

EDF

A leader in nuclear sustainable production

**A major actor in the Nuclear Renaissance
Worldwide**

Michel Debes
Electricité de France
EDF Generation
michel.debes@edf.fr

Nuclear energy in France



A prominent contribution to energy sustainability

- 77 % of electricity production in France
- CO2 free and clean resource
- long term energy independence
- within an energy mix to adapt to electricity market needs,
and development of renewable

EDF Nuclear facilities in France

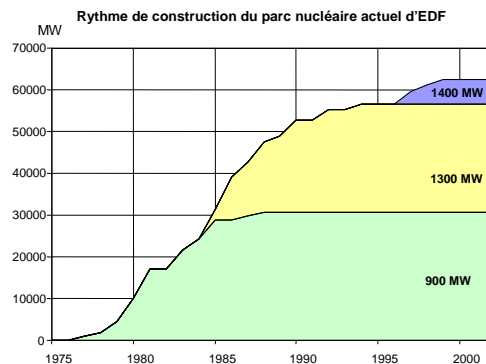


Nuclear production, main results:

→ 417,6 TWh in 2008, availability 79,2% ,

≈ 77% of electricity generation in France

First priority: The Safety of operating plants



58 PWR reactors in operation, on 19 sites; 63,13 GW

Single technology: PWR (Pressurised Water Reactor)

3 standardized series :

A major safety and economic benefit

- 900 MW: 34 units, 31 GW

- 1300 MW: 20 units, 26 GW

- 1500 MW (N4): 4 units, 6 GW

An experience as architect engineer and operator unique in the world

- 44 GW commissioned between 1980 and 1990

- average operation time: 23 years (9 to 30 years)

- Preparation of third ten years periodic reassessment process for 900 and 1300 MW

- Experience feedback: ~ 1350 reactor years

One new EPR plant in construction at FLA3, to be commissioned in 2012, and one EPR to be constructed at Penly

Decommissioning program: 9 reactors (6GGR, HWGCR Brennilis, Creys Malville, Chooz A)

An efficient production tool without CO2 release



- **Electricity production (EDF) in 2008: 478,3 TWh, of which 417 TWh nuclear**
 total capacity 93 GW: Nuclear 63,13 GW (65%), hydro 20 GW (21%), fossil 13,2 GW (15%)
 417,6 nuclear (87,3%), 44,8 hydro (9,4%), 15,8 fossil (3,3%)

- **a highly competitive production mix, mainly nuclear**

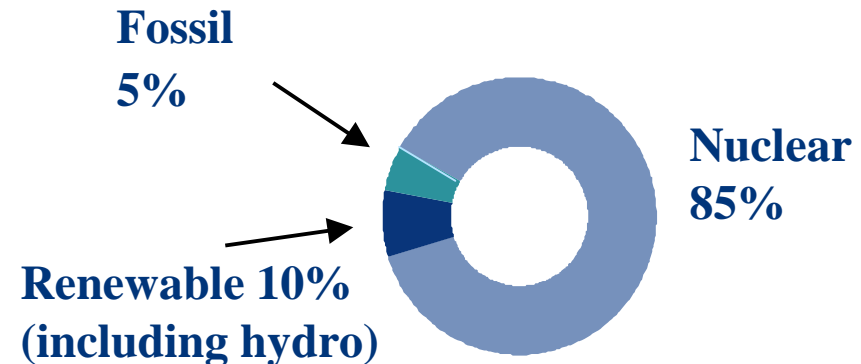
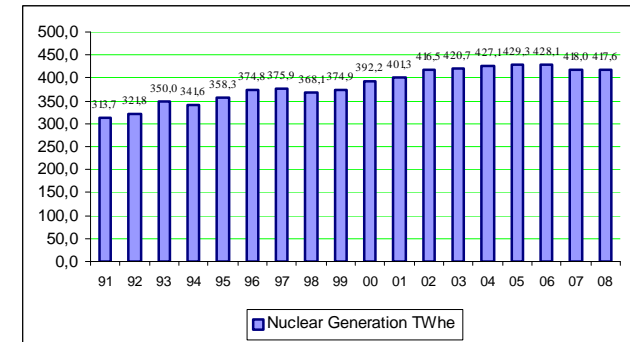
- **95% independant from fossil fuel**

