Reactor Noise Analysis Applications in Canadian Pressurized Heavy Water Reactors (PHWRs)

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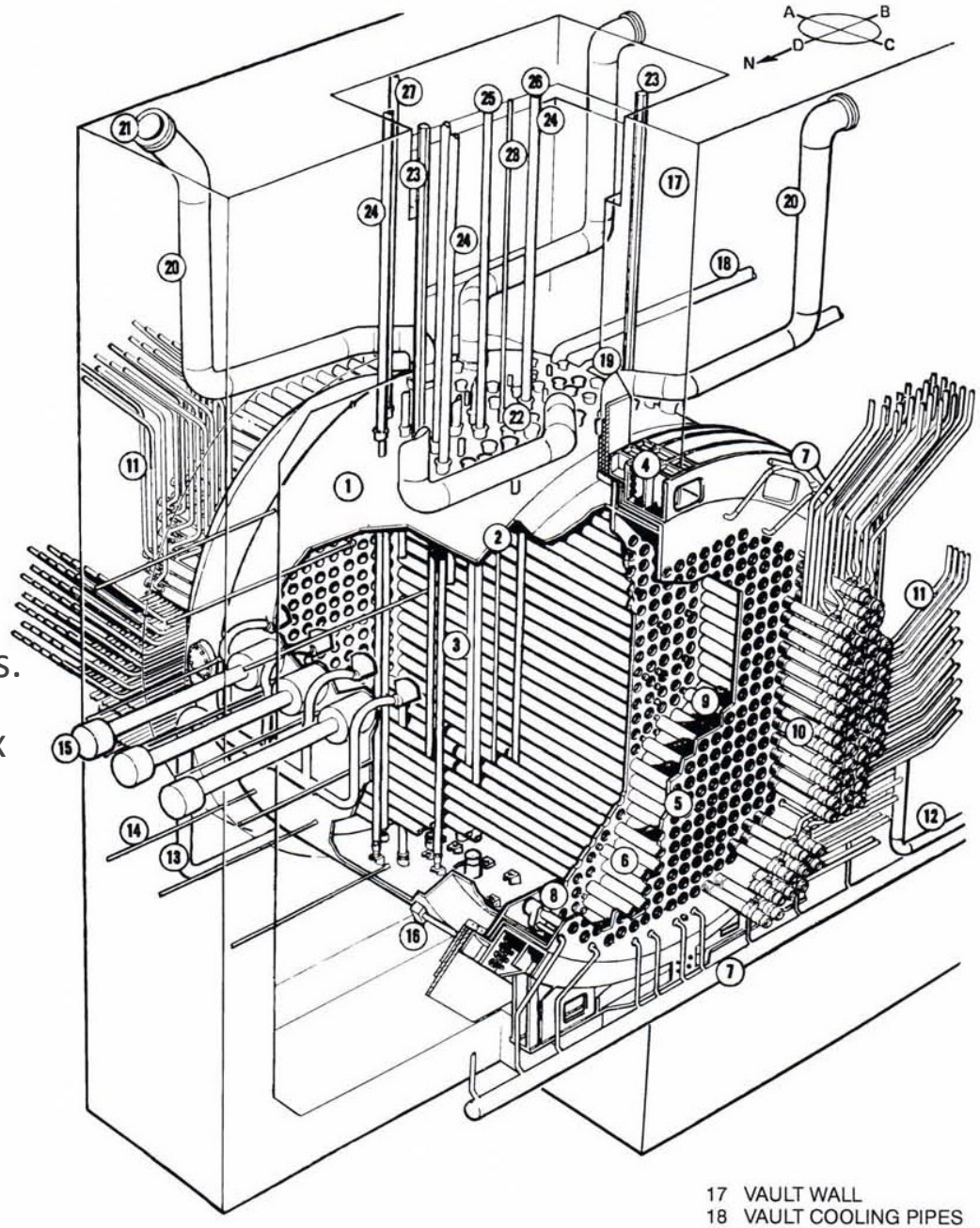
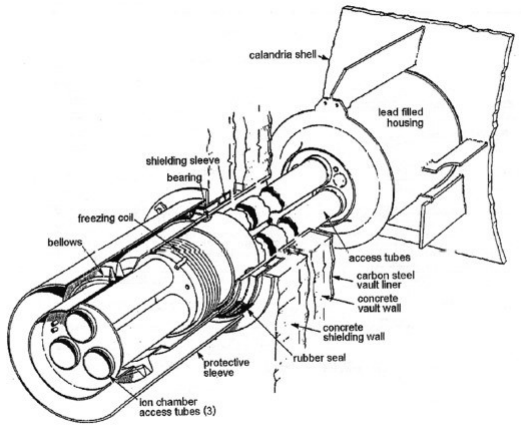
19 Operating CANDU PHWR Units in Canada (13.5 GWe capacity)

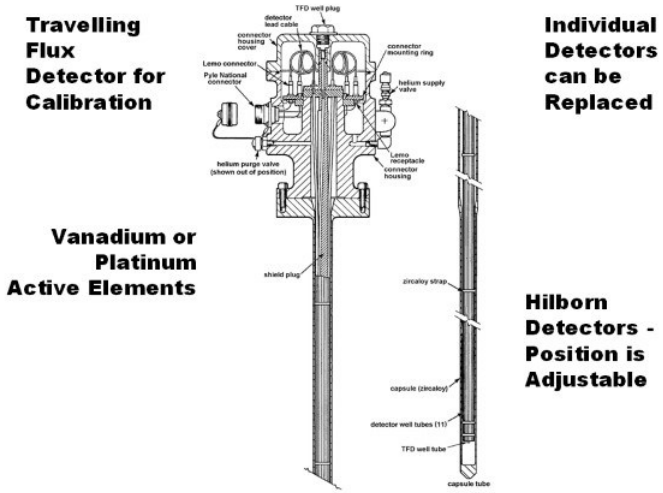
CANDU reactor core signals available for Noise Analysis

