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Evaluation of Waste Streams associated with LWR Fuel Cycle Options

Focus on Steady State Recycling and Fabrication of PWR MOX and Recycled UOX fuel

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Outline

- I - Overview of analysis tools and methods, inputs and outputs
- II - Phase 4: Steady state reprocessing and fabrication of PWR MOX and recycled UOX Fuel.

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Overview of AREVA's models

- **AREVA focus is on Recycling Activities (section 2.4 of specification)**

- **The recycling model includes:**
  - A user interface on an excel sheet with modifiable input data
  - Excel calculations and CESAR code data
  - All data is based on operational experience at La Hague recycling plant & MELOX Mox fabrication plant
  - The model created can be modified and allows future revisions

- **Input data for task 2.4 is related to outputs from tasks 2.1 and 2.2**

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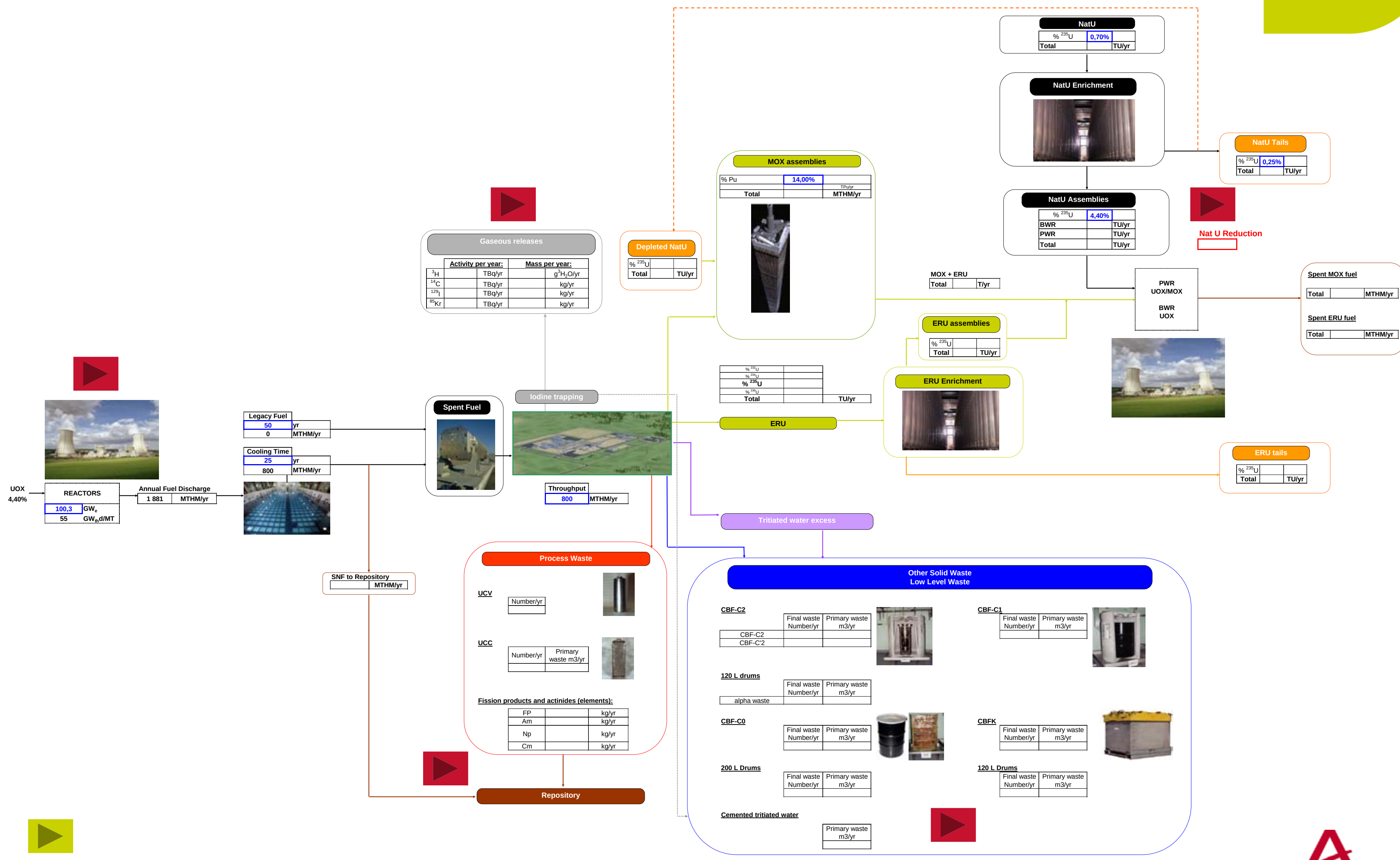
Overview of AREVA's recycling model



