Performance of Fuel Technology on AP1000® Reactors

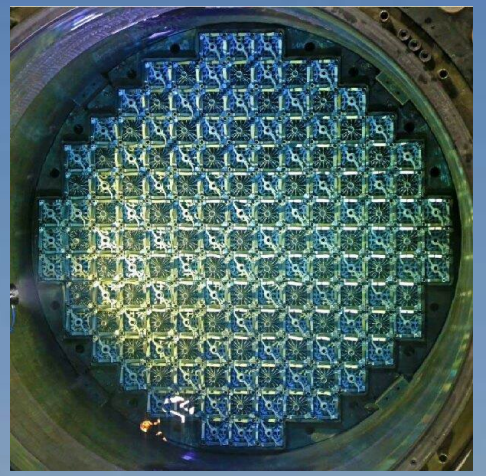
Florent Taborda – PWR Fuel Solutions Manager



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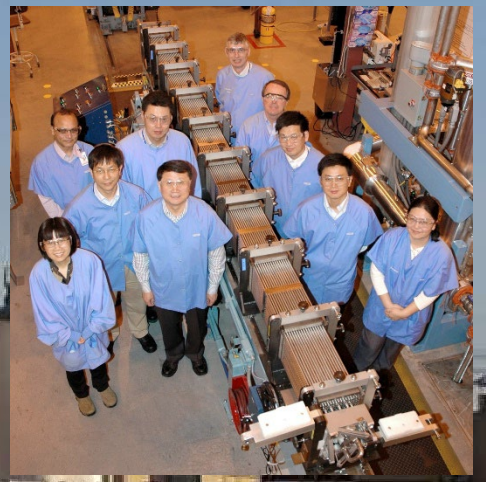
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How are AP1000 plant advanced fuel features performing so far?



Core Technologies

1. Advanced First Core
2. MSHIM™ Core System
3. BEACON™ & Automatic Core Operations

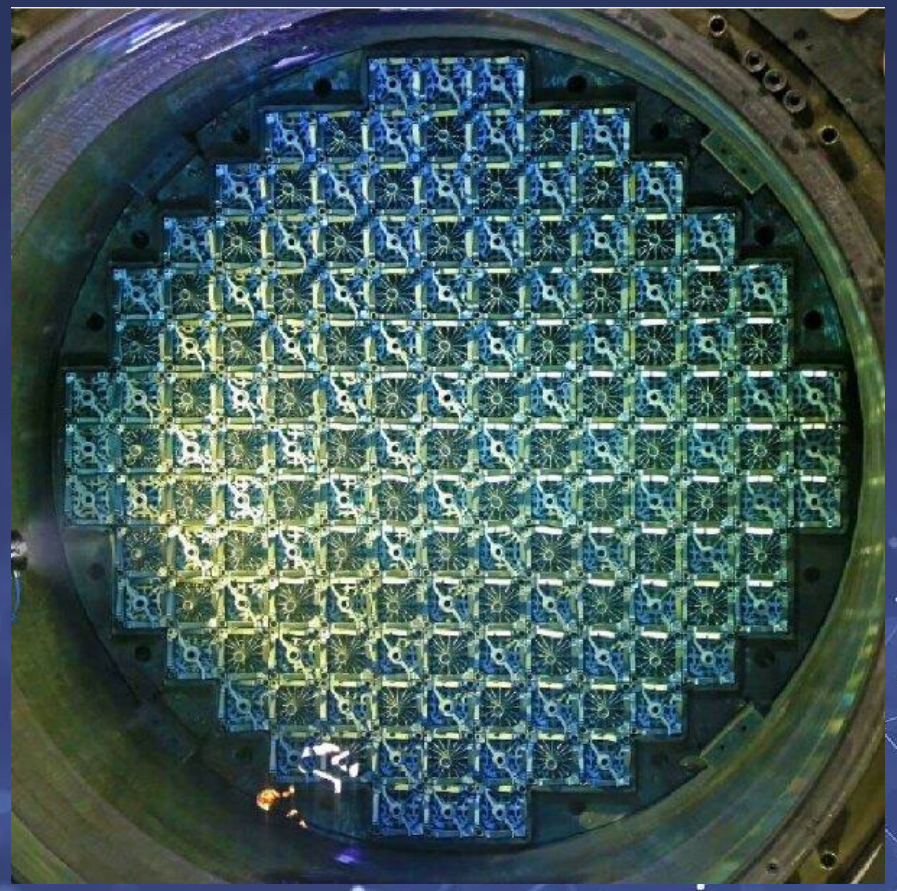


Fuel Hardware

1. Fuel Performance
2. Customers Options for Long-Term

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The Advanced First Core Overview

