How innovative approaches & technologies throughout the Fuel Cycle are supporting NPP Operations while anticipating future back-end Challenges

Dr. Mustapha Chiguer, Jean-Michel Grygiel

AREVA
1, Place Jean Millier 92084
Paris-la-Defense, France
mustapha.chiguer@areva.com

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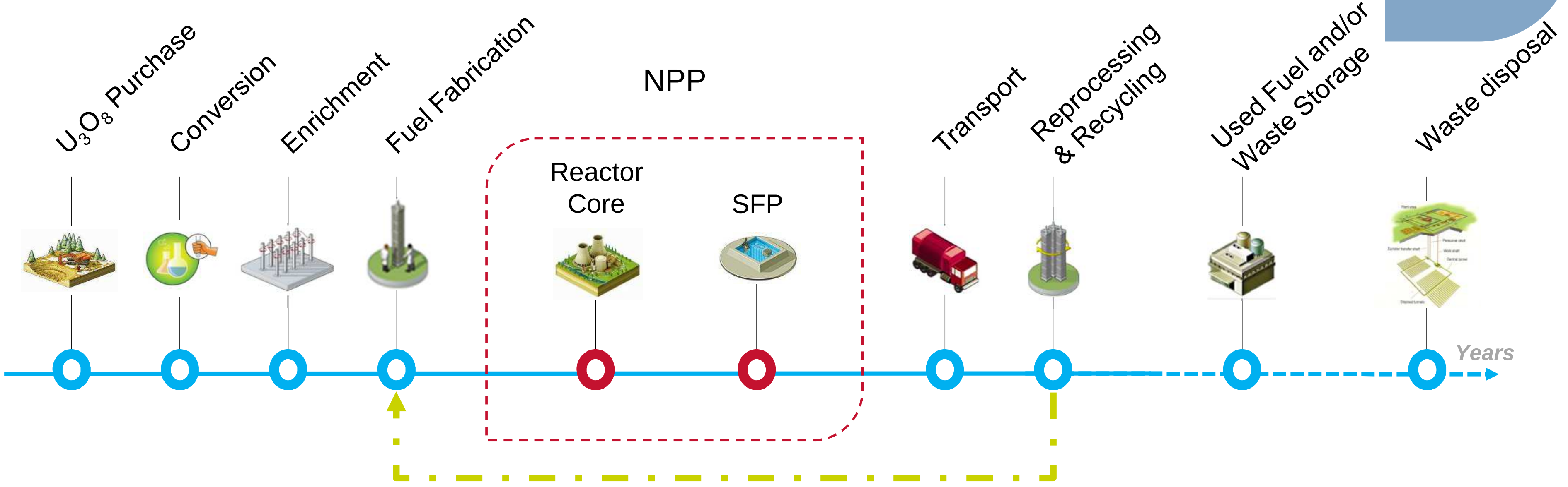
Main drivers …and challenges



Risk Reduction

- Nuclear safety
- Non-proliferation & security
- Environmental impact & footprint
- Public acceptance
- Cost or financial Uncertainties

Nuclear System Performance

- Increase energy independence
- Optimize cost of nuclear electricity
- Increase Plant availability and Performance
- Save natural resources (uranium, DGR footprint, …)
- Minimize waste generated

Structuring Policy and Regulation

International Agreements

ex. Joint Convention on the Safety of SF & RW Management of 1997
"Each Contracting Party shall ensure the prime responsibility for the safety of SF or RW rests with the holder of the relevant license"

European Union Directive

European Council Directive 2011/70/Euratom of July 19, 2011
"Each Member state shall have ultimate responsibility for management of SF and RW generated in it"