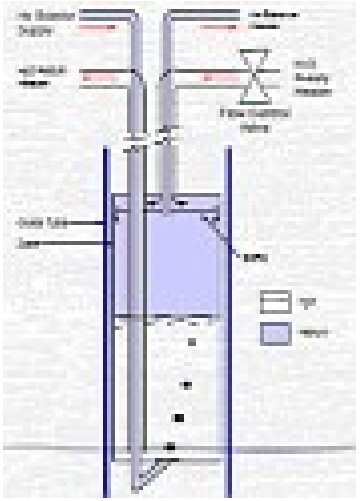
- 360-480 Fuel Channels per reactor
  - on 28.6 cm square lattice; 6 m in-core length;
  - Each with 12 fuel bundles, ~300 C, ~7.5 MPa D_2O coolant
- Selected (2 - 10%) fuel channels are instrumented for pressure, flow, temperature – signals available for noise analysis
- Header pressures and temperatures; and Feeder temperatures are monitored and available for noise analysis.
- All reactivity control and shutdown devices, and in-core flux detectors are located (in vertical and horizontal assemblies) in the low-pressure, low temperature D_2O moderator – signals available for Noise Analysis.
- Ion chambers (ICs) are located in housings on two sides of the calandria – Lin, Log, Log Rate signals from each IC available for noise analysis



CANDU Core Neutronics Instrumentation used in Noise Analysis







Ion Chamber (IC) Housing

- Up to 3 ICs each for Reactor Regulating system, Shutdown system 1 and Shutdown system 2.
- 100% prompt response

In-Core Flux Detector (ICFD) Assembly

- Regional Overpower Protection (ROP) and Zone Control (ZC) ICFDs are ~ 1m (3 lattice pitches long); 90% – 105% prompt
- Spatial control Vanadium (V) ICFDs are ~ 30 cm (1 lattice pitch) long; 9% prompt
- 100-200 ROP, 28 ZC and up to 102 V ICFDs

Liquid Zone Controller (LZC)

- Light water filled compartments used for bulk and zonal power control
- 14 LZCs per CANDU reactor

Noise data acquisition at CANDU stations

Pickering, Darlington, Bruce:

- Temporarily connected 25 input Data AcQuisition (DAQ) chassis
- 16-bit ADC; up to 2000 Hz sampling
- Input signal isolation, Anti-aliasing low-pass filtering.
- Synchronized data acquisition for up to 10 DAQ chassis (250 signals)

Routine neutronics data campaigns at 500 Hz sampling for reactor trip tests

Data taken during DAQ hook-up phase (reactor full-power steady state) used for noise analysis.

Point Lepreau:

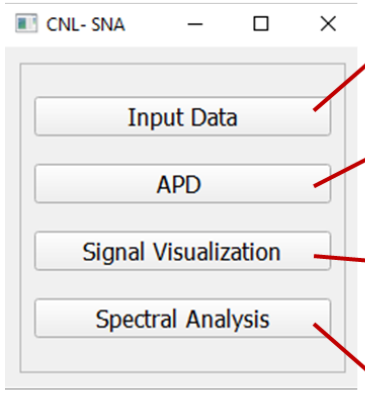
- Permanently connected High Speed Data Logger (HSDL) system with 128 to 256 input channels
- 16-bit ADC; 50 Hz sampling
- Signal acquired at end of detector electronics chain
- No anti-alias filtering
- Only 10 minutes of data saved per auto or manual trigger

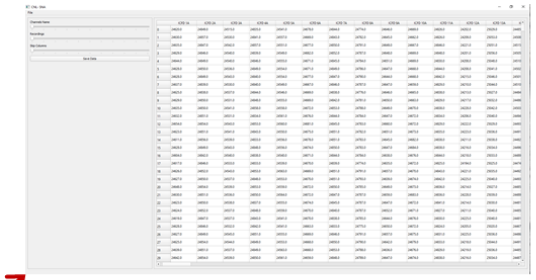
Data automatically collected during reactor transients including all reactor trips.

HSDL was manually triggered and 1 to 2 hours of reactor full-power steady state data collected for noise analysis

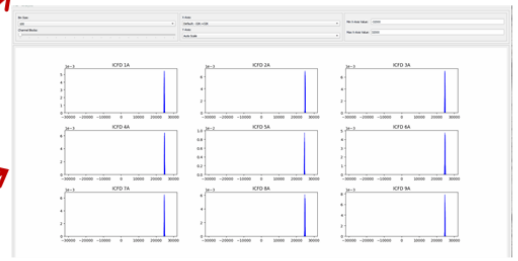
CNL-SNA: New program developed for Signal Noise Analysis

The **CNL-SNA** is a signal-processing software system that analyzes fluctuations in core instrumentation signals recorded during steady-state operation.

