SEVERE ACCIDENT: HARDENING OF STANDARDS AND QUALIFICATION REQUIREMENTS FOR NUCLEAR PRESSURE TRANSMITTERS

H.FABBRO and R.DESGEORGE
Rolls-Royce – Nuclear, Instrumentation & Controls
23 Chemin du Vieux Chêne, 38240 MEYLAN - FRANCE
Herve.Fabbro.cn@Rolls-Royce.com; Romain.Desgeorge.cn@Rolls-Royce.com

J.C. PERES
Rolls-Royce – Nuclear, Instrumentation & Controls
23 Chemin du Vieux Chêne, 38240 MEYLAN - FRANCE
Jean-Christophe.Peres.cn@Rolls-Royce.com

ABSTRACT

Nuclear power stations are designed according to the nuclear safety principle: the achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation hazards.

This principle is applicable from the design to the dismantling of the power station, including normal and accident (and post-accident) operation.

To take into account the world experience (incident or accident as Fukushima), international safety authorities recommends to reinforce safety functions and qualification requirements level.

Concerning the instrumentation, devices like sensors are mainly impacted by the following constraint improvements:

- Radiation resistance in normal and accident conditions:
    - Higher total dose;
    - Dose Rate;
    - Nature of radiation;
- Pressure and Temperature profile in terms of:
    - Magnitude of pressure and / or temperature (higher);
    - Duration of higher constraints (longer).

All these specifications induce:

- The creation of a new qualification level – Severe Accident (SA) or equivalent;
- An impact on the sensor technology to improve the resistance to harsh environment.

Finally, the paper will present in details the evolution of the requirements and will sum up the advantages and disadvantages of different technologies to meet the severe accident conditions.

Key Words: Severe Accident Pressure Transmitters

1 INTRODUCTION

Nuclear power stations are designed according to the nuclear safety principles: the achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation hazards.

This principle is applicable from design to dismantling of the power station, including normal and accidental operating.

Designers can predict more precisely the ambient conditions in the different operating phases. The main consequences are:

- Reduction of constraints in normal conditions (for the majority of measurement) as:
- Definition of downgraded conditions for incident (seism qualified sensors) as:
- Definition of higher qualification level – Severe accident:

These new requirements can have an impact on the design of the sensors to reach a high level of:

- Accuracies (in all conditions);
- Lifespan;
- Minimum Long Term drift.

2 REQUIREMENT EVOLUTION

2.1 New project requirements

To improve the performance of new units and their resistance to accident conditions, new requirements were appearing as:

- Instrumentation more accurate in operation;
- Resistance to radiation increased;
- Seism spectrum reinforced or completed with test as “crash plane”;
- Instrumentation lifespan more in ad equation with nuclear unit lifetime increasing Post-accident situation (typically 1 year under radiation dose and temperature defined)
- Flood resistance (temporary immersion)

Based on the experience, the improving of the model and the simulation tools, the forecast ambient conditions are more accurate.

The normal used radiation, for the lifespan of the power plant, has been modified from hundreds kGy (decades ago) to few kGy.

Some downgraded conditions appeared:

- Higher pressure and/or temperature;
- None expected radiation (incident, typically 50kGy).

The accident conditions are more graduated (for example LOCA, MLSB, SA) with:

- Pressure & Temperature profile more constraining (long duration);
- Higher radiation dose;

- Radiation type.

Thanks to these forecast conditions, transmitters suppliers shall:

- Predict more precisely:
  - The accuracy of sensor in conditions (normal, incidental, accidental);
  - The transmitter lifespan;
- Find the best compromise between the sensor technology, the performance and the cost.

2.2 Qualification requirement

Initially, the standards defined the qualification methods and the requirement levels, independently of the project.

For the recent new build and based on Rolls-Royce experience, the standards continue to describe the way to qualify the sensors, but the level of constraints is now much more linked to the project or local normative constraints/standards.

The Table 2.1 sums up the most restrictive requirement, for different kind of Pressurized Water Reactor (PWR), associated to severe accident conditions.

