# DESIGN OF A SAFETY MODULAR CONTROL SYSTEM FIRST IMPLEMENTED FOR THE REASSESMENT OF OSIRIS IRRADIATION DEVICES

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## ABSTRACT

*The safety functions of the control system of nuclear reactors must comply with strict requirements. These requirements are not strictly formalized for the irradiation devices of research reactors but for homogeneity reasons they must be similar to the ones of the reactor itself. That is the reason why requirements in terms of single failure criterion, redundancy, positive safety design and independence have been adapted for the specificities of OSIRIS reactor irradiation devices.*

*In OSIRIS reactor, the general architecture adopted for the control system of irradiation devices splits safety and process functions into separated cabinets using different technologies. Process functions are usually carried out by a programmable logic controller. Faced to the lack of industrial products suited to its needs to perform safety functions, OSIRIS reactor utility designed, developed and qualified analog safety modules like a trigger module named MSR2 or a voting logic module named MSR-V2/3. Qualification program also included tests with modules and chassis assembled in a cabinet. The solution was modular to adapt to the multiplicity of irradiation needs and compact enough to be installed in an existing reactor.*

*During the last safety reassessment of OSIRIS irradiation devices, compliance studies, feedback from past experience and safety analyses have led to identify necessary modifications. Prospective analyses and cost/benefit studies permitted to select other suitable improvements and optimize their expected benefits. The replacement of the safety cabinets of CHOUCA irradiation device was decided to improve physical separation, electromagnetic compatibility and for functional needs of future irradiations. It was the first implementation of the MSR2 technology.*

*The implementation of new cabinets is now complete. This operation was a success and did not disturb the irradiation program of OSIRIS. These cabinets have brought advances in terms of safety, reliability and flexibility and have improved OSIRIS irradiation capabilities. The solution developed for is simple, modular, and has a competitive cost. It might be used in other nuclear facilities. Technical exchanges have already been initiated to determine how the future Jules Horowitz Reactor can benefit from this work.*

## 1. SAFETY REASSESSMENT OF OSIRIS IRRADIATION DEVICES

To respond to the request of the French Safety Authority and keep its irradiation devices at the highest level of safety standards, the CEA undertook the reassessment of the irradiation devices of OSIRIS reactor [1] (Cf. figure 1). This work was done in parallel with the periodic reassessment of OSIRIS reactor and AMENOPHIS project, a batch of modifications of the reactor.

To optimize the investments, a prospective work was launched to select a list of sustainable devices within the numerous models developed for OSIRIS reactor during the last decades. A final list of devices to be reassessed was finally settled: MOLFI, CHOUCA, ISABELLE 1, GRIFFONOS, VERCORS and IRMA. New devices like PHAETON, MERCI, MOSAIC, RAJAH, FLOREAL, DIAMINO had been designed during recent years in respect with new safety standards. These devices did not need reassessment.

| Irradiation device | Experimental use of the device | Irradiation device | Experimental use of the device |
|---|---|---|---|
| CHOUCA | Irradiation of structure or cladding materials for LWR and HTR | MERCI | Irradiation of fuel rod samples |
| ISABELLE 1 | Power ramps on LWR fuel rods [2] | RAJAH | Irradiation of aluminium samples |
| GRIFFONOS | Irradiation of highly instrumented fuel rods | FLOREAL | Irradiation of aluminium samples |
| VERCORS | Irradiation of fuel pellets | PHAETON | Irradiation of material or fuel samples at high temperature |
| IRMA | Irradiation of structural materials like vessel steel samples | DIAMINO | Irradiation for actinide transmutation |
| MOLFI | Production of radioisotopes for medical use<br>(MOLFI is not an experimental device but its safety report is treated with the same standards) | | |

**Tab 1 - Irradiation devices of OSIRIS reactor**

The reassessment of the devices permitted suitable improvements on the control cabinets of some devices.

