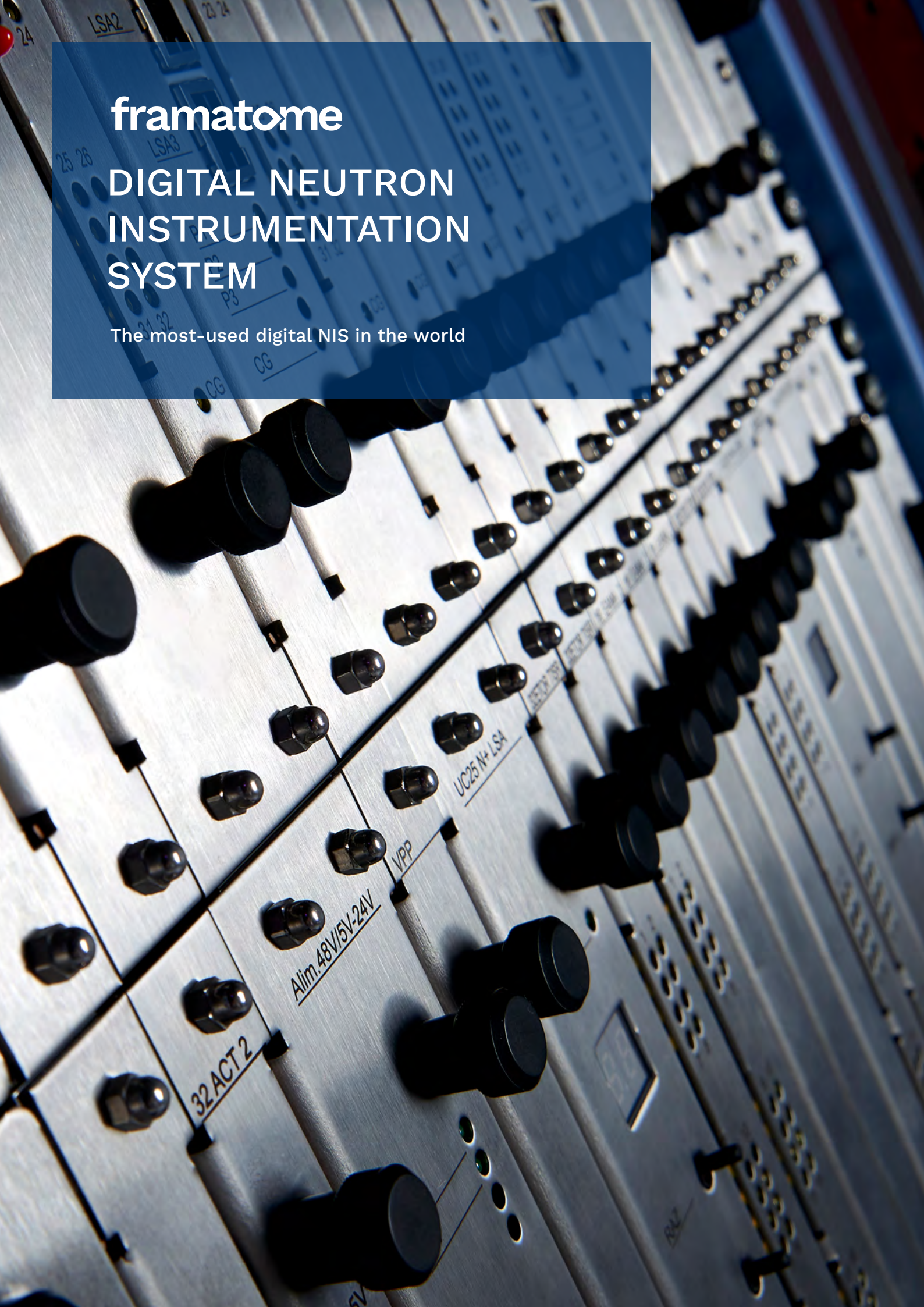
framatome

DIGITAL NEUTRON INSTRUMENTATION SYSTEM

The most-used digital NIS in the world



Principles

Framatome in-house digital solution for excore neutron flux monitoring.

The Framatome neutron instrumentation system (NIS) provides permanent monitoring of instantaneous nuclear power (i.e., neutron flux), and calculation of power fluctuations as well as axial power distribution of the reactor.

