Westinghouse: Leading Nuclear Technology Innovation

October 2015
International Nuclear Atlantic Conference, Sao Paulo, Brazil

James Wyble, Vice President, Americas
Carlos Leipner, Vice President, Latin America
Westinghouse Electric Company

- Founded in 1886 in Pittsburgh, Pennsylvania, by George Westinghouse
- Responsible for some of the world’s most important achievements:
  - Alternating current technology
  - First commercial radio broadcast (KDKA-1920)
  - USS Nautilus nuclear submarine
  - First camera on the moon
  - Commercial nuclear power
Westinghouse Electric Company Today

Operating Plants Business
Delivers operating plant products and services, including global field services, instrumentation and control, welding and machining, and installation-related functions

Decommissioning, Decontamination and Remediation
Deploys global technologies and forms local partnerships to carry out long-term projects

Engineering Center of Excellence
Supports all product lines by driving common engineering capabilities and accelerating innovation

New Plants and Major Projects
Delivers both new-plant projects and major projects for new and operating plants on a global basis

Nuclear Fuel and Components Manufacturing
Designs and delivers fuel for PWR, BWR, VVER, and AGR reactors, and oversees manufacturing operations worldwide
Strategically Positioned to Develop and Support the Worldwide Fleet
Westinghouse in Brazil

Actively supports the Brazilian nuclear community and participates with leading universities to develop local talent and leadership
Developing New Talent

Alice Cunha – Winner of 2015 WNU Nuclear Olympiad

Andre Rebello – 2nd Place at INAC 2013 Junior Poster Technical Session
Why Nuclear Power

7.3 Billion
2015 World Population

1 Billion Live on Less than US$1.25/day
750 Million Lack access to clean water
1.3 Billion lack access to electricity

Access to reliable and clean electricity is an imperative to our future: Nuclear Power has a Important Role to Play

Ref: United Nations, World Bank, water.org, worldenergyoutlook.com
Status of Nuclear in the World and US Today

World Electricity Production 2012

- Total 22,752 TWh
  - 40.2% Coal
  - 22.4% Gas
  - 16.5% Hydro
  - 10.8% Nuclear
  - 7.4% Solar & Wind
  - 2.7% Other

Source: IEA Electricity Information 2014
Status of Nuclear in the World and US Today

Nuclear Generation by Country 2013

Source: IAEA PRIS Database
Status of Nuclear in the World and US Today

2014 US Electricity Generation

- Coal: 39%
- Natural gas: 27%
- Nuclear: 19%
- Hydropower: 6%
- Other renewables: 7%
- Petroleum: 1%
- Other: 1%

Ref: Nuclear Energy Institute (NEI), World Nuclear Association (WNA)
Status of Nuclear in the World and US Today

Sources of Emission-Free Electricity 2014

- Nuclear: 62.9%
- Hydro: 19.9%
- Solar, Wind & Geothermal: 17.1%

Ref: Nuclear Energy Institute (NEI), World Nuclear Association (WNA)
Comparison of Life-Cycle Emissions
Tons of Carbon Dioxide Equivalent per Gigawatt-Hour

- Coal: 979
- Gas: 462
- Biomass: 253
- Solar PV: 53
- Geothermal: 42
- Hydro: 26
- Nuclear: 13
- Onshore Wind: 12

Source: Annex III: Technology-specific cost and performance parameters. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Edenhofer, O., et al., Cambridge University Press, 2014. The numbers shown are the median of studies examined by the IPCC in grams CO₂e per kWh and are converted to tons CO₂e per GWh.
Nuclear Power: A Sustainable Alternative

Current high-level waste volume after the plant’s lifetime of operations would fill an area about the size of a football field five yards deep

• ~48,000 metric tons
• ~½ ton per fuel assembly
• ~100,000 assemblies
• Only ~5% is waste
Nuclear Power: A Sustainable Alternative

Plant Neighbors More Favorable to Nuclear Energy Than General Public

Overall, do you strongly favor, somewhat favor, somewhat oppose, or strongly oppose the use of nuclear as one of the ways to provide electricity in the United States? (%)

- **Plant Neighbors**
  - 83 strongly favor
  - 50 somewhat favor
  - 33 somewhat oppose
  - 16 strongly oppose
  - June 2015

- **General Public**
  - 68 strongly favor
  - 27 somewhat favor
  - 42 somewhat oppose
  - 16 strongly oppose
  - March 2015

*6th Biennial National Survey of U.S. Nuclear Power Plant Neighbors 2015*
Nuclear Power: A Competitive Source

U.S. Electricity Production Costs
1995-2014, In 2014 cents per kilowatt-hour

Production Costs = Operations and Maintenance Costs + Fuel Costs. Production costs are based on FERC filings submitted by regulated utilities and do not include some costs such as capital and indirect costs. Production costs are modeled for utilities that are not regulated.

