Re-Use of Used MOX LWR Fuel

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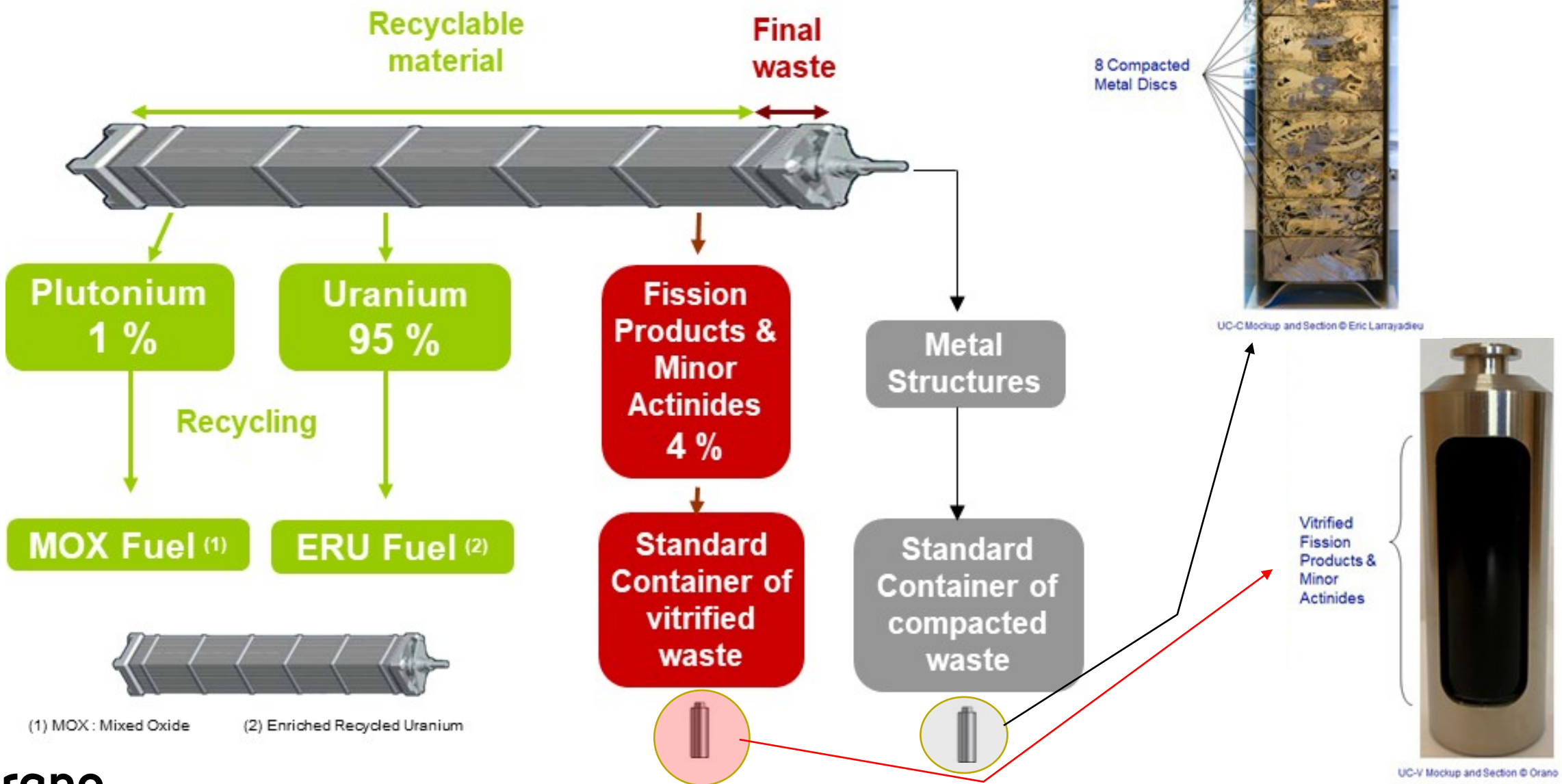
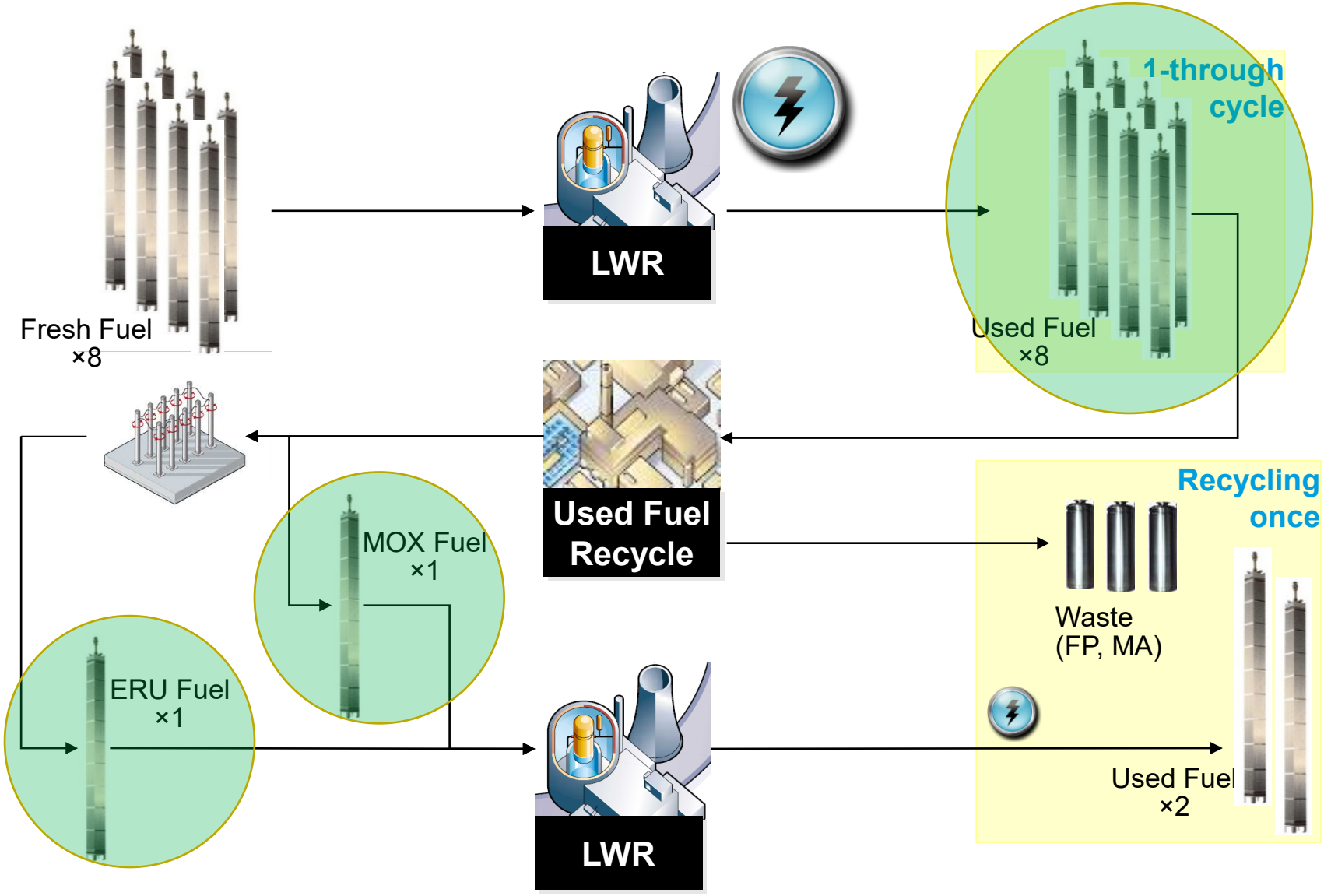
The Value Inside UNF