The NIS is designed to integrate with the Reactor Protection System (RPS) and plays a key role in the safety Instrumentation & Control (I&C). Its measurements are used to:

- Initiate reactor trip and safety functions
- Control the reactor power during plant operation (i.e., refueling, start-up, shutdown, power operation)
- Generate alarms in the reactor building or control rooms
- Monitor neutron power during or after an accident (post-accident)
- Perform specific start-up tests (e.g., reactivity measurement) or core monitoring during operation (e.g., neutron noise analysis)

The NIS is composed of:

- Excore neutron flux detectors
- Organic or mineral cables with dedicated connectors
- Signal conditioning electronics
- Control and protection processing electronics
- Qualified boards, racks and cabinets
- Ergonomic local or remote human-machine interface for supervision and maintenance
- Ergonomic testing devices and related reporting
- Separate elements (e.g., handling tools, audio boxes in reactor building, etc.)

Framatome NIS can be tailored to meet customer specifications

Architecture

Thanks to its adaptability, Framatome NIS can be used both for new build and modernization projects, for all types of reactors.

System architecture

Framatome NIS technology can address various system architectures and redundancies. A typical NIS consists of three types of measurement channels:

- Source range channels (SRC), for shutdown and start-up operations
- Intermediate range channels (IRC), for start-up operations and post-accident monitoring
- Power range channels (PRC), for power operations, composed of up to six sections along reactor height for more precise measurements of axial power deviation

These channels can be adapted to any kind of safety architecture thanks to the flexibility of Framatome Spinline technology:

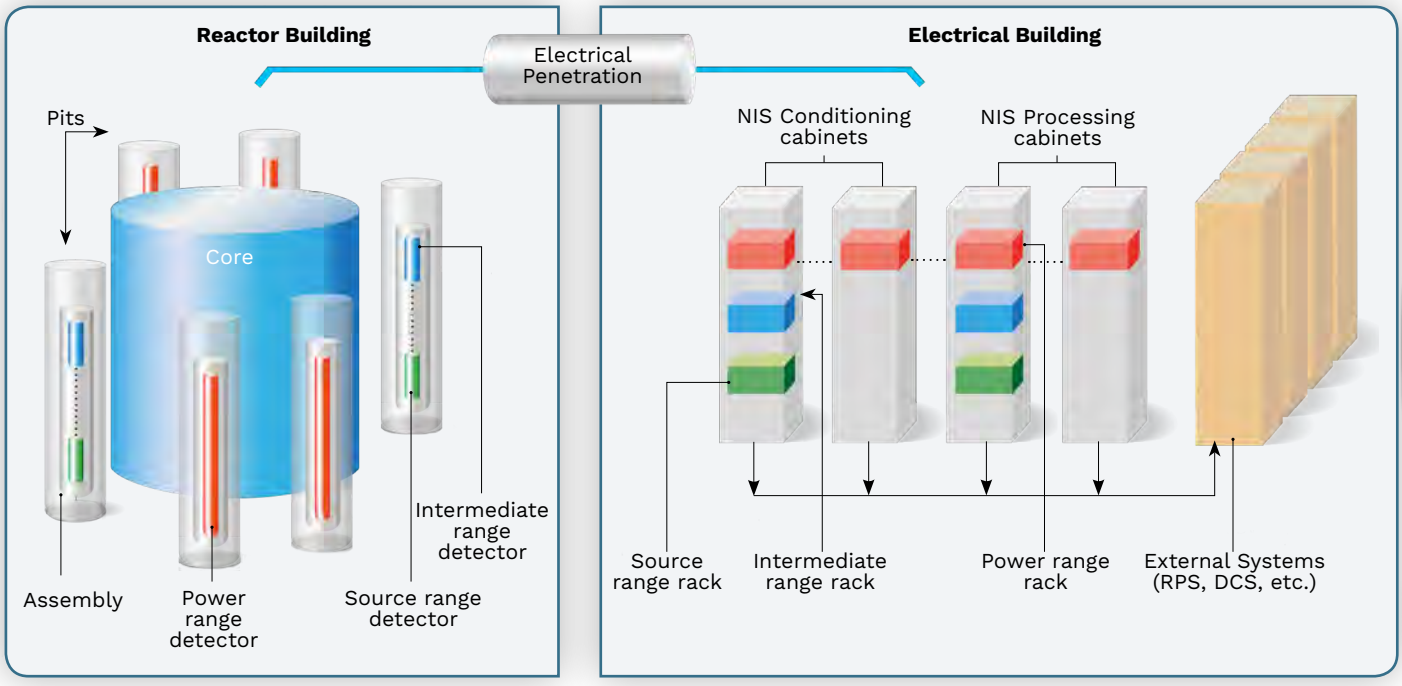
- Four-fold redundant safety divisions, each with one measurement channel of each type
- Three-fold redundant safety divisions, each with three-fold redundant measurement channels

