1st International Conference on LWR Fuel Performance, Modelling and Experimental Support

September 14–19, 2025

Nessebar, Bulgaria

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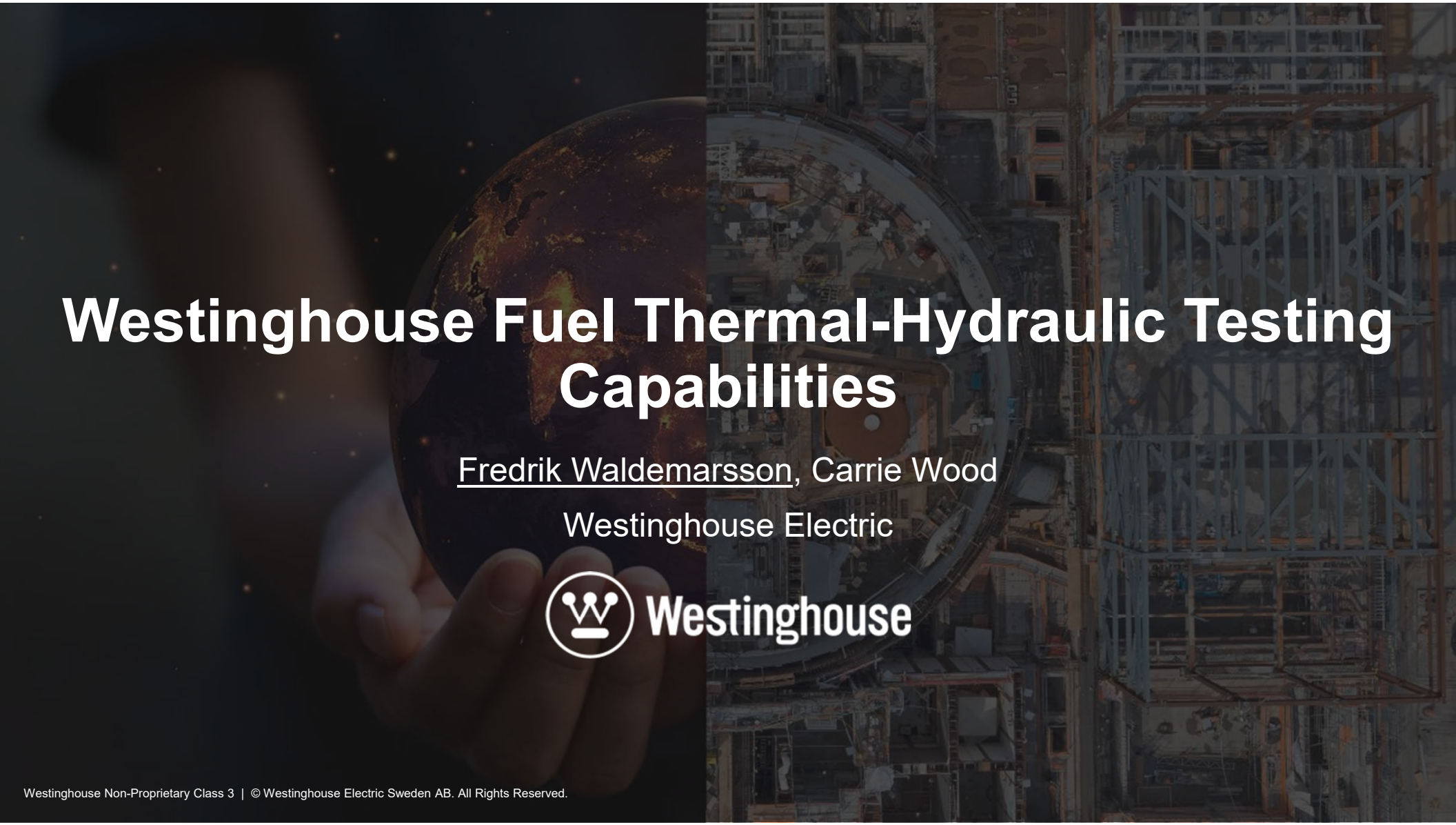

Westinghouse Fuel Thermal-Hydraulic Testing Capabilities

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Westinghouse Electric

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  - VIPER
  - VISTA
- Westinghouse Sweden Test Loops
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  - FRODE
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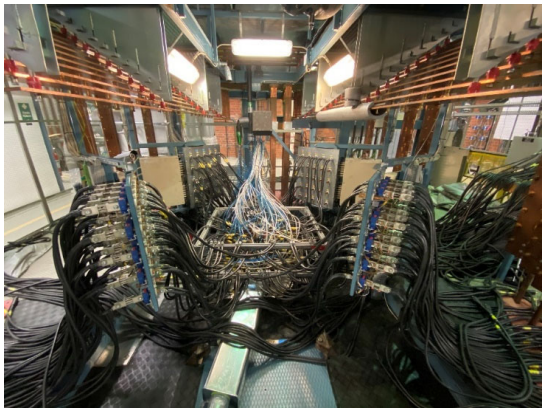
Introduction