Table 2.1: Typical SA requirement for different kind of Pressurized Water Reactor (PWR)

Project Name / ***Influence***	***Reactor type*** ***CPR1000/M310***	***HUALONG N°1***	***EPR***
Normal temperature	+50°C	+55°C	+55°C
Ageing radiation for 60 years (γ)	60kGy – orange zone 500kGy – red zone	60kGy – orange zone 500kGy – red zone	210kGy – orange zone 375kGy – red zone
Accident radiation : ***Dose***	1000kGy / 7 days	1000kGy / 7 days 2000kGy / 1 year	800kGy 1500kGy
Radiation type	$\beta + \gamma$	$\beta + \gamma$	$\beta + \gamma$
Pressure & Temperature profile	150°C / 6 bars abs During 7 days	150°C / 5 bars abs During 15 days	170°C / 6.5 bars abs During 1 day + 110°C / 2 bars abs During 6 days

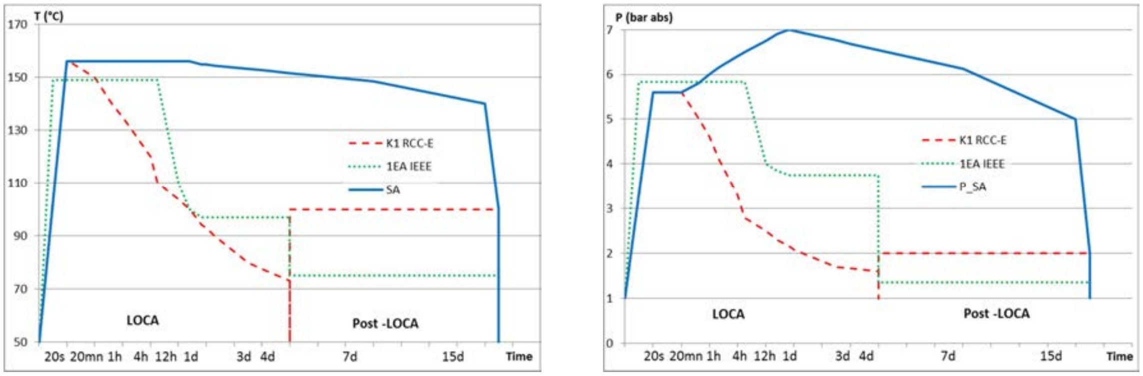
The table below reminds the accident requirement defined in RCC-E and IEEE and the severe accident requirement used by Rolls-Royce.

Table 2.2: Example of standards requirement for PWR

Qualification / ***Influence***	***LOCA*** ***K1 according to RCC-E***	***1EA according to IEEE 323***	***Severe Accident (SA)***
Normal temperature	+50°C	+54°C	+55°C
Ageing radiation (□)	250kGy	88kGy	10 to 200kGy
Accident radiation : ***Dose***	600kGy	1000kGy / 1 year	2000kGy
Radiation type	γ	γ	$\beta + \gamma$
Pressure & Temperature profile	*Cf.* Figure 2.1 Red curves	*Cf.* Figure 2.1 Green curves	*Cf.* Figure 2.1 Blue curves

As shown on the **Figure 2.1**, the main difference in the definition in the accident requirement is the duration: 16 days instead of 4.

Figure 2.1: P&T profile for LOCA and SA



Note: The seism requirements are also reinforced with a modification of the spectrum to take into account:

- A magnitude margin (typically of 50%);
- Spectrum frequency or added test for crash plane.

2.3 Radiation aspect

In nuclear instrumentation, the proof of resistance to radiation is an important item. The radiations exist in normal operation, accident and post-accident conditions.

In the different standards, the qualification test conditions are well described for normal ageing (with rate dose low - 1kGy/h typically) and accident (higher rate dose - 10 to 30kGy/h). The rate dose for post-accident is not especially defined. The post-accident was considerate with less importance than today. In new projects, the radiation after accident and during a non-negligible period is specified.

Use a high rate dose for the accident radiation is consistent with the reality. However, the resistance to radiation with a rate dose important is, generally higher than with a low rate dose.

In consequence, if the accidental radiation rate dose is different of ageing one, a margin should be taken in the computing of the past-accident radiation.

The nature of radiation is improved in the recent project. Instead of specify γ radiation, β one is also mentioned. During qualification, the tests are mainly performed with γ only. In this case, an agreement between suppliers and customers shall be find to determine which equivalent radiation dose (γ_{eq}) will affect the transmitters:

- $\gamma_{eq} = \gamma+\beta$ if the conclusion is the transmitter is also sensitive to β radiation;
- $\gamma_{eq} = \gamma+K*\beta$ if the conclusion is the transmitter is low sensitive to β radiation (or if customers impose a margin in this case typically K = 10%);
- $\gamma_{eq} = \gamma$ if the conclusion is the transmitter is totally insensitive to β radiation

3 TECHNOLOGICAL IMPACT

3.1 General description of transmitters

A transmitter is a device measuring a physical quantity (pressure, flow …), which is converted into a conditioned and calibrated electric signal.