The overall measurement range can be adapted from 5 x 10^{-2} nv up to 1 x 10^{11} nv according to customer requirements (1 nv=1 neutron/cm^2/s).

Refueling channels can also be added to monitor the reactor neutron flux more closely during refueling activities.

The NIS features adequate overlaps, ensuring smooth switch-over between ranges.

Framatome also provides a wide range measurement channel that can cover the full range from 1 nv to 2x10^{10} nv when associated with a compatible detector. In addition, this wide range channel meets requirements for post-accident requirements, as defined in US NRC RG 1.97, when coupled to a fission chamber-based detector.



Typical NIS components and interfaces with external systems.

Technical features

Broad range of features based on 50 years of customer feedback.

Measurement and control channels

Measurement channels monitor the neutron flux over a range of 12 decades. Overlap ensures continuous processing from the source range level to the power range level and a smooth switching over between SRC, IRC and PRC. Similarly, our wide range channel can cover more than 11 decades and meets post-accident requirements when coupled with an adequate detector. Protection functions (automatic trip, limitation, safety features) can be implemented directly in the measurement channels or in separate dedicated protection channels.

Control channels process the data supplied by measurement channels and provide operational information such as measurements, equipment operating status and alarms to the main control room and other plant systems. They also feature local information hubs for the diagnosis and maintenance of the NIS.

Design features

- Independence: safety divisions and their measurement channels are functionally and electrically fully independent from each other
- Self-test: extensive self-tests implemented in the processing units ensure safe operation of the system through early hardware failures detection
- Network: Framatome proprietary class 1E NERVIA network enables deterministic communication between channels, while maintaining functional and electrical independence
- Cybersecurity: high level cybersecurity using proprietary applications, proprietary protocols and access rights protection
- Reliability: high-quality designs and components ensure high reliability figures for the electronics

Software

Framatome NIS software comprises:

- Safety class 1E software (i.e., IEC category A and IEEE class 1E) for measurement and protection channels
- Software for the control unit that can be developed to any safety category
- Standard classified software for the supervision and monitoring unit

Software parameters of the processing units can be adjusted during operation to fine-tune the response of each channel to specific site requirements.

Use of proprietary class 1E safety library for specific neutron measurement functions that have a proven history (e.g., count rate calculation, doubling time algorithms, and Kalman filtering), can be adjusted to any specific application.

Performance

High performance electronics and digital processing ensure high accuracy and fast response time for seamless integration into the overall plant I&C architecture. Performance can be tuned to customer requirements.

Qualification, Testing and Maintenance

Framatome NIS is qualified to the most stringent and recent IEC and IEEE standards (please refer to the “Standards / Technical Specifications” section).

Like every processing system using the Spinline technology, the NIS system is supported by a set of available dedicated tools, helping operators to perform system monitoring and maintenance, such as:

- LDU: Local Display Unit, allows the operator to display values of changeable parameters and to make modifications to them
- MMU: Monitoring and Maintenance Unit, used to process the result of self-diagnostic tests in order to help the maintenance personnel identify the location of the required corrective action in case of a failure
- ATU: Automatic Testing Unit, used to perform electronics and detectors periodic tests by injecting signals to inputs and detect any hardware faults on all the protection signal paths

Human-machine interface

The NIS human-machine interface provides:

- Functional and operational information, such as raw or processed measurements (e.g., neutron flux, corrected neutron flux, doubling time, etc.), displayed in format of textual values, bar graphs or reports
- Information about the status of the NIS system conditions, equipment status signaling to support maintenance activities (e.g., fault annunciation)
- Display charts giving a follow-up of operating and setting parameters, such as the emergency trip threshold, and make it possible for the operator to print selected information
- Events and trends logging

Excore neutron detectors

Designed, manufactured or assembled in the Framatome facility for more than 50 years.

