Replacing the St. Lucie Simulator Reactor Core and NSSS Models

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Topics

- **Background Information**
  - St. Lucie Nuclear Power Plant
  - St. Lucie Unit 2 Simulator

- **L3 MAPPS Reactor Core & Reactor Coolant System (RCS) Models Technical Solution**
  - Comet Plus™/Orchid® Core Builder Reactor Core Model
  - ANTHEM™/Orchid® Modeling Environment NSSS Model

- **St. Lucie Reactor Core & RCS Models Upgrade Project**
  - Project Scope of Work
  - Project Schedule
  - Other Simulator Ongoing Projects

- **Conclusions**
Background Information
St. Lucie Nuclear Power Plant

- Operated by Florida Power & Light (FPL)
- Located on Hutchinson Island between Fort Pierce and Stuart
- Combustion Engineering (CE) 2-Loop PWR
  - 2 Steam Generators
  - 4 Reactor Coolant Pumps
  - Pressurizer
- Two-Unit Plant
- Electrical Output: 1,002 MWe/Unit
- In 2003, NRC extended both operating licenses
  - Unit 1: March 2036
  - Unit 2: April 2043
St. Lucie Unit 2 Simulator

• Originally delivered by L3 MAPPS (then part of CAE) in the mid-1980s

• Hardware
  – 6 large control room panel sections and 27 peripheral panels located around the control room
  – Legacy I/O system replaced with compact I/O system in 2015 by L3 MAPPS

• Software
  – Orchid® simulation environment
  – Legacy FORTRAN models except reactor core and RCS models

• External systems
  – Simulated DCS (Foxboro IA) by L3 MAPPS
  – Simulated QSPDS by L3 MAPPS
  – Simulated Turbine Control System Controls/Stimulated Turbine Control System HMI by Westinghouse
  – Radiation Monitoring System by EVI

• Classroom simulators (8 Orchid® Touch Interface bays)
St. Lucie Simulator Contract Awards

Third-Party Vendor Project

L3 MAPPS Projects

- 1984
- 1993
- 2002
- 2004
- 2009
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017

- Full Scale Simulator
- Classroom Simulator
- Foxboro IA (DCS) Simulation
- Rehost
- Rehost
- Orchid® Instructor Station Upgrade
- Classroom Simulator
- CVCS Yokogawa Controllers
- I/O System PC Replacement
- CVCS Yokogawa Controllers Update
- Rehost
- Foxboro IA (DCS) Simulation Update
- Classroom Simulator
- Unit 1 SDC Part Task Trainer
- I/O System Replacement
- Reactor Core & RCS Models Upgrade
- Reactor Core & RCS Models Upgrade
- Computer System Upgrade
- I/O System Test Bench & Training

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St. Lucie Simulator Reality

- Recently lost experienced simulator software engineer and instructor
  - Both have now been replaced
- Another simulator software engineer close to retirement
- Multiple model vendors involved with simulator support
- Long-term plant operating license (Unit 1: 2036 and Unit 2: 2043) → PLEX
- Why replace the reactor core and RCS models in 2009?
  - Original models delivered with the FSS in 1984 (lagging the industry)
- Why upgrade with a third-party simulation vendor?
  - Lowest price (required by the Extended Power Uprate project)
Why replace the reactor core and RCS models again?

• Third-party models difficult to maintain
  – No graphical interface for the reactor core model
  – No graphical interface for the RCS model

• RCS model instabilities under certain conditions

• Interface issues with legacy models

• Models not under configuration management

• High costs charged by third-party vendor for subsequent work post-warranty

• Multiple simulator vendors (making fixing complex interface deficiencies harder)
High-Fidelity Reactor Core Model

• Orchid® Core Builder → Reactor Core Modeling Tools
  – Configures Comet Plus™ reactor core model (e.g. fuel assemblies, control rods, in-core/ex-core instrumentation, etc.)
  – Imports fuel code raw data
  – Generates Comet Plus™ reactor core model neutronics data
  – Supports offline and online model design, tuning, monitoring, testing and validation
  – Intuitive visualization
  – Reactor Core Model Initializer
  – Initial Condition (IC) Migration Tool

• Large installed base

• Comet Plus™ → Reactor Core Model
  – Nodal Expansion Method (NEM)
  – Full 3-dimensional model
    ▪ 1 node per fuel assembly plus reflector nodes radially
    ▪ Up to 26 axial nodes
  – 2 energy groups
  – 6 groups of delayed neutrons
  – 23 groups of decay heat precursors
  – Full diffusion equation solved each time step (no adiabatic or quasi static approach)
Reactor Core Modeling Tools

• Offline
  – 2-D and 3-D plots to analyze and detect anomalies in the design data
  – Assembly-wise comparison of simulated parameters against design data
  – Static reactivity calculator for any given core condition
  – Integral and differential control rod worth calculator/plotter
  – Temperature coefficient calculator/plotter
  – Report generation

• Online
  – Numerical and graphical monitoring (2-D and 3-D) of real-time parameters including in-core and ex-core detector responses for engineering and/or training purposes
Reactor Core Model Initializer

• Automates initialization of the Comet Plus™ reactor core models at Full Power Steady State (FPSS)
  – cycle, burn-up, rod positions, Xenon and Samarium FPSS reactivities
  – stabilizes reactor core model with thermal-hydraulics feedback

