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# SAFETY SYSTEM FOR THE RESPECT OF NUCLEAR REQUIREMENTS OF SPIRAL2 FACILITY

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## Abstract

The SPIRAL2 Facility at GANIL is based on the construction of a superconducting, CW, ion LINAC (up to 5 mA - 40 MeV deuteron beams and up to 1 mA - 14.5 MeV/u heavy ion beams) with two experimental areas called S3 and NFS.

For safety system, SPIRAL2 project system engineering sets up a specific reinforced process, based on V-Model, to validate, at each step, all the requirements (technical, nuclear safety, quality, reliability, interfaces...) from the functional specifications to the final validation.

Since 2016, safety devices have been under construction and in test phase. These tests which are pre-requisites to deliver the first beam demonstrated that both functional and safety requirements are fulfilled. Currently, all of them are in operation for the LINAC and NFS commissioning phases.

This contribution will describe the requirements, the methodology, the quality processes, the technical studies for two system examples, the failure mode and effects analysis, the tests, the status and will propose you a feedback.

## INTRODUCTION

GANIL is a nuclear physic laboratory based in France since 1980 and SPIRAL2 is a new facility to extend the capability of GANIL.

Officially approved in May 2005, the SPIRAL2 radioactive ion beam facility (Fig. 1) is based on two phases: A first one including the accelerator, the Neutron-based research area (NFS) and the Super Separator Spectrometer (S3) dedicated to heavy nuclei studies, and a second one including the RIB production process and building, and the low energy RIB experimental hall called DESIR [1, 2].

In 2013, due to budget restrictions, the RIB production part was postponed, and DESIR was planned as a continuation of the first phase.

The first phase SPIRAL2 facility is now built and Desir is under study. The accelerator is installed [3]. The French safety authority agreement is now validated since 2019 according the validation of all safety system and the accelerator is under testing. A first p-beam was accelerated in the LINAC at 33 MeV and injected to experimental hall (NFS) at the end of 2019 [4]. Actually, the accelerator is under commissioning with nominal current at high duty cycle.

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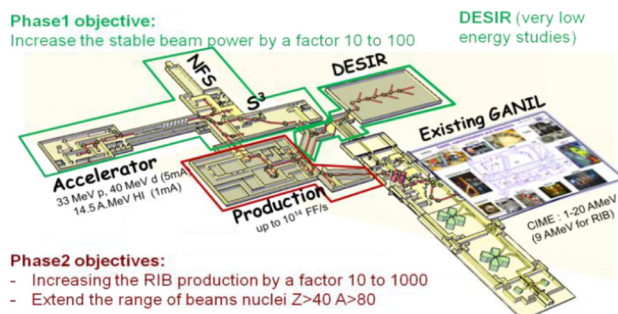


Figure 1: SPIRAL2 project layout, with experimental areas and connexion to the historical GANIL facility.

## PROBLEMATIC

The GANIL/SPIRAL2 facility is considered as an “INSTALLATION NUCLEAIRE DE BASE” (INB), administrative denomination for nuclear facilities according to the French law. The GANIL is under the control of the French Nuclear Safety Authority. The classification of the SPIRAL2/GANIL facility in the INB field is due to the characteristics of the beams at the last acceleration state and the use of actinide target.

The goals are to protect workers, public and environment against all identified risks (in normal running, the maximum individual dose is fixed to 1 mSv per year for a worker, and for the most exposed public in the external environment, the impact of the installation is fixed to a maximum value of 10  $\mu$ Sv per year).

Concrete building (14.000 m<sup>3</sup>) and an 8 meters underground beam axis, without beam power control is not sufficient for protection against external exposure to ionizing radiation. Active safety systems are then required to control beam losses as well as the operating range.

## METHODOLOGY

The objective was to provide all safety system according to the safety requirements (functionalities, independence, dependability, and quality insurance) and according to the beam operation constraints (in particular the safety systems availability).

Since 2010, we have established a system engineering management. It is a very structuring approach for a complex project. The Systems engineering focuses on the needs definition for the customer and for the functional requirements, from the beginning of the cycle (V Model Fig. 2), by documenting the requirements, then with the synthesis of the conception (design), the realization and the validation of the system.

