Reactor Noise Analysis Benchmark Exercise in Connection with SMORN-III

J. Hirota and Y. Shinohara
Japan Atomic Energy Research Institute, Tokai Research Establishment

At the 23rd meeting of the NEACRP held in September 1980, it was recommended to add Phenix data to the real reactor noise data to be analyzed. We received the Phenix data tape from Dr. J. Gourdon (CEN-Cadarache) in January 1981. A draft specification of the Reactor Noise Analysis Benchmark Test was distributed to members of the International Organizing Committee asking comments by the end of February; the severest criticism was on the point that the exercise is a numerical test, not a physical one.

At the meeting of the International Organizing Committee held in April, further more comments were given by the members; it was strongly recommended to change the selection of the data to be analyzed for the Phenix data. The final specification revised taking these comments into consideration was sent off to applicants by the end of April. Prior to this distribution, the test data tape was already sent off to the applicants in the middle of April.

We have received fifteen results up to now from France, F.R. of Germany, Hungary, Netherlands, Sweden, U.S.A. and Japan. Considerable differences exist in magnitude and pattern of the functions among the results obtained by different applicants, which indicates the usefulness of the present numerical test as the 1st step of the benchmark exercise.

At SMORN-III, it is scheduled to hold the informal meeting restricted to the applicants on Tuesday, 27th October (20.00 - 22.00); the results will be reviewed by Prof. N. Suda prior to his presentation in Session 9 on Friday, 30th. It is expected that almost all applicants will attend this informal meeting discussing the results and a physical benchmark test in near future. It will be quite appropriate and worth-while to plan the 2nd benchmark exercise during SMORN-III.
Benchmarks Test for SMORN-III

A. General Information

A.1 Objective

The objective of this benchmark test is to make comparison among the results obtained for identical test data by different noise analysis methods and thereby to identify data processing problems to be solved before a reliable data base of processed reactor noise can be established. The test is therefore aimed at computational rather than physical benchmark.

The reason for limiting the test to the computational benchmark are: (1) only one session may probably be shared for the benchmark test discussion in SMORN-III; (2) much more time is necessary for preparing meaningful physical benchmark test problems and for the discussion, and (3) a computational benchmark test should precede a physical benchmark test which may be a topic of a future meeting.

The test data distributed to the applicant should be analysed, according to the task specification described in C, using the methods which the applicant considers to be most appropriate. The results will be compared for different methods and conditions of analysis, e.g. analog vs. digital; time domain vs. frequency domain; sampling interval; pre-processing modes, etc.

A.2 Test Data

Each applicant or group of applicants will receive an analog data tape (1 inch wide, 14 channels, 3600 feet long) in which are copied three types of noise data consisting of artificial noise from Japan, Borssele reactor noise from the Netherlands and Phenix reactor noise from France. Although the tape contains various data, only the data recorded in Channels 1 and 2 of the artificial and Borssele data, and Channels 1 and 5 of the Phenix data, will be used for the present test. As it is intended to make a computational benchmark test, the data have been chosen from the numerical but not from the reactor physics point of view.

The purpose of including data not used in the present test is to convey to the applicants some parts of the original source data which may be used in a future physical benchmark test if it is considered to be useful.

The original source data is described in detail in Appendix 1, but note that there are some differences between the actual ordering of the channels on the tapes distributed and the description in this document. For the Borssele data, channels 1 (IN 12) and 2 (LOG) on the tape are to be analysed and correspond to channels 9 and 10 respectively in Table 2.1 of Appendix 1. Only the second recording of the Phenix data has been included on the tapes and channels 1 (THM 2018) and 5 (Z1MARS) on the tapes are to be analysed, corresponding to track numbers 3 and 2 respectively in Table 3.2 of Appendix 1.
A.3 Schedule and Mailing Address

The source noise data for the tests and the reporting format will be sent to the applicants in April 1981. The applicants are requested to send their results to:

Dr. Jitsuya HIROTA  
Japan Atomic Energy Research Institute  
Tokai Research Establishment  
Tokai-mura, Naka-gun  
Ibaraki-ken 319-11  
JAPAN

to arrive in Japan by the end of August 1981 at the latest, in order to make it possible for a reporter to summarise the results at SMORN-III.

A.4 Review Paper

A review paper will be presented on the results of the benchmark test. The attendance to this presentation is not restricted to the contributors to the benchmark test, but is open to all the SMORN-III participants.

In this review, general comparisons of the analysed results are made and, if there is some remarkable difference, its possible origin will be discussed. As a rule, the contributor of any particular result will not be identified.

During SMORN-III, it is planned to have an informal meeting of the contributors to the benchmark test. The objective is to elaborate the comparisons and prepare a detailed report, apart from the SMORN-III proceedings, on the test results.
B. Description of the Data Tape

The data tape contains the following signals in the order as shown in Figure 1.

A: Checking signals at the beginning of data copying.
B: Artificial noise data with the original calibration signals.
C: Borssele reactor noise data with the original calibration signals.
D: Phenix reactor noise data with the original calibration signals.
E: Checking signals at the end of data copying.

