

CMS5 Benchmarking against VVER-440 Plant Data

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Studsvik

OUTLINE

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STUDSVIK SCANDPOWER SOFTWARE & SERVICES

Reactor Design & Performance



CASMO5
2D Square/Hex Lattice Physics (Commercial LWR)



HELIOS-2
2D Gen-Geometry Lattice Physics (Research & Advanced Reactors)



Peacock
Continuous energy Monte Carlo



SIMULATE5
3D Nodal Simulator (Commercial LWR)



SIMULATE5-K (S5K)
3D Kinetic Nodal Simulator for Transient Analysis



CMSBuilder
Loading Pattern Design Optimization

Operation Support



GARDEL
Advanced Core Monitoring & Reactivity Management



SIMULATE3-R (S3R)
Cycle-Specific Core Model for Training Simulators



GARDEL-SIM
GARDEL for Training Simulators

Spent Fuel Analysis & Storage



MARLA
Spent Nuclear Material Tracking & Management



SNF
Spent Nuclear Fuel Analysis



CASKLOAD
Dry Spent Fuel Storage Planning & Optimization

Engineering & Consulting Services

INTRODUCTION

- CMS5 for VVER
  - CASMO5
    - ✓ Starts with CASMO-4E (Extended Capability CASMO-4)
    - ✓ VVER-440, VVER-1000 & VVER-1200 → year 2017
    - ✓ 586-group nuclear data library based on ENDF/B-VII.1

      (Others commercially available)

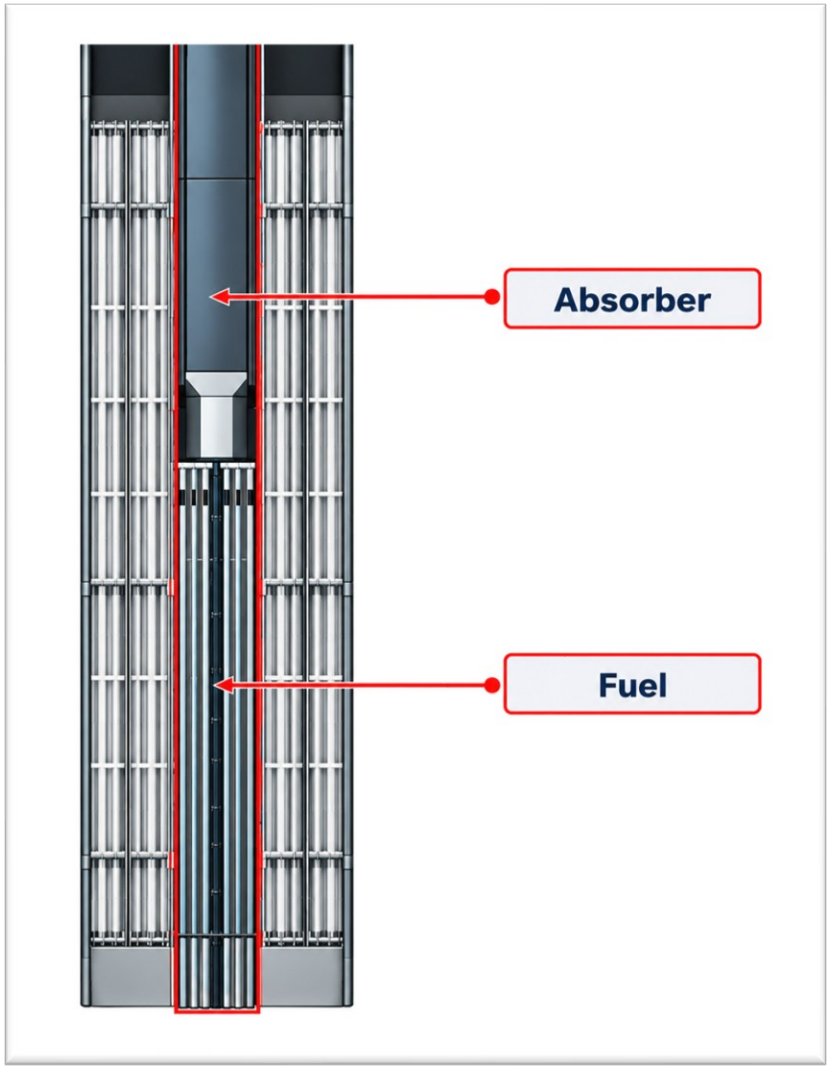
INTRODUCTION

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  - SIMULATE5
    - ✓ VVER-1000 & VVER-1200 → year 2018

      (hexagonal solver)
    - ✓ VVER-440 → year 2022

      (control assembly: fuel + absorber)