- Light Water Reactors (LWRs) rely on complex core thermal-hydraulic behavior to ensure safe and efficient operation.
- As advanced fuel designs are developed to support more demanding reactor operation, advanced modeling and rigorous testing are essential to optimize performance, address emerging challenges and meet regulatory requirements.
- This presentation highlights Westinghouse current Thermal-Hydraulic testing capabilities



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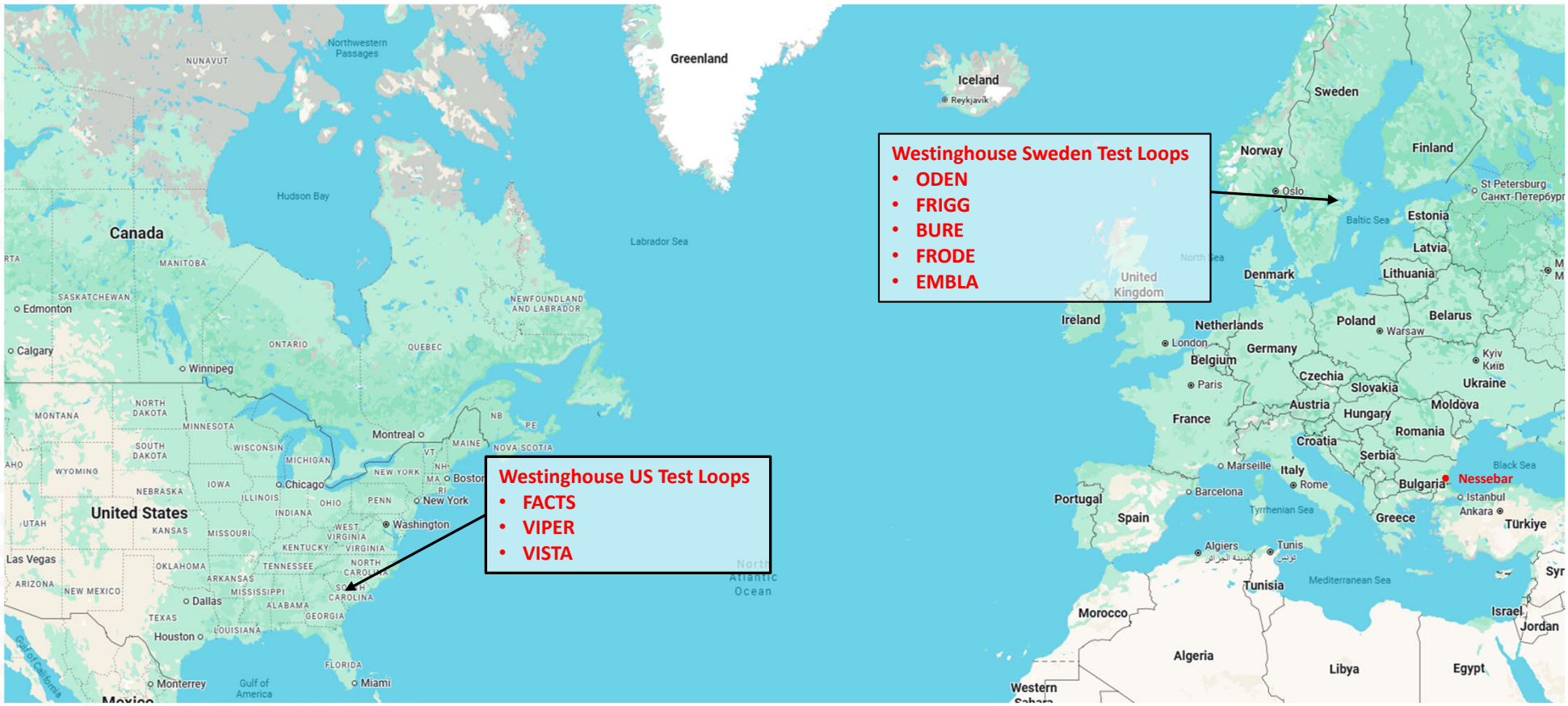

