Watts Bar Unit 2

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Watts Bar Unit 2 Overview

- Completed Watts Bar Unit 2 safely, with quality, and by using lessons learned
- Moved directly and diligently into complex Power Ascension Testing (PAT) Program while protecting Unit 1
- Successfully addressed unique challenges of bringing a newly completed unit into operation the first time
- Operating two-units safely, reliably
- Continuing to use and to share lessons learned within TVA and with industry

Watts Bar Unit 2 Completion – A Look Back

- Watts Bar Unit 2 Completion Project approved by TVA Board in 2007
- Original project milestones outlined in approval were not met, including cost and schedule due to:
  - Organizational and management capabilities being misaligned with unique project characteristics
  - Low initial estimates and impeded planning resulting from a lack of understanding of the work to be done
  - Not executing a robust execution plan or fully utilizing available capabilities
  - Inadequate oversight and project assurance

Watts Bar Unit 2 Completion – A Look Back

- New management team established in 2011
  - Performed analyses of issues and remaining work
  - Developed a revised estimate to complete based on recalculation that plant was actually 35% to 40% complete, not 70%
  - Incorporated lessons learned from Browns Ferry Unit 1 and most recent plant startups
  - Took actions to improve performance
- Board approved resuming construction efforts in 2012
- Operating license issued in October 2015

Watts Bar Unit 2 Completion – Lessons Learned

- Lessons learned incorporated included:
  - Organize for success
  - Develop estimate based on detailed analysis and lessons learned and ensure buy-in of cost and schedule
  - Develop a clear execution strategy
  - Measure what needs to be achieved
  - Manage risk
  - Value oversight
  - Engage the workforce
  - Strengthen and expand operational readiness program
  - Strengthen departmental operational readiness
  - Ensure likeness of Unit 1 and Unit 2
  - Develop and implement a program to ensure the adequacy of operational procedures

Watts Bar Unit 2 Completion – Lessons Learned

- Browns Ferry Unit 1 lessons learned included:
  - Staffing
  - Ownership of transition and operational readiness programs
  - Implementation of operational standards
  - Performance of departmental operational readiness self-assessments
  - Development of comprehensive transition plans
  - Use of dedicated resources to determine unit differences
  - Preparation of testing and operations procedures
  - Implementation of labeling process
  - Use of a dedicated tagging crew
  - Scheduling system integration and risk reviews
  - Identification and procurement of spare parts

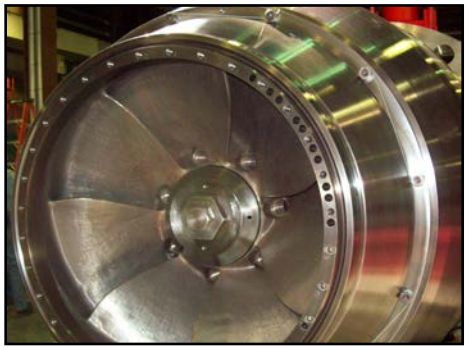
Watts Bar Unit 2 Completion – Results

- Safety
  - Over 33.7 million work hours without lost-time
  - Recordable injury rate of 0.27 since October 2012
  - Low allegation rate
- Quality
  - Quality Control rate consistently above 98%
  - Quality validated through testing
- Performance
  - Over 1,600 critical hours achieved and over 685,000 megawatt-hours of electricity produced during PAT
  - Did not cause a Unit 1 reactor or turbine trip

Watts Bar Unit 2 Completion – Results

- Make Like New
- Replaced, rebuilt, and refurbished systems, structures, and components
  - Ensured licensing, design, and equipment vendor specifications were met
  - Constructed and refurbished unit to “like new” condition

- Scope included
  - Active components
  - Passive components
  - Safety-related
  - Quality-related
  - Non-quality related

