Nuclear Power Plants
The Turbine Island

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Paris, 21st October 2013
The Turbine Island Agenda

1. Alstom in Nuclear
2. Turbine Island Basics
3. Turbine Island – Key Products & Solutions
4. Recent Projects
Alstom in Nuclear

Nuclear Island + Turbine Island + BoP = Nuclear Power Plant
Alstom in Nuclear
Turbine Islands based on ARABELLE™ technology
Alstom in Nuclear
World N°1 supplier of nuclear steam turbine generators

55 years of experience: 136 nuclear units in operation = 113 GW

30% of all the world’s nuclear plants have an Alstom steam turbine

North America
8 GW
8 units

Europe
90 GW
103 units

South Korea
5 GW
6 units

India
2 GW
6 units

China
6 GW
6 units

South Africa
2 GW
11 units

North America
8 GW
8 units

Europe
90 GW
103 units

South Korea
5 GW
6 units

India
2 GW
6 units

China
6 GW
6 units

South Africa
2 GW
11 units

30% of all the world’s nuclear plants have an Alstom steam turbine
EDF French Nuclear Fleet
Various generations of nuclear steam turbines

CP0 – CP1
900 MW

P4 – P’4
1300 MW

N4 – ARABELLE
1550 MW
Nuclear Business
Competitive Positioning

• Competitors worldwide experience (50 & 60 Hz grids)

<table>
<thead>
<tr>
<th>TG supplier</th>
<th>Toshiba</th>
<th>GE</th>
<th>Power Machines</th>
<th>Mitsubishi</th>
<th>Siemens</th>
<th>Alstom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Largest unit in commercial operation (as of Sept. 2012)</td>
<td>1100 MWe Higashi-Dori 1 (50 Hz)</td>
<td>1410 MWe Palo Verde 2 (60 Hz)</td>
<td>1060 MWe Tianwan 1 (50 Hz)</td>
<td>1180 MWe Genkai 3 (60 Hz)</td>
<td>1500 MWe Isar 2 (50 Hz)</td>
<td>1550 MWe Chooz B1 (50 Hz)</td>
</tr>
<tr>
<td>Largest unit under construction (as of Sept. 2012)</td>
<td>1400 MWe Braka 1-4 (50 Hz)</td>
<td>1455 MWe Shin-Kori 3 (60 Hz)</td>
<td>1200 MWe Leningrad II 1 (50 Hz)</td>
<td>1370 MWe Lungmen 1 (60 Hz)</td>
<td>1720 MWe Olkiluoto 3 (50 Hz)</td>
<td>1750 MWe Flamanville 3 (50 Hz)</td>
</tr>
</tbody>
</table>

• Color code:

  Green = currently in Operation
  Blue = currently under Construction
The Turbine Island
Agenda

1. Alstom in Nuclear
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3. Turbine Island – Key Products & Solutions
4. Recent Projects
Inside a Nuclear Power Plant
Primary, Secondary, Tertiary Loops

- Non-contaminated steam goes to steam turbine
- No turbine island containment needed

The Pressurised Water Reactor (PWR)
Inside a Nuclear Power Plant
Primary, Tertiary Loops

- Contaminated steam goes to steam turbine → special gland sealing system
- Turbine island needs some containment (concrete shielding) + specific material choices

The Boiling Water Reactor (BWR)
What is specific to Nuclear Power Plants?
Much larger steam volume flow

![Graph showing steam volume flow vs. steam turbine generator output (MW)]

- **Fossil**
- **Nuclear**

- Nuclear \( \rightarrow \) large volume flows \( \rightarrow \) need for long blades \( \rightarrow \) high centrifugal forces

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[ALSTOM logo]
What is specific to Nuclear Power Plants?

Wet steam conditions
Steam Expansion Line
Mollier Diagram – N4 Reactor

“cold” steam at LP inlet:
- small LP axial thermal expansion
- reduced axial clearances
- possibility to fit a 4th LP

- HP
  P: 71 bar
  T: 287°C
  x: 0.4%

- MSR
  P: 10.7 bar
  T: 183°C
  x: 14.6%

- IP
  P: 10.1 bar
  T: 268°C

- LP
  P: 0.055 bar
  x: 12.5%

Entropy $S$ (kJ/kg.K)
Enthalpy $H$ (kJ/kg)
EPR - Flamanville 3
Simplified steam-water cycle