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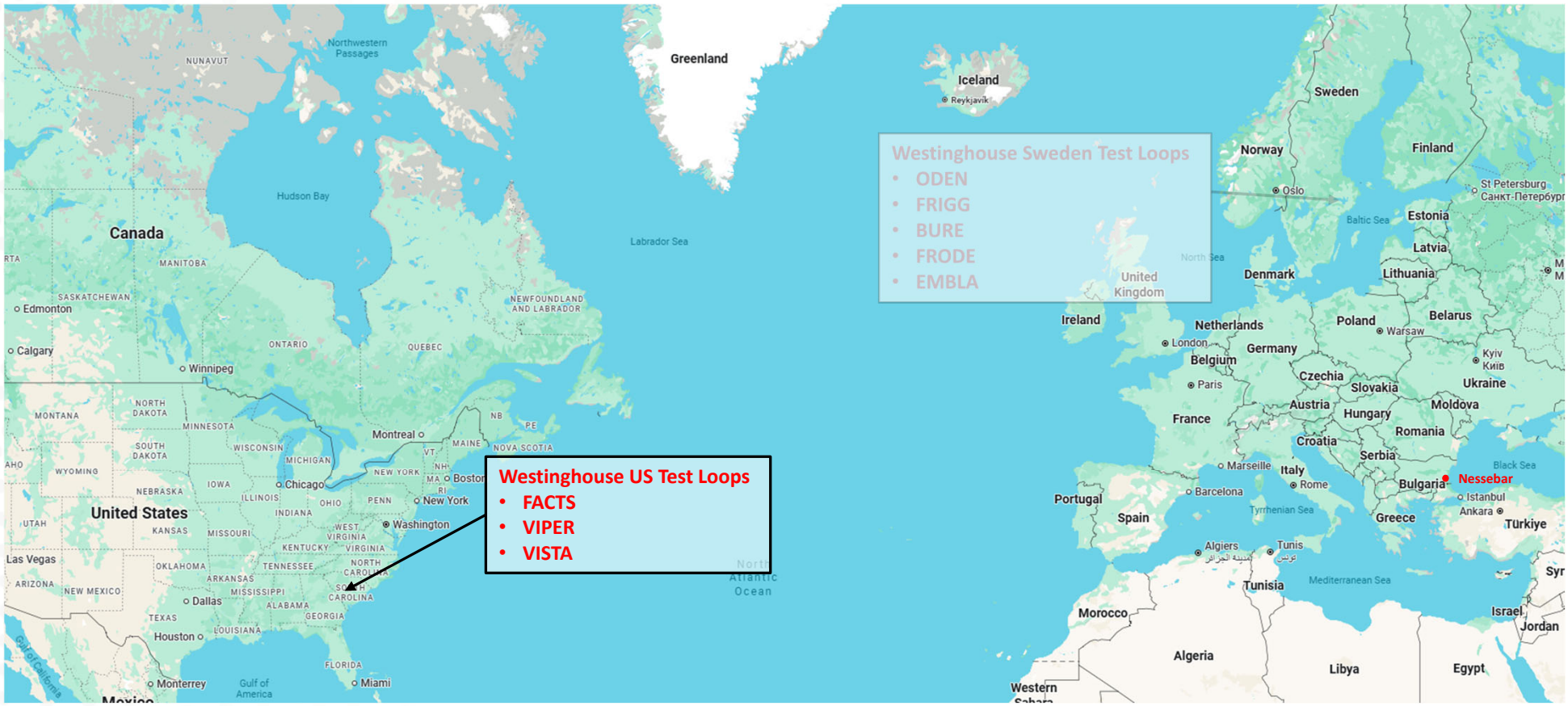

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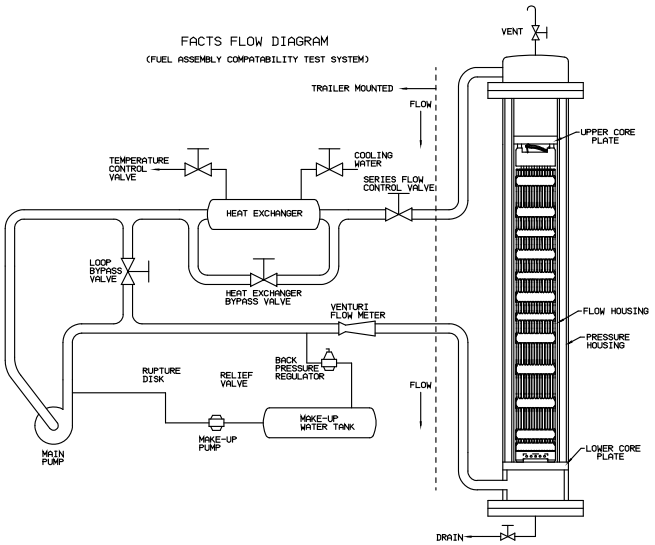
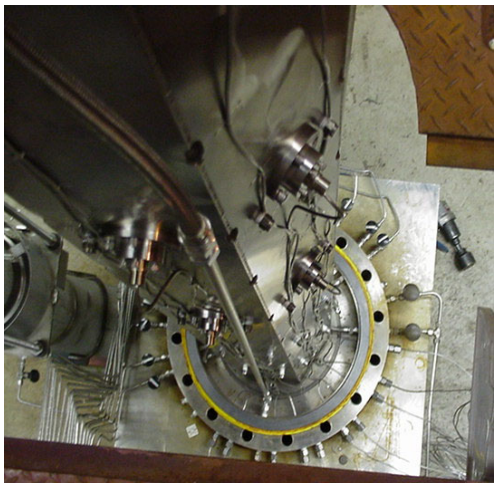
FACTS VVER/PWR Loop