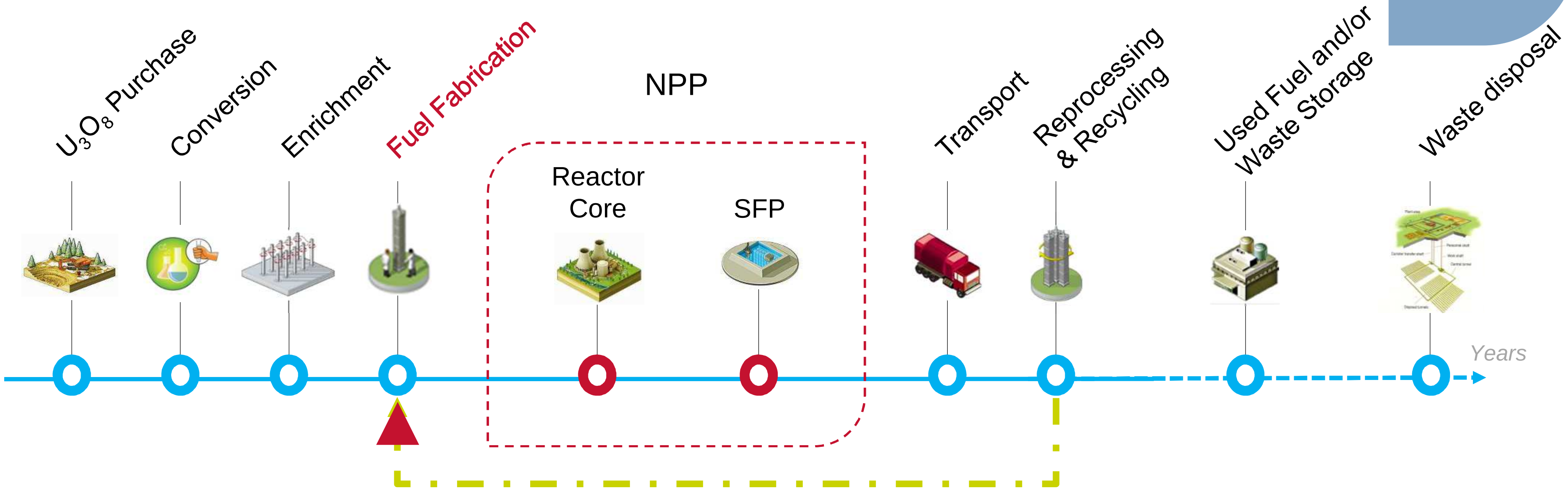
National Policy

French Nuclear Waste Act of June 28, 2006
"Nuclear Operators Commit for SF & RW Mgt funding while minimizing industrial footprint"

- **By authorizing Nuclear activities on its soil, the state take a Long term responsibility regarding Used Fuel & RW Management policy**
- **By Operating NPP or Facility, Operators take also Long Term responsibility**

LT Responsibility requires a look at the individual Fuel Cycle steps and how they all impact each other

At the Front-End
the **Fuel** is a technology demanding and driven business



Front-End

- Containment and Handling of nuclear material

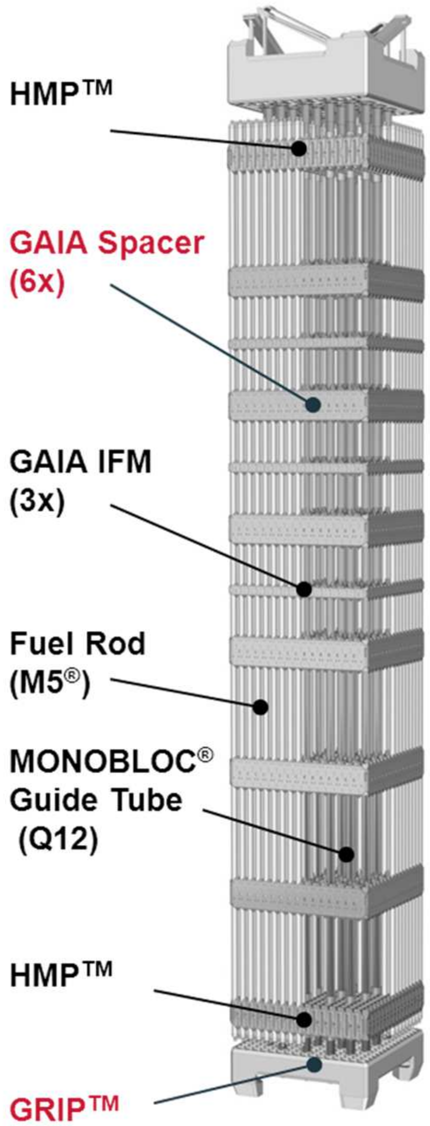
In the Reactor (all together for 3 to 6 years)

- Containment of the nuclear material, the cladding is the first barrier
- Maintaining geometry, chain reaction control
- Extracting power
- Ability of the core to cool down in the event of an accident

Back-End, On leaving the reactor

- Containment and handling of the nuclear material
- Removal of decay heat
- Ability to be stored
  - Wet or dry conditions
  - For more and more extended time
- Ability to be reprocessed and recycled
- Ability to be transported
- Ability to be disposed in DGR

Case 1 – GAIA fuel,
Innovation based on Proven products and high performance Features



GAIA
New Generation Fuel

Based on Current AREVA fuel designs,

- HTP™ with its proven robustness against GTRF failures
- AFA-3G™ with its excellent thermal-hydraulic performance

High-performing features

- **Reinforced MONOBLOC™ guide tube**
- **High density chromium doped pellets**
- **GRIP™ bottom nozzle**
- **M5® Cladding**