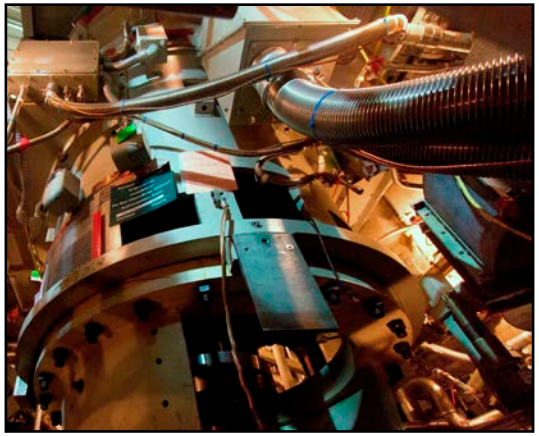


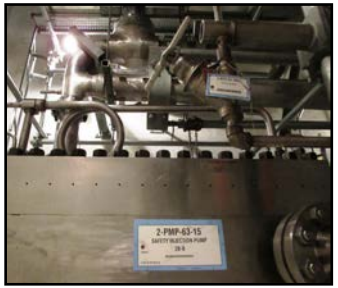
Watts Bar Unit 2 Completion – Results

- Piping replaced to address flow accelerated corrosion
- Alloy 600 addressed
- Switchyard upgraded, transformers refurbished and tested

Watts Bar Unit 2 Completion – Results

- Auxiliary and Reactor Building
  - –New reactor coolant pumps
  - –Pump motors rebuilt, including reactor coolant pump motors
  - –Control panels reworked
  - –~100 transmitters replaced





Watts Bar Unit 2 Completion – Results

- Auxiliary and Reactor Building
  - Valves
    - 470 valves replaced
    - Internals disassembled, inspected, and cleaned, lubricants changed
    - Actuator diaphragms replaced, positioners replaced/rebuilt, and limit switches replaced
    - New Safety Injection System vent valves installed

Watts Bar Unit 2 Completion – Results

- Auxiliary and Reactor Building
  - Replaced ~180 molded-case circuit breakers
  - Replaced ~2,300 primary safety-related system components
  - Implemented Reactor Coolant System/pressurizer weld mechanical stress improvement process
  - Implemented split pin replacement
  - Conducted passive inspections
    - Over 800 unique pipe inspections
    - 27 heat exchangers
    - 24 pumps
- Replaced all 8 essential raw cooling water pumps at intake pumping station

Watts Bar Unit 2 Completion – Results

Ice Condenser New Equipment

- Glycol chillers
- Power supplies
- Glycol system isolation valves
- Safety-related isolation valve hand switches

Ice Condenser Equipment Replaced or Refurbished

- Air handler units
- Air handler unit motors
- Intermediate deck doors
- Damper hand switches
- Ice baskets
- Passive visual inspections at ~30 locations

Watts Bar Unit 2 Completion – Results

- Main Control Room
  - Instruments and controls made to match those on Unit 1
  - New equipment installed
    - Rod Position Indication System
    - In-core Instrument System
    - Reactor Vessel Level Indication System
    - Integrated Computer System
    - Annunciator System
    - Panel indicators, recorders, and controllers
  - Switches refurbished, tested, and reinstalled
  - ~80,000 feet of new wiring installed

Watts Bar Unit 2 Completion – Results

- Turbine Building
  - Moisture separator reheaters replaced
  - Main turbine oil tank cleaned and coated inside and out and high velocity flush of oil system performed
  - Piping susceptible to flow accelerated corrosion replaced
  - Main feedwater pumps upgraded
    - Turbine rotors were replaced by Siemens
    - High-pressure and low-pressure inlet valves rebuilt
    - Control panel reworked with new indicators, switches, and lights
  - Stand-by main feedwater pump
    - Pump and motor rebuilt
    - Control panel reworked with new indicators, switches, and lights

Watts Bar Unit 2 Completion – Results

- Turbine Building
  - –Turbine upgraded
  - –Main condenser retubed to remove copper, installed SEA-CURE stainless steel tubing
  - –Electric hydraulic control system improved
    - ▪ Pump motor rebuilt
    - ▪ New constant pressure pump installed
    - ▪ Tank cleaned and inspected
    - ▪ Control panel refurbished with new switches and indicators
  - –~215 piping inspections
  - –Main steam and feedwater piping internal inspections

Watts Bar Unit 2 Completion – Results

- Digital upgrades made including:
  - New digital, dual-channel voltage regulator for main generator and exciter
  - New digital supervisory instrumentation for main turbine
  - New local instrument control panel for generator stator cooling hydrogen

