From Gen I to Gen III

Gabriel Farkas

Slovak University of Technology in Bratislava
Ilkovicova 3, 81219 Bratislava
gabriel.farkas@stuba.sk
Evolution of Nuclear Reactors

- **Generation I** - demonstration reactors
  - Shippingport
  - Dresden, Fermi I
  - Magnox

- **Generation II** - working in the present
  - LWR-PWR, BWR
  - CANDU
  - AGR

- **Generation III** - under construction
  - ABWR
  - System 80+

- **Generation III+** - Evolutionary Designs Offering Improved Economics for Near-Term Deployment

- **Generation IV** - R&D
  - Highly Economical
  - Enhanced Safety
  - Minimal Waste
  - Proliferation Resistant

Timeline:
- 1950
- 1960
- 1970
- 1980
- 1990
- 2000
- 2010
- 2020
- 2030

14.9.2010
Nuclear Share in Electricity Generation in 2007

Note: The nuclear share in Taiwan, China was 19.3%.

14. 9. 2010
Expected development in nuclear technologies

- Prolongation of lifetime of existing nuclear reactors
- Construction of new reactors in frame of Gen. III and IV.

Figure 1
Replacement staggered over a 30-year period (2020 - 2050)
Rate of construction: 2,000 MW/year

Average plant life: 48 years
Nuclear in Europe

(Nuclear ~ 32% of total EU electricity production)

FR, 45.5%
GE, 16.3%
UK, 7.9%
BE, 4.8%
SE, 7.3%
NL, 0.4%
RO, 0.5%
LT, 1.1%
SI, 0.6%
SK, 1.7%
HU, 1.4%
BU, 1.8%
FI, 2.4%
CZ, 2.5%
Other 12.4%

Source PRIS
Central & Eastern Europe - Nuclear Landscape

Poland
- 1 RBMK 1300
- 2 VVER1000

Czech Republic
- 4 VVER440
- 2 VVER1000
- CEZ/ 67% State owned

Slovak Republic
- 4/6 VVER440
- ENEL 67% owned

Romania
- 2 Candu PHW
- Nuclearelectrica State owned

Ukraine
- 2 VVER440
- 13 VVER1000
- NNEGC State owned

Lithuania
- 1 RBMK 1300
- Min. of Energy

Hungary
- 4 VVER440
- MVM State owned

Bulgaria
- 2/4 VVER1000
- NEC State owned

Russia
- 6 VVER440
- 8 VVER1000
- 11 RBMK
- 1 BN600
- 4 Graph Mod BWR
- Rosenergoatom State owned

Armenia
- 1 VVER440
- Armatomenergo, State owned

Poland
- 14. 9. 2010 6
New Build

- CEZ: Temelin 3 & 4 – 2019/2020 – 2026 (plus 3 plants)
  - Dukovany
  - Bohunice (Slovak Republic)
- Hungary: 2 units
- Poland: 6 units 2020 first unit
- Lithuania: 2 units 2018
- Bulgaria: 2 units
- Romania: 2013/2014 (Candu Units at Cernavoda)
  - New greenfield units (non Candu) being assessed
- Slovenia: 1 unit
World chart of countries with nuclear power and countries considering seriously about built of NPP.
Reactors in operation worldwide (2006)

- PWR: 265
- BWR: 94
- CANDU/D2O-PWR: 44
- GGR/AGR: 18
- RBMK: 16
- FBR: 2

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Distribution of reactors according to regions and types

- Asia: 111
- N. America: 122
- Europe: 198
- L. America: 6
- Africa: 2

- PWR: 65.4%
- BWR: 2.9%
- PHWR: 6.0%
- GCR: 2.4%
- LWGR: 3.1%
- FBR: 0.2%

14. 9. 2010
Number of reactors in built.

- PWR: 25
- PHWR: 4
- BWR: 2
- FBR: 2
- LWGR: 1
Gen 3 reactors in built (2007).

Počet reaktorov reálny / plánovaný
Reactor evolution

- Gen 1 developed in the period of 1950 – 60, practically shut down except reactors built and operated in the England. Ordinarily prototype NPP.
- Gen 2 represents mainly operated reactors in France, Russia and the other European countries, Japan, USA. Life time extension from 30-40 years to 50-60 years.
- Gen 3 (and Gen 3+) represents advanced reactor types. The first advanced reactors built in Japan, another under construction or prepared for order.
- Gen 4 – always under development, estimated commissioning in ~ 2020, commercial use in ~ 2030.
Characteristics of the Gen 2

- Evolutionally connected with Gen 1
- Emphasis on the safety
- Use of the passive safety elements
- At present – they create the base of nuclear power industry in the world, significantly prolonged lifetime from 30-40 to 50-60 years
- Always in offer CPR 1000, VVER 440
1963 at Novovoronezh - The first unit, known as WWER-210
1969 - second prototype, a 365 MW(e) From these prototypes, a standardized 440 MW(e) nuclear power plant, called WWER-440, was developed.
1972 - The first WWER-440s use the standard plant design referred to as model V-230 (Novovoronezh Unit 3).
A later model of WWER-440 designated as V-213 was commercially introduced in 1980/81 in Rovno (Units 1 and 2).
In 1980 first unit of next generation and higher capacity of 1000 MW(e) was commissioned in former USSR in Novovoronezh, unit 5.
Ningde – 4 units of Gen 2 (China)
Characteristics of the Gen 3

