Nuclear Power in France

Dr. Luc H. Geraets
Vice President, GDF SUEZ Nuclear Activities
May 13, 2010

Nuclear Power in France (and Belgium)

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1. Nuclear in France (and Belgium) in a nutshell
2. Early steps
3. From GCR to PWR
4. Fuel cycle
5. Wastes
6. Decommissioning
7. Research & Development
8. Nuclear capacity maintenance and growth
9. Economics
10. Human Resources & Public Acceptance
11. Risks

Conclusions

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Nuclear Power in France in a nutshell

- 75% of French electricity from nuclear origin
- France world largest net exporter of power
  - ✓ Low cost of generation
  - ✓ Huge benefit on the trade balance (MEUR 3,000/year)
- Development of nuclear technology and exports
  - ✓ Reactors
  - ✓ Fuel products and services
- New build of Generation III under way

Nuclear in Belgium: GDF SUEZ nuclear legacy and legitimacy

- **Stakeholder in Western first commercial PWRs**
  - ✓ BR 3 (1962-1987)
  - ✓ Chooz A (1967-1991)

- **Operator of 7 reactors in Belgium**
  (3 at Tihange and 4 at Doel)

- **The Group capacities : 5 930 MW**
  - ✓ Belgium 4 060 MW
  - ✓ France 1 170 MW (Chooz B and Tricastin)
  - ✓ Germany 700 MW (Unterweser, Gundremmingen B&C, Krümmel)

- **Strengths**
  - ✓ **Independent** from suppliers & vendors.
  - ✓ **Several** reactors types (PWR)

- **Objective : pursue operation after 2025**

Nuclear in France and Belgium

Source: US EIA

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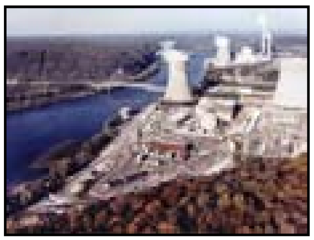
Concepts and their evolution

Generation I

Early Prototype Reactors



- Shippingport
- Dresden, Fermi I
- UNGG
- BR3

Generation II

- LWR-PWR, BWR
- CANDU
- VVER440/RBMK
- Magnox, AGR
- SENA

Generation III

Advanced LWRs

- ABWR
- System 80+
- AP600
- **AP1000**
- **EPR**
- VVER1000
- **ATMEA**
- APWR

Evolutionary Designs Offering Improved Economics

Generation IV

- Highly Economical
- Enhanced Safety
- Minimal Waste
- Proliferation Resistant

Gen I | Gen II | Gen III | Gen IV

1950 1960 1970 1980 1990 2000 2010 2020 2030

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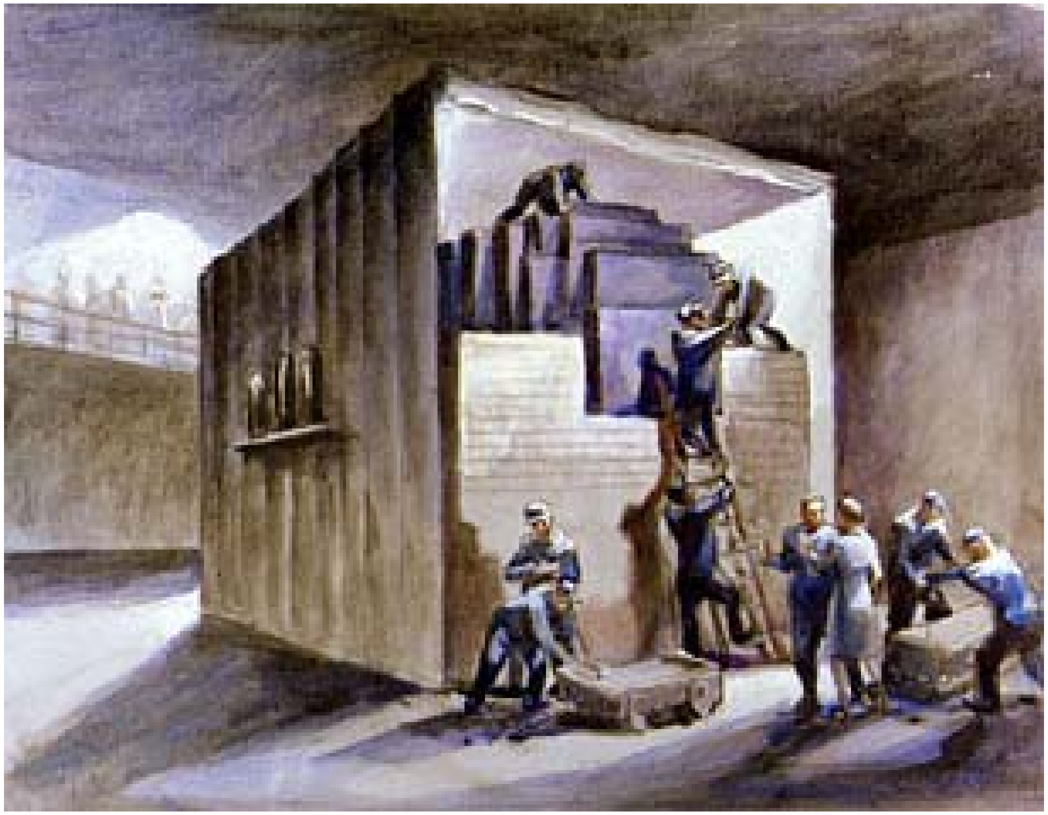
Early steps in the world



Fermi Pile (1942): first critical chain reaction

Early steps in the world (cont'd)

- **From the abandoned squash court to the industrial use**
  - ✓ **Fermi pile (Chicago, 1942)**
  - ✓ **Arco, ID (1951)**
  - ✓ **Obninsk (1954)**
  - ✓ **Calder Hall (1956)**

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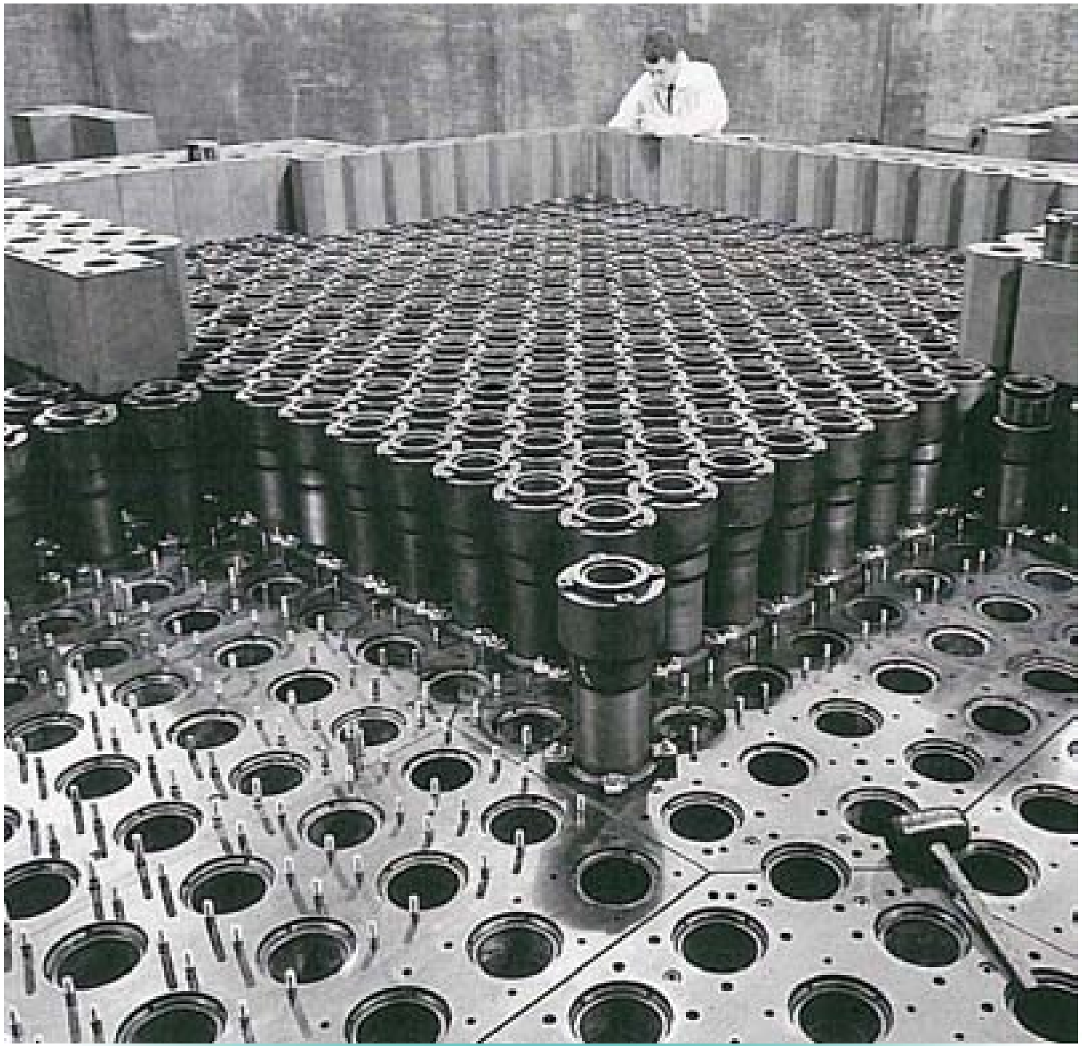
Early steps in France and Belgium

- Creation of the CEA (Atomic Energy Commission) (1945)
- ZOE (1948)
- EL2: 2 MW thermal neutron reactor (Saclay, 1953)
- CEA Gas cooled reactors (Marcoule)
  - ✓ G1 (2 MW, 1956)
  - ✓ G2 (40 MW, 1958)
  - ✓ G3 (40 MW, 1960)
- Gas cooled heavy water reactor (Brennilis, 1967, 70 MW)
- Fast neutron reactors
  - ✓ Rapsodie (Cadarache, 1962)
  - ✓ Phenix (Marcoule, 1973, 233 MW)
- Belgium takes the PWR lead
  - ✓ BR3 (11 MW, 1962)
  - ✓ Eurochemic (Mol, 1966)
  - ✓ Chooz A (260 MW, 1967)
  - ✓ Tihange 1 (870 MW, 1975)

Early steps (cont'd)

- Scarcity and cost of enriched uranium (+ dependency) => EDF selects the gas-graphite design
  - ✓ Chinon A1 (70 MW, 1963), A2 (200MW, 1965), A3 (480 MW, 1966)
  - ✓ Saint-Laurent des Eaux A1 (480 MW, 1969), A2 (515 MW, 1971)
  - ✓ Bugey 1 (540 MW, 1972)
- CGE of France buys a BWR license from GE
- International cooperation
  - ✓ Euratom Treaty (1957)
  - ✓ French-Belgian partnerships

