NUCLEAR ENERGY IN FRANCE

ACHIEVEMENTS

MAIN PROSPECTS AND CHALLENGES

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NUCLEAR POWER IN FRANCE

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- **France, like Japan, has no domestic fossil fuel resources :**

--> ensuring long term energy independence is a fundamental policy
--> with a major role of safe, competitive and long term nuclear power
--> along with energy saving and diversification of energy supply

- **Reduction of greenhouse gases emission (Kyoto protocol) :**

--> strengthens the role of nuclear as clean energy resource

- **Electricity production in France, in the context of market opening :**

--> 5% fossil ,
--> 15% renewable (hydro..)
--> 80% nuclear generation : --> 427 TWhe in 2004 (87% EDF production)
main objective: safe and competitive operation in the long run

NUCLEAR POWER IN FRANCE

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→ **58 standardized PWRs** 34 * 900 MW **(20 loaded with MOX)**
63000 MW 20 * 1300 MW
in operation 4 * 1500 MW

→ **launching of EPR project**

→ **Fast Reactors :**

Phénix (250 MW), experimental
Super Phénix (1200MW), shut down for non technical reason
--> role of Fast Reactors as an option in the far future…

→ **Nuclear generation safety, effectiveness and competitiveness,**
- **along with preservation of nuclear energy resources**
- **and high level waste treatment** (reprocessing recycling, 1991 back end law...),

→ **essential for clean, economic, and sustainable development in France, now and in the long term**

NUCLEAR GENERATION IN FRANCE

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Nuclear Power Plants

Pressurized Water Reactor (REP)

58 units ; 63 GWe

34 * 900 MW

(20 loaded with MOX, 2 with REPU fuel)

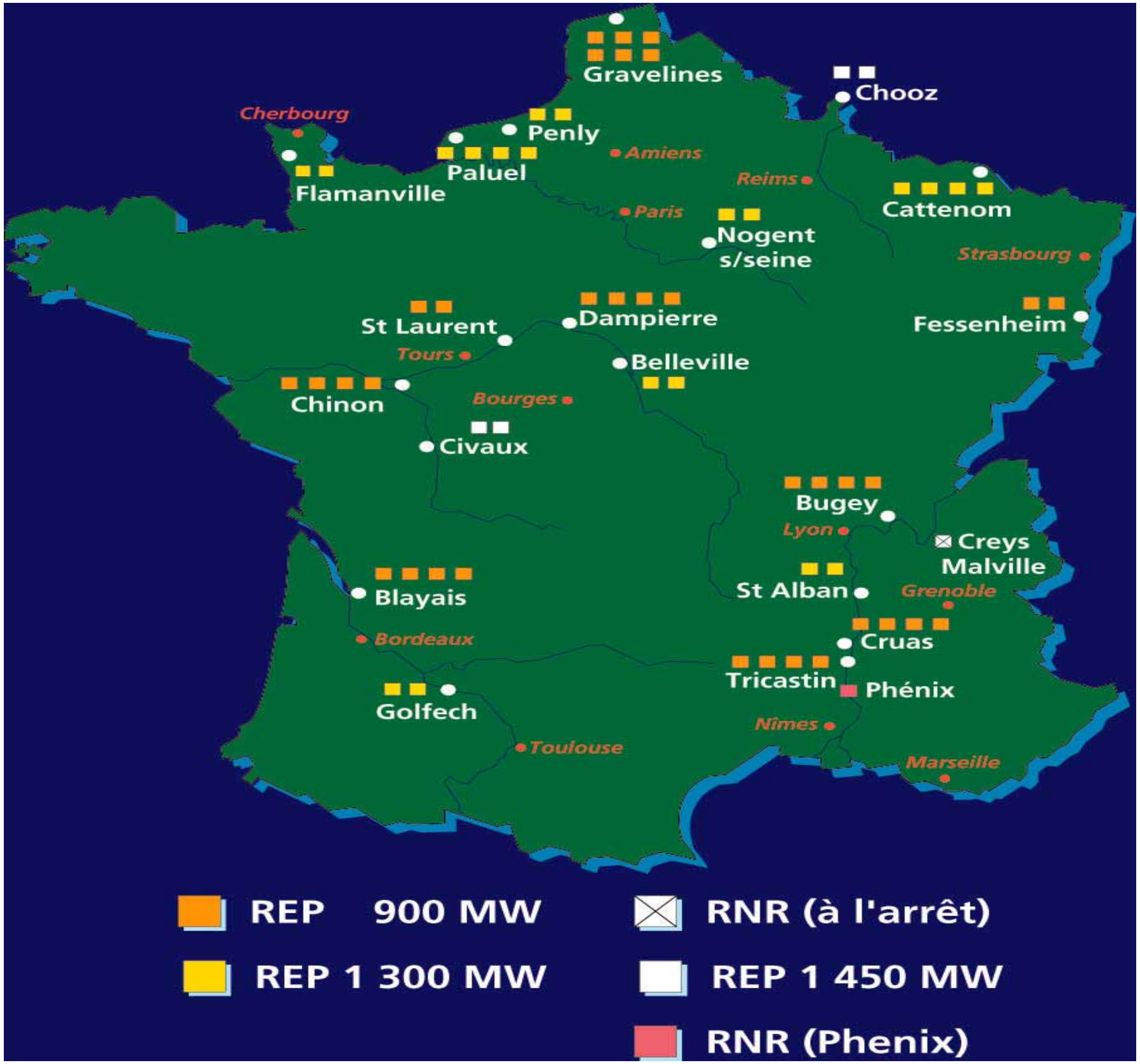
20 * 1300 MW

4 * 1500 MW (N4)

Standardized units,

20 years average

+ new EPR to be erected at Flamanville



Sodium Fast Reactor (RNR)