Source: ABB Velocity Suite
Updated: 6/15

Ref: Nuclear Energy Institute (NEI), World Nuclear Association (WNA)
Nuclear Power: A Competitive Source

Fuel as a Percentage of Electric Power Production Costs

2013

- Fuel 78%
- Fuel 86%
- Fuel 34%
- O&M 22%
- O&M, 11%
- O&M 66%
- 31%
- 42%
- Conversion Fabrication
- Waste Fund
- Enrichment
- Uranium

Ref: Nuclear Energy Institute (NEI), World Nuclear Association (WNA)
## Nuclear Power: A Competitive Source

### U.S. Capacity Factors by Fuel Type

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Average Capacity Factors (%)</th>
</tr>
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<tbody>
<tr>
<td>Nuclear</td>
<td>91.7</td>
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<tr>
<td>Geothermal</td>
<td>68.8</td>
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<tr>
<td>Coal (Steam Turbine)</td>
<td>60.9</td>
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<tr>
<td>Gas (Combined Cycle)</td>
<td>47.8</td>
</tr>
<tr>
<td>Hydro</td>
<td>37.5</td>
</tr>
<tr>
<td>Wind</td>
<td>33.9</td>
</tr>
<tr>
<td>Solar</td>
<td>27.8</td>
</tr>
<tr>
<td>Oil (Steam Turbine)</td>
<td>12.8</td>
</tr>
<tr>
<td>Gas (Steam Turbine)</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Ref: Nuclear Energy Institute (NEI), World Nuclear Association (WNA)
Nuclear Power: A Competitive Source

Levelized Cost of Electricity (USD)

Ref: Nuclear Energy Institute (NEI), World Nuclear Association (WNA)
Westinghouse Technology Innovation

• We are proud to have a vast and varied team of world-recognized technical experts who develop, test and refine Westinghouse technology in engineering disciplines that span the nuclear industry

• Westinghouse Technology Innovation is making the operating fleet more efficient, safer and more competitive
Primary Side Technology Advancements

- **Zephyr® Advanced Acquisition System**
  - Suitcase ECT System
    - Streamlined Equipment, Weight, Connections
    - Fast Set-Up/Start-Up & Tear-Down
    - Intelligent Planning and Optimized Cycle Time
    - Software Flexibility
    - Yields Eddy Current (bobbin) Acquisition 25-35% faster
  - Revolutionary Probe Delivery
    - Air Assisted
    - Probe Speed Optimization

- **TITAN™ Analysis System**
  - Two unique, but complimentary EPRI-qualified bobbin auto analysis programs
    - Up to 75% reduction of production analysis crew (for auto/auto)
    - Addresses NDE resource limitations & reduces human performance events
  - EPRI-qualified RPC/Array auto analysis program
  - Single Pass Analysis
Zephyr® Details

- **Zephyr® Equipment Elements**
  - Pegasys® Robot
    - End effector w/tubesheet seal
  - Omni Probe Pusher
    - Air regulator
  - Software
    - Eliminates waste
  - Probe
    - Customized LLMC probe
    - Conduit
    - Poly
Zephyr® Details

- Pegasys Robots
- Zephyr Tubesheet Seal
- Zephyr Air Regulator and Sealed Conduit
- Omni Probe Pushers and Poly
Zephyr® Details

• Field Experience
  – Pilot Implementations at Catawba and Palo Verde in 2014
  – Zephyr® Implementation at Palo Verde in 2015
    • ¾” Tubing; System 80 Steam Generator
    • Over 25,000 tubes inspected
    • 24 hours of schedule reduction
    • Eliminated the need for a cold core mid-loop/nozzle dams
    • 50% reduction in probe use
    • 50% reduction in dose
  – Zephyr® Implementation at Byron 1 in 2015
    • 11/16” Tubing; B&W Steam Generator
    • Over 26,000 tubes inspected
    • 50 hours of schedule reduction
    • 25% reduction in probe use
    • 40% reduction in dose