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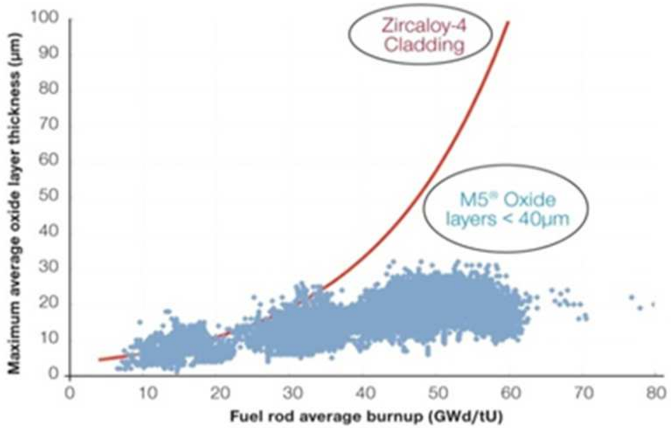
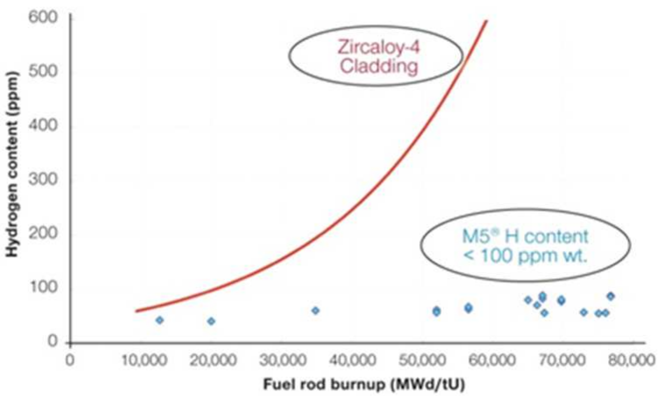
Case 1 – GAIA fuel,
Innovation based on Proven products and high performance Features

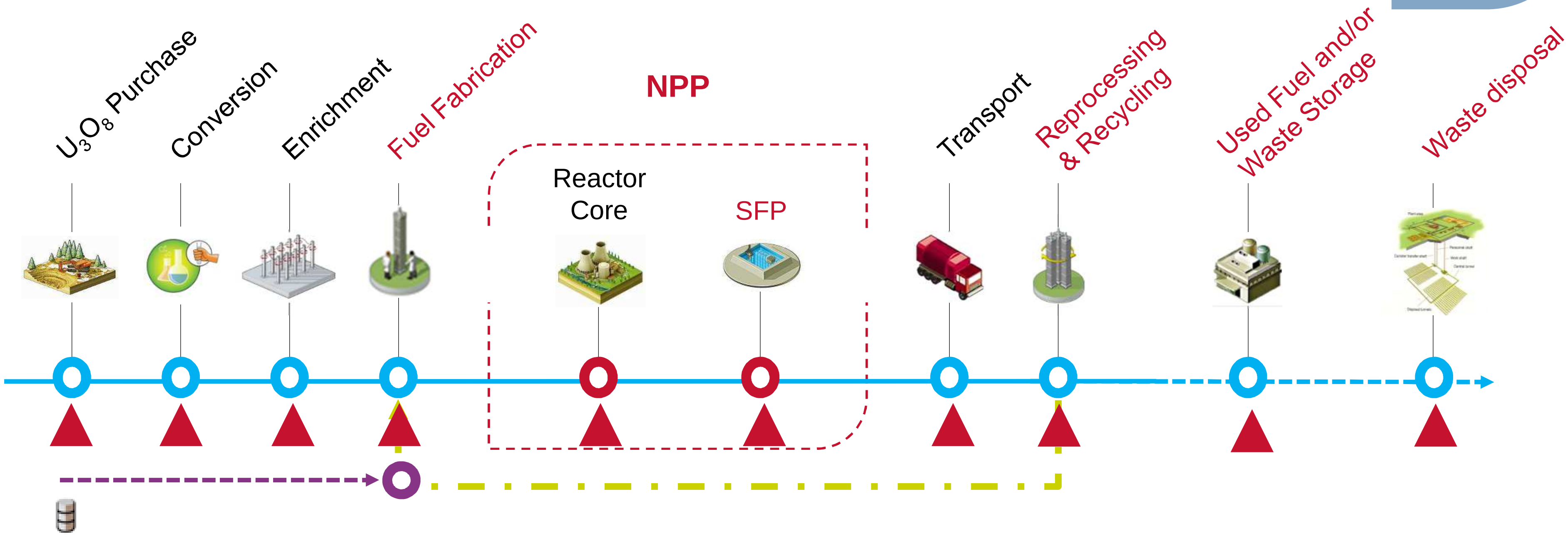
- **Enhanced Reliability and Robustness through :**
  - **Superior rod supports ensuring that GTRF margins are kept for long cycles and severe environments**
  - **Increased margins against incomplete rod insertion and FA distortion**
  - **Superior debris fretting efficiency**
- **Increased Flexibility**
  - **M5® excellent corrosion resistance allows higher BU**
  - **Chamfered pellets made of chromium doped fuel:**
    - *Reduce the risk of chipping and increase margins re. PCI allowing more flexible Plant Operation*
    - *Increase design margins at the EoL conditions which is supported by a low volume of fuel rod spring*
  - ***M5® higher resistance to corrosion and low Hydrogen uptake are both key to flexible used fuel Management*** **corrosion resistance and ductility (ex. Storage, Extended interim storage periods, Transport after storage)**





Excellent LT Behavior through enhanced resistance and lower sensitivity to highly irradiated cladding and Fuel Assembly Structure