- Primary objectives
  - Pressure drop
  - Vibration
  - Debris filter efficiency
- Operating boundary conditions
  - Pressures up to 15.5 bar
  - Inlet temperature up to 121°C
  - Flow range from 0 to 150 kg/s
- Full scale single fuel assembly
- Built to be transportable
- Standard loop for defining Westinghouse PWR fuel loss coefficients historically

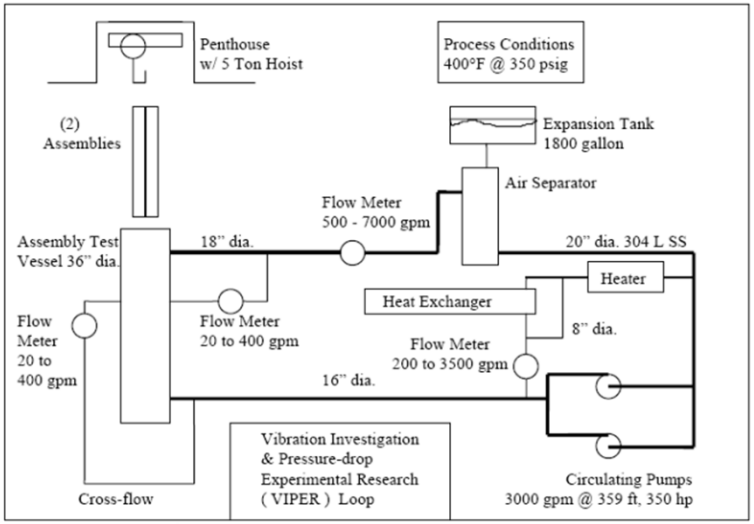


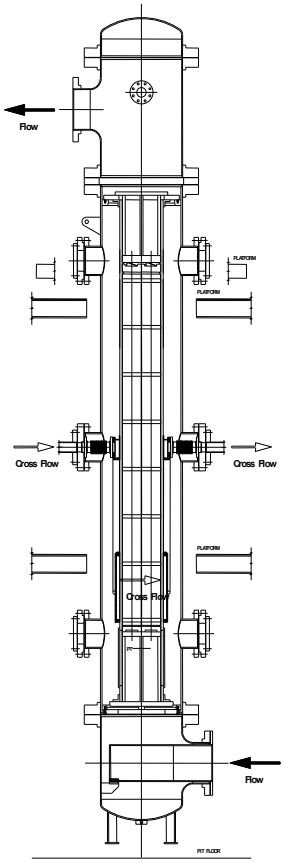


Built in the 1980's

VIPER VVER/PWR Loop

- Primary objectives
  - Pressure drop
  - Vibration
  - Grid-to-rod fretting
- Operating boundary conditions
  - Pressures up to 25 bar
  - Inlet temperature up to 203°C
  - Axial Flow range from 0 to 400 kg/s
  - Cross Flow range from 0 to 16.5 kg/s
- Full scale, single or dual assemblies
  - May contain rods with non-enriched uranium
- Standard loop for defining Westinghouse PWR and VVER fuel grid-to-rod fretting performance





Built in the late 1990's

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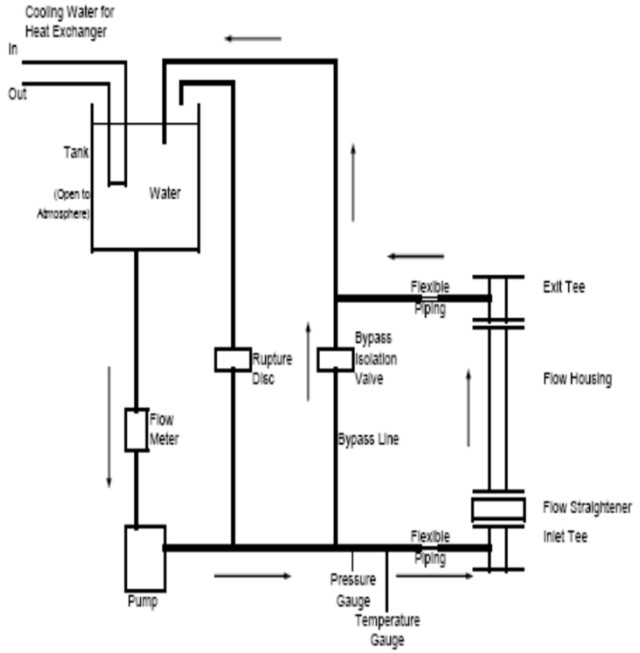
VISTA VVER/PWR Loop

- Primary objectives
  - Pressure drop
  - Vibration
  - Flow Velocity profile measurement capability (Laser Doppler Anemometry)
- Operating boundary conditions
  - Pressures up to 5.5 bar
  - Inlet temperature up to 27°C
  - Flow range from 0 to 25 kg/s
- 1.5 m axial scale, 5x5 radial rod configuration
- Inexpensive scoping testing prior to FACTS or VIPER testing