Piling graphite plots in Chinon A2



Source: Areva

Bugey

Source: Areva

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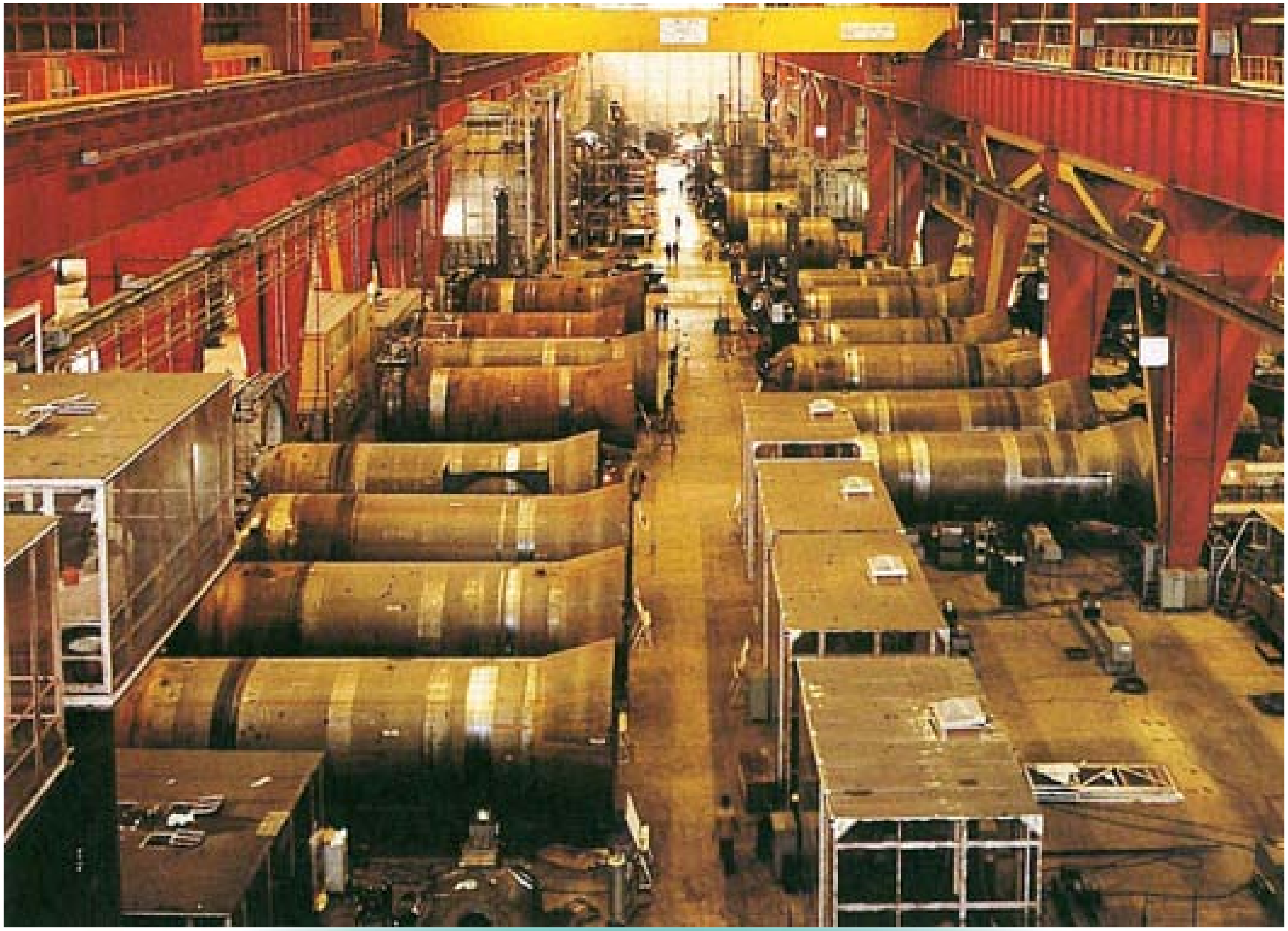
From GCR to PWR

- European countries heavily dependent on oil and gas imports from MEA
- 1973 embargo: oil price quadrupled in 5 months
- France depends on imports for 76% of its energy supply
- GCR reactors produce less than 2% of the energy used in France
- Enriched uranium becomes available
  - ✓ Pierrelatte
  - ✓ Eurodif

⇒ August 4, 1974: France abandons the gas-graphite design from CEA and the BWR from CGE/GE and launches its PWR programme

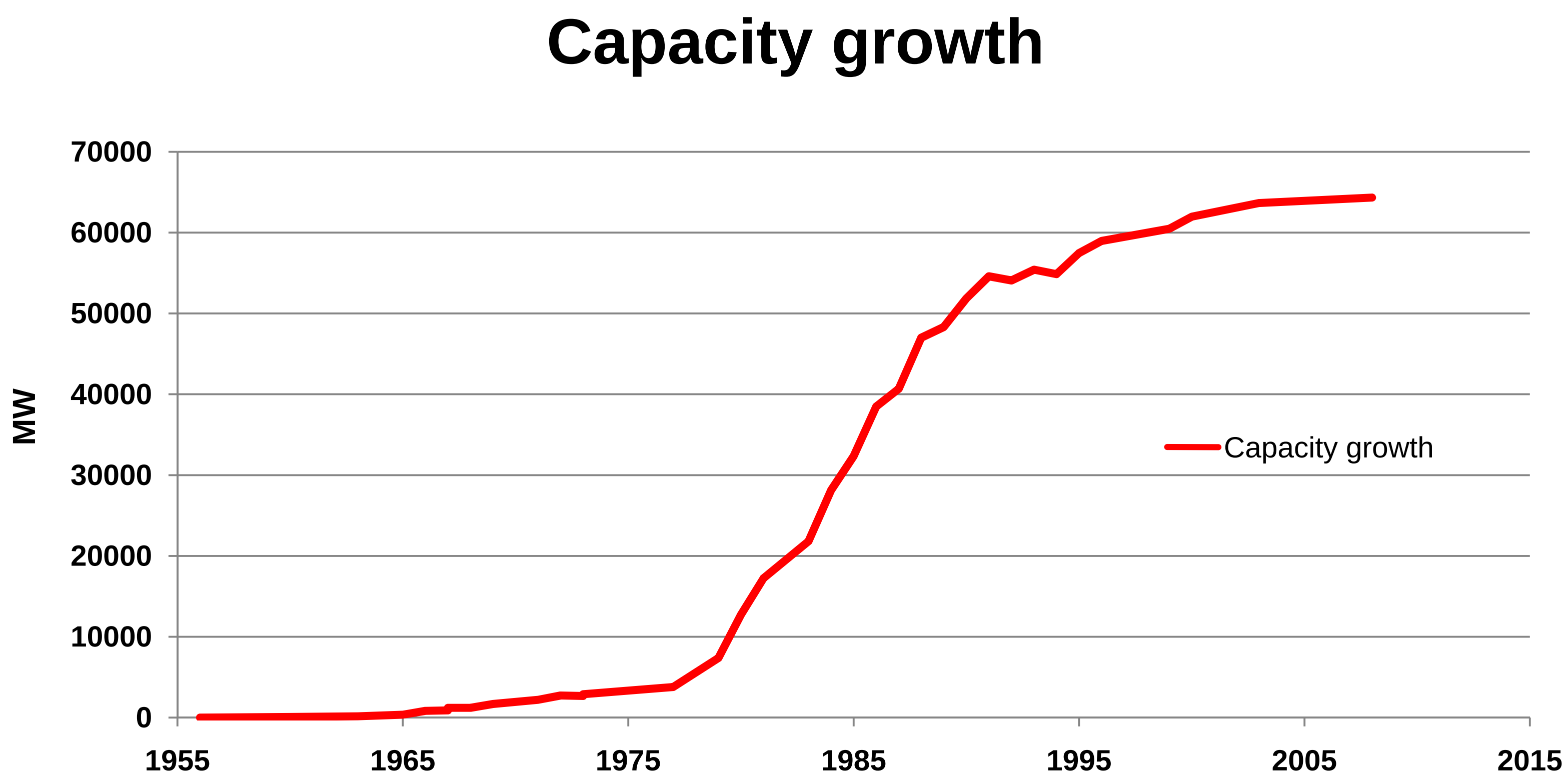
CP0 (1974, 5 units of 900 MW)	P4 (1977, 8 units of 1300 MW)
CP1 (1974, 16 units of 900 MW)	P'4 (1979, 12 units of 1300 MW)
CP2 (1976, 10 units of 900 MW)	N4 (1984, 4 units of 1450 MW)

Chalon Saint Marcel

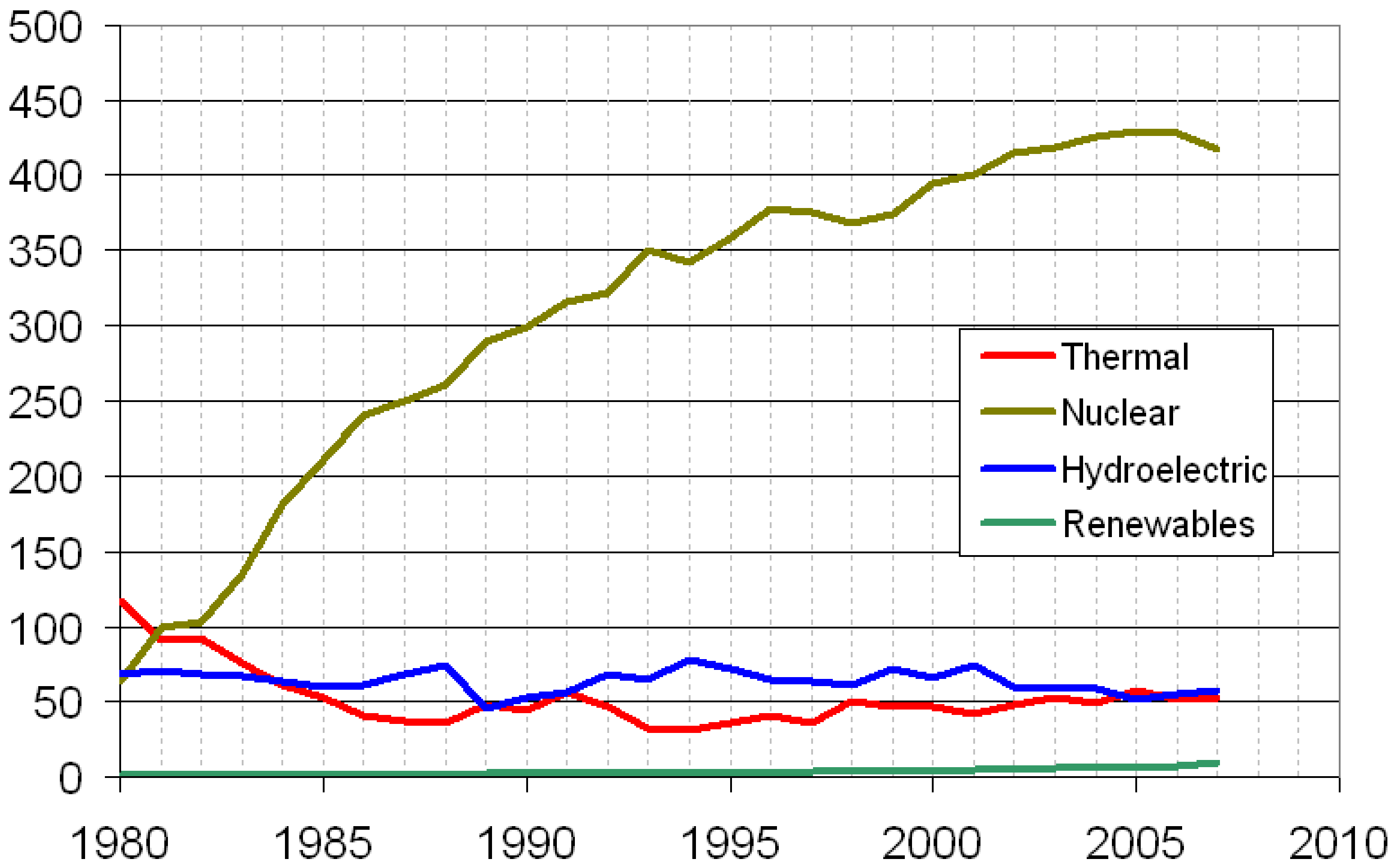


Source: Areva

French nuclear capacity growth



Electricity production in France by source (TWh)