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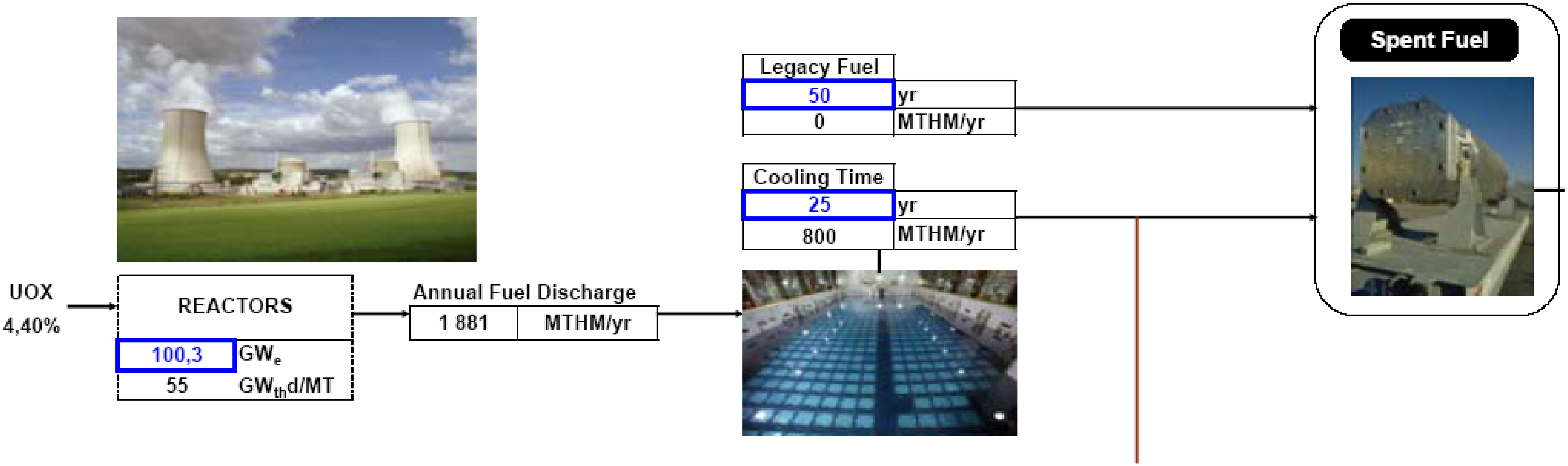
Overview of AREVA's recycling model



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Overview of AREVA's recycling model

SNF to Repository

	MTHM/yr

Process Waste

UCV

Number/yr

UCC

Number/yr	Primary waste m3/yr

Fission products and actinides (elements):

FP		kg/yr
Am		kg/yr
Np		kg/yr
Cm		kg/yr

Repository

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Overview of AREVA's recycling model