Primary Loop

Secondary Loop

Tertiary Loop

Steam and water pipes from/to NI

100% steam bypass to condenser

De-aerating feed-water tank

Circulating water pumps

Busbars

Generator, exciter

Core

HP heaters

LP heaters

CI auxiliaries cooling HEX

Condensate extraction pumps

Condenser, vacuum system, debris filters

Drain tanks

MSR drain pumps

Feed heaters pumps

MSR

HP

IP

LP

Core

Feed heaters pumps

MSR drain pumps

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Drain tanks

MSR drain pumps

Feed heaters pumps

MSR

HP

IP

LP
World Nuclear Power Plants
Half-speed dominates the market above 700 MW

- France, U.S.A., Canada, Japan, South Korea, Brazil, Taiwan, South Africa, etc.:
  - all nuclear units in operation are **half-speed**

- China:
  - since 2005, all nuclear turbines (with output > 700 MW) ordered are **half-speed**

**Source: Alstom databases**

Above 1200 MW, only half-speed → to keep reasonable stress levels
Full Speed vs. Half Speed – what makes the difference? Case study: Ling Ao 1 vs. Ling Ao 3

Half speed expansion lines in HP, IP and LP sections are much more efficient.
A challenge for turbine designers
Covering a wide range of reactors & heat sinks

Typical LP exhaust volumetric flow for a given application: 1 reactor/1 site

Reactors
- EPR
- ESBWR
- APWR1500
- ADWR
- AP1000
- VVER1200
- CPR1000
- ATMEA1
- PHWR700

India
Finland
A challenge for turbine designers
Covering a wide range of reactors & heat sinks

Typical LP exhaust area needed for a given application: 1 reactor/1 site

Reactor thermal output in MWth
Condenser backpressure in mbar

5 000 MWth
4 500 MWth
4 000 MWth
3 500 MWth
3 000 MWth
2 500 MWth
2 000 MWth

250 m²
200 m²
150 m²
100 m²
75 m²
50 m²

Reactors
EPR
ESBWR
APWR
ABWR
AP1000
VVER1200
CPR1000
ATMEA1
PHWR700

Site cooling
water temp. °C

50 m²
75 m²
100 m²
150 m²
200 m²
250 m²
The Turbine Island Agenda

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Integrated Packages
Turbine Island (TI)
Integrated Packages
Secondary Loop Package (SLP)
Turbine Islands
key components

- Grid equipment
- 4-pole generator
- Condensate extraction pumps
- Circulating water pumps
- Reactor feed-water pumps
- HP & LP feed-water heaters
- Modular condenser
- Steam turbine
- MSR
- Turbine Islands
- Grid equipment
- 4-pole generator
- Condensate extraction pumps
- Circulating water pumps
- Reactor feed-water pumps
- HP & LP feed-water heaters
- Modular condenser
- Steam turbine
- MSR
The Turbine Island Agenda

1. Alstom in Nuclear

2. Turbine Island Basics

3. Turbine Island – Key Products & Solutions
   *The steam turbine*

4. Recent Projects
Turbine Technology
Use of more efficient single flow steam expansion

60% of the power output comes from single flow steam expansion
ARABELLE™ Steam Turbine
Advanced compared to previous generation

ARABELLE™
Efficient configuration
Single flow use

PREVIOUS GENERATION
Traditional configuration
Double flow use

ARABELLE™ uses more efficient single flow steam expansion
ARABELLE™ Steam Turbine
A specific design to maximise single flow steam expansion & efficiency
How to improve turbine efficiency?

- Efficiency increases with blade aspect ratio

Longer blades have better efficiency
ARABELLE™ Characteristics
Combined HP/IP Module, Unique in the Market

• Single flow HP and IP for best efficiency
• Combined HP/IP for maximum power density
• Same footprint for 50 and 60 Hz
• Designed to fit all large commercialised reactors

• HP/IP rotor delivers up to 60% of the overall output
ARABELLE 1700 50 Hz
Flamanville 3 HP-IP casing

Flamanville 3 rough machined HP-IP casing in VOEST ALPINE foundry
ARABELLE™ References
Ling Ao 3+4 – 2 x 1080 MW

Ling Ao 3 HP-IP casing in Dong Fang Works
ARABELLE™ References
Flamanville 3 – 1 x 1750 MW

- HP/IP rotor entering balancing pit, Belfort factory
ARABELLE™ References
Flamanville 3 – 1 x 1750 MW

- LP2 welded rotor, fully bladed, Belfort factory
ARABELLE 1000 for Ling Ao 3
Last Stage Blades : LSB57

Fully bladed LP57 rotor entering Belfort balancing pit (Ling Ao 3)
The Turbine Island

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   *The generator*
4. Recent Projects
GIGATOP 4-pole for Flamanville 3
A highly efficient turbo-generator

- 2000 MVA
- Cos-phi = 0.9
- 1500 rpm
- 4 poles, 3 phases
- 23 kV
- Brush-less exciter
- H₂ and H₂O cooled
- Stainless steel cooling tubes
- H₂ pressure: 6 bars(g)
- Triple-circuit hydrogen sealing system
- 99% efficiency