- **a clean enegy mix: small CO2 releases**

EDF in France ≈ 40 g/kWh

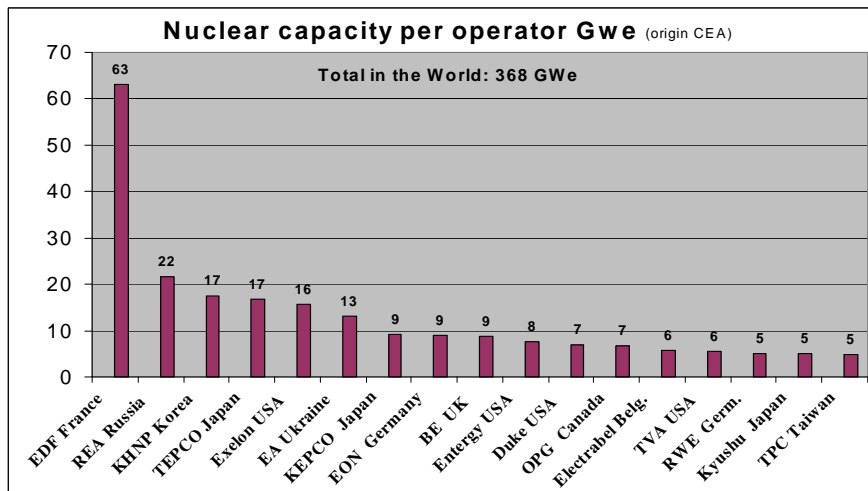
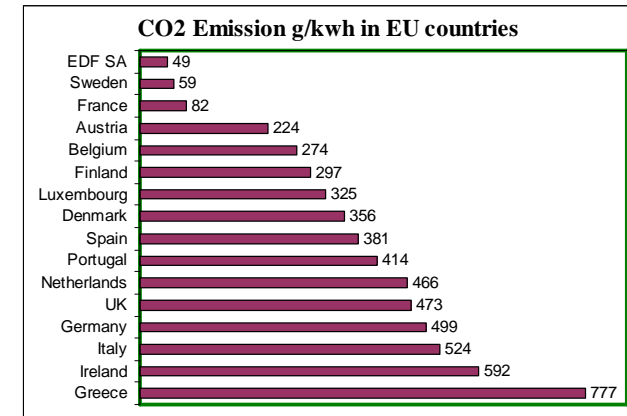
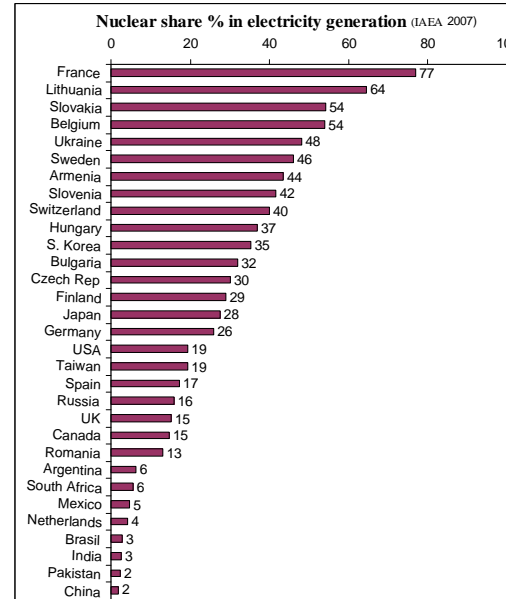
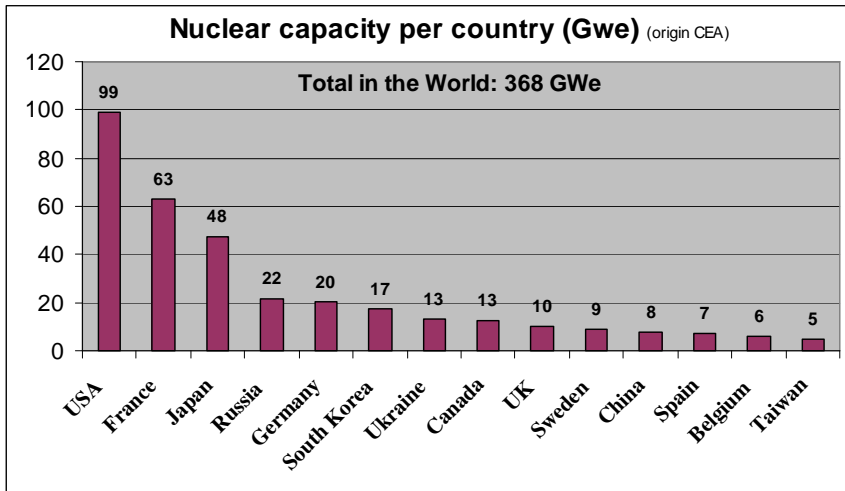
Europe ≈ 400 g/kWh

- **EDF share in nuclear production in Europe:**
 including BE: 9,5 GW nuclear
 EDF share 45% in EnBW (4 GW nuclear)



Nb: CO2 emission/kwh: nuclear 4,2g (U mining/processing: 0,9g; enrichment 2,1g of which 1,6g for electricity; production: 0,6g, of which 0,4g construction and 0,003g disamantling; fuel cycle: 0,6g fabrication, reprocessing, disposal...);
 Lignite: 1200g; Coal 1000g; Oil: 900g; Gaz CCG: 450 g; Photovoltaic: 50 g; Biomass: 40; Wind: 10 g; Hydro: 5g

France and EDF in the nuclear world



- France is the 2nd largest nuclear country after the US
- EDF is the largest nuclear operator,
- 95 % of electricity produced is generated without CO2 emission
- . EDF France: 40 gCO2/kwh (nuclear: 4gCO2/kwh)
- . Europe: 400 gCO2/kwh

EDF strategy for sustainable nuclear generation

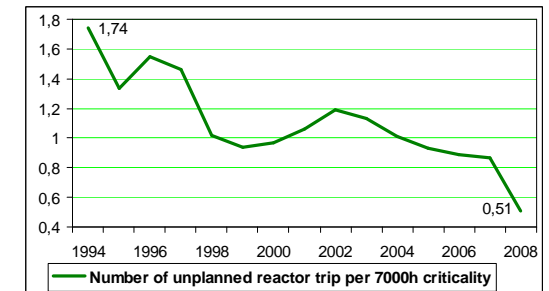


- Remain an industry standard worldwide (58 units in France)
 - Nuclear safety
 - Competitiveness, availability and operational performances
 - Plant long term operation management
 - fuel cycle and waste management efficiency
- Succeed in the EPR Flamanville 3 project, and EPR Penly 3
public debate and acceptance
safety, quality, schedule, cost...
- Become a major actor in the international renaissance of the nuclear industry :
UK, USA, China, Italy, Others ?
- One major challenge:
maintaining and developing the skills needed to achieve these objectives

