# CMS5 Benchmarking against VVER-1000 Plant Data

Emiliya L. Georgieva & Tamer Bahadir

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# OUTLINE

# STUDSVIK SCANDPOWER SOFTWARE & SERVICES

## Reactor Design & Performance

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

**SIMULATE5**
*3D Nodal Simulator (Commercial LWR)*

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

**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)
  - SIMULATE5
    - ✓ VVER-1000 & VVER-1200 → year 2018 (hexagonal solver)
    - ✓ VVER-440 → year 2022 (control assembly: fuel + absorber)

# CMS5 – BENCHMARKING FOR VVER

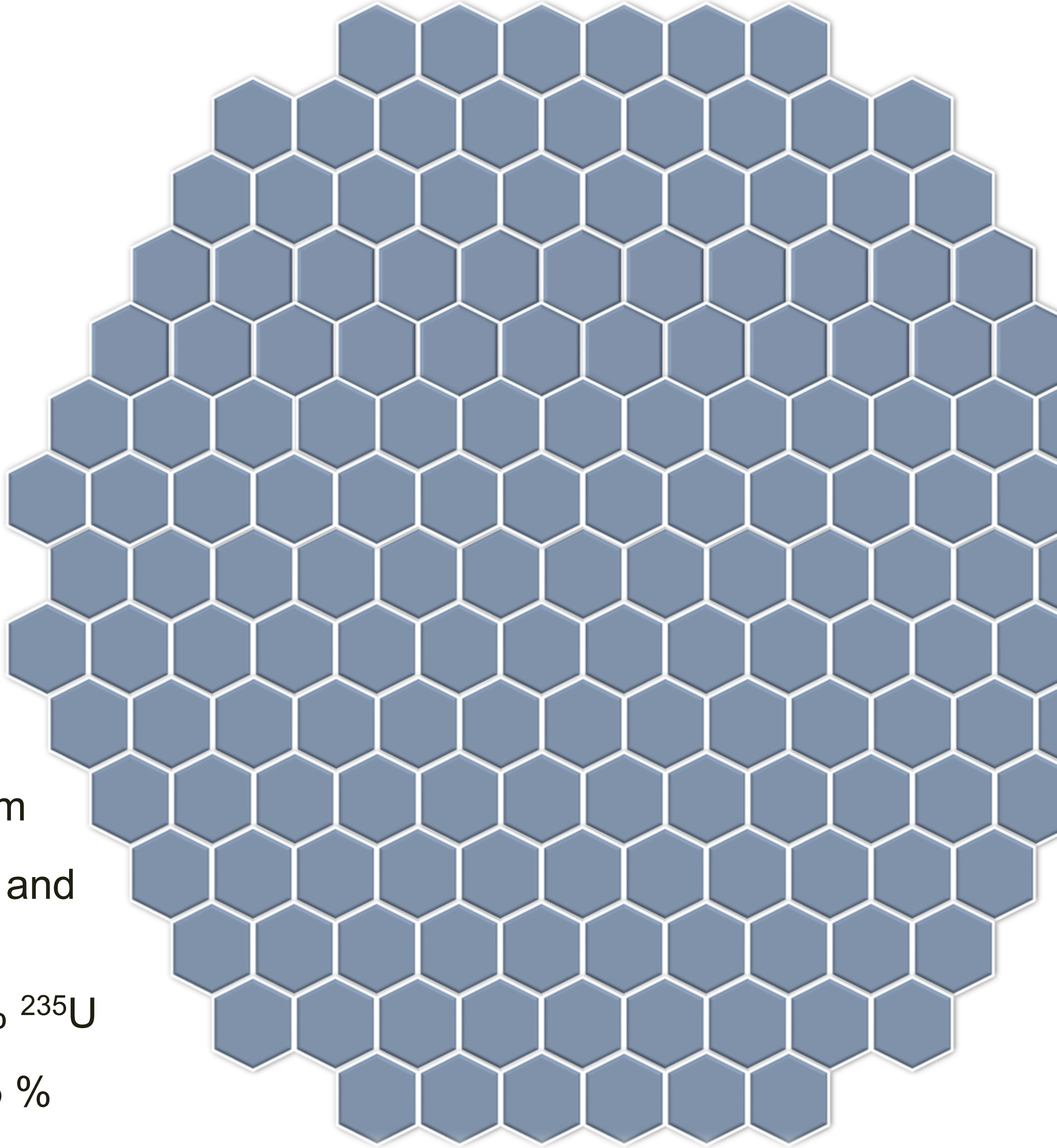
- Comparison vs. Monte Carlo solution
  - 2D cores with realistic VVER-1000 fuel assembly designs by TVEL (Russia)
    - ✓ MIDICORE Benchmark
    - ✓ FULLCORE Benchmark
  - 2D cores with realistic VVER-440 fuel assembly designs by TVEL (Russia)
    - ✓ FULLCORE Benchmark
    - ✓ FULLCORE RK3+ Benchmark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

- VVER-1000/V320 pressurized water reactor
  - Thermal power 3,000 MW(th)
  - Generator power 1,000 MW(e)
  - Primary pressure 15.7 MPa
  - Inlet coolant temperature at rated power 286 °C
  - Total coolant flow rate ~88,000 $m^3/h$
- Core
  - Active height – 3.53 m; effective diameter – 3.16 m
  - 163 hexagonal fuel assemblies with 312 fuel pins and 19 instrument/guide tubes
    - ✓ $UO_2$ with maximum average enrichment 4.4 % $^{235}U$
    - ✓ U-Gd oxide with maximum content of $Gd_2O_3$ 5 %



