Signal validation and fault detection by reactor noise analysis in NPPs

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A new algorithm developed for automated noise-based validation of station signals

Reactor is complex enough to produce noise signals which are

- coupled/correlated to a certain extent, and
- exhibit permanent features in their coherence/phase functions at steady-state operation

Basis for validation: experience shows that frequency-domain coupling patterns of noise signals reflect the dynamic behaviour of

- the underlying physical processes,
- the interactions among system components, and
- measurement instrumentation,

therefore they can serve as the basis for signal validation / fault detection

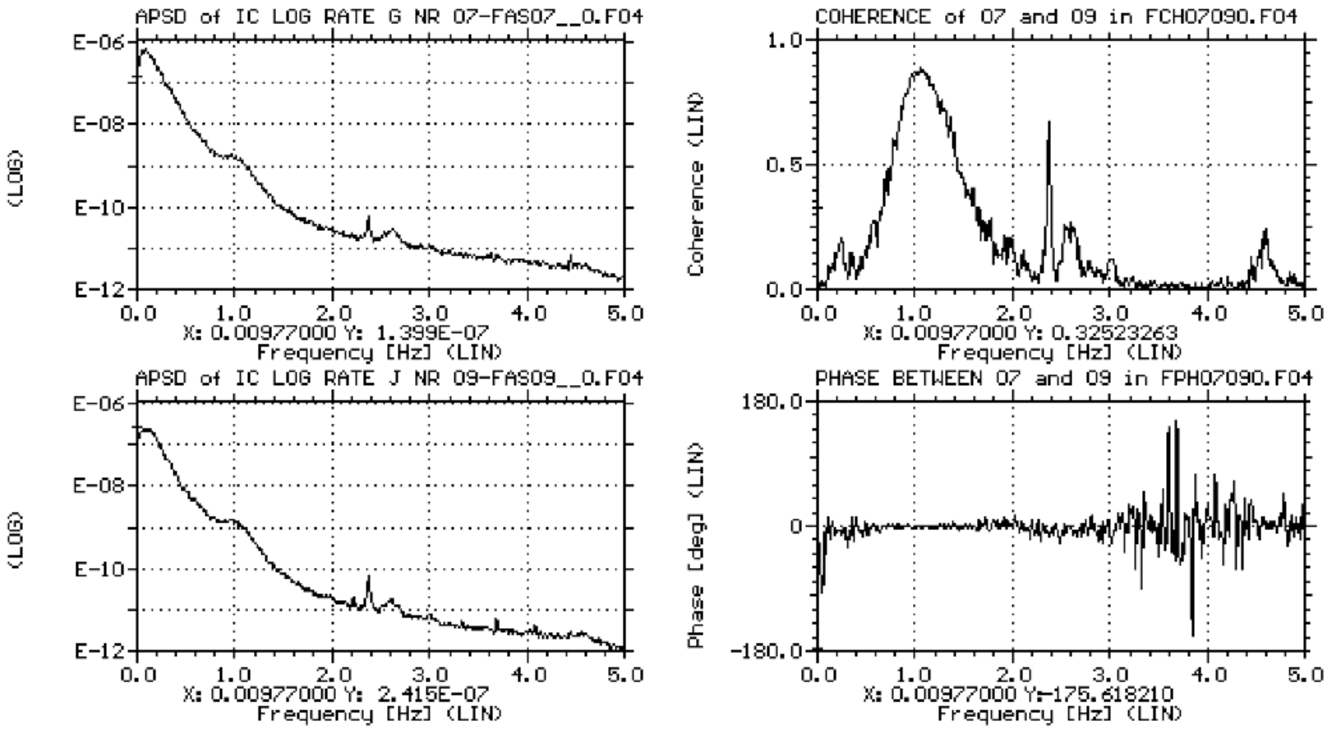
Definition: signal coupling noise signatures are the coherence and phase functions of all signal pairs in the group of selected signals of N

Notes:

- It needs simultaneous recording of all N number of signals in the group
- Output: N-variate coherence and phase functions (in an NxN matrix form)

Validation is performed through a systematic comparison of the coherence/phase functions of noise signals, in all possible pair-wise signal combinations, to established baseline patterns

Example of “signal coupling noise signatures”