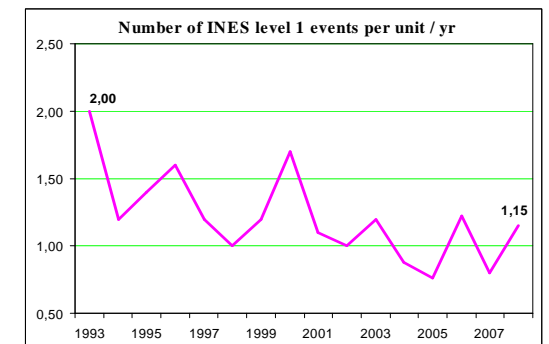
Safety: a priority at all levels



- **Safety indicators (per unit per year):** stability over last 5 years
9,2 significant events (INES rated 0),
< 1 unplanned automatic trip in 2008 (per 7000 h criticality),
1,2 INES rated event



- **Radiological protection:**
ALARA progress, average collective dosimetry: 0,8 Man.Sv per reactor/yr



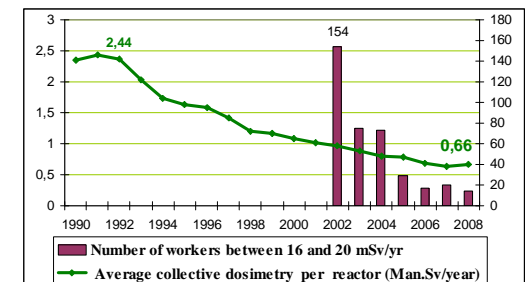
- **International assessments and peer reviews:**
IAEA Osart, WANO peer reviews (2 to 3 per year)

- **International controls:** safeguards, material accounting

- **Internal control structures:**

General Inspectorate for Nuclear Safety at Presidency level
Nuclear Inspectorate at Nuclear Generation Division level
Safety Quality Mission at Plant level

**==> Under the control of Nuclear Safety Authority
(June 13, 2006 Act on nuclear safety and transparency)**



EDF NPP's performance : annual generation output



High seasonality load in France

Winter / summer consumption ratio 1,6

→ outages in spring, summer (sea cooled units), autumn

Mix of operating cycle lengths

production equilibrium, full power in winter:

16 to 18 months for 1300 MW, N4 and CP0 plant

12 to 14 months for CPY 900 MW plants (28 units)

Extensive use of load following mode:

Primary Frequency control ($\pm 2\%$ Pn)

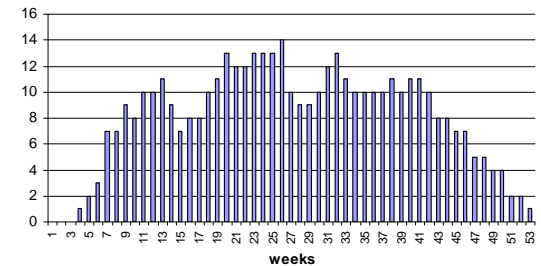
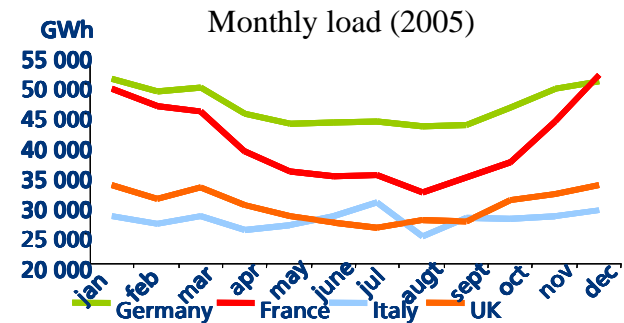
Secondary Frequency control ($\pm 5\%$ Pn),

Daily load follow (100% to 30% Pn, 3% Pn/mn),

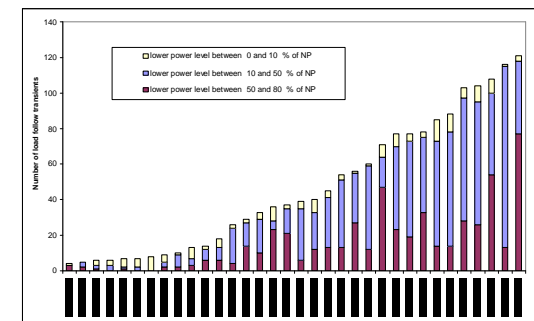
Intermediate power operation

Ku nuclear utilisation factor: around 95%

Load rejection success rate: 88% (average)



Ex: weekly number of refueling outages (2006)



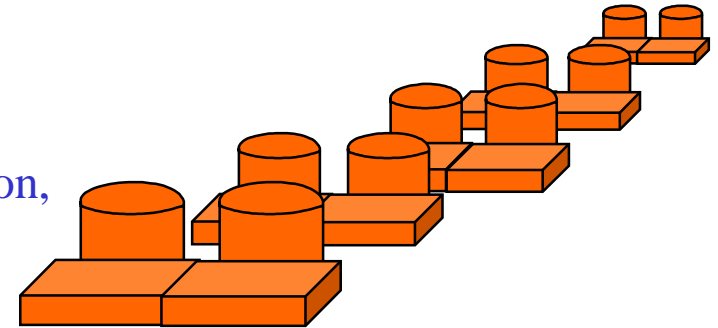
Ex: Load variations per cycle on 900 MW (2006)

Standardization benefits and anticipation



Benefits of standardization:

- Quality and efficiency of construction and engineering studies, construction cost and schedule,
- Safety and experience feedback, lessons learned and anticipation,
- economics and optimization of resources for engineering, operation and maintenance



1300 reactor.years of operation

A lever to detect any deviation and to anticipate risk of failure before any impact

- preventive program and controls on each series
- plants have been put in operation within 15 years timespan
- development of experience feedback on a large scale on similar plants to implement preventive measures at a early stage, along with use of international experience feedback
- periodical ten years safety assessment on all plant series, plant behavior and equipment check up
- aging assessment of main equipments (vessel, containment, SG...)

