Reprocessing / Recycling of Used Fuels
40 years of experience illustrated by
La Hague operation

Jean-Pierre Gros
Executive Vice President, Recycling Business Unit
Chief Executive Officer, MELOX
Recycling for an even safer used fuel management

- Over 190 000 tHM of used fuel have been unloaded worldwide
  - ≈ 70% are currently stored in pools (January 2011)

- The Fukushima events have put in the centre stage the need to review the management options implemented for used nuclear fuel inventories which still continue to grow:
  - The cumulated LWR used nuclear fuel inventories should double by 2030 considering a scenario based on a 583 GWe installed nuclear capacity

- Recycling is a safe solution for the used fuel management
  - Minimization of the volume and radiotoxicity of final waste
  - No fissile materials in the final waste (no IAEA safeguarded materials)
  - Benefits from recycled fuels
A market structured around main regional recycling platforms driven by national Back-End policies

Used fuel stocks, annual unloadings and regional stakes (2030)

2030 timeframe: a potential scenario

boundaries evolution between R/WS/DS closely depend on factors such as reactor pool saturation, additional safety requirements

In 2030, annual fuel unloadings from recycling countries (7000 tHm) will largely outset those from non recycling countries (5000 tHm)
Recycling is recognized as a key element to the safe nuclear operation in countries representing more than 50% of annual unloadings by 2030.

Annual LWR unloadings - 2030 timeframe – 583 GWe nuclear capacity

Back-end Policies worldwide 2030 timeframe
AREVA Safety alliance for Safe and Optimized Used Fuel Management

- Harden pools to meet potential new safety guidance & requirements
  - Safety and risk Analysis
  - Safety Upgrades (ex. Improving robustness of cooling capabilities, remote control, SFP make-up)
  - Safety procedures (ex. Enhancing contingency arrangements and training)

- Reduce used fuel and radionuclide inventories in reactor pools
  - Near term, by shipping used fuel for Recycling (ex. less than 1 year of cooling)
  - Should provisions for recycling not foreseen in the near term, AREVA Dry Storage solutions store used fuel with five years of cooling

- Enhance racking configurations safety as a consequence of density reduction
As of today, AREVA treated ~75% of the fuel worldwide, i.e. ~26,500 tons out of ~35,000 tons.

Source: AREVA, World Nuclear Association, IAEA publications
MOX fuel production capacity
(tons of MOX / year)

Cumulative production, as of dec. 2010
(tons of MOX)

* Initial Design Capacity
ERU LWR fuel fabrication facilities

Annual nominal average capacity (tHM)

<table>
<thead>
<tr>
<th>Facility</th>
<th>Capacity (tHM)</th>
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<tbody>
<tr>
<td>AREVA Romans</td>
<td>150</td>
</tr>
<tr>
<td>AREVA Lingen</td>
<td>100</td>
</tr>
<tr>
<td>AREVA Richland</td>
<td>100</td>
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<tr>
<td>MSZ Elektrostal</td>
<td>50</td>
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<tr>
<td>GE Willmington</td>
<td>50</td>
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<td>MNF Tokai</td>
<td>50</td>
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Source: AREVA and data from international organization
Back-End international projects

**USA**

Savannah River Site:
- Design and construction of the MOX Fuel Fabrication Facility (MFFF) through a Shaw & AREVA consortium
- Contract for liquid waste remediation project (including vitrification) through a consortium

Hanford Reservation:
- Contracts for waste disposal and site remediation projects through URS & AREVA and CH2MHILL & AREVA consortia

China
- Potential recycling plant project

Japan
- Rokkasho-Mura:
  - Technical and operational assistance for the recycling plant
  - Design project for the J-MOX plant (MOX fabrication)

**UK**

Sellafield Sites:
- M&O contract for the Sellafield sites through a URS, AREVA & AMEC consortium
- AREVA focus on technical assistance and operational performance improvement
- Commissioning of a new cladding line for the Sellafield MOX Plant

**UK**

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Operational Experience with recycled fuel

Used Recycled fuel management

Conclusion
In accordance with the law and our contracts, our customers remain the owners of their waste, and therefore it must be returned to its original country.