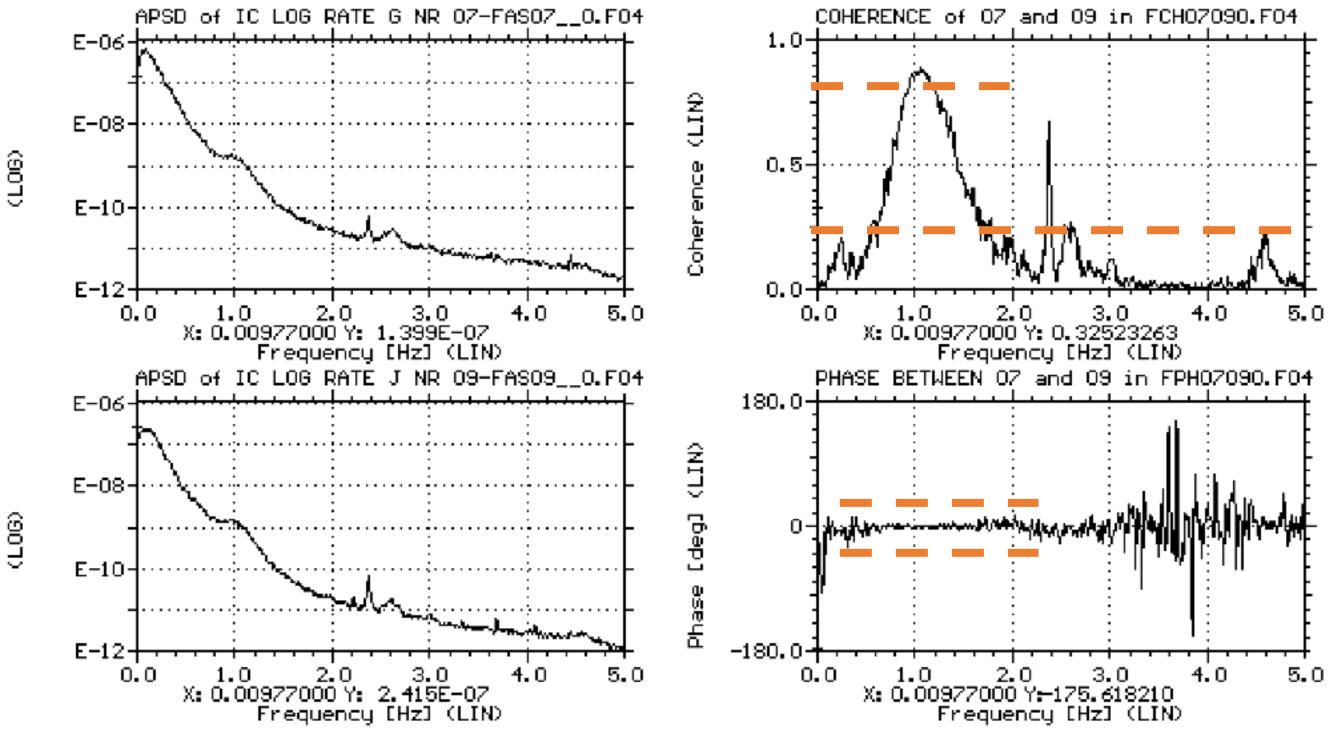
Normalized APSD, coherence and phase functions of log rate output noise signals of two ion chambers

Learning period:

1. to establish what can be considered as <u>normal couplings</u>, based on what was found in the majority of signals pairs, as typical coherence and phase functions – establishing a <u>normal baseline</u>

2. to envelope the coherence and phase functions with simple inequalities, that is, boxing them in, with <u>acceptance limit values</u> – establishing numerical <u>acceptance criteria</u>

Example of acceptance limits



Normalized APSD, coherence and phase functions of log rate output noise signals of two ion chambers

Example of noise-based validation of a signal set

Signal set to be validated

- 14 liquid level signals in the 14 zones of the reactor core
- 14 in-core neutron signals assigned to the 14 zones of the reactor core