→ A lever for long term operation management

Operation time extension for Nuclear fleet: an asset and a challenge



Every 10 years, a safety reassessment process is performed for each series of plants;

- reassessment and updating of the licensing basis, experience feedback, new knowledge or evolutions,
- probabilistic studies, backfitting (cost / benefit analysis), seismic assessment, aging assessment of main components (nuclear vessel, containment, qualification of equipment,
- compliance assessment and checking
- as a result, a new safety referential and an improvement programme is proposed to ASN

An on going process for preparation, strategic decision, studies, realisation

- 900 MW: last VD2 in 2009; first VD3 at TRI1: restart approval ; FSH1: beginning of VD3 outage...
- 1300 MW: VD2 in progress; VD3 in preparation (FOAK in 2015)...

A 40 years operation time can be technically attained for existing plants

- implementation of systematic maintenance program and periodical safety updating of the units,;
- a sustained R&D effort, focused on long-term behaviour of main components, in particular for equipments seen as non replaceable (reactor vessel, containment building), aging ability file for each component,
- creation of the Material Aging Institute at EDF R&D with other major industrial partners...

The EDF objective is to extend the operation time beyond 40 years, up to 60 years, under ASN control

- technically possible, notably for equipments seen as non replaceable (reactor vessel, containment building);
- At the end of 2006, more than 47 license renewal have been granted up to 60 years in the USA which confirms the possibility of an extended operation time (with a different regulatory framework)

Ten years outages and operation duration management Industrial Program



Objective: to maintain open the option of an operation duration of up to 60 years for the whole nuclear fleet.

A realistic objective, as shown by:

- french and international experience feedback (EF) for same kind of reactors
- continuous improvement in safety level and performances: periodic safety review process, R&D programs....

An industrial program which relies on:

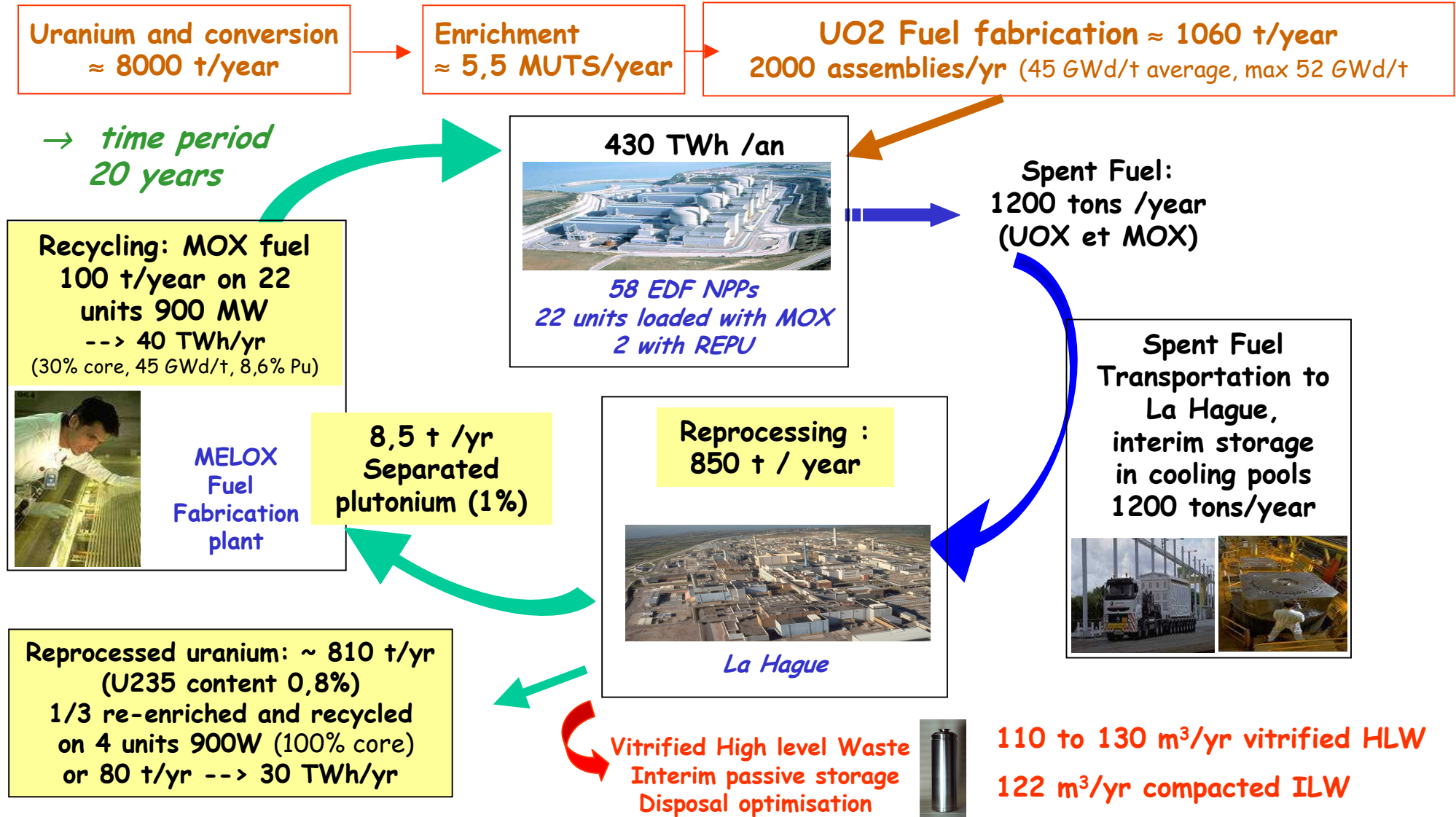
- pursuing the continous safety level improvement and environment protection improvement program (feedback from VD3 900, preparation of VD3 1300...)
- anticipation program for aging effects or obsolescence of components

