BELGIAN EXPERIENCE IN STEAM GENERATOR REPLACEMENT AND POWER UPRATE PROJECTS

L. Vanhoenacker
Deputy General Manager

Atoms for the future 2012
2012/10/24

CHOOSE EXPERTS, FIND PARTNERS
Outline

- Nuclear Energy in Belgium
- SGR & Power uprate in Belgium
- The new steam generators
- Organisation of project: multi contract approach
- Safety studies
- Replacement work studies
- Replacement work: outage
- Conclusion
NUCLEAR IN BELGIUM

• 1944: Uranium from Congo (Belgian colony) transferred to the USA

• As compensation Belgium got:
  - access to the knowhow for non military applications of the nuclear energy
  - a10 M$ investment in the Belgian Nuclear Research Centre (CEN-SCK - Mol)

• 1962: commissioning of the first PWR in Europe (BR3) at Mol

• 1967: First commercial PWR Chooz, (50% EdF, 50% Belgian Utilities)

• 1968: order of the PWR Doel 1&2 and Tihange 1

Le ministre Spinoy démarre le BR 3
### Belgian PWR'S in operation

<table>
<thead>
<tr>
<th>Site</th>
<th>Country</th>
<th>Loops</th>
<th>Diameter</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doel 1 &amp; 2</td>
<td>W</td>
<td>2 loops, 14 x 14</td>
<td>8ft</td>
<td>440 MWe</td>
</tr>
<tr>
<td>Doel 3</td>
<td>FRA</td>
<td>3 loops, 17 x 17</td>
<td>12ft</td>
<td>1000 MWe</td>
</tr>
<tr>
<td>Doel 4</td>
<td>W</td>
<td>3 loops, 17 x 17</td>
<td>14ft</td>
<td>1015 MWe</td>
</tr>
<tr>
<td>Tihange 1</td>
<td>FRA</td>
<td>3 loops, 15 x 15</td>
<td>12ft</td>
<td>960 MWe</td>
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<tr>
<td>Tihange 2</td>
<td>FRA</td>
<td>3 loops, 17 x 17</td>
<td>12ft</td>
<td>1000 MWe</td>
</tr>
<tr>
<td>Tihange 3</td>
<td>W</td>
<td>3 loops, 17 x 17</td>
<td>14ft</td>
<td>1015 MWe</td>
</tr>
</tbody>
</table>

= 56% of the consumed electricity
<table>
<thead>
<tr>
<th>Unit</th>
<th>NSSS supplier</th>
<th>MSI</th>
<th>Power (MW)</th>
<th>Number of assemblies</th>
<th>Lattice</th>
<th>Fission length( ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Thermal</td>
<td>Electrical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doel 1 &amp; 2</td>
<td>Westinghouse</td>
<td>1975</td>
<td>2 x 1311</td>
<td>2 x 433</td>
<td>121</td>
<td>14x14</td>
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<tr>
<td>Doel 3</td>
<td>Framatome</td>
<td>1982</td>
<td>3054</td>
<td>1006</td>
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<tr>
<td>Doel 4</td>
<td>Westinghouse</td>
<td>1985</td>
<td>2988</td>
<td>1038</td>
<td>157</td>
<td>17x17</td>
</tr>
</tbody>
</table>
## TIHANGE NPPS

<table>
<thead>
<tr>
<th>Unit</th>
<th>NSSS supplier</th>
<th>MSI</th>
<th>Power (MW)</th>
<th>Number of assemblies</th>
<th>Lattice</th>
<th>Fission length (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Thermal</td>
<td>Electrical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tihange 1</td>
<td>FRA / W</td>
<td>1975</td>
<td>2865</td>
<td>962</td>
<td>157</td>
<td>15x15</td>
</tr>
<tr>
<td>Tihange 2</td>
<td>Framatome</td>
<td>1983</td>
<td>3054</td>
<td>1008</td>
<td>157</td>
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<td>2988</td>
<td>1054</td>
<td>157</td>
<td>17x17</td>
</tr>
</tbody>
</table>
• Safety rules and standards : US rules

• Additional safety features :
  ✓ double containment,
  ✓ a liner on the primary containment
  ✓ Bunkerized second level protection (external hazards including air craft crash)