CMS5 – BENCHMARKING FOR VVER

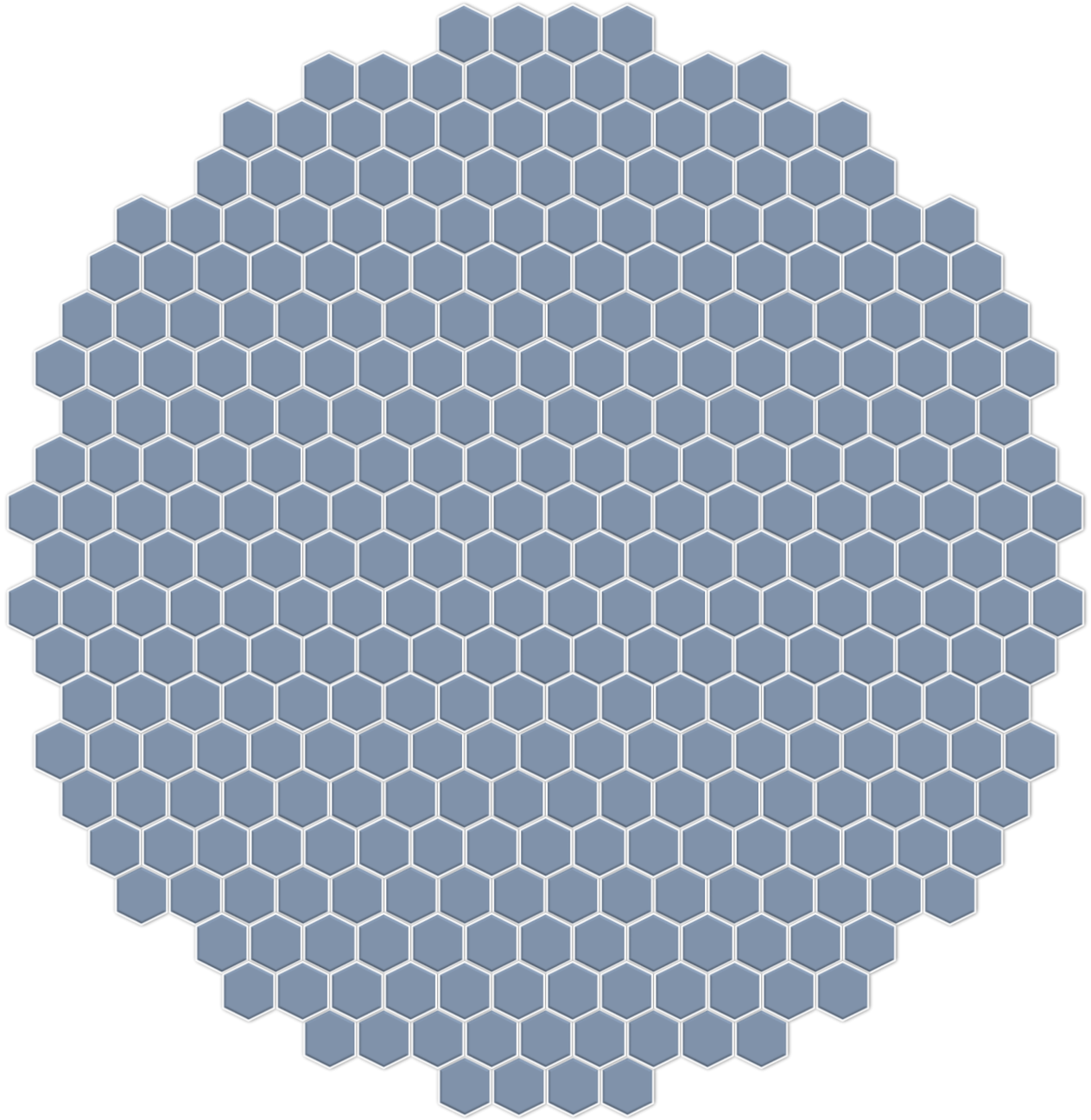
- Comparison vs. Monte Carlo solution
  - 2D cores with realistic VVER-1000 fuel assembly designs by TVEL (Russia)
    - ✓ MIDICORE Benchmark
    - ✓ FULLCORE Benchmark
  - 2D cores with realistic VVER-440 fuel assembly designs by TVEL (Russia)
    - ✓ FULLCORE Benchmark
    - ✓ FULLCORE RK3+ Benchmark
    - ✓ Extended FULLCORE Benchmark

CMS5 – BENCHMARKING FOR VVER

- Comparison vs. plant data
  - X2 Benchmark
    - ✓ Khmelnytskyi 2 NPP, initial 4 fuel cycles
    - ✓ VVER-1000 fuel assembly designs by TVEL
  - Comparisons to a VVER-1000 NPP
    - ✓ 9 consecutive fuel cycles
    - ✓ VVER-1000 fuel assembly designs by TVEL (Russia) and Westinghouse (Sweden)
  - Comparisons to a VVER-440 NPP
    - ✓ 7 consecutive fuel cycles
    - ✓ VVER-440 fuel assembly designs by TVEL (Russia)