Scope of supply

Framatome designs, manufactures and supplies measurement systems for various types of reactors:

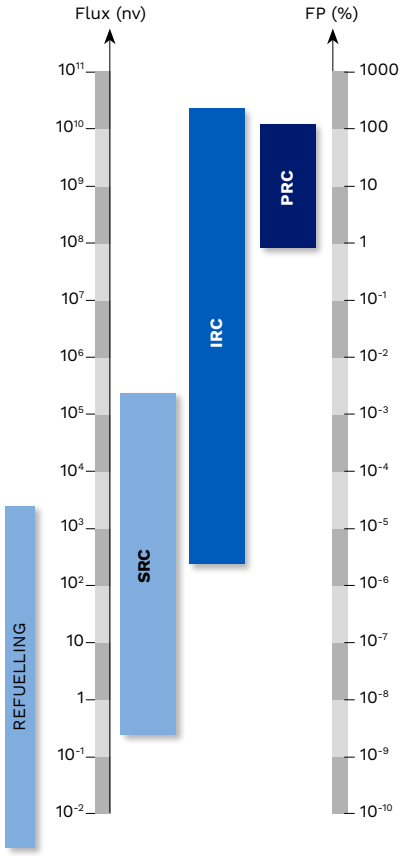
- PWR - Pressurized Water Reactors
- GCR - Gas Cooled Reactors
- RBMK - Graphite Moderated Reactors
- FBR - Fast Breeder Reactors
- PHWR - Pressurized Heavy Water Reactors
- Naval Reactors
- Research Reactors
- SMRs and Advanced Reactors

Framatome provides the full NIS scope: detectors, assemblies, connectors, cables for source, intermediate, power and wide ranges.

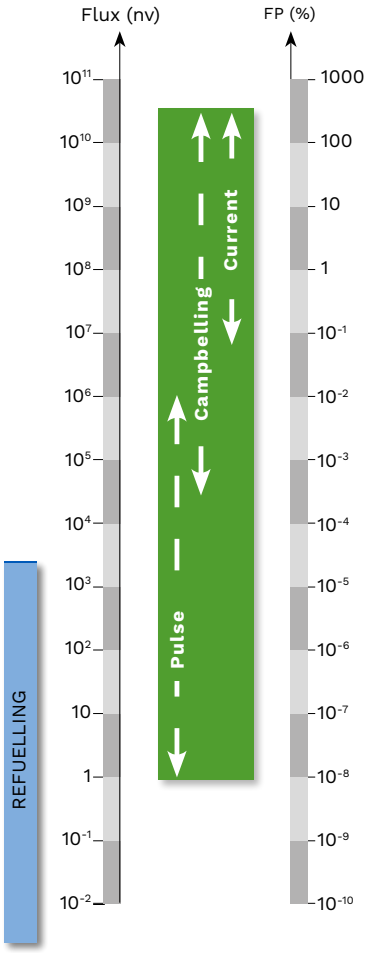
Framatome supplies the following types of detectors:

- Boron coated proportional counter: three typical outer diameters: 25, 48 and 76mm
- Compensated ion chambers
- Non-compensated ion chambers: typically 1 section, or 2 / 4 / 6 sections with two typical diameters 50 and 80mm
- Fission chambers
- Helium-3 proportional counter
- Post-accident gamma ion-chamber
- N16-gamma ion chamber (high energy gamma)

Filing gas: mixture (Ar, N_2, He) or Hydrogen.
Connectors: HN type, post-accident qualified.



Typical Flux ranges measure with our Source, Intermediate and Power channels systems



Example of flux measurement and associated modes using our wide range system with fission chamber (post-accident compatible configuration)

Applied standards

The detectors are tested, verified and qualified according to international nuclear standards.

In particular, for validating the detection characteristics: neutron sensitivity, gamma sensitivity & detection range and also for evaluating the performances in various conditions including post-accident conditions and specific gamma spectrum:

- Tests to environmental conditions (applied standards: IEC 780, IEEE 323, IEEE 344):
  - Temperature, typically 950 hours at 135°C (275°F)
  - Humidity, typically 48 hours at 55°C (131°F) and 95% relative humidity
  - Pressure, typically 6 bars (87 psi)
  - Vibration tests
- Gamma irradiation: typically up to 850kGy (85Mrads)
- Test to seismic conditions
  - All continuous operation behavior tests have been performed according to the following standards: NF M64-001, IEC 60068, IEC 60980, IEEE 323, IEEE 344, EDF radiation tests specification CRT 91 C 113
  - Accident stress tests have been performed according to the following standards: NF M64-001, EDF seismic tests specification CRT 91 C 112, EDF radiation tests specification CRT 91 C 113
  - Seismic stress tests are performed according to the following processes: 5 cycles on S1 (Seismic all project spectra – Horizontal spectra): biaxial test on horizontal OX/OZ and vertical OX/OY axles; 1 cycle on S2 (Seismic all project spectra – Vertical spectra): biaxial test on horizontal OX/OZ and vertical OX/OY axles.