• Organisation
  ✓ Utility
  ✓ Tractebel Engineering the Owner’s Engineer
  ✓ A multi-contracts approach
# SGR & Power Uprate in Belgium

<table>
<thead>
<tr>
<th>NPP</th>
<th>Initial supplier</th>
<th>Commissioning</th>
<th>SGR&amp;PU</th>
<th>Power uprate(%)</th>
<th>Uprated NSSS power (MWth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doel 1</td>
<td>Westinghouse</td>
<td>1974</td>
<td>2009</td>
<td>10</td>
<td>1311</td>
</tr>
<tr>
<td>Doel 2</td>
<td>Westinghouse</td>
<td>1975</td>
<td>2004</td>
<td>10</td>
<td>1311</td>
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<tr>
<td>Doel 3</td>
<td>Framatome</td>
<td>1982</td>
<td>1993</td>
<td>10</td>
<td>3064</td>
</tr>
<tr>
<td>Doel 4</td>
<td>Westinghouse</td>
<td>1985</td>
<td>1996</td>
<td>0</td>
<td>3000</td>
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<tr>
<td>Tihange 1</td>
<td>Framatome</td>
<td>1975</td>
<td>1995</td>
<td>8</td>
<td>2875</td>
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<tr>
<td>Tihange 2</td>
<td>Framatome</td>
<td>1983</td>
<td>2001</td>
<td>10</td>
<td>3064</td>
</tr>
<tr>
<td>Tihange 3</td>
<td>Westinghouse</td>
<td>1985</td>
<td>1998</td>
<td>0</td>
<td>3000</td>
</tr>
</tbody>
</table>
New Steam Generators

- SGR & Power uprate in Belgium
- The new steam generators
- Organisation of project: multi contract approach
- Safety studies
- Replacement work studies
- Replacement work: outage
- Conclusion
SG replacement: Why?

- Different corrosion phenomena and degradation observed
- High risk for tube rupture
- Important inspection program to be conducted
- Increased plugging of the SG tubes
- Impact on the outage length
- Impact on the dosimetry
SG replacement: Why?

GV/A - Evolution of the plugging

Year
Plugging
maximum
medium
New Steam Generators

• Design changes in the steam generator
  - New material for U-tubes: inconel 690
  - New design of anti-vibration bars
  - Anti-stratification device
  - Triangular pitch of the SG tubes bundle
  - Tube diameter smaller

Increased heat transfer area
SG replacement = an opportunity

- Heat transfer area $\uparrow$
- Thermal power $\uparrow$
- Electrical power $\uparrow$

$\rightarrow$ A new operating point (Tavg-Power)
Multi contract approach

• SGR & Power uprate in Belgium
• The new steam generators
• Organisation of project : multi contract approach
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• Replacement work : outage
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Multi contract approach

• **Via international calls for bid**
  - Selection of the SG supplier
  - Selection of the safety studies provider(s)
  - Selection of the replacement work provider

• **Tractebel Engineering in charge of the project management**
  - Feasibility study (technical and economical point of view)
  - Calls for bid and selection of the suppliers/providers
  - Project management from the feasibility studies to the end of the commissioning tests
Multi contract approach

• A need for a correct and updated database to be shared by all the actors
  - Set up and maintained updates during the project by Tractebel
  - Characteristics of equipment, free volumes, thermal characteristics of material, thermalhydraulics data, setpoints of protection systems, description of regulation and control systems, mass flowrates and delivery curves, pressure drops, uncertainties, internal volume of the containment...

• A need to be able
  - To verify and approve the studies performed by the suppliers
  - To perform some studies (critical ones)
  - To present and defend the analyses in front of the Safety Authorities
Multi contract approach