Brings to 0 the balance of used fuel and fissile materials at NPP EoL



PRECYLING

The concern
Recycle all nuclear Materials prior to reactor End-of-Life (EoL)

- **Single or small reactor fleets**
- **Limited lifespan**

Advanced Recycling Solution

Brings to 0 the balance of used fuel and fissile materials at NPP EoL

- **Drastically reduces all risks related to LT Management of used fuels**
- **Reduces Front-End requirements**

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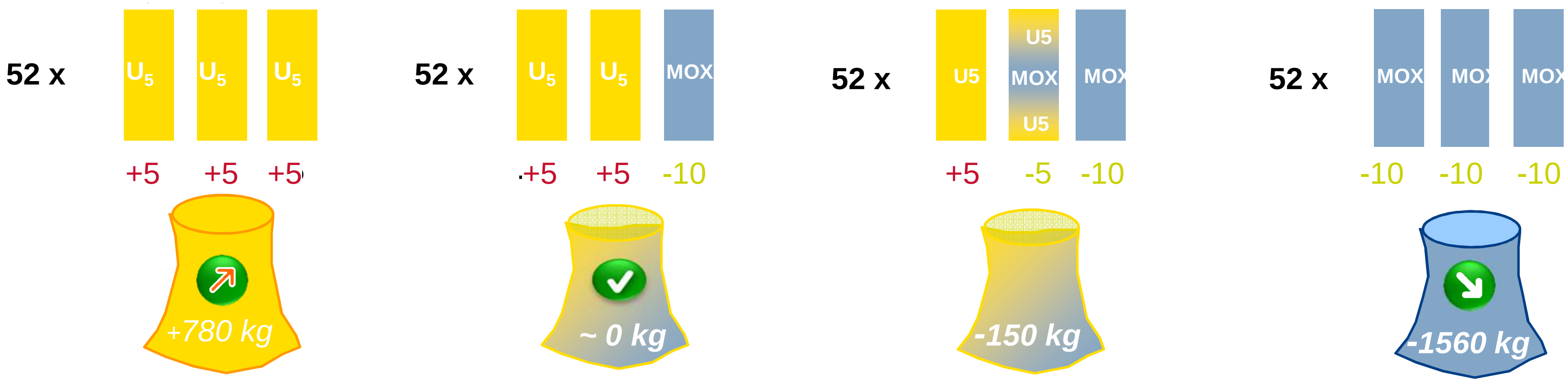
Brings to 0 the balance of used fuel and fissile materials at NPP EoL

Core’s Plutonium balance sheet at the end of every 3 cycles



*100 % UOX Core **

Production of Pu in Uranium Core during electricity generation*

*30 % MOX Core **

No production of Pu in 30% MOX Core during electricity generation*

*~40% MOX Core **

Consumption of Pu in ~40 % MOX Core During electricity generation*

*100 % MOX Core **

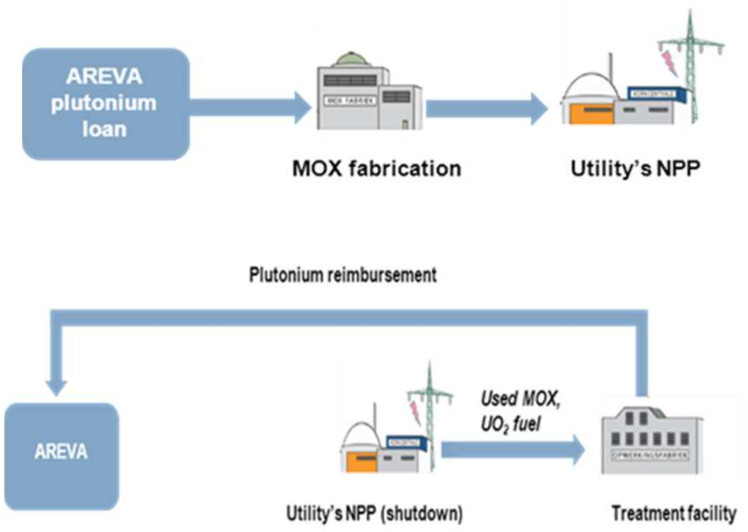
Consumption of Pu in 100% MOX Core During electricity generation*

Early and Sufficient Pu consumption key to offset Pu production during electricity generation in Uranium Oxide fuel