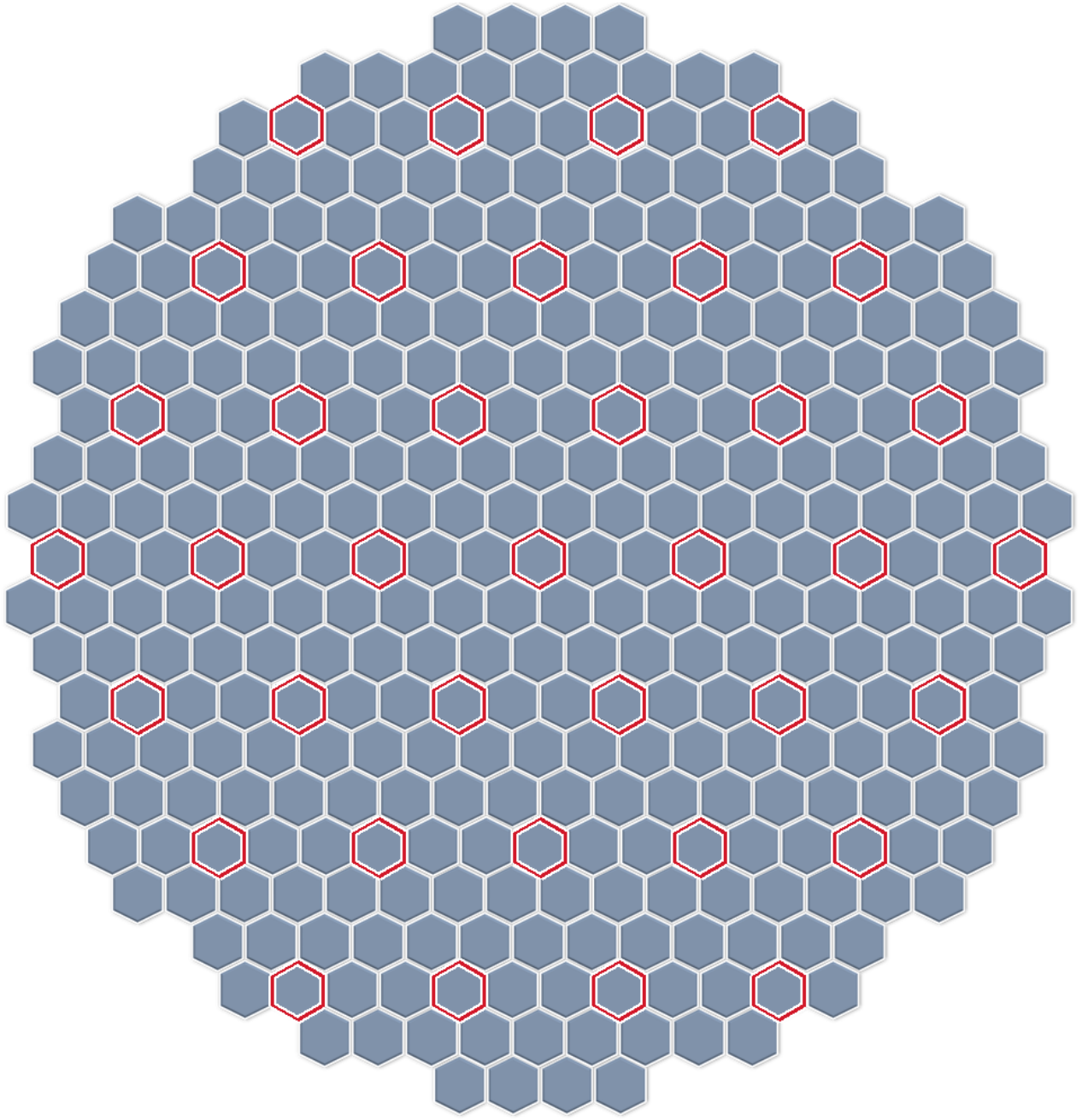
VVER-440 PLANT

- VVER-440/V213 pressurized water reactor
  - Thermal power 1,375 MW(th)
  - Generator power 415 MW(e)
  - Primary pressure 12.5 MPa
  - Inlet coolant temperature at rated power 265 °C
  - Total coolant flow rate ~43,000 m^3/h



VVER-440 PLANT

- VVER-440/V213 pressurized water reactor
- Core
  - Active height – 2.48 m; effective diameter – 2.88 m
  - 349 hexagonal fuel assemblies with 126 fuel pins and 1 instrument tube
    - ✓ UO_2 with maximum average enrichment 4.4 % ^{235}U
    - ✓ U-Gd oxide with maximum content of Gd_2O_3 3.35 %
  - 37 control assemblies