## 2. THE I&C OF IRRADIATION DEVICES

Most irradiation devices irradiated in OSIRIS reactor possess their own control systems.

This control system may be used to regulate experimental parameters. For example, each CHOUCA, PHAETON or IRMA irradiation devices contains six electrical resistances. A very precise regulation of the temperature at six different stages is operated by the control system of the devices using thermocouples placed in or nearby the irradiation load.

Some devices must also be monitored for safety reasons. For example, the confinement of some device like CHOUCA or GRIFFONOS is assured by two concentric tubes, used as confinement barriers (Cf. figure 2). These barriers are separated by an intermediary gas circuit. The pressure of this gas and the internal pressure are monitored to generate alarms and reactor scram if important variations of these pressures are measured.

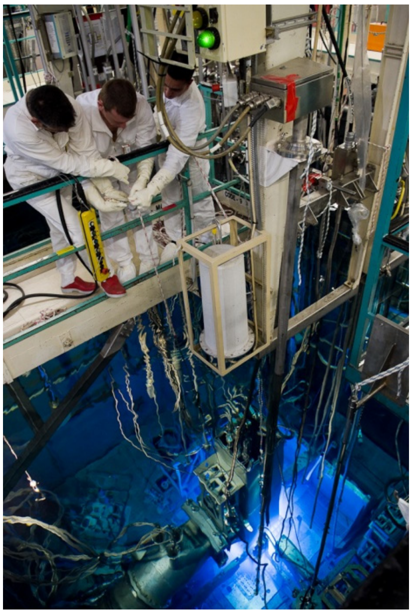

Figure 1 - Reactor pool of OSIRIS

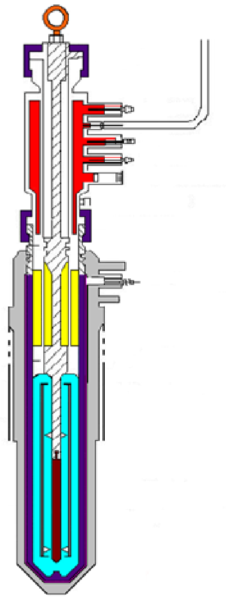

Figure 2 - Schematic view of the pressure tube of a device

On OSIRIS reactor irradiation devices, safety actions like reactor scram are treated separately from process actions (regulation of electrical heating of the irradiated samples etc.). Process functions are useful to operate the experimental devices but they cannot be taken into account in safety demonstrations. That is why they are not submitted to the same kind of requirements as safety control system. However, it strictly required that process functions do not compromise safety actions.

## 3. REQUIREMENTS FOR SAFETY I&C OF IRRADIATION DEVICES

To maintain its devices at the highest level of safety and to prepare the last periodic reassessment of the devices, the CEA had worked on a list of suitable requirements to apply to the safety control system of OSIRIS irradiation devices. These requirements were mainly issued from [10] and [11]:

- Single Failure Criterion (SFC): each piece of equipment must be able to perform its task in the presence of any single failure. Such a failure results in the loss of capability of a component to perform its intended safety function(s), and any consequential failure(s) which result from it. As a consequence, plausible common cause failures must be identified so that their probability of occurrence could be reduced or even suppressed thanks to design or operation measures.
- Redundancy: a minimum redundancy is required to fulfil the Single Failure Criterion. Redundancy consists in the provision of alternative structures, systems or components, so that anyone can perform the required function regardless of the state of operation or failure of any other. These structures can be identical or even diverse to avoid common modes.
- Positive safety design: Any active failure of any of the parts of a system must not prevent its functions to be performed. For example, the voting logic considers the lack of a signal or the lack of electrical power as scram signal on the corresponding channel or electric way.
- The Independence of the channel used for voting logic is also required
    - Mechanical protection and geometrical separation of redundant pieces of equipment must be sufficient to avoid common mode in the neighborhood (fire, flooding or handling risks).
    - Electrical separation: The electrical isolation must be so that the failure of any equipment belonging to one of the three electrical channels must not