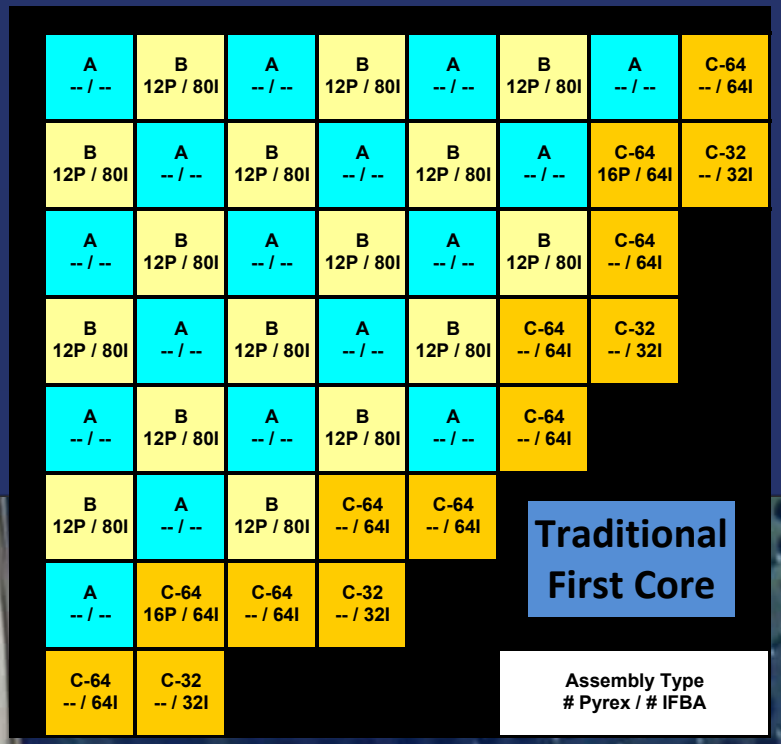


- The first cores on most reactors used simple core designs that typically used three different enrichments with the highest enrichment assemblies on the core periphery
- Higher efficiency or low neutron leakage reload core designs were developed to improve fuel utilization.
- These higher efficiency designs use fuel enrichments in each reload & some with low enriched axial blankets at the top & bottom of each rod in low neutron leakage designs.
- Westinghouse patented an Advanced Core Design for AP1000 with a first core design that mimics a low-leakage reload core design and delivers our customers major cost savings in uranium and uranium enrichment – or Enriched Uranium Product (EUP).

AP1000 plant Advanced First Core

Traditional “3-Region” First Core

- High Enrichment on periphery “leaks neutrons”
- Inefficient use of uranium & Enrichment



A = Low Uranium Enrichment

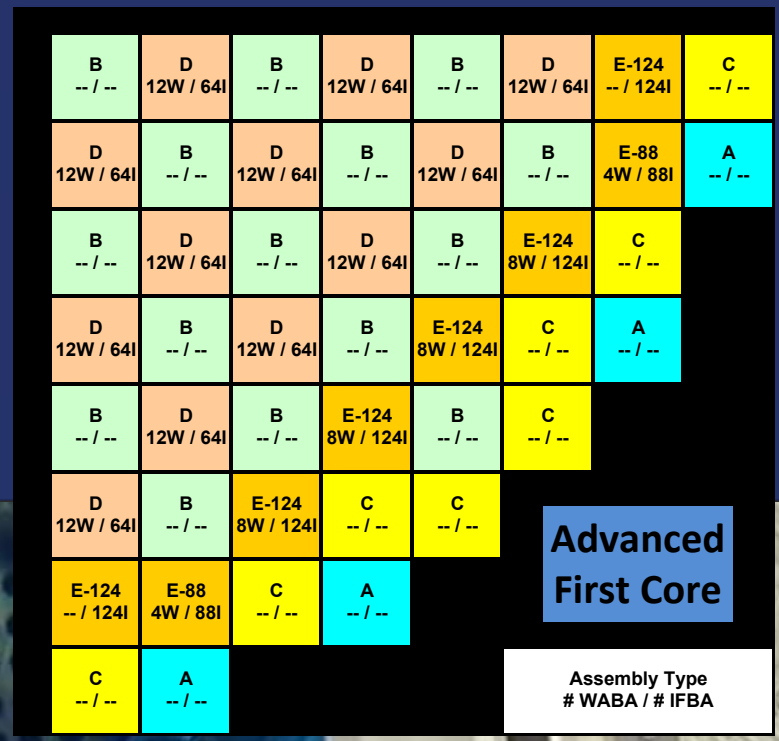
B = Medium Uranium Enrichment

C = High Uranium Enrichment

Large numbers of Neutrons from the Highest enriched fuel are lost from the core

Advanced “5-Region” First Core with “Axial Blankets”

- Simulates Low Leakage Reload Cycle
- Easily Transitions to Equilibrium Reload Cycles