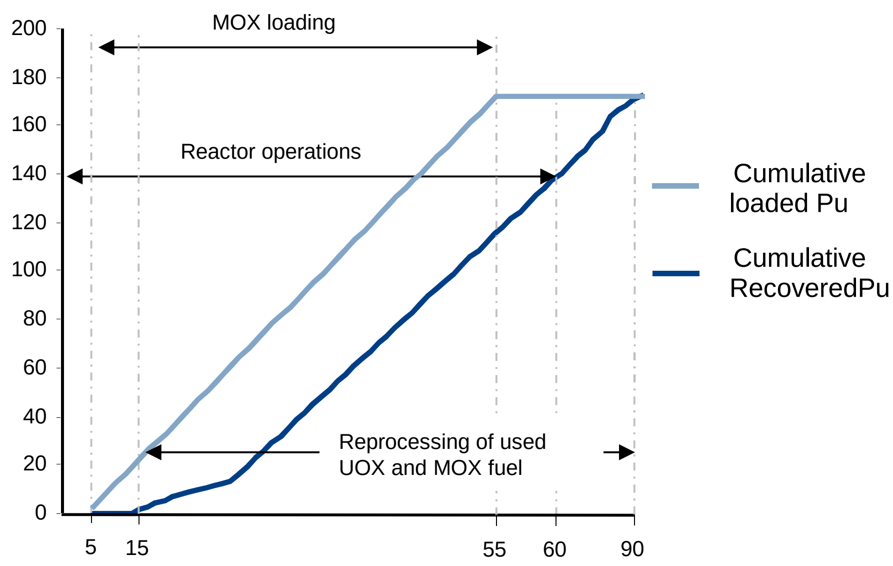
* *Based on eq 900 MWe*

Case 2 – The PreCycling
A Dutch Case at EPZ - Borsele

PreCycling scheme & principle

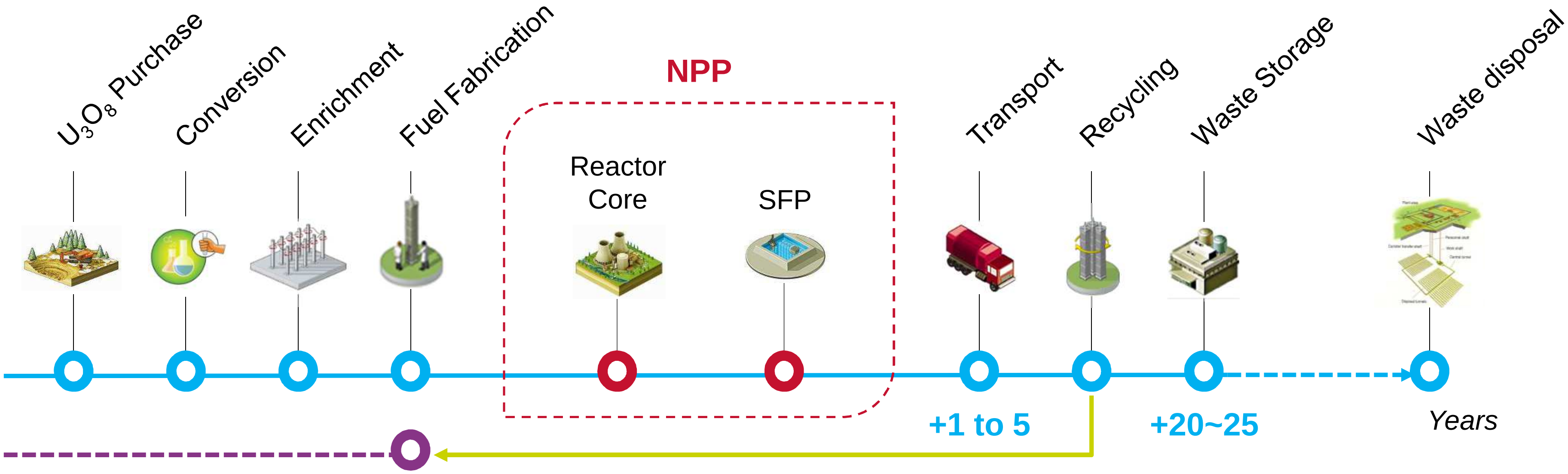


Evolution of Pu balance with PreCycling scheme



1. AREVA loans MOX that will be loaded in the reactor from 2014 until 2026. Last MOX assembly will be discharged by 2033
2. Until 2033, the NPP will be operated with Uranium fuel only. Plutonium resulting from treatment will be transferred to AREVA as a re-imbursement of the loaned Plutonium
3. No Dutch plutonium left; only residues will be returned to Netherlands for storage & disposal (No Used Uox or MOX Fuels left!)

Case 2 – Zero end-of-Life materials balancing thanks to optimized rate MOX Core



Direct disposal

			SFP/ISFSF	Pu Balance	HLW Packages
8,390 tU	6,090 kSWU	+11.4 tPu	2,540 FAs	+11.4 tPu	2,540 m^3

Recycling

			SFP/ISFSF	Pu Balance	HLW Packages
6,710 tU	5,480 kSWU	+10.3 tPu	506 FAs	+7.2 tPu	406 m^3

Pre-Recycling

			SFP/ISFSF	Pu Balance	HLW Packages
5,250 tU	4,280 kSWU	0.0 tPu	0.0 FAs	0.0 tPu	540 m^3