- Flamanville 3 generator final assembly and running tests in Alstom factory
- Validation of manufacturing quality
- Validation of the design, of the electrical performances
## The Turbine Island

**Agenda**

1. Alstom in Nuclear
   - Turbine Island Basics
   - Turbine Island – Key Products & Solutions
     - The heat exchangers
   - Recent Projects
Key Components
Heat Exchangers for Nuclear Plants

1. Condenser
2. Moisture separator reheater (MSR)
3. HP heater
4. LP heater
5. Feedwater tank and deaerator

Auxiliary water/water coolers
High velocity separators (HVS)
Nuclear purification system (NPS)
Nuclear Heat Exchangers
Flamanville 3 deaerating feed-water tank

• Designed by Alstom
  - In 3 separate pieces
  - 98 t + 90 t + 98 t
  - Transported separately
  - Welded at site

• When assembled, final dimension is:
  47.1 m x 5.9 m x 5.3 m
Nuclear Heat Exchangers
A Complete Condensing System

- Single or multiple pressure condensers
- Optimised tube bundle arrangement for high performances
- Compact arrangement with LP turbines directly feeding duplex LP1&2 FW heater located in condenser neck
- Optimised condensate extraction with 3x50% pumps
- Optimised vacuum hogging / holding system
The Turbine Island

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   *The main pumps*

4. Recent Projects
Key Components
Pumps for Nuclear Plants

Concrete volute circulating water pump
Condensate extraction pump
Feedwater pump
Intermediate cooling pump
Residual heat removal pump
Essential service pump
Open/closed loop cooling pump
Vacuum pump
Flamanville 3 NPP:

- Direct sea-water cooling of the condenser tubes
- 2 x 50% pumps arrangement
- 110,000 m$^3$/h each (30.5 m$^3$/s each)
- 15.4 m head
- Rotate at 151 rpm

- Civil engineering works on suction ducts (Sept. 2009)
• Flamanville 3 CWP impeller heat treatment (photo credit: Ferry Capitain)
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ARABELLE™ References
Flamanville 3 – 1 x 1750 MW

- Nuclear reactor: EPR (PWR)
- Turbine type, output: ARABELLE 1700, 1 x 1750 MW
- Generator type: GIGATOP 4-pole
- Steam parameters:
  - Live steam: 75 bar / 290°C
  - Exhaust: 46 mbar
- Customer: EDF
- Country: France
- City / region: Normandy

- Schedule:
  - Order year: 2006
  - Comm. year: 2016
ARABELLE™ References
Flamanville 3 – 1 x 1750 MW
Flamanville 3 – 1750 MWe
ARABELLE™ - Turbine & Generator

- Turbine HP/IP rotor entering balancing pit, Belfort factory, France
ARABELLE™ References
Flamanville 3 – 1 x 1750 MW

- Generator rotor
Flamanville 3 – 1750 MWe
ARABELLE™ - Turbine & Generator

- Generator test, Belfort factory, France
Flamanville 3 – 1750 MWe
ARABELLE™ - Turbine & Generator

Site in January 2013
**ARABELLE™ References**
**Ling Ao phase II – 2 x 1080 MW**

<table>
<thead>
<tr>
<th>Item</th>
<th>Details</th>
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</thead>
<tbody>
<tr>
<td>Nuclear reactor:</td>
<td>CPR1000 (PWR)</td>
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<tr>
<td>Turbine type, output:</td>
<td>ARABELLE 1000, 2 x 1080 MW</td>
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<tr>
<td>Generator type:</td>
<td>GIGATOP 4-pole</td>
</tr>
<tr>
<td>Steam parameters:</td>
<td>Live steam: 64 bar / 280°C</td>
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<td></td>
<td>Exhaust: 56 mbar</td>
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<td>Customer:</td>
<td>DEC for LDNPC</td>
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<tr>
<td>Country:</td>
<td>China</td>
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<tr>
<td>City / state:</td>
<td>Dapeng / Guang-Dong</td>
</tr>
<tr>
<td>Schedule:</td>
<td>order year 2005 comm. year 2010 &amp; 2011</td>
</tr>
</tbody>
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**References**

- Ling Ao phase II – 2 x 1080 MW
ARABELLE™ References
Ling Ao phase II – 2 x 1080 MW
ARABELLE™ References
Ling Ao phase II – 2 x 1080 MW
Lingao 3 LP exhaust hood in Dong Fang Works
ARABELLE™ References
Ling Ao phase II – 2 x 1080 MW

Synchronized in July 2010, ahead of schedule

Measured output level above guarantee

Ling Ao 3, China - 1080 MW