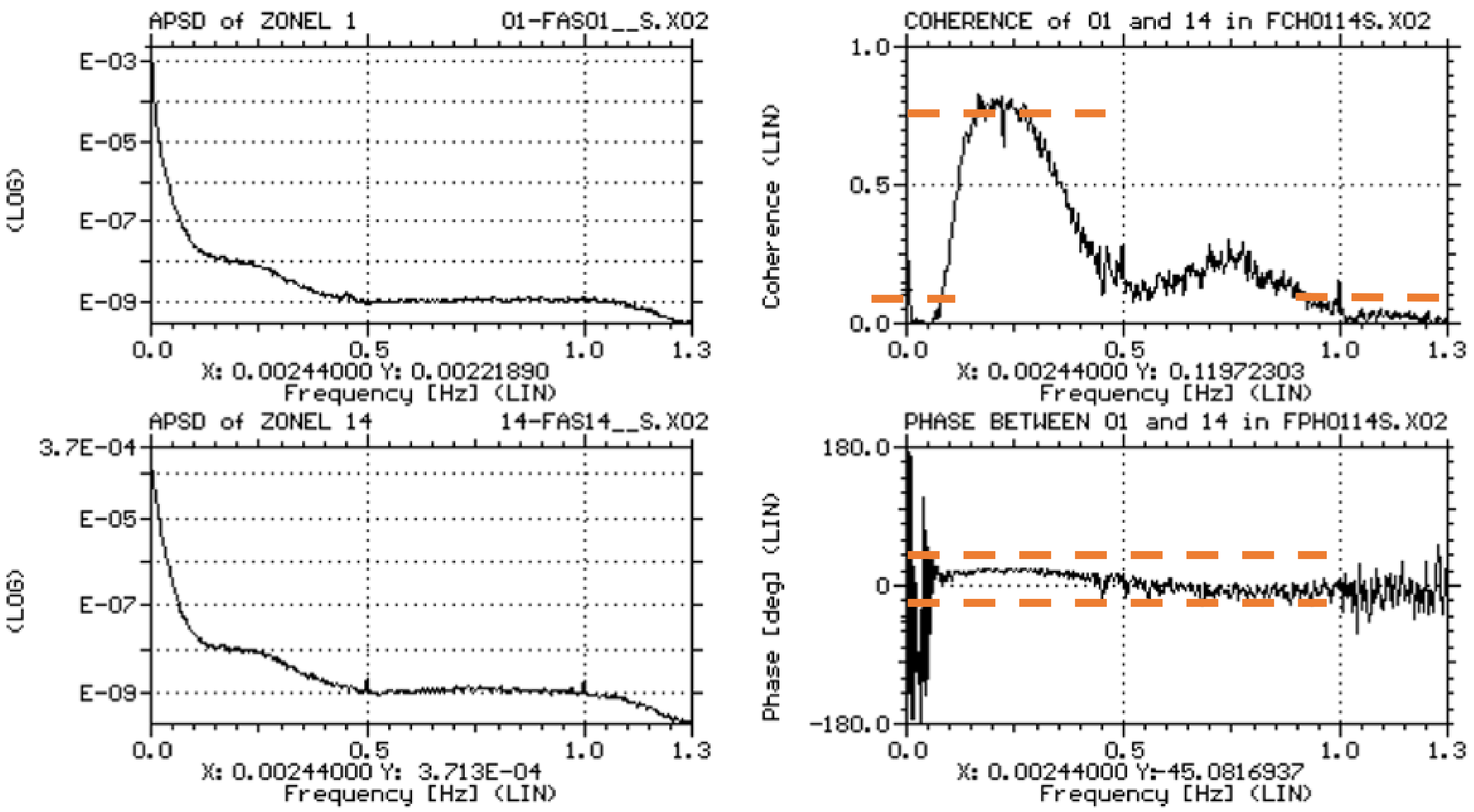
Assumption:

- Normal baseline of noise signatures have been established (91 signal pairs)
- Acceptance criteria have been established

Steps required in the application period:

- New measurement of the same 28 noise signals sampled simultaneously
- Coherence and phase functions are calculated for all signal pairs

Example of liquid level and liquid level coupling – normal baseline with acceptance limits