Orano La Hague Reprocessing Plant

- La Hague capacity of 1,700 MT/yr
- Reprocessed 40,000 MT of UNF since 1976
- 10,000 MT of this UNF is of foreign origin
- Also includes used MOX fuel
- Complete waste management system included at plant (no tanks of fissile products left behind)
- 300 hectares (750 acres)

Classic Recycling of UNF



Used LWR MOX Fuel Issues & Offered Solutions

To address the following questions:

1) What can be done with used MOX fuel in the absence of recycling and subsequent use in advanced reactors?

2) What can be done with the growing quantities of spent MOX fuel accumulating at LWR sites?

3) How can advanced reactors potentially benefit from recycled used MOX fuel?

4) How can the plutonium vector continue to be degraded in MOX fuel and limit the overall accumulation of plutonium?

Orano R&D has developed multiple solutions involving used LWR MOX fuel:

- **MOX-2 Recycle Scheme**
- **Borssele NPS Scheme**
- **MSR actinide converter and treatment-recycling plant**

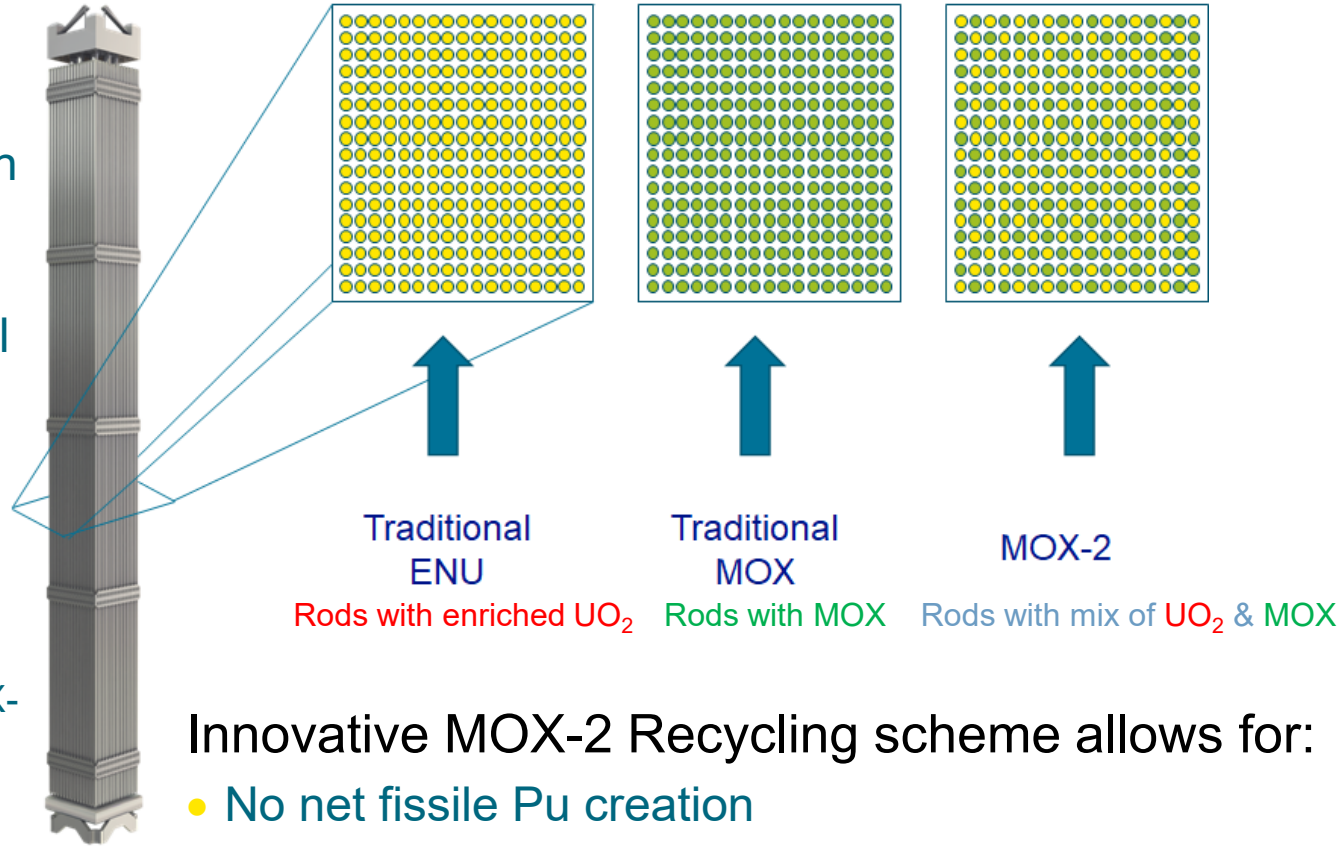
Covered in advanced fuel cycle papers (e.g., Waste Management 2023 by Arnaud Gay “MCRE: Importance of Molten Salt Reactor in Pu Management”)