- Electrical systems connecting main control room and plant equipment upgraded and refurbished

- Controls for non-nuclear equipment upgraded and refurbished to better ensure reliable power generation

Watts Bar Unit 2 Completion – Results

- Performed ~8,900 component-level tests
- Completed ~85 clean plans for 33 systems
- Completed ~840 Unit 2 surveillances
- Completed 107 Pre-operational Test Instructions and 27 Acceptance Test Instructions
- Completed N-stamping 28 safety systems and certified/stamped major Westinghouse assets
- Turned over 87 systems
- Met regulatory requirements and achieved licensing milestones
- Transitioned to a dual-unit organization
- Undertook PAT

Watts Bar Unit 2 Completion – Results

Regulatory Milestones Achieved	Timeframe
Nuclear Regulatory Commission (NRC) briefing held	October 2014
Advisory Committee on Reactor Safeguards recommendations issued	February 2015
Full compliance with FLEX Mitigating Strategies	March 2015
NRC Cyber Security inspection completed	April 2015
NRC Notation Paper issued	May 2015
NRC Operational Readiness Assessment Team inspection completed	June 2015
NRC Final Status Report issued	October 2015
Full Power License issued	October 2015

Watts Bar Unit 2 Completion – Results

Pre-operational Testing Milestones Achieved	Timeframe
Completed Open Vessel Testing	July 2014
Completed Primary Hydrostatic Testing	September 2014
Completed Secondary Hydrostatic Testing	December 2014
Established backfeed	February 2015
Established main condenser vacuum	March 2015
Completed ice loading	May 2015
Completed Hot Functional Testing	August 2015
Completed Structural Integrity Test/Containment Integrated Leak Rate Test	August 2015
Completed Integrated Safeguards Testing	September 2015

Watts Bar Unit 2 PAT – Results

- Moved Unit 2 from core load to full power in a controlled, conservative, and documented manner
- Demonstrated Unit 2
  - Will operate as designed and in a manner which protects the public's health and safety
  - Meets licensing requirements
  - Has been properly constructed
  - Is capable of withstanding anticipated transients and postulated accidents
  - Will be a reliable generation asset

Milestone	Timeframe
Initial Mode 6- Core Load began	December 4, 2015
Initial Mode 5 - Cold Shutdown entered	December 10, 2015
Initial Mode 4 - Hot Shutdown	March 19, 2015
Initial Mode 3- Hot Standby entered	June 30, 2016
Post-Core Load Pre-Critical Testing Phase Complete	May 14, 2016
Initial Mode 2 - Startup entered	May 23, 2016
Initial Criticality and Low Power Phase completed	May 24, 2016
Initial Mode 1 - Power Operation entered	May 25, 2016
Initial generator synchronization	June 3, 2016
30% Plateau completed	June 16, 2016
50% Plateau completed	July 14, 2016
75% Plateau completed	July 29, 2016
100 Planteau completed	October 19, 2016

Prior to each test performance, test coordinators ensured plant conditions were acceptable and systems were fully functional to support testing

Watts Bar Unit 2 PAT – Results

- Successfully completed 7 of 7 PAT plateaus
  - Nuclear Regulatory Commission reviewed completed plateaus, no issues identified
  - Each power ascension test was completed and performed as planned
  - No re-testing was required
  - Completed transient testing demonstrates plant responds as designed
  - Experienced a few emergent issues that were not unexpected as Unit 2 was tested and brought to full power
  - No events, significant issues, or plant trips occurred prior to generator synchronization – Issues occurred on systems that could not be tested in Hot Functional Testing
  - No significant open equipment issues impacting the continued safe and reliable operation of the plant

Watts Bar Unit 2 PAT – Results

- For U.S. Westinghouse 4-loop plants, the PAT windows for Watts Bar Unit 2 are comparable, with exception of fuel load to criticality
  - From fuel load to criticality, lessons learned were implemented
    - Completion of over 2,000 work orders to ensure system performance and configuration control
    - Paper closure through Engineering for plant completeness and configuration control
    - Closure of ~430 licensing commitments for regulatory compliance
    - Brought surveillance testing in frequency for operational enhancement
- Watts Bar Unit 2 testing issues have been better than average for new U.S. plants