- **Advantages of this approach**
  - Selection of the best supplier in each domain
  - Cost effective
<table>
<thead>
<tr>
<th>Unit</th>
<th>SG Supplier</th>
<th>Studies</th>
<th>Replacement</th>
<th>Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doel 3 (SGR &amp; PU) 1993</td>
<td>Siemens</td>
<td>Siemens &amp; Tractebel</td>
<td>Siemens</td>
<td>Tractebel</td>
</tr>
<tr>
<td>CNT1 (SGR &amp; PU) 1995</td>
<td>Mitsubishi</td>
<td>Westinghouse</td>
<td>Framatome</td>
<td>Tractebel &amp; EDF</td>
</tr>
<tr>
<td>Doel 4 (SGR) 1996</td>
<td>Framatome</td>
<td>Westinghouse</td>
<td>Siemens</td>
<td>Tractebel</td>
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<tr>
<td>CNT3 (SGR) 1998</td>
<td>Framatome</td>
<td>Framatome &amp; Tractebel</td>
<td>PCI (W)</td>
<td>Tractebel</td>
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<tr>
<td>CNT2 (SGR &amp; PU) 2001</td>
<td>Mitsubishi</td>
<td>Framatome &amp; Tractebel</td>
<td>PCI (W)</td>
<td>Tractebel</td>
</tr>
<tr>
<td>Doel 2 (SGR &amp; PU) 2004</td>
<td>Mitsubishi</td>
<td>Framatome GmbH</td>
<td>PCI (W)</td>
<td>Tractebel</td>
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<tr>
<td>Doel 1 (SGR &amp; PU) 2009</td>
<td>Mitsubishi</td>
<td>Tractebel</td>
<td>PCI (W)</td>
<td>Tractebel</td>
</tr>
</tbody>
</table>
Safety studies

- SGR & Power uprate in Belgium
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The studies

- **Objective:**
  - To justify the new operating point with the new thermal power
  - To verify the criticity requirements (transport, pools,...) due to a change of the fuel enrichment

- **Final Safety Report has to be revisited**
  - Neutronics and thermalhydraulics studies
  - Verification of the capacity of the safety and auxiliary systems
  - Mechanical studies
The safety studies

• A program has to be defined
  - The three concerned domains
    • Kinetics & thermalhydraulics, mechanics, systems
  - List of the studies to be reanalysed
  - List of studies that can be justified without a complete reanalysis

• Program to be approved by the Safety Authorities at the beginning of the project.
  - A first deliverable with the database
The safety studies: neutronics and thermalhydraulics (Doel 1& 2)

• **A reference core:**
  - A cycle length of 12 months with a stretch-out of 3 months
  - Enrichment of 4.6 %
  - FQ=2.30  FDH= 1.65

• **Core Thermalhydraulics studies (DNB)**
  - Statistical method (primary flow excluded)
THE DNB OPT SOFTWARE (DEVELOPED INHOUSE)

• Determination of the new operating point

  1. Low primary temperature (mechanical constraints)
  2. Turbine characteristics
  3. Delta P of 110 bars
  4. DNB margin under accidental conditions
  5. Protection OTΔT and OPΔT
  6. Hot leg temperature

Figure 2: Authorized operating zone

- Low temperature limit
- Turbine limit
- Proximity of OTDT limit
- LOFA limit
- Hot leg temperature limit
- Maximal power
The safety studies: neutronics and thermalhydraulics (Doel 1 & 2)

- **Chapter 15 studies (stretch-out conditions included)**
  - Codes as used
  - Relap5 mod 2.5, LOFTRAN, WCOBRA/TRAC, NOTRUMP
  - Cobra 3 CP
  - Panther, Panbox3

- Each code (each version) undergoes an audit by the Safety Authority and has to be approved

- Each new methodology (=never used in the country) needs to be validated by the Safety Authority.
DE-COUPLED VERSUS COUPLED APPROACHES

1. De-coupled approach – deterministic – physical phenomena treated independently:
   - Simplifications by ignoring 3D effects
   - Conservative assumptions to cope for lack of proper representation of core spatial dynamics
   - Not easily applicable to accidents characterized by non-symmetric conditions at the core inlet or by heterogeneous cores

2. Coupled approach – Best-estimate evaluation of integral plant dynamics treating the problem as a whole:
   - Evaluation of phenomena with more accurate knowledge of margins regarding regulatory limits (licensing)
COUPLING 3D NEUTRON KINETICS TO T-H SYSTEM

RELAP System

PANTHER Core

1D thermal-hydraulic system

Exchange of boundary conditions

3D neutron kinetics + 1D T-H core
COUPLING 3D NEUTRON KINETICS TO T-H SYSTEM

- Data exchange process between RELAP5 and PANTHER codes for a 3-core regions temperature model