Advanced Recycling Approach MOX-2 Scheme

Innovative MOX-2 Recycling scheme:

- A pattern (optimized per reactor core design) of fresh enriched natural uranium (ENU) is mixed with fresh mixed oxide (MOX) fuel to create a MOX-2 fuel assembly
- After irradiation in a core, the MOX-2 assembly will be recycled with:
  - The used ENU providing Pu having a good isotopic vector
  - The used MOX providing Pu with a degraded isotopic vector
  - The larger quantity of Pu from the used ENU rods diluting the Pu from the used MOX rods
  - The net produced Pu having an acceptable isotopic vector for creating new MOX fuel rods for incorporation back into a MOX-2 assembly

Being examined as an option for SMRs



Innovative MOX-2 Recycling scheme allows for:

- No net fissile Pu creation
- Continuous degradation of Pu isotope vector
- Only remaining waste needing disposal by the client are the Universal Canisters (UC-V and UC-C)

Advanced Recycling Approach Borssele NPS Scheme

- **Currently Operating Nuclear Reactors: 1**
- **Name: Borssele Reactor**
- **Type: Pressurized Water Reactor (PWR)**
- **Generation: 500 MWe**
- **1973: First Commercial Operation**
- **1976: First Contract Signed for Recycling at La Hague**
- **2003: First use of Enriched Recycled Uranium (ERU) Fuel**
- **2014: First use of Mixed Oxide (MOX) Fuel**
- **2015: Nearly 400 MT of UNF recycled**
- **2034: Last year of operation**

Borssele NPS in the Netherlands

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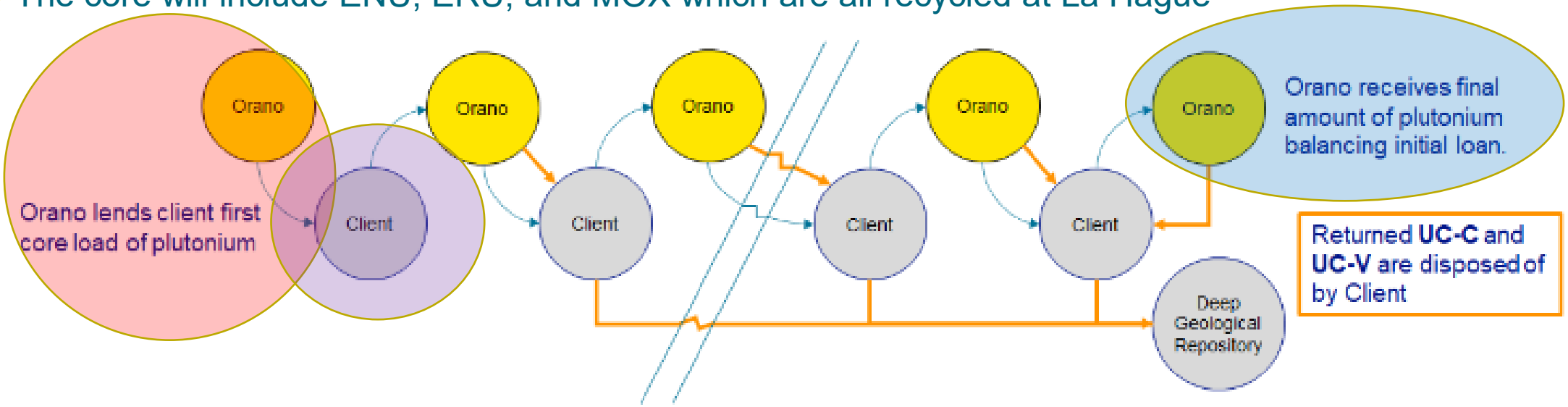
Advanced Recycling Approach Borssele NPS Scheme