A = Lowest Uranium Enrichment

B = Low Uranium Enrichment

C = Medium Uranium Enrichment

D = Higher Uranium Enrichment

E = Highest Uranium Enrichment

Neutron losses reduced with higher enrichments away from periphery

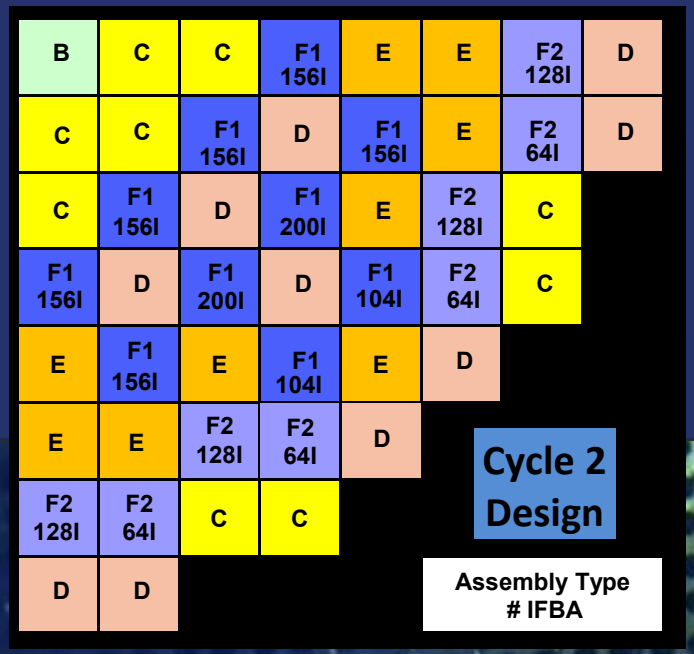
The Advanced First Core has **delivered as promised** with smooth first cycle operation, easy transition to equilibrium reload cycles while delivering significant savings in EUP to customers

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AP1000 plant Fuel Transition to Equilibrium

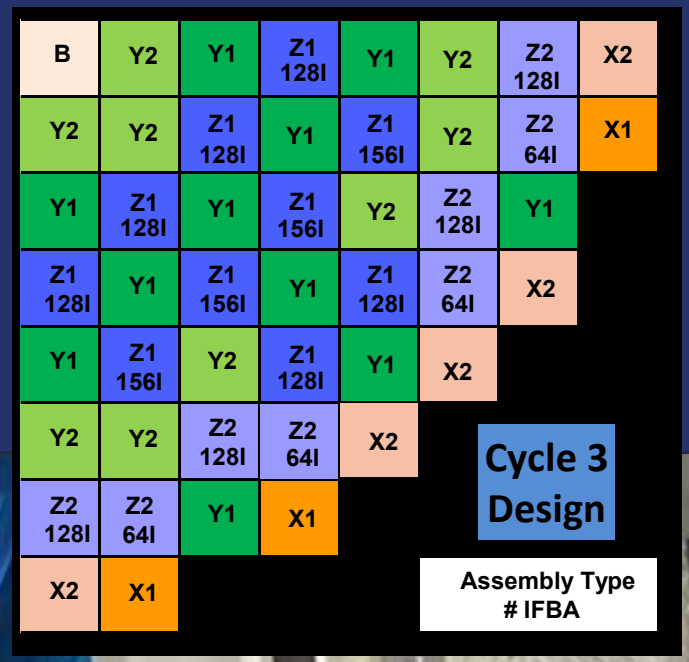
AP1000 plant Cycle 2 Loading Pattern

- 64 Fresh Assemblies
- Energy Output – 510 EFPD
- Region Average Discharge Burnup – 40,535 MWD/MTU



AP1000 plant Equilibrium 18 Month Loading Pattern (cycle 3+)

- 64 Fresh Assemblies
- Energy Output – 510 EFPD
- Region Average Discharge Burnup – 50,558 MWD/MTU