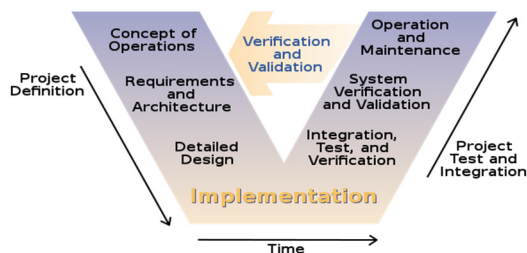


Figure 2: V cycle.

For the safety systems, SPIRAL2 Project uses a specific Quality Management Plan for the Safety (QMPS). This plan is naturally based on the Deming cycle but relies, on the establishment of a particular task force managed to reach the set of the requirements. This task force contributes to validate the conformity (Fig. 3) at each breakpoint or reviews of the V cycle. This checking chain is composed of an independent technical validation, a nuclear safety control, an independent dependability checking, a validation of the integration in the building and the interface conformity with the other processes, a quality and documentation checking. All of those links are required to obtain the safety level for SPIRAL2.



Figure 3: Chain for Safety Quality Management Plan.

Concerning the dependability checking, a Failure Mode and Effects Analysis (FMEA) was realized to eliminate dangerous failures. Criticality is not taken into account. The single failure criterion was selected as dependability criterion. Redundancy, hard-wired systems and dissimilar redundancy are using for the design principle.

### FIRST EXAMPLE: SAFETY MACHINE PROTECTION SYSTEM

Controlling the accelerator device activation due to beam losses (beam losses limited to 1 W/m for D+ beams), along with the target and Beam dump activation as well as the operating range is then required with a Safety Enlarged Machine Protection System (EMPS) [5]. This safety EMPS is a part of the entire MPS.

#### Beam Intensity Monitoring Subsystem

In order to control continuously the intensities and the losses, non-destructive beam intensity measurements are set up along the accelerator. The use of two kinds of non-destructive measurement chains DCCT (Bergoz NPCT-175-C030-HR) and homemade ACCT is justified by the difference of detection principles and by their complementarities (Fig. 4) [6].

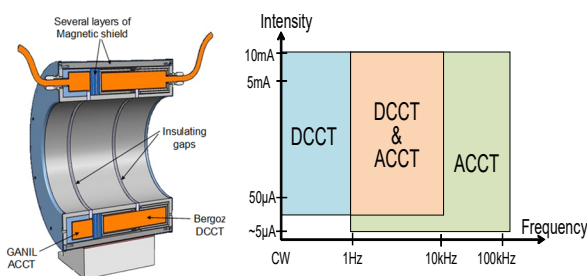


Figure 4: ACCT/DCCT bloc section and operating range.

The DCCTs measure the intensity of continuous and chopped beams with a slow response time. The minimum intensity that can be measured is a few 10 µA due to the offset level. The homemade ACCTs are very efficient, they are faster with rise times about 1 µs and with minimum levels less than 5 µA.

The ACCT or DCCT signal is converted into a pulse frequency entering counters. The threshold values must take into account the qualified uncertainty measurement. A beam cut alarm signal is generated if the counter sets off.

#### Beam Cuts Treatment Subsystem

This safety-classified subsystem is the core part of the SPIRAL2 MPS; it is a simple and secured one, based on two hard-wired system with a PLC for the operation control (Fig. 5). This system relies in particular on the following beam monitor subsystems:

- ACCT/ DCCT monitors
- Scintillation monitors (BLM) [7]
- Time of Flight monitor
- Beam dump activation control subsystem [8]
- Beam dump Cooling subsystem

It receives alarms from each subsystem. Therefore, it activates the beam cut through commands sent to safe and slow beam stops in the low energy beam line (response time: 1.5 s) in association with a temporary RF stop on the RFQ (response time < 1 ms).