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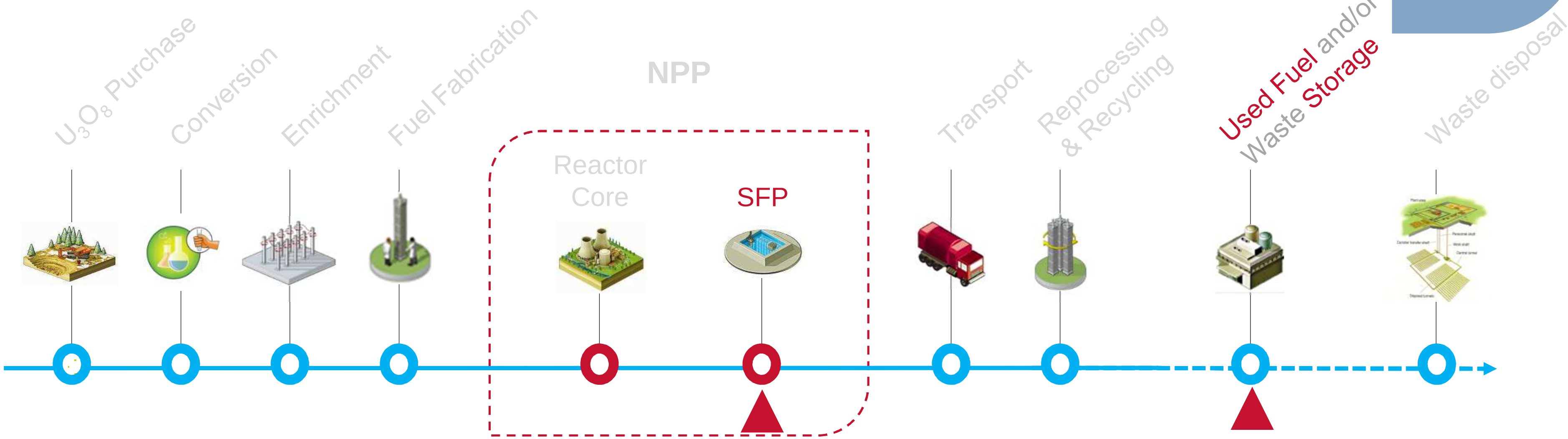
Decay Heat Removal, a continuous challenge as safety cases keep changing and Facility EoL and End-point fading



Confluence of reasons

- Extension of NPP lifetime,
- Delays in BE strategy implementation,
- Fukushima Lessons Learned
- Limited remaining capacity at SFP
- More stringent safety requirements at existing SFP

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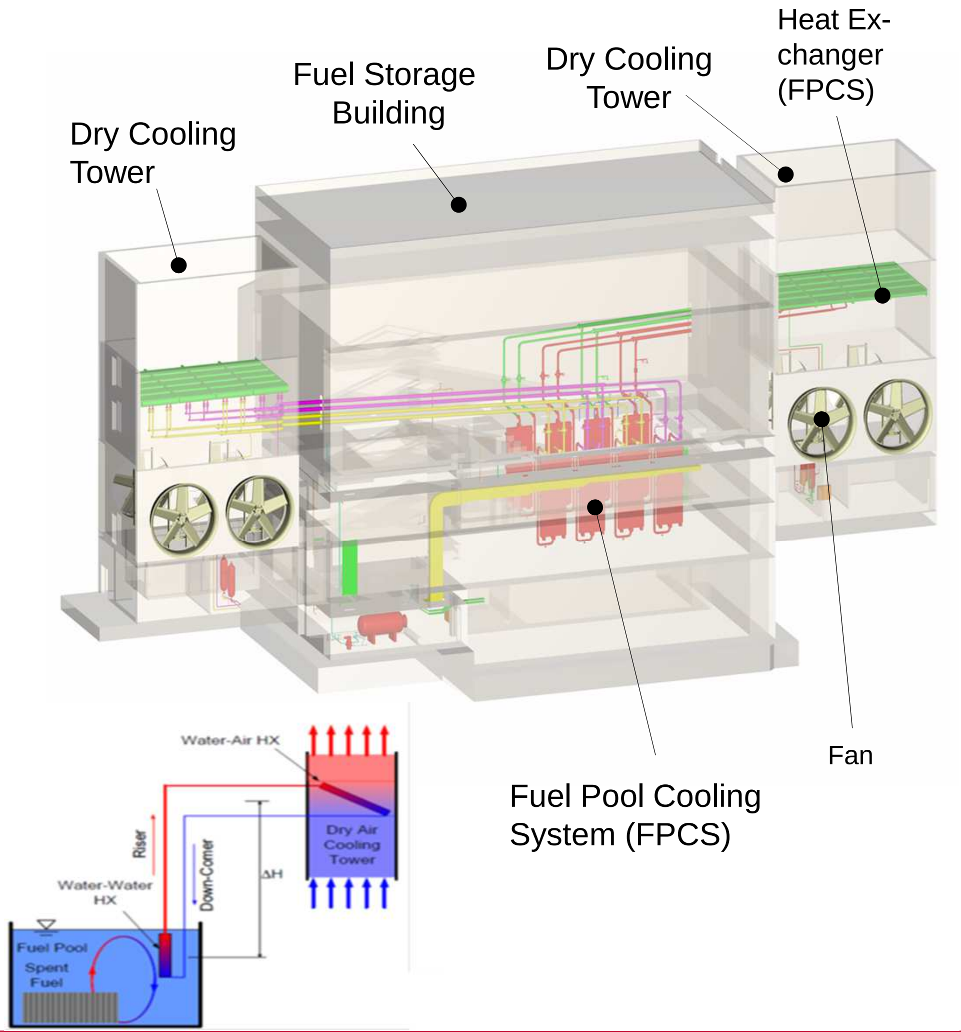
AREVA Wet Passive Cooling brings response