Built in the late 1990's

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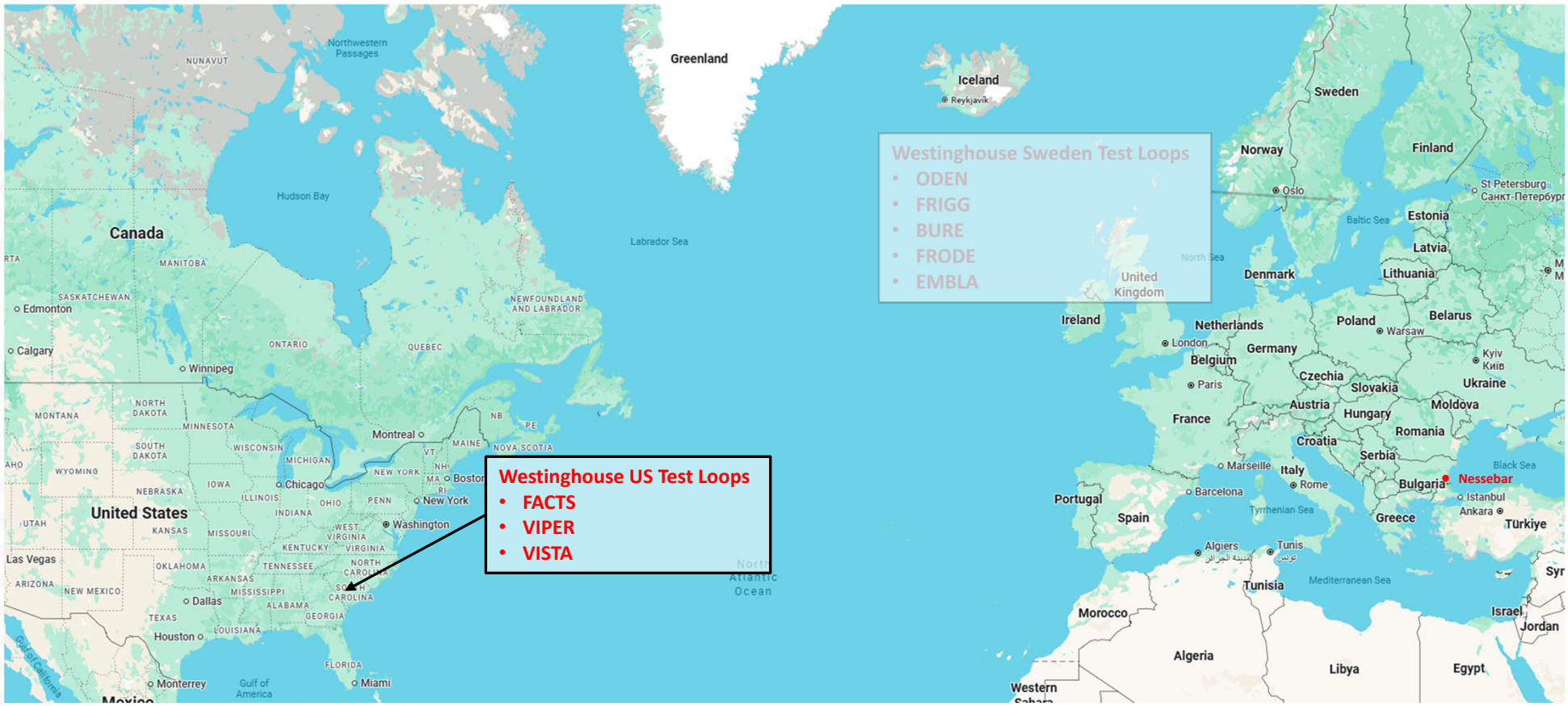