The transmitter consists of 2 parts:

- The sensor is the mechanical part which is directly affected by the measurand (for example: pressure, flowrate) and which generates a signal related to the value of the measurand;

- The converter is the electronic part which processes the electrical quantities of the sensor to provide a conditioned signal conforming to the required format.

The two structure types of transmitters are:

- Integrated structure where the electronic converter is mounted as an integral part of an assembly containing the sensing element;
- Separated structure where the electronic converter is mounted at a removed location (locally or remotely) from an assembly containing the sensing element but connected to the sensor by signal line.

3.2 Technological impact

The new qualification levels imply some modifications on the sensors itself.

To resist to the harder ambient constraints (pressure or temperature) associated with long duration the body sensor and electronic case have to be reinforced:

- Material;
- Connector steam proof even after high radiation dose;
- Case design to ensure a good steam proof and / or waterproof

The material and components used shall also be changed or adapted to resist to:

- β radiation (especially the electronic)
- γ radiation (organic material and electronic)

The electronic components have to be chosen according to the operation conditions and in particular with their radiation resistance. The table 3.1 gives the typical average dose acceptable versus component technology

Table 3.1: Typical Radiation resistance dose

Component Type	***Digital***	***Integrated circuit***	***Transistors and passive components***
Radiation Level (kGy)	0.05	50	Few 100

For the converter, any digital electronic is forbidden for the SA qualified transmitters.

This type of technology is sensitive to radiation and the accuracy could not be insured.

Even in case of separated structure, the analog electronic is imposed by designers. Indeed, in accidental conditions, return of experiment (as Fukushima) proves that some radiation particles could be present in the electrical building. The dose level reached could be enough to disturb digital components.

3.3 Advantages and disadvantages of different structures

The transmitter performances depend on several parameters:

- For the sensor it is material, design, integration and assembling of sensor, technology of measurement cells (crystal / piezoelectric, capacitive, inductive, LVDT, strain gauge …).
- For the converter it is the component type, electronic design, the protection against harsh environment, …
- The structure type, integrated one or separated one

An important difference between all technologies is the structure. For integrated transmitters, they have the same constraints for the sensor and the converter. The separated structure allows dissociating the constraints between electronic and measurement cell. Due to that the transmitter performances are different in normal, accident and post-accident conditions. The table 3.2 sums up the main advantages and disadvantages of both structures.

Table 3.2: Structure – Advantages & Disadvantages

Structure	*Conditions*	*Advantages*	*Disadvantages*
Integrated transmitter	Normal	Good functional accuracy Fast thermal compensation 2 wires	Radiation effect on electronic Long term drift Lifespan = 10-20 years
	Accident & Post-accident	Less sensitive to fast transient temperature	Radiation effect important Accuracy low
Separated transmitter	Normal	Long term drift low No radiation effect on electronic Lifespan = 40-60 years Maintenance easy event reactor in operation	Functional accuracy Fast thermal compensation 4 wires
	Accident & Post-accident	Good accuracy Low radiation effect on electronic	Accuracy sensitive to fast temperature transition

4 CONCLUSIONS

This document deals with hardening of standards and qualification requirements for nuclear pressure transmitters.

To improve the efficiency and the accident resistance of power plants, the qualification requirements are increased. New qualification levels more constraining are appeared. The main difference is in the radiation dose and the accident profile which is longer (16 days instead of 4). The radiation nature (γ_{eq} = f(γ;β)) and qualification conditions (temperature / rate dose) have to take into account.

These new specifications impact the transmitters. Their design has to be adapted or changed to reach the performances level asked. These improvements concern the sensor and the electronic converter.

The difference of transmitter structure (integrated or separated) is presented. Even if both one are qualified, the comparison shows the one is more efficient in normal conditions while the second is better in accident. The choice will be made by compromise between the requirement in normal, accident and post-accident conditions.

5 REFERENCES

1. *IEC/IEEE 60780-323 Nuclear facilities - Electrical equipment important to safety - Qualification* International Electrotechnical Commission (2016)
2. *IEC 60770 Transmitters for use in industrial-process control systems* International Electrotechnical Commission (2010)
3. H.M. HASHEMIAN *Maintenance of Process Instrumentation in Nuclear Power Plants* Springer Verlag (2006)
4. H.M. HASHEMIAN *Sensor – Performance and Reliability* ISA (2005)