The contents of each noise data are as follows: (See Appendix 1 for further information).

1. Artificial noise

Channel No. 1: neutron density
2: vessel pressure with additive noise
3: inlet water velocity
4: location of boiling boundary
5: heat flux per unit length
6: inlet water enthalpy
7: recirculation flow
8: void volume in core
9: noise source $f_2$
10: noise source $f_{10}$

2. Borssele reactor noise data

Channel No. 1: in-core detector signal (IN 12)
2: ex-core detector signal (LOG)
3: in-core (IN 15)
4: ex-core (LIN)
5: in-core (IN 14)
6: ex-core (D 62)
7: in-core (IN 13)
8: ex-core (D 72)
9: in-core (IN 16)
10: ex-core (D 82)
11: in-core (IN 11)
12: ex-core (D 52)
13: pressure (YAO1 P001)
14: pressure (YAO2 P001)

3. Phenix reactor noise data

Channel No. 1: subassembly outlet temperature (TATA 2018)
2: subassembly outlet temperature (TATA 2024)
3: ex-core ion chamber (ZIMR41)
4: subassembly outlet temperature (TATA 2119)
5: ex-core ion chamber (ZIMR51)
6: pump inlet temperature (P3MT25)
7: primary pump flowrate (P1MQ02)
8: secondary pump flowrate (S1MQ01)
9: IHX primary inlet temperature (P1MT01)
10: IHX secondary inlet temperature (S1MT01)

The recorded data can be reproduced in real-time when the tape is played back at 1-7/8 ips in Intermediate Band (IRIG band).
Fig. 1: Order of signal recording in the data tape
C. Tasks and Related Information

C.1 Tasks

The test data recorded in the magnetic tape consist of three sets of noise signals. They are the artificial noise synthesized using a hybrid computer and the real reactor noise from two operating power reactors, Borssele reactor (PWR) and Phenix (FBR). For each set of noise data, you are requested to analyze the noise data recorded in channels 1 and 2 of the artificial and Borssele data, and channels 1 and 5 of the Phenix data, and report the standard deviations and the following functions in graphical form:

1) Normalized Auto-Correlation Functions: $\overline{C}_{11}(T), \overline{C}_{22}(T)$
2) Normalized Cross-Correlation Function: $\overline{C}_{12}(T)$
3) Auto Power Spectral Density Functions: $P_{11}(f), P_{22}(f)$
4) Cross Power Spectral Density Function: $P_{12}(f)$
5) Coherence Function: $\text{Coh}_{12}^2(f)$

Note: for suffix 2 read suffix 5 in the case of the Phenix data

C.2 Definitions of the Functions

For random variables $x_i(t)$, i.e. the noise signals recorded in channel 1 ($i=1$ or 2), the functions in the tasks are defined as follows:

1) Normalized Auto-Correlation Function: $\overline{C}_{i1}(T)$

$$\overline{C}_{i1}(T) = \frac{C_{i1}(T)}{C_{i1}(0)}$$

where

$$C_{i1}(T) = \mathbb{E}[x_i(t)x_i(t+T)] - (\mathbb{E}[x_i(t)])^2$$

2) Normalized Cross-Correlation Function: $\overline{C}_{12}(T)$

$$\overline{C}_{12}(T) = \frac{C_{12}(T)}{\sqrt{C_{11}(0)C_{22}(0)}}$$

where

$$C_{12}(T) = \mathbb{E}[x_1(t)x_2(t+T)] - \mathbb{E}[x_1(t)]\mathbb{E}[x_2(t)]$$

3) Auto Power Spectral Density Function: $P_{i1}(f)$

$$P_{i1}(f) = \int C_{i1}(T)e^{-j2\pi f}dT$$

4) Cross Power Spectral Density Function: $P_{12}(f)$

$$|P_{12}(f)| = \sqrt{\text{Re}[P_{12}(f)]^2 + \text{Im}[P_{12}(f)]^2} : \text{magnitude}$$

$$\angle P_{12}(f) = \tan^{-1} \left\{ \frac{\text{Im}[P_{12}(f)]}{\text{Re}[P_{12}(f)]} \right\} : \text{phase}$$

$$-\pi \leq \angle P_{12}(f) \leq +\pi \quad \text{(in the sense of ATAN2 in FORTRAN)}$$

where

$$P_{12}(f) = \int C_{12}(T)e^{-j2\pi f}dT$$

5) Coherence Function: $\text{Coh}_{12}^2(f)$

$$\text{Coh}_{12}^2(f) = \frac{|P_{12}(f)|^2}{P_{11}(f)P_{22}(f)}$$
C.3 Format for graphical data presentation

1. Each graphical data should be presented in the format specified. Figure must be drawn in black ink with clear lines and sizeable letters. It is difficult to reproduce from "dye-line" prints or from prints with weak lines. Each figure must be labelled in the margin with at least the figure title and the author's name.