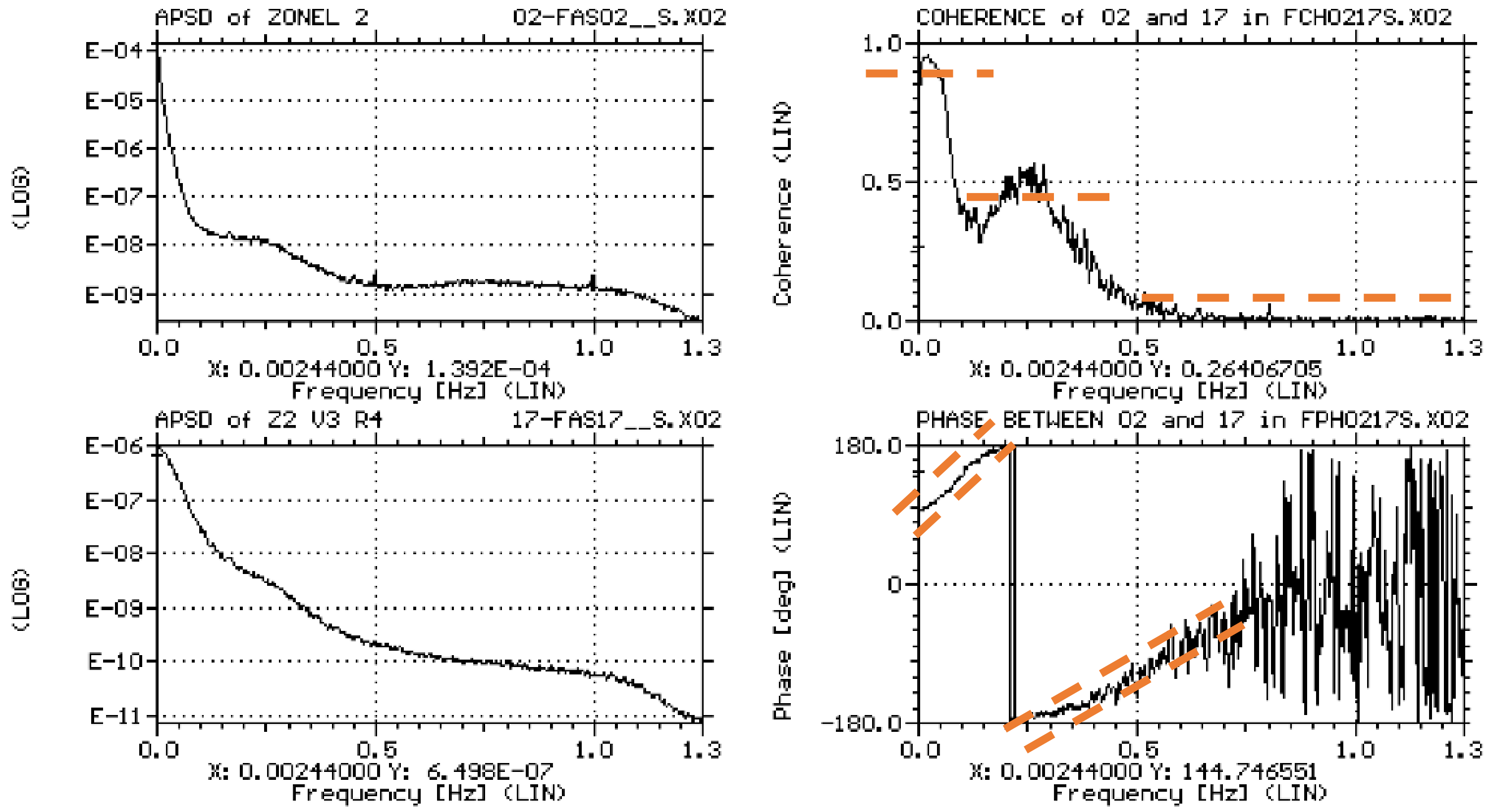


Normalized APSD, coherence and phase functions of two liquid zone control level signals