Tritiated water excess

Other Solid Waste
Low Level Waste

CBF-C2

	Final waste Number/yr	Primary waste m3/yr
CBF-C2		
CBF-C'2		

CBF-C1

Final waste Number/yr	Primary waste m3/yr

120 L drums

	Final waste Number/yr	Primary waste m3/yr
alpha waste		

CBF-C0

Final waste Number/yr	Primary waste m3/yr

CBFK

Final waste Number/yr	Primary waste m3/yr

200 L Drums

Final waste Number/yr	Primary waste m3/yr

120 L Drums

Final waste Number/yr	Primary waste m3/yr

Cemented tritiated water

Primary waste m3/yr

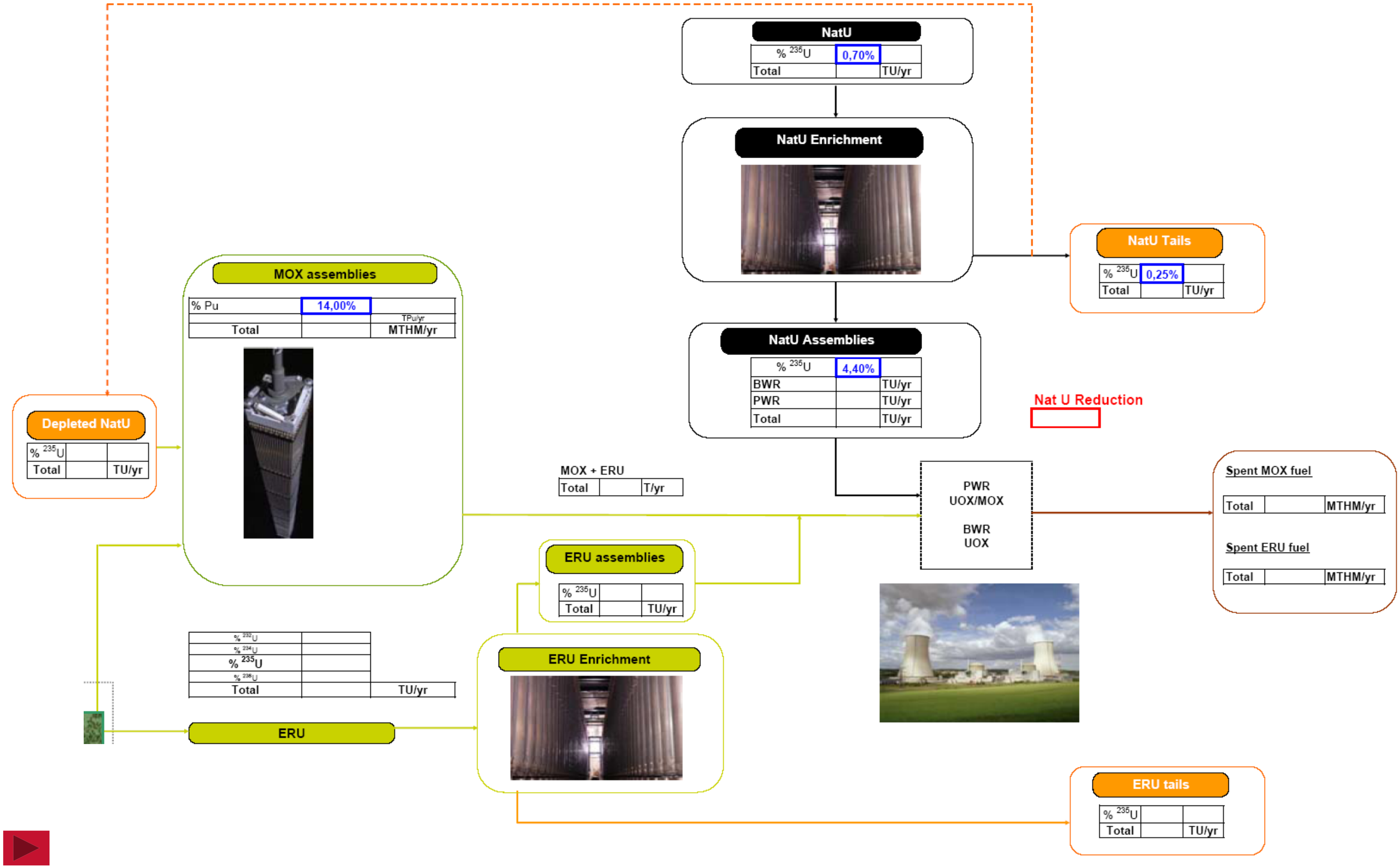
Overview of AREVA's recycling model

Gaseous releases

	Activity per year:		Mass per year:	
^{3}H		TBq/yr		$g\,^{3}H_2O$/yr
^{14}C		TBq/yr		kg/yr
^{129}I		TBq/yr		kg/yr
^{85}Kr		TBq/yr		kg/yr

Iodine trapping

Overview of AREVA's recycling model



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The NWTRB recycling model : Generalities about inputs and outputs

- **NWTRB work and model focuses on evaluating isotopic streams in assemblies and waste forms:**
  - Steady State Recycling (variable sized facility)
  - Fabrication of PWR MOX Fuel
  - Fabrication of Enriched Recycled Uranium (UOX) Fuel
  - A calculation tool, focused on back end only.