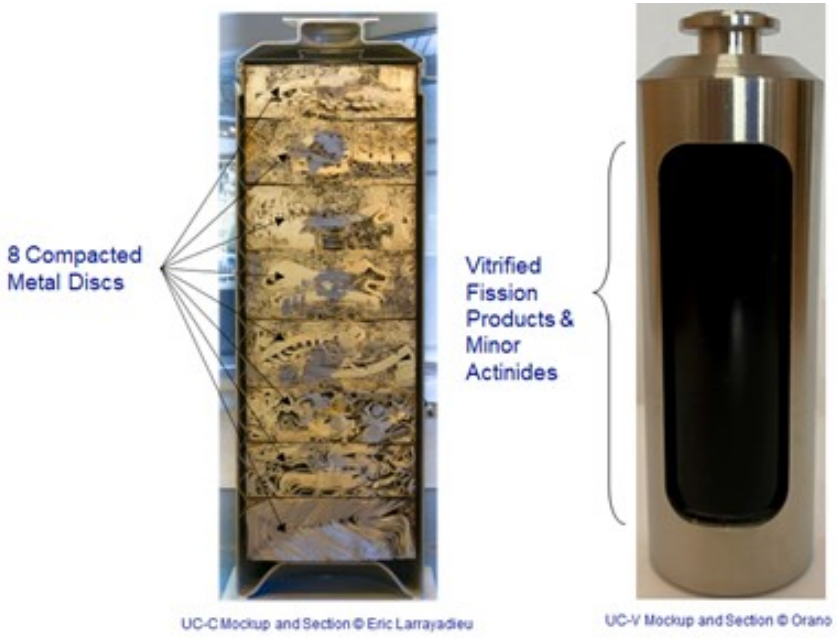
Also known as MOX with pre-cycling model (announced in 2015)

- Objectives of the concept:
  - Balancing plutonium during irradiation cycle, allowing reprocessing of all used fuel including used MOX fuels
  - No remaining UNF after shutdown of reactor with only residues (UC-V and UC-C) returned to the country of origin
- Pre-cycling model has 2 steps:
  1. Orano makes available the plutonium required for the fabrication of MOX assemblies for Borssele. This plutonium is "loaned" to Borssele under a loan-reimbursement schedule.
  2. Plutonium will be separated from Borssele's used fuel at La Hague and this plutonium will be returned to Borselle reactor. This step will include reprocessing of Borssele's final core with recovered Pu returned to Orano as loan-reimbursement.
- The core will include ENU, ERU, and MOX which are all recycled at La Hague



Advanced Recycling Approach Borssele NPS Scheme

- Over 400 MT UNF recycled to date
- At end of reactor operation life, the Borssele NPS will have no fissile material present
- Only HLW will be returned to Borssele
- HLW will be found in Universal Canisters which will be stored in COVRA HABOG

