INTEGRAL NUCLEONIC MEASUREMENT SYSTEM
OBSEOLESCENCE-FREE

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ABSTRACT

Presentation of an ex-core & in-core integral nucleonic measurement chain system covering all neutron flux and gamma flux measurement requirements in Nuclear Power Plant cores.

The mentioned integral system is a line of electronic chains aimed at receiving signals from standard and wide-range (Campbellian mode) fission counters, compensated and non-compensated ionization chambers, gamma chambers, and Self-Powered Neutron Detectors (SPND).

This is an evolutionary design from the early 1970s, when necessary changes were made to eliminate dependency on critical components of early obsolescence probability. The entire system is based on the BIN/NIM standard, while the careful selection of highly-reliable electronic parts with guaranteed second and third source manufacturers, as well as the use of high-quality printed circuit boards, ensures a product line of high stability over time.

The latest design incorporates a measurement parameter digital transmission module through a field bus communications driver, which allows sending data to safety-related systems without need of a point-to-point connection. Efforts are presently focused on the qualification of this communications module so that it may be used in Safety Applications.

1 INTRODUCTION

We present the integral nucleonic measurement system covering the entire range of needs arising from the measurement of Power Reactor core nuclear parameters.

For the last ten years, and to a growing extent, the obsolescence of the critical parts of the designs in force has been posing a threat worthy of consideration. Furthermore, when modernizing the instrumentation, new parts must be selected with the utmost care, as there is also a risk of early obsolescence of critical parts. In this case, obsolescence may be attributed to other causes beyond strictly technical reasons, such as the consumption of the product not meeting the commercial expectations of the manufacturer and, thus, ending up being prematurely discontinued.

The hierarchical structure of a system follows the simplified general diagram below:

![Figure 1: System hierarchical structure](image)
Within this hierarchical structure, and in the specific case of “in-house” designs, the critical elements are the parts, as these are generally subject to third suppliers on which no control is possible as to availability, validity, and possible obsolescence of the supplies.

Today, a careful design must thus place special emphasis on a quite elaborate selection of products that ensure the long-term continuity of the system on the basis of the guarantee of availability of its constituent parts.

The way this process of careful selection of parts is carried out during the design stage is part of this presentation.

The system presented sprang during the early 1970s, with an original design based on discrete technology with quite low degree of integration. These are systems basically conceived to measure neutron flux and/or ionizing radiation as critical indicator of the behaviour of a reactor core. The results of these measurements are used both as main parameters of the plant’s safety systems - RPS (Reactor Protection System), or PAM (Post-Accident Monitoring) -, as well as in plant control systems - SCS (Supervision and Control System).

## 2 RELIABILITY AND SYSTEM DESIGN REQUIREMENTS

The design requirements of the integral nucleonic measurement system are summarized in the list below:

From a safety standpoint:
1. Reliability
2. Single failure criterion
3. Fail Safe
4. Fault Tolerant
5. Control over Common-Cause Failures
6. Qualification for use in nuclear installations, particularly in reactors
7. High Quality
8. Robustness

From a performance standpoint:
9. Accuracy
10. Precision
11. Availability
12. High response speed
13. Long life cycle
14. Short and long term stability
15. Capability to communicate with other plant systems for the transmission of parameters measured and processed by the system

Different techniques are applied to achieve these design premises, such as the following:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Applied technique</th>
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<tbody>
<tr>
<td>Reliability</td>
<td>Selection of high quality components</td>
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<td></td>
<td>Derating methodology</td>
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<td></td>
<td>Redundant systems</td>
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<td></td>
<td>Well-proven technology</td>
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<td></td>
<td>Design control</td>
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<td></td>
<td>Self-diagnosis capacity</td>
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<td></td>
<td>Quite low failure to demand or high MTTF equivalent</td>
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<td></td>
<td>Failure self-warning</td>
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<tr>
<td>Qualification</td>
<td>Qualification program based on standards such as IEEE Class 1E, etc.</td>
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<tr>
<td>Availability</td>
<td>Redundant systems with 2 out of 3, or 2 out of 4 decision logic</td>
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<td></td>
<td>Minimum Mean Time to Repair</td>
</tr>
<tr>
<td>Requirement</td>
<td>Applied Technique</td>
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<td>------------------------------</td>
<td>-------------------------------------------------------------</td>
</tr>
<tr>
<td>Single failure criterion</td>
<td>Redundant systems</td>
</tr>
<tr>
<td>Fault Tolerant</td>
<td>Prevention of failure propagation with protective designs</td>
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<td></td>
<td>Incorporation of redundancies within critical stages</td>
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<tr>
<td>Robustness</td>
<td>Derating methodology</td>
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<td></td>
<td>Use of solid and resistant mechanical structures</td>
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<tr>
<td>High Quality</td>
<td>Well-proven technology</td>
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<td></td>
<td>QA plan</td>
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<td></td>
<td>V&amp;V plan</td>
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<tr>
<td>Long life cycle</td>
<td>Careful selection of components available from several suppliers</td>
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<td></td>
<td>Stockpiling</td>
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<tr>
<td>High performance</td>
<td>Demanding requirements</td>
</tr>
</tbody>
</table>