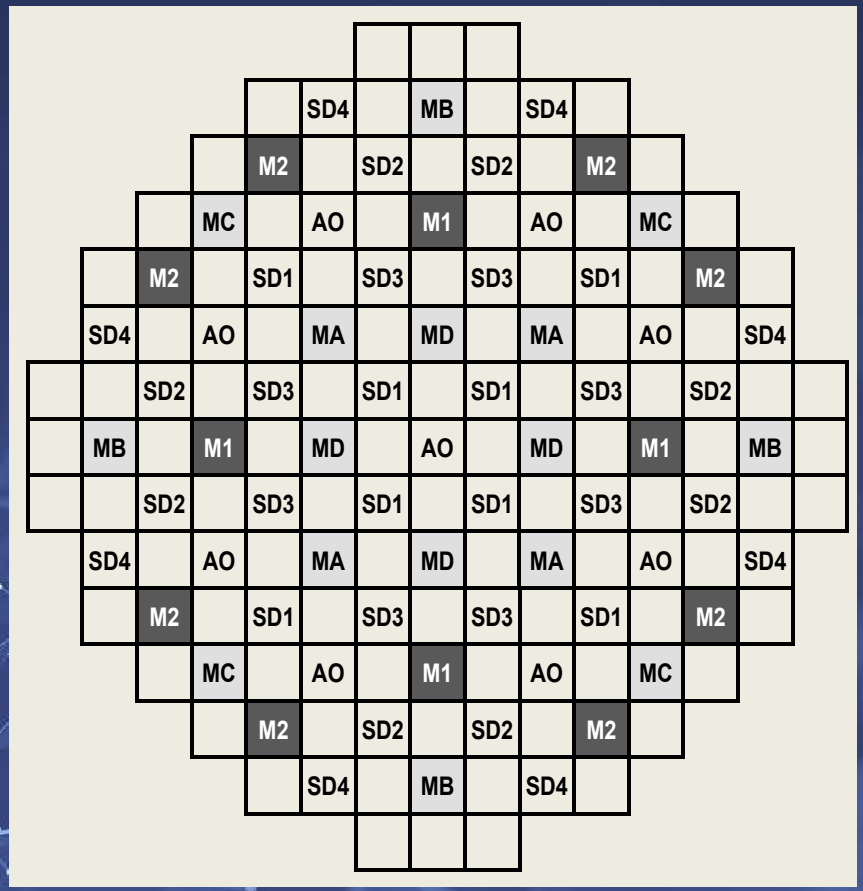
Fuel discharged after cycle 1 is low-energy fuel with low burn-up and little or no uranium enrichment, while higher enriched fuel achieves much higher burn-ups at end of cycle 2 ready for equilibrium cycles

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Reactor Control on AP1000 plants

- Typical operating plants have one control rod type (RCCA) used in both “shutdown” and “control” functions
  - Plants usually operate with lead control bank slightly inserted (“bite” position) and control power (T_{avg}) by changing “chemical shim” (boron in coolant) multiple times a day
- AP1000 PWR uses two different control rod types for 3 distinct functions:
  - “Black” RCCAs for reactor shutdown (SD)
  - “Black” RCCAs for AFD control (AO) and large load changes (M1 and M2)
  - Reduced worth “Gray” rods (GRCA) in MA – MD banks for “Mechanical Shim” for frequent power (T_{avg}) control
  - Chemical Shim is only changed as needed due to fuel and burnable absorber depletion, about once every 1 – 2 weeks

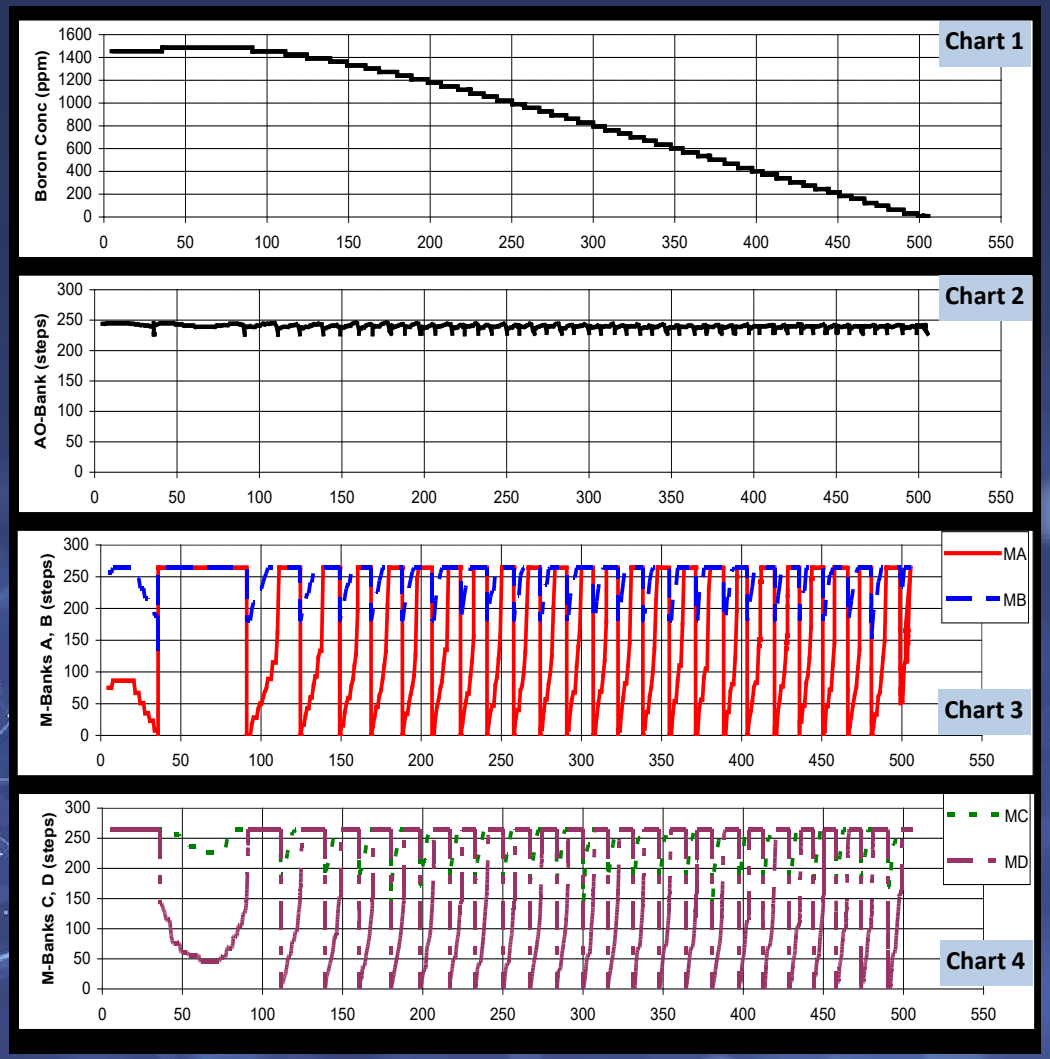
Note: Use of MSHIM illustrated in next few slides