Used nuclear fuel recycling

- Customers’ reactors
- Interim or long-term storage center
- Packaged Final WASTE (Vitrified and Compacted)
- Recycling of RECOVERABLE MATERIAL
- Used nuclear fuel
- Recycled fuel

AREVA
96% of the content of used nuclear fuel is recyclable

The composition of light water fuel after irradiation in a reactor

- **Uranium**: 95%
- **Plutonium**: 1%
- **Fission Products**: 4%
- **Recyclable material**
- **Final waste**

**Recycling**

**MOX Fuel**: (1) MOX: Mixed Oxide

**ERU Fuel**: (2) Enriched Recycled Uranium

**Standard Container of vitrified waste**

**Standard Container of compacted waste**

**Metal structures**
Recycling allows the **reuse of the energy still contained within** used fuel, saving up to **25% of natural Uranium**

1 gram of Plutonium or 100 grams of Uranium supply more energy than one ton of oil.
Benefits for Utilities – Waste Management Agencies

The final waste in case of current recycling are conditioned into a stable and compact form suitable for transport, storage and final disposal.

- Encapsulation of Fission Products in a stable, homogeneous, and durable glass matrix with a long-term predictable behaviour.
- Compaction of structural pieces (hulls and end-pieces).
- Both the glass matrix and compacted waste are encased in a standard “Universal Canister” (UC).
Recycling, a major asset of nuclear energy

- Brings a safe solution to used nuclear fuel management contributing to minimizing the build-up of stored inventories
- Addresses in a responsible way the issue of nuclear waste, “Achilles’ heel” of nuclear energy, through a proven standardized solution: reduction of waste volume by 5 and radiotoxicity by 10
- Saves of up to 25% in natural uranium, accommodating today growth of clean energy demand in a sustainable manner
- Strengthens energy independence without spoiling nuclear energy competitiveness
  - Comparable economics to Direct Disposal
  - Minimize fuel cycle cost uncertainties
- Reinforces proliferation resistance
Recycling is a way to further strengthen proliferation resistance

- Recycling plutonium in MOX fuel
  - consumes roughly one third of the plutonium (single recycling)
- The ultimate waste (Vitrified and Compacted Waste) do not contain IAEA-safeguarded fissile materials
- Existing Recycling facilities have been designed and constructed to satisfy all relevant national and international standards for the safekeeping of nuclear materials
- The Recycling facilities and the separated fissile materials are safeguarded both by EURATOM and the IAEA
Recycling, a competitive solution

Recycling is economically comparable to direct storage

The back-end process represents around 5% of the kWh cost
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AREVA la Hague: the first stage of recycling

Used fuel

Unloading and Interim storage

Treatment operations
(shearing - dissolution - separation - purification)

Interim storage

Recycled fuel

Hulls and end-pieces

Fission products

Uranium

Plutonium

Standard Canister of vitrified waste (CSD/V)

Standard canister of compacted waste (CSD/C)

A few years

A few days

A few years

At each stage, nuclear material is accounted for in accordance with EURATOM and IAEA safeguards
International Trends

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La Hague in 1962
La Hague in 1964
Visit at La Hague in 1966 of Alain Peyrefitte, Minister for Research
Used Fuel transportation
40 years ago
A team at the HAO Control Room
1961
Start of construction of a recycling plant named UP2 dedicated to used fuel from UNGG (Natural Uranium-Graphite-Gas) reactors

1967
UP2 goes into industrial operation by CEA

1973
Steep acceleration, further to the 1973 oil crisis, of the French Nuclear program based on PWRs– Impact on LH evolution

1976
CEA is authorized to modify UP2 through the implementation of a 400 tons/year recycling facility dedicated to EDF’s PWR used fuel – In the same time UP3 project aimed at treating up to 800 tons/yr of foreign used fuel is unveiled

1979
First ship dedicated to Japanese Used fuel transportation arrives at the Cherbourg Harbor

1978
Signature of UP3 contracts with Foreign customers

1994
UP2 800 is commissionned with the aim of doubling the initial 400 tons/year capacity

1996
The La Hague Plant global capacity reaches 1700 tons/year
La Hague Ramp-Up History

- **UP2-400**: 10 years
- **UP3**: 5 years
- **UP2-800**: 1 year

Metric tons treated:
- Licensed capacity: 1700 metric tons
- 1976-1986: UP2-400 (10 years)
- 1986-1990: UP3 (5 years)
- 1990-1996: UP2-800 (1 year)
La Hague today
La Hague Plant: from start of construction to maturity….