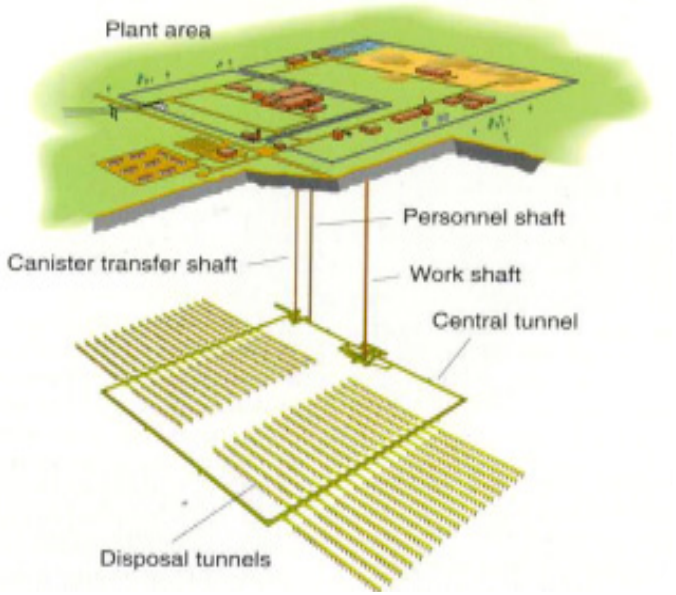


- Waste Facility Built: 2003
- Name: COVRA HABOG Waste Facility
- Holds all HLW from Borssele at a single facility about the size of a small soccer (football) stadium