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MSHIM™ Operation and Control Strategy

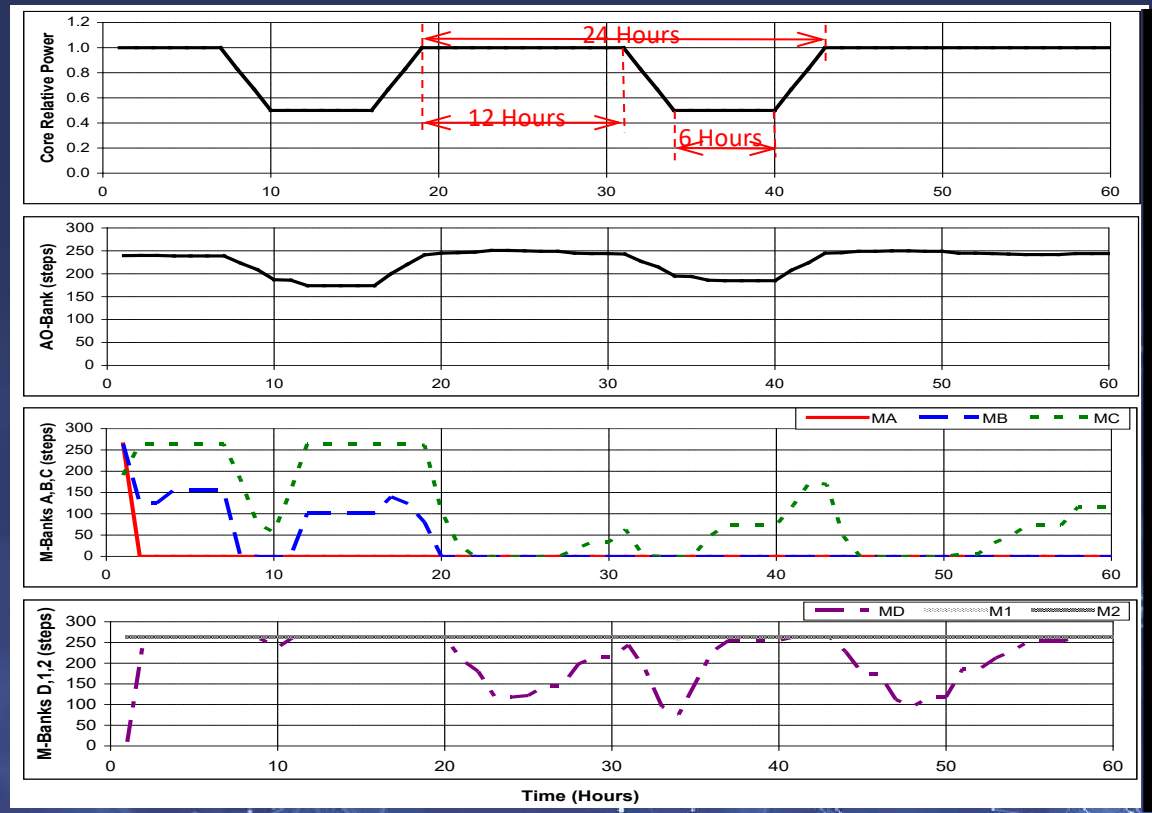
- The Gray M banks move throughout the day to control core reactivity (T_{avg})
  - The insertion sequence of GRCAs changes during cycle to minimize axial burnup shadowing of fuel assemblies
  - Soluble boron in coolant is changed less frequently as fuel and burnable absorbers deplete to keep gray M banks in desired operating range
- AO bank moves to control AFD
- All rod bank motions are controlled automatically by reactor control system
- **Reactor operations are greatly simplified**