Another excellent FOAK deployment at Bryon
Secondary Side Technology Advancements

- Westinghouse’s Stellar® Nozzles
  - Provides clear jet collimation throughout the entire tube bundle;
    Used at Catawba, Wolf Creek, Farley and Fort Calhoun Spring 2015
  - 70-100% increase in sludge removal
  - More effective removal of scale and hard collars
  - No failed cleanliness exams

Demonstrated Significantly Improved Cleaning Power in Less Time
Secondary Side Technology Advancements

• Reptil Automated Inbundle Inspections
  – Demonstrated on upper support plate at Catawba 2
  – Provides integrated:
    – Positional feedback
    – Speed & safety controls
    – Metadata capture (Column, Row, Elevation)
  – Average of 80% dose reduction
  – Faster, better quality inspections

• Additional Value
  – Industry leading retrieval capabilities and speed
  – Custom designed tooling and mock-ups to aid performance
Chemical Based Cleaning

• Westinghouse has the most comprehensive solution to steam generator secondary side maintenance including:
  – EPRI/SGOG Chemical Cleaning
  – Advanced Scale Conditioning Agents (ASCA)
  – iASCA
  – Consolidated Deposit Extraction (CODE)

Westinghouse’s portfolio provides maintenance flexibility
EPRI/SGOG Chemical Cleaning
Reasons for Application

• Address Steam Generator issues:
  – Corrosion risk
  – Tube fouling
  – Degradation of thermal hydraulic performance
    – Heat Transfer
    – Level Instability

• Clean tube support plate crevices

• Remove tube scale from freespan surfaces, which can form artificial crevices and initiate ODSCC

• Improve Eddy Current Inspection Quality

Referred to as “hard” chemical cleaning; the most aggressive cleaning method
EPRI/SGOG Chemical Cleaning

Westinghouse Experience

- Asco 2 – Fall 14
- Asco 1 – Spring 14
- St. Alban 1 – Spring 11
- St. Laurent B1 – Summer 11
- Belleville 2 (Summer 2010)
- Cattenom 4 (Spring 2010)
- Chinon B3 (Summer 09)
- Cattenom 3 (Summer 09)
- Cattenom 1 (Spring 09)
- Point Beach (Fall 08)
- Belleville (Fall 08)
- Cruas 2 (Fall 08)
- Cruas 3 (Spring 08)
- Vogtle Unit 2 (Spring 07)
- Vogtle Unit 1 (Fall 06)
- Diablo Canyon Unit 2 (Oct. 2004)
- Diablo Canyon Unit 1 (April 2004)
- Robinson (Oct. 2002)

- Beaver Valley 1 (Sept. 2001)
- Comanche Peak 1 (Oct. 1996)
- Sequoyah 2 (April 1996)
- Wolf Creek (March 1996)
- Bruce A Unit 1 (Nov. 1995)
- Sequoyah 1 (September 1995)
- Callaway (April 1995)
- Surry 1 (Dec. 1994)
- Bruce A Unit 3 E Bank (July 1994)
- Bruce A Unit 3 W Bank (June 1994)
- Surry 2 (June 1994)
- Bruce A Unit 4 Prehtrs (July 1993)
- Bruce A Unit 4 E Bank (July 1993)
- Bruce A Unit 4 W Bank (April 1993)
- Doel 4 (March 1992)
- Kori 1 (Oct. 1990)
- ANO-1 (October 1990)
- Maine Yankee (April 1987)
- Millstone 2 (March 1985)
EPRI/SGOG Chemical Cleaning

- Process Module & IX Modules
- 10 Mix Tanks
- Control Module
- Chem Lab & Chem Handling
- 2 Cooling Towers
- Package Boiler
- Diesel Generators
- Electrical Module
Chemical Cleaning Technologies
New Developments

• **ASCA**
  - More than 40 applications worldwide
  - Removal totals have significantly increased while still retaining thermal hydraulic benefits
    - Results include 5-24% increase in steam pressure following FB cleanings