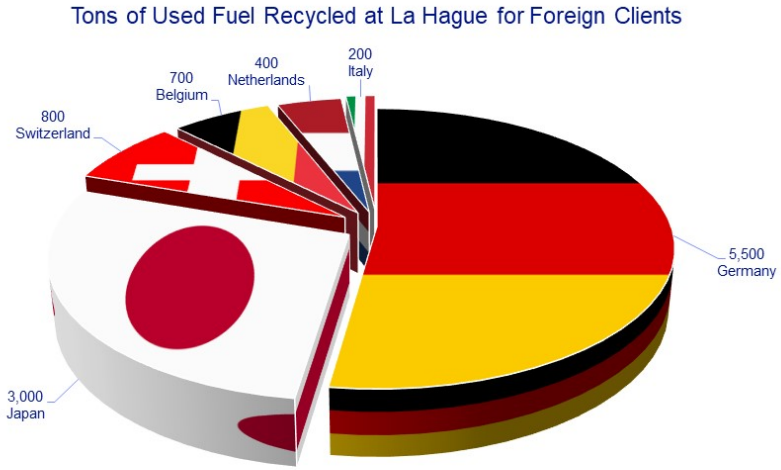
Photo Credit: *Knowledge*

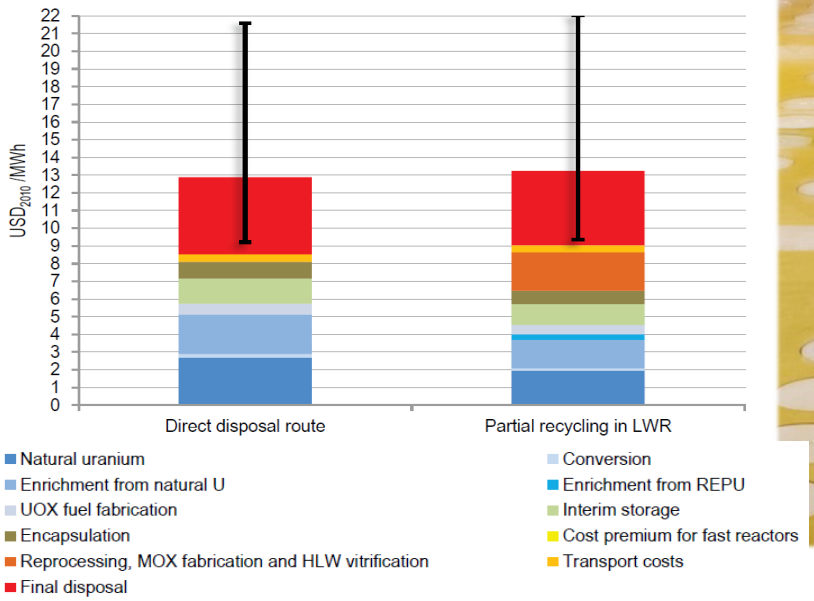
Conclusions

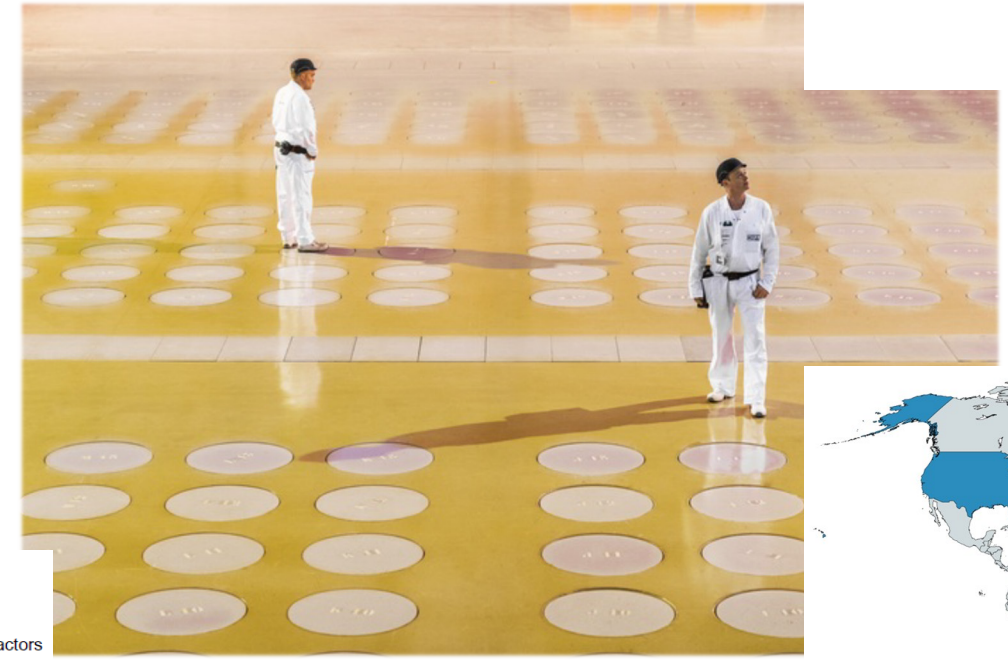
- Orano through continuous R&D has developed several approaches to re-use of used MOX LWR fuel including:
  - MOX-2 recycling scheme with MOX rods inter-mixed within a fuel assembly with ENU rods
  - Borselle NPS scheme with pre-cycling such that no fissile material is left at end of reactor operation
- Both these schemes result in:
  - A balance of the quantity of Pu produced and utilized in these mixed cores
  - Degradation of the Pu isotopic vector (buildup of more even isotopes of Pu which are stronger absorbers) – less attractive
- These schemes also include the benefits of recycling, including but not limited to:
  - Improve security of the fuel supply (close loop & diverse fuel supply)
  - Save natural Uranium (25% savings of natural uranium resources)
  - Improved waste form for future repository (less volume, less heat, less toxic, standardized, no safeguarded material)
  - No or reduced need for interim storage
- Issues do need resolution: MOX-2 fuel assembly design, heat buildup from re-recycled

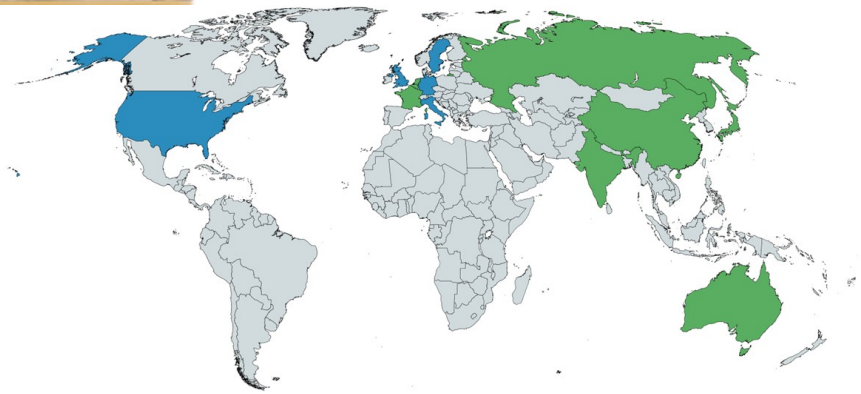

Plant area
Personnel shaft
Canister transfer shaft
Work shaft
Central tunnel
Disposal tunnels

Questions?