2. Power spectral density functions should be presented on a logarithmic scale of 6 (vertical) x 4 (horizontal) decades. The scale of one decade should be equal to 4 cm. Units should be Hz for the vertical axis and Hz for the horizontal axis. The frequency range should be from $5 \times 10^{-3}$ Hz to $5 \times 10$ Hz.

In addition, to facilitate the detailed comparison, power spectral density functions should be presented on another logarithmic scale of 4 (vertical) x 1 (horizontal) decade, with the frequency range from 0.2 to 2.0 Hz for the artificial noise, from 2.0 to 20 Hz for the Borssele noise, and from 0.1 to 1.0 Hz for the Phenix noise, respectively. In this case, 6 cm. should correspond to one decade for the vertical axis and 16 cm. to one decade for the horizontal axis.

3. The phase of the cross power spectral density function and the coherence function should be presented on linear scale for the vertical axes, while the horizontal axes should be the same as in the case of power spectral density functions. 10 cm. should correspond to (0 to 1) for the coherence and (-$\pi$ to +$\pi$ radian) for the phase, respectively.

4. Normalised correlation functions should be presented on linear scale both for vertical and horizontal axes. 10 cm. should correspond to (0 to 1) for the vertical and (0 to 10 sec) for the horizontal axis, respectively. If the correlation function does not decay sufficiently at the lag time of 10 sec., another graph should be added taking 10 cm. for 100 sec.

5. Location of the data points computer should be indicated in your graphs or in the form of a list.

Note: If the specified format size is not convenient for you, you may choose another graph size keeping the ratio of vertical to horizontal scales the same as that for the case above and not changing the graph size significantly.

C.4 Questionnaire

The applicants to the tests are requested to fill in the questionnaire in D. This information will be useful for making comparisons among the test results reported.
D. Questionnaire

Name: ____________________________________________

Organization: ______________________________________

Business Address: __________________________________

1. From where did you obtain the test data?
   (a) [ ] JAERI
   (b) [ ] NEA Data Bank
   (c) [ ] Others
   If your answer is (a), please write the identification number of the tape.

[__________________________________________]

If the answer is (c), please specify the source of the data and the means of acquisition.

[__________________________________________]

2. If the test data analyzed is in analog form, please write the model and its main specifications of the data recorder used for playing back the tape.

[__________________________________________]

3. If the source noise data analyzed is in analog form, please answer how you processed the data.
   (a) [ ] processed in analog form throughout the analysis.
   (b) [ ] processed in digital form except for analog-digital conversion of the source noise data at the outset of the analysis.
   (c) [ ] combination of analog and digital processings.
   If your answer is (b) or (c), please write the number of bits for quantization of the analog noise data.

[__________________________________________]
4. The system used for analyzing the data is
   (a) [ ] commercially available.
   (b) [ ] specially organized by yourself.
   If your answer is (a), please write the model of the analyzer.

5. Please draw the block diagram of your data analyzing system.
6. Does your analysis include pre-processing of the source noise data?
   (a) [ ] Yes
   (b) [ ] No
   If your answer is "Yes", please specify the type of pre-processing.

7. What type of method did you use for analyzing the data?
   (a) [ ] Blackman-Tukey method
   (b) [ ] Fast or Direct Fourier Transform method
   (c) [ ] Auto-regressive (moving average) model fitting
   (d) [ ] Maximum entropy method
   (e) [ ] Others

   Please state the specific feature of your algorithm, the order of the AR model, the criterion for determination of the order of the model, etc.

8. Please write your analyzing conditions in the form of the table attached with this questionnaire. If the space is not enough, please use separate sheets for additional information.

   Directions for filling the table.
   (a) Since the frequency resolution depends upon the analyzing method, please specify the definition of the frequency resolution which you used.
   (b) If the data analyzed is in analog form, the data length used for an analysis should be expressed by the time spent for retrieving the analog data required for an analysis at the playing back speed of 1-7/8 ips.
   (c) Please write in columns (7) and (8) only identification numbers of your description of the filter (F) and window (W) such as F1, F2, F3, or W1, W2, W3, etc., and it is requested to use separate sheets for describing full information concerning filters and windows such as transfer functions of filters, correlation functions of windows or graphical presentations of their characteristics.
9. Numerical data obtained by the analysis.
   1) Standard deviation of the noise recorded in Channel 1
       Artificial noise:
       Borssele noise :
       Phenix noise :
   2) Standard deviation of the noise recorded in Channel 2
       Artificial noise:
       Borssele noise :
       Phenix noise :

10. Error evaluation (optional).
    Please comment on the error evaluation of your results, and super-impose the error-bar on your graphical data if possible.