Acquiring a 20 years perspective for investment decision

Studies on power uprating on 1300 MW (within authorization decree limits)

Nuclear fuel cycle industry in France

A major contribution to energy sustainability



Nuclear fuel cycle industry in France

A major contribution to energy sustainability



The current reprocessing recycling strategy is a major asset for sustainable nuclear energy in the following respects:

- **Ensuring a safe and long lasting confinement of high level waste by vitrification in inert glass canisters under a reduced volume,**
a safe and long-lasting containment, internationally recognized
in a suitable form to be stored and ultimately disposed of in an optimised package,
under limited volume (130 m³/year for 400 TWh) and disposal cost;
- **Reducing the quantity of stored spent fuel,**
7 UO₂ spent fuel result in 1 MOX spent fuel, in which plutonium is concentrated (5%);
- **Recycling of plutonium and recovered uranium, while getting back energy output**
produces 40 TWh/yr (10% of nuclear production) in 20 units (30% of the core)
4 units feeded with REPU fuel (100% core),
- **Maintaining the possibility in the far future to use the plutonium resource**
concentrated in MOX spent fuel, under small volume, full safeguards
leaves open the possibility to reuse Pu in future GEN4 fast reactors

The management of radioactive material and waste



- **Management of Radioactive waste: 4 industrial principles**

- limiting production at the origin limiter,
- sorting out according to activity level and lifetime,
- conditioning under a stable package, recycling of valuable material
- isolating from man and environment

- **Radioactive waste are produced in a limited quantity :**

- 1 MWh gives raise to 11 g of radioactive waste of which 90 % short lived
- long lived waste (B+C) \approx 1g/MWh, of which vitrified HLW (FP+MA) \approx 0,15 g/MWh

- **Radioactive waste are identified, classified, accounted for and confined**

solutions for their safe disposal are defined and financed

- **Low and intermediate short lived waste, and very low level waste, are disposed of and confined in a safe and definitive way (volume 90%; activity < 1%)**

Sorted, Conditioned, Disposed of in two surface repositories operated by Andra (Aube centers)




- **High level waste, long lived, are stored in a safe way, within vitrified canisters and passive storage facility (1 ha for 40 years of french nuclear fleet production),**

waiting for implementation in a geological disposal center under study by Andra (Bure)

Waste disposal routes



Half-life :
30 years

	Short lived	Long lived
VLLW Very Low Level Waste	Very Low Level Waste: subsurface 	
LILW Low to Intermediate Level Waste	LILW short lived: subsurface 	<ul style="list-style-type: none"> ▪ Graphite ▪ LILW long lived
HLW High Level Waste	High Level Waste Deep repository (Used Fuel reprocessed) 	

Studies for future back end options: the June 2006 law on Sustainable management of Radioactive Material and Waste



1/ R&D studies to be pursued on three complementary lines:

- Partitioning and transmutation of HLW, in relation with studies on future reactors, to assess the industrial perspectives for those systems (2012) and to develop a prototype reactor (timeframe 2020 - with a focus on Sodium cooled fast reactors);
- Geological disposal, as a reference solution, in order to prepare a licensing procedure (site selection, design options..) in 2015 and implementation in 2025;
- Interim storage: new capacities, or existing to be adapted, for 2015, according to the needs;

2/ A National Program for the Management of Nuclear Material and Radioactive Waste, featuring reduction of the quantity and toxicity of radioactive waste, notably through spent fuel reprocessing and treatment of radioactive waste;

3/ Financial settlements

- for local economic development and R&D expenses (Andra),
- for cost assessment for HLW management options and related provisions (long term liabilities) with dedicated financial assets.

The EPR project :
a « robust » design
under construction at Flamanville 3
Studies for Penly 3