Source: US EIA

Rules and regulations

- Strong standardisation required
- Framatome and EDF plant drawings valid for a series of units (no North indicated)
- Development of “procedures” for fabrication and erection (anywhere in the world)
- Field procedures always the same (strict QA programme)
- Formalisation of French Design and Construction Rules (“RCCs”) into a “bible” of reference regulations:
  - RCC-E
  - RCC-G
  - RCC-I
  - RCC-M
- Belgium, instead of developing a comprehensive nuclear regulation, opted for the full endorsement of the US set of rules

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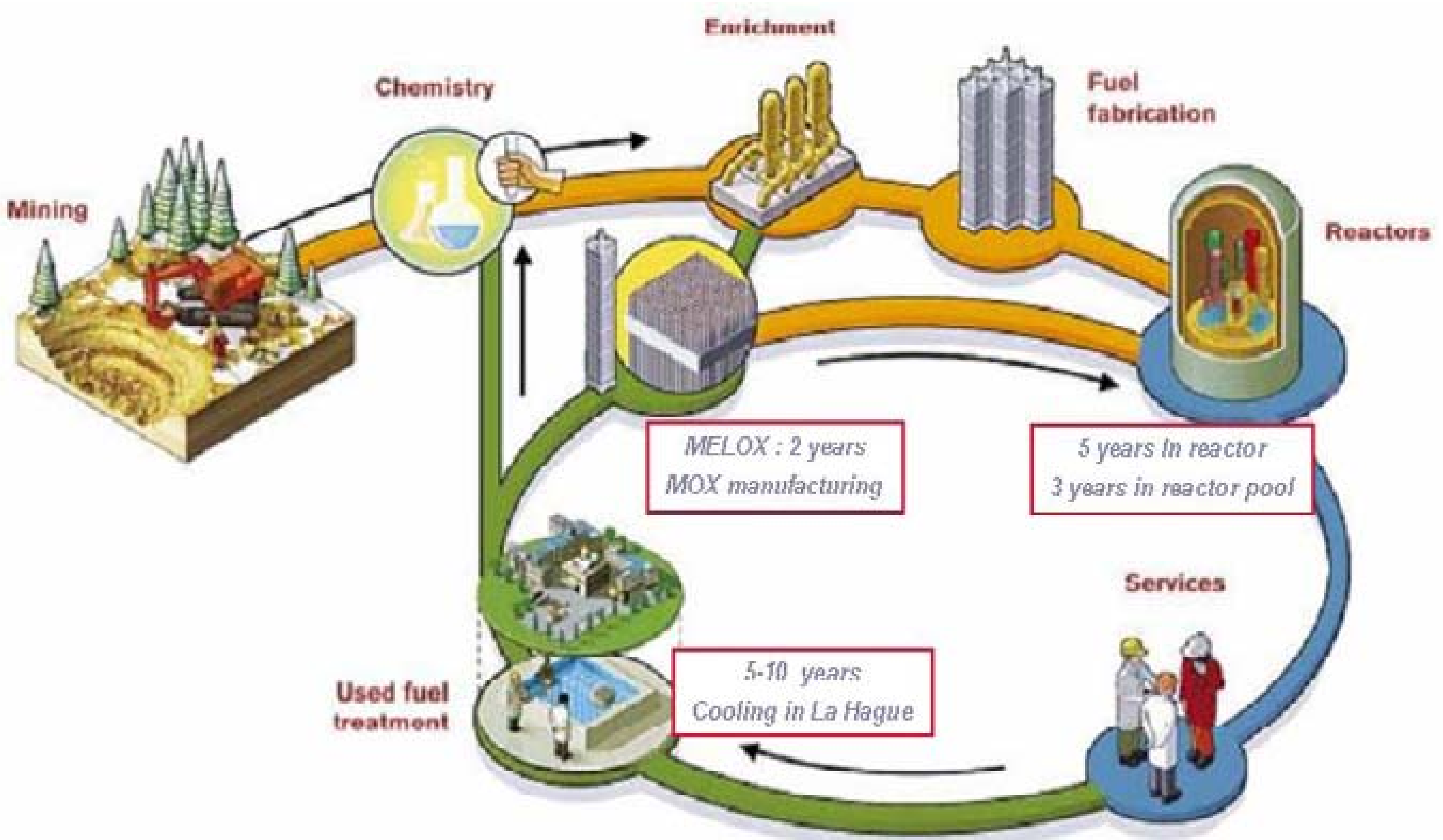
Fuel cycle



Source: Areva

Uranium mining in France

- The largest European supplier for decades (since 1946)
- Last mine (Jouac) closed in 2001

Source: IRSN

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Fuel cycle: front end

- Uranium mining
  - Domestic uranium mines exhausted
  - Uranium imports from Canada, Niger, Australia, Kazakhstan, Russia
  - Recent mining contract for Areva in Jordan
- Other steps of the front end fuel cycle: France self-sufficient
  - Conversion: Comurhex (Pierrelatte), Comurhex II (Malvesi, Pierrelatte)
  - Enrichment: Eurodif, GBII
  - Fuel fabrication: several plants in France and Belgium, incl. MOX fabrication

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Fuel cycle: back end

- Eurochemic in Belgium (OCDE)(1966-1974)
- France has selected the closed fuel cycle
  - Recovery of uranium and plutonium for re-use
  - Reduction of the volume of high level wastes for disposal
- Areva NC (formerly Cogema) La Hague facility
  - Capacity of 1,700 tonnes per year of used fuel
  - Pu sent to Melox plant for MOX fabrication
  - RepU sent to Comurhex for conversion
- Research and development areas for the next decade
  - COEX process (uranium/plutonium co-extraction and precipitation) -> Gen III
  - Separation of long lived radio-nuclides (Am, Cm) -> Gen IV blanket
  - GANEX extraction of actinides for homogeneous recycling -> Gen IV fuel

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Wastes

- ANDRA established 1991 as the national radioactive waste management agency
- Nuclear Materials and Waste Management Programme Act passed in 2006
  - ✓ Deep geological disposal is the reference solution for high level and long-lived radioactive wastes
  - ✓ 2015 is the target date for licensing a repository
  - ✓ 2025 is the target date for opening it
- Reprocessing and recycling of heavy metal
- Prototype Gen IV reactor by 2020 to test transmutation of long-lived actinides

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Types of (solid) wastes

- Spent fuel
  - Recycling
  - Final disposal
- High level wastes
  - From recycling of fuel: vitrified F.P., sleeves, heads and tails, compacted technological wastes
  - From dismantling: reactor vessel internals
- Medium level wastes
  - Ion exchange resins, filters (primary and secondary systems)
- Low and LL level wastes (incl. dismantling wastes)
  - Back-end of evaporators used for liquid waste handling
  - Filters (HVAC systems)
  - Shielding clothes
  - Organic fluids (oil)
  - Metals, pieces of equipment, miscellaneous

Classification of wastes

- Short-lived radioactive waste
- Long-lived radioactive wastes

Operational

Under investigation

<table>
<tr><th></th><th>Short-lived
(half-life < 30 years)</th><th>Long-lived
(half-life > 30 years)</th></tr>
<tr><td>Very low level
(VLL)</td><td colspan="2">VLL Waste Disposal Facility (Aube)</td></tr>
<tr><td>Low level
(LL)</td><td rowspan="2">LL/IL Waste Disposal Facility (Aube)</td><td>Investigations on repository projects
Commissioning in 2013</td></tr>
<tr><td>Intermediate level
(IL)</td><td></td></tr>
<tr><td>High level
(HL)</td><td colspan="2">Investigations conducted in accordance
with the Act of 2006</td></tr>
</table>

Waste handling, conditioning and final storage

<table>
<tr><th>Type of wastes</th><th>Interim storage</th><th>Final storage</th></tr>
<tr><td>Spent fuel</td><td>Wet storage in pools
Dry storage in casks</td><td rowspan="2">Underground storage after cooling</td></tr>
<tr><td>High level wastes</td><td>Vitrification</td></tr>
<tr><td>Medium level wastes</td><td>Cementation
Hot compaction</td><td rowspan="2">Above ground storage
Geological repository</td></tr>
<tr><td>Low level wastes</td><td rowspan="2">Incineration
Cementation
Compaction
Absorption</td></tr>
<tr><td>LL level wastes</td><td>Free release
Landfill
Above ground storage</td></tr>
</table>

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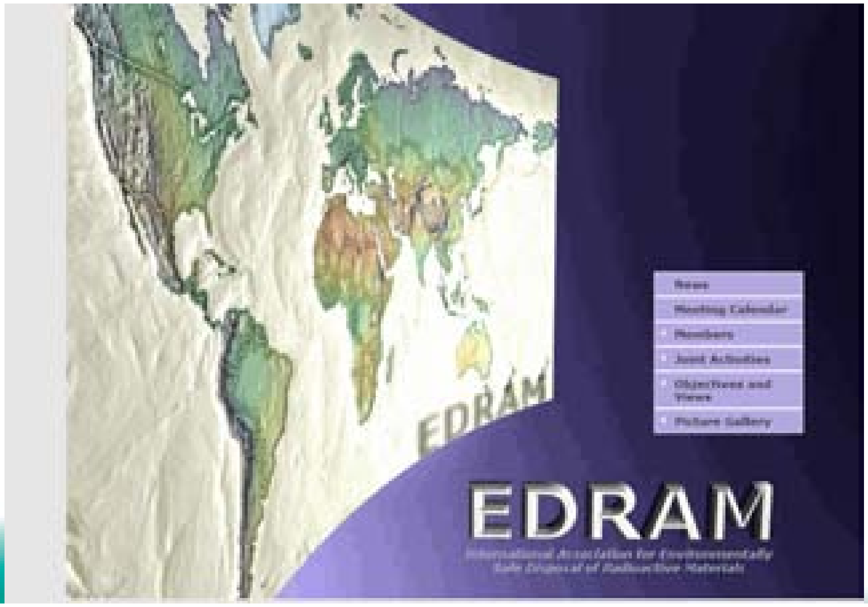
Examples of final storage facilities