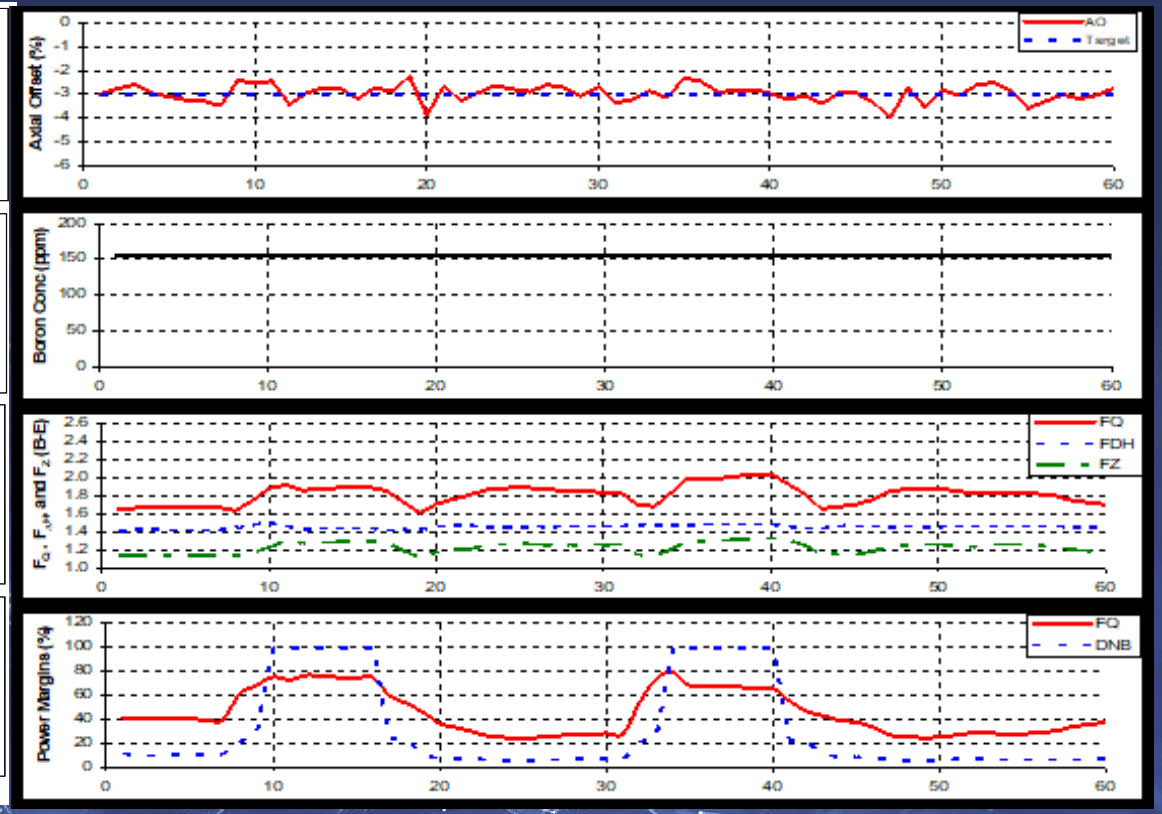


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AP1000 plant MSHIM Control - Example

Load Follow Example – Near End-Of-Cycle





- No change in soluble boron concentration is needed during the load follow
- M banks move to keep T_{avg} on program
- AO bank moves to keep Axial Flux Deviation (AFD) on target
- Control rod motions automated (just like baseload)
- Peaking factors and power margins well controlled

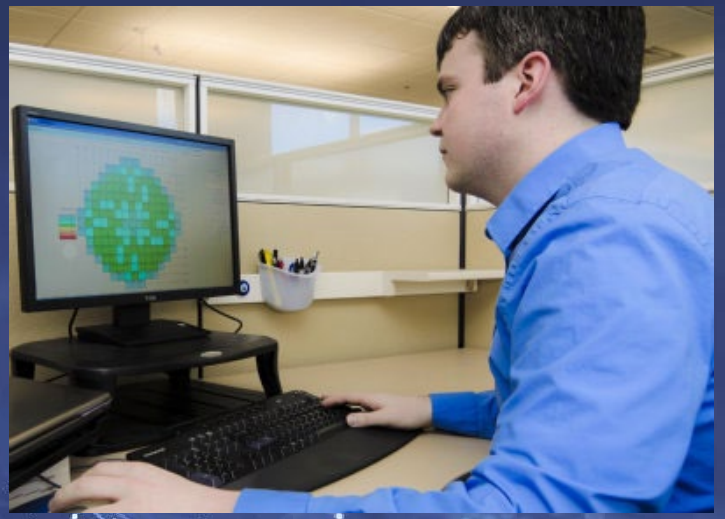
MSHIM is **delivered as promised**.
The combination of traditional “black” control rods with innovative “gray” rod system allows highly automated operation, eases load follow, and significantly reduces boron adjustments

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BEACON™ Core Monitoring System

….Much More Than Core Monitoring

- AP1000 implements state of the art BEACON Direct Margin Monitoring (DMM) along with fixed self-powered detectors for online core monitoring enabling:
  - Real-time core monitoring and Technical Specification surveillance
  - Constant power margin monitoring (such as DNB and PLHR)
  - Continuous shutdown margin monitoring
  - Immediate and trending data for reactivity management planning including
    - Planning for coolant boron adjustments
    - GRCA insertion exchanges, etc.

