Technological development: towards responsible and sustainable nuclear energy

Philippe Pradel
Head of the Nuclear Energy Division
French Atomic Energy Commission (CEA)
Low carbon energy scenario for 2050

Today, nearly 2 billion people without electricity
Climate challenge & sustainable nuclear energy

- **1st low carbon track**: Electricity,
- **2nd low carbon track**: transportation,
- **3rd low carbon track**: residential and tertiary sector

<table>
<thead>
<tr>
<th></th>
<th>World</th>
<th>EU</th>
<th>France</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric power in the final energy consumption mix</td>
<td>16%</td>
<td>20%</td>
<td>23%</td>
</tr>
<tr>
<td>Nuclear electricity / total electric power output</td>
<td>15%</td>
<td>30.5%</td>
<td>78.5%</td>
</tr>
</tbody>
</table>

Int.Conference on Nuclear Energy in the 21st Century  April 21st. 2009,  Beijing
2008 Vision: nuclear part in the energetic mix

- **Installed Nuclear GWe**: 371 GWe
- **Expected Plants Shut downs**: 270 GWe
- **Life Time Extention and Power Uprate**: 150 GWe
- **NEW BUILD MARKET**: 480 GWe

**2006**

**2030**

- **Around 300 PWR 1500 MWe by 2030**
- **And 1000 PWR 1500 MWe by 2050?**

**A target for nuclear contribution in the energy mix by 2050:**
30% such as in European Union

*Around 2500 PWR 1500 MWe*
Gen III on the tracks with safety improved EPR

- A 1600 MWe reactor, lifetime 60 years
- A mature concept, based on current PWRs’ experience
- Significant improvements in safety and economy

Olkiluoto (Finland) / TVO by 2012

Flamanville (France) / EdF by 2012

Taishan1&2 (China) / CGNPC by 2013 & 2014
Gen III on the tracks with today envisaged EPR around the world

USA: 4 EPR with Constellation Energy Group, operated by 2016

United Kingdom: 4 EPR with British Energy, operated by 2017

Italy: Intent to restart a nuclear program

India: 2 up to 6 EPR

South Africa: Eskom interested by EPR

USA: 4 EPR with Constellation Energy Group, operated by 2016

France: a second EPR with EdF under project (Penly)(2017)

USA: 4 EPR with Constellation Energy Group, operated by 2016

Development, investment & operation of more than 10 EPRs by 2020, Potential Countries: United Arab Emirates, Jordan, Vietnam …
EPR Safety Objectives

- Enhanced defense in depth to reduce by a factor ten the number of significant incidents and global frequency of fusion core meltdown,

- Significant reduction of release and consequences in any situation (including fusion core meltdown),

- Improved resistance of the reactor containment to external impact and majored seism
Towards a high safety level with the rising multinational safety initiatives

- An International Nuclear Safety Harmonization, but:
  - Liabilities in regard to safety remain a national obligation, which can not be assigned to supra-national authorities,
  - Technologies are not the only one safety parameter, « Safety Culture » and an appropriate institutional framework are also necessary

- A long-standing Coopération (>50 years) between:
  - Institutional actors (IAEA ...),
  - Safety Authorities Cooperation (INRA, WENRA...),
  - And Operators (WANO ...).

- The 2 driving forces behind harmonization:
  - MDEP (Multinational Design Evaluation Prog.) Initiative to assess the new reactors the safety authorities
  - European Construction

- Present International Safety Initiative such as MDEP to be fostered
2008 Vision: world spent fuel amount

LWR Once-through

LWR + Fast Neutrons (conversion factor = 0.5)

<table>
<thead>
<tr>
<th>Year</th>
<th>Mass NL (kTons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>0</td>
</tr>
<tr>
<td>2010</td>
<td>1000</td>
</tr>
<tr>
<td>2020</td>
<td>2000</td>
</tr>
<tr>
<td>2030</td>
<td>3000</td>
</tr>
<tr>
<td>2040</td>
<td>4000</td>
</tr>
<tr>
<td>2050</td>
<td>5000</td>
</tr>
<tr>
<td>2060</td>
<td>6000</td>
</tr>
<tr>
<td>2070</td>
<td>7000</td>
</tr>
<tr>
<td>2080</td>
<td>8000</td>
</tr>
<tr>
<td>2090</td>
<td>9000</td>
</tr>
<tr>
<td>2100</td>
<td>10000</td>
</tr>
</tbody>
</table>

World spent fuel production / year

<table>
<thead>
<tr>
<th>Year</th>
<th>Amount (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2030</td>
<td>10 000</td>
</tr>
<tr>
<td>2050</td>
<td>20 000</td>
</tr>
</tbody>
</table>

700 000 t by 2050,
Around 400 EPR spent fuel pits,
+ 2 pits / year
Closing the fuel cycle, towards sustainability ...