Main assumption: core inlet T distribution

Conservative mixing ratios/distributions derived from a limited number of experimental results
The safety studies: neutronics and thermalhydraulics (Doel 1& 2)

- The Steam Line Break accident at hot zero power
  - The concern: the DNB
  - A limiting accident as a result of the increased heat transfer area
  - A specific methodology developed by Tractebel Engineering
  - Coupling of the Relap 5 (system code) and Panther (neutronics code)
  - A better simulation of the interactions between the core physics and the thermalhydraulics
  - Conservative boundary and initial conditions
Results for the Doel 1 NPP

- **DNBR MIN = 1.6**
  - without coupling

- **Licensing DNBR with coupling**
  - DNBR licensing limit = 1.45

- **Best estimate DNBR**
  - DNBR licensing limit = 1.45
The safety studies: neutronics and thermalhydraulics (Doel 1& 2)

- The LBLOCA
  - WCOBRA/TRAC et COCO
  - Superbounded methodology
  - Selection of the boundary and initial conditions depending on the period concerned (blowdown, refill, reflood)
  - Different break sizes to be analysed
  - The decrease of the thermal conductivity of the fuel in function of burnup taken into account
Safety studies

• SAR Chapter 15 analysis Important issues
  
  - Limiting accident among
    • Large Break Loss Of Coolant Accident
    • Main Steam Line Break
    • Feedwater Line Break
  
  - Modifications limited to
    • Protections system
    • Procedures
    • Technical Specification
The safety and auxiliary systems

• **Important issues**
  - Pressure in the containment following a SLB (different break sizes and power to be considered)
  - Capacity of the secondary safety valves
  - The cooling of the fuel pool
  - Long term capacity of the auxiliary feedwater
  - Capacity of the component cooling system after a LBLOCA (long term cooling)
The mechanical studies

• Justification of the new SG
• Justification of the primary systems including the internals of the reactor vessel
• Verification of the mechanical response of the fuel assemblies
• Justification of secondary side components with specific attention for temperature stratification in feedwater lines
• Leak before break justification
• Stretch-out conditions to be covered (limiting since low temperature)
The mechanical studies linked to the replacement activities

• Calculation of the tolerated displacements following the cutting of the old SG

• Resistance of the primary containment during the cutting operation and after

• Resistance of the secondary containment during the cutting operation and after
Replacement work studies

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Replacement work studies

• **ALARA Safety**
  - Shielding studies, dosimetry forecast
  - Conventional safety studies, protection

• **Schedule**
  - Scheduling of SGR activities and integration with Electrabel activities
  - Approximately 2500 activities to be scheduled

• **Storage**
  - Definition and management of stocking area and means of handling during the outage
Replacement work : outage

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Replacement work : outage - Through material hatch
The Bi-bloc methods
Replacement work: outage – Top down method
Erection of the crane

CRANE’S SPECIFICATION:

CAPACITY: 1.300 ton
SPHERE or ACTION: 64 m
HEIGHT: 89 m
FOUNDATION: 25 ton / m²
CONTRACTOR: W/PCI / MAMMOET
ARRIVAL OF THE NEW STEAM GENERATORS IN ANTWERPEN HARBOUR AND DOEL SITE
29/04/2004
Arrival on the site

- **SG LENGTH:** ± 20 m
- **WEIGHT:** ± 300 ton

- **NUMBER OF TUBES:** 4,820
- **HEAT TRANSFER AREA:** 5,110 m²
- **TUBE THICKNESS/DIAMETER:** 1.09 / 19.05 mm
Cutting the secondary containment

WEIGHT OF EACH BLOCK: 18.5 ton (13.5 concrete + 5.0 structure)

16/05/2004
Cutting of the primary containment

**CUTTING MACHINE**
**MINIMUM MATERIAL DEFORMATION**

**OPENING DIAMETER FOR EACH SG**
± 5.50 m

**STEEL THICKNESS**
2.54 cm

19 AND 21 OF MAY
Removal of the old SG
Replacement work : outage – Top down method Lifting of Old SG’s
End of the removal (± 2 HOURS)
Replacement work: outage – Top down method Lifting of New SG’s
Introducing the new SG
Introducing the new SG
Welding the primary containment