PHENIX near Marcoule

NUCLEAR GENERATION IN FRANCE

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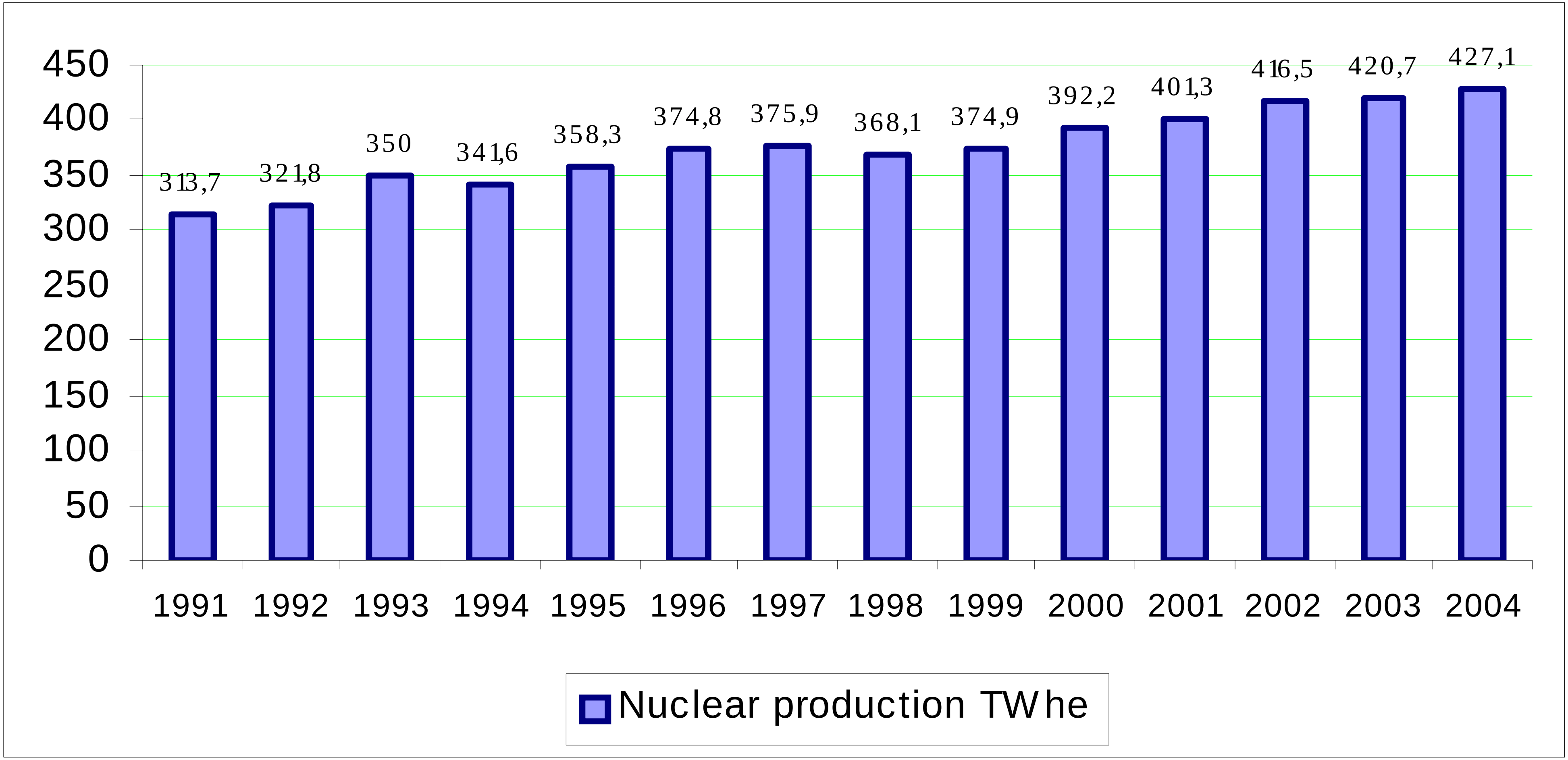
Nuclear Power Generation (TWh): 427,1 TWh in 2004, 80% of electricity production



NUCLEAR GENERATION IN FRANCE

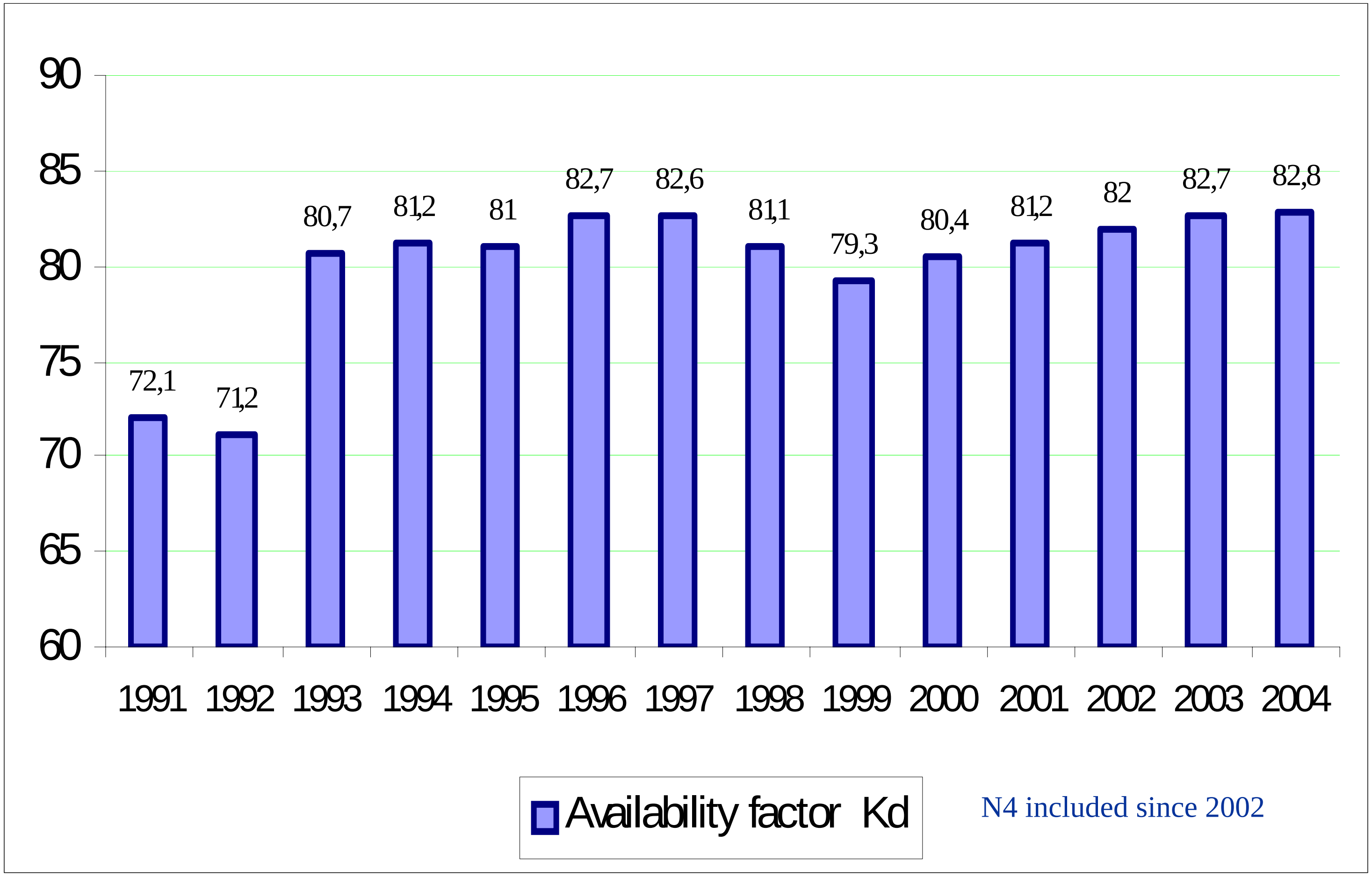
A high level of reliability

Necessity to progress:

- outage management and planning "be on time"