Acceptance Criteria and Penalty Parameters

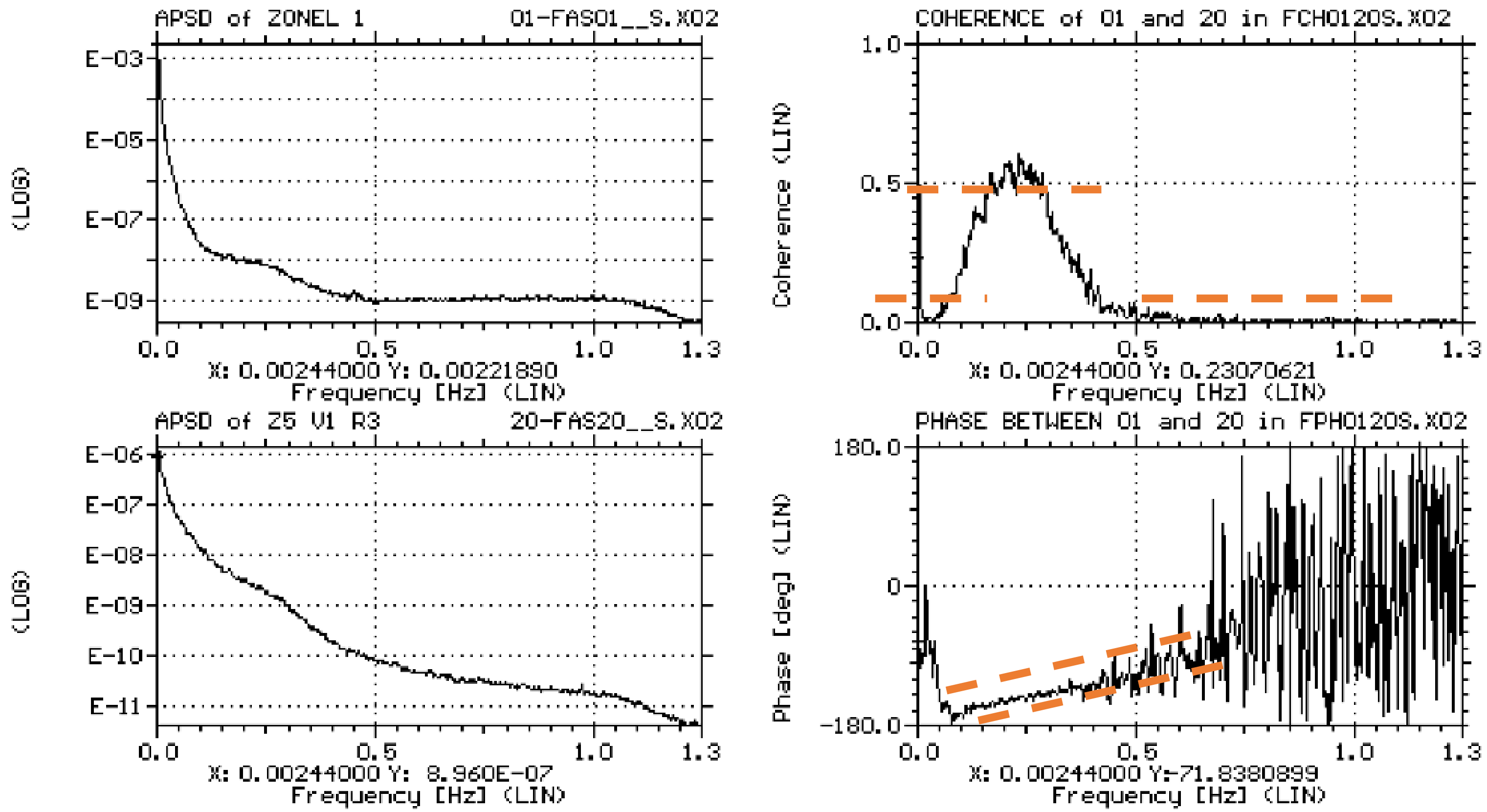
Acceptance Criteria	Penalty Parameter, P
COH > 0.75 over 0.2 Hz - 0.3 Hz	If COH ≤ 0.75, then P = (0.75 – COH) / 0.75
COH < 0.1 for f < 0.1 Hz	If max COH ≥ 0.1, then P = (max COH – 0.1) / 0.9
COH < 0.1 for f > 1.0 Hz	If max COH ≥ 0.1, then P = (max COH – 0.1) / 0.9
ABS(PHA) < 45 over 0.2 Hz - 0.3 Hz	If ABS(PHA) ≥ 45, then P = (ABS(PHA) – 45) / (180 – 45)