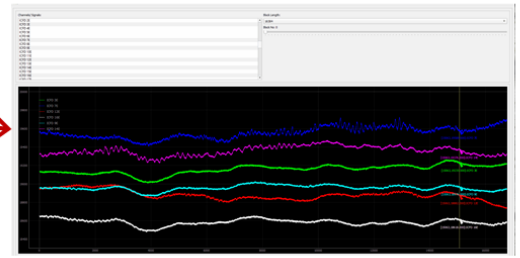




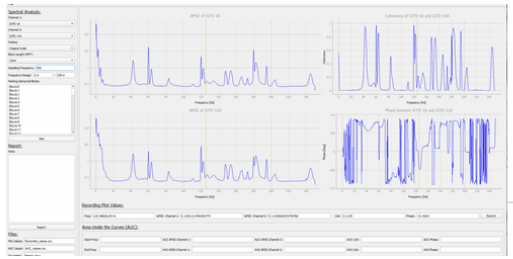
- The primary function of the **input data** module is to examine the raw data set and reformat it to be compatible with the CNL-SNA analysis modules



- Allows the user to investigate the **statistics** of recorded signals for each channel and inspect their **amplitude distribution**.



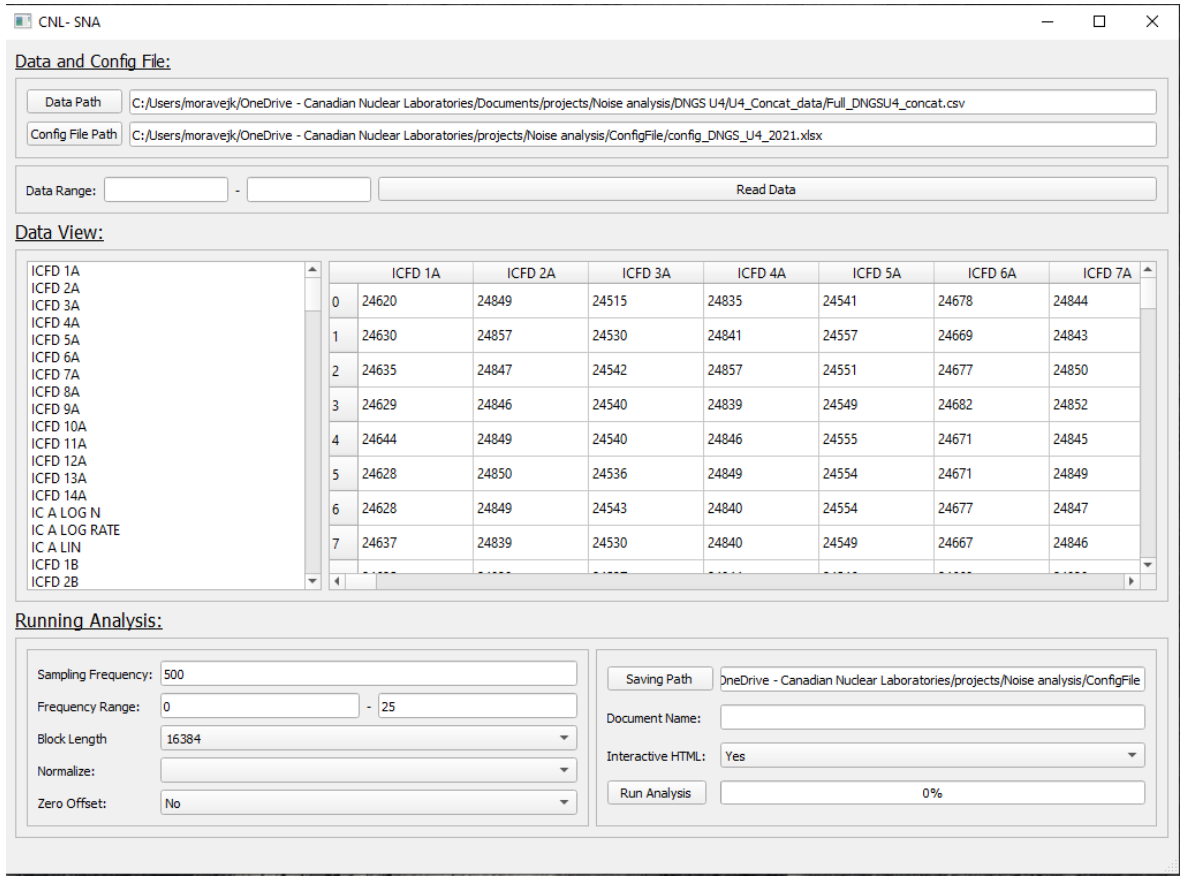
- Enables the user to interactively view recorded instrumentation signals, allowing for **visual inspection** and evaluation of their qualities.



- The Spectral Analysis tab allows the user to estimate the **APSD**, **CPSD**, **Coherence**, and **Phase** between two signal pairs.