- increasing operating cycle length

Trends in nuclear power plant availability : 82,8% in 2004



Nuclear as a clean and sustainable energy

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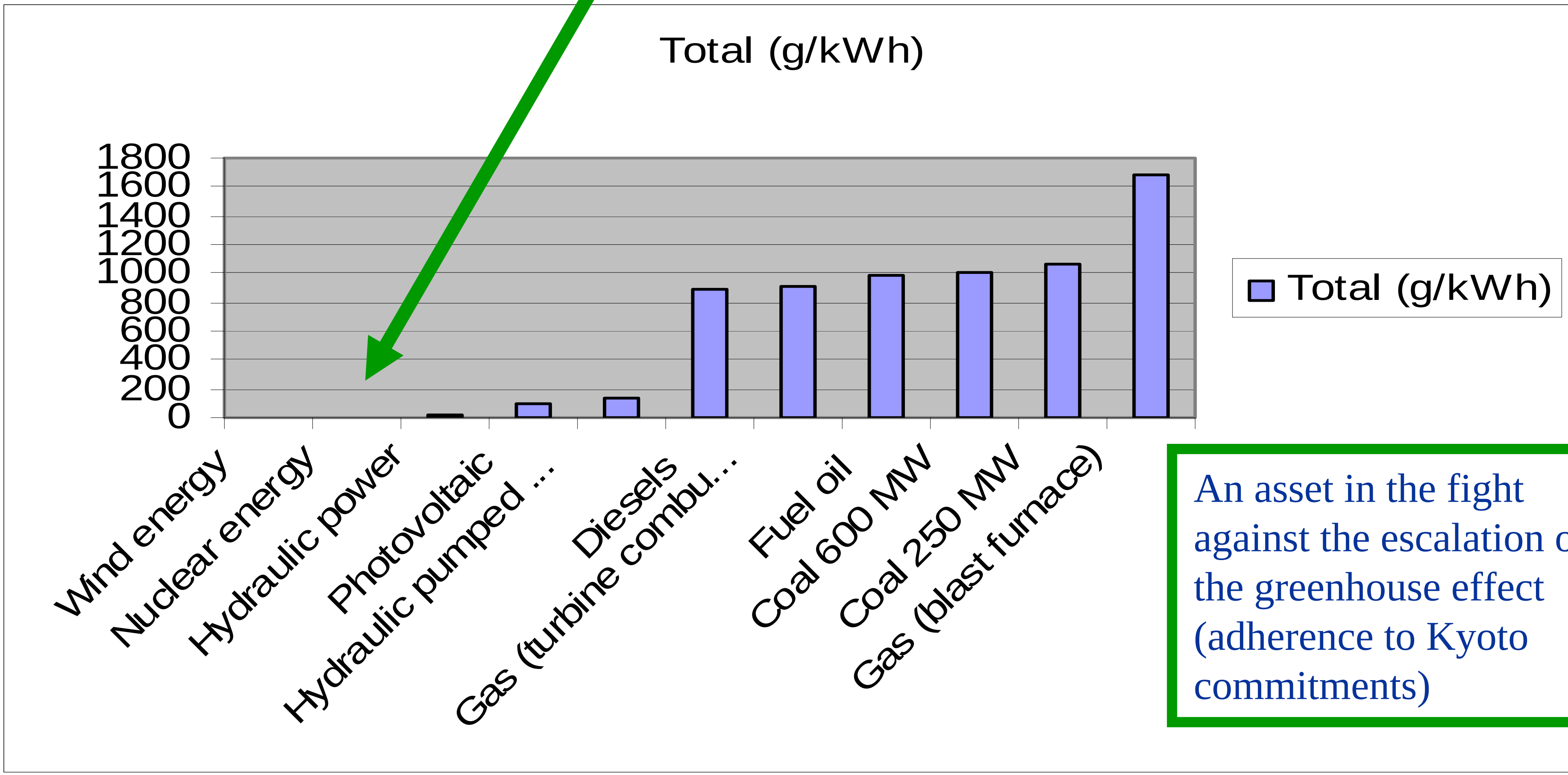
Environment : CO2 Emissions

95 % of electrical power is generated in France without any CO_2 emissions, thanks to nuclear and hydro generation



An asset in the fight against the escalation of the greenhouse effect (adherence to Kyoto commitments)

Nuclear as a clean and sustainable energy

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Punctual delivery of safe, clean and competitive electricity for our customers

Limited impact on natural environment : integration into geographical sites,

Waste volume control and tracking:

reduction of operationnal waste, treatment and storage of nuclear waste

→ Spent fuel reprocessing as an asset for sustainable development

- vitrification of high level waste and volume reduction (130 m3/year for 400 TWh)
- recycling of valuable materials: plutonium (MOX fuel) and uranium
- reduction of spent fuel quantity in cooling pools interim storage
- preservation of energy resources for future energy needs and fast reactors

MAIN PROSPECTS AND CHALLENGES

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Short and mid term: technical and economical optimisation of nuclear fleet

- Safety management and culture
- increasing availability: improved outage planning and management, better anticipation and maintenance workload reduction

A major economic goal is to improve nuclear fuel energy efficiency, and to implement new fuel and core management in order :

- to have longer operating cycles and reduce fuel cost
- and to reduce the amount of nuclear spent fuel for the same energy output.

Preparation of the future

- long term operation of existing NPPs and studies up to 50/60 years
- periodic safety reassessment, experience feedback, backfitting
- EPR project (advanced PWR) launched in 2004 → **Nuclear open to the future**
- participation to GEN 4 advanced reactors programs
- and also: dimantling of oldest GGR shutdown reactors

MAIN PROSPECTS AND CHALLENGES

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→ **Main challenges for nuclear energy sustainability:**

- Maintaining **a high level of safety**:
  safety culture management, ten years safety reassessment process, radiological protection….;

- Maintaining overall **competitiveness of nuclear energy** in the long term:
  a necessary condition for its development and public acceptance;

- Pursuing the development of efficient **management of high level waste** and fuel consistency,
  meeting the long term financial liabilities for spent fuel, back end, and dismantling;