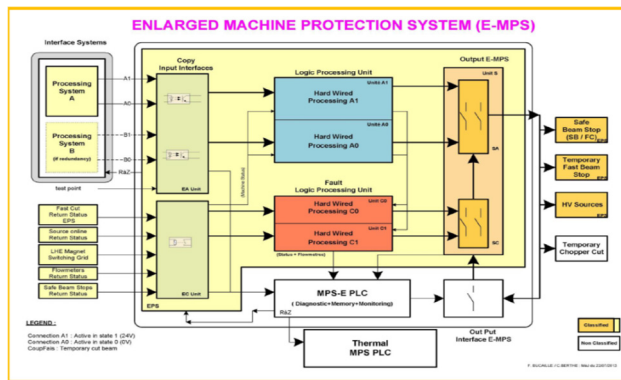


Figure 5: Redundant hard-wired system.

The overall response time was determined by the thermal and activation calculations with safety margin. The expected response times are for the fastest 15 ms (10 ms for the detection, 4 ms for the treatment and 1 ms for the beam cut) to a few seconds for slower ones.

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## SECOND EXAMPLE: LIMITATION OF DISSEMINATION SYSTEM

The need is to minimize the risk of a volatile contamination transfer through the beam lines. This transfer would be caused by a shockwave due to an air inrush in the vacuum chamber [9]. The main characteristics are:

- A contamination velocity considered of 900m/s (this speed was measured at CERN [10]).
- The use of discharge gauges and fast isolation valves with time closing from 10 to 25 ms (Fig. 6).
- An installation of few valve control systems (the closing of these valves depends of the beam path configuration in the high-energy beamlines [11]).
- This System is coupled to a fast Beam cuts treatment and actuator subsystems (RF of RFQ cavity).

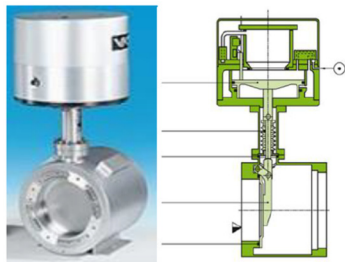


Figure 6: Fast valve of VAT Company.

Taking into account the wave front speed and the fast isolation valve response time, the fast valves are located over 17m (Fig 7) to the target and the sensor for all beam paths and with redundancy (17m / 900m.s<sup>-1</sup> > valve time closing).

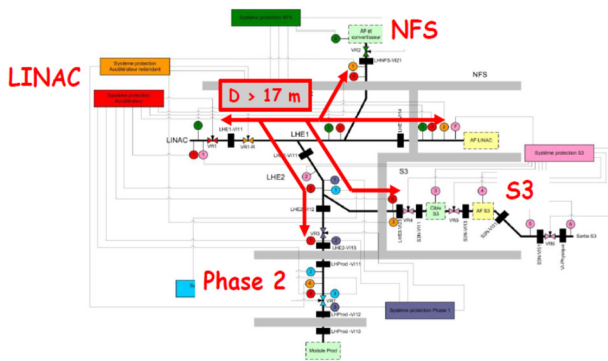


Figure 7: Synoptic of high-energy beam lines.

Concerning the scenario and the timing (Fig. 8):

- In first, if we have a fast vacuum increase, the discharge gauge detected it in 1ms,
- 2 ms later, the valve control box activate the fast valve and the safety command subsystem.
- 1 ms after, the safety command subsystem activates in parallel a temporary fast beam cut with the radiofrequency of the RFQ cavity
- 1 ms later, the 200kW beam are cut-off and the fast isolation valve begin to move
- 1,5 s after a slow beam cut is down (beam stopper in the beam line)

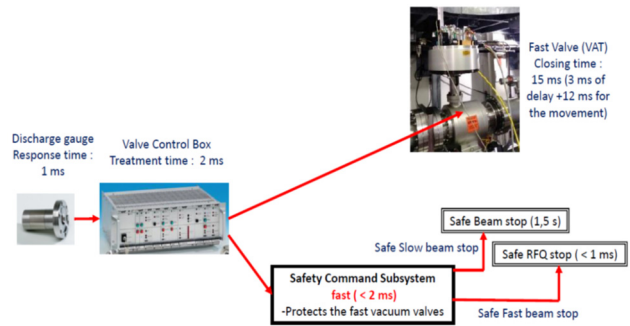


Figure 8: Scenario and timing.