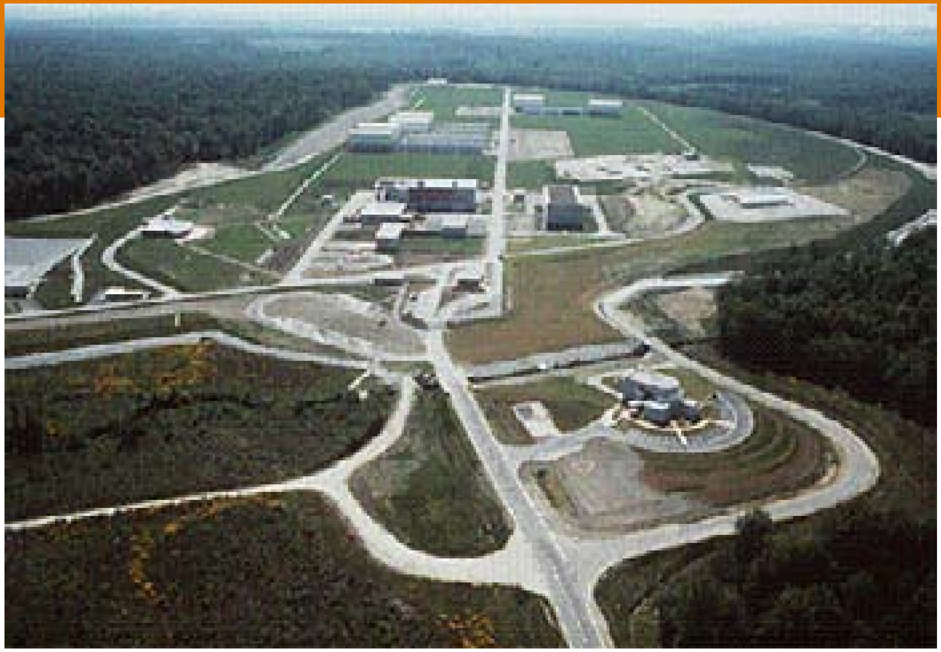
- Low level wastes storage
  - Centre de l'Aube
  - Morvilliers
  - Geological clay repository

- High level wastes (incl. spent fuel) storage

- Pictures from EDRAM (http://www.edram.info/en/)



Centre de l'Aube Disposal Facility (LL/IL-SL)



- Commissioning:	1992
- Service lifetime:	60 years
- Capacity :	1,000,000 m^3
- Disposed waste:	200,000 m^3
- Disposal area:	30 ha
- Monitoring:	300 years

Financed by major waste producers

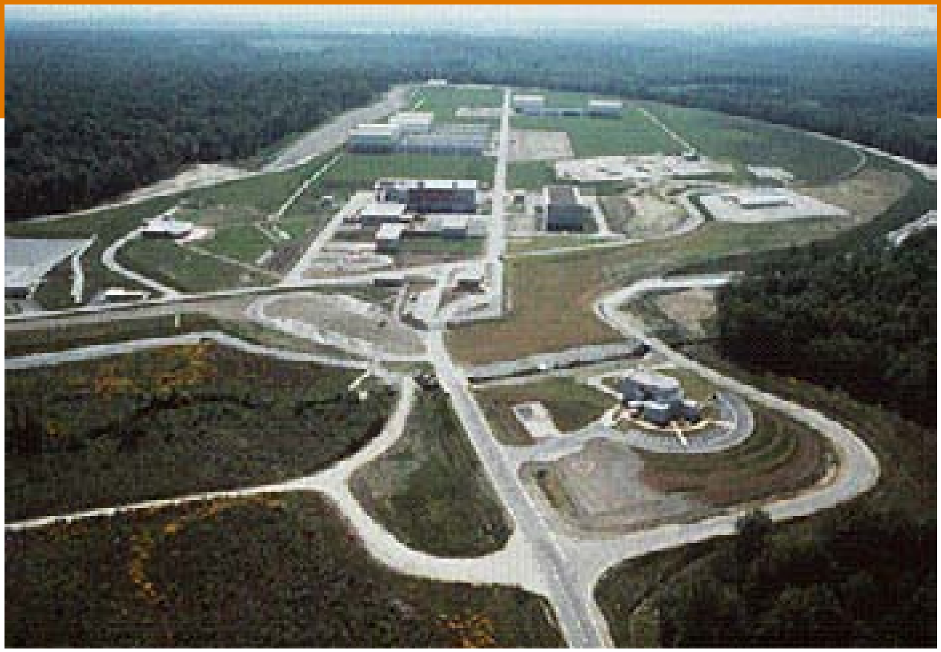
Initial investment: 221 M€

Costs (excluding taxes and insurance): ~25 M€/y

VLLW Disposal and conditioning facility – Morvilliers

Project launching: 1999/2000	
Commissioning: Summer 2003	
Area	45 ha
Capacity	650,000 m^3
Service lifetime	30 years
Quantity of disposed waste	~45,000 t

Centre de l'Aube Disposal Facility (LL/IL-SL)



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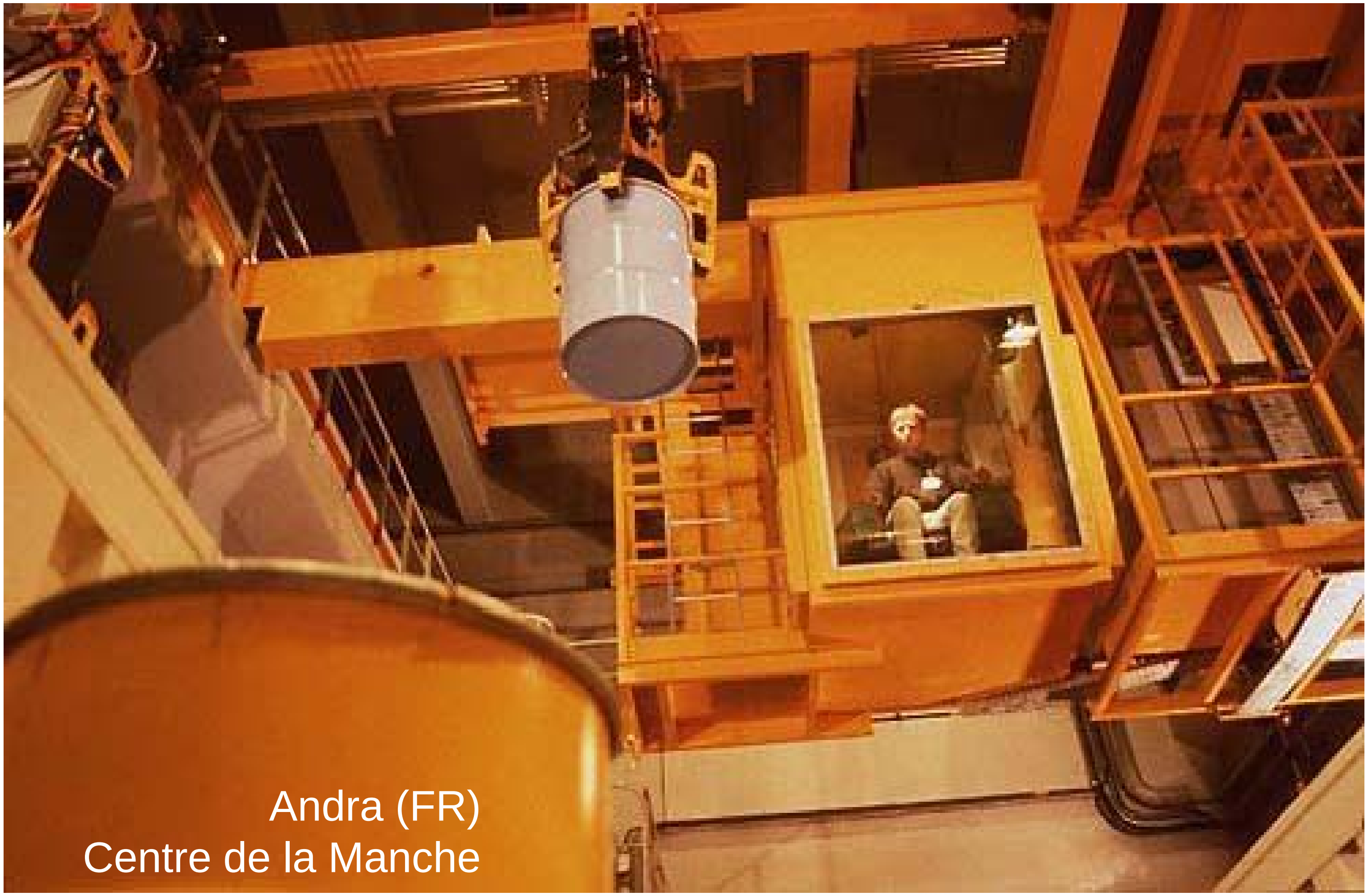
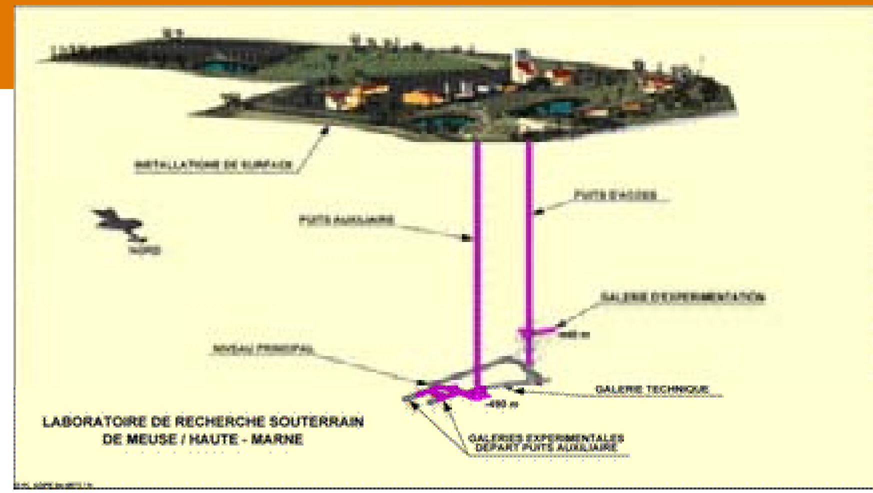
IL/LL wastes



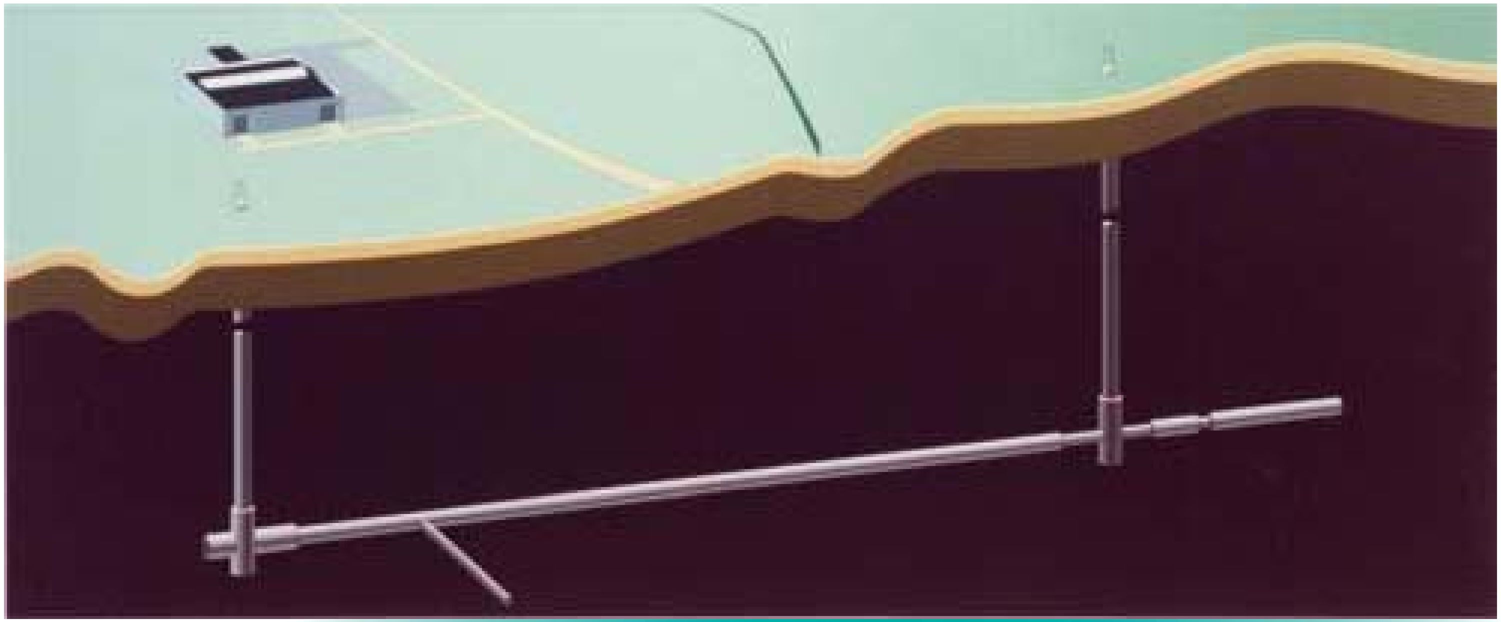
Investigations on clay formation for IL/HL – LL waste disposal (Bure)