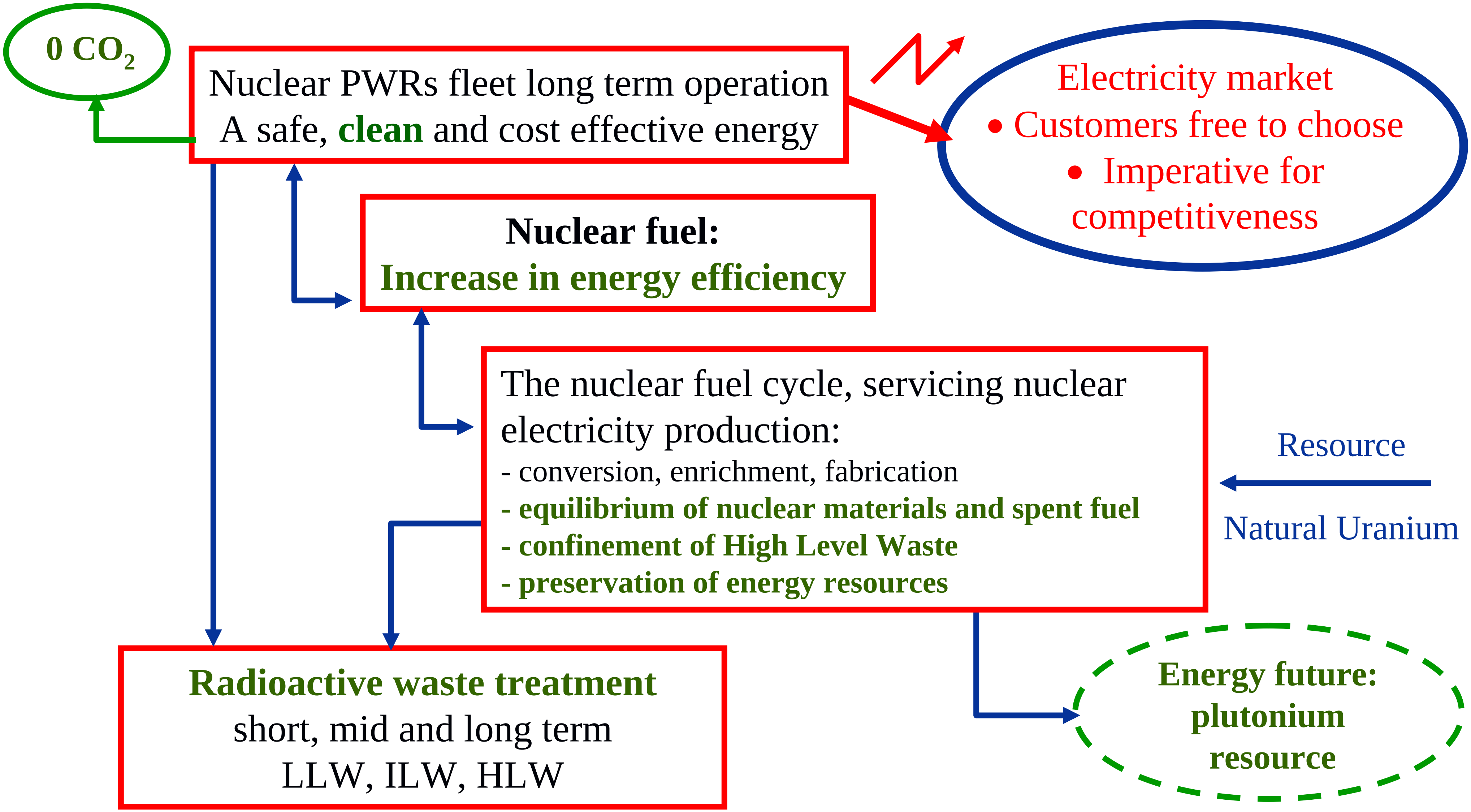
- **Maintaining the nuclear option**, with long term operation of existing NPPs,
  advanced LWR reactors (EPR) and future design (Generation IV),

- Providing continued effective **proliferation resistance** of nuclear energy systems,
  through intrinsic barriers and extrinsic safeguards, physical protection;

- Preserving future options for energy resource and nuclear fuel supply (**full use of U resource**) ;

→ **And also enhancing public acceptance:** transparency, understanding of long term energy issues

The place of nuclear fuel cycle servicing electricity sustainable production



The choice for reprocessing and recycling strategy

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- **Reprocessing of spent fuel has been implemented in France from the beginning**
  to enhance energy independence, along with a fast breeder reactors program
  and with the prospect of an increasing worldwide demand...

- **Spent fuel represents a valuable energy resource**
  (1%) plutonium as long term energy resource, under safeguard rules
  (95%) recovered uranium, still sligthly enriched
  (4%) fission products and minor actinides (Am, Cm, Np) to be treated as waste.

- **High level waste vitrification and recycling of valuable energetical material and remain the main options for the back end of the fuel cycle**

--> the vitrification process is a major factor for long terme safe confinement of high level waste
--> decision in 1984 to recycle plutonium in PWR 900 MW, using a mixed uranium / plutonium fuel (MOX),
--> first MOX loading in 1987 at Saint Laurent B, extended since to 20 units PWR 900 MW
--> preservation of long term energy resource (use of plutonium for future fast reactors)

- **The choice for reprocessing - recycling was made by other developed countries**
  Belgium, Switzerland, Japan, Germany (until 2005…) …

Nuclear industry in France
A major contribution to energy sustainability

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- **Nuclear fuel** , for **420 TWh**:

  UO2: ≈ 1050 HMt / yr, burn up : max 52 GWd/t → can be reduced with higher burn up
  MOX: ≈ 100 HMt / yr, burn up : max 42 GWd/t

  current studies to improve fuel performances and burn up
  - to enhance nuclear production system competitiveness (fuel cost, longer operating cycle)
  - to reduce the quantity of spent fuel and waste

- **Closed fuel cycle: reprocessing at Cogema - La Hague**

  volume reprocessed ≈ 850 HMt/yr today, with possible industrial flexibility
  vitrification of high level waste (fission products + minor actinides), small volume **(130m3/yr)**

- **Recycling and MOX fabrication at Melox plant** :

  recycling of separated plutonium, 100 HMt MOX/year along with reprocessing (→ **40 TWh/yr**)
  spent MOX fuel contain concentrated plutonium under a limited volume:
  → a resource option for starting future GEN4 fast reactors

- **Recycling of reprocessed uranium,** according to natural uranium market

  currently on implemented on 2 units (→ **12 TWh/yr**), storage as energy resource

Sustainable development :
A better use of irradiated fuel material

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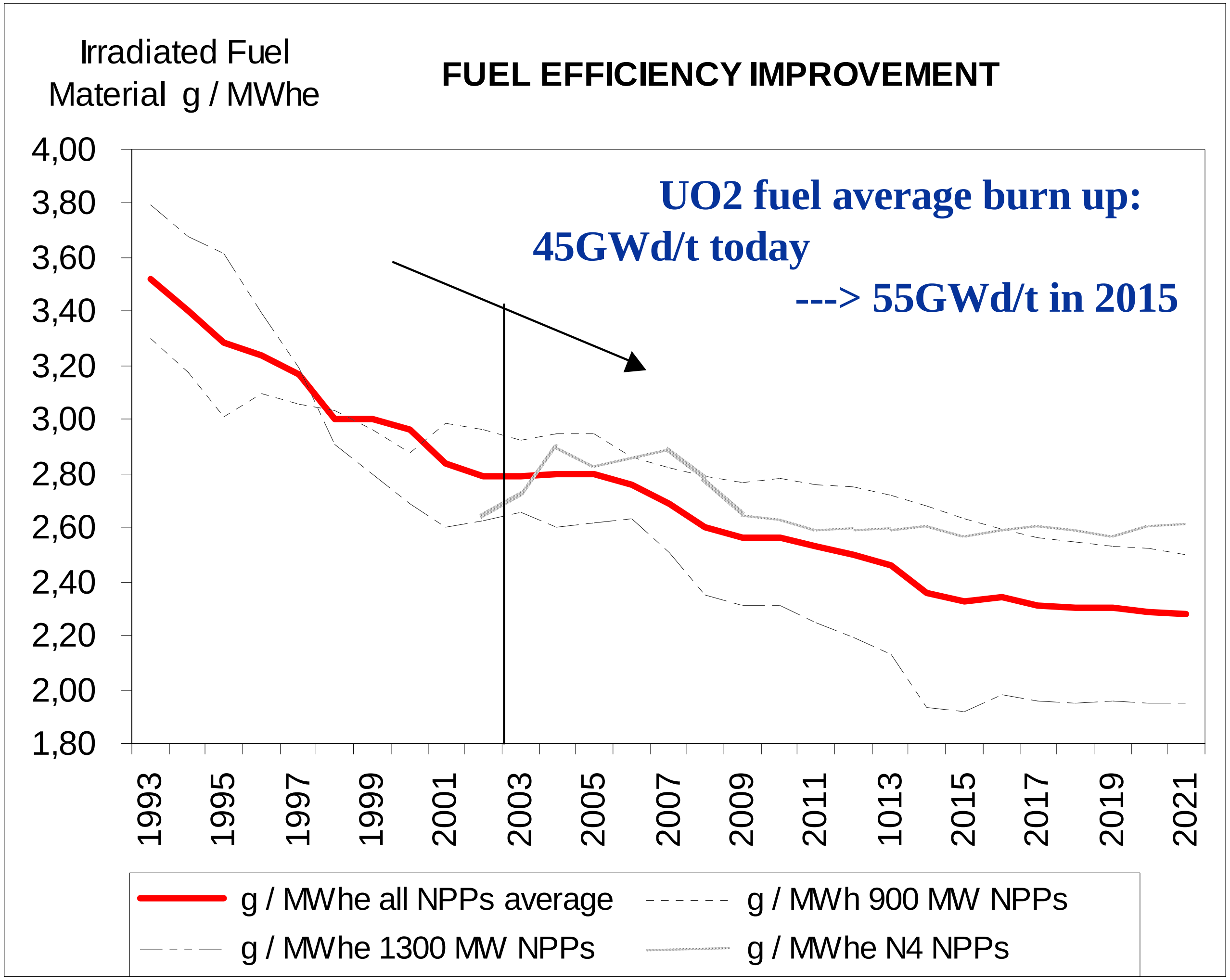
A global increase
in fuel efficiency:
from 3,5 g/MWh ten years ago
to 2,8 g/MWh today