First step: Pu recycling in LWRs,
Conditioning of waste

Continuous progress has been made in the processing of spent fuel, recycling of nuclear material and conditioning of waste

Next step: Recycling of minor actinides to reduce thermal load and radio-toxicity of waste is the object of on-going research

- Recycles 96% of spent fuel materials
- Saves 30% of natural resources
- Costs less than 6% of the kWh total cost
- Reduces by 5 the amount of wastes
- Reduces by 10 the waste radiotoxicity

Adapted technologies allow a safe conditioning of wastes to guarantee their long term confinement and stability, for dozens of thousands of years.
Closing the Fuel cycle... and an industrial reality

More than 25 years of unequalled experience in France:

- Until now: \(\sim 20\ 000 \text{ Mt}_{\text{HM}}\) spent fuel reprocessed and more than \(1200 \text{ Mt}_{\text{HM}}\) MOX fuel recycled
- \(1100 \text{ Mt}_{\text{HM}}/\text{yr}\) of spent fuel discharged from the French PWRs
- Up to \(1700 \text{ Mt}_{\text{HM}}/\text{yr}\) of spent fuel reprocessed (domestic + foreign)
Nuclear Plants for new comers: reactor + Fuel services + Education & training

➢ To address the expectations of customers interested in developing nuclear energy production plants (*power range, design for site flexibility and various grid conditions*...),

➢ Combining reliable and proven nuclear technologies, including fuel cycle facilities (*glass canister storage*...)

➢ Answering non proliferation criteria,

➢ Setting an ambitious training offer

**RR21 Characteristics:**
- Power range 10 MW,
- Pool type reactor
- Inherently safe fuel (no fuel melting),
- Spent Fuel recovered for treatment and recycling,
- Easy handling,
- Easy experimental work
Nuclear renaissance in the world

End of 2007
439 reactors in operation
372 Gwe installed
33 reactors under construction
Nuclear renaissance in the world

North & South America  Europe  Russia  Asia

- Nb of reactors
- ~4000 tHM spent fuel

Used nuclear fuel 2007 inventory: 170,000 tons
Estimate in 2030: 400,000 tons!

(Source: AREVA Group)
Nuclear renaissance in the world

North & South America  Europe  Russia  Asia

 Nb of reactors

 treatment plant

 ultimate waste

 Drastic waste reduction with only few recycling plants

(Source: AREVA Group)
Nuclear Renaissance Challenges: Back End Facilities

Commitments and international obligations with regard to safety, security and non-proliferation standards, shall be strictly observed.

1. The stockpiling in indefinite interim storage is not a responsible management of the fuel back-end, in the perspective of a wide nuclear renaissance,

2. Spent fuel recycling shall be carried out vitrified waste sended back to countries of origin, to be safely and economically stored, waiting for final disposal: for a safer, a more secure and a more proliferation resistant spent fuel management.

3. A global service offer for spent fuel reprocessing and recycling shall be set up with the appropriate international framework, i.e; the IAEA umbrella.

4. Supply of recycling plants based on best available proven technologies:
   - by current La Hague / Rokkasho and future facilities
   - operated by major players
   - Distribution of the recycling facilities on a regional basis with respect of commercial contracts.
Adapted initiatives taking into account the best available technologies, towards the emerging economies to enlarge the access to the nuclear energy in terms of:

- electricity production without green gas emission (up to 40-50% in 2050),
- natural resources conservation,
- waste minimisation,
- potential for new applications (hydrogen, desalination, heat…)

**RENAISSANCE**

**SUSTAINABILITY**
Sustainability: Development of Fast Neutrons Systems with closed fuel cycles

**Durability**

- **Prototypes (2015 – 2030)**
- **Industrial deployment (by 2040)**

**R&D sharing in GEN IV Forum**

**International harmonization of prototypes**

*In a bi or trilatéral framework Example (USA-Japon-France) of the Sodium FBR*

**INPRO**

- **Dialogues between technologies suppliers and operators,**
- **Clarification of user’s needs**
International FBR Prototypes Partnerships

**ASTRID Prototype**
- **Advanced Sodium Technological Reactor for Industrial Demonstration**
- **Prototype electric power production (250–600 MWe)**
  to demonstrate promising technologies for the commercial SFR
- **Convincing demonstration** of improvements proposed for weak points of previous SFRs
- **Resource savings**: operation with recycled materials, enhanced safety and proliferation resistance
- **Waste management**: progressive evaluation and demonstration of minor actinide recycling

**ALLEGRO Prototype**
- **Test bed for GFR technology**;
- **Innovative Fuel development**
- **Transmutation technology development**
- **Specific Heat processes loops**
- **Irradiation facility**

Alternative and Advanced Techno. Gas Fast Reactor (75 MWth)

MOX fuel fabrication facility for the Mox driver core and capability for fuel S/A tests (advanced fuels, MA-bearing fuels)
Atoms for Prosperity