Example of liquid level – neutron flux coupling in the same zone



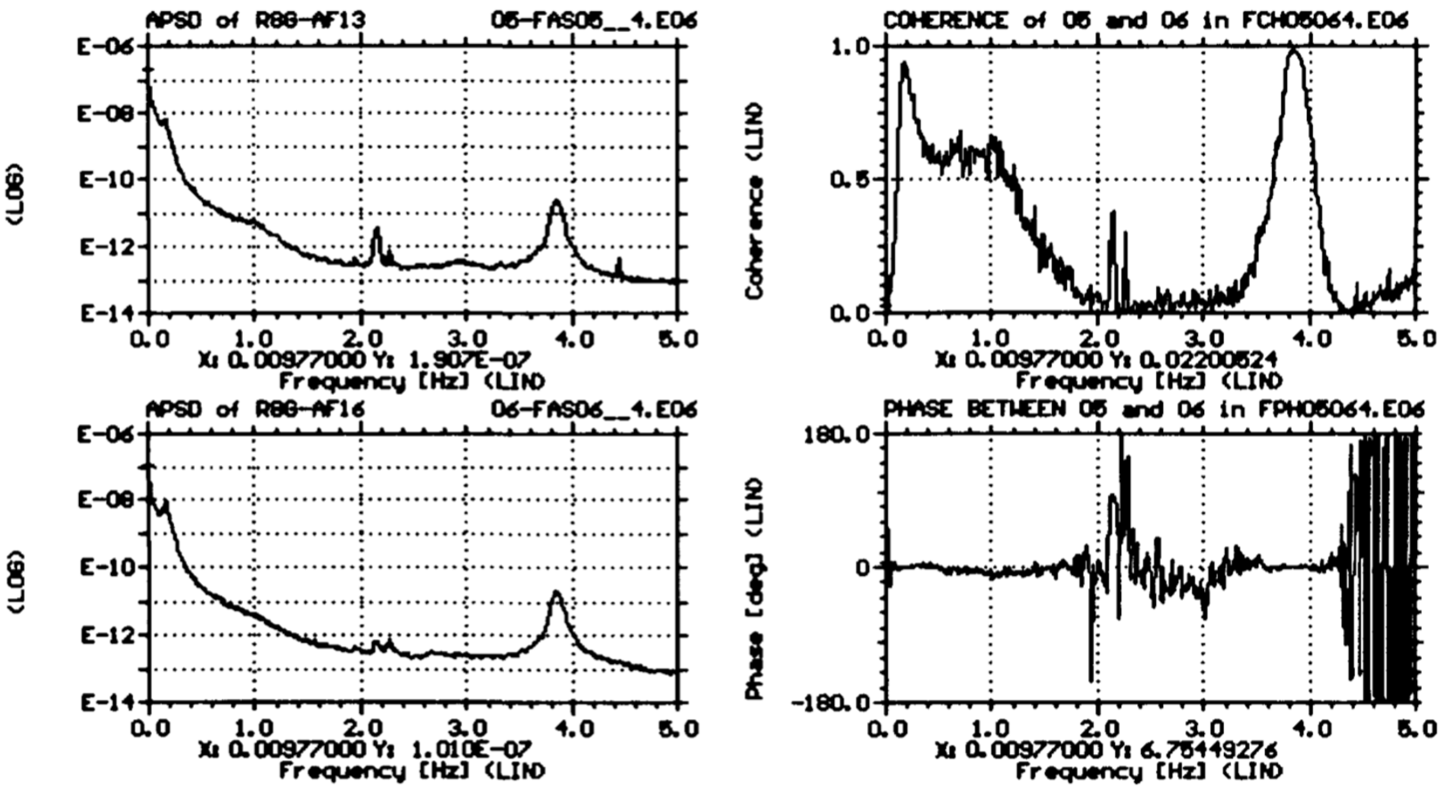
Normalized APSD, coherence and phase functions of liquid zone control level and neutron flux signals in the <u>same zone</u>