2000-2005:

- 27 deep boreholes drilled since 1994
- 40 m drift opened at -445 m
- 485 m drift opened at -490 m
- 145 boreholes drilled from experimental drifts
- 1,500 sensors connected to a centralised DB by real-time transmission
- 4 km of cores collected
- 40,000 samples collected



Hades (Mol, BE)



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Decommissioning

- France
  - 8 first generation gas cooled, graphite moderated units
  - PHENIX fast reactor
  - SUPERPHENIX fast reactor
  - Chooz A PWR
  - Brennilis GCHWR
- Belgium
  - BR-3 PWR

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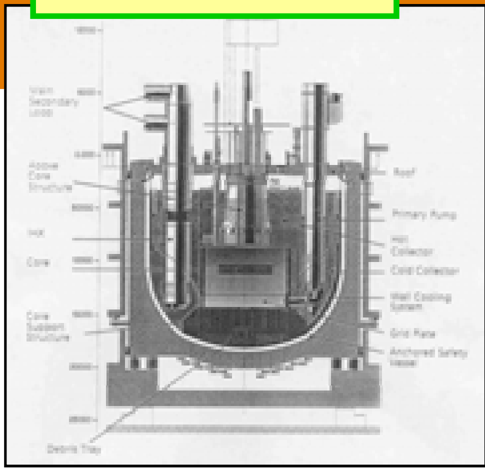
Research and development (CEA)

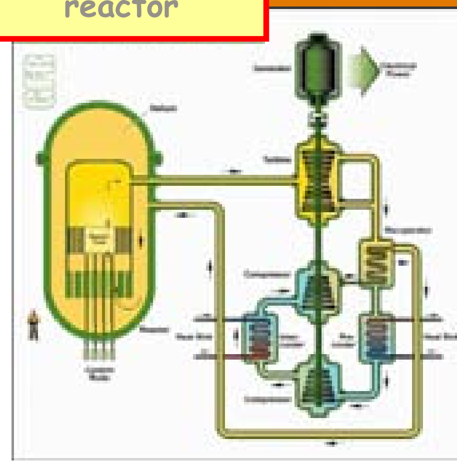
- Defence applications
  - Simulation programmes
  - Nuclear warheads and nuclear propulsion
- Technologies
  - Micro and nanotechnologies
  - Software technologies
  - Health technologies
- Energy
  - Safe operation of existing nuclear plants
  - Nuclear wastes
  - Nuclear fuel developments
  - Nuclear systems for the future (Participation to the Gen IV programme)
  - New energy technologies
    - Development of hydrogen energy for transport applications
    - Development of solar energy and energy management in buildings

Generation IV reactors (2040?)

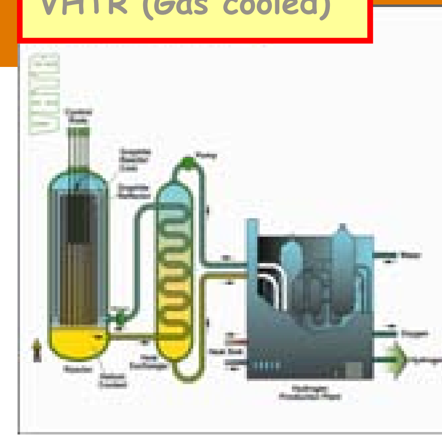
Sodium fast reactor

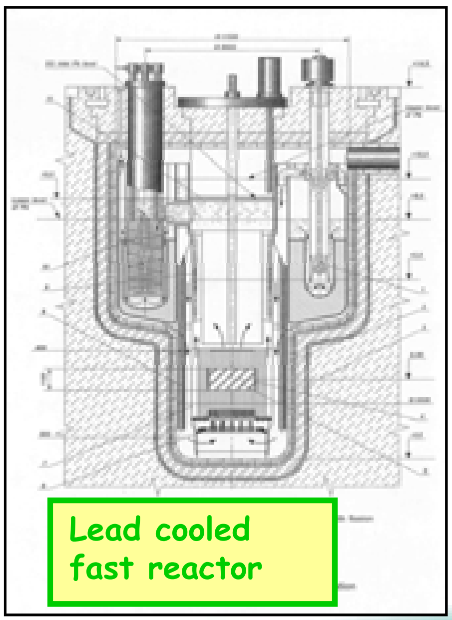


Gas cooled fast reactor



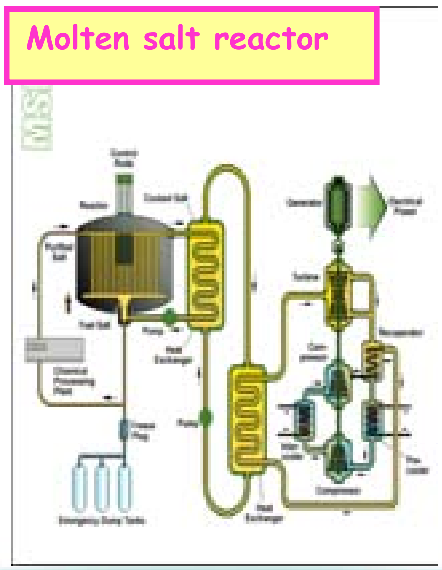
VHTR (Gas cooled)



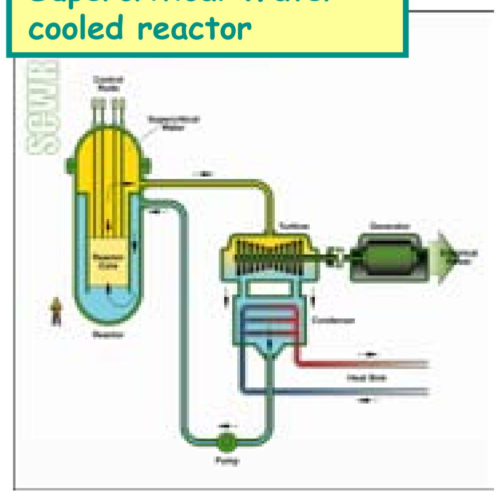


Lead cooled fast reactor

Molten salt reactor



Supercritical Water cooled reactor



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New reactors

- ASTRID (2020) sodium cooled fast reactor
  - 600 MWe prototype of a commercial series
  - Na cooled
  - "Self generating" rather than breeder (low net Pu production)
  - High burn up
  - Minor actinides in fuel elements (heterogeneous recycling in uranium blanket)
  - Intermediate Na loop
  - Tertiary coolant still undecided
- ALLEGRO (2025) gas cooled fast reactor
  - 50-80 MWt
  - Ceramic core (850°c) or MOX core (560°C)
  - Secondary coolant pressurised water
- VHTR (2025)
  - 600 MWt
  - Heat applications (He production e.g.)

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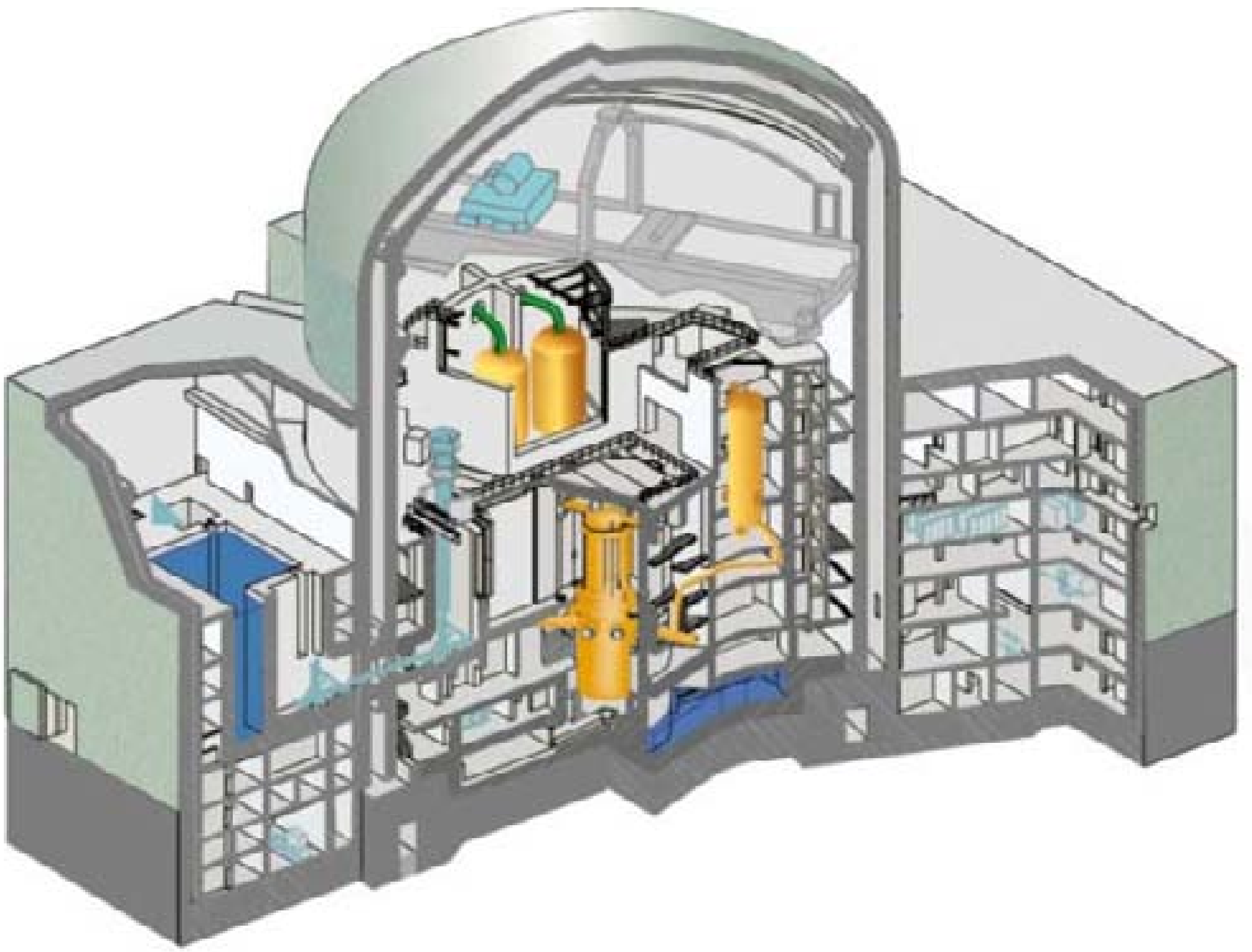
Nuclear capacity maintenance and growth