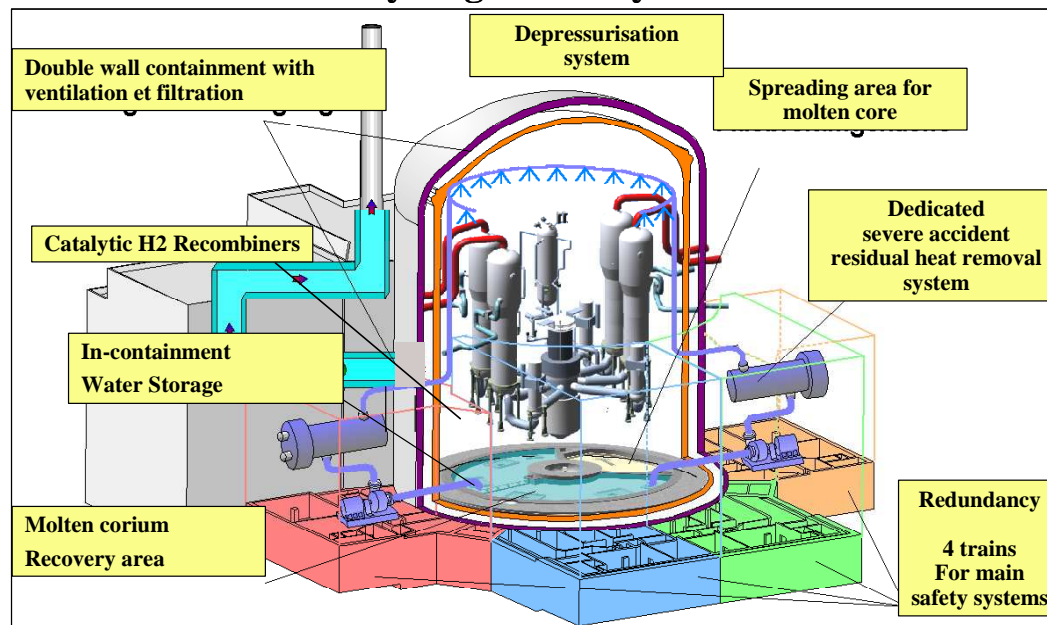
EPR : a « robust » design under construction at Flamanville 3



- An evolutionary and proven design, embedding improvements resulting from experience feedback and French German cooperation since more than 10 years
- 4 EPR under construction (Olkiluoto 3, Flamanville 3, Taishan 1 and 2)



Main Safety Engineered systems



Flamanville 3

- Site selection: october 2004
- first concrete: end of 2007
- Commissioning: 2012

+ EDF project for a second EPR at Penly in partnership
To comfort security of supply in France and Europe in the years to come
Public debate planned 1st semester 2010

The EPR project : FLA 3



Launch of the First of a Kind EPR in France, as provided by the Program Law of energy policy guidelines of July 13, 2005, in order to preserve the nuclear option in France



Industrial stakes:

- Maintain EDF's leadership and human resource in nuclear development
- Prepare the renewal of EDF's fleet, with a proven Gen 3 reactor before 2020, and fabrication capacities
- An evolutionary design for a proven design, with improvements resulting from experience feedback

Operation and Safety Improvement:

- Net power capacity 1600 MW, service life of 60 years (at design stage)
- increased reliability in operation, availability factor 91%, annual generation ~13 TWh
- reduction of the likelihood of a major accident and limitation of consequences (core-catcher with cooling)
- design based enhanced protection against hazards (fire, earthquake, flooding, extreme weather, plane crash..)

Environmental improvement:

- reduction of the quantity of materials irradiated in the reactor by 30 %,
- reduction of liquid radioactive waste and gaseous release / MWh by 30 % (apart tritium and C14)

Economy: - levelized generation cost of FOAK FLA3: 54 Eu₂₀₀₈/MWh; EPR in France: 55 to 60 Eur/MWh; CCG: 61 Eu/MWh (oil: 50\$/b) to 68 Eu/MWh (CO₂: 20 Eu/t)

**EDF international nuclear development :
« Leading the energy change »
for low carbon energy sources**

EDF international nuclear development



Using EDF experience

- as architect engineering, project management and nuclear fleet operator
- and from building, commissioning and operating FLA 3,

and taking benefit of standardized units for construction and sustainable operation, focused on 1650 MW EPR model, using wherever possible the FLA 3 standard design:
time savings (licensing, engineering), investment savings (purchasing, engineering), international feed-back within the EPR series under operation, master and limit adaptations whilst complying with local regulation and requirements (e.g. digital I&C)

EDF has the ambition to to invest in the construction and operation of nuclear plants abroad, in the framework of partnership adapted to the specificity of each country;