MANUAL WELDING
Closing the secondary containment
Conclusion

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## Conclusion

<table>
<thead>
<tr>
<th>Year</th>
<th>Important accident</th>
<th>Duration outage</th>
<th>Duration of intervention on RCS</th>
<th>SG dosimetry</th>
<th>Total dosimetry</th>
<th>Power Uprate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>0</td>
<td>96 days</td>
<td>40 days</td>
<td>1955 mSv</td>
<td>3169 mSv</td>
<td>10%</td>
</tr>
<tr>
<td>1995</td>
<td>0</td>
<td>93 days</td>
<td>31 days</td>
<td>1637 mSv</td>
<td>3089 mSv</td>
<td>8%</td>
</tr>
<tr>
<td>1996</td>
<td>0</td>
<td>92 days</td>
<td>27 days</td>
<td>633 mSv</td>
<td>1231 mSv</td>
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<tr>
<td>1998</td>
<td>0</td>
<td>76 days</td>
<td>20 days</td>
<td>624 mSv</td>
<td>1240 mSv</td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>0</td>
<td>63 days</td>
<td>17 days</td>
<td>648 mSv</td>
<td>1450 mSv</td>
<td>10%</td>
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<tr>
<td>2004</td>
<td>0</td>
<td>65 days</td>
<td>15 days</td>
<td>196 mSv</td>
<td>420 mSv</td>
<td>10%</td>
</tr>
<tr>
<td>2009</td>
<td>0</td>
<td>75 days</td>
<td>15 days</td>
<td>244 mSv</td>
<td>718 mSv</td>
<td>10%</td>
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</table>
### Doel 2: The milestones

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/2000</td>
<td>Decision to replace the steam generators</td>
</tr>
<tr>
<td>08/2001</td>
<td>The order of the new SG</td>
</tr>
<tr>
<td>09/2001</td>
<td>Decision to uprate the power</td>
</tr>
<tr>
<td>10/2001</td>
<td>Definition of the new operating point (Tavg-power)</td>
</tr>
<tr>
<td>11/2002</td>
<td>Start of the licensing</td>
</tr>
<tr>
<td>11/2002</td>
<td>Order of the replacement work</td>
</tr>
<tr>
<td>04/2004</td>
<td>Final Autorisation by the Safety Authority</td>
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<tr>
<td>07/05/2004</td>
<td>Off the grid</td>
</tr>
<tr>
<td>12/07/2004</td>
<td>Reconnected to the grid</td>
</tr>
<tr>
<td>26/07/2004</td>
<td>Operation at the new operating point (+ 10 %)</td>
</tr>
</tbody>
</table>
Conclusion: key success factors

- **During studies and operation**
  - Selection of subcontractors with proven experience
  - Very detailed studies and preparation
  - Coordination studies including Electrabel, Tractebel Engineering and the subcontractors
  - Close interaction with the Safety Authorities

- **During operation**
  - A well prepared and detailed program
  - Lessons learned from previous projects
  - Close and transparent collaboration between all involved partners
  - Eye for safety matters
ADDITIONNAL POWER UPRATES

• Modifications applied to the turbine (low pressure) on Doel 3, Tihange 1, Tihange 2, Tihange 3 et Doel 4 with improved technologies

• As a consequence of those Primary and secondary side uprates the total netto produced electricity has been increased by 456 MWe, or 8.32 %
EVOLUTION OF THE POWER

**Thermal Power (MWth)**

- Puissance thermique (MWth)
- +6.07%

**Electrical Power (MWe)**

- Puissance électrique (MWe)
- +8.32%
CONCLUSIONS

- GDF Suez has more than 45 years of experience

- All those projects have been conducted by GDFSUEZ (Electrabel as utility and Tractebel Engineering as owner’s engineer) in total independence from the NSSS suppliers with as consequences
  - An power increased of 8.32 %
  - A reinforcement of the operation and engineering competences
  - With strong innovations in methods
  - A total mastering of the design basis

- Steam generator replacement at Doel NPP on “youtube”
  - http://www.youtube.com/watch?v=UC0dIND5bvA