- Long term operation
  - in France
    - 2002: life extension of 900 MW units (30 to 40 years)
    - 2006: life extension of 1,300 MW units (30 to 40 years)
  - In Belgium
    - 2009: 10 year extension of Doel-1 and -2 and Tihange 1
- Power uprate
  - in France
    - 2003: power uprate of N4 from 1,450 to 1,500 MW
    - 2008-2010: power uprate of 5 900 MW units by 3%
    - 2015-2025: power uprate of 1,300 Mw units (20 reactors) by 7%
  - In Belgium
    - From 1993 to 2009: 8.6% capacity increase
- New build

EPR development and construction in France and abroad

- EPR new 1650 MW Generation III+ reactor
  - developed by Framatome and Siemens from 1990 onwards
  - With support from EDF and German utilities
  - Based on N4 and Konvoi
- Olkiluoto 3 (Finland)
  - Ordered 12/2003 (EPC contract to Consortium Areva-Siemens)
  - Construction license 02/2005
  - Operation 2013?
- New French standard approved in 2004
- Flamanville 3
  - decided in 2006
  - First concrete poured in 12/2007
  - Commercial operation expected in 2013
- 2 Chinese plants
- Penly 3 decided in 2010

EPR



Source: Areva

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Olkiluoto : lifting of the dome

Olkiluoto 3

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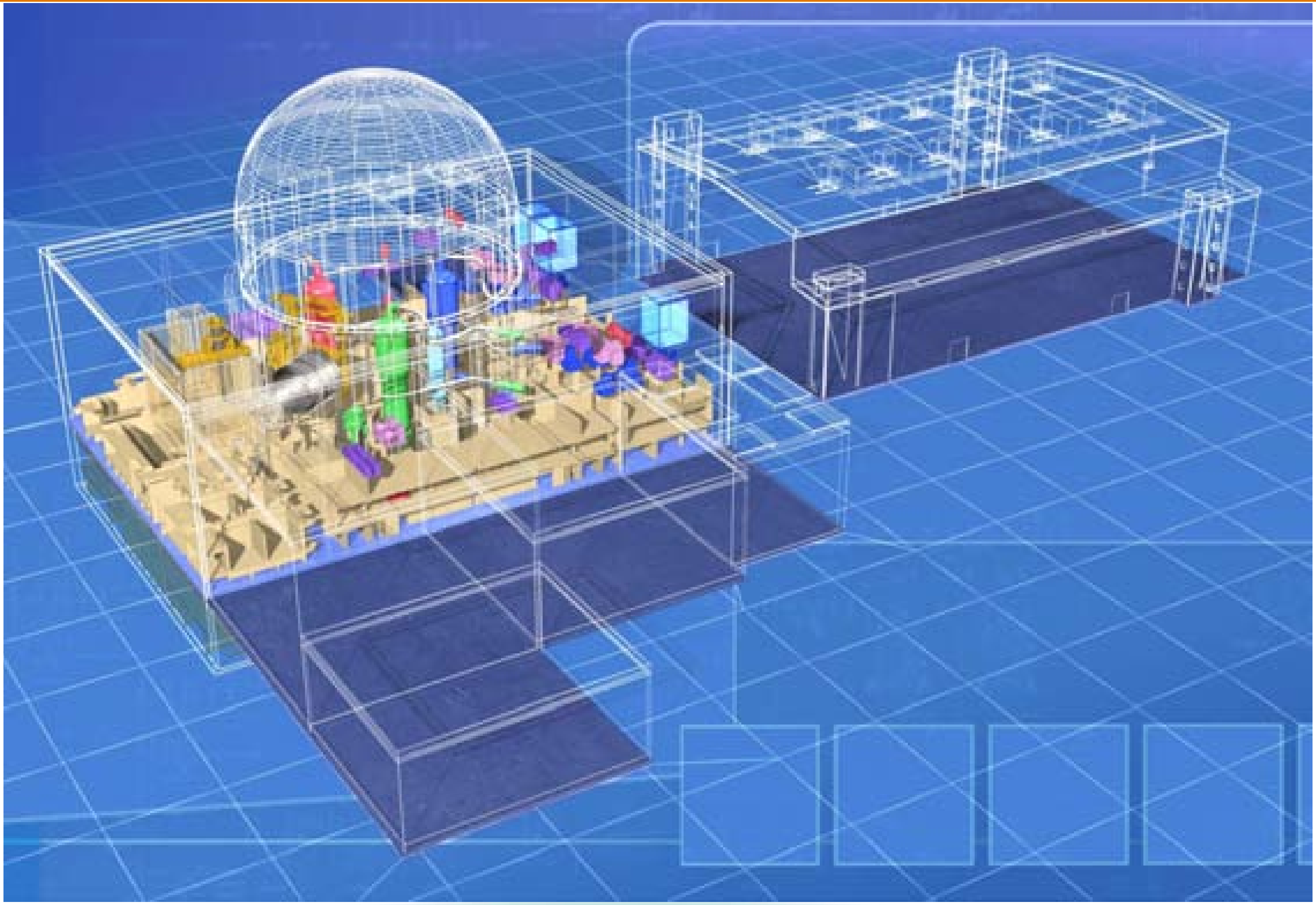
ATMEA1™ development

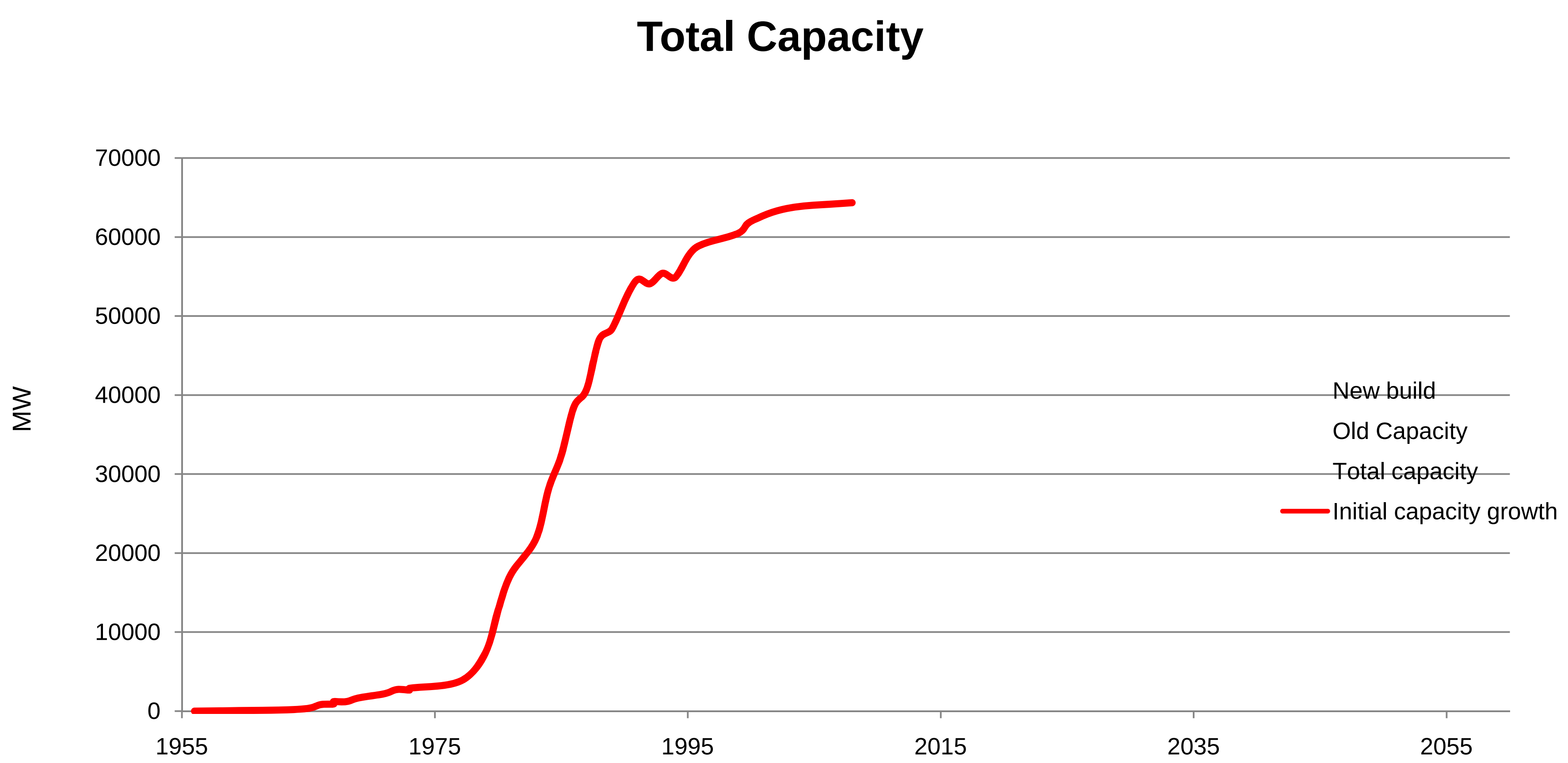
- ATMEA1™ new 1100 MW Generation III+ reactor
  - developed by ATMEA, a joint venture of Areva and Mitsubishi Heavy Industries (MHI)
  - Based on EPR and APWR
- To be vetted by ASN in 2011