Last September, we realized the overall validation with the beam. So with the excellent subsystem time characteristics, we have a margin of 2,65 ms over an effective time of 0,35 ms to protect the valve from the beam! This safety system was validated with requirement compliance (Fig. 9).

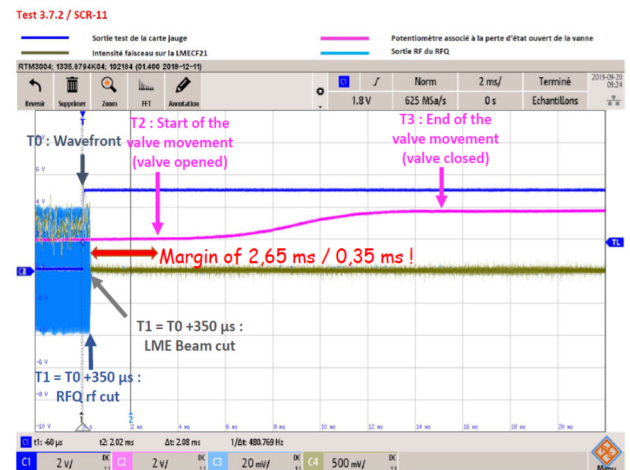


Figure 9: Validation tests in 2019.

## TESTS AND SAFETY VALIDATIONS

For each subsystem, the second phase of the V-cycle has been respected [12, 13]. It concerns the followings: unit tests, subsystems tests and global tests, functional tests and tests in a degraded situation according to the FMEA during the design phase (Fig. 10).

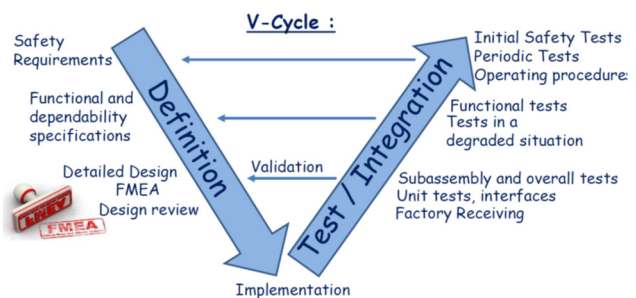


Figure 10: SPIRAL2 Safety V cycle.

Each deviation from the validated design reference requires analysis, processing and validation by the six links of the chain for PMQS. After iteration and complete agreement of the six links, the modifications are carried out



with an updating of the different documents (diagrams, technical design files, FMEA ...). A safety-specific quality summary file is completed to prepare the operation phase and to be potentially audited during inspections of the nuclear safety authority.

## CONCLUSION

Since 2019, the 22 safety systems for Accelerator and NFS are now installed, tested, validated and in operation in compliance with the Safety requirements and with the quality management.

This status allowed the first Linac beam in 2019 and the first beam test in NFS.

The last French Safety Authority inspection in 2020 revealed no significant deviation: The SPIRAL2 facility is safe!

For the safety systems in order to respect the nuclear requirements of SPIRAL2 facility, our main feedback concerns the followings:

- The required very low beam level for the detection (for example few  $\mu\text{A}$  with beam current monitors) integrating the definition of global uncertainties is brilliantly achieved through a specific development for SPIRAL2.
- All safety systems architecture, have progressed to be very reliable and have been hardened by Failure Mode and Effects Analysis (FMEA) through the use of principle like redundancy, dissimilarity, simplification, auto-testing and degraded mode studies
- The performances for every fast system are achieved with margins
- The V-cycle time is long for some system between the start of the design in 2011 and the overall validation in 2019 because time is the main adjustment variable. There has been no change in the safety, the technical performances and the cost requirements.

The goal is reached: Providing complex instrumentation, with multidisciplinary teams, meeting the SPIRAL2 safety and quality requirements, is a technical and human challenge that the SPIRAL2 team has raised.

The new and important work, that has been done on the SPIRAL2 project, to make a high intensity accelerator a safe installation, should allow our accelerators to progress and be safer.

Such as needs = Such as designed = Such as installed and tested = Such as in operation

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