prevent the emission of a signal in the other electrical channels. Common modes are prevented by using three independent electrical supplies for each of the three redundant ways.
- The continuity of electrical supply: The power supplies of the equipment of each electrical way must be independent and have its own backup.
- Testing ability: The design of the equipment must permit to carry out periodic tests of its capability to fulfil the safety functions it was designed for.
- Qualification: A qualification process must demonstrate the ability of the equipment to ensure its mission in every plausible condition during its lifetime, with the performance required.
- Signalisation: The signalisation must particularly include a signal in control room in case of scram signal or Electrical default of a channel.

For OSIRIS irradiation devices, three sensors are always used for the measurements that can induce a safety functions like a reactor scram. A 2/3 voting logic is used to reduce the risk of inadvertent scram signal. This voting logic reduces the level of redundancy to two.

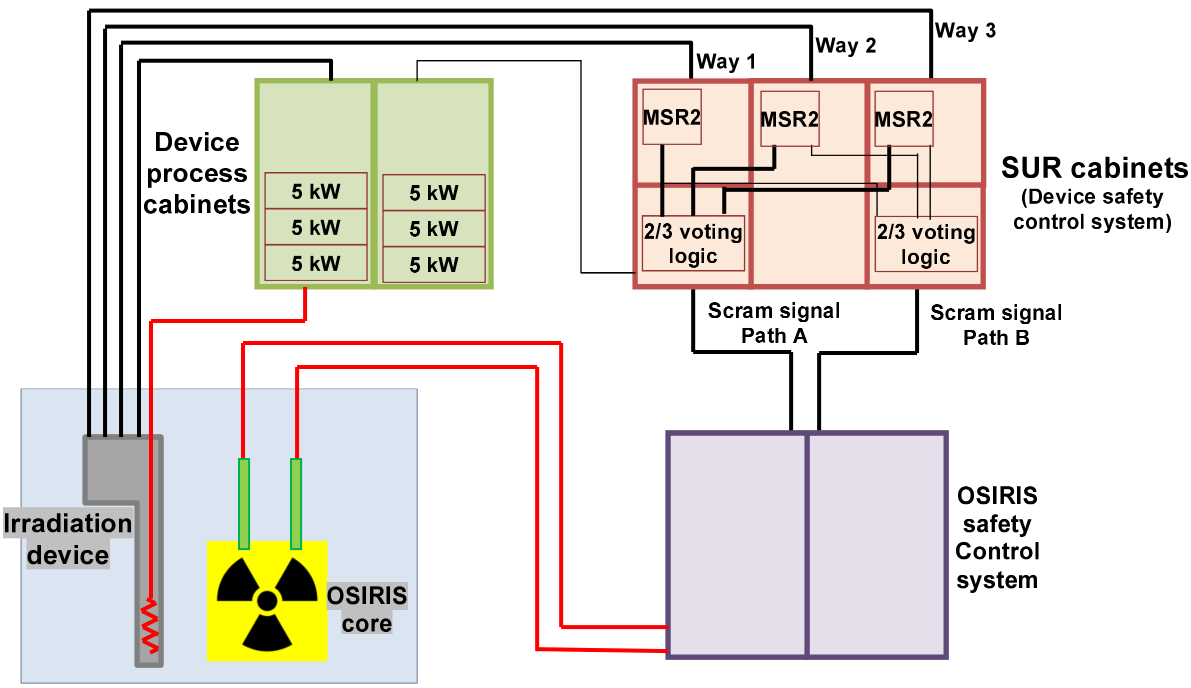

Figure 3 - Schematic view of devices control system

The general design of OSIRIS reactor in terms of electrical supply and protection system has consequences on the design of the control system of the irradiation devices. Basically in OSIRIS, the control system of a device must treat three signals of three independent sensors (way 1, way 2 and way 3) and generates two scram signals (path A and path B) to the safety control system of the reactor. (Cf. figure 3)

## 4. NEW SAFETY CABINETS FOR CHOUCA DEVICES

To answer the needs of recent irradiation programs, new safety actions appeared to be necessary. It was the case for the extinction of the electrical heating of the experimental samples and of the closure of some valves on gaseous circuits (Cf. MELODIE experiment [12]).