Watts Bar 1	70 Days	29 Days	82 Days
Watts Bar 2	**171 Days**	**11 Days**	**91 Days**
Average for Westinghouse 4-Loop Plants	115 Days	57 Days	101 Days

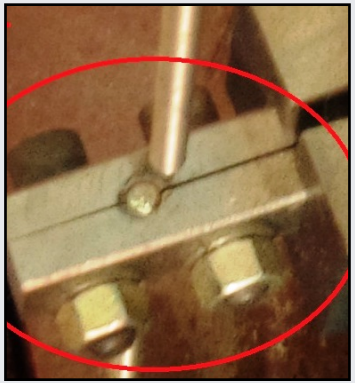
Unit 2 PAT – Emergent Issues Prior to Generator Synchronization

Issues	Actions Taken
Pause and reset	– Addressed changes needed in organization and expertise due to unique challenges presented by complexities of initial power ascension – Gave majority of workforce a needed break – Provided opportunity to understand issues and refocus Operations performance - Actions taken included organizational adjustments, alignment to standards and expectations, additional on-shift oversight, paired observations with shift managers, and enhanced control board walk downs
Pressure operated relief valve change-out	– 1 of 2 pressurizer power operated relief valves failed open-to-close stroke time test – Had previously met acceptance criteria – Valve replaced and satisfactorily tested
Primary and secondary check valve repairs	– Rebuilt 31 check valves after Hot Functional Testing – No opportunity to test until Reactor Coolant System achieved normal operating temperature and pressure – Several valves required additional work – 7 total repairs during PAT – All valves currently repaired
Auxiliary Feedwater System repairs	– Turbine-driven auxiliary feedwater terry turbine was removed and sent to factory for repairs identified during Hot Functional Testing ▪ Turbine could not be re-tested until after fuel load when normal temperature and pressure was achieved ▪ All turbine steam plugs leaked during re-testing, which they had not done during Hot Functional Testing ▪ Plugs were not accessible to repair without disassembling the turbine and removing it from pedestal ▪ Repairs made and testing identified issue with 2BB motor-driven auxiliary feedwater pump packing – Replaced the 2BB motor-driven auxiliary feedwater pump – Installed a range-flow packing – a new design to improve reliability of pumps for long-term performance
Resistant temperature detector (RTD) replacements	– RTDs do not respond until Reactor Coolant System temperature is greater than 350° – 20 RTDs in the Reactor Coolant System must work – All RTDs functioned during Hot Functional Testing – 3 were replaced due to response time – Not uncommon to have failures during initial startup – Experienced 4 on Unit 2 ▪ Issues most likely resulted from handling and storage prior to and during construction installation – All RTDs currently are functioning properly

Watts Bar Unit 2 PAT – Emergent Issues Following Generator Synchronization

Issue – Turbine Abnormal Noise	Conservative Decision	Quality Issue	Human Performance
– Noise heard at ~1,500 RPM at low-pressure C turbine to generator area – Found damage of coupling guard, foreign material determined to have migrated to drain system – Turbine worked properly during Hot Functional Testing – Turbine was disassembled between Hot Functional Testing and generator synchronization in support of Sequoyah – Issue occurred during reassembly and was due to improper clearance/foreign material exclusion – Issue could not be detected until turbine was rolled – Lacked the opportunity to detect the issue until turbine was rolled	Yes	Yes	Yes

Watts Bar Unit 2 PAT – Emergent Issues Following Generator Synchronization

Issue – Governor Valve Linear Variable Differential Transformer	Conservative Decision	Quality Issue	Human Performance
– The #1 high-pressure turbine governor valve failed open, resulting in steam header pressure rate trip and an automatic reactor trip with safety injection – Plant systems performed as designed – Cause was a vibration stress fracture of a linear variable differential transformer – This was a coarse steel bracket – Fabricated and installed new brackets for governor valve – Vibration stress facture was caused by turbine testing at 1,800 RPM and lower power for an extended period of time – Governor valve slightly open during turbine roll-up and at low power with the Unit 2 turbine design, which is different from Unit 1 – No longer a need to operate plant in this condition due to turbine testing being completed – Established monitoring plan as precautionary action going forward	Yes	No	No
			