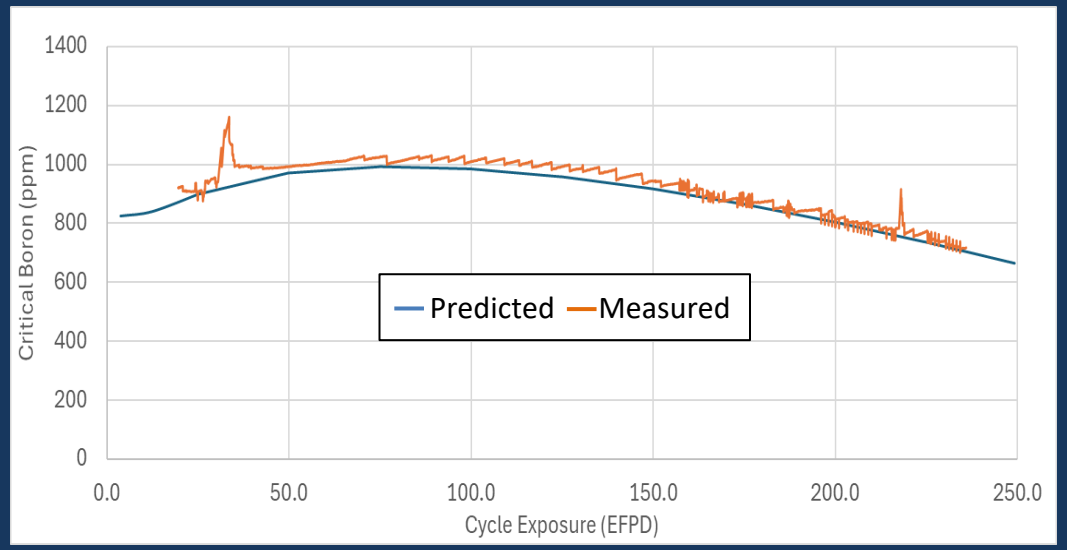


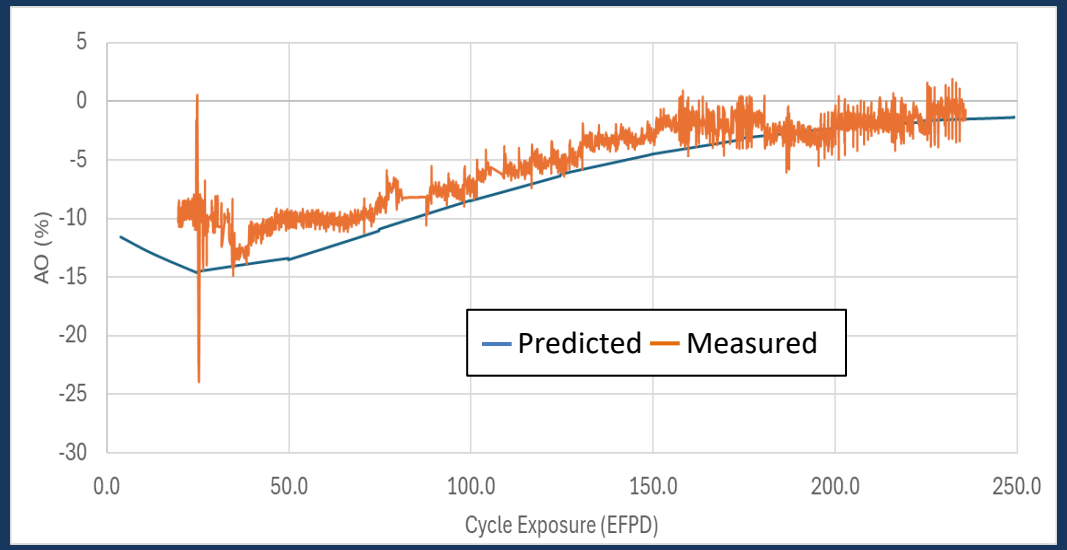
MSHIM can reliably control the reactor within programmed parameters while BEACON is needed to perform the analysis to determine the most efficient and fully compliant settings for MSHIM

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AP1000 plant Core Operational Performance

- The measured critical boron concentration and axial offset values closely match the predicted values during the initial cycle and validate the predictions of global reactivity during depletion of the Advanced First Core
- The measured critical boron & core axial offset reflect MSHIM operating strategy through the cycle.