- **Model aims at estimating:**
  - Gaseous releases for select radionuclides
  - Solid process wastes
  - Technological wastes (secondary wastes)
  - New fuel assemblies
  - Other resource material (e.g., tails)

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The NWTRB model and the COSAC code

Fixed Input:

- Quantity of fuel
- cooling time
- burnup

↓

CESAR code for isotopic transformation and content and energy equivalence

↓

Excel macros for La Hague and Melox type recycling plant throughput

↓

NWTRB model:

Data based on

La Hague and MElox

Multiple input:

- Reactors type and fuel cycle
- Scenarios comparison

↓

Neutronic codes, Bateman equations, ORIGEN, ICRP tables

↓

COSAC integration for isotopic flux, heat calculations, radiotoxicity, prolifeeration index

↓

COSAC codes

Benchmarked with NFCSS IAEA code

Benchmarked with COSI on OECD scenario

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Recycling Model - Input fuel

2.4.1.1 Type of fuel

- PWR assemblies fabricated using new uranium
- Initial enrichment 4.4%
- Burn up 55 GWd/MT

2.4.1.1 Cooling time before recycling

- Three possible cooling times can be selected on the excel sheet: 5 years, 25 years, 50 years

2.2.2.1 Yearly annual discharge

- Based on an assumption of 100.3 GWe of current generation capacity, and a plant capacity factor of 90%
- Equivalent to 315 GW (thermal) based on plant data as of 2009

↓

Resulting annual discharge 1880 MT/y

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Recycling model characteristics

- **Radioisotopic compositions for SNF established using the "CESAR" code**
  - **For each isotope, the mass of isotope (in g/THM), its activity and thermal power are calculated.**
  - **Actual fuel (mix of legacy and output fuel) is calculated.**

- **2.4.1.8: Recycling capacity**
  - Three capacities can be selected in the model : 800, 1500, 3000 MT/y
  - 800 MT/y capacity has been included to allow assessment of proposed U.S. Pilot Recycling Facility
  - If the recycling capacity is higher than the annual discharge rate (3000 MT/y vs 1880 MT/y), the difference is made up by using legacy fuel that is either 25 or 50 years old (operator's choice) → this leads to an interesting and more realistic case than "draft scenarios" 4/5/6 for which the results are expected to be approximately double the results from scenarios 1/2/3.

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Recycling Model Output

▶ 2.4.2.3 MOX fuel

- MOX fuel is fabricated using the plutonium recovered in the recycling process and fresh U tails bearing 0.25% ^{235}U (1)
- Plutonium total mass and isotopic composition derive from the initial characteristics of the SNF
- Plutonium content in MOX fuel is adjustable by the operator between 9% and 14%
- Maximum Pu content in MOX (limited by safety) is 12.5% in MELOX plant (reactor grade) and 6.3% in MFFF (weapon's grade)

▶ 2.4.3.3 ERU fuel

- ERU fuel is fabricated using the uranium recovered in the recycling process and re-enriched
- Uranium total mass and isotopic composition derive from the initial characteristics of the SNF
- ERU fuel is enriched to 5% 235U to be approximately equivalent to the initial 4.4% enriched fuel and the ERU tails are set to 0.25% 235U

(1) **« Draft scenarios » 2.4.1.**

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Recycling Model Output

- **2.4.2.2: Reduction in total natural uranium demand**
  - This percentage corresponds to the quantity of natural uranium spared by using MOX fuel and ERU fuel from the products of recycling.
  - It can be calculated as follows :

(equivalent MOX fuel tonnage) + (equivalent ERU fuel tonnage) / (yearly annual discharge)

  - **Note:** Equivalent MOX fuel annual tonnage is based on a plutonium content in a MOX yielding the same energy within the same time as the initial NatU fuel (4,4%), supposing that MOX is fabricated on line with the recycling (no Am). The Pu content is therefore between 9% and 12% according to the cooling time.

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Outline

- **I - Overview of analysis tools and methods, inputs and outputs**
- **II - Phase 4: Steady state reprocessing and fabrication of PWR MOX and recycled UOX Fuel.**

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Results for the 2.4.1. scenarios

- **Scenarios:**

Scenario	1	2	3	4'	5'	6
Recycled discharged fuel (Mt/yr)	1500			1880		
Fuel cooling (yrs)	5	25	50	5	25	50
Legacy Fuel recycled (Mt/yr)	NA			1119		
Legacy fuel cooling				50		

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Results for the 2.4.1. scenarios

- **Fission products and Minors Actinides separated and sent to final respository**