CNL-SNA: Automated Processing of Noise Signals

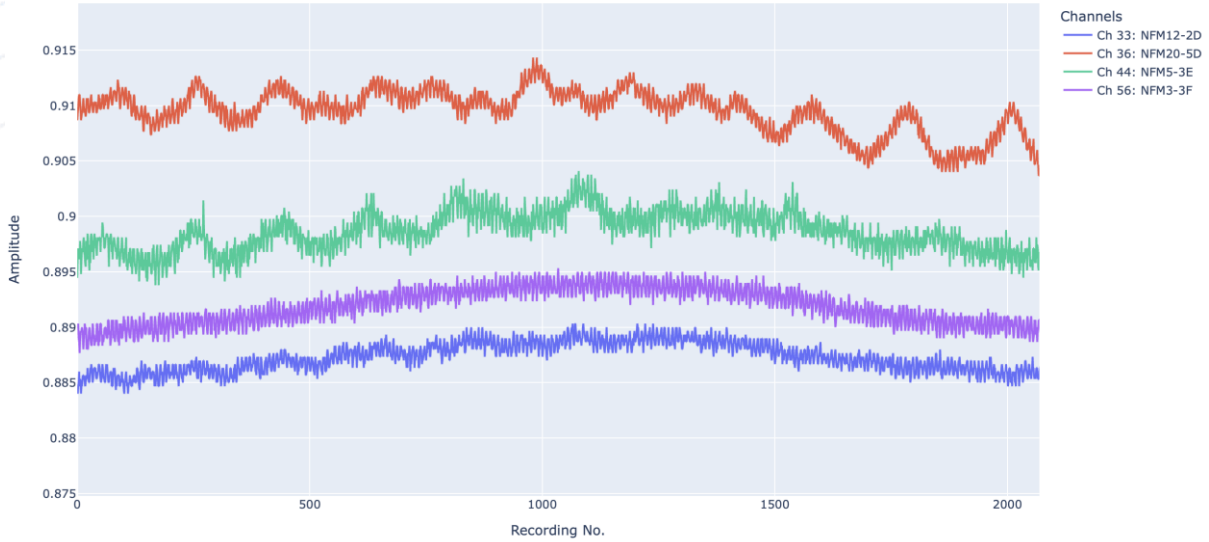
- The system is designed to execute automated processing of noise signals, delivering comprehensive and systematic results.
- The designed scheme encompasses all typical signal sets that can be selected and processed in noise measurements across all CANDU designs
- The system generates Noise Spectral Functions for signal validation of:
  - Ion Chambers
  - ICFDs
  - LZC Level Signals
  - LZC Level and RRS ICFD signals
  - Noise coupling between the LZC Level signals and the IC-LIN signals

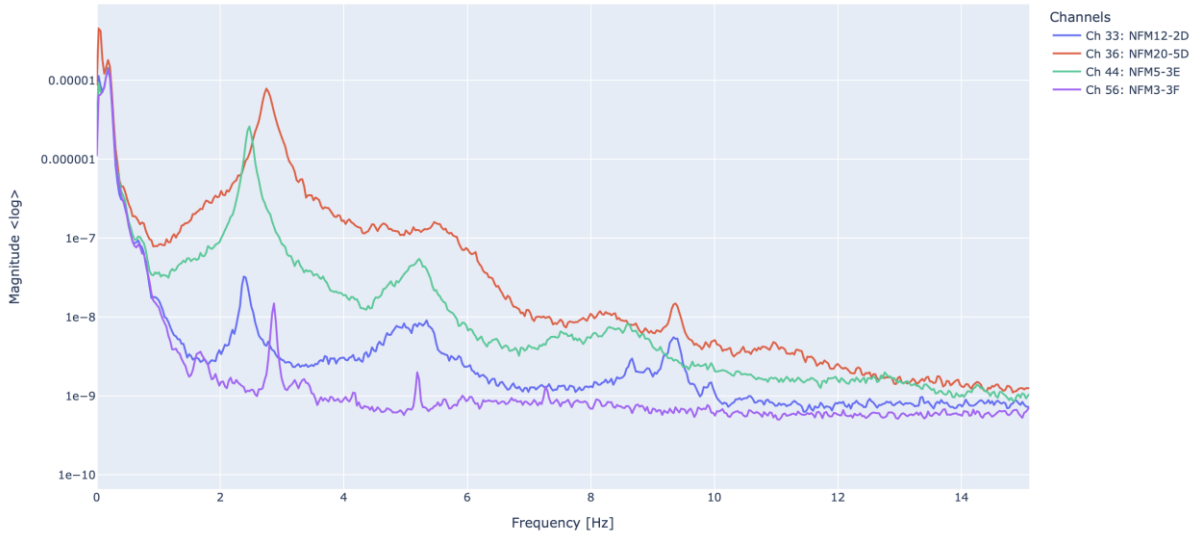


Examples of recent Canadian PHWR noise analysis applications and results

Time series data and Auto Power Spectral Densities (APSDs)