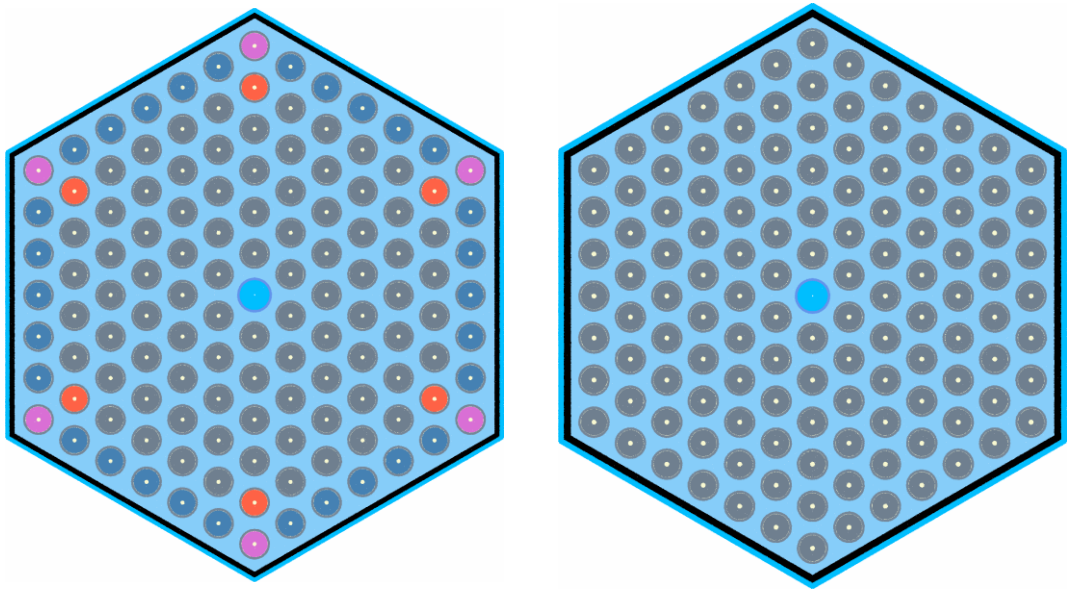


VVER-440 PLANT MODEL

- Fuel and Reflector
  - CASMO5 lattice physics code & ENDF/B-VII.1

VVER-440 PLANT MODEL

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  - Segments
    - ✓ Two-dimensional single assembly calculations in full geometry

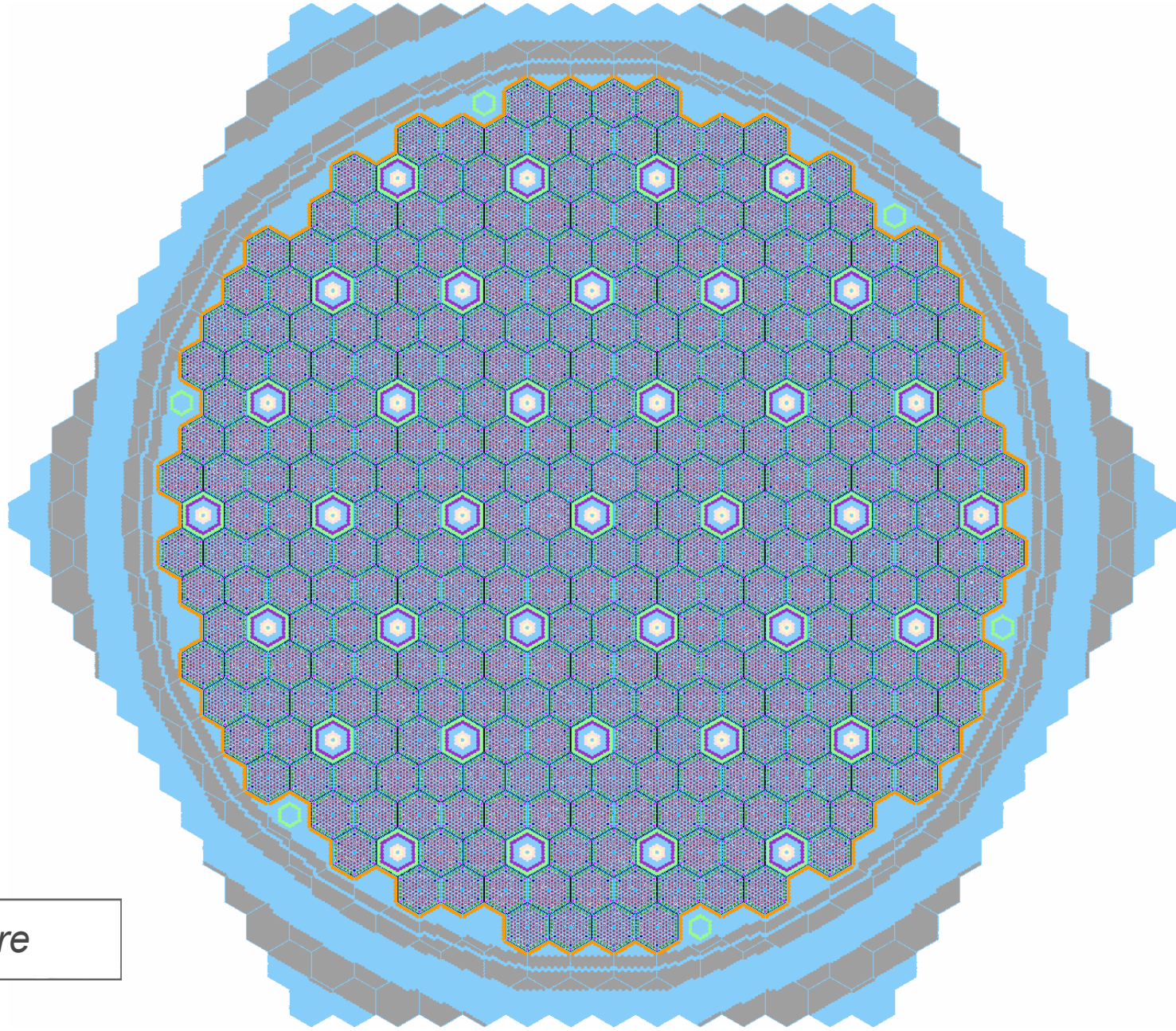


Fuel Segments

VVER-440 PLANT MODEL

- Fuel and Reflector
  - CASMO5 lattice physics code & ENDF/B-VII.1
  - Segments
    - ✓ Two-dimensional single assembly calculations in full geometry
  - Radial reflector & Control assembly
    - ✓ Multi-assembly calculation in full core with baffle and barrel