The design of this system evolved and was adapted to new requirements arising from the coming of new technologies that improved performance, allowed the possibility of miniaturizing, and, finally, yielded global improvement as to quality and reliability. Large Scale of Integration (LSI) technologies were used more and more, the latest designs incorporating ASIC and FPGA technology.

In many cases, the obsolescence of parts resulted in the restatement and modernization of designs to solve the problem of element unavailability.

In the selection of the new replacement components, special care was taken to choose those with second and third suppliers of top quality level. In the case of critical design components, we resorted to stockpiling so as not to be affected by the comings and goings of the market, to ensure maintenance, and to project new measuring chain productions. This measuring system is thus presented as Obsolescence-Free.

The designs in turn incorporated new features to be adapted to the changes offered and required by the new technologies, such as the following:

- Remote configuration capacity
- Online self-diagnosis method
- Communications interface ensuring electric and functional independence
  - discrete, point to point,
  - through a digital communications channel, through the use of field buses

Special care was always taken to observe the compatibility of the components backwards so as to ensure the maintenance of the systems already installed.
3  SYSTEM LIFE CYCLE

The system is conceived, implemented, and maintained through the application of a design plan of the following characteristics:

![Figure 2: System Life Cycle](image)

The life cycle of the system, divided into their different stages or phases, is carefully conducted, while the necessary design modifications are duly supervised through standard methods.

All activities are organized within the System Life Cycle with the implementation of a program that includes the following plans:

- Project Management Plan
- Design/Development Plan
- Verification & Validation Plan
- Configuration Management Plan
- Quality Assurance Plan

4  NUCLEAR SAFETY QUALIFICATION

The qualification plan ensures the safe application of the system in nuclear installations. This plan is based on the IEEE qualification standard for the Nuclear Engineering area.

The qualification plan is adjusted to the type of system from a safety standpoint, following IAEA’s classification:
Hence, the qualification plans include the following activities and application of standards in accordance with the system class:

- **Safety Systems:**
  - IEEE 1E applicable standards (IEEE 323 and 344)
  - FMEA (IEEE 352)
  - EMC/EMI-type tests / Compliance Certification

- **Safety-Related Systems:**
  - Type Test or Conformance Certificates
  - EMC/EMI Compliance Certification
  - Seismic and Vibration Compliance Certification

The integral nucleonic measurement system is specifically classified as Safety System and it is qualified as Class 1E component, following the methodology recommended by the standard IEEE 323.

5 **NUCLEONIC MEASUREMENT SYSTEM**

The following is the full measurement chain line presented:

- Source or Start-up channel (FC)
- Intermediate channel (IC)
- Power channel (IC or CIC)
- Wide Range log channel and (WRFC)
  - Wide Linear auto-range channel (mainly used for automatic reactor power control)
- Gamma measurement channel (may be used as global reactor power corrector through the $^{16}\text{N}$ measuring method) ($\gamma$C)
- SPND channel, (mainly used for in-core instrumentation) (SPND)

These chains generally respond to the same configuration, with special features given by the characteristics of the sensor and the measuring principle.

The following is the basic general chain configuration:
Signal detection:
  Detector
Initial signal processing
  Pulse amplifier
  Charge pre-amplifier
  Pre-amplification
Processing
  Logarithmic or linear amplifier (with or without auto-range capacity)
  Quadratic amplifier (Campbellian mode)
  Period or Rate extractor
  Rate meter
Auxiliary elements
  High voltage power supply units
  Low voltage power supply
  Communication units:
    Discrete signal electric isolation units
    Digital signals
    Analogue signals
  Digital communication units (Field Buses)
Physical support for the units
  Cabinet mechanical specifications
  Input-output connector specifications

6  TYPICAL UNIT EXAMPLE

The selected example is the Wide Range log channel (mainly used for Reactor Protection Systems) and Wide Linear auto-range channel (mainly used for Automatic Reactor Power Control) showing the Channel Unit including the High Voltage Power Supply, the Pulse and Campbell Processor, the Log and Linear Amplifier, the Pulse and Campbell Generator and the Head-Preamplifier.

Figure 3: Wide Linear auto-range channel