Projects are engaged to further progress:
from 2,8 g/MWh today
to 2,3 g/MWh around 2015

→ fuel cost reduction

→ reduction of irradiated fuel material for the same energy

→ reduction of the number of spent fuel assemblies for the same electric production



→ Benefits of the closed fuel cycle strategy

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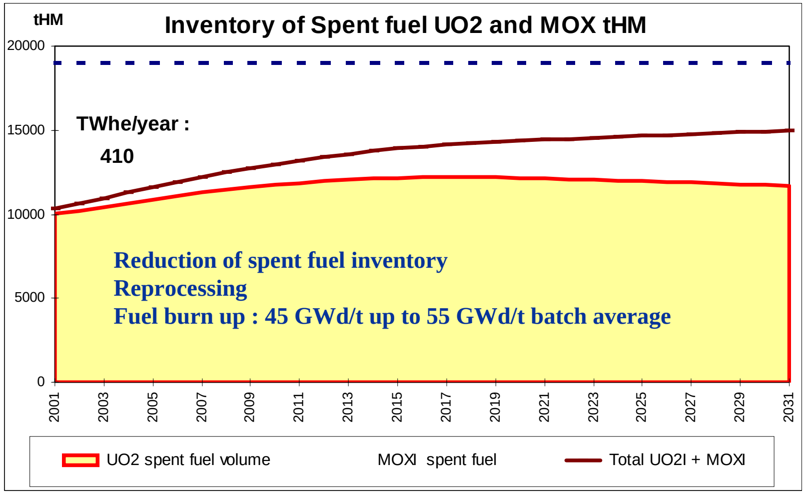
- **Vitrification of high level nuclear waste**
  a safe and long-lasting confinement, internationally recognized
  concentration in limited volume (130 m3/year)
  optimisation of storage / final disposal options

Around 130 m3/year HLW within glass canisters storage for EDF nuclear production each year (420 TWh/y)

- **Recycling of Plutonium as a valuable energy resource**
  30% Pu is consumed, produces **30 to 40 TWhe/yr**
  (8 to 10% of nuclear production)



- **Reduction of spent fuel quantity** :
  7 UO2 --> 1 MOX

- **Preservation of long term energy resources**
  concentration of Plutonium in MOX spent fuel
  limited volume, full safeguards,
  leaves open the possibility to reuse Pu for future fast breeder reactors.

- **Separation of recovered uranium**, slightly enriched, for recycling
  currently 40 t/yr, 2 reloads on 2 dedicated 900 MW units Cruas 3/4, REPU fuel equivalent to UO2 3.7%

MOX UTILIZATION IN EDF NPPs

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First MOX loaded in 1987 at Saint Laurent B
Gradually implemented on 20 units of 900 MW series

- Dampierre 1/2/3/4, Gravelines 1/2/3/4, Tricastin 1/2/3/4, Saint Laurent 1/2, Blayais 1/2, Chinon 1/2/3/4 authorized by initial decree and after a safety review by French Safety Authority

- minor adaptations of the plant :
  4 additional control rods, boron concentration, enhanced security procedures …

- core management: UO2 3,25%, 30% MOX, Pu 5%, (36 UO2 + 16 MOX), 3 cycles
  --> average burn up UO2 and MOX : 36 GWd/t

- MOX fuel assembly of Framatome-ANP design AFA - 2G
  fabricated first at Dessel, Cadarache and then at Melox --> no fuel failure

- licensed transportation cask for fresh MOX fuel, safeguarded convoy

--> A proven experience feedback :
no difference with UO2 fuel, no difficulty, no fuel failure....

MOX UTILIZATION IN EDF NPPs

EDF Electricité de France

--> Progressive improvement of UO2 / MOX core management

- 1993: optimised hybrid reloads UO2 3.7% by 1/4, 30% MOX, Pu 5% (25 kg) by 1/3, (28UO2+16MOX)
  reduction of the vessel neutron fluence (40% improvement compared with UO2)
- 1998: increase of total Pu content : 5% --> 7% to match Pu fissile isotopic composition

--> **UO2 average burn up 45 GWd/t , MOX average burn up 38 GWd/t**

Extension of MOX use on 20 reactors in 1997 : Chinon B 1/2/3/4

after local public enquiry and new authorization decree

As of today : MOX use extensive experience feedback

- 20 reactors loaded with MOX, more than 150 reactor.years
  and more than 1500 MOX assemblies loaded, **--> no fuel failure**
- MOX fuel with advanced AFA-3G Framatome design
- reactors with MOX are autorized for load following
- **--> same operating and safety conditions as for UO2 fuel**

MOX UTILIZATION IN EDF NPPs

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SAFETY : SAME LEVEL AS UO2 FUEL

- neutron spectrum --> 4 additional control rods, boron concentration increase
- 3 zones of different Pu content (interface MOX / UO2)
- fuel rods internal gas pressure: lower initial pressurization, larger free volume....
- power ramp test : no PCI rupture, good behaviour; RIA test : no difference with UO2
- technical specifications for primary water activity: same as UO2
- transportation of spent fuel in TN12 cask, resin for neutron protection : 4 MOX + 8 UO2

OPERATING EXPERIENCE FEEDBACK : NO DIFFICULTY, SAME AS UO2

- same authorized operating range, lower Xenon effect
- authorization for load following and stretch, same as for UO2

LIQUID AND GAZEOUS RELEASES, DOSIMETRY : NO IMPACT

- gamma and neutron dosimetry for fresh fuel and spent fuel transportation adressed by ALARA approach