Application: Data Validation

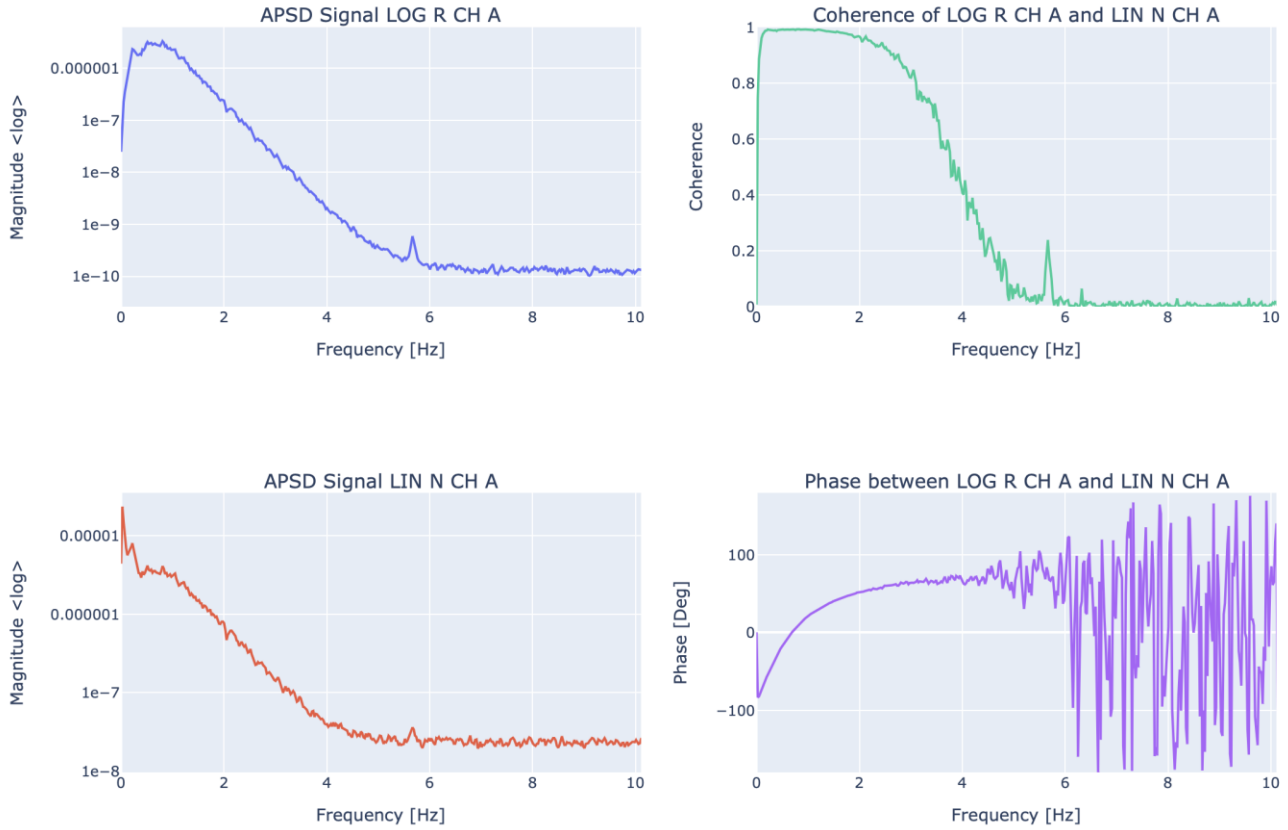




Time series data and APSDs of ICFDs from Channels D, E and F in BNGS-A Unit 4 (2022) (sampling rate – 500 Hz)

Coupling between Linear and Log Rate signals of an Ion Chamber

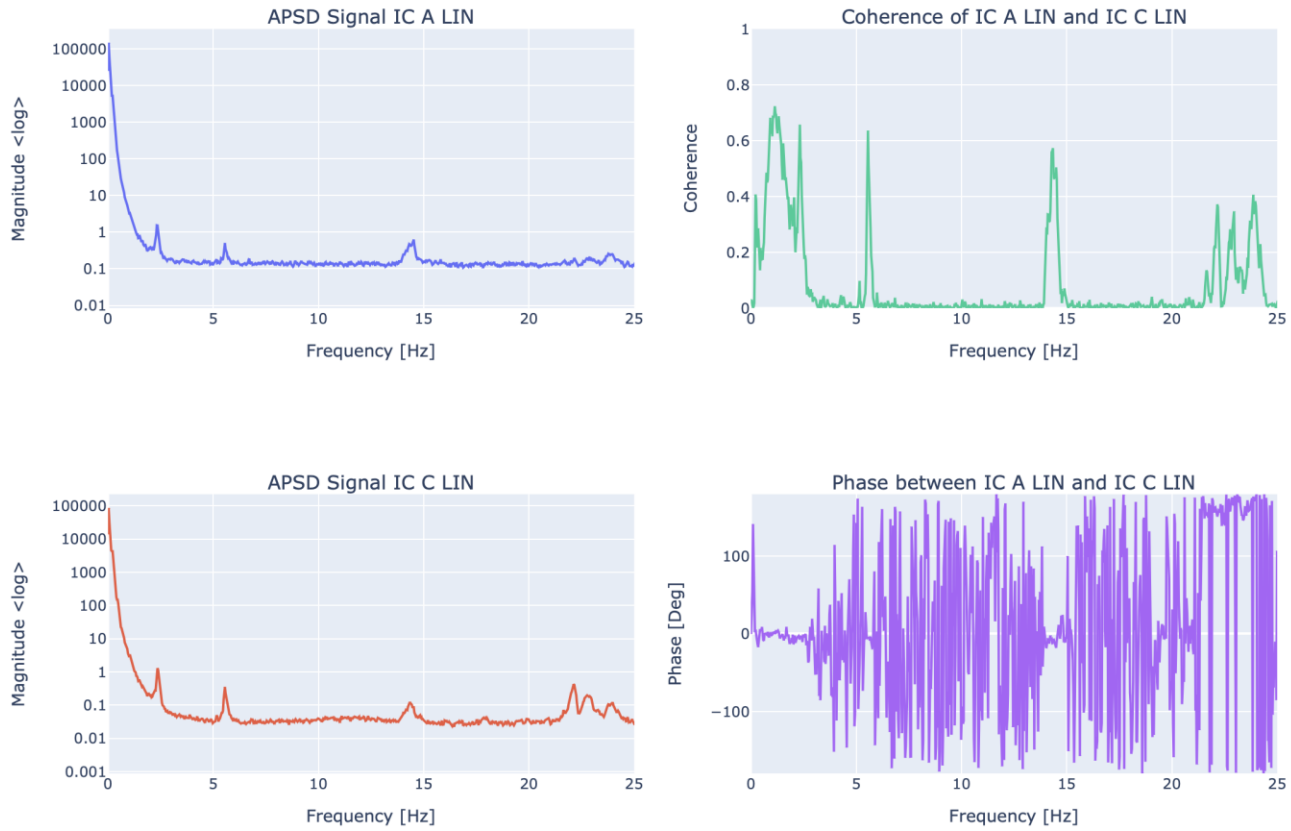
Application: Ion Chamber Signal Validation and Fault Detection