11. Please write other findings if any.

12. Please write your comments and suggestions concerning the benchmark test.
The name of the variable:

<table>
<thead>
<tr>
<th>(1) Frequency range [Hz]</th>
<th>(2) Sampling rate [1/sec]</th>
<th>(3) Number of averaging</th>
<th>(4) Data length used for an analysis [sec]</th>
<th>(5) Total length of analyzed data [sec]</th>
<th>(6) Frequency resolution [Hz]</th>
<th>(7) Type of filter analog or digital</th>
<th>(8) Type of window</th>
<th>(9) Play back speed of the tape [ips]</th>
<th>(10) Maximum correlation lag [sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>analog digital</td>
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<td></td>
<td></td>
<td></td>
<td>analog digital</td>
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<td>analog digital</td>
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<td>analog digital</td>
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<td>analog digital</td>
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<td>analog digital</td>
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<td></td>
<td></td>
<td></td>
<td>analog digital</td>
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</tr>
</tbody>
</table>

Total frequency range analyzed is from \( \text{Hz} \) to \( \text{Hz} \).
APPENDIX 1

Description of the recorded noise data

1. Artificial Noise data

A simplified boiling water reactor model of JPDR-II was built on a hybrid computer. Independent artificial noise signals from noise generators are fed to the model at a few points. Fig.1.1 shows the block diagram of the linearized model of JPDR-II, and the transfer functions with arbitrary parameters are listed in Table 1.1.

Noise signals recorded are adjusted so that they have the same order of standard deviations, and coherence functions approach to unity at higher frequency due to the model without detection noise.

The recorded noise signals of the selected system variables are as follows:

Channel 1 : $x_1$ Neutron Density
2 : $x_2$ Vessel Pressure
3 : $x_3$ Void Volume in Core
4 : $x_4$ Heat Flux per Unit Length
5 : $x_5$ Inlet Water Velocity
6 : $x_6$ Location of Boiling Boundary
7 : $x_7$ Inlet Water Enthalpy
8 : $x_8$ Recirculation Flow
9 : Noise Source $f$
10 : Noise source $f^2$
Fig. 1.1 Block diagram of the linearized model of JPDR-II for the artificial synthesized noise.
Table 1.1 Transfer Functions

<table>
<thead>
<tr>
<th>$G_{fb}(s)$</th>
<th>$k_{fb}[1 + T_{fb}^s]^{-3}$</th>
<th>$G_{p1}(s)$</th>
<th>$k_{p1}[1 + T_{p1}^s]^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G_{f}(s)$</td>
<td>$k_{f1}[1 + T_{f1}^s]^{-1}$ + $k_{f2}[1 + T_{f2}^s]^{-1}$</td>
<td>$G_{p2}(s)$</td>
<td>$k_{p2}[1 + T_{p2}^s]^{-1}$</td>
</tr>
<tr>
<td>$G_{e}(s)$</td>
<td>$k_{r1}s^{-1} + k_{r2}[1 + T_{r2}^s]^{-1}$</td>
<td>$G_{p3}(s)$</td>
<td>$k_{p3}[1 + T_{p3}^s]^{-1}$</td>
</tr>
<tr>
<td>$G_{k1}$</td>
<td>constant</td>
<td>$G_{p4}(s)$</td>
<td>$k_{p4}[1 + T_{p4}^s]^{-1}$</td>
</tr>
<tr>
<td>$G_{k2}$</td>
<td>constant</td>
<td>$G_{b1}(s)$</td>
<td>$k_{b1}[1 + T_{b1}^s]^{-1}$</td>
</tr>
<tr>
<td>$G_{v1}(s)$</td>
<td>$k_{v1}[1 + T_{v1}^s]^{-1}$</td>
<td>$G_{b2}(s)$</td>
<td>constant</td>
</tr>
<tr>
<td>$G_{v2}(s)$</td>
<td>$k_{v2}[a_{v2} + b_{v2}(1 + T_{v2}^s)^{-1}]$</td>
<td>$G_{b3}(s)$</td>
<td>$k_{b3}\exp(-\tau_d^s)$</td>
</tr>
<tr>
<td>$G_{v3}(s)$</td>
<td>$k_{v3}[1 + T_{v3}^s]^{-1}$</td>
<td>$G_{b4}(s)$</td>
<td>$k_{b4}[1 + T_{b4}^s]^{-1}$</td>
</tr>
<tr>
<td>$G_{v4}(s)$</td>
<td>$k_{v4}[1 + T_{v4}^s]^{-1}$</td>
<td>$G_{e1}(s)$</td>
<td>$k_{e1}G_{e2}(s) + k_{e1}^s$</td>
</tr>
<tr>
<td>$G_{w1}(s)$</td>
<td>$k_{w1}[a_{w1} + b_{w2}^s]$</td>
<td>$G_{e2}(s)$</td>
<td>$k_{e2}[(1 + \lambda_1^s)^{-1} - (1 + \lambda_2^s)^{-1}]$</td>
</tr>
<tr>
<td>$G_{w2}(s)$</td>
<td>constant</td>
<td>$G_{e3}(s)$</td>
<td>$k_{e3}G_{e2}(s)$</td>
</tr>
<tr>
<td>$G_{w3}(s)$</td>
<td>$k_{w3}[1 + T_{w3}^s]^{-1}$</td>
<td>$G_{e4}(s)$</td>
<td>$k_{e4}G_{e2}(s)$</td>
</tr>
</tbody>
</table>
2. **Borssele Reactor Noise data** (Original tape from Dr. E. Türkcan)

**Reactor:**
The reactor of the 450 MW reactor station at Borssele is a PWR with two primary coolant loops, built by KNK.