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# VVER-1000 PLANT MODEL

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

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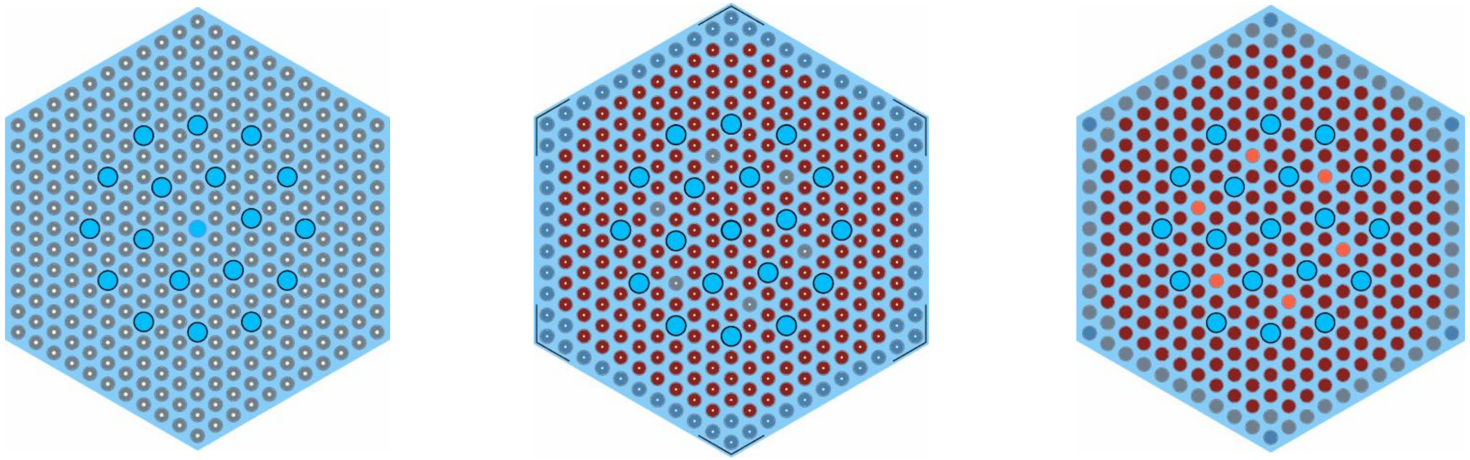
    - ✓ Two-dimensional single assembly calculations in full geometry



*Fuel Segments*

# VVER-1000 PLANT MODEL

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  - Radial reflector
    - ✓ Multi-assembly calculation in full core with baffle and barrel

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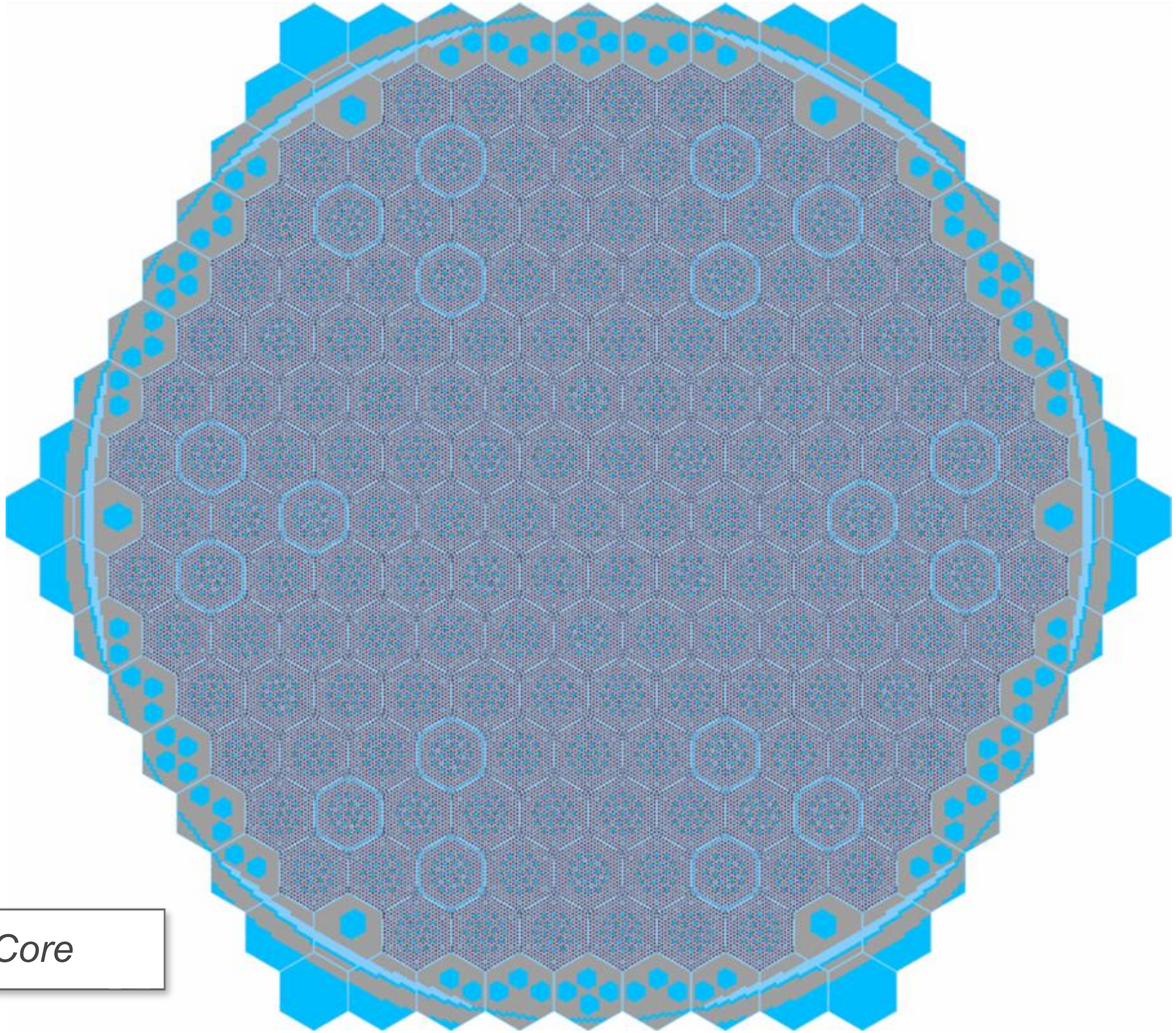

2D Core

# VVER-1000 PLANT MODEL

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  - Top & bottom reflectors
    - ✓ One-dimensional fuel and reflector calculations

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    - ✓ Multi-assembly calculation in full core with baffle and barrel
  - Top & bottom reflectors
    - ✓ One-dimensional fuel and reflector calculations
- Four-group cross-section library

| *Thermal* | *Resonance Fine* | *Resonance Shielded* | *Fast* |
|---|---|---|---|
| 0.625 eV | 10 eV | 10 keV | 20 MeV |