APSD, coherence and phase functions showing coupling between Linear and Log Rate Outputs of Channel A Ion Chamber in PLGS (2022)

Coupling between Linear signals from different Ion Chambers

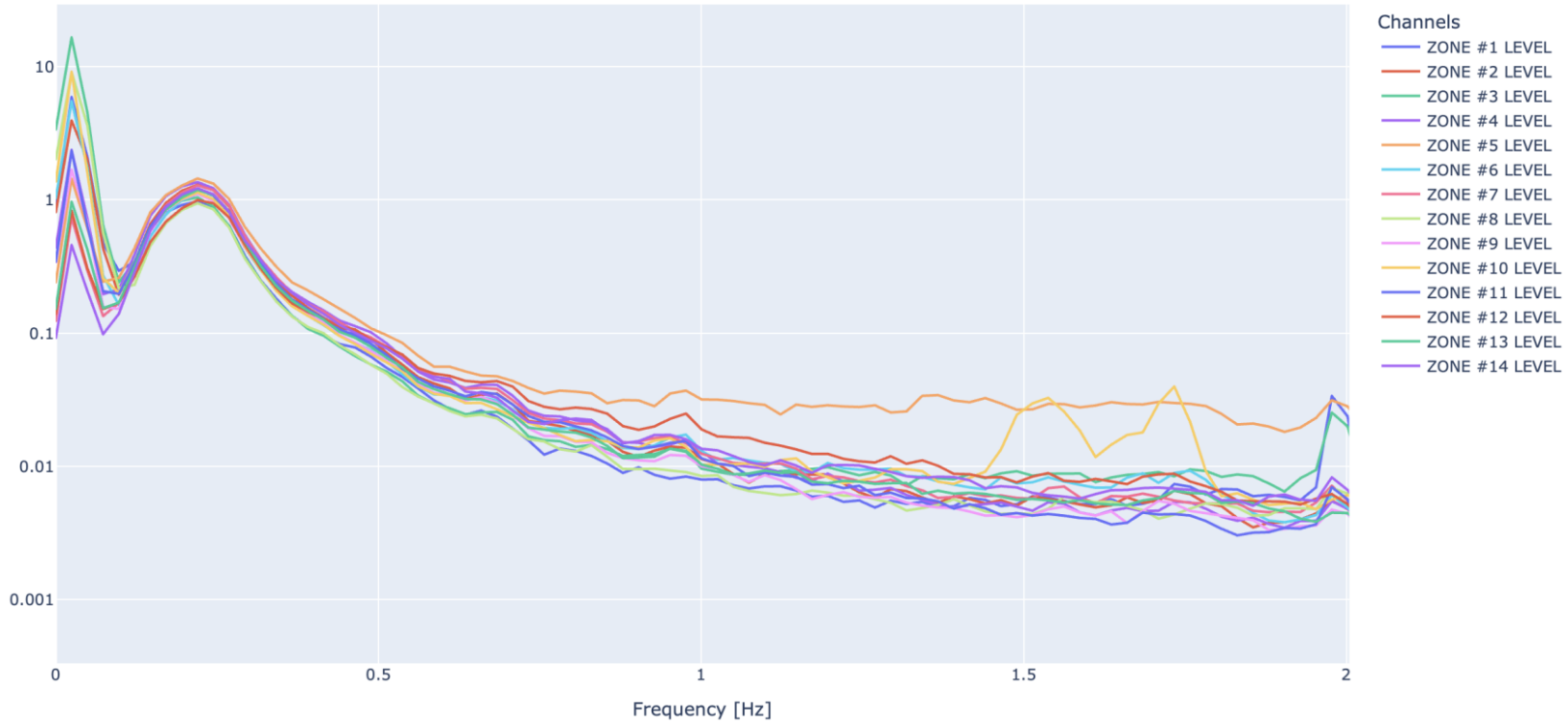
Applications: Ion Chamber Signal Validation and Fault Detection; Vibration Monitoring



APSD, coherence and phase functions showing coupling between Linear output signals of Ch A and Ch C Ion Chambers in DNGS Unit 4 (2021)