**Experiment:**
Date 13-3-1979
Identified as B6/2 E126
$P_{th} = 1360$ MW
$P_e = 447$ MW
Boron concentration = 750 ppm.

**Detectors:**
Ion-chambers model KNU-42 (Excore)
Incore neutron detectors - Cobalt self-powered neutron detectors (20 cm sensitive length).

**Electronics:** See fig. 2.2.

**Tape recorder:** Ampex type PR 2200. FM, 1" tape.

**Data recording:** $3^{3/4}$ ips (dc to 1.25 kHz, $S/N = -41$ db). Intermediate band. Harmonic distortion 1.5%, 1 volt rms. level.

**Content of the data tape:**

<table>
<thead>
<tr>
<th>Footage counter (feet)</th>
<th>Signal contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 - 34</td>
<td>- 2000 mV dc</td>
</tr>
<tr>
<td>35 - 63</td>
<td>+ 500 mV dc</td>
</tr>
<tr>
<td>65 - 93</td>
<td>+ 2000 mV dc</td>
</tr>
<tr>
<td>95 - 123</td>
<td>+ 3500 mV dc</td>
</tr>
<tr>
<td>125 - 223</td>
<td>White Noise (about 210 mV rms)</td>
</tr>
<tr>
<td>225 - 274</td>
<td>Sinus 20 Hz (19.9 Hz about $4\nu_{ef}$)</td>
</tr>
<tr>
<td>275 - 3419</td>
<td>Borssele Reactor Noise Data $\equiv$ E126</td>
</tr>
<tr>
<td>3419 - 3440</td>
<td>(see following table)</td>
</tr>
<tr>
<td></td>
<td>Zero Input</td>
</tr>
</tbody>
</table>
Table 2.1

Borssele Reactor Noise Data

Data Recording: 3 3/4 ips. footage counter (ft): 275 to 3419 ft.

<table>
<thead>
<tr>
<th>CHANNEL</th>
<th>DETECTOR Ident.</th>
<th>MEAN (dc in V)</th>
<th>GAIN of Noise Amp.</th>
<th>rms (in V) (0.01 to 32 Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. In Core</td>
<td>IN 16</td>
<td>3.56</td>
<td>20</td>
<td>0.25</td>
</tr>
<tr>
<td>2. Ex Core</td>
<td>D 82</td>
<td>1.59</td>
<td>200</td>
<td>0.48</td>
</tr>
<tr>
<td>3. In Core</td>
<td>IN 15</td>
<td>5.01</td>
<td>50</td>
<td>0.29</td>
</tr>
<tr>
<td>4. Ex Core</td>
<td>LIN</td>
<td>0.79</td>
<td>200</td>
<td>0.27</td>
</tr>
<tr>
<td>5. In Core</td>
<td>IN 14</td>
<td>5.15</td>
<td>50</td>
<td>0.30</td>
</tr>
<tr>
<td>6. Ex Core</td>
<td>D 62</td>
<td>1.53</td>
<td>200</td>
<td>0.49</td>
</tr>
<tr>
<td>7. In Core</td>
<td>IN 13</td>
<td>5.24</td>
<td>50</td>
<td>0.39</td>
</tr>
<tr>
<td>8. Ex Core</td>
<td>D 72</td>
<td>1.59</td>
<td>200</td>
<td>0.53</td>
</tr>
<tr>
<td>9. In Core</td>
<td>IN 12</td>
<td>4.75</td>
<td>50</td>
<td>0.38</td>
</tr>
<tr>
<td>10. Ex Core</td>
<td>LOG</td>
<td>0.87</td>
<td>200</td>
<td>0.37</td>
</tr>
<tr>
<td>11. In Core</td>
<td>IN 11</td>
<td>3.16</td>
<td>100</td>
<td>0.49</td>
</tr>
<tr>
<td>12. Ex Core</td>
<td>D 52</td>
<td>1.52</td>
<td>200</td>
<td>0.61</td>
</tr>
<tr>
<td>13. Pressure</td>
<td>YA01 P001</td>
<td>0.54</td>
<td>20</td>
<td>0.38</td>
</tr>
<tr>
<td>14. Pressure</td>
<td>YA02 P001</td>
<td>0.55</td>
<td>50</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Primary system pressure signals range: 130-150 kgf/cm² (50 kgf/cm² = 1 volt).

Normalization of data during the analysis:

A. results in Volt or Volt²/Hz:

scale A = \( \frac{\text{range of ADC in Volt}}{2^x} \times \frac{1}{\text{Gain of Amplifier}} \)

\( x = \) number of bits of ADC.