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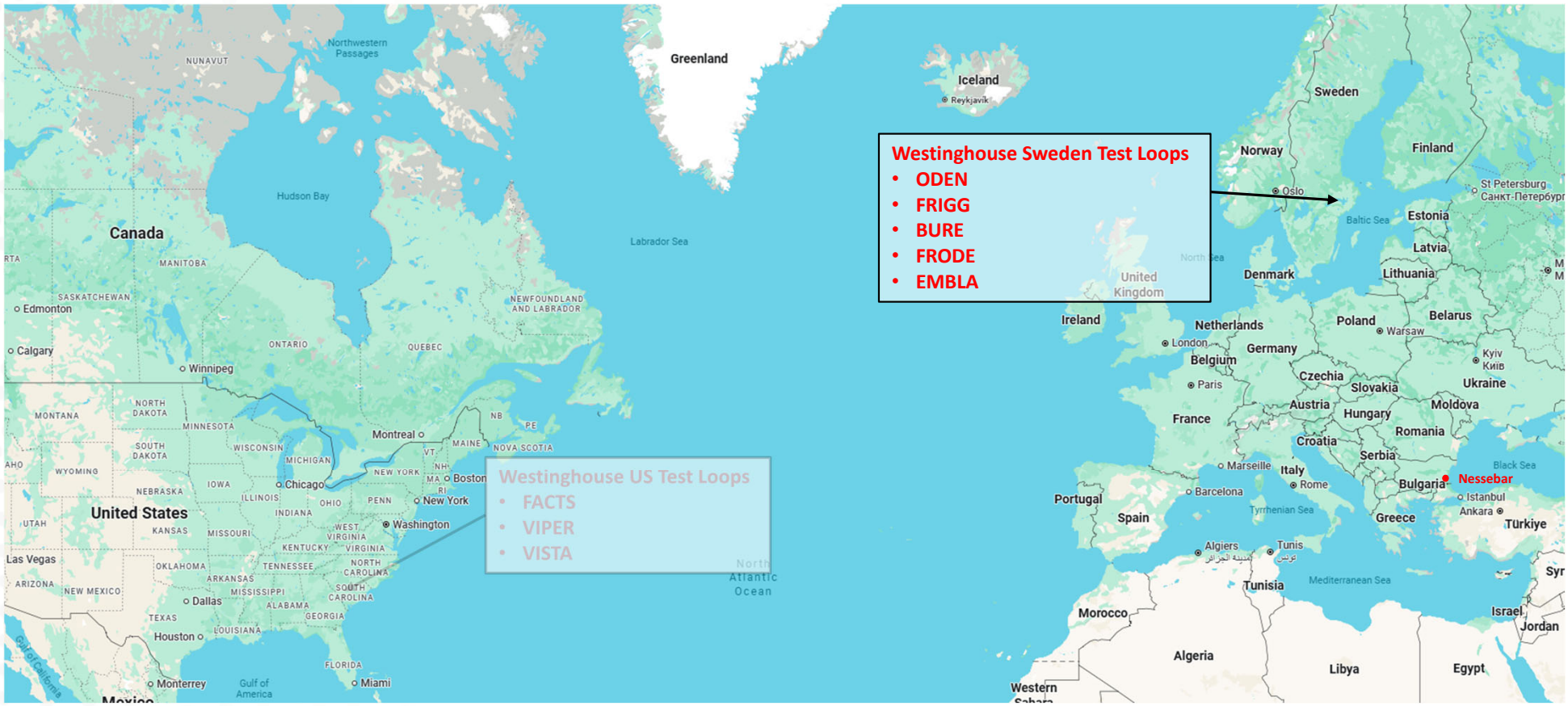

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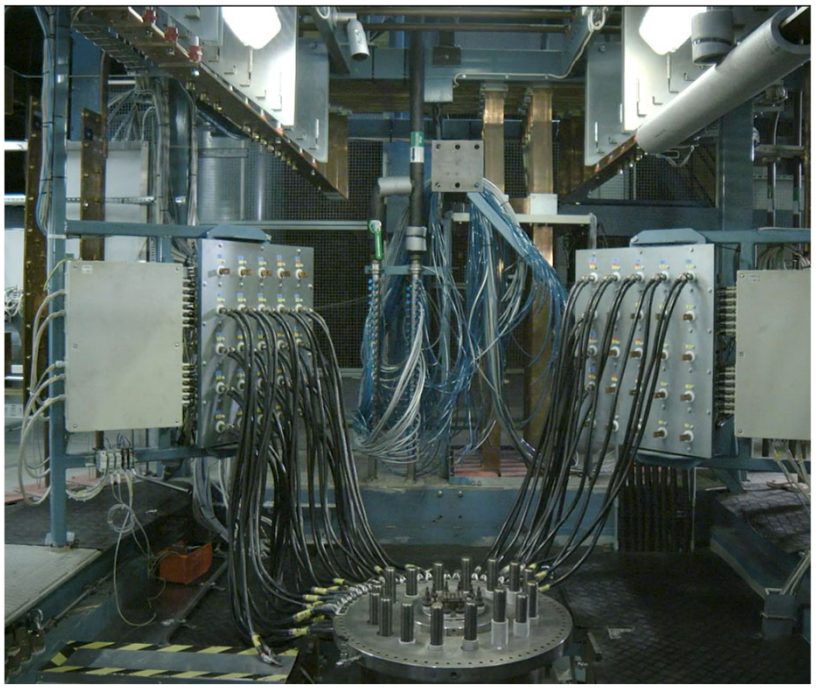
ODEN VVER/PWR Loop

- Primary objectives
  - Critical heat flux
  - Mixing
  - Pressure drop
- Operating boundary conditions
  - Power up to 12 MW
  - Pressures up to 200 bar
  - Inlet temperature up to 366°C
  - Flow range from 0.7 to 22 kg/s
- Full axial scale with 5x5 or 6x6 or 19 rod hex radial configuration
- Directly electrically heated rods monitored with ~8 thermocouples each