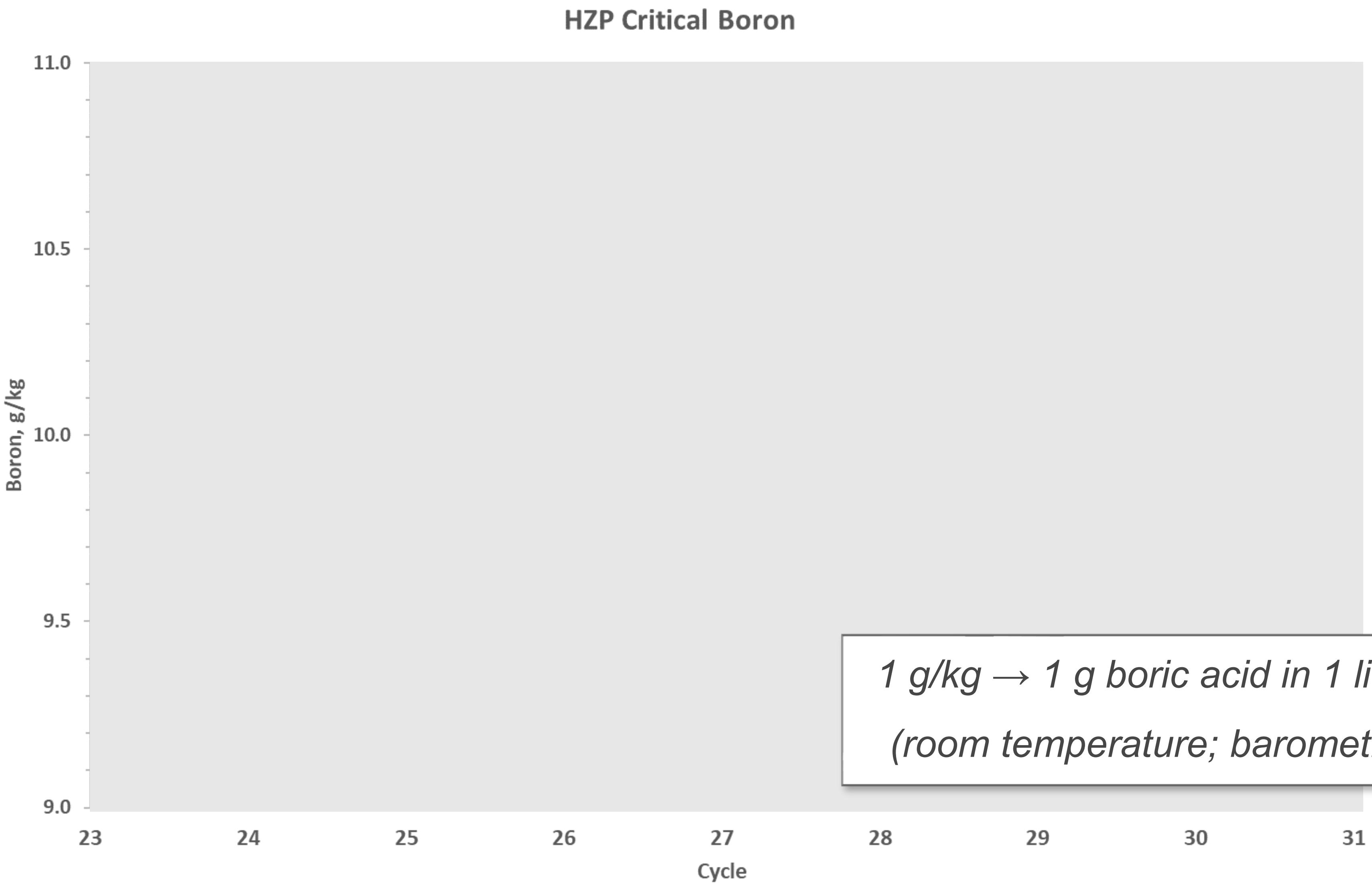
# VVER-1000 PLANT MODEL

- Reactor core
  - SIMULATE5 multigroup nodal code

# VVER-1000 PLANT MODEL

- Reactor core
  - SIMULATE5 multigroup nodal code
  - Full core geometry
    - ✓ 163 fuel assemblies and 48 radial reflector assemblies
    - ✓ Fuel assembly → 6 radial & 30 axial nodes
  - Spacer grids
  - SPND tubes
  - 10 control rod banks
  - Cycles 24 – 32
    - ✓ Jump-in cycle initialization
    - ✓ Reactor power and positions of the control rod banks