B. Normalized data:

scale B = scale A \( \times \frac{1}{\text{mean (in Volts)}} \)

(e.g. for neutron detector signals)

C. Normalization to physical units:

scale C = scale A \( \times \) Range (in physical units)

(e.g. for pressure signals).

Note: Due to the additional filter at in-core neutron detector circuit (Krohn-Hite) one will find:

- at 9.2 Hz (reactivity effect) phases:
  - phase between all ex-core n-detectors = 0°
  - phase between all in-core n-detectors = 0°, but phase between in-core/ex-core = -55°.
Fig. 2.1.

WATER IN

IN-CORE NEUTRON DETECTORS

EX-CORE NEUTRON DETECTORS

(470MWₐ - PWR)
BORSSELE EXPERIMENT: Block diagram of the instrumentation

Incore n-det.

Excore n-det.

Pressure det.

Borssele instr. $f_c > 100 \text{ Hz}$

Noise amplifiers
- high pass: 0.01 Hz
  -12 dB/oct
- low pass: 40 Hz
  -24 dB/oct

Krohn-Hite
- 40 Hz
-48 dB/oct.

Filter
- 40 Hz
-36 dB/oct

FM-AMPEX
- PR 2200
- 3 3/4 IPS
1. Recording Mode (for all the tracks):

- Frequency modulation "FM"
- Standard ING- "IB"
- Output level for nominal modulation: 1.414 volt

1.2. Recording and reproducing speeds: magnetic tape recorder

- The tape is the recopy of two distinct recordings
- Specifications, for the tape utilisation, are given in the following table 3.1.
- The figure 3.1 describes the recopy process.
### Table 3.1.1

<table>
<thead>
<tr>
<th></th>
<th>Recover</th>
<th>Operation</th>
<th>Laboratory time</th>
<th>Signals bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Repro.</td>
<td>Record</td>
<td>Real time</td>
<td>in real time</td>
</tr>
<tr>
<td>speed</td>
<td>Speed</td>
<td>Speed</td>
<td>(VRP2=labo. Speed)</td>
<td>time domain</td>
</tr>
<tr>
<td>&quot;VRCl&quot; IPS</td>
<td>&quot;VRPI&quot; IPS</td>
<td>&quot;VRCl2&quot; IPS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>first recording</td>
<td>7 1/2</td>
<td>60</td>
<td>30</td>
<td>$V_{RP2} \times \frac{4}{15}$</td>
</tr>
<tr>
<td>(AMPEX 1300)</td>
<td>(Bell Howel 4020)</td>
<td>(Bell Howel 4020)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>second recording</td>
<td>15 / 16</td>
<td>60</td>
<td>15</td>
<td>$V_{RP2} \times \frac{64}{15}$</td>
</tr>
<tr>
<td>(Bell Howel 4020)</td>
<td>(Bell Howel 4020)</td>
<td>(Bell Howel 4020)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**1.3 - Tape description (see para. 1.2)**

**Tape length (in feet)**

| 36 | 360 | 1760 | 1800 | 1836 | 2520 | 360 |

**track №1**

<table>
<thead>
<tr>
<th>Test</th>
<th>Noise signals on tracks</th>
<th>Test</th>
<th>Noise signals on track</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>1 to 10</td>
<td>S</td>
<td>1 to 10</td>
</tr>
<tr>
<td>g</td>
<td>- 4 neutron channels</td>
<td>g</td>
<td>- 2 neutron channels</td>
</tr>
<tr>
<td>n</td>
<td>- 6 control rod accemeters</td>
<td>n</td>
<td>- 6 temperatues</td>
</tr>
<tr>
<td>a</td>
<td></td>
<td>a</td>
<td>- 2 flow meters</td>
</tr>
</tbody>
</table>

**Description of the test signals**

- Sine wave
  - 1 volt cc
  - 30 Hz in real time

**Fig. 3.2**
1.4 - Definition of the parameters used and symbols

Five parameters are given for the recording exploitation:

1. total electronic gain \( G \)
2. cut off (low pass) frequency of the isolated amplifier \( f_2 \)
3. high pass frequency \( f_1 \) or the indication of a DC compensation
4. sensitivity of the detector in "volt [Physical units]^{-1} \( \alpha \)
5. the mean value in "physical units" \( \overline{X} \) or in "volt" \( \overline{V_{X}} \)

(\( \overline{V} \) is given before amplification)
2 - DETECTORS DESCRIPTION AND SYMBOLS

2.1 - General view

Phenix Instrumentation location: the definition of the code number "T" is given in the table 3.2.1. Only some devices are represented:

- 1 between 3 primary pumps
- 1 " 3 secondary pumps
- 1 " 6 control rods
- 1 " 3 intermediate heat exchangers