- **1999**: Construction of the “ACC” compaction facility and of the R4 facility.
- **2002**: ACC Commissioning.
- **2010**: Cold crucible vitrification.
- **2010**: First CSD-B production.
1999: construction of the « ACC » workshop for the compaction of hulls and end-pieces
Linked to the future by innovation and improvements
Opting for Total Occupational Health & Safety

700 Resources
On-site experts devoted to Occupational H&S, Nuclear Safety and Radiation Protection 24/7

Accident frequency rate < 1
Compared to the average figures for France, the La Hague plant’s accident frequency rate is more than 10 times lower and the accident severity rate is 20 times lower

AF \approx 0.4 (September 2011)
Strict environmental monitoring – Focus on La Hague Plant

**Gaseous and liquid emissions strictly managed**
- Low-level radioactive effluents purified prior to emission
- Emissions largely reduced over the years
- Full compliance with strict authorizations

**A wide range of measurements**
- Around 20,000 samples are taken each year
- Around 70,000 analyses are performed each year

Monitoring is carried out on:
- atmosphere, land (surface water, grass, milk, etc.),
- sea (coastal water, seaweed, shellfish, fish, etc.)

Under the control of the authorities, who also perform their own inspections
From a radiological standpoint, the site’s impact* is 100 times lower than natural radioactivity levels.

AREVA
La Hague
< 0.02 mSv / an

Natural exposure
2.4 mSv / year

*Impact calculated since 2004 using a model produced by the GRNC (Groupe Radio-écologie Nord-Cotentin), making allowance for the results of the AREVA public enquiry (1998), for a reference group: population likely to be the most highly exposed due to its position and lifestyle.
A few comparisons

- A scan: 10 mSv
- Natural exposure in the Limousin area: 6 mSv per person per year
- Average Natural Exposure in France: 2.4 mSv per person per year
- An abdominal X-ray: 1 mSv
- A chest X-ray: 0.1 mSv
- Consuming 1 ½ liters of mineral water every day for a year: 0.03 mSv
- A transatlantic flight: 0.02 mSv
- A 400-meter change in altitude: 0.02 mSv per person per year
- Consuming 200 g of mussels: 0.02 mSv
- Annual impact of the emissions from AREVA-La Hague: < 0.02 mSv per person per year
40 years of operational experience with recycled fuel

- More than 6400 MOX FAs already used in LWRs
- Performance: equivalent to UO₂ fuel
- More than 6400 ERU FAs already used in LWRs

Not exhaustive
MOX fuel performances

Not exhaustive

Maximum achieved burnups: 62 GWd/t PWR and 58 GWd/t BWR

2007: MOX Parity (EDF) shifts BU from 36-38 to 50 GWd/t

- UNITED STATES
- SWITZERLAND
- GERMANY
- FRANCE
- BELGIUM

Not exhaustive
ERU fuel performances

Not exhaustive

FAs

UNITED STATES
U.K.
SWITZERLAND
SWEDEN
NETHERLANDS
JAPAN
GERMANY
FRANCE
BELGIUM

00-05 05-10 10-15 15-20 20-25 25-30 30-35 35-40 40-45 45-50 50-55 55-60 60-65
Optimizing the future with...

The 100% MOX option

[Image of a nuclear power plant]
The future of recycling

- Standard EPR reactor with 100 % MOX core enables:
  - To reach best performances for the fuel, same as 100 % UO2 core
  - To design an optimized homogeneous MOX fuel
  - To recycle the energy, from 8 EPR reactors with 100 % UO2 core

AREVA GEN 3+ reactors are designed for an optimized recycling of the energy
Used MOX fuel to be managed simply as used UO$_2$ fuel

- Optimizing the transition towards new generation of reactors
  - Preservation of used MOX fuel for later recycling to provide the required Pu in a limited number of FAs
  - Treating used UO$_2$ fuels rather than used MOX fuel allows significant reduction of the used fuel inventory to be interim stored (reduction by a factor of 8)

- Or MOX used fuel can be managed like UO2 used fuel:
  - Recycling used MOX fuel for immediate reuse in reactors,
  - Dry or wet interim storage solutions have already been efficiently implemented for MOX used fuel pending the implementation of definitive solutions.

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Cumulated used MOX fuel treated (tHM)
TRANSPORT

Totally safe transportation
Over 35,000 tons of used fuel safely transported since 1975.
Conclusions

- The Fukushima events have put in the centre stage the need to review the management options implemented for used nuclear fuel inventories
  - which are significant
  - which will still continue to grow
- Choosing an outcome to the Used Fuels stored currently in reactor pools involves a large combination of technological, financial, political and licensing parameters
- Recycling offering a safe solution for the ultimate management is a pillar in the development of Nuclear Energy in the post-fukushima era
  - Safe & Robust
  - Volume / 5
  - Radiotoxicity / 10
  - No “IAEA” fissile materials
  - Benefits from recycled fuels
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