Scenario	1	2	3	4’	5’	6
FP (kg/yr)	69 942	69 971	69 979	139 912	139 948	139 959
Am (kg/yr)	1 249	2 650	3 178	3 937	5 693	6 356
Np (kg/yr)	1215	1264	1 360	2 538	2 599	2 721
Cm (kg/yr)	216	111	55	312	180	109

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Results for the 2.4.1. scenarios

Reduction in Natural Uranium demand

Scenario	1	2	3	4’	5’	6
Reduction %	18%	16%	15%	34%	31%	30%

Uranium tails

Scenario	1	2	3	4’	5’	6
0,25% NatU tails (MT/y)	12 548	12 929	13 057	10 057	10 492	10 647
0,25% ERU tails (MT/y)	1 252	1 254	1 254	2 505	2 507	2 507

Results for the 2.4.1. scenarios

- **Assemblies fabricated**

Scenario	1	2	3	4’	5’	6
NatU 4,4% PWR assemblies (MT/y)	913	958	973	623	674	692
NatU 4,4% BWR assemblies (MT/y)	627	627	627	627	627	627
ERU 5% PWR assemblies (MT/y)	140	140	140	280	281	281
14% Pu MOX assemblies (MT/y)	134	123	118	255	242	236
Pu 241 in recycled Pu	12.5%	5.2%	1.6%	8.8%	3.9%	1.6%
Pu 239 in recycled Pu	50.7%	55.0%	57.3%	53.0%	55.8%	57.3%

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Streams

100% HM of used fuel

Recycling

- **Uranium 95%** → **RepU** — **RepU fuels between 5 and 10% of EDF electricity**
- **Plutonium 1%** → **MOX** — **MOX fuels about 10% of EDF electricity**

Process waste

- **Fission products, fines 4%** → **Vitrification** → **UC-V**

- **Hulls and end pieces** → **Compaction** → **UC-C**

Techno. waste

- **GTCC, TRU** / **Low level waste** → **Compaction, Cementation** → **C0, C1, C2…**

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Wastes Volumes from Recycling in France

Direct Disposal | **Recycling**

UNF
Geologic Disposal*

Used fuel

~1.4 m³ / assembly
100%of activity

Volume varies depending on UNF storage canister design

17*17 PWR
463.3 kgHM/ assembly

HLW/ILW-LL
Geologic Disposal*

Vitrified and compacted process and technical waste

~0.6 m³ / assembly
>99% of activity

LLW
Surface/Near Surface Disposal

Cemented waste, compacted waste…

~0.6 m³ / assembly **
<1% of activity

Based on operational data from La Hague and MELOX reference plants and ANDRA disposal studies
* Volumes for wastes in geologic disposal includes the volume of the waste disposal package
**Waste generated by an 1000 tHM/yr recycling plant using current technology (La Hague and MELOX reference plants)

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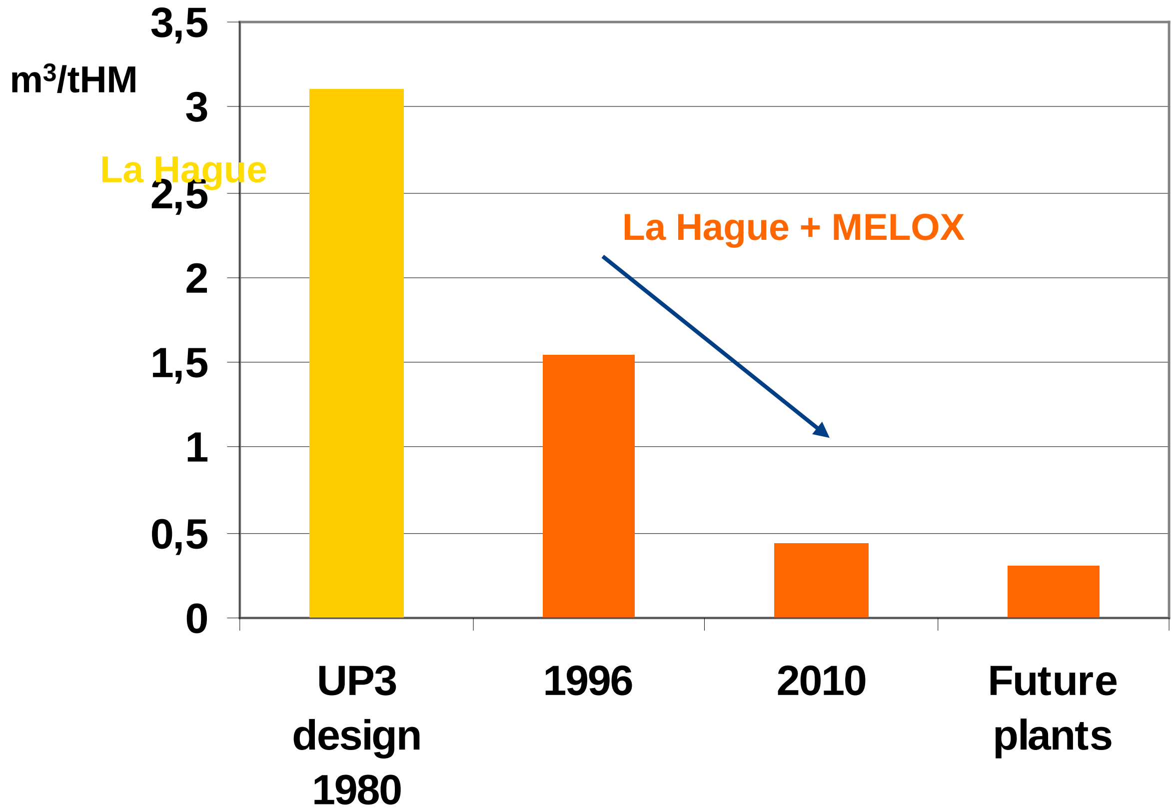
Continuous improvements