- Fail-safe decay Heat Removal Solution
- Qualified and proven Solution
- Flexible and adaptable solution:
  - **New build or existing facility**
  - **Footprint to various site-specific conditions**

Case 3 - Decay Heat Removal, A challenging duty operation due to a confluence of safety, life extension management and lack of end-point



Main benefits
AREVA Wet Passive Cooling

- **Ensures cooling of the pool in case of loss of power supply (SBO)**
  - No emergency Diesel required
  - No safety-related I&C is required
  - Avoids active single failure criterion for the fuel pool cooling function
- **Marginal Operational Costs**
  - Dedicated maintenance and repair concept for full time
- **Easily licensable**
- **Small footprint and adaptable to almost every site specific conditions**
- **Proven design and construction & operation experiences gained**

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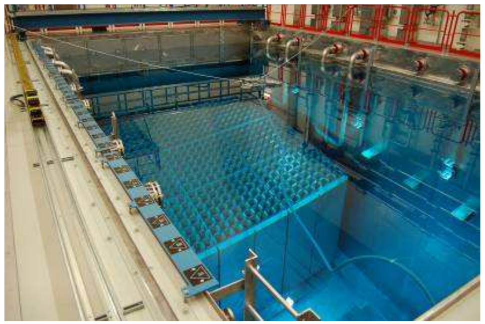
Case 3 - Decay Heat Removal
A Swiss Case at Goësgen

- **Main design features**
  - Storage building dim. 35m x 17m
  - Capacity: 1008 SF assemblies (UOX & MOX)
  - Minium cooling period prior to receive SF
- **Passive Fuel Cooling System**
  - Decay Heat Power to be removed from the SFP: 1,0MW maximum
  - Heat removal from the spent fuel pool is achieved by natural circulation supported by fans during normal operation
- **The fuel pool cooling system is designed to manage accidents without active components**
  - Free convection in the SFP
  - Natural convection in the intermediate cooling system
  - Natural ventilation in the dry cooling towers



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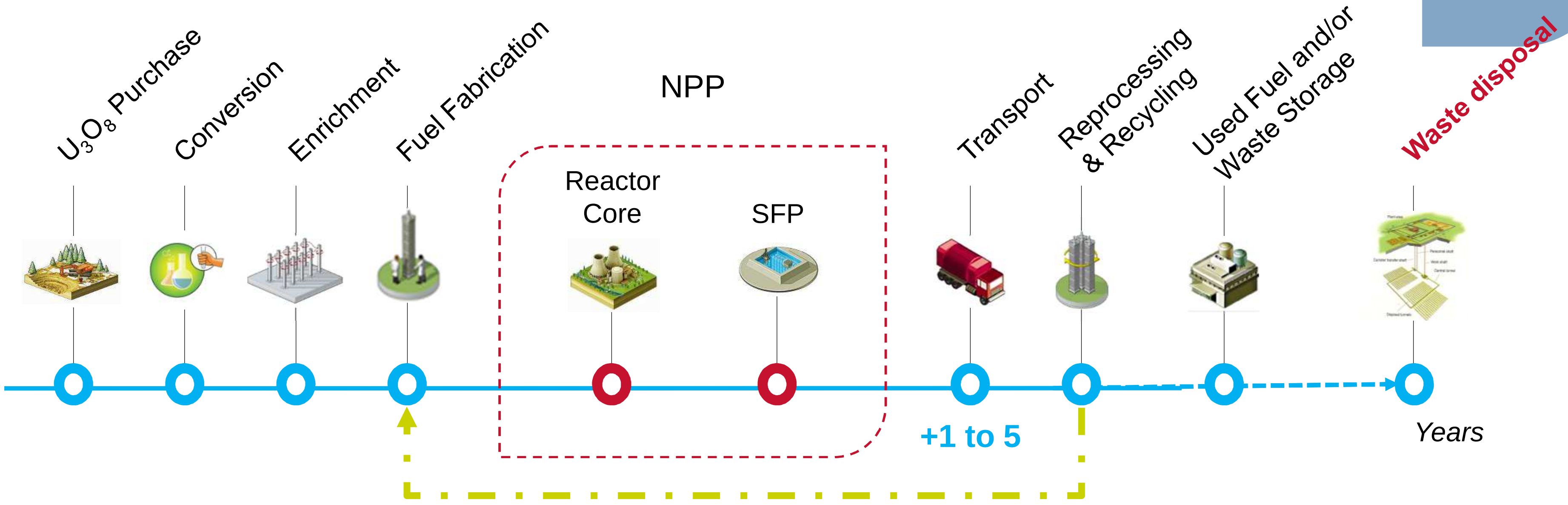
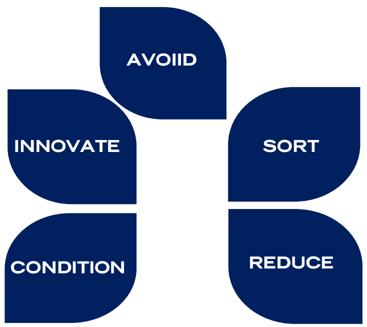
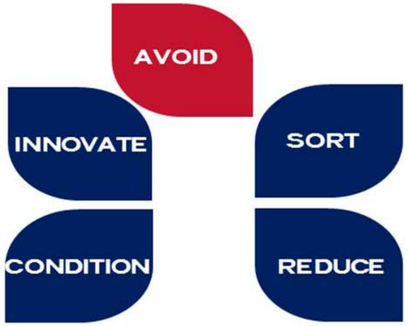
Case 4 - Radioactive Waste Management: how to take-up present and future challenges