MOX UTILIZATION IN EDF NPPs

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QUALITY OF FABRICATION OF MOX (Quality Assurance) :

Fabrication control is under vendor responsibility,
under overall quality surveillance by EDF, focusing on key points :

- surveillance of qualification tests and files
- surveillance program of fabrication stages, on a sample basis
- acceptance of assemblies fabrication files
- organizational and technical audit, follow up...
- application of RCC-C (Design and Construction Code for PWR Fuel Assemblies)

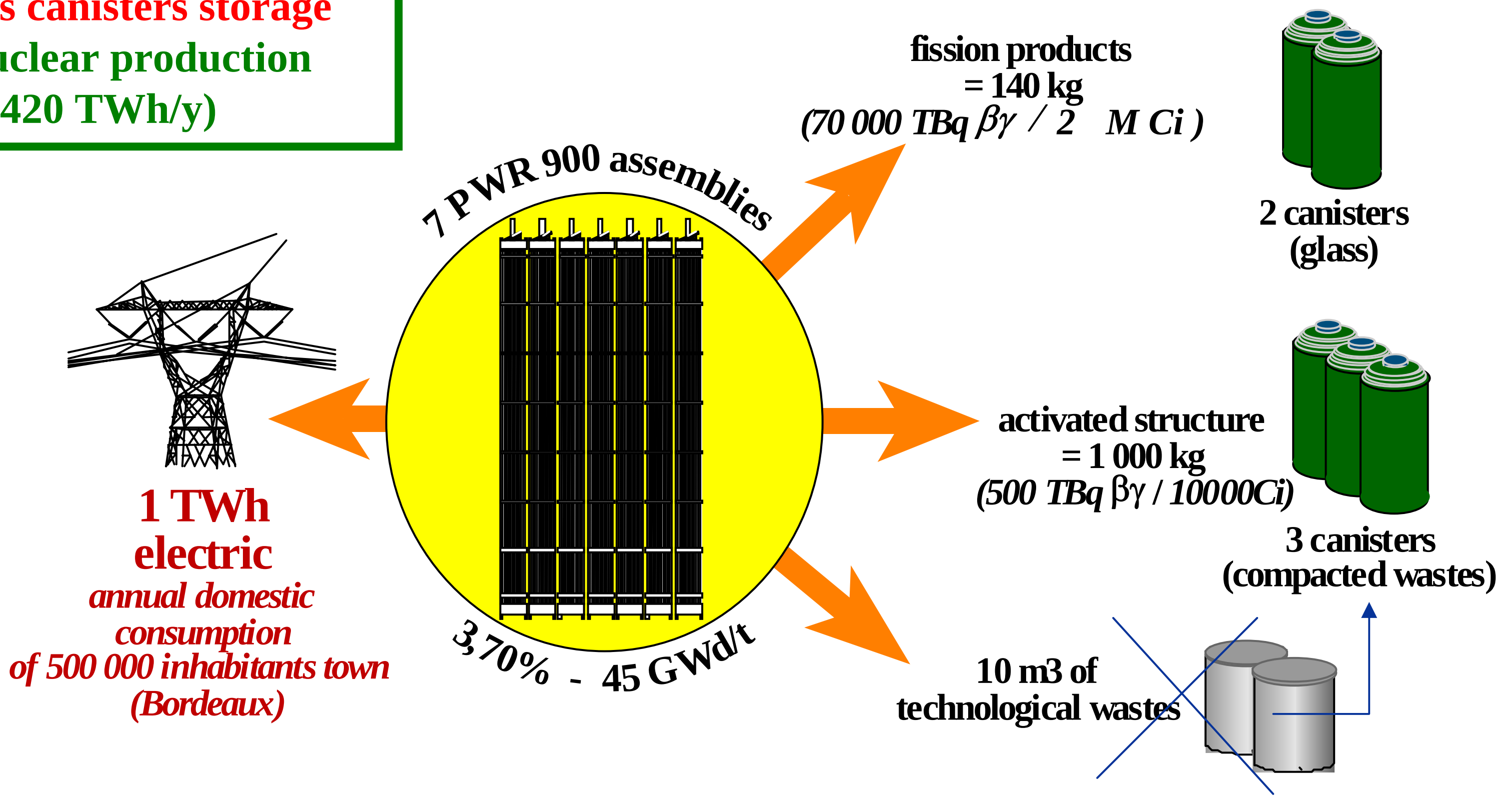
FUTURE PROGRESS FOR MOX : MOX PARITY 52 GWd/t in 2006

Good behaviour of MOX fuel with higher burn up
Feasibility of MOX fuel management improvement, 3 cycles --> 4 cycles like UO2
--> "Parity MOX" project : max 52 GWd/t with 8.65% Pu content,
--> average burn up 48 GWd/t for MOX, equivalent to UO2 enriched at 3.7%

- minor adaptations (4 more additional control rods, boron adjustment): preparation of safety file
- along with loading 100 HMt/yr MOX --> possibility to recycle all the separated Pu
- implementation in 2005/2006 , instruction and approval by Safety Authority

Vitrification of fission products and minor actinides and resulting waste

Around 130 m3/year HLW within glass canisters storage for EDF nuclear production each year (420 TWh/y)



1 assembly	*= 450 kg of Uranium*
	= 140 kg hulls and nozzles
1 canister	*= 200 litres*

Preserving future options for energy resource and nuclear fuel supply

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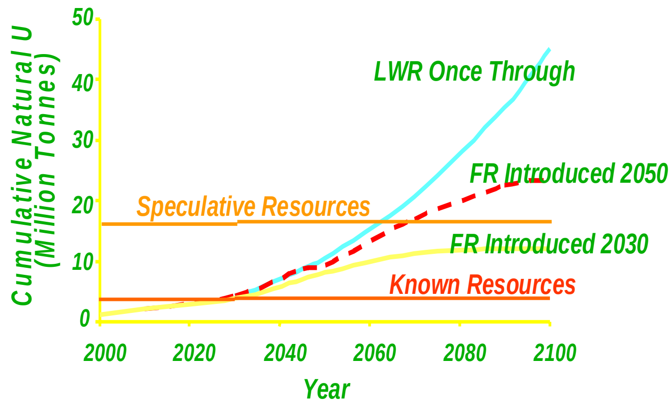
Generation IV Program : prospective view for future reactors and nuclear resources 2035 / 2050

Resources Extension

- *Closing the fuel cycle has again a major impact*
- *Resources may be extended for 1000 y*



Generation IV system	Acronym	Neutron spectrum	Nuclear fuel cycle
Fast reactor, Sodium cooled	SFR	fast	closed
Fast reactor, lead cooled	LFR	fast	closed
Fast reractor, Gas cooled	GFR	fast	closed
Very high temperature reactor	VHTR	thermal	open
Water reactor, supercritical	SCWR	Thermal then fast	open then closed
Molten salt reactor	MSR	therrmal	closed

Maintaining long term nuclear option

--> Closed fuel cycle to save energy resource and importance given to fast reactors

--> Need of Plutonium to start fast reactors to fully use long term uranium resource:

14t of Pu is needed to start 1GW fast reactor (10t equivalent Pu239)

= quantity produced by one PWR 1GW reactor during 50 years of operation

--> Use of plutonium concentrated in MOX spent fuel, through reprocessing

Adequation between current plutonium management and deployment of future GEN4 fast reactors

The current strategy of spent fuel reprocessing and recycling enables to constitute a plutonium inventory, without surplus, in spent fuel (concentrated in MOX) waiting to be reprocessed when necessary to enable GEN4 fast reactors deployment (SFR) by the years 2035 to 2080.