ATMEA1

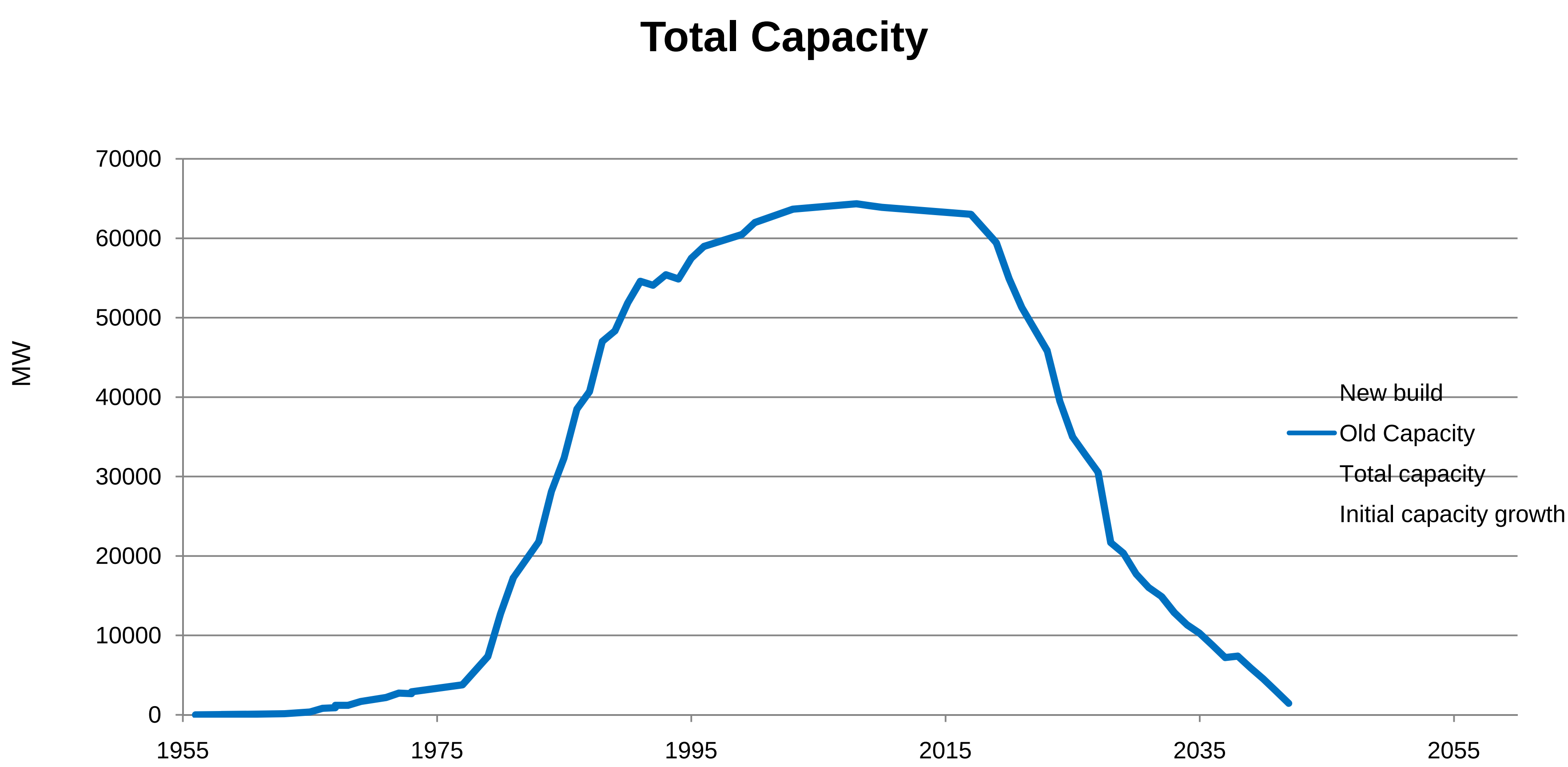


Source: ATMEA

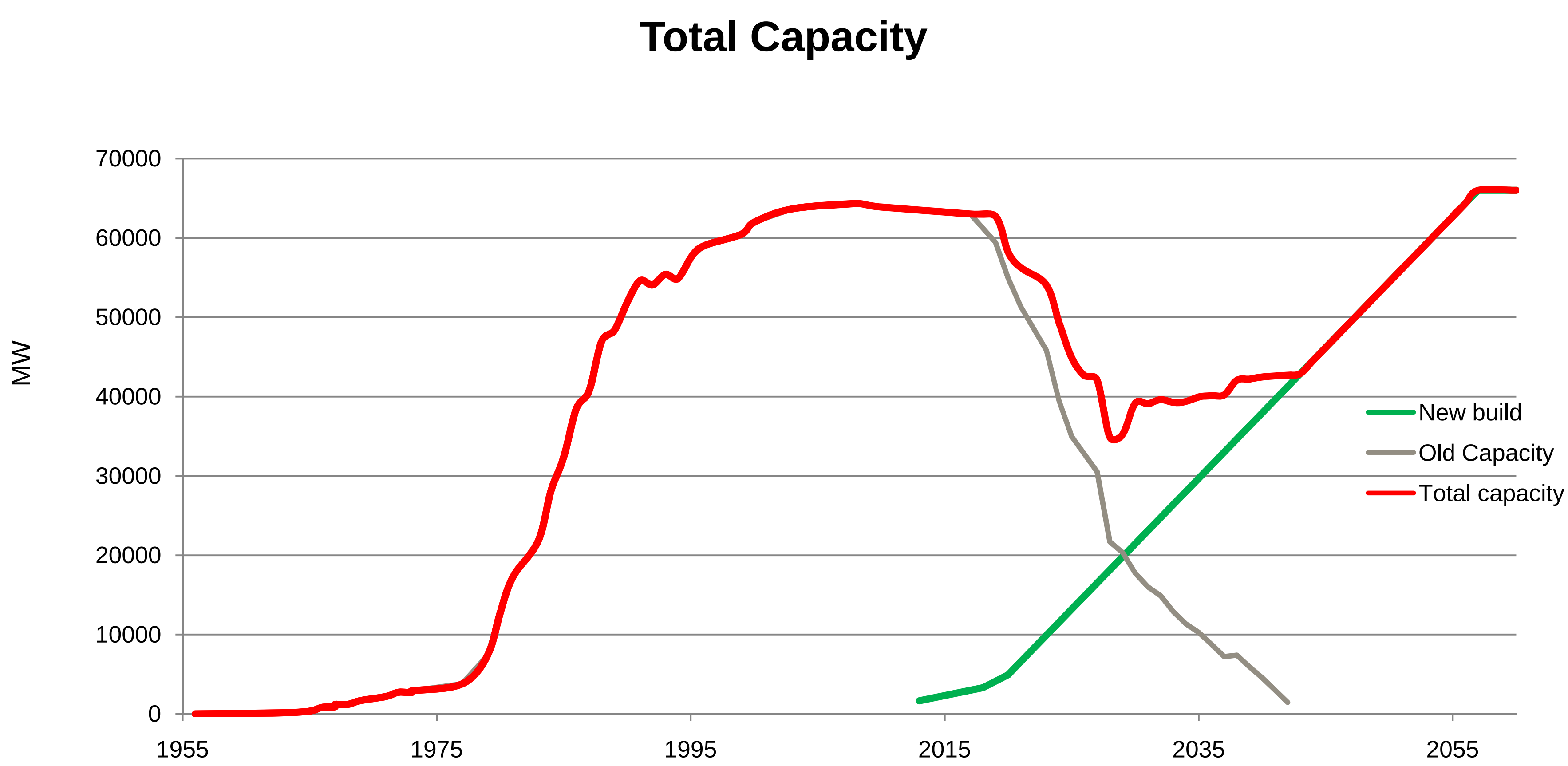
Capacity growth



Capacity growth and decline



Capacity growth, decline and new build



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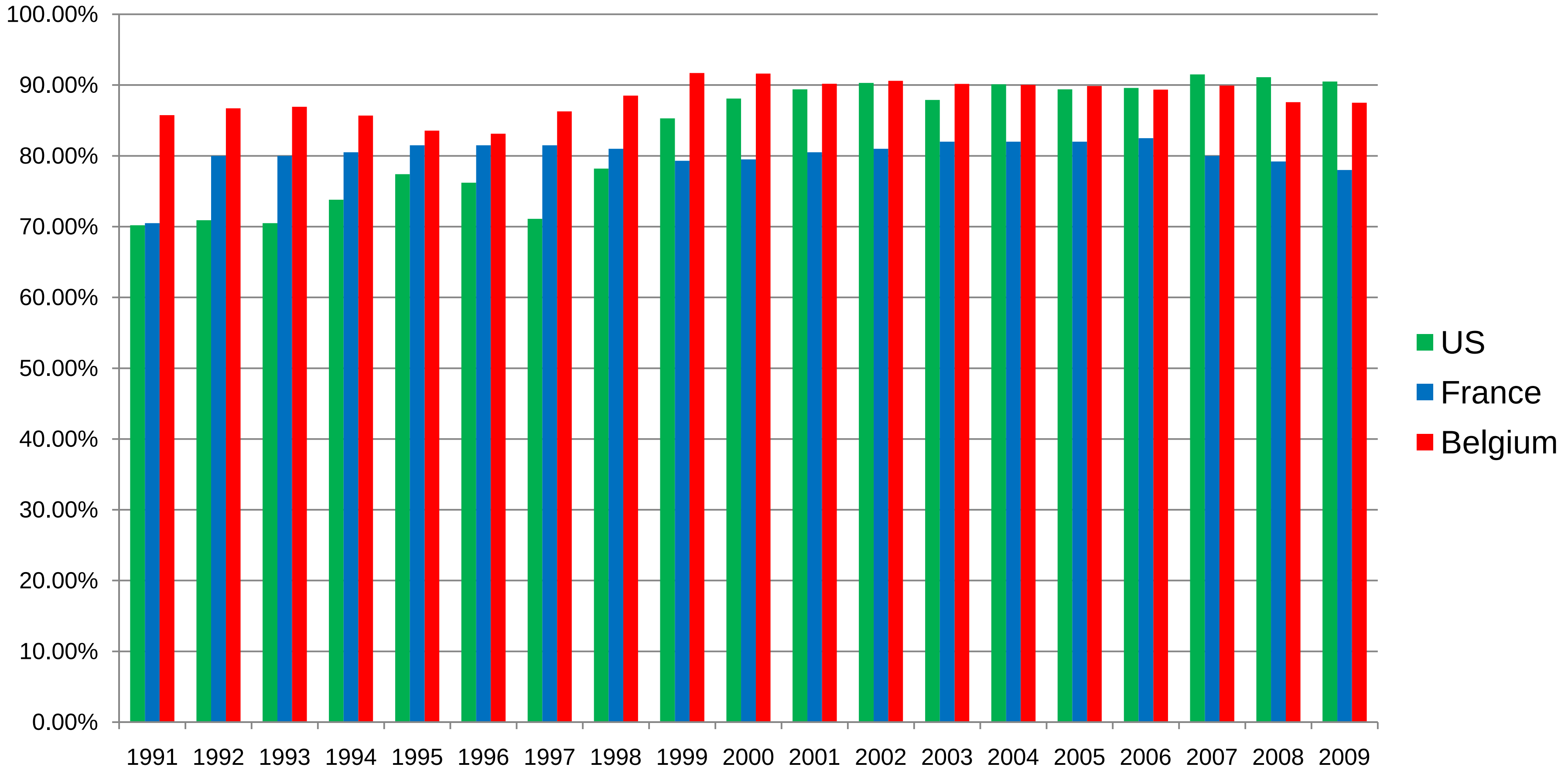
Economic factors

- France net exporter of electricity e.g. to
  - Italy
  - UK
  - The Netherlands
- Cost of generation around EUR 4.3c/kWh
  - Existing plants: around EUR 4.3c/kWh
  - Flamanville 3: 5.4 EUR c/kWh
  - Penly 3: above 6 EUR c/kWh
- Back end costs around 5%
- Large nuclear capacity in France => Load following mode
- 42 reactors inland => generation output limited in hot summers

Nuclear plant capacity factors



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Public acceptance

- Nuclear industry needs, and looks for, transparence
  - Public entitled to know
  - Industry has nothing to hide
  - Nuclear activities are strongly regulated and monitored
  - Public acceptance is conditional on transparence
  - Numerous successful initiatives (PIME Awards)
- Transparence not necessarily perceived by the Public
  - Security and confidentiality
  - Emotional content and myths
  - Very technical quickly
  - Track record far from being perfect…
  - Several players (Utilities, regulators, etc.) with different visions