### 4.1 Industrial constraints

The CEA has first searched for existing industrial products corresponding to its needs [13].

Industrial digital centralised safety system, even when developed for the nuclear industry, did not appear to be a suitable solution. The qualification of a digital solution (Cf. [8]) was considered as expensive and not adapted for a fleet of experimental devices whose configurations can change from a reactor cycle to another (roughly every month).

The principle of a modular architecture was preferred to a centralised. It seemed more adapted to the different types of configuration of the experiences. In addition such architecture allowed partial refurbishment during the successive outages of the reactor without interfering with OSIRIS experimental program.

It also appeared that most modern industrial products did not meet the needs of the CEA in terms of safety requirements and functionalities.

That is the reason why, in the absence of industrial products suited to its needs, the CEA decided to develop and qualify its own products.

## 4.2 The beginning of the development of a safety analog solution

The CEA had started to work on the design of new safety modules in 2008 for the needs of a future program of irradiation in PHAETON experimental device.

A first phase of this development was dedicated to the design, the study and the realisation of prototypes of safety electric equipment (Cf. figure 4).
Three kinds of modules and two kinds of associated racks were designed and manufactured:

- MSR2_ANA: Reactor Safety Modules of 2d generation for ANAlog sensors,
- MSR2_TOR: Reactor Safety Modules of 2d generation for ON/OFF sensors,
- MSR_V2/3: Reactor Safety Modules with 2/3 voting logic,
- CSR_V2/3:Reactor Safety Racks for 2/3 voting logic,
- CSR2: Reactor Safety Racks for MSR2_Tor and MSR2_Ana modules.

Figure 4 – MSR2-ANA and MSR-V2/3 modules

Tests of compliance with EMC (Electromagnetic Compatibility) standards [9] were performed for each module, rack and measuring system. Another series of tests was done in regard to temperature and humidity conditions.

This irradiation project and the development of these modules were interrupted after the first series of prototypes had been manufactured and tested.

## 4.3 Refurbishment of CHOUCA safety cabinets for reassessment reasons

The reassessment of the experimental devices put in evidence a particular need of

refurbishment for the safety control of CHOUCA devices due to:
- insufficient qualification in regard to electromagnetic compatibility (EMC) [9],
- difficulties of qualification of software included in some component [8],
- suitable improvement of physical separation between safety channels and between safety and process parts [6],
- needs of new safety signals and actions for future irradiations [12].

The replacement of these safety cabinets was an opportunity to include the MSR2 modules, recently designed.

Before the refurbishment, the architecture of the control of the CHOUCA devices was the following. Each CHOUCA had its own control cabinet including safety functions (scram signal generation), monitoring of irradiation parameters (temperature, pressure), and regulation of the electrical heating of the devices by 6 power units.

The refurbishment consisted in using these cabinets for the process function and moving safety functions to new cabinets (called SUR cabinets). These new cabinets, based on MSR2 technology were designed to treat the signals of three experimental devices (Cf. figure 5). This mutualisation minimises the cost and reduces the space needed for new equipment. For each device up to 6 physical measures can be treated by each electrical way. The technology of the new SUR cabinets is fully analog, except for the Human Machine Interface (HMI). However, every digital component is totally separated from the safety functions by the use of specific MSR2 output, protected by a qualified galvanic isolation.

Figure 5 - CHOUCA SUR cabinet installed in OSIRIS reactor

The program of qualification that had been applied to the MRS2 modules and racks was completed for the SUR cabinets.