Watts Bar Unit 2 PAT – Emergent Issues Following Generator Synchronization

Issue – Steam Leaks	Conservative Decision	Quality Issue	Human Performance
– **Have experienced steam leaks** – **Expected these types of issues** ▪ No opportunity to find until turbine is placed in service and lines are pressurized ▪ Start-up plan included provisions to make temporary repairs once all leaks were identified as we came up in power ▪ Over 30 temporary repairs were made following Unit 1 startup, then permanently repaired in the mid-cycle outage – **Examples of issues during Unit 2 PAT** ▪ Test valve separated from high-pressure steam line to the moisture separator reheater and could not be temporary repaired, unit was removed from service ▪ 2 test lines separated from turbine exhaust line and could not be temporary repaired, unit was removed from service ▪ These test lines are not used for operation, could have been cut or capped – They provide no operational function or current test function – **Repairs made, extent of condition performed, expanded** – **Actions taken included cutting off and capping lines, re-welding test lines, adding weld overlays** – **Have cleared most temporary leak repairs during outages**	**Yes**	**Yes**	**No**

Watts Bar Unit 2 PAT – Emergent Issues Following Generator Synchronization

Issue – Loss of Main Feedwater Pump	Conservative Decision	Quality Issue	Human Performance
– Operators lost loop drain seal and vacuum on the 2B main feedwater pump, tripping the pump – An operational alignment issue resulted in the trip of the pump – 2B main feedwater pump had been in service for an extended period for testing and other pump had not been put in service – Limited ability to test main feedwater pumps during Hot Functional Testing because plant conditions did not support • Auxiliary feedwater was water supply to steam generators • Chemistry cleanup plan excluded use of main feedwater pumps until after Hot Functional Testing • Issues with control circuits were not resolved until after Hot Functional testing – Actions taken included assigning lead after Hot Functional Testing to resolve test issues, performing limited uncoupled runs using auxiliary steam to main condenser, and bringing in experienced support staff to manage main feedwater pump work/issue	No	No	Yes

Watts Bar Unit 2 PAT – Emergent Issues Following Generator Synchronization

Issue – Main Generator Hydrogen Leakage	Conservative Decision	Quality Issue	Human Performance
– First leak manifested itself in a step increase in hydrogen usage – Sound troubleshooting and accurate instruments noted change in bushing temperature – After the unit was shut down as part of PAT, it was taken to Mode 3 for troubleshooting which identified a collapsed teflon hose – Support/refute matrix developed, repair made and the unit was returned to service – No root cause performed – Narrow focus, symptom-based mindset – Second leak manifested itself at about the same power level as the first leak – Conditions/symptoms were identical – Unit was shut down, repair was made, and more extensive support/refute matrix was developed – Found a blank plate installed similar to what is utilized during factory leak rate testing – Blank plate removed, unit returned to service – Issue resulted in a loss of 22 days of testing	Yes	Yes	Yes

Watts Bar Unit 2 PAT – Emergent Issues Following Generator Synchronization

Issue – Main Feedwater Pump Fitting Leak	Conservative Decision	Quality Issue	Human Performance
– Oil leak developed internal to the high-pressure governor control block – Was not visible or detectable to the operator – A main feedwater pump speed reduction occurred as leak worsened – Operators manually tripped the plant to prevent a low/low steam generator level trip – Cause was determined to be the wrong application/type of fitting for oil line – Extent of condition performed – All other similar fittings inspected, with one requiring replacement – Determined to be a legacy issue, undiscovered during refurbishment – 2nd main feedwater pump had not yet been placed in service because power level did not require it – Had 2nd pump been in service, no transit would have occurred, no trip would have been necessary – Leak would have been repaired online	Yes	Yes	No

Watts Bar Unit 2 PAT – Emergent Issues Following Generator Synchronization

Issue – Main Bank Transformer Fault/Fire	Conservative Decision	Quality Issue	Human Performance
– Catastrophic failure of transformer occurred due to a fault that originated internal on low side winding – Unit 2 was at 98.5% power preparing to go to 100% for the first time when fire occurred – No indication of abnormal conditions, no gasses detected in transformer oil, no temperature concerns – Root cause in progress – Response teams established ▪ Environmental, Failure Cause/Extent of Condition, Damage Assessment, Scope, Repair/Replacement	No	Yes	No