Gamma detectors: post-accident ion chamber for measuring the gamma dose rate in the containment after an accident. The detector has an internal alpha source to produce a permanent test signal to validate the operation of the channel.

Please refer to the neutron detectors technical sheet for more details.


RAZ
Abort
LSA2
LSA3
P1
P2
P3
CG
32 ACT 2
Alim. 48V/5V-24V
VPP
UC25 N+ LSA
Exploit.
Réserve

Conditioning

Reliable and accurate even at low flux levels.

Description

The detector signal conditioning is implemented in the analog hardware and is directly connected to the excore detectors. It shapes and amplifies the detectors signal to a standard signal range for easy acquisition and digitalization by the processing part, or for direct output delivered for independent separate systems.

Typical signals conditioned:

- Pulses from proportional counters detectors, up to 1 X 10^6 cps
- Low level and wide range current generated by non-compensated or compensated ionization chambers from 10^{-12} A up to 10^{-3} A
- Fluctuations (i.e., Campbelling)

These signals are processed by dedicated excore NIS boards:

- Fast pulse amplifiers
- Pulse discrimination and shaping
- High voltage supplies
- Automatic or fixed range switching amplifiers for current measurement

The conditioning part can also deliver specific output signals:

- Raw signal outputs for reactivity meter interface and measurement
- Neutron noise signal for core vibration monitoring

The conditioning boards also include inputs and outputs to perform:

- Parameters management (i.e., modification and monitoring) for high voltage setpoint and discriminating setpoint
- Periodic tests of the conditioning board
- Periodic test of neutron detector through curve plotting for aging monitoring

Conditioning boards for SRC / INT / PWR channels

Functions

Conditioning functions are specifically designed for increased performance and do not use logarithmic amplifiers, allowing:

- Count-rate measurements with a flexible accuracy / response-time trade-off to fit each individual customer needs
- Accurate current measurements over the whole range without the need for regular recalibration

All the measurements and internal parameters are permanently transmitted to processing units and can be monitored through the networks.

The signals are digitized by the processing functions and can be exploited for:

- Trip and automatic actuation functions for reactor
- Control and operation of the reactor
- Special tests (e.g., reactivity meter, neutron noise analysis, etc.)

Focus on our wide range system compatible with post-accident measurements.

Our wide range system can cover the neutron flux from 1 nv to 2e10 nv when associated with a single detector compatible with this range (Framatome also supplies such detectors). Thanks to its three different measurement modes (pulse, campbelling and current modes) and automated commutation between these modes based on the flux level (when associated with a processing unit such as Framatome Spinline technology), the system can easily be adapted to cover this full range or only a smaller fraction, for example the equivalent of source or intermediate ranges only, or two of the ranges (SRC+INT or INT+PWR), and this with a single detector able to measure the chosen range defined by the end user.

When coupled with a fission chamber-based detector, the system is compliant to post-accident requirements according to US NRC RG 1.97.

Wide range module

Processing

Based on Framatome digital safety platform: Spinline, used in more than 90 plants in the world.

Description

The signal processing is implemented in the NIS digital processing units. It acquires and digitizes detector signals provided by the signal conditioning as well as additional signals from external sources and performs all calculations and comparisons needed for safety and regular plant operation.

The results of this processing are transmitted to other systems (e.g., reactor trip system, safety actuation systems, limitation systems, etc.) in various forms (e.g., binary, analog, or digital outputs signals.)

This part of the protection channel is based on Spinline technology.

The digital processing provides the following benefits:

- Improved accuracy
- Improved response time
- Better reliability
- Reduction of the number of mechanical components
- Improved self-testing
- Monitored adjustment operations
- Overall acknowledgement of the status of the system
- Well suited to modern supervision means and tools
- Possibility of complex and accurate functions (e.g., temperature correction)
- Easy maintenance by signaling failure identification and location

Software

The software is rigorously developed for safety systems performing IEEE class 1E and IEC category A (according to IEC 60880).