# VVER-1000 RESULTS – HZP CRITICAL BORIC ACID




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

*(room temperature; barometric pressure)*

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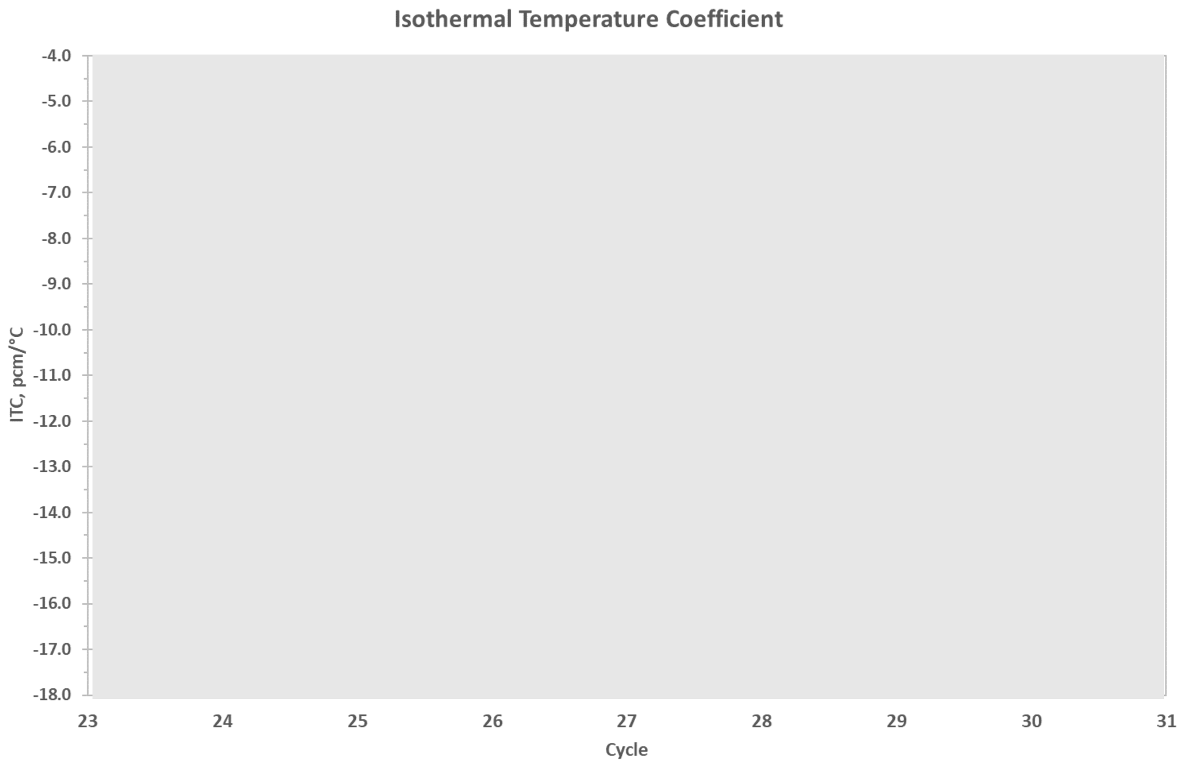
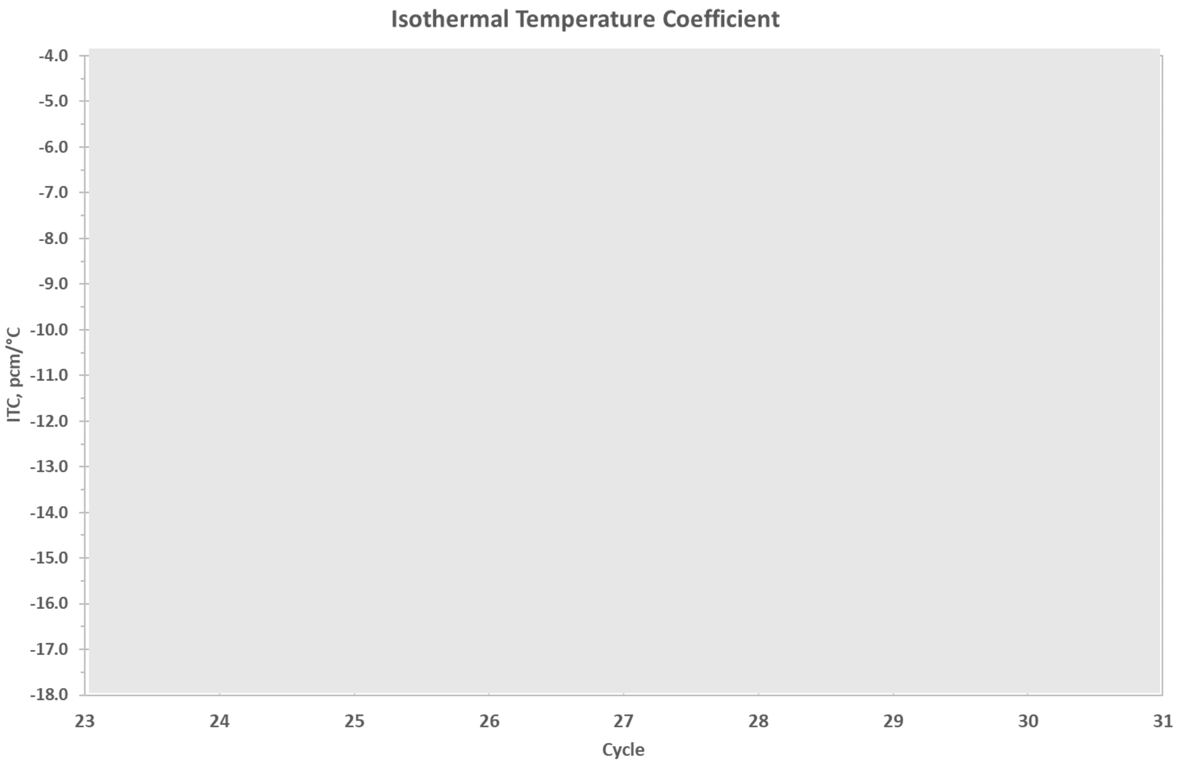
# VVER-1000 RESULTS – ITC