Watts Bar Unit 2 PAT – Emergent Issues Following Generator Synchronization

Issue – Main Bank Transformer Fault/Fire

– **Corrective actions taken**
- Adjusted power supply configuration for Unit 1 reactor coolant pumps due to visual indications of potential heat damage to bus ducts that fed the pumps
- Drained the oil from three main bank transformers, including the spare replacing the damaged transformer, and conducted internal visual inspections
- Fully evaluated the 2A, 2C and the spare main bank transformers for extent of condition, as well as inspected associated bus ducts and other electrical equipment
- Identified and corrected a few minor issues, including removing broken studs identified on the 2A main bank transformer, and on the spare transformer – repaired an air gap between the flex braids and a bushing, removed foreign material, replaced insulation around the coil, wrapped a steel standoff, and realigned a radial spacer
- Installed newly fabricated sections of the 500kV neutral bus and transfer bus
- Installed new 2A reactor coolant pump bus, followed by megger testing of the 6.9kV start bus
- Removed damaged main bank transformer
- Put spare transformer in service, as well as 2A and 2C
- Perform testing to validate Unit 2 switchyard equipment will perform as designed
- Complete switchyard environmental cleanup and ground/gravel remediation
- Complete switchyard painting, housekeeping, and demobilization

Watts Bar Unit 2 PAT – Lessons Learned

Lessons Learned	Actions Taken
Fuel transfer equipment reliability	– Took time during and following fuel loading to ensure reliable system for next refueling
Iron transport and sulfate concentrate minimization in steam generators	– Developed start-up plan that utilized a combination of start-up filters, red iron filters, and use of condensate demineralizers – Established and followed chemistry holds – Placed high priority on changing filters and keeping filters clean
Distributive Control System slow to update	– Ensured 20-plus databases that update the system were in synch
Containment spray pump seal issues	– Installed new design
Thermal expansion and pipe vibration data	– Adjusted shims and spring cans to reduce vibration and movement
Card failures associated with WINCISE	– Corrected size capacitor on cards – first-time equipment in industry
Display monitors failing on the Nuclear Instrumentation System and Digital Control System displays in control room	– Addressed unshielded power cables
Reactor Vessel Level Indication System performance	– Developed detailed plan and gathered data to make adjustments and ensure more reliable level indications

Post-PAT Performance

		Number of Reactor /Turbine Trips			
Unit	Commercial/ Restart	1st 9 Months	1st 18 Months	2nd 18 Months	18 Month U.S. Median in Startup Year
Browns Ferry Unit 1	02-Jun-07	4	4	1	1
Watts Bar Unit 1	27-May-96	1	4	2	2
Comanche Peak Unit 2	03-Aug-93	4	7	3	2
Seabrook Unit 1	19-Aug-90	4	9	7	3
Comanche Peak Unit 1	13-Aug-90	7	10	8	3
limerick Unit 2	08-Jan-90	2	2	2	3
Watts Bar Unit 2	19-Oct-16	2	2	NA	NA

- New plant startups have historically not matched performance of operating plants for a period of time
- Minimum time before performance approaches industry normal values is about 18 months, a typical first cycle
- Agreement between Institute of Nuclear Power Operations and TVA that majority of Watts Bar Unit 2 Plant Information Center data will be ‘greyed out’ for the first cycle of operation

Watts Bar Unit 2 Summary

- Watts Bar Unit 2 is a safe, high-quality asset.
- Extensive work has been performed to ensure the unit will be safe and reliable, margin was built in, and required regulations were met.
- The team took the time to resolve issues the right way, stopping and fixing problems prior to moving forward in order to ensure the safety of workers and the plant, and the readiness of equipment.
- Lessons learned were incorporated into construction, testing, and startup; we continue to learn and to share our experiences with the industry.
- The Watts Bar team has moved diligently through complex and comprehensive PAT while protecting Unit 1, identifying and resolving issues, and addressing the unique challenges of bringing a new unit into operation.


TVA