APSDs of Liquid Zone Control (LZC) levels

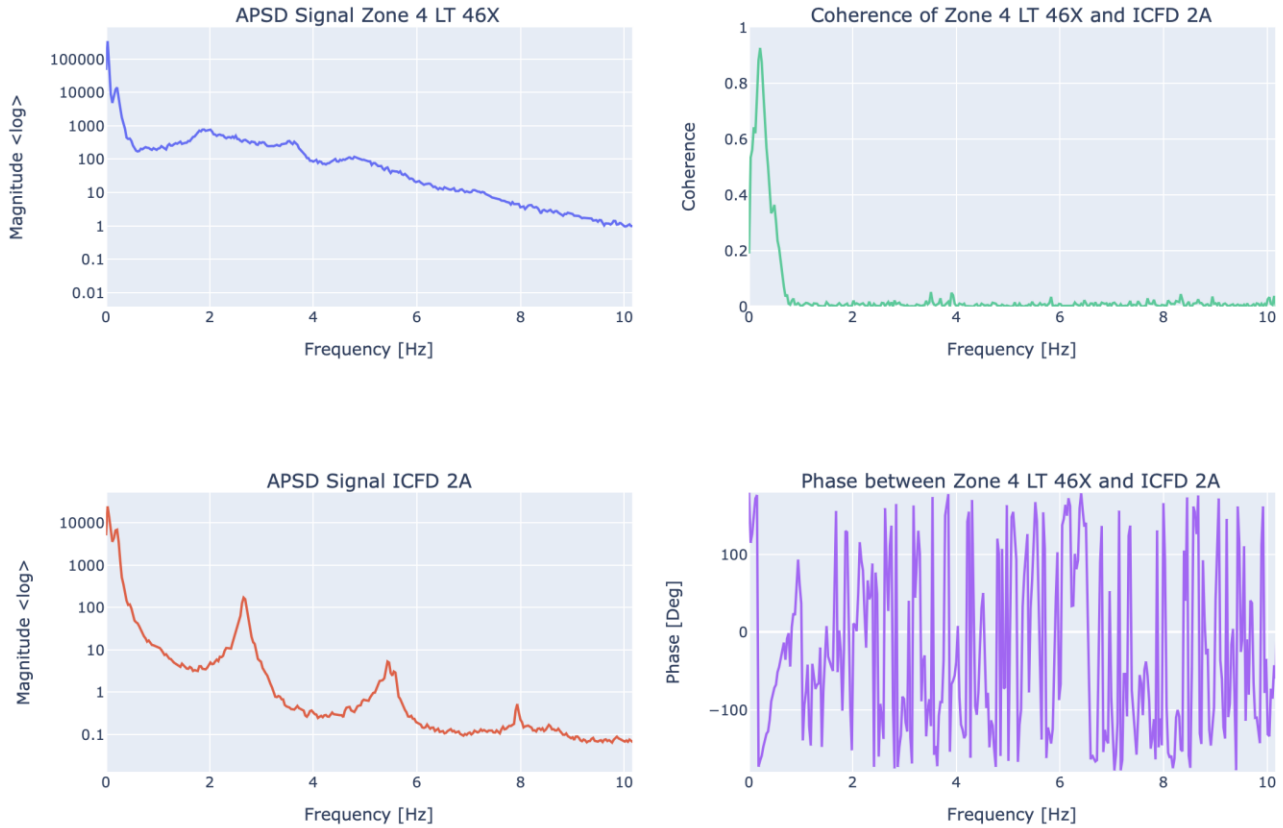
Applications: Reactor Regulating System Troubleshooting; ICFD prompt fraction



APSD functions of the 14 LZC level signals in PLGS (2022)

Coupling between Liquid Zone Control level and ICFD signals

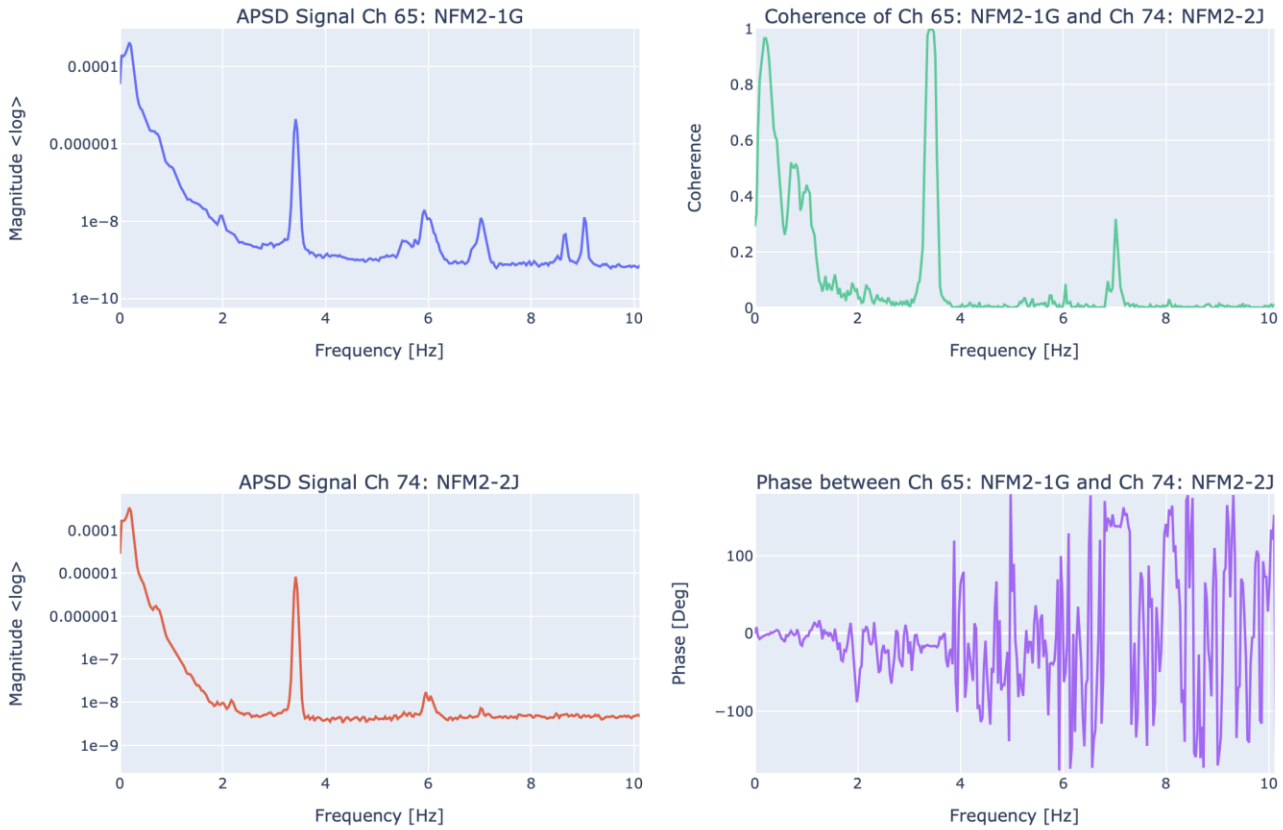
Applications: Reactor Regulating System Troubleshooting; ICFD prompt fraction