- Standardized design of all the reactor types: - licensing, minimization of the investment costs and constructions time
- More simple and robust structural design, more easy operation, less sensitivity to operating parameters change
- Higher load factor and longer life time appr. 60 years,
- Significantly reduced failure probability with the consequence of a core melting
- Resistance to the serious damage with radiological consequences, also in the case of airplane fall
- Higher burnup – which reduces the amount of nuclear fuel, as well as the spent fuel
- Use of burnup absorbers to extend the reactor campaign
- Use of recycled fuel (MOX)
Differences of the Gen 3+

- Simplified structural design
- Lower capital costs
- Effective fuel exploitation
- Enhanced passive/inherent safety elements
- Flexibility of power operation (EPR from 25% $N_{\text{nom}}$ to 60% $N_{\text{nom}}$ by trend of 2.5% and to 100% $N_{\text{nom}}$ by trend of 5% ).
Additional requirements for Gen 3

1. No evacuation of people needed in case of accident
2. Better utilization of uranium and less production of waste
3. Designed for 60 years life-time
4. Comparable national contribution
Simplification and Standardization are Key to Future Nuclear Plant Construction

- Simplicity and standardization in **Design** through reduced number of components and bulk commodities

- Simplicity in **Safety** through use of passive safety systems

- Simplicity in **Construction** through modularization

- Simplicity in **Procurement** through standardization of components and plant design

- Simplicity in **Operation and Maintenance** through use of proven systems and components, and man-machine interface advancements

**Improved Safety, Competitive Economics and Good Performance**
Reactors accomplishing European Utility Requirements

- EPR – AREVA
- AES 92 (now 2006) – GIDROPRESS
- SWR 1000 – AREVA (SIEMENS)
- AP 1000 - WESTINHOUSE
NRC licensed or close before obtaining the license

- ESBWR - Hitachi-GE
- US EPR – AREVA
- US APWR – Mitsubishi
- ACR – AECL, IRIS – Westinghouse, PBMR – ESKOM (project strictly restricted in February 2010), S4 – Toshiba, GT MHR - GA
EPR

- Standardized project for F from 1995
- Net power: 1600 - 1760 MWe
- Flexible operation
- Enables to follow the daily consumption diagram
- Burnup 65 MWd/kg
- Thermal efficiency 36%
- Core loading with MOX
- Design life time 60 years
- Under construction – Olkiluoto, Flamanville, plan Penly, at the beginning of construction in Taishan
- Loss of 4 units for Abu Dabi, won South Korea concept CPR 1000 (Gen 2) (February 2010)
- One of the variants for CEZ a.s.
RPV - EPR Olkiluoto

Delivered in January 2009
AP 1000

- Net power 1000 MWe
- Standardized project
- Modular concept
- Design life time 60 years
- 2 units under construction in China
- in selection: ČEZ a.s. for ETE3&4, EDU5 (Bohunice 5)
# Modular System of AP 1000

<table>
<thead>
<tr>
<th>Module Type</th>
<th>Number</th>
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<tbody>
<tr>
<td>Structural</td>
<td>122</td>
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<tr>
<td>Piping</td>
<td>154</td>
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<tr>
<td>Mechanical Equipment</td>
<td>55</td>
</tr>
<tr>
<td>Electrical Equipment</td>
<td>11</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>342</strong></td>
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</tbody>
</table>

- **Pump/Valve Module**
- **Raceway Module**
- **Structural Module**
- **Depressurization Module**

14. 9. 2010
AES 2006-Gidropress

- Based on VVER 1000
- Net power 1150 – 1200 MWe
- Thermal efficiency 36,55 %
- Design life time 50 year
- Use of MOX fuel,
- Extended safety standards: improved seismic resistance, enhanced passive safety elements, posilnené pasívne prvky bezpečnosti, double containment, frequency of a core melting of $1 \times 10^{-7}$ year$^{-1}$
- Double unit conception
- Investment costs per installed 1kW – 1200 US$,
- Construction time: 54 months
- Under construction: AES92 Novovoronež II, Leningrad II (commissioning in 2013 to 2014), China, India, two units planned for Belene Bulgaria, in selection ČEZ a.s.
- Variant MIR 1200 – interest of ČR
Global challenges and constraints

Forecast of the new NPP demand till 2030, GW

- NPP technologies should be developed that provides sustainability
- Increase of scopes of NPP construction – resource base should be increased in according scale
- Development of localization and technology transfer
- Considerable investments are required for nuclear power infrastructure
- Flexible financing mechanisms as well as schemes of investors attraction are necessary to develop
- Yesterday – EPC / EPCM; today – BOT / BOO (new comers to the nuclear club!)
NEA scenario - increase in numbers of reactors in the world

Existing capacity
NEA high
NEA low

...1400 reactors in 2050

439 reactors in June 2008

600 to...
<table>
<thead>
<tr>
<th>Year (Platform)</th>
<th>1900</th>
<th>1920</th>
<th>1940</th>
<th>1960</th>
<th>1980</th>
<th>2005</th>
<th>2015</th>
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<tbody>
<tr>
<td>Thermal Efficiency</td>
<td>12%</td>
<td>18%</td>
<td>34%</td>
<td>43%</td>
<td>48%</td>
<td>51%</td>
<td>56%</td>
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Water / Steam Cycle – focused on Turbine

<table>
<thead>
<tr>
<th>subcritical</th>
<th>supercritical</th>
<th>ultrasupercritical</th>
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</thead>
<tbody>
<tr>
<td>simple</td>
<td>reheat</td>
<td></td>
</tr>
</tbody>
</table>

- 350 bar / 700 °C / 720 °C
- 300 bar / 600 °C / 620 °C