Developed according to the customer specifications, typical functions for NIS applications are:

- Raw count rate calculation including filtering
- Neutron flux calculation based on current measurement, calibration and correction
- Changing rate (e.g., doubling time)
- Filtering of signals
- Comparison to set points to generate alarms, reactor tip signals, interlocks
- Audio channels
- Reactivity calculation

Cycle time for typical NIS applications is as low as 10 milliseconds.

The functions have been used on various projects and benefit from a significant safe operation experience.

Functions performance (i.e., response time and accuracy) can be tailored easily to individual customer requirements by adjusting changeable parameters. Functions can be adapted to individual customer-specific functional requirements.

The benefits of a proven digital technology

About Spinline

Spinline is a modular digital solution dedicated to developing or upgrading safety systems used in all types of nuclear reactors. It has been specifically designed to implement any IEEE class 1E or IEC category A I&C safety function. Spinline has been successfully installed in more than 90 nuclear reactors all over the world with 50 years of successful operating experience. Framatome is the most experienced safety I&C provider in the world.

Spinline can be used in protection systems, such as RPS, NIS, Safety feature actuation systems (ESFAS) and Diesel Load Sequencing System, both in new nuclear power plants and for modernization of existing safety I&C systems in operating plants.

Please refer to Spinline technical sheet for more details.


LSA2
LSA3
P1
P2
P3
CG
VPP
Alim 48V/5V-24V
5V
24V

Customer benefits

The reliability and safety of modern yet proven technologies that can adapt to customer needs and meet local regulations.

The Framatome NIS is based on Spinline technology, which is one of Framatome digital safety platform for International Electrotechnical Commission (IEC) category A and Institute of Electrical and Electronics Engineers (IEEE) class 1E applications.

It offers high levels of performances (e.g., neutron flux ranges, accuracy and time response) while ensuring high reliability, improved EMC robustness and compliance with the most demanding qualification standards. Thanks to its technical features it can meet the requirements of any reactor type, by complying with existing interfaces and interfacing with any type of safety or control system.

Framatome can provide the complete NIS, including detectors, conditioning and processing electronics as well as human-machine interfaces, covering the whole range of neutron flux power in nuclear power plants and research reactors.

Framatome proven digital NIS technology allows for:

- High level of safety and reliability to support high plant availability
- Accurate neutron flux display for better plant operation
- Wide range of measurements
- Elimination of additional electronics between detectors and the NIS cabinets (i.e., no electronics inside the reactor building or just outside the penetration)
- Easy and efficient maintenance
  - Automatic periodic tests of electronics and detectors with extensive monitoring capabilities
  - Easy parameters adjustment with high stability
  - Ease of operation
- High level technical guidance and expertise support for detectors, electronics, commissioning
- Low inventory requirements
- Use of up-to-date components, improved long-term support
- Ergonomic human-machine interface
- A complete scope coverage thanks to “classic” boron detector-based Source / Intermediate / Power channels and wide range, post accident channels using fission chamber-based detectors

A robust, standardized and proven technology

Experience and references

Framatome is the world leader of digital NIS.

Framatome has more than 50 years of experience in the design and delivery of Neutron Instrumentation Systems for both new builds and modernizations.

As of today, Framatome has provided NIS to more than 115 nuclear reactors in the world.

We are the number one supplier of digital excore neutron instrumentation systems in the world.

Selected Framatome Neutron Instrumentation System references

Standards

Developed specifically for nuclear safety functions according to the most demanding international & local nuclear standards and regulations.