VVER-440 PLANT MODEL



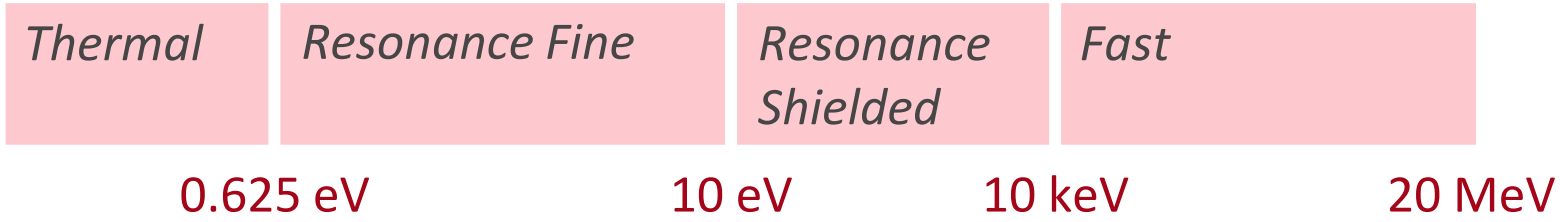
2D Core

VVER-440 PLANT MODEL

- Fuel and Reflector
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  - Segments
    - ✓ Two-dimensional single assembly calculations in full geometry
  - Radial reflector
    - ✓ Multi-assembly calculation in full core with baffle and barrel
  - Top & bottom reflectors
    - ✓ One-dimensional fuel and reflector calculations

VVER-440 PLANT MODEL

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    - ✓ One-dimensional fuel and reflector calculations
- Four-group cross-section library



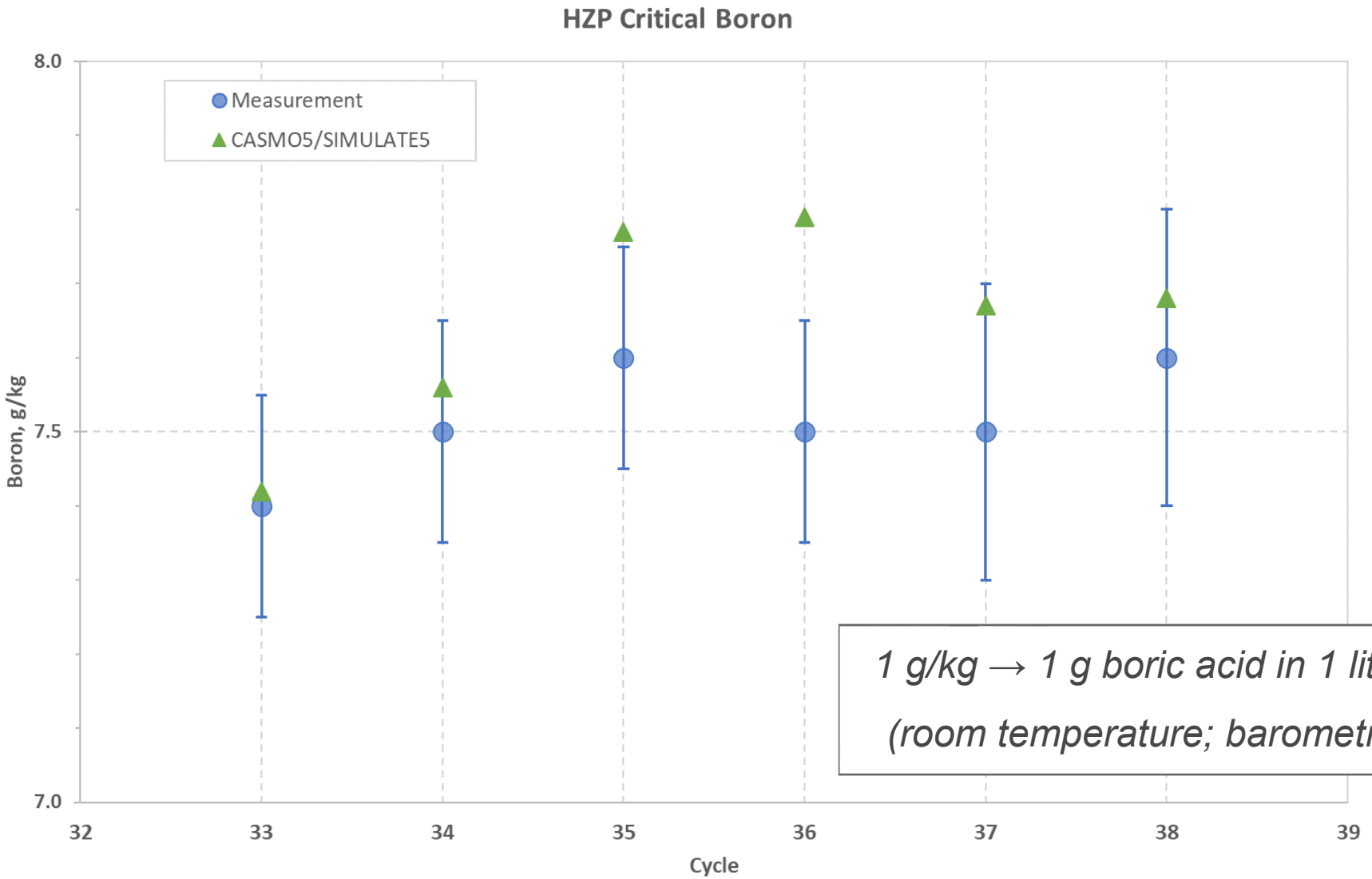
VVER-440 PLANT MODEL

- Reactor core
  - SIMULATE5 multigroup nodal code

VVER-440 PLANT MODEL

- Reactor core
  - SIMULATE5 multigroup nodal code
  - Full core geometry
    - ✓ 312 fuel assemblies, 37 control and 72 radial reflector assemblies
    - ✓ Fuel assembly → 6 radial & 21 axial nodes
  - Spacer grids
  - SPND tubes
  - 6 control banks
  - Cycles 33 – 39
    - ✓ Jump-in cycle initialization
    - ✓ Reactor power and positions of the control banks