The progressive concentration of plutonium in MOX spent fuel enables:

(i) a safe storage in cooling pool, under a limited volume (industrial experience does exist as of today)

(ii) to maintain the annual reprocessing quantity at a reasonable level during the phase of MOX spent fuel reprocessing, in order to separate plutonium for starting fast reactors.

==> enables to preserve an option for a sustainable energy production system in the long term, in adequation with the capacities of industrial tools.

FUEL CYCLE PROSPECTIVE :
…and fuel cycle consistency in the long run.

• Verification of global consistency with existing fuel cycle facilities and industry process, possibly adapted

• No new investments :
→ existing plants and fuel cycle facilities operated in the long run

• Anticipation of safety studies and administrative authorizations

• Preparation of future adaptations for higher fuel burn up…

→ cost reduction
consistency with existing HLW funding

Replacement of existing fleet and emergence of GEN4 fast reactors

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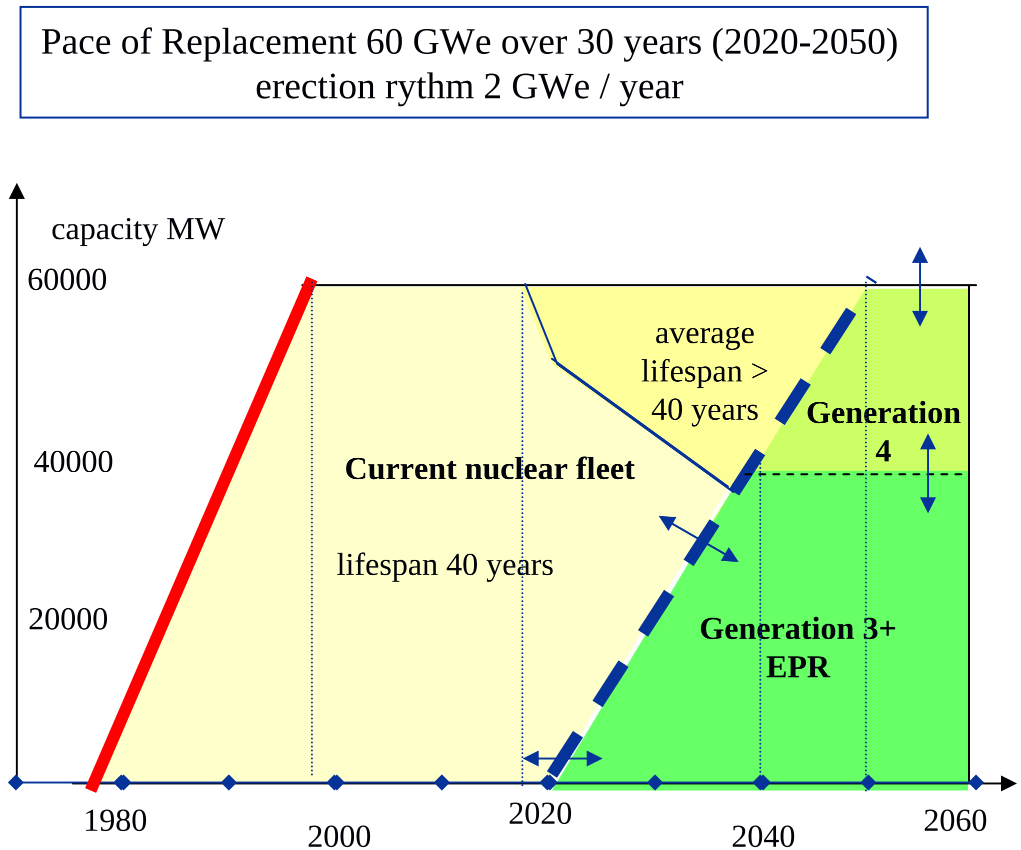

An hypothetical scenario for current nuclear fleet replacement:

- average lifespan 49 years, smoothing of replacement over 30 years;

- deployment of EPR series by the years 2020/2030

- GEN4 fast reactors by the years 2035/2040 (in an worldwide energy and resources situation calling for an increase in nuclear production share)

Other scenario:
- deployment of EPR fleet;
- and deployment of GEN4 reactors by the year 2080

Long term nuclear industry view

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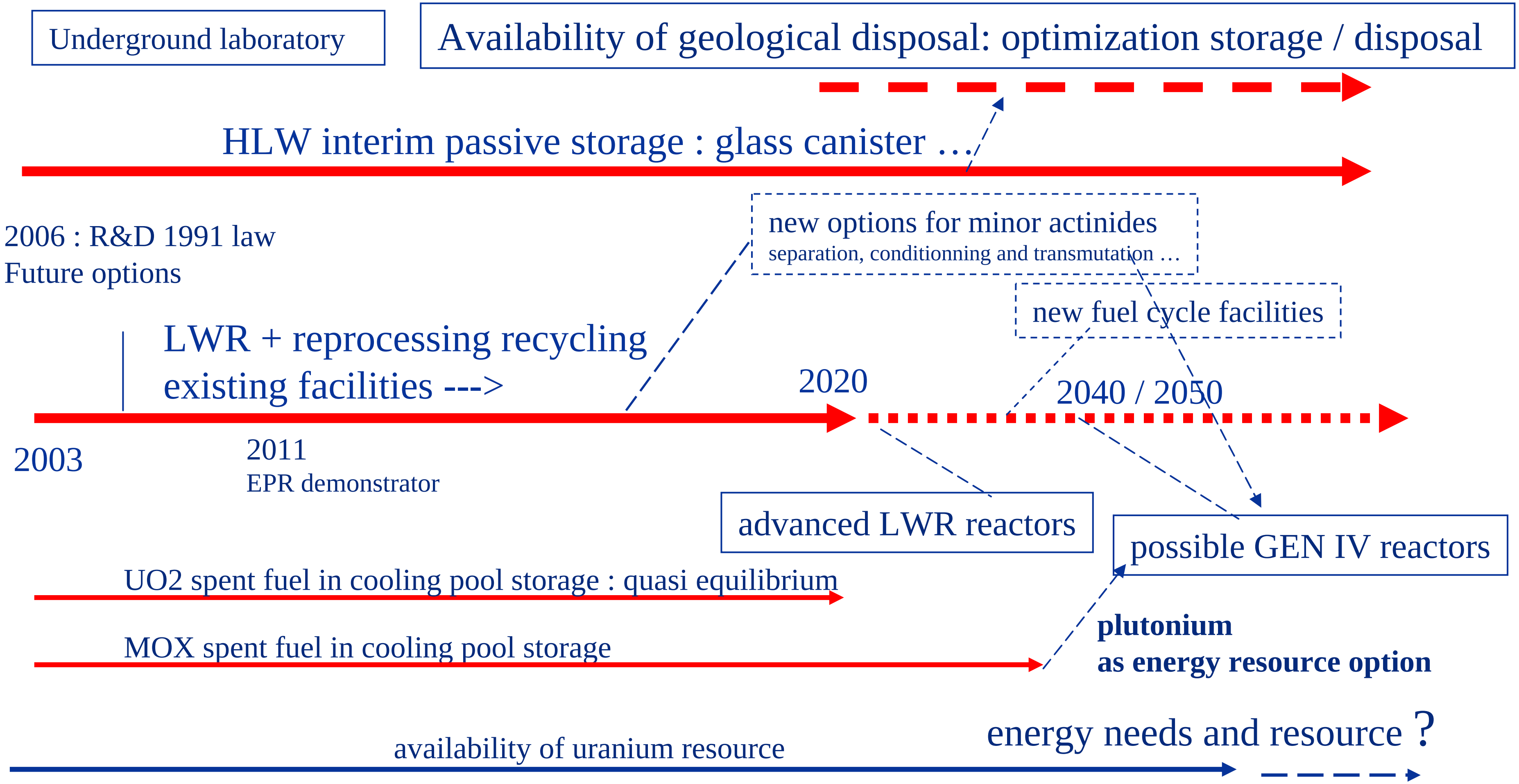