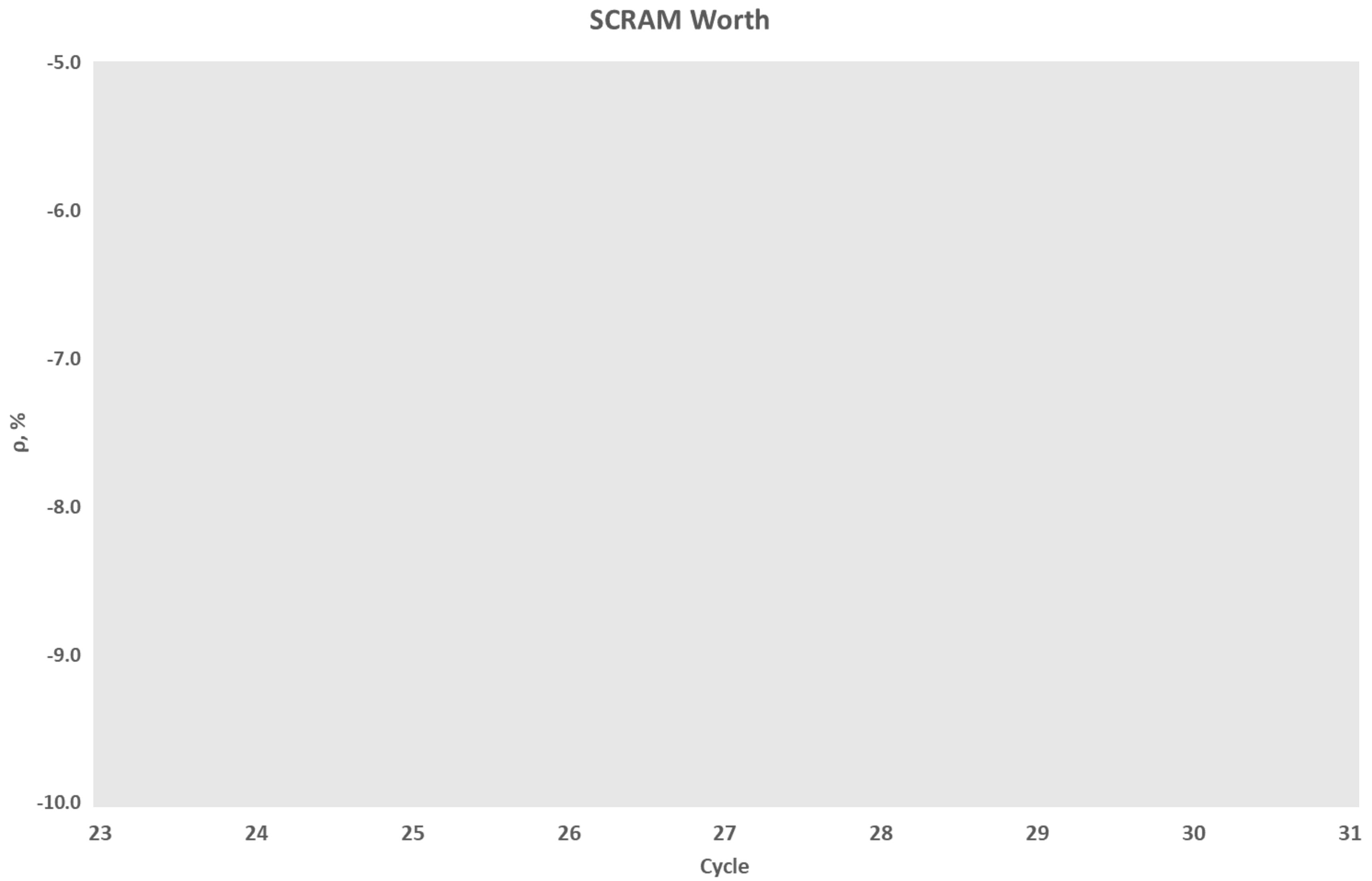



*Initial State*




*Final State*

# VVER-1000 RESULTS – SCRAM WORTH

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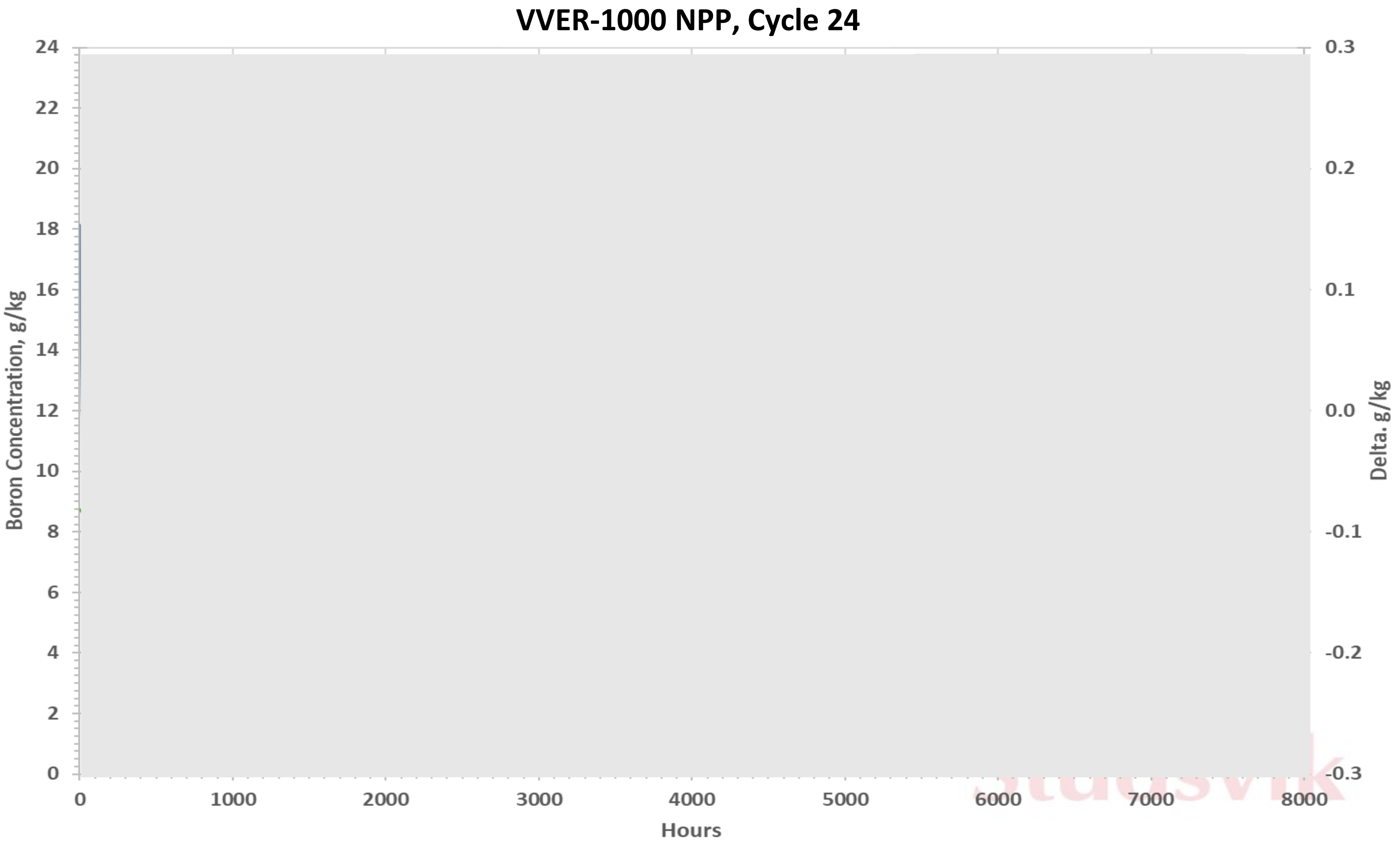
# VVER-1000 RESULTS – BORON LETDOWN



