MOX Fuel in PWR
EDF Experience

Sino-French Seminar on the Back End of the Nuclear Fuel Cycle

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GENERAL PRESENTATION OF FRENCH NUCLEAR FUEL CYCLE
The French NPP fleet

- 58 PWR units in operation (total installed capacity 63,130 MWe)
  - 900 MWe: 34 units
  - 1300 MWe: 20 units
  - 1500 MWe: 4 units
- 1 PWR in construction: EPR 1600 MWe

Until the end of 2014

- 80,000 Fuel Assemblies (FAs) loaded in reactor (4,500 MOX and 1,350 ERU)

In 2014, EDF’s generation:

- Nuclear: 415.9 TWh (90.4%)
- Hydraulic: 37.5 TWh (8.1%)
- Fossil: 6.9 TWh (1.5%)
THE FRENCH FUEL CYCLE STRATEGY

NUCLEAR FUEL CYCLE

- Uranium mines
- Reversible disposal in deep geological formations (2025)
- Long-lived nuclear waste
- Treatment and storage facilities
- Spent fuel reprocessing plants
- Customers
- Short-lived nuclear waste
- Natural uranium
- Enrichment plants
- Fuel fabrication plants
- EDF’s operating fleet

EDF
Since 1980, in accordance with the French Energy Policy, EDF decided to implement a “one-through” closed fuel cycle.

- The irradiated fuels are sent to La Hague reprocessing plant where uranium, plutonium are separated from waste (fission products and minor actinides).
  - The reprocessed uranium is enriched to produce ERU fuel
  - The plutonium is mixed with depleted uranium to produce MOX fuels in MELOX plant at Marcoule.
- Once irradiated, MOX and ERU spent fuels are safely stored in pools, waiting for the achievement of multi-recycling in GEN IV fast breeder reactors

Reprocessing allows reduction of waste in volume and saves uranium resources

- MOX fuel and ERU fuel utilization enabled to save approximately two years of uranium consumption
- Reduction of the volume of nuclear waste by a factor of 4
- The “one-through” closed fuel cycle is a first step towards the fully closed fuel cycle with Pu multi-recycling in GEN IV fast breeder reactors
The amount of about one annual discharged fuel is processed each year to produce Pu for the manufacture of MOX (Mixed Oxide) fuel:

- About 1,000 t of heavy metal from spent fuel give 10 t of Pu and 120 t of MOX
- It is required to reduce interim storage of Pu, because of progressive creation of americium reducing its quality; so recycling separated Pu is not delayed
- MOX assemblies fabrication is similar to UOX, major differences are in radioprotection arrangements

24 PWR 900 MWe units licensed for MOX utilization

- Licensing began in 1987
- The two last units (Blayais 3 and 4) were licensed in 2013, MOX loading is planned in 2017-2018.
REACTOR ADAPTATION FOR MOX UTILISATION IN PWR
REACTOR ADAPTATION FOR MOX

- With 30% MOX in the core => higher Pu content (0.5% -> 2%)
  - Higher energy spectrum
  - Reduced efficiency of reactivity control devices (boron, RCCAs)

⇒ To compensate for this effect

- In the primary circuit
  - For reactivity control in operation and during shutdown
    - Reinforcement of the control rods pattern (8 new RCCAs added)
    - Increase of boron concentration in the boron make-up tank up to 7500 ppm

- In the safety injection system
  - To meet safety criteria for over cooling accidents and LOCA
    - Increase of boron concentration of the refueling water storage tank (up to 3000 ppm)
CORE MANAGEMENT

- History of core management
  - 30% of MOX fuels in the core
    - Zoning of fuel for MOX / UOX flux interface:
      - 3 zones with specific Pu content
  - Energy equivalence increase:
    - From 1987 to 1995:
      - 3 batches for UOX and MOX, annual cycle
        - Each reload: 16 MOX (3.25% equivalent) + 36 UOX (3.25%)
        - Pu content: 5.3% (fissile Pu: 70% total Pu)
        - UOX max BU: 36 GWd/t, MOX max BU: 42 GWd/t
    - From 1995 to 2007:
      - 4 batches for UOX and 3 batches for MOX, annual cycle
        - Each reload: 16 MOX (3.25% equivalent) + 28 UOX (3.7%)
        - Pu content: 5.3% (fissile Pu: 70% total Pu)
        - UOX max BU: 36 GWd/t, MOX max BU: 42 GWd/t
        - then 7.08% (fissile Pu: 63% total Pu)
    - From 2007 to 2014:
      - 4 batches for UOX and MOX, annual cycle “Parity MOX” core management
        - Each reload: 12 MOX (3.7% equivalent) + 28 UOX (3.7%)
        - Increase of Pu content: 8.65% (fissile Pu: 63% total Pu)
        - UOX/MOX average discharge: 48 GWd/t
        - UOX/MOX maximum BU: 52 GWd/t