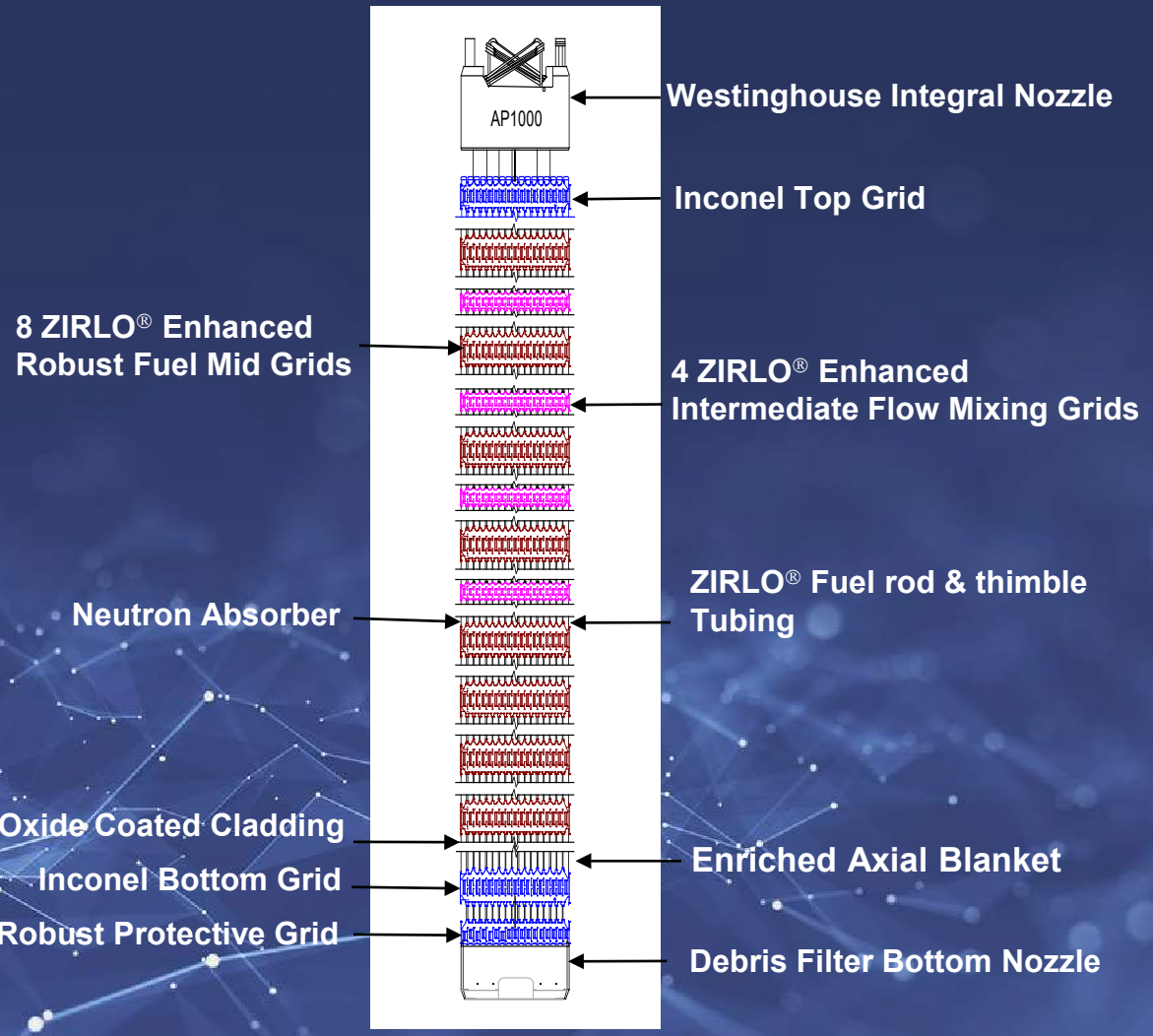
- MSHIM is an extremely robust power distribution control strategy working with the advanced control rod system, the chemical & volume control system, and the continuous online core monitoring system (BEACON).
- MSHIM meets utility requirements of “no boron change” load follow and provides automatic reactor control during baseload and normal operating transients.

The Advanced First Core, BEACON-DMM analysis capability, MSHIM functionality, and the automation of the AP1000 reactor control system combine to **deliver as promised** an efficient, predictable, reliable, and safe core operation that sets the standard for others to match

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AP1000 plant Fuel Hardware - Performance

- **Operational highlights:** The six operating units are performing exceptionally well in terms of startup, reliability, and overall operational performance.
- **Hardware Design Experience:** Design based of decades of high performing and reliable operational experience of the 17x17 Robust Fuel Assembly platform.
- **Refueling efficiency:** The design allows for shorter and more efficient refueling outages with a record-breaking initial refueling outage of just 28.14 days for Sanmen Unit 2.
- **Other performance features:** Capable of load following, allowing it to integrate effectively with renewable energy sources.




Thank You
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