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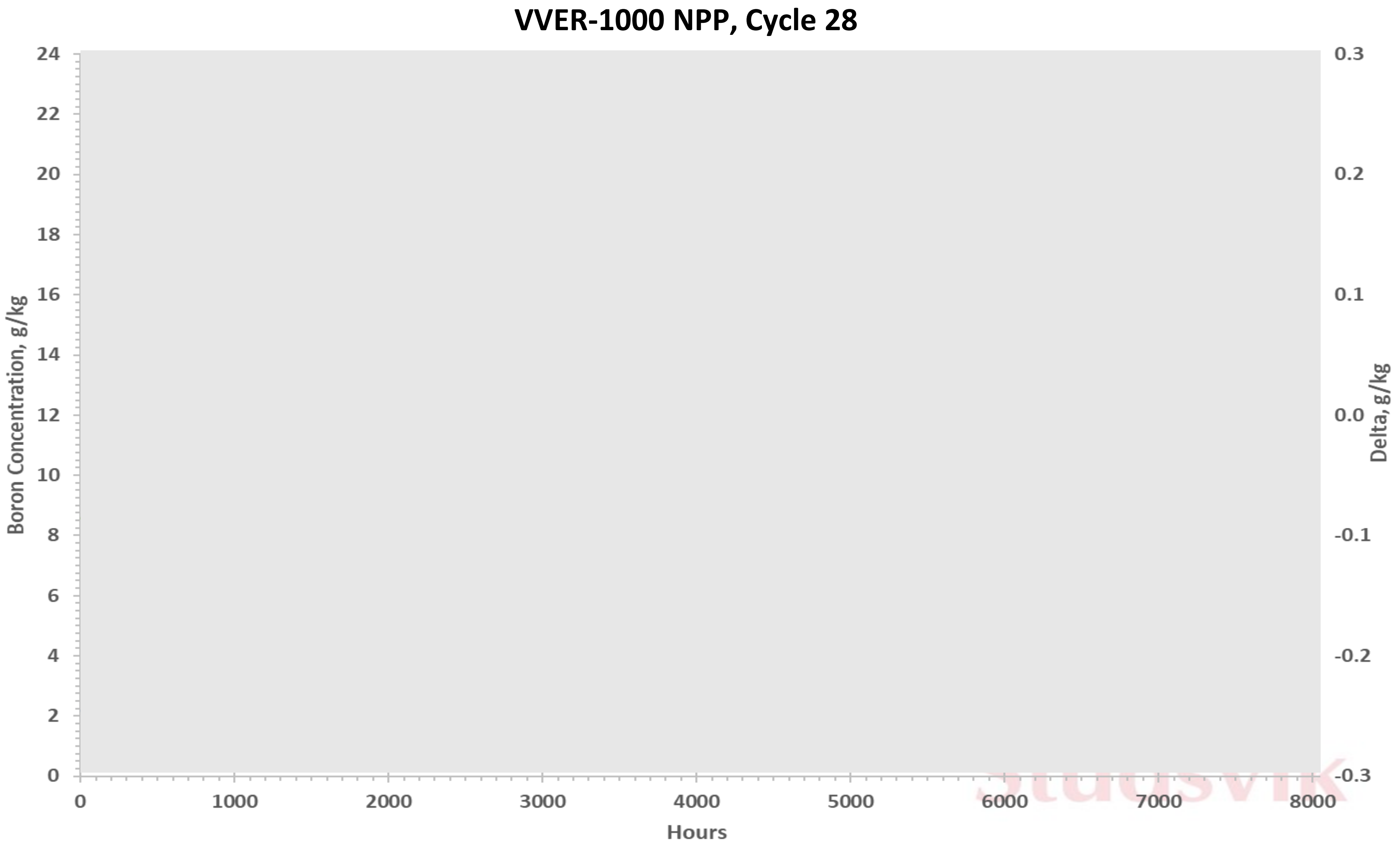

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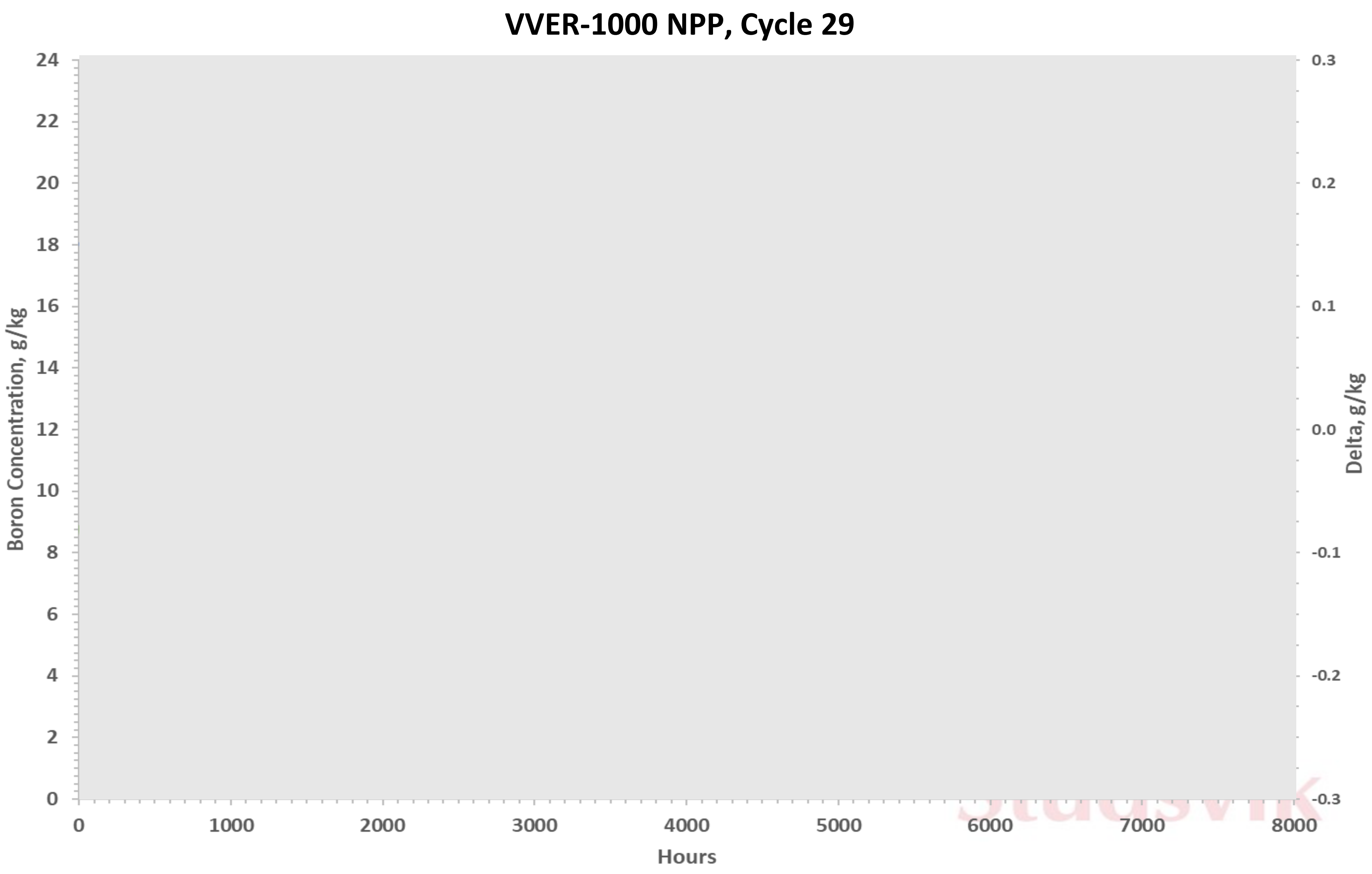