Tons of Used Fuel Recycled at La Hague for Foreign Clients
200
Italy
400
Netherlands
700
Belgium
800
Switzerland
5,500
Germany
3,000
Japan


USD2010 /MWh
Direct disposal route
Partial recycling in LWR
Natural uranium
Enrichment from natural U
UOX fuel fabrication
Encapsulation
Reprocessing, MOX fabrication and HLW vitrification
Final disposal
Conversion
Enrichment from REPU
Interim storage
Cost premium for fast reactors
Transport costs



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Other Benefits of Orano and their Universal Canisters

Easy to Transport

- Orano has approved transport containers available for used fuel assemblies being transported to La Hague.
- Universal Canisters are standardized for transport when returned to client.

Easy to Handle

- Universal Canisters standard sizes and dimensions

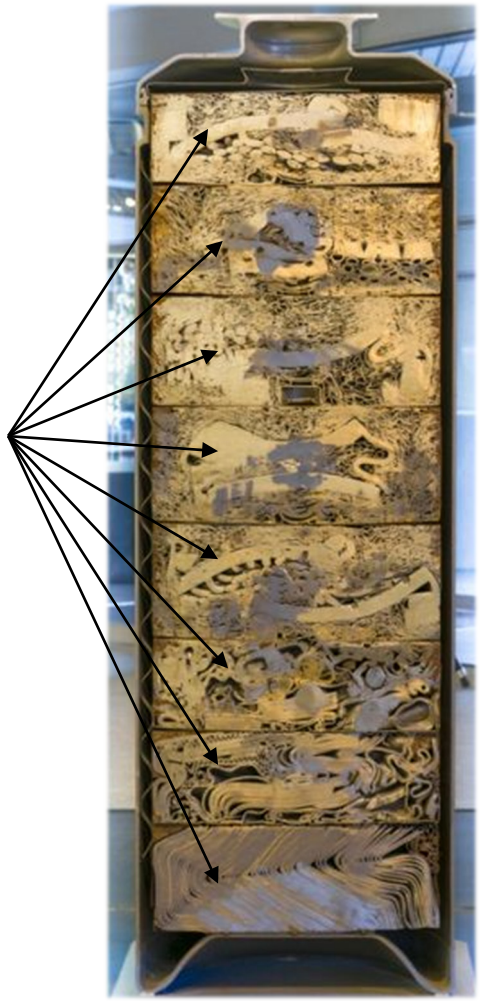
Support Future Disposal Policy

- Can accommodate any final disposition

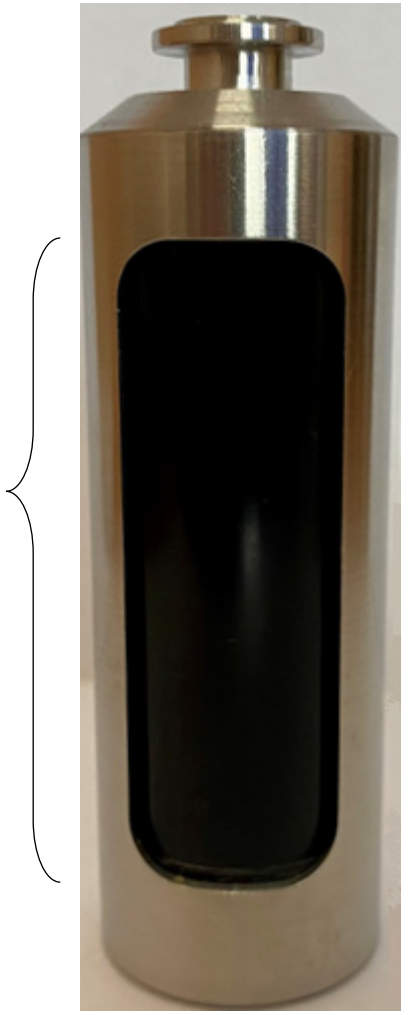
  Mined Deep Geological, Deep Borehole, etc.

Simplifies Final Disposal Site Design

- Since there is no uranium or plutonium
  - *No IAEA Nonproliferation Safeguards*
  - *No Nuclear Criticality Safety Design*



UC-C Mockup and Section © Eric Larrayadieu



UC-V Mockup and Section © Orano