Nuclear sustainability and perspective along time

CONCLUSION

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Nuclear generation plays a major role in France, as a safe, clean, economic and independent energy resource, and will continue in the long term.

The closed fuel cycle strategy implemented in France, involving reprocessing of spent fuel and MOX recycling, has gained an extensive experience feedback and has reached an industrial and mature stage with existing plants and enables further progress in fuel efficiency and optimisation of back end operations.
In a long term prospective, the reprocessing-recycling policy enables, taking advantage of existing fuel cycle facilities:

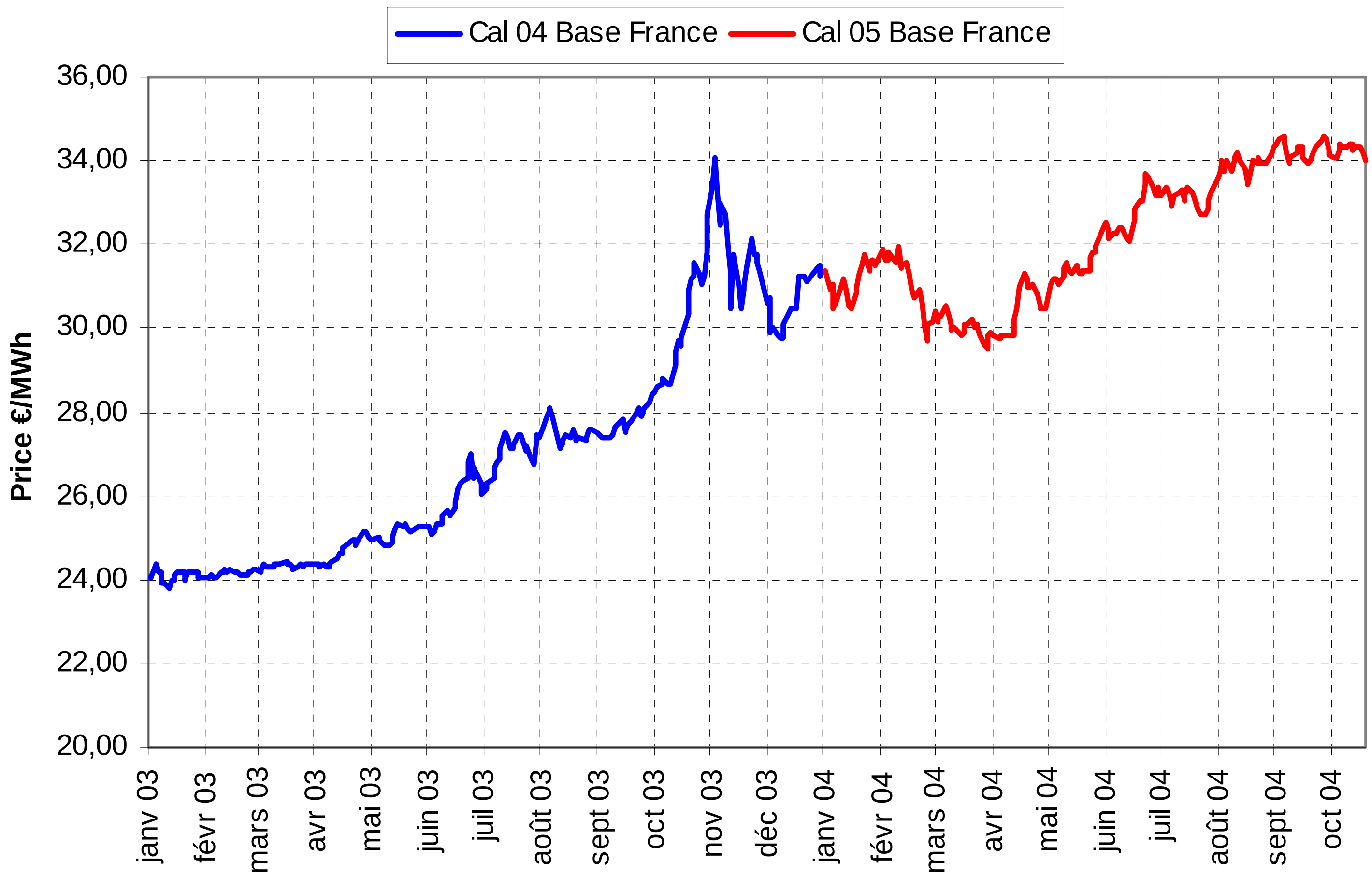
- a safe management and stabilization of nuclear material along fuel cycle, in order to reach a global equilibrium both for separated plutonium and for spent fuel;

- a safe and long term confinement for High Level Waste by vitrification,leaving various long term options (R&D back end studies…) open;

- preservation of future energy resources with the plutonium concentrated in MOX spent fuel, under safeguard rules.

Element of price dynamics

Forward prices



34 Euros/MWh

PUBLIC INFORMATION

- No difference for public information concerning UO2 and MOX
- Public inquiry for MOX extension at Chinon B 1/2/3/4 in 1997 :
  no specific question, good local acceptation
  but questions and political debate at national level …
- Meeting with local information committee around NPPs (CLI)
  local mayors and elected representatives, media, associations, local authorities ...
- Public information and visitor centers, schools and educational information…
- A policy of enhancement of transparency and public information
- Use of INES scale for reactors events

--> no specific question at local level concerning MOX use
MOX experience is now well established, no difference with UO2 fuel

PUBLIC INFORMATION

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- Debate at national level:
  reprocessing and MOX use opposed by "Green" Party, some associations...
  share of nuclear in future energy mix…

- A recent hearing at French National Assembly (november 2001) :
  --> major political leaders have expressed the need to continue and develop nuclear energy and long term energy resources policy

- A governmental study on economy of nuclear energy in France has stressed :
  --> the major importance and economic robustness of nuclear energy and fuel cycle,
  --> the economic importance for long term operation of existing plants and facilities

- Draft laws under discussion :
  future electrity investments program, transparency and nuclear information,
  control of safety and radiological protection…