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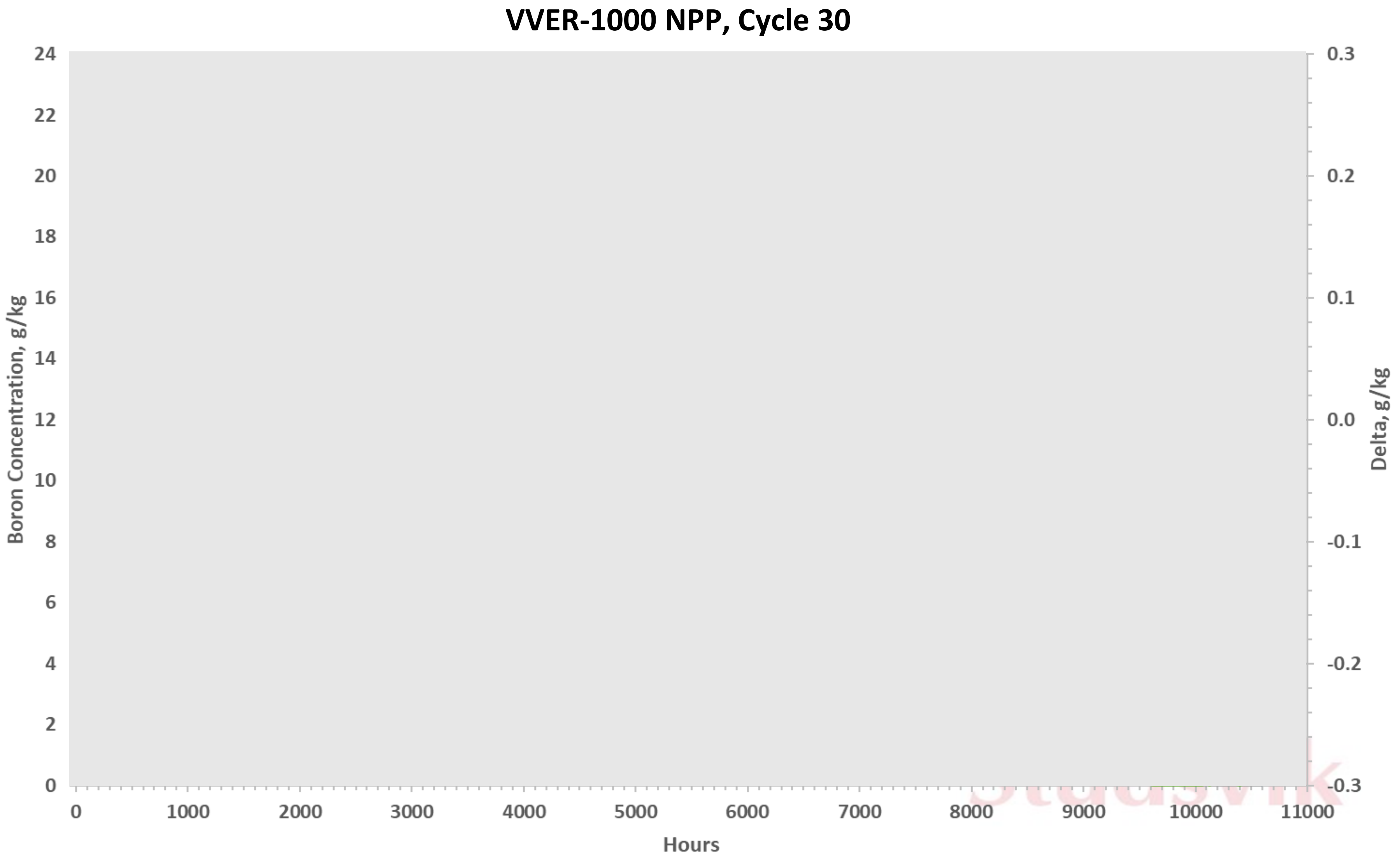