The first phase of this qualification work corresponded to the collection of requirements, the analysis of existing standards and the definition of a qualification plan. Six Investigation groups (IG) were defined [5] [6] [7]:
- IG1: Reference (General documentation : mechanics, electricity, operation),
- IG2: Functional characteristics (functional analysis and modelling),

- IG3: Performance and Failure Modes Effects and Criticality Analysis (FMECA),
- IG4: Electro Magnetic Compatibility (EMC) [9],
- IG5: Environment (temperature, hygrometry),
- IG6: Electrical relays.

In the second phase, the results of phase 1 were integrated into the quality program of new safety system. The necessary additional studies and analysis were also identified and defined.

Qualification tests had already been realised on MSR2 modules and their racks. The SUR cabinets having been manufactured, the modules were integrated in the cabinets and a qualification campaign of the global system could then be realised.

In the third phase, once every qualification tests had been realised, the qualification was validated and integrated into a final qualification report.

## 5. CONCLUSION

A first set of safety cabinets of the new generation, for three CHOUCA irradiation devices were implanted in OSIRIS reactor in 2012 and first used in autumn 2012 without encountering unexpected difficulties. A second set of cabinets has recently been installed and successfully tested during the summer 2013. This implementation of the SUR cabinets in OSIRIS did not disturb the irradiation program.

To renew the safety control system of its experimental devices, the CEA has developed and qualified a new generation of safety modules, racks and integrated them in qualified cabinets. The analog technology that is used is modular, simple and has a competitive cost. These new cabinets installed in OSIRIS, based on the MSR2 equipment, have brought advances in terms of safety, reliability and flexibility. It improved OSIRIS irradiation capabilities.

This technology provides a qualified solution and could be used in other nuclear facilities in association with digital controller in charge of process treatments. Technical exchanges have already been initiated to determine how the future Jules Horowitz Reactor [3][4] can benefit from this work.

## 6. REFERENCES

[1] Safety reassessment of irradiation devices in OSIRIS Research Reactor – The Case of GRIFFONOS
J.-S. ZAMPA and Al
TOPSAFE 2012 – Helsinki

[2] “OSIRIS reactor for fuel, material and other irradiations”- 12th International - Group On Research Reactors IGORR 2009 – 28-30 October 2009 – Beijing (CHINA) - S. LOUBIERE and Al.

[3] Experimental Devices in Jules Hoowitz Reactor dedicated to the fuel studies in support to the actual and future nuclear power plant
Th. DOUSSON and Al.
IGORR 2012 – Prague

[4] Experimental Devices in Jules Horowitz Reactor dedicated to the material studies in support to the current and future nuclear power plant
C. COLIN and Al
IGORR 2012 – Prague

[5] Industrial process measurement and control – Evaluation of system properties for the purpose of system assessment
IEC 61069
[6] Nuclear power plants – Instrumentation and control systems important to safety – Classification of instrumentation and control functions
IEC 61226
[7] Dependability management
IEC 60300
[8] Nuclear power plants – Instrumentation and control systems important to safety – Software aspects for computer-based systems performing category A functions
IEC 60880
[9] Electromagnetic compatibility (EMC)
IEC 61000
[10] Design and Conception Rules for Electrical Equipment of Nuclear Islands – RCC-E
AFCEN
[11] Instrumentation and control systems important to safety in nuclear power plants: safety guide - Safety standards series N° NS-G-1.3
Vienna : International Atomic Energy Agency, 2002
[12] Instrumentation Status of the MELODIE experiment, an advanced device for online biaxial study of the irradiation creep of LWR cladding -
P. GUIMBAL and Al
ANIMMA 2013 – Marseille
[13] Etude de faisabilité d'un Contrôle-Commande numérique pour les irradiations expérimentales dans le réacteur nucléaire Osiris du CEA"
Victor Silva
Mémoire - Conservatoire National des Arts et Métiers de Paris - 07/05/2009