Built in early 2000, first commercial test in 2011

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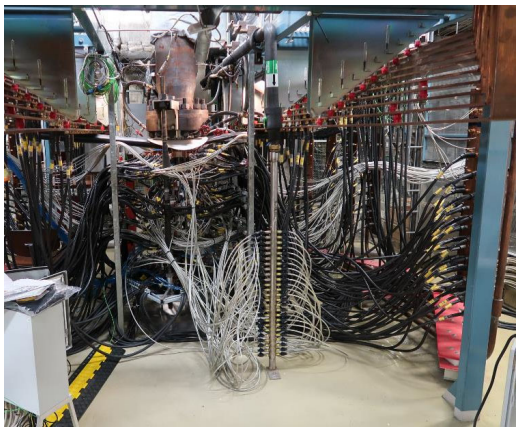
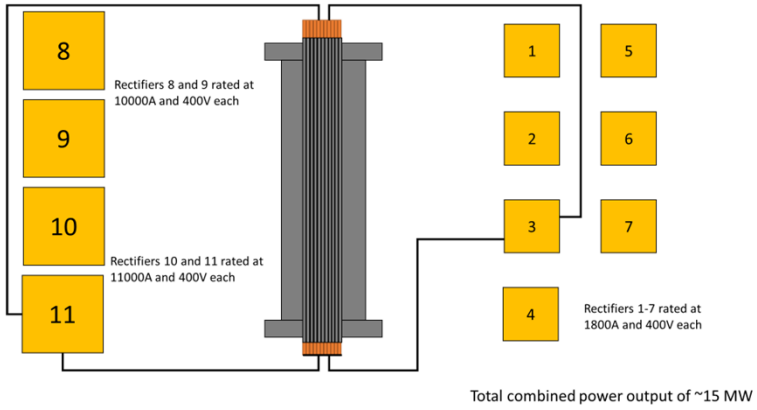
FRIGG BWR Loop

- Primary objectives
  - Critical heat flux
    - Static and transient (power and flow)
  - Pressure drop
  - Hydraulic stability
  - Local void and flow velocity
- Operating boundary conditions
  - Power up to 15 MW
  - Pressures up to 100 bar
  - Inlet temperature up to 311°C
  - Flow range from 2 to 25 kg/s
- Full axial and radial scale up to 11x11 radial rod configuration
- Indirectly electrically heated rods monitored with ~8 thermocouples each
- Flexible radial power configuration during operation





Built in the 1960's
Latest upgrade ~2020

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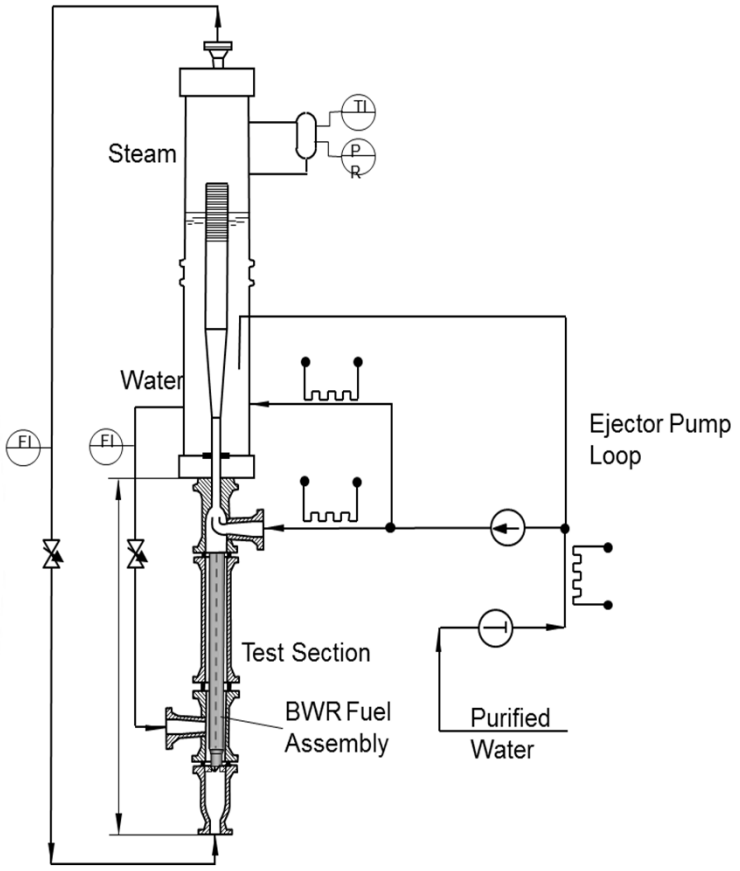
BURE BWR Loop

- Primary objectives
  - Vibration
  - Fretting
- Operating boundary conditions
  - Pressures up to 85 bar
  - Inlet temperature up to 300°C
  - Flow rate up to 25 kg/s
- Can be run in single or two-phase mode (steam injection)
- 1:1 BWR fuel mockup containing non-enriched uranium rods
- Typical test time ~700 hrs