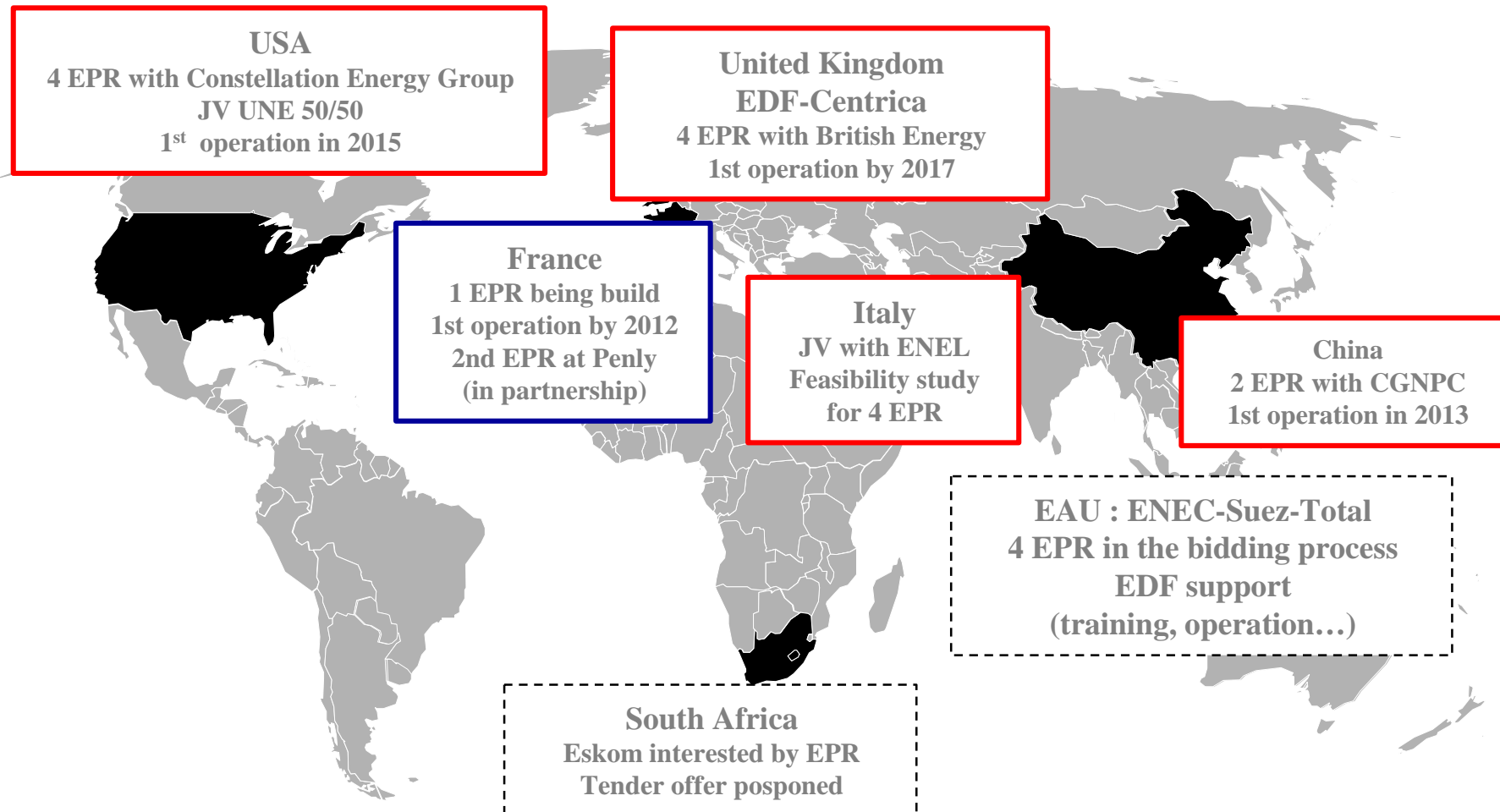
- up to 12 EPR units to be commissioned up to around 2020,
- with a corresponding effort in competence development and human resources.

EDF strategy and criteria to engage on a New Nuclear Build Abroad



- Countries choosing to develop nuclear energy in the short-term
- Countries where EDF is welcome
- Countries with favorable conditions for investors in nuclear energy
 - comprehensive and stabilized legal framework
 - effective regulatory system
 - management policy of nuclear materials and radioactive waste
- Public opinion and governmental authorities in favor
- Projects based on proven reactor designs
- Local partners with good track record in building and operating electricity generation
- Financial criteria meeting the Group's financial targets and risk policy

A strategy focused on 4 countries to develop, invest, build and operate 12 EPR at the horizon 2020



United Kingdom with BE: a reinforcement in the EDF group electricity production



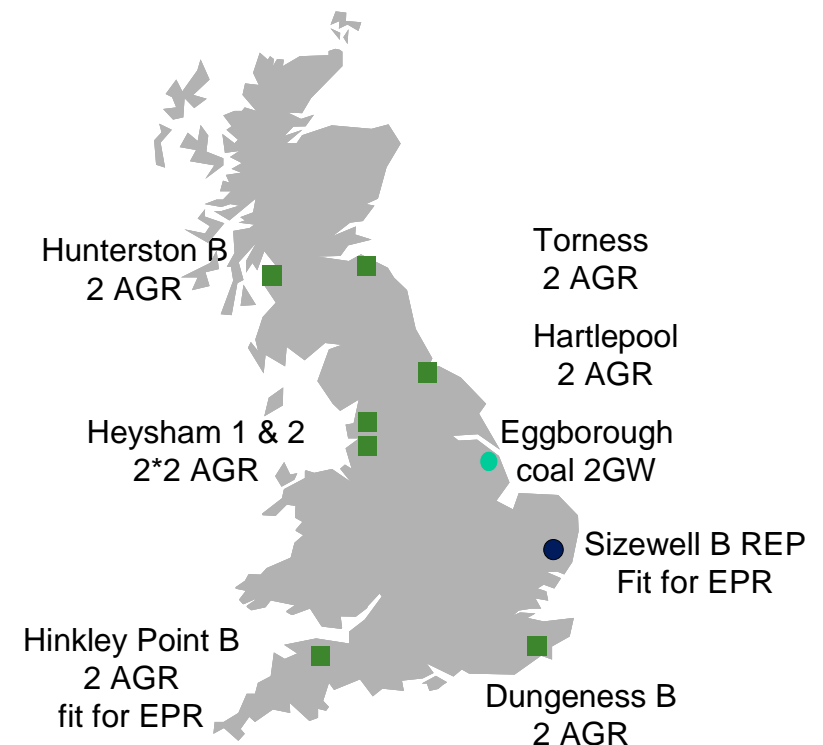
Nuclear in UK:

- 12 GW (15% of UK installed capacity ; 20% of power generation)
- BE operates 15 units en 8 sites (14 AGRs - \approx 550 Mwe each - on 7 sites; 1 REP 1200 MW on 1 site)
- NDA operates 4 units (Magnox) on 2 sites
- Licensing with 2 stages: generic design approval and site licensing; scheduled duration 3,5 years
- most nuclear units are to close around 2025
- Sizewell B (PWR) is to be the last to operate after 2025

Key points :