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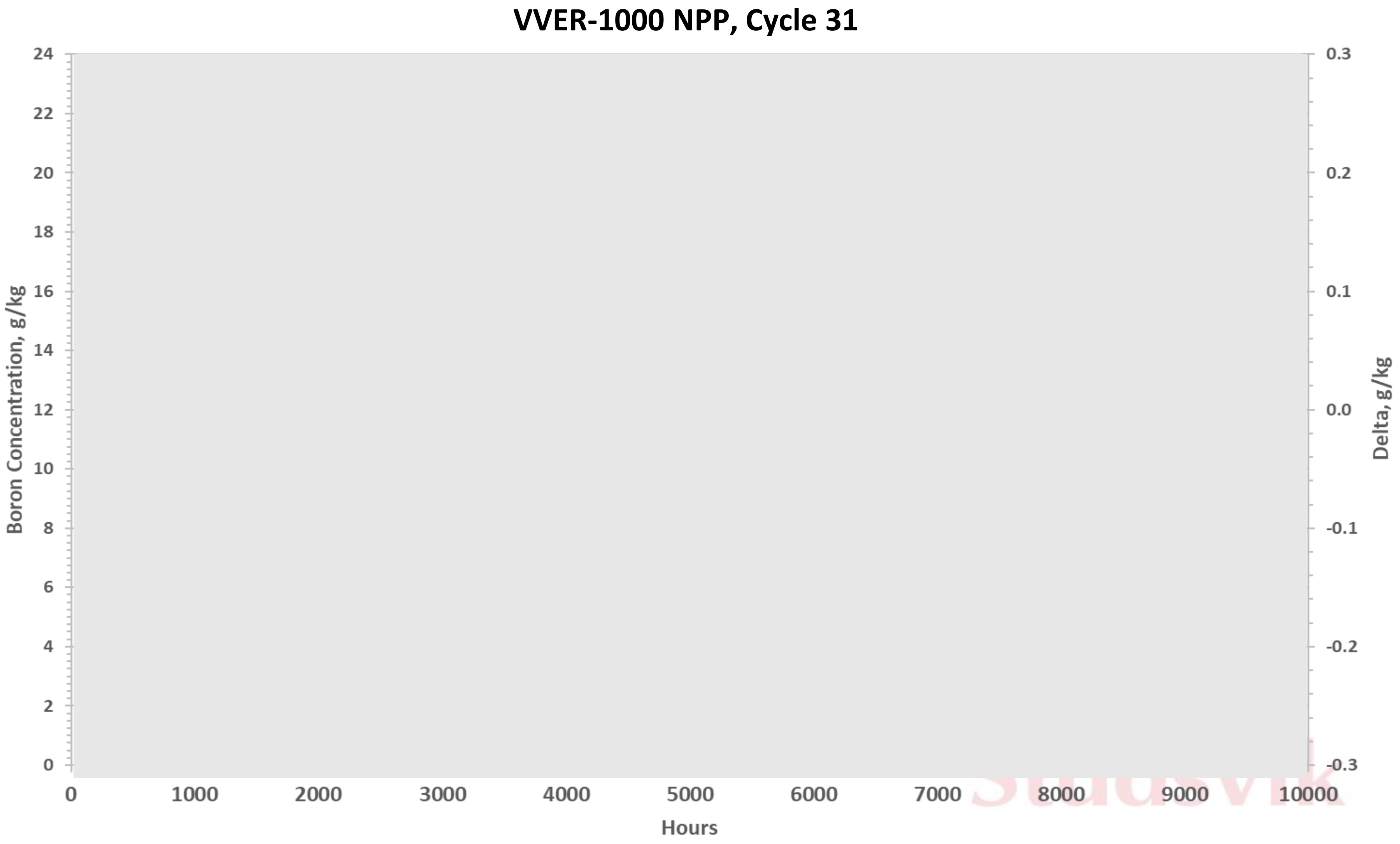

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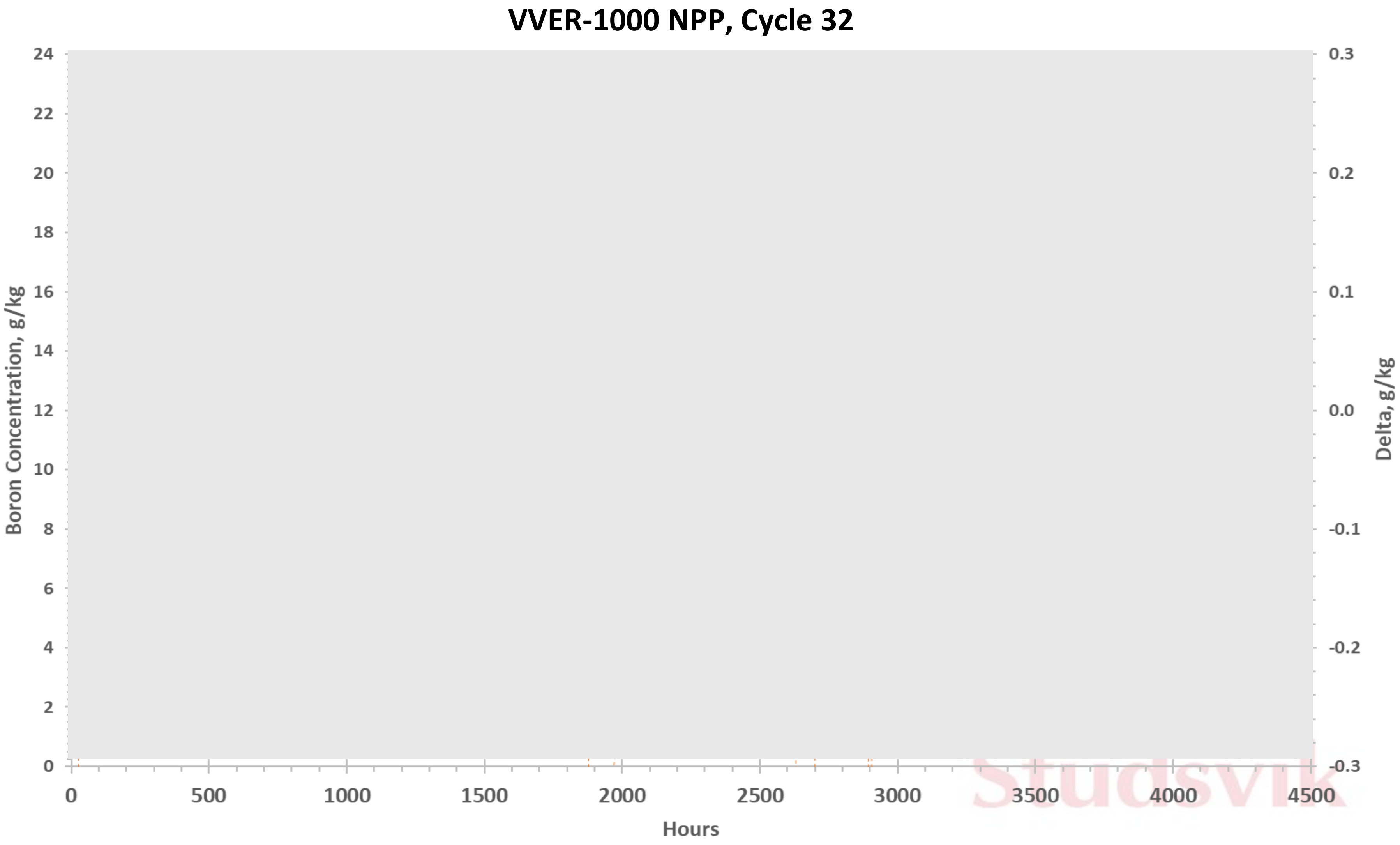

# CONSLUSION

- The accuracy of the CMS5 predictions is demonstrated with comparisons to a VVER-1000 plant measurements for 9 cycles in a row as follows
  - low power physics tests at BOC (critical boric acid, ITC & SCRAM worth)
  - boric acid concentration vs cycle exposure in clock hours
- The Studsvik Scandpower CMS5 code package for VVER
  - commercially available fuel vendor independent software suite
  - supports VVER-440, VVER-1000 & VVER-1200 reactors

# THANK YOU!

emiliya.georgieva@studsvik.com

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