- Decrease of fissile Pu content in reprocessed UOX fuel when BU increases
  - Necessity to increase Pu content in MOX for energy equivalence
FUEL BUILDING ADAPTATION FOR MOX

- Gamma and neutron activities of MOX fresh fuel (Pu238, Am241)
  - Risk of higher exposure of the operators during transportation and handling

- Fuel receipt and storage adaptation (for radiological reasons)
  - Handling crane reinforcement (hardware and software) : capacity, reliability, safe and limited movements
  - Direct storage under water
  - Visual examination by video camera of each fresh MOX FA under water
  - Emergency switch on the fuel building ventilation (red mushroom head switch)
  - Reinforced safeguards on the plant during MOX handling (sensor cameras, fuel building access, …)

- Spent fuel transport after 3 or 4 years cooling time
  - Slower decrease of decay heat in MOX
TRANSPORTATION OF FRESH MOX FUEL

- **Fresh Fuel transportation by MX8 Cask:** design similar to spent fuel cask
  - In operation since July 2004

- **Main goals:**
  - Improved transport safety and nuclear materials safeguards
  - Reduced doses during unloading

- **Doses reduction achievements:**
  - Average value in 2012: 0.7 mSv / shipment
  - Maximum value: 1 mSv / Shipment (half gamma, half neutron)
  - Thanks to handling automation, limited number of operators and biological protection use
TRANSPORTATION OF IRRADIATED MOX FUEL

- **Spent MOX fuel transportation in standard spent fuel casks**
  - Each cask load with 4 MOX (center zone) and 8 UOX (peripheral zone)
  - About 40 to 60 shipments per year to La Hague reprocessing plant
  - Similar average dose for UOX and MOX shipments
  - Less than 1% of the annual collective dose due to spent fuel transport

- **TN 112 ; new spent fuel cask dedicated to MOX fuel**
  - Capability : 12 MOX FAs
  - Better protection regarding neutron flux than TN12
  - To obtain more flexibility in spent fuel transport
  - First TN112 in operation from 2008, second TN112 in 2015
MOX LICENSING AND REGULATION

- Safety reports needed for a new core management licensing with MOX fuel
  - Accidental transients studies review
  - New Operating technical Specifications
  - Material and documentation modifications technical reports

- Safety reports needed for licensing of a new fuel assembly (MOX)
  - Neutronic design report
  - Thermo-hydraulic design report
  - Mechanical design report
  - Rod thermo-mechanical design report
  - LOCA

- Operation feed-back experience: yearly report during MOX fuel irradiation
  - Core physics start-up tests and flux maps: good agreement between predicted and calculated values
  - Assembly visual examination during outage: geometry, corrosion (as expected)
  - Doses during fresh fuel deliveries and in operation

- Parity MOX:
  - Implementation decided in 2001, 2 years needed to perform the safety studies and 4 years for licensing (cladding corrosion, Fuel Gas Release, ..)
MOX IMPACT ON REACTOR OPERATION
IMPACT SUMMARY

- No change regarding plant availability of the PWR 900MWe fleet:
  - Same annual cycle
  - Light increase of outage duration due to increase of decay heat

- No significant impact regarding operational maneuverability
  - For all units with MOX fuel, load follow has been authorized in 1995, after 5 years of smooth operation on Saint-Laurent 1 and 2
  - Better axial flux stability during power transients (reduced Xenon efficiency)

- No increase in the small amounts of waste release in the environment
  - Reduced volume of effluents (30%) during power transients
  - Similar gaseous and liquid waste release for MOX and UOX plants

- No impact on radioprotection.
  - Doses during outage mainly due to maintenance
  - Low sensibility to fuel (BU or Pu content)

- In case of disruption in the supply chain, MOX fuels can be replaced by UOX fuels in reload batches.

- No impact of Fukushima event specific to MOX
CONCLUSION
CONCLUSION

- The different steps of the nuclear fuel cycle are strongly connected
- The whole strategy saves nuclear material and allows to reduce waste in volume
- Burning MOX fuel in reactor is a routine operation for EDF, nevertheless some operation aspects are specific to MOX, mainly regarding logistics
- From 2007, implementation of MOX Parity fuel management achieves the balance of MOX and UOX fuel performance
- Every stage is involved in technical and economical performance of the nuclear generation
- Burning MOX in PWR is a first step towards the sustainable fuel cycle that will lead to Pu multi-recycling in GEN IV fast breeder reactors.
THANKS