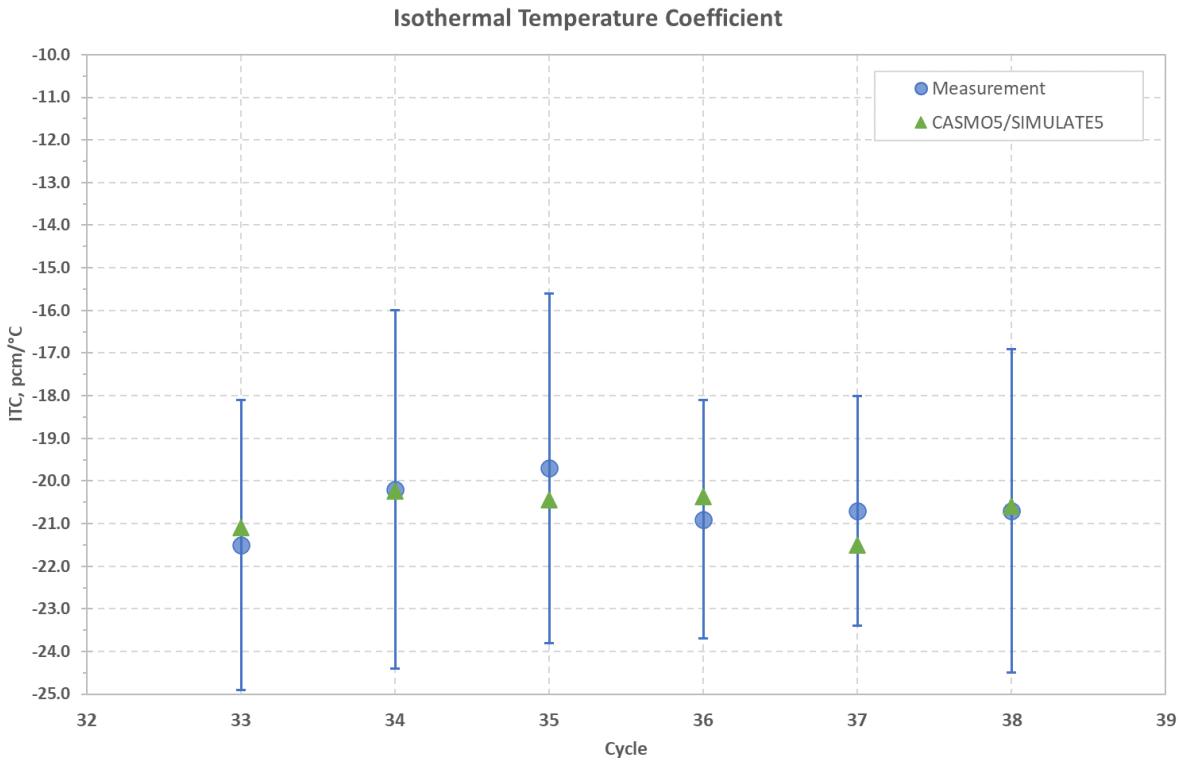
VVER-440 RESULTS – HZP CRITICAL BORIC ACID



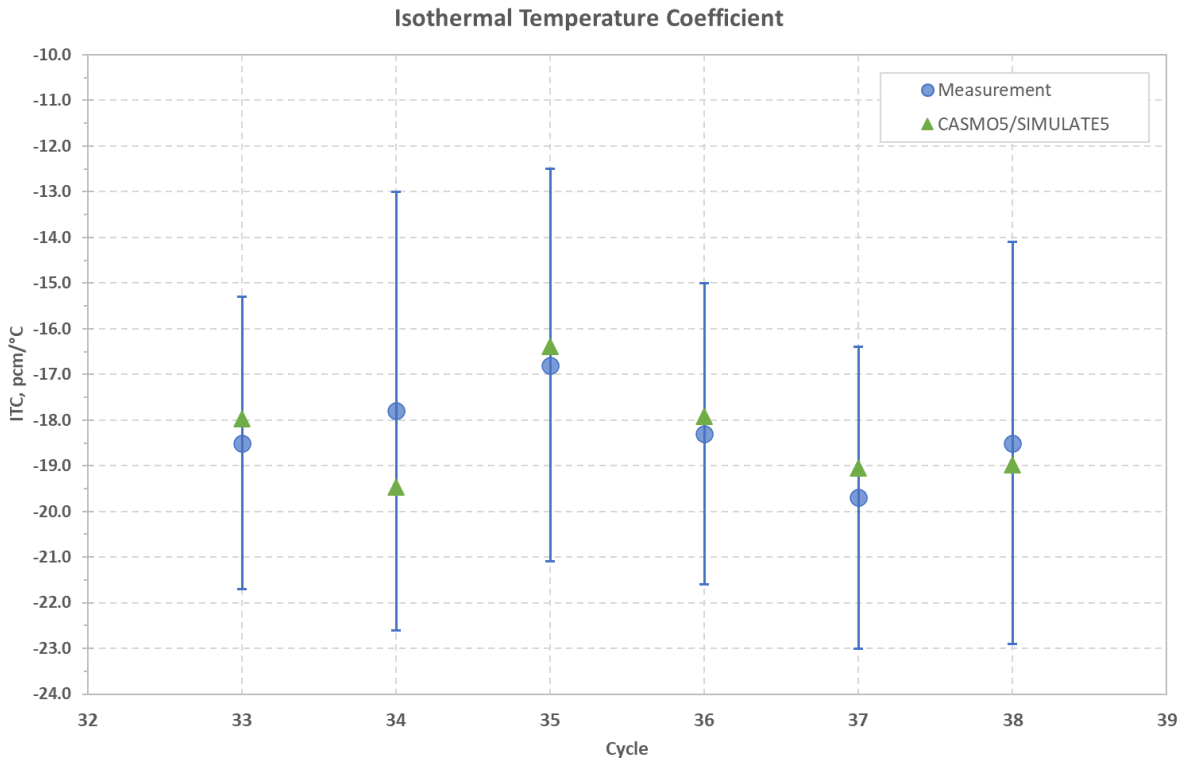
1 g/kg → 1 g boric acid in 1 litre (kg) water