- **Adhere to 5 « golden rules »**
  - Avoid waste at source
  - Maximize sorting and decontamination
  - Reduce volumes
  - Condition at the earliest
  - Initiate the right R&D at the right time

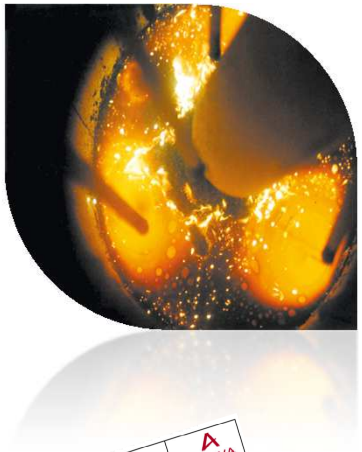


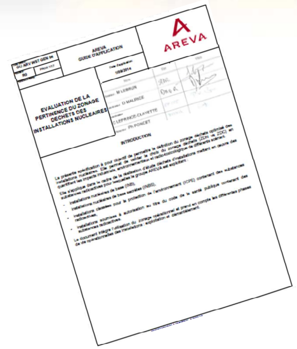
- **Innovate for legacy waste and already planned inventory**
  - by adapting existing routes with the aim at increasing performance
  - by creating new routes only when necessary
- **Ambition a « zero waste » nuclear future**
  - Pursue R&D efforts for long term nuclear evolution

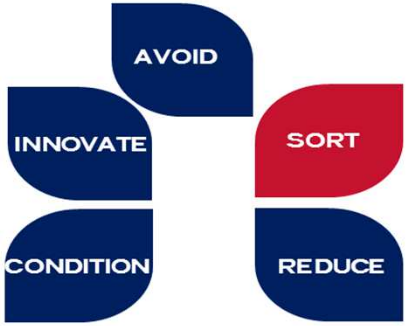


Radioactive Waste Management:
how to take-up present and future challenges

- **Target the zero waste objective**
  - **when designing**
    - A stepwise approach serving this ambition
    - Example : the cold crucible melter
      - Lifetime x 10 ➢ less technological waste
    - Integration of operational feedback
  - **when operating**
    - Strengthen the zoning of facilities and equipment ergonomics
      - Systematic assesment of the waste zoning relevance







Radioactive Waste Management:
how to take-up present and future challenges

« Decategorizing » whenever possible

THE EXAMPLE OF ULTRASONIC TREATMENT OF PuO_2 CANS

	Very short lived waste *containing radionuclides with a halflife of < 100 days*	Short lived waste *in which the radioactivity comes mainly from radionuclides with a half-life ≤ 31 years*	Long lived waste *containing mainly radionuclides with a half-life > 31 ans*
Very low level (VLL)	**Management by radioactive decay on the production site**	***Recycling or dedicated surface disposal*** *(Industrial centre for collection, storage and disposal (Cires) disposal facility in the Aube département)*	
Low level (LL)	*then disposal through routes dedicated to conventional waste*	***Surface disposal*** *(Aube waste disposal facility)*	***Shallow depth disposal*** *(being studied pursuant to the Act of 28 June 2006)*
Intermediate level (IL)			
High level (HL)	Not applicable[1]	***Deep geological disposal*** *(being planned pursuant to the 28th June 2006 Act)*	

Conclusion and Takeaway

- **Do consider entire life cycle when developing and implementing Operation or technology innovations**
  - Discourage local optimization at the expense of overall system performance
- **The best waste being the waste that hasn't been generate**
  - Avoid Waste, if not, do recycle
- **Do not miss opportunity**
- **Trends across nuclear countries, in cascading Used Fuel and Waste management responsibility, are encouraging**
  - EU members' 2011 Council Directive on the responsible and safe management of Spent Fuel and Radioactive Waste
  - IAEA's 2014 Scientific Forum on Comprehensive & integrated "cradle-to-grave" approach for the Management of NW

Thank you for your attention

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