General safety requirements

International	IAEA GSR part 2	Leadership and Management for safety (2016)
	IAEA SSG-30	Safety classification of structures, systems and components in nuclear power plants (2014)
	IAEA SSR-2/1	Safety of nuclear power plants: Design
	IAEA SSG-2	Deterministic safety analysis for nuclear power plants
	IAEA SSG-39	Design of instrumentation and control systems for nuclear power plants
	IEC 60671	Nuclear power plants – Instrumentation and control systems important to safety – Surveillance testing
	IEC 60812	Analysis technique for system reliability. Procedure for failure mode and Effect Analysis
	IEC 61226	Nuclear power plants – I&C systems important to safety – Classification of I&C functions
	IEC 61227	Nuclear power plants - Control rooms - Operator controls
	IEC 61500	Nuclear power plants – Instrumentation and control important to safety – Data communication in systems performing category A functions
	IEC 61513	Nuclear power plants – I&C systems important to safety - General requirements for systems
	IEC 62003 ed2:2020	Nuclear power plants - Instrumentation, control and electrical power systems - Requirements for electromagnetic compatibility testing
USA	10 CFR 50	General design criteria for nuclear power plants (appendix A)
	NUREG 800, chap.7	Standard review plan for the review of safety analysis reports for nuclear power plants
	IEEE 338	Standard for criteria for the periodic surveillance testing of nuclear power generating station safety systems
	IEEE 603	Standard for criteria for safety systems for nuclear power generating stations
Europe	RCC-E	Design and construction rules for electrical and I&C systems and equipment
	RFS	Fundamental safety rules for nuclear reactors
	CRT	Technical rules file (EDF)

Specific hardware design requirements

International	IEC 60960	Functional criteria design for a safety parameter display for nuclear power stations
	IEC/IEEE 60780-323	Nuclear power plants - Electrical equipment of the safety system - Qualification
	IEC 60709	Nuclear power plants - Instrumentation and control systems important to safety - Separation
	IEC 60068-2	Environmental testing
	IEC/IEEE 60980-344	Nuclear Facilities - Equipment Important to Safety - Seismic qualification
	IEC 60987	Hardware design requirements for computer-based systems
	IEC 62566	Development of HDL-programmed integrated circuits for systems performing category A functions
	IEC 62566-2	Nuclear power plants – Instrumentation and control important to safety – Development of HDL-programmed integrated circuits – Part 2: HDL-programmed integrated circuits for systems performing category B or C functions
	IEC 62808	Nuclear power plants - Instrumentation and control systems important to safety - Design and qualification of isolation devices
	IEC 61000-4 series	Electromagnetic compatibility
USA	IEEE 308	Standard criteria for class 1E power systems for nuclear power generating stations
	IEEE 379	Standard application of the single-failure criterion to nuclear power generating station safety systems
Europe	EN 50081-2	Electromagnetic compatibility - Generic emission standard
	EN 50082-2	Electromagnetic compatibility - Generic immunity standard
	EN 55011	Industrial, scientific and medical (ISM) radio frequency equipment - radio disturbance characteristics - limits and methods of measurement

Specific software design requirements

International	IEC 60880	Nuclear power plants - Instrumentation and control systems important to safety - Software aspects for computer-based systems performing category A functions
	IEC 62138	Nuclear power plants – Instrumentation and control systems important to safety – Software aspects for computer-based systems performing category B or C functions
USA	IEEE 7-4.3.2	Standard criteria for digital computers in safety systems of nuclear power generating stations
	NRC 1.152	Criteria for use of computers in safety systems of nuclear power plants
	NRC 1.168	Verification, validation, reviews and audits for digital computer software used in safety systems of nuclear power plants
	NRC 1.169	Configuration management plans for digital computer software used in safety systems of nuclear power plants
	NRC 1.170	Software test documentation for digital computer software used in safety systems of nuclear power plants
	NRC 1.171	Software unit testing for digital computer software used in safety systems of nuclear power plants
	NRC 1.172	Software requirements specifications for digital computer software used in safety systems of nuclear power plants
	NRC 1.173	Developing software life cycle processes for digital computer software used in safety systems of nuclear power plants
	NRC RG 1.89	Environmental qualification of certain electric equipment important to safety nuclear power plants
	NRC RG 1.97	Instrumentation for light-water-cooled nuclear
Europe	RFS	Software for safety systems

Framatome is an international leader in nuclear energy recognized for its innovative solutions and value added technologies for the global nuclear fleet. With worldwide expertise and a proven track record for reliability and performance, the company designs, services and installs components, fuel, and instrumentation and control systems for nuclear power plants. Its more than 15,000 employees work every day to help Framatome's customers supply ever cleaner, safer and more economical low-carbon energy.

Visit us at: www.framatome.com, and follow us on Twitter: @Framatome_ and LinkedIn: Framatome.

Framatome is owned by the EDF Group (75.5%), Mitsubishi Heavy Industries (MHI – 19.5%) and Assystem (5%).

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