(room temperature; barometric pressure)

VVER-440 RESULTS – ITC

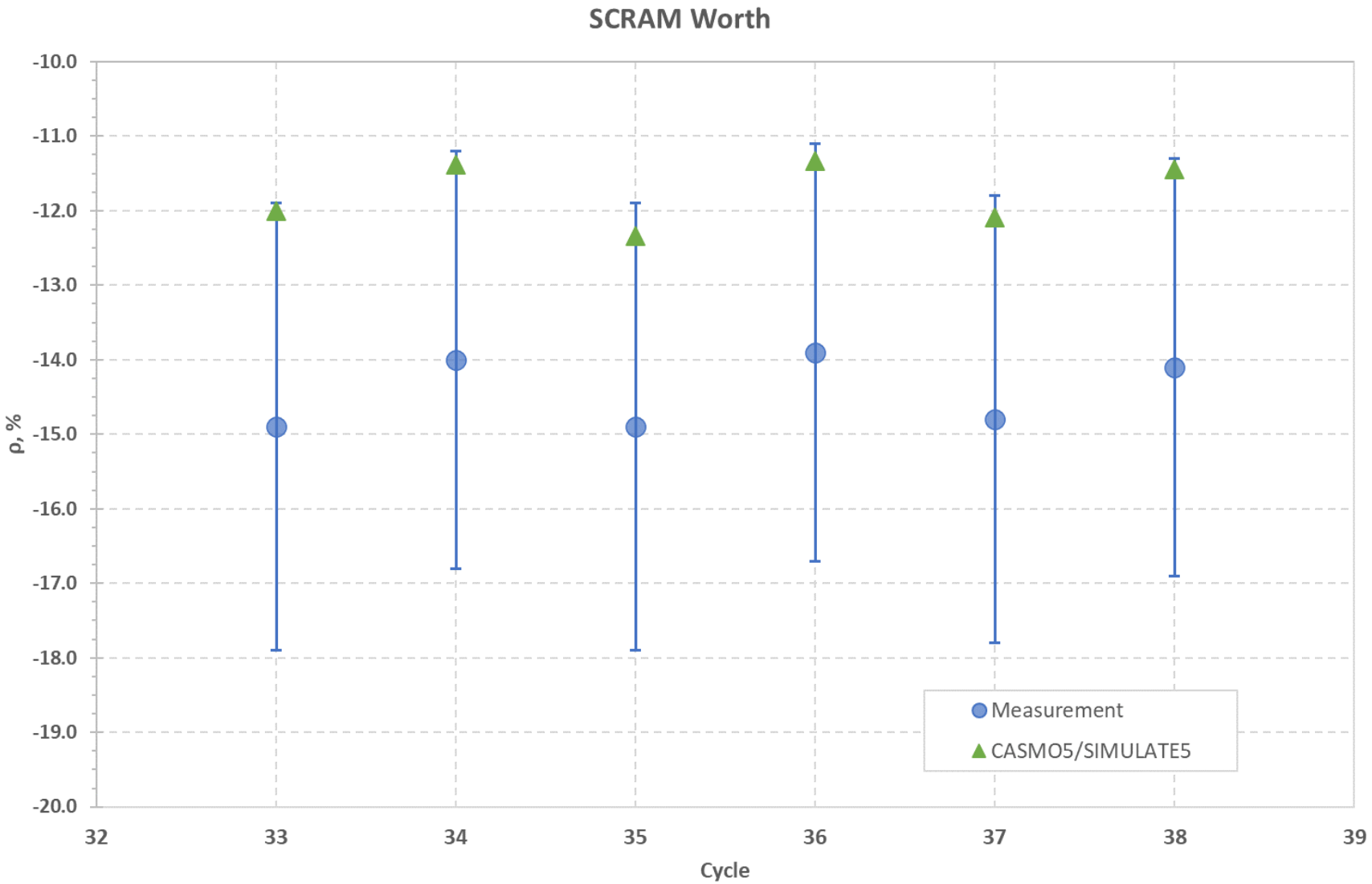


Initial State

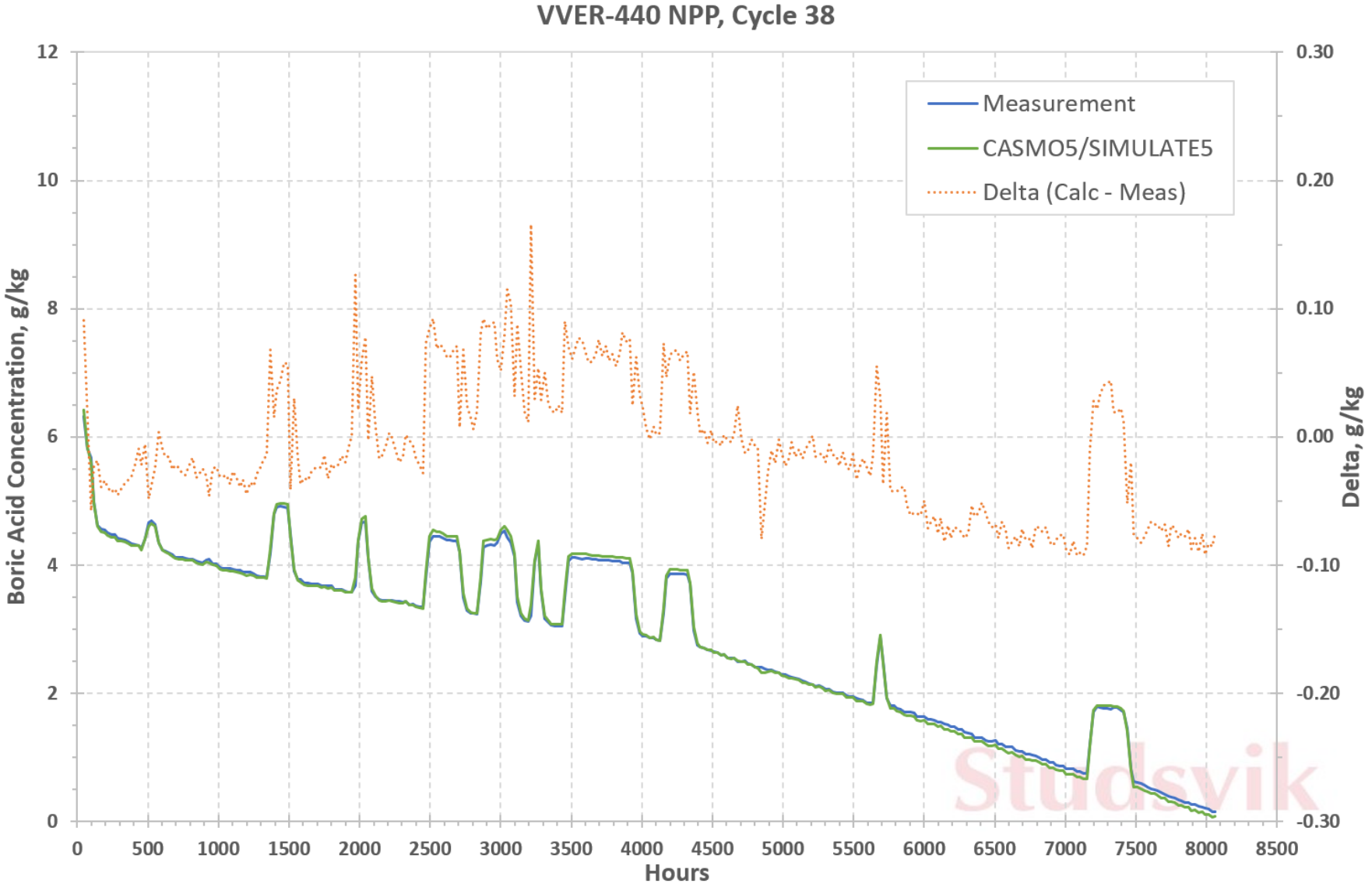


Final State

VVER-440 RESULTS – SCRAM WORTH



VVER-440 RESULTS – BORON LETDOWN



CONSLUSION

CMS5 prediction accuracy is demonstrated by comparison with VVER-440 plant measurements over **seven consecutive fuel cycles**

1

Start-up core physics tests

Good agreement with plant measurements for critical boric acid concentration, ITC and SCRAM worth

2

Boron letdown

Good agreement between calculated and measured boric acid concentration as a function of cycle exposure (operating hours)

STUDSVIK SCANDPOWER SOFTWARE & SERVICES FOR VVER

REACTOR TYPE

VVER-440

VVER-1000

VVER-1200

Fuel-vendor-independent commercial software suite

FULL FUEL-LIFE-CYCLE COVERAGE

FUEL & CORE DESIGN

Fuel design
Fuel-cycle analysis
Core-load design

TRANSIENT & SAFETY

Transient analysis
Real-time applications
Safety analysis

CORE OPERATIONS

Online core monitoring
Refueling
Core shuffling

SPENT-FUEL MANAGEMENT

Spent-fuel safety analysis
Storage planning
Long-term isotopic data

INTENDED USERS Fuel vendors • Utilities • Plant operators • Safety authorities • Research institutes

THANK YOU!

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