• **iASCA**
  - Developed to increase removal capacity of ASCA solutions while maintaining low corrosion levels
  - Increased deposit dissolution capacity in a single ASCA step over existing ASCA processes
  - Not designed for thermal hydraulic benefits, focus on large mass of removal

• **Consolidated Deposit Extraction (CODE)**
  - Only process available in the industry capable of dissolving TTS collar binding species (e.g. Silica, Aluminum species)

Accessible $\text{Fe}_3\text{O}_4$, Cu, etc. removed, but $\text{AlOOH} / \text{SiO}_2$ “skeleton” remains
iASCA/CODE Equipment
External Set-up

- Waste Tanks
- Sludge Lance Trailer
- Containment Berm
- Temporary RCA Boundary
- Waste Frac Tanks
- Berm
TTS iASCA/CODE Equipment Containment

- Pumps and Chemicals
- Splash screens
- Spill Kit
- Process Heater
- Vent Drum
- Containment Berm
Optimizing Steam Generator Chemical Cleaning

Performance of a chemical cleaning provides many benefits to the plant:

• Removes large amounts of deposits from the SG without excessive corrosion of surface materials
• Helps extend SG operation
• Helps prevent plant capacity loss
• Enhances steam generator and plant performance
• Helps prevent costly steam generator replacement
• Offsets impact of sludge lancing skips
• Can be customized to meet plant needs
World-Class Training Center at Waltz Mill Site

Above: Reactor Coolant Pump motors

Top: Reactor vessel head; diver training

Left: Steam Generator mock-ups

Right: Refueling system
Westinghouse Technology to Enhance Safety

- PWR & BWR External Assessments
  - Seismic, Flooding, PRA,
- PWR SHIELD Passive Thermal Shutdown Seal
- Containment Venting System
- Hydrogen Management
- Spent Fuel Pool Protection
  - SFPIS
  - EFPCS
- SBO Coping Strategies
- Severe Accident Mitigation
RCP Seal Technology Summary

• The SHIELD® Shutdown Seal has the most operating experience in US nuclear power plants

• The SHIELD® SDS is the only low leakage seal endorsed by the US Nuclear Regulatory Commission for crediting in FLEX applications

• WEC is making substantial investments and is committed to working with our customers to improve RCP seal reliability and performance

• Overall objective of programs is to achieve seal life of 12 years
Product Overview – Description of Operation

**SHIELD Passive Thermal Shutdown Seal**

- **#1 Seal**
- **#2 Seal**
- **#3 Seal**

**#1 Leak Off**

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Westinghouse Non-Proprietary Class 3

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Product Overview – Principles of Operation

- Solid Retaining/Seat Ring
- Shaft Sleeve
- Solid Polymer Sealing Ring
- Piston Ring
- Wave Spring
- Retracting Thermal Actuator
- #1 Seal Leakoff
SHIELD® Passive Thermal Shutdown Seal Cut-Away: **Normal** Operation

- **Solid retaining/seat ring**
- **Shaft Sleeve**
- **Retracting Thermal Actuator**
- **Solid Polymer Sealing Ring**
- **Piston ring**
- **Wave Spring**
- **Modified #1 Insert**
- **#1 Seal Leakoff**
SHIELD® Passive Thermal Shutdown Seal Cut-Away: Loss of All Seal Cooling - Activation
SHIELD® Passive Thermal Shutdown Seal Cut-Away: Loss of All Seal Cooling - Sealing

- Solid retaining/seat ring
- Shaft Sleeve
- Solid Polymer Sealing Ring
- Piston ring
- PRESSURE
SHIELD Shutdown Seal

Enhancing Safety
Innovating for the Future

- Development of thermoacoustic sensors for Sodium-cooled Fast Reactors (Westinghouse-ANL-University of Pittsburgh)
- Integral Inherently Safe Light Water Reactor (Georgia Tech-Westinghouse plus other universities and labs)
- Accident Tolerant Fuel development (WEC and multiple partners)
- Consortium for Advanced Simulation of Light Water Reactors (CASL)
- Small Modular Reactor SMR

Members of the Westinghouse-ORNL team with 2014 high-performance computing (HPC) Innovation Excellence Award for AP1000® core physics simulations using the CASL Virtual Environment for Reactor Applications (VERA)

Using collaborative innovation to get ideas into the pipeline and deliver products to market faster
Advantages of Westinghouse AP1000™ Plant

Proven Technology and Innovative Passive Safety Systems

Passive safety replaces mechanical and electrical systems – harnesses natural forces like gravity, convection, and condensation to achieve safe shutdown.