Example of liquid level – neutron flux coupling in different zones



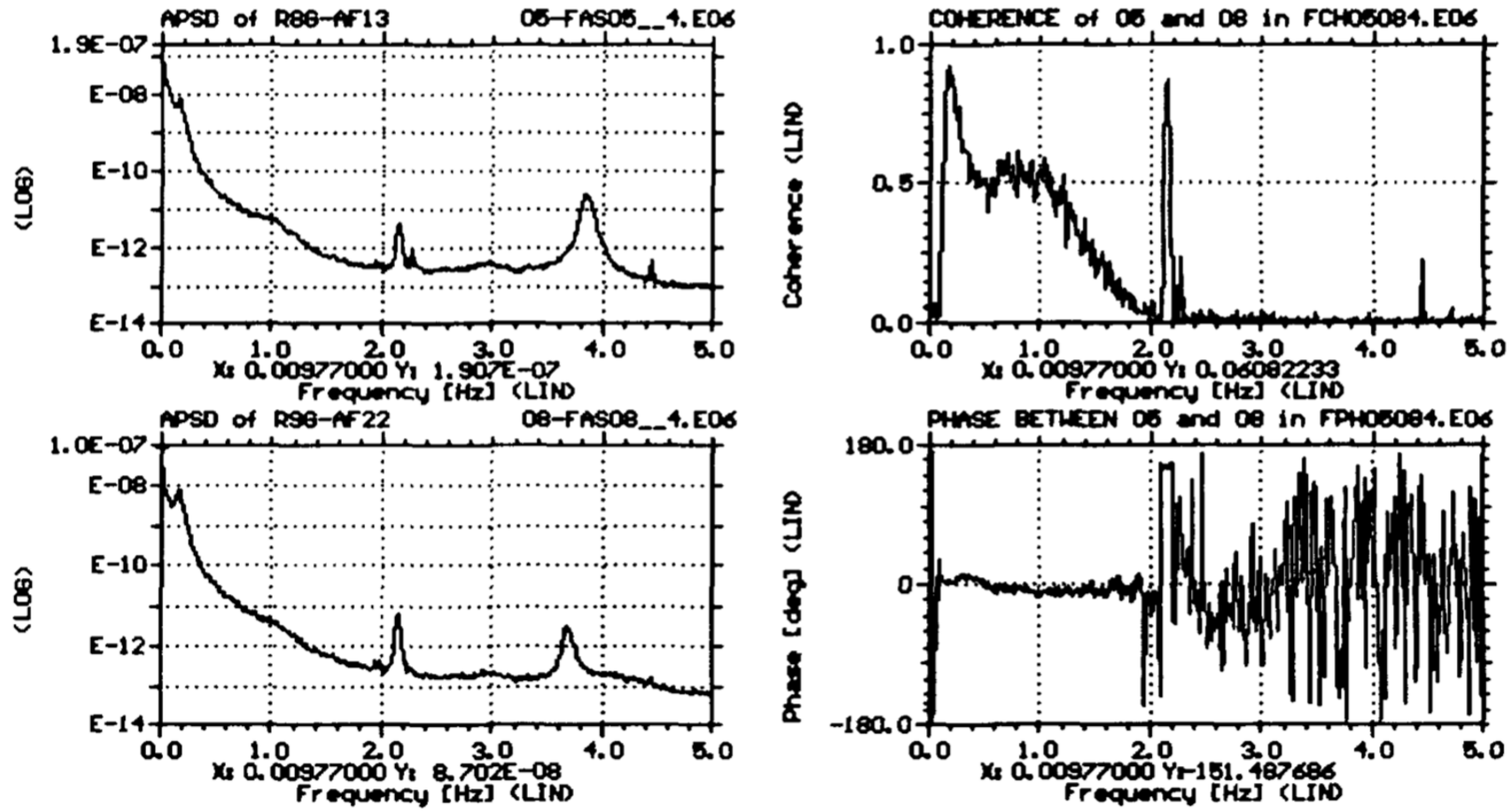
Normalized APSD, coherence and phase functions of liquid zone control level and neutron flux signals in different zones

Example of neutron flux – neutron flux coupling in different zones, but located in the same detector tubes (vibrating)



Normalized APSD, coherence and phase functions of two neutron flux signals in different zones

Example of neutron flux – neutron flux coupling in different zones, located in two different detector tubes (vibrating)



Normalized APSD, coherence and phase functions of two neutron flux signals in different zones

Application period:

1. Calculate coherence and phase functions of new measurements to be validated (same DAQ systems and operating conditions as before)
2. Check the new coherence and phase functions of all 91 signal pairs against acceptance criteria
3. If their coherence/phase functions violate any criteria, both signals are given an equal penalty number (proportional to deviation)
4. Performing the same comparison for all 91 signal pairs

Application period (continued):

5. At the end of the comparison loop, signals with maximum penalty parameters are declared as faulty and excluded from the signal set
6. The comparison loop is repeated with the remaining signals
7. Signals with maximum penalty values are declared as faulty and excluded from the signal set
8. Loop comparison continues until no violation is detected in the remaining signal set – signals declared validated

Important issues

- Noise data acquisition systems – standardized and run by procedures
  - Permanently installed noise DAQ systems (ideal for signal validation)
  - Portable noise DAQ systems (connecting/disconnecting station signals)
- Establishing baseline acceptance criteria in the learning period – done by experts, need to be updated periodically
- Signal processing in the application period – automated and standardized for the selected signal groups

Important issues

- No modelling of the systems producing the measured noise signals is needed – signal validation is formal, not a diagnostic application
- Validating signals in comparison loops – automated
- Flagged signals, and the systems producing them, need closer inspection
- Most of the time, signals meet the acceptance criteria and are validated
- Comparison based on noise-coupling can detect signal/system faults at their early stages

Thank you!

Questions?