Fig.3.4: Schematic view of PHENIX
<table>
<thead>
<tr>
<th>x Number</th>
<th>Physical definition</th>
<th>Used symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ion chambers &quot;out of core&quot; and &quot;under the vessel&quot;</td>
<td>Z1 MR 41, Z1 MR 51</td>
</tr>
<tr>
<td>2</td>
<td>ion chambers &quot;in core&quot;</td>
<td>Z1 MR 12, Z2 MR 12</td>
</tr>
<tr>
<td>3</td>
<td>accelerometers located near the top of the control rod mechanisms</td>
<td>to BCMG 01, BCMG 06</td>
</tr>
<tr>
<td>4</td>
<td>outlet temperature of a subassembly</td>
<td>TATA code number of the subassembly</td>
</tr>
<tr>
<td>5</td>
<td>pump inlet temperature = core inlet temperature</td>
<td>P3 MT 25</td>
</tr>
<tr>
<td>6</td>
<td>Intermediate heat exchanger: primary inlet temperature</td>
<td>P1 MT 01</td>
</tr>
<tr>
<td>7</td>
<td>Intermediate heat exchanger and secondary loop: secondary inlet temperature</td>
<td>S1 MT 01</td>
</tr>
<tr>
<td>8</td>
<td>Primary pump flow meter (electromagnetic)</td>
<td>P1 MQ 02</td>
</tr>
<tr>
<td>9</td>
<td>Secondary pump flow meter (electromagnetic)</td>
<td>S1 MQ 01</td>
</tr>
</tbody>
</table>

![Bloc scheme representation](image-url)

**Fig. 3.5**: Bloc scheme representation
2.2 - Some Detectors characteristics

a/ - Temperature

Sensitivity of the chromel/alumel thermocouples:

4.2·10⁻⁶ volt.°C⁻¹

Core outlet temperature position: see figure 3.4.

b/ - Neutron detectors

Four ion chambers can be used for noise measurements.

The following table or figures give the basic characteristics of these detectors.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Technical code</th>
<th>basic characteristics</th>
<th>sensitivity Ax[nCM⁻²sec⁻¹]⁻¹</th>
<th>PHENIX Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z1MR41</td>
<td>CCS</td>
<td>γ compensated ion chamber (Bore)</td>
<td>1.7·10⁻¹⁴</td>
<td>under the vessel</td>
</tr>
<tr>
<td>Z1MR51</td>
<td>CCS</td>
<td></td>
<td></td>
<td>see Figure 3.6</td>
</tr>
<tr>
<td>Z1MR12</td>
<td>CFUCO2</td>
<td>High temperature Fission chamber (gas cooled)</td>
<td>2·10⁻¹³</td>
<td>In core: see Figure 3.7</td>
</tr>
<tr>
<td>Z2MR12</td>
<td>CFUCO2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In all the cases a linear current electronic device is used.
### Table 3.1 - First recording:

30 feet to 1700 feet

(See tables 3.1.1 and 3.2.1)

<table>
<thead>
<tr>
<th>Track Number</th>
<th>Symbol</th>
<th>G</th>
<th>( f_2 ) [Hz]</th>
<th>( f_1 ) [Hz] or DC</th>
<th>( \nabla ) [Physical units]</th>
<th>( \nabla ) [Volt]</th>
<th>( \alpha ) [Volt/(m sec)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ZIMR41</td>
<td>20</td>
<td>1000</td>
<td>( 10^{-2} )</td>
<td></td>
<td>9.07</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>ZIMR51</td>
<td>5</td>
<td>1000</td>
<td>( 10^{-2} )</td>
<td></td>
<td>9.11</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>ZIMR12</td>
<td>10</td>
<td>1000</td>
<td>( 10^{-2} )</td>
<td></td>
<td>9.46</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Z2MR12</td>
<td>20</td>
<td>1000</td>
<td>( 10^{-2} )</td>
<td></td>
<td>5.36</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>BCMGO1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>1 volt/(m sec)</td>
</tr>
<tr>
<td>6</td>
<td>BCMGO2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>BCMGO3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>BCMGO4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>BCMGO5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>BCMGO6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
Table 3.2 - Second recording:
1800 feet to 2520 feet
(See Tables 3.1.1 and 3.2.1)

<table>
<thead>
<tr>
<th>Track Number</th>
<th>Symbol</th>
<th>G</th>
<th>( f_2 ) (Hz)</th>
<th>( f_1 ) (Hz) or DC</th>
<th>( \bar{x} ) Physical units</th>
<th>( V ) Volt</th>
<th>( \alpha ) [Volt/Physical unit]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ZIMR41</td>
<td>20</td>
<td>1000</td>
<td>10(^{-6})</td>
<td></td>
<td>8.96</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>ZIMR51</td>
<td>5</td>
<td>1000</td>
<td>10(^{-6})</td>
<td></td>
<td>9.10</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>TATA2018</td>
<td>5000</td>
<td>100</td>
<td>DC</td>
<td>517°C</td>
<td>42.10(^{-6}) ( V \cdot \circ )C (^{-1})</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>TATA2119</td>
<td>5000</td>
<td>100</td>
<td>DC</td>
<td>614°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>TATA2024</td>
<td>5000</td>
<td>10</td>
<td>DC</td>
<td>592°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>P3MT25</td>
<td>10000</td>
<td>10</td>
<td>DC</td>
<td>397°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>PIMQ02</td>
<td>1000</td>
<td>10000</td>
<td>DC</td>
<td></td>
<td>- 9.10(^{-3})</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>S1MQ01</td>
<td>1000</td>
<td>10000</td>
<td>DC</td>
<td></td>
<td>+ 9.10(^{-3})</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>P1MT01</td>
<td>10000</td>
<td>10</td>
<td>DC</td>
<td>568°C</td>
<td>42.10(^{-6}) ( V \cdot \circ )C (^{-1})</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>S1MT01</td>
<td>20000</td>
<td>10</td>
<td>DC</td>
<td>348°C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.3 - PHENIX operating parameters during these recordings

