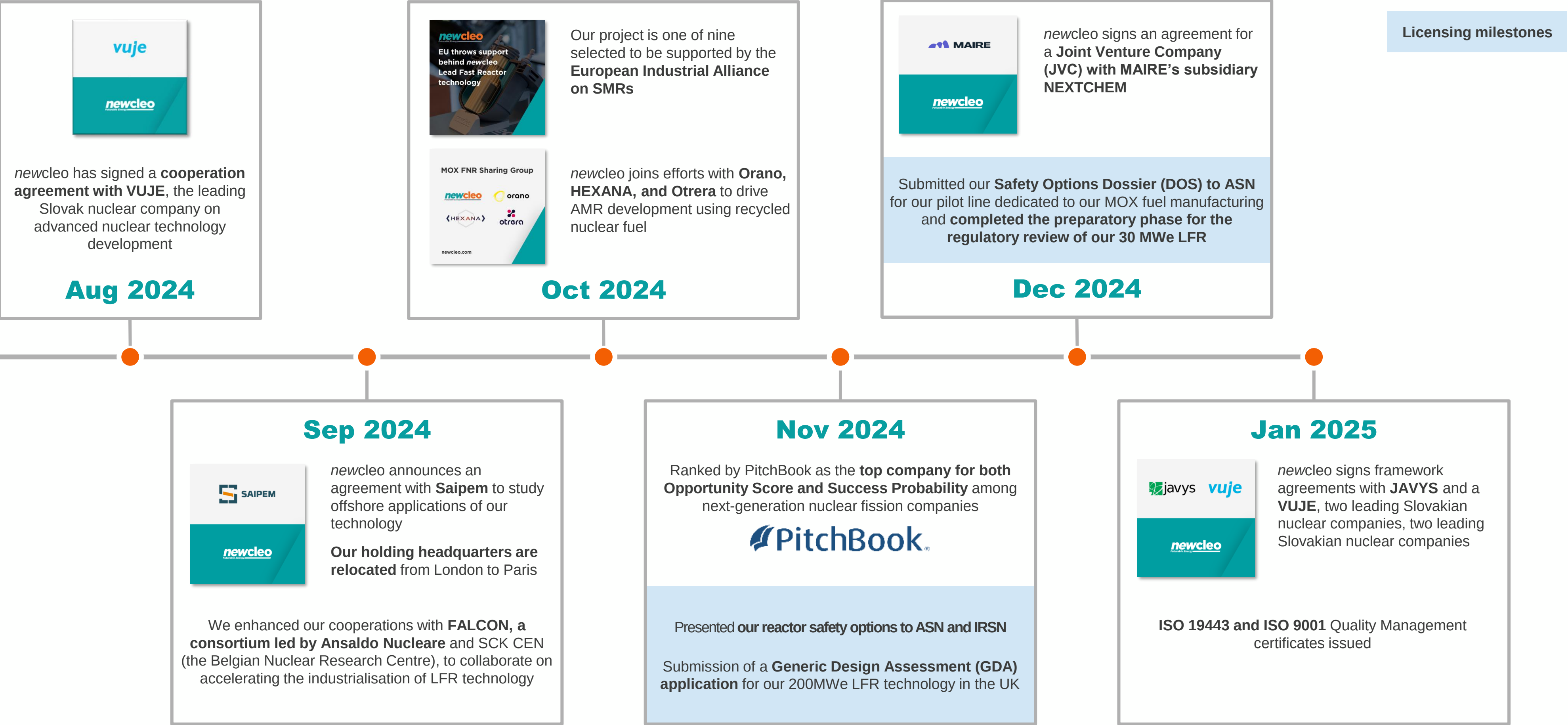
Gloveboxes design



FASTER – Development & Qualification program



Key milestones in the last months



Thank you



newcleo's reactor