Built in the 1970's
Will be largely renovated in ~2026

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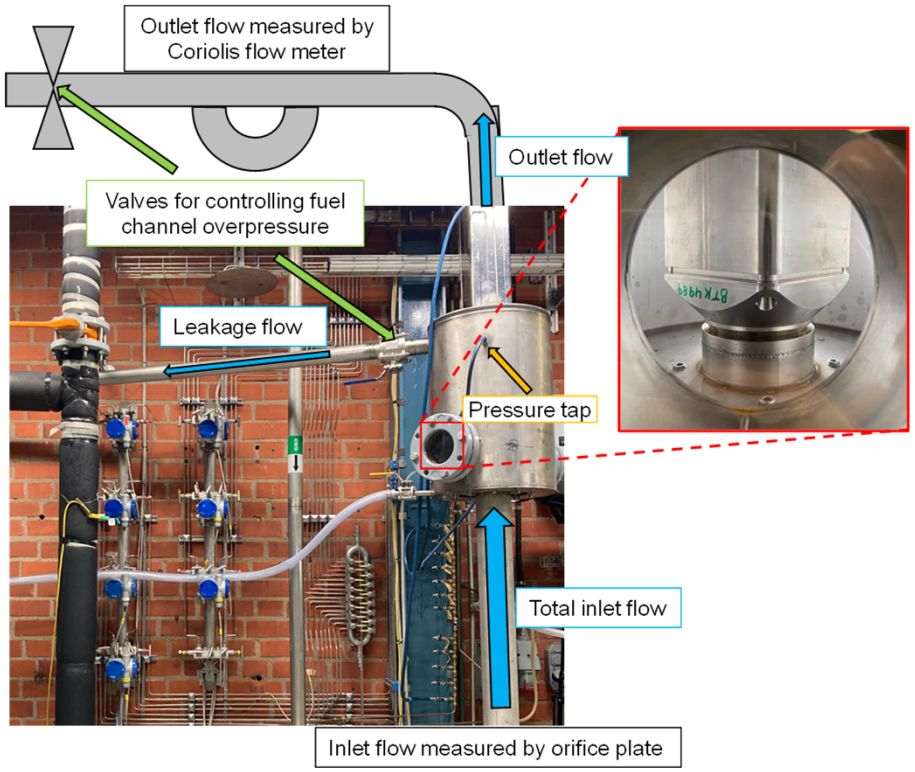
FRODE BWR Loop

- Primary objectives
  - Pressure Drop
  - Debris filter efficiency
  - Local flow velocity
  - Hydraulic lift force
  - Clogging
  - Leakage flow
- Operating boundary conditions
  - Open loop, atmospheric pressure
  - Inlet temperature up to 85°C
  - Flow rate up to 30 kg/s
- Full radial scale BWR fuel, shortened axial scale
- Flexible and versatile



Built in the 1960's
Continuously upgraded and modified

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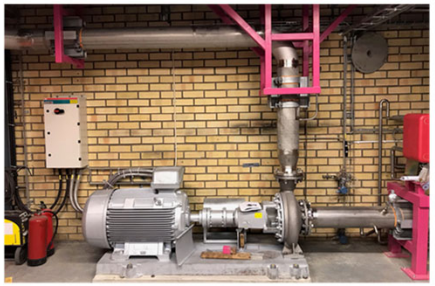
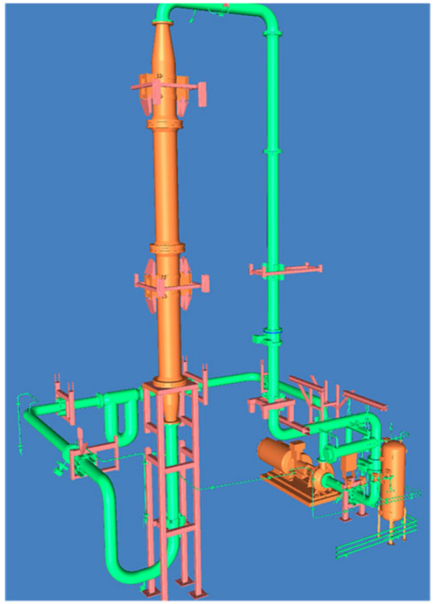
EMBLA VVER/PWR/BWR Loop

- Primary objectives
  - Single phase detailed axial pressure drop
- Operating boundary conditions
  - Pressures up to 18 bar
  - Inlet temperature up to 150°C
  - Flow rate up to 590 m^3/h (~150 kg/s)
- Full scale fuel assemblies
- Special features
  - Built with large focus on accurate flow measurement
  - Dual flow measurements
    - Primary, Coriolis flow meter
      - Uncertainty of 0.1% (1σ)
    - Secondary, orifice plate
      - Uncertainty of 0.6% (1σ)
  - Long inlet straight
  - Inlet designed to have a fully developed flow at bundle inlet





Built 2022
VVER1000 and VVER440 tests performed

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Summary

- Fuel development requires advanced modeling and rigorous testing.
- Westinghouse has the capability to investigate the Thermal-Hydraulic characteristics of our entire fuel fleet in-house.
- Fuel laboratories open for both internal and external testing.

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