Delivery Certainty

Standard design, experience from current projects and modular construction enable “n^th of a kind” delivery performance.

Regulatory Certainty

Reviewed by multiple countries; first Generation III+ reactor to receive design certification from the U.S. NRC.
AP1000 Plant
Simplicity in Safety Design

Passive Technology Employs Natural Forces

- Evaporation
- Condensation
- Natural Circulation
- Compressed gasses (nitrogen, air)
- System performance has been proven by extensive testing and approved by the U.S. NRC
- No reliance on operator action for 72 hours
## AP1000 Plant – Regulatory Certainty

<table>
<thead>
<tr>
<th>Reviewing Authority</th>
<th>Type of Review</th>
<th>Date</th>
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<tbody>
<tr>
<td></td>
<td>AP1000 Plant Final Design Approval for DCD Revision 19</td>
<td>December 2011</td>
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<tr>
<td></td>
<td>AP1000 Plant Construction Permit Received</td>
<td>March 2009 (Sanmen) September 2009 (Haiyang)</td>
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<tr>
<td></td>
<td>AP1000 Plant Interim Design Acceptance</td>
<td>December 2011</td>
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<tr>
<td></td>
<td>AP1000 Plant Passed Phase 2 of 3 Stage Pre-Licensing Review</td>
<td>July 2013</td>
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<tr>
<td></td>
<td>AP1000 Plant Formal Certification of Compliance</td>
<td>May 2013</td>
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<tr>
<td></td>
<td>AP1000 Plant Conformance with Advanced Light Water Reactor Utility Requirements Document</td>
<td>February 2003</td>
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</tbody>
</table>
AP1000 Plant – Delivery Certainty

- AP1000 plant design minimizes risk
  - Modular approach enables parallel activities and shorter construction

- Engineering is complete
  - Significant effort spent to achieve

- Eight units under construction world-wide means subsequent units will derive significant benefit from
  - Design and process maturity
  - Supply chain maturity and experience
  - Lessons learned

- Fleet of AP1000 plant operators will provide network of sister plants who share operating experience
The AP1000 PWR: Designed for Greater Project Certainty and Shorter Schedule

Modular construction means more work done in parallel

- Factory production of modules
- Transport Modules
- On-site module assembly

Plant Operation

- Plant Order
- Site Survey and Preparation
- Site Construction
- Construction and module assembly

Shorter schedule – increased safety – improved quality
Progress of U.S. Projects: Summary

• Nuclear Island basemat concrete pours completed for V.C. Summer Units 2&3; Vogtle Units 3&4
• Containment Vessel Bottom Head (CVBH) set in nuclear island for Vogtle Units 3&4; V.C. Summer Units 2&3
• First CV Ring set for V.C. Summer Unit 2 and Vogtle Unit 3; fabrication of additional rings continues at both sites
• Component and module fabrication proceeding; major modules CA20 and CA05 set at Vogtle Unit 3 and V.C. Summer Unit 2
• Reactor Vessels delivered for initial units at each site; additional equipment and component deliveries continue to proceed
Sanmen Site Progress: Time Lapse View  
2009 to 2015

Photos © Sanmen Nuclear Power Company Ltd.
Summary

• Nuclear energy continues to provide multiple benefits as a source of electricity generation and will play an increasing role in meeting world energy needs.

• A worldwide fleet approach for standard nuclear design provides maximum efficiencies for long-term, competitive electricity generation.

• The AP1000 plant technology is the right size and is passive, standardized and licensed:
  – Environmentally responsible source of electricity
  – Unmatched licensing pedigree
  – Provides certainty of schedule and cost; reduced project risk

*Westinghouse: Partnering with Brazil to provide safe, reliable, competitive nuclear generation for years to come!*
THE FIRST TO INNOVATE
THE NEXT TECHNOLOGY SOLUTION
http://www.westinghousenuclear.com/