- Between 1980 and 2010, HLW/GTCC volumes have been reduced by a factor of 5



- For future plants, reduction by more than 25%

Process and techno waste - GTCC/HLW including GTCC(TRU)

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Low level waste streams

Tritiated water excess

Other Solid Waste
Low Level Waste

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Final waste Number/yr	Primary waste m3/yr

200 L Drums

Final waste Number/yr	Primary waste m3/yr

120 L Drums

Final waste Number/yr	Primary waste m3/yr

Cemented tritiated water

Primary waste m3/yr

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I II

Results for the 2.4.1. scenarios

- **Waste generated, does not include tritiated water**
- **Rough extrapolation to be consolidated based on 800 tons recycling plant data**
- **For scenarios 1, 2 and 3, 381 MT of used fuel are sent directly to repository**

Scenario	1 2 and 3	4’, 5’ and 6
UCV (vitrified canisters)	1050 canisters	2100 canisters
UCC (Compacted hulls)	1050 canisters	2100 canisters
Surface waste – primary volumes / yr	~1500 m3	~2100 m3
Undergroud repository waste- primary volumes / yr	~20 m3	~35 m3
TRU waste – primary volumes / yr	~80 m3	~115 m3

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Assumptions & Future Improvements

- **For the case where the recycling plant capacity will process the entire annual discharge of SNF, a fraction of this SNF (about 1/3rd) will be BWR SNF:**
  - BWR fuel is commonly recycled in La Hague plant
  - The model assumes the radioisotopic composition for BWR SNF is the same as for PWR SNF ("CESAR" results)
  - No significant differences in the results are expected as a result of this assumption
    - → Fission Products yield is expected to be the same
    - → Neutron thermalization is different, thus isotopic compositions of U, Pu may be different
  - Future updates to model will allow for input of actual BWR compositions and hence, confirm results

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Assumptions & Future Improvements

- **Repository footprint**
  - Future studies can be conducted to tailor the waste streams (based on characteristics of input SNF [cooling time, burnup, etc.] and design of processes) to optimize:
    - → usage of repository space for different types of repositories
    - →LLW volumes and classes

- **Evolution to a "pile-up" scenario**
  - Non-steady state analysis of the contents/volumes of each portion (interim storage, pools, repository, etc.) of a recycling-disposal scenario ("modified open cycle") can be integrated into future versions of the model.

"CESAR": the reference code

- Used in La Hague recycling plant, AREVA engineering sections, AREVA TN, CEA, IRSN
- Integrates depletion chains describing
  - 46 actinides,
  - 208 Fission Products
  - 125 activation products of fuel impurities and structures
- Neutronic libraries (cross section sets) supplied by CEA reference calculation "DARWIN" code for neutron physics
  - Applicable to a wide range of fuels (LWR, MOX, RepU…)
  - Cross section given as a function of burnup and initial enrichment (or Pu content)
- Validation process from experimental results
  - Analyses from irradiated fuel rod samples
  - Hundreds of analyses from fuel assembly dissolutions in La Hague plant

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