- 4 EPR can be constructed on BE sites (Hinckley Point, Sizewell...)
- consistent with the UK Government objective to promote competition for new build (site transfer...)
- EDF will rely on expertise and human resources of BE to build these plants

BE sites



“Set EDF as an industrial and financial player of UK’s nuclear new phase”

P. Gadonneix, 07/25/2006



- Replicate Flamanville 3 with an aim to develop up to 4 EPR in the UK, **benefiting from standardisation effect**
- Investor / Architect Engineer / Operator
- Combined EDF and British Energy capacities for the development of new nuclear power plants, benefiting from strong operating know-how and nuclear engineering expertise of the British Energy and EDF teams
- Build up a strong case in order to get public acceptance
- Develop Local Partnerships
- Increase EDF Energy’s vertical integration

UK EPR Build key dates:

- GDA assessment: 2010; Strategic site assessment + site licensing: 2011
- preparatory work: 2011 / 2013; construction: 2013 / 2017: first concrete in 2012
- first unit to be commissioned in 2017

China

CGNPC : a long term partnership with EDF



The Chinese electric sector:

622 Gwe (2006), coal 78%, hydro 20%, nuclear 0,8%

Objective for nuclear in 2020: nuclear up to 4 to 5%

40 GW operating, + 20 GW under construction

CGNPC (China Gang Dong Nuclear Power Company) : a nuclear leader in China

4 GW operating (Daya Bay 1/2, Ling Ao 1/2),

+ 20 GW under construction or projected

construction of CPR 1000 (Gen 2+); choice for AP1000, EPR (Gen 3)

CGNPC builds and operates NPPs, the technology of which is well known to EDF with high performances in safety and availability

A cooperation between EDF and CGNPC since more than 20 years:

support for construction and operation of Daya Bay 1/2, Ling Ao 1/2 and 3/4

(1000 MW reactors delivered by AREVA)

China: Partnership with CGNPC

China Gangdong Nuclear Power Company



Key objectives:

- be a co-investor/operator on nuclear projects based on technology known to EDF, while providing technical support to the project
- creation of the Taishan Nuclear Power Company TNPC JV (August 10, 2008)
 - 30% EDF, 70% CGNPC - in Taishan - Gangdong province
 - . TNPC is owner and operator of 2 EPR 1700 MW developed by AREVA
 - . governance rule for safety and performance
 - . construction start Fall 2009; first concrete autumn 2009
 - . commissioning forecast: unit 1 in 2013 ; Unit 2 in 2014
- subsequent development of a wider partnership with CGNPC in terms of engineering or as an investor in other Chinese or international projects

Industrial scheme:

- industrial model: project management / construction / commissioning / operation
- Use of the EPR Flamanville 3 reference model
- EPR at Taishan: taking into account the EPR Flamanville 3 experience and initial feedbacks (project started 18 months earlier)

United States: Partnership with Constellation



Key objectives

- develop an industrial partnership and invest in a leading US nuclear operator to build EPR together
- leverage on EDF's experience and know-how in nuclear energy

Partnership agreement with Constellation Energy - July 2007

Key points

- setting-up and development of a 50/50 JV: Unistar Nuclear Energy LLC
 - . priority given to the development of a first series of 4 EPR redesigned for 60 Hz and US licensing (Areva and Bechtel)
 - . 3 sites made available to the joint-venture by Constellation Energy
 - goal for Calvert Cliff 3: first concrete 2011, first EPR in service in 2015

EDF proposal to acquire 50% of Constellation Energy's Nuclear generation and operation business

Italy : industrial agreement with ENEL



Italy was a precursor in civil nuclear in Europe, followed by a moratorium decided in 1987

Now a political will to relaunch nuclear:

- July 9, 2009, act adopted by Italian Senate in favour of Nuclear production in Italy
- More positive public opinion
- Favourable economic environment for the development of nuclear energy

=> **EDF participation in the nuclear renewal in Italy**

- ENEL partnership in EPR at Flamanville 3 (12,5%)
involvement of ENEL engineers in the project
- Industrial agreement with ENEL
consortium 50/50 for feasibility studies to build 4 EPR
ENEL participation in the EPR in Penly

Benefits of standardization for economics and safety



- Fleets of international standardized designs offer a broad basis for construction and long term operation experience feedback
 - Design improvements can be anticipated and implemented across the fleet, risk of a design shortcoming affecting the whole fleet can be prevented due to high probability of early detection of design flaws
 - Standardized designs facilitate investment by allowing for a streamlined and predictable licensing procedures, reducing construction time & cost, and releasing strain on regulatory resources
 - Public confidence in regulatory decision increases
 - New nuclear states: gain maximum safety and efficiency from, for instance, a European nuclear fleet feedbacks
- => If well managed, standardized advanced plants will bring additional safety layers for design, construction, long term operation and increased efficiency for engineering, operational resources and cost management.

Key factors for success



- Adapting to the country and its industrial environment
 - Drawing on the expertise of local benchmark electricity players involved in the construction and operation of nuclear fleet (British Energy, CGNPC, CEG,...)
 - Adapting the organisational model, in particular through industrial agreements with local engineering companies: CGNPC-CNPEC, Bechtel (USA), AMEC (UK),...
- Using wherever possible the Flamanville 3 / FOAK projects as reference models, whether in Americas, Asia, Europe,...
- Gaining from our strong French base (=> standardisation effect)
 - pooling the resources needed for the different projects
 - accumulating know-how and resources, experience feedback sharing
 - drawing out standard construction and operating rules
 - long term operation of a standardized fleet
 - benefit for safety, economy and performances
- Relying on the Group's existing resources, skills and expertise