APSD, coherence and phase functions showing coupling between Zone 4 LZC level fluctuations and ICFD 2A in DNGS U4 (2021)

Coupling between ICFDs located in same horizontal assembly

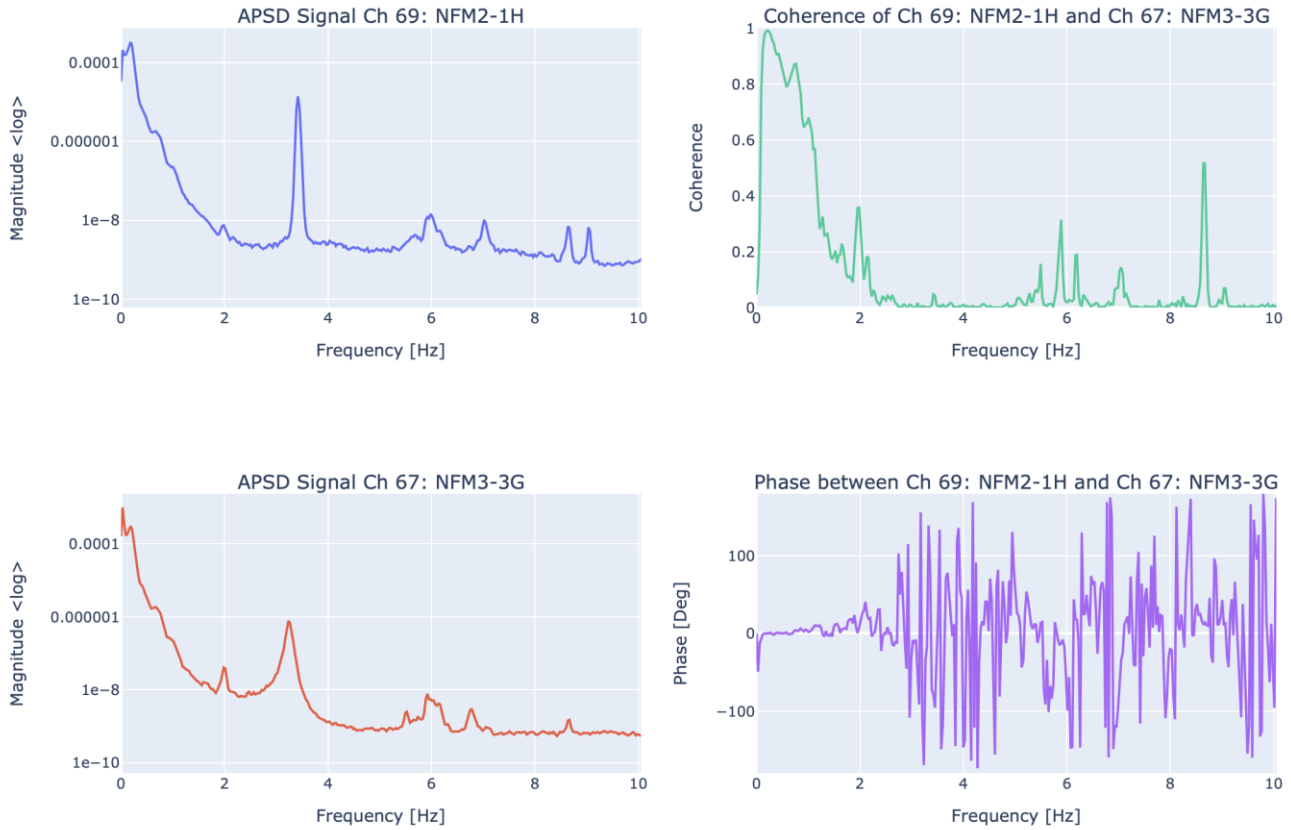
Applications: ICFD signal validation; vibration monitoring



APSDs, coherence and phase of ICFDs 1G and 2J co-located and separated by a large distance in horizontal assembly NFM2 of BNGS-A U4 (2022)

Coupling between axially separated ICFDs with common Fuel Channels

Applications: Fuel Channel on-line condition monitoring



Examples of fuel channel vibrations as sensed by SDS2 horizontal ICFDs located in different flux detector assemblies in BNGS-A U4 (2022)

Conclusions

- New noise analysis program CNL-SNA developed and geared towards automated analysis of large noise datasets.
- Reactor steady-state data from CANDU units, recorded opportunistically by DAQ systems configured for reactor trip tests, were found to be viable for noise analysis.
- Spectral features and cross-correlations behaviour of detector noise signals showed characteristic patterns which can be monitored to validate their correct functioning and to provide early warnings of faults and incipient failures of these safety-critical sensors.
- Global 0.2 Hz flux oscillation seen in all CANDU reactors very useful for
  - Validation of Liquid Zone Controller function
  - Tracking relative prompt fraction of in-core flux detectors
- Neutronics noise signals are sensitive to vibrations of reactor core components, especially flux detector assemblies and fuel channels (stay tuned for next presentation).
- **Renewed interest in noise analysis applications for Canadian PHWRs**

Thank You!