• Provides real-time view of important reactor core parameters (e.g. power, average fuel and moderator temperatures, axial imbalance, core reactivity, etc.)
Initial Condition (IC) Migration Tool

- Automates process to create ICs at same power level (not necessarily 100% reactor power)
  - from one fuel burn-up (e.g. BOC) to another (e.g. EOC)
  - from one cycle to the next
Fuel Codes

• Fuel cycle-specific data
  – Import raw fuel data generated by fuel codes
  – Import module (called “Fuel Data Connector”) can be modified by the end user if the fuel code is upgraded or changed resulting in data format changes
  – Limited fine tuning required

• Examples of fuel codes data processed by Orchid® Core Builder
  – CASMO-3, SIMULATE-3, PRESTO (Studsvik Scandpower)
  – PANTHER (British Energy/BNFL)
  – CORD-2 (JSI, Slovenia)
  – POWDERPUFS-V (AECL)
  – ANC, PHOENIX (Westinghouse)
  – SCIENCE (Areva NP)
  – MICROBURN-B2 (Siemens)
Advanced Thermal-Hydraulic Model: ANTHEM™

- Used for Nuclear Steam Supply Systems and other plant systems requiring high-fidelity two-phase models
- Two-phase, non-equilibrium, non-homogeneous (drift flux) model
- Standardized mathematical model
- Graphically configured and tested in Orchid® Modeling Environment for any plant configuration
- Easy to interface with L3 MAPPS or third-party reactor core models
ANThEML Model Details & Validation

• Accurately simulates
  – Normal and abnormal plant conditions
  – Major transients such as steam line breaks, loss of feedwater, tube leaks, load rejection and turbine trips
  – Draining, filling and venting, as well as nuclear plant mid-loop operations

• Features
  – Extensive nodalization
  – Multi-nodal fuel model
  – Extensive heat transfer package
  – Semi implicit numerical scheme

• Large installed base
St. Lucie Reactor Core & NSSS Models Upgrade Project
Project Scope of Work Overview

- **Replace Process Models**
  - Reactor Core (Comet Plus™/Orchid® Code Builder)
  - Primary: Reactor Coolant System (ANTHEM™/Orchid® Modeling Environment)
    - Reactor Coolant Pumps (RCPs)
    - Steam Generators (S/Gs)
    - Pressurizer
    - Quench Tank
  - Secondary (ANTHEM™/Orchid® Modeling Environment)
    - Steam Generators up to main steam header
- **Retain Instrumentation & Control Systems (legacy FORTRAN)**
- **Training**
Process Interfaces

- New process models will interface with the following legacy process models
  - Containment & Sumps
  - Chemical & Volume Control System (CVCS)
  - Safety Injection System
  - Gaseous and Liquid Waste Disposal
  - Service Gas
  - RCPs Seals
  - Feedwater
  - S/G Blowdown
  - Auxiliary Feedwater Turbine
  - Main Steam (from Main Steam Header up to the Condenser)
Reactor Core Model - Nodalization

- 7,618 nodes
  - Radial Nodalization: 221 fuel assemblies + 72 reflector nodes
  - Axial Nodalization: 24 active fuel levels + 2 reflector levels (top and bottom)
• **Speedup Factors**
  - Xenon / Samarium
  - Decay Heat / Fuel Burn-up

• **Equilibrium Factor**
  - Xenon

• **Suppression Factors**
  - Boron / Xenon / Samarium
  - Fuel Temperature (Doppler)
  - Moderator Temperature
  - Control Rods
  - Fuel Burn-up

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Reactor Core Model - Orchid® Core Builder 2-D Runtime
Reactor Core Model - Orchid® Core Builder 3-D Runtime
RCS Model – Orchid® Modeling Environment Loop A Schematic
## Project Schedule

- **Contract Award** → May 2017
- **Design** → 2 months
- **Software Development** → 5 months
- **Integration** → 1 month
- **Pre-Factory Acceptance Testing** → 1 month
- **Factory Acceptance Testing** → 1 month
- **Deficiency Clearance/Training** → 2 weeks
- **Site Acceptance Testing** → 3 weeks

**Overall Project Schedule** → ~12 months
Other Ongoing Projects for St. Lucie

• Computer System Upgrade
  – Simulation Servers
  – Main DCS Server
  – Engineering/Instructor Workstations
  – Network Switches/Color Laser Printers
  – Exam Security Indicator
  – Latest Operating Systems/Microsoft SQL Server
  – Selective Orchid® Tools Upgrade

• I/O System Test Bench
  – Trainer/Demonstrator
  – I/O System Training
    ▪ Hardware (controllers, modules, etc.)
    ▪ Software (Orchid® Input Output)
Conclusions

- FPL, like other utilities, is facing several simulator challenges
  - Resources
  - PLEX
  - Need for model replacement to fix deficiencies
  - Multiple simulator vendors
- What appears to be the lowest cost solution is not always the most cost-effective solution over the life of the simulator
  - Need for premature upgrade if technical solution is not adequate or unmaintainable or if model maintenance costs are too high
  - Better due diligence (or more robust vendor selection process) before contract award is key
Conclusions

- L3 MAPPS offers high fidelity and proven models for both the reactor core and the RCS
  - Equipped with rich and intuitive graphical interface for both development, testing/validation and runtime
  - Validated against engineering analysis codes and plant data
  - Easy fuel cycle update process
  - Strong interface between the reactor core and RCS models
  - Large and satisfied user base
Thank You