Date : 1980, October

Thermal Power : 588 MW

Electrical Power : 258 MW

Core temperature rise : 168 °C (mean value)

Rotation speeds of the :
- 3 primary pumps : 820 r/minute
- 3 secondary pumps : 800 r/minute
Fig. 3.6
For nominal power level:

1. Operating position of the "Z1MR12" Channel

2. "Z2MR12"

Fig. 3.7
For all the tracks: \[ -1 = 0.5 \text{ volt} \]

"\#" events 1 or 2: due to control rod adjustment (burn-up compensation)
List of Applicants
for
The Reactor Noise Analysis Benchmark Test

March 31, 1981
| Australia | R.W. Harris | Australian Atomic Energy Commission  
Research Establishment  
PMB Sutherland  
N.S.W. 2232 |
|----------|------------|---------------------------------------------------------------|
| France | P. Bernard | Commissariat à l'Energie Atomic Centre  
d'Etudes Nucléaires de Cadarache  
B.P. No.1  
13115 Saint Paul Lez Durance |
| F.R. of Germany | H. Massier  
M. Edelmann  
W. Vath  
F. Mitzel  
D. Wach | Kernforschungszentrum  
Postfach 3640  
07500 Karlsruhe  
Gessellschaft für Reaktorsicherheit mbH  
Forschungsgelände  
8046 Garching |
| Hungary | J. Valko | Hungarian Academy of Sciences  
Central Research Institute for Physics  
Reactor Physics Department  
1525 Budapest 114, P.O.B. 49 |
| Italy | N. Pacilio  
V. Tosi | C.N.E.N.  
C.S.N. Casaccia  
C.P. 2400 Rome |
| Japan | Y. Fujita  
H. Ozaki  
Y. Kuroda | Mitsubishi Atomic Power Industries  
Nihonjisho Bludg. No.2  
1-2-1 Taito, Taito-ku, Tokyo  
Tukai University  
Faculty of Eng., Depart. of Nuclear Eng.  
2-28 Tomigaya, Shibuya-ku, Tokyo |
| | K. Saito  
H. Konno  
H. Fujita | University of Tsukuba  
Sakura-mura, Nihiari-gun  
Ibaraki-ken |
| | T. Tsunoda  
J. Wakabayashi | Nippon Atomic Industry Group Co., Ltd.  
4-1 Ukimishima-cho, Kawasaki  
Kanagawa-ken  
Kyoto University  
Institute of Atomic Energy  
Gokasho, Uji  
Kyoto-fu |
<table>
<thead>
<tr>
<th>Country</th>
<th>Name</th>
<th>Institution and Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Netherlands</td>
<td>E.B.J. Kleiss</td>
<td>Interuniversity Reactor Institute, Mekelweg 15, 2629 JB Delft</td>
</tr>
<tr>
<td></td>
<td>E. Türkcan</td>
<td>Netherlands Energy Research Foundation, ECN, P.O. Box 1, 1755 ZG Petten</td>
</tr>
<tr>
<td></td>
<td>J.H.C.v.d. Veer</td>
<td>N.V. KEMA, P.O. Box 9035, 6800 ET Arnhem</td>
</tr>
<tr>
<td>Poland</td>
<td>A.T. Mikulski</td>
<td>Institute of Nuclear Research, Department of Reactor Physics, 05-400 - Otwock-Swierk</td>
</tr>
<tr>
<td>Sweden</td>
<td>F. Akerhielm</td>
<td>Studsvik Energiteknik AB, S-611 82 Nyköping</td>
</tr>
<tr>
<td>U.K.</td>
<td>E.J. Burton</td>
<td>Risley Nuclear Power Development Laboratories, Engineering Acoustic Department, Risley, Warrington, Cheshire, WA3 6AT</td>
</tr>
<tr>
<td>U.S.A.</td>
<td>R.C. Kryter</td>
<td>Oak Ridge National Laboratory, Instrumentation &amp; Control Div., Bldg. 3500, P.O. Box X, Oak Ridge, TN 37830</td>
</tr>
<tr>
<td></td>
<td>S.M. Wu</td>
<td>University of Wisconsin-Madison, Depart. of Mechanical Eng., 1513 University Avenue, Madison, Wisconsin 53706</td>
</tr>
</tbody>
</table>