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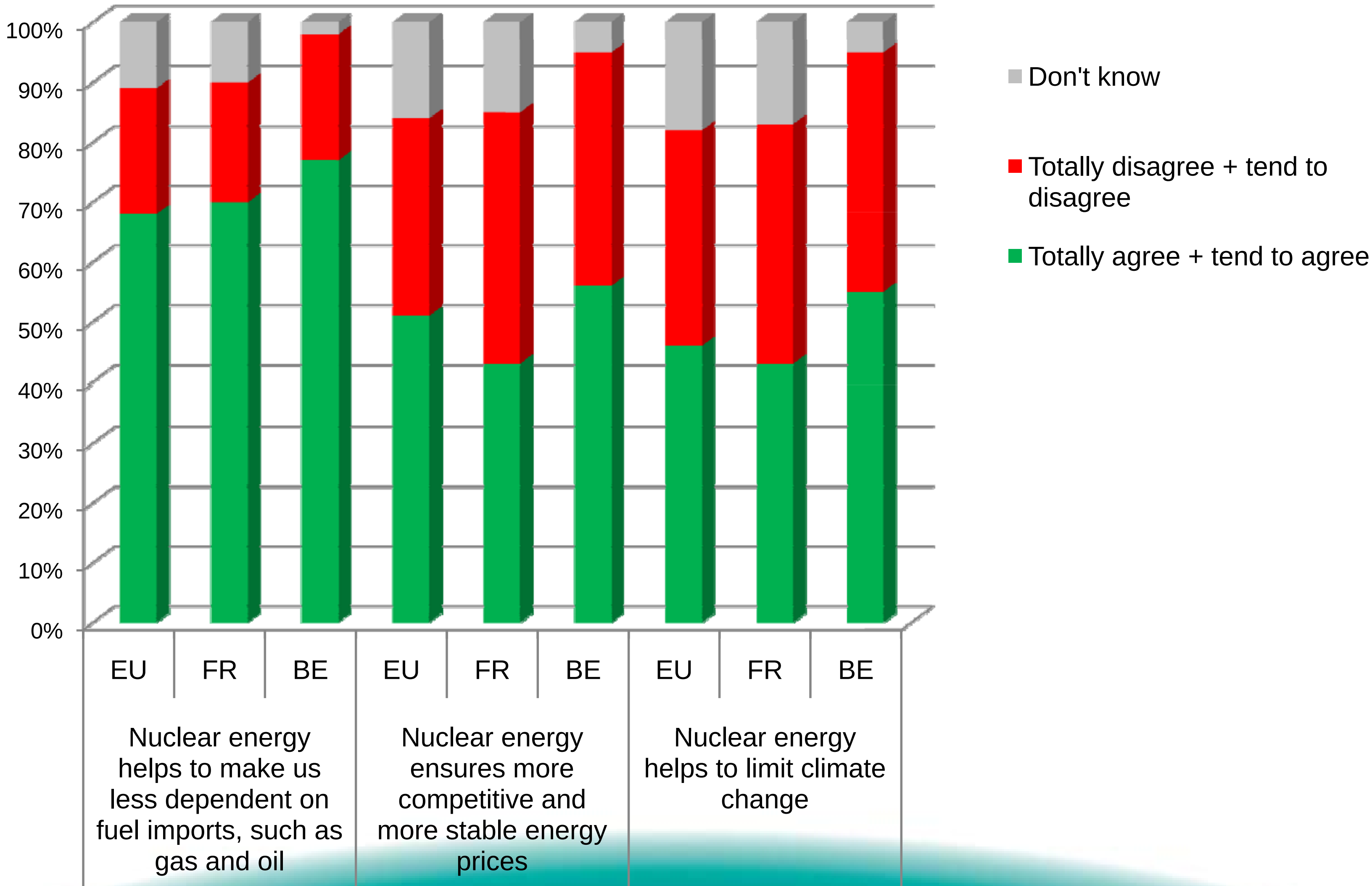
Public acceptance (cont'd)

- Nuclear industry needs to improve communication and make it
  - More affordable
  - Closer to public expectations
- The Public needs to make up an objective mind
- Common responsibility (utilities, regulators, governments, Representatives in the Parliaments, NGOs)
- Proliferation remains an issue…
- …as communication about solutions for long-lived nuclear wastes

Nuclear power generation in Western Europe

- Energy-Climate package (20-20-20)
- Triple challenge
  - Security of supply
  - Competitive, stable and predictable electricity prices
  - Reduction of GHG emissions:
- Public opinion (Eurobarometer)
  - Nuclear helps energy independence: 68%
  - Competitive, stable and predictable electricity prices: 51%
  - Nuclear helps global warming: 46%

Eurobarometer 2009 (April 2010)



Nuclear power generation in Western Europe

- Main obstacles
  - Licensing and Construction delays (Olkiluoto-3)
  - Quality control, Inflation, technical and regulatory changes (Flamanville-3)
  - Cost increase

Public acceptance (cont'd)

YOU ARE AGAINST NUCLEAR POWER AND YOU ARE PROBABLY RIGHT

YOU ARE FOR NUCLEAR POWER AND YOU ARE PROBABLY RIGHT

Agenda

1. Nuclear in France (and Belgium) in a nutshell
2. Early steps
3. From GCR to PWR
4. Fuel cycle
5. Wastes
6. Decommissioning
7. Research & Development
8. Nuclear capacity maintenance and growth
9. Economics
10. Human Resources & Public Acceptance
11. **Risks**

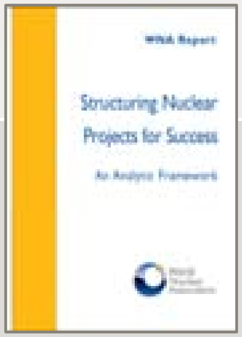
Conclusions

Risk management of nuclear new build

- Risk matrix and risk mitigation
- Nuclear power generation in Western Europe
- Some key issues
    - Regulatory stability
    - Supply chain
    - Budget and schedule
    - Grid connection

High level risk matrix

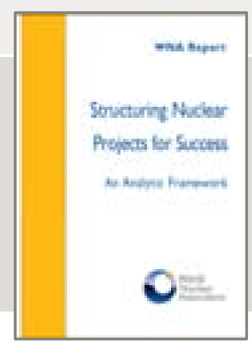
	Development	Construction	Operation	Decommissioning
Technical	• Regulatory assessment • Site suitability • Environmental impact • Planning approach	• Safety • Design completion/changes • Regulatory assessment/approvals • Vendor & Contractor performance • Equipment supply chain • Skilled and experienced workforce • Construction quality • Transport routes to site • Industrial schemes and relations • Plant performance	• Safety • Plant performance • Skilled and experienced workforce • Nuclear event elsewhere • Nuclear event • Environment • Fuel supply chain	• Safety • Design completion/changes • Regulatory assessment/approvals • Vendor & Contractor performance • Equipment supply chain • Skilled and experienced workforce • Construction quality • Transport routes to site
Business Case	• Economics • Demand forecast • Spent fuel and radioactive waste disposal	• Design changes • Delay	• Electricity trading arrangements • Electricity price • Carbon price • Fuel costs • Capital additions • Early closure • Cost of wastes and spent fuel disposal • Decommissioning fund performance	• Decommissioning fund
Societal and political	• General public support and local approval • Policy supporting the need for nuclear power • Policy for waste management • Decommissioning and waste management mechanisms • Carbon pricing mechanism • Environmental policy			



GDF SUEZ

High level risk mitigation

	Development	Construction	Operation	Decommissioning
Technical	• Internationally accepted designs • Building on existing nuclear sites	• Develop sound contractual arrangements for involved parties • Invest in supply chain infrastructure • Good training programmes • Invest in transport infrastructure near the site • Previous construction experience • Strong project management	• Involvement in WANO, INPO, etc. • Good training programmes • Invest in new nuclear fuel facilities • « Fleet » approach to reactor management • Invest continuously in plant maintenance and improvement	• Decide on decommissioning strategy as early as possible • Invest in workforce traning
Business Case	• Seek investments from major power users • Build business case on various demand scenarios	• Stick to standardised designs • Use good mix of permanent and contract staff	• Develop sound long term power contracts • Develop good balance of fuel contracts • Nuclear knowledge management	• Contribute to well-defined fund as required
Societal and political	• Public debate and hearings • Regular opinion polling • Gaining cross party political support • Emphasise environmental advantages of nuclear • Develop Waste Management policy with government			



GDF SUEZ

Crunch points and obstacles in the regulatory process

- Regulatory framework sufficiently clear to provide a **stable** and **predictable** environment to utilities and investors
  - ✓ There should be clear regulation on political decision making, competition rules, electricity price, siting, licensing, planning, liabilities, waste management, decommissioning, …
- Large public and political **consensus** in favour of nuclear energy to minimize the risk of political changes (e.g. after elections) impacting the regulatory process
- Safety Authorities **share** their **experience** to ease the licensing process
  - ✓ Use of experience feedback, coherent assessment methodologies, avoid to repeat the same work, share knowledge and documentation, …

Sourcing nuclear capabilities : understanding supply and demand for human capital

- We can expect a significant number of NNB projects worldwide in the next decades creating an important **gap between supply and demand** for human resources
  - ✓ Recruitment and training networks to be reinforced and developed on an international level
  - ✓ Not always easy to find personnel willing to work abroad, especially experienced people used to work at the same NPP for years
- Important to have a **good view on the planning** in order to organize recruitment and training in due time
  - ✓ Concerns both technical and engineering/management level
  - ✓ Academic training, basic nuclear training, specific trainings (maintenance, simulator, …)
  - ✓ Internal knowledge management including knowledge transfer from senior workers to new ones

Sourcing nuclear capabilities : understanding supply and demand for human capital (cont'd)

- Take into account the **global workforce needs** in the target country
  - ✓ Competitors
  - ✓ Suppliers and Supply chain
  - ✓ Safety Authorities
  - ✓ Engineering

Delivering on budget : mitigating against a rising cost base and market flux

- Contractual measures
- Contingencies
  - ✓ Should reflect level of knowledge and control on the design, construction process, regulatory process, …
- Long term contracts and partnerships with suppliers
  - ✓ In order to ensure high quality and security of supply at predictable cost
- Large scale orders and synergies
  - ✓ Having several projects in parallel provides flexibility in terms of availability of materials and equipment
- Monitor ongoing NNB projects and use experience feedback
  - ✓ Lessons learned in other projects should help anticipating and mitigating part of potential issues

GDF SUEZ

Getting connected : securing transmission connections and capacity at a time of high demand

- **Regulatory framework** should clearly define the decision making process to achieve required grid reinforcement works
  - Permitting process and possible public consultations
- **Financing** of the grid reinforcement works must be defined and secured
- **Competitive** call for tender process for the grid reinforcement studies and works
- Interface with NNB projects in terms of **schedule** and **hardware**
- Interfaces with **running plants and other projects** impacting the grid

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GDF SUEZ Nuclear Future

- **Existing plants**
  - Operate the nuclear power stations for as long as the legal, technical and economical frameworks allow, with nuclear safety as the top priority
  - Implement the decision of the Belgian Federal Government to extend by 10 years the operation of Doel 1-2 and Tihange 1
- **New capacities**
  - Maintain the share of nuclear energy in a balanced energy mix
  - Own and Operate 3rd generation nuclear power plants by 2020
  - Huge investment justifies selectivity
  - Outside Europe invest on key markets
- **Engineering and services**
  - Support the Group development
  - Be involved in major nuclear projects for external customers

In France as elsewhere…

- Nuclear renaissance is on its way
- Major obstacles could jeopardize the revival
- Absolute need to communicate professionally and efficiently to maintain and improve public acceptance

Thank you for your attention !