Excellence Center: NPC (Nuclear Physics Center)
Director: Etienne Liénard

Table 1: List of work packages (WP)

WP No	Work Package Title	Start Month	End month
1	Management	1	72
2	NFS Experiments	9	60
3	S^3	3	72
4	DESIR	11	72
5	Interdisciplinary research	3	71
6	Graduate School	1	70

Table 2: Work package description

Work package number	1	**Person in charge**		Etienne Liénard (LPCC)
Work package title	Management			
Start month	1	**End month**	72	
Objectives Management of the project, relation with university of Caen and SAB				
Description of work (where appropriate, broken down into tasks), lead partner and role of participants - Collaboration LPC Caen, GANIL and CIMAP - Production of reports - Organisation of SAB* meetings *: SAB constitution: Marcella Grasso (DAS IN2P3, marcella.grasso@admin.in2p3.fr), Riccardo Raabe (KULeuven Belgium, riccardo.raabe@kuleuven.be), Ian Sims (URennes, ian.sims@univ-rennes1.fr), Sandrine Courtin (UStrasbourg, director of IPHC, sandrine.courtin@iphc.cnrs.fr)				
Deliverables (brief description and month of delivery) - Intermediate reports (end of each year, one month before SAB meeting) - Last report (one month after last SAB meeting)				

Work package number	2	**Person in charge**		François-René Lecolley (LPCC)
Work package title	NFS Experiments			
Start month	9	**End month**	60	

Objectives Safety optimisation of nuclear power plants: improvement of neutron cross-sections impacting the precision of reactor modelling and ageing of fuel pins for 3rd and 4th generation nuclear reactors

Description of work (where appropriate, broken down into tasks), lead partner and role of participants

In this WP, experiments will be conducted at Spiral2-NFS by LPC Caen using the SCALP detector consisting in measuring the cross-sections of fluorine and oxygen for (n,alpha) reactions The use of the SCALP detector (a scintillating Ionization Chamber developed at LPCC) at NFS will contribute to reduce uncertainties on these cross-sections which have a strong impact on the precision of reactor and nuclear reaction modelling and even on the prediction of fuel swelling.

In addition, the LPCC team will be involved in the precise characterization of the NFS neutron flux using various detectors, which will also contribute to reduce the cross-section measurement uncertainties.

These works will be conducted in collaboration with the GANIL-NFS team (responsible X. Ledoux) as well as IPHC Strasbourg for the NFS beam characterization. Additional collaborators may join the collaboration during the projects.

This WP is divided in two tasks:

T-1-1 Measurements of (n,alpha) cross-sections of fluorine and oxygen

T-1-2 Characterization of the neutron flux delivered by the SPIRAL2-NFS facility

Deliverables (brief description and month of delivery)

- PhD defense (M7, Y5)
- Papers submission to international journals (M5,Y4 and M12, Y5)
- Oral presentations at international conferences (M1,Y4 and M2, Y5)
- WP reports (15 days before WP1 report)
- Milestones 1 : Proposals submitted to NFS PAC (M9, Y1 and M9, Y2)
- Milestones 2 : Short reports on experiments carried out (M3, Y4 and M3, Y5)

Work package number	3	**Person in charge**		Hervé Savajols (GANIL) & Antoine de Roubin (LPCC)
Work package title	S^3			
Start month	3	**End month**	72	

Objectives Commissioning of S^3, S^3-LEB & S^3-SIRIUS and day1 experiments

Description of work (where appropriate, broken down into tasks), lead partner and role of participants

S^3-Spectrometer

The Super Separator Spectrometer is a major experimental system being developed as part of SPIRAL2. It has been designed for physics experiments with very low cross sections, taking full advantage of the very high stable beam intensities that will be provided by the SPIRAL2-LINAC superconducting linear accelerator. These intensities will open up new opportunities in several areas of physics. Among the major new themes in contemporary nuclear physics that will be tackled are the study of the properties of super-heavy and very heavy elements (i.e. heavier than the Uranium atom, which is the heaviest element naturally present on Earth), and the spectroscopy of very exotic nuclei in the vicinity of nuclei with the same number of protons and neutrons). The common feature of these experiments is the need to separate very rare events from very intense background noise.

The spectrometer separator uses cutting-edge technology based on a set of superconducting multipole triplets of high-acceptance that provide very high transmission efficiency for the nuclei of interest while offering high selectivity. S^3 is based on two optical stages, a momentum achromat combined with a mass spectrometer, ensure the rejection of the incident beam that has not interacted with the production target and an in-flight mass selection that is unique in the world for the rare nuclei transmitted.

The spectrometer separator is in the final stage of construction and testing, with progressive commissioning of the beam scheduled for the second semester of 2025. This complex instrument will require two years of fine-tuning to achieve the expected nominal performance.

To maximize the performance of this device, the beam must be carefully aligned on the optical axis and all the magnetic elements (around 460 magnetic coils) must be adjusted to correct optical aberrations and thus guarantee high selectivity for the selection of rare events. It can be difficult to achieve this by manual adjustment, based on theoretical optical simulations that do not take into account errors in the alignment of the beam on the target, the mechanical alignment of the equipment and the magnetic field integral of the magnets. We propose to investigate *Machine Learning* (ML) by using algorithms and computer techniques that train complex systems from raw data rather than a priori models. Machine learning techniques are now technologically mature enough to be applied to particle accelerators and spectrometer settings.

Postdoc
The commissioning of S^3 is scheduled to begin in the second half of 2025 for a period of two years. A post-doc is needed to strengthen the commissioning team for 2025-2026.
Skills: Nuclear physics, spectrometer optics, instrumentation, software

S^3-LEB

S^3-LEB is a very innovative tool that combines state of the art laser spectroscopy, decay spectroscopy and mass spectrometry techniques to study ground and isomeric state properties, such as nuclear moments, spins and masses, of any nuclei produced by S^3. S^3-LEB operates at low energy ensuring thus a high beam

quality and a noise free environment, which are crucial conditions for high precision measurements. This apparatus will allow us to study the evolution of nuclear structure far away from stability, in regions of the nuclear chart that were out of reach until S^3.

The S3-LEB apparatus is in its final stage of off-line commissioning and is ready to go into beam operation in 2025 and 2026. The first experimental campaign of S3-LEB will be dedicated to neutron deficient erbium isotopes, it will then be followed with measurements in the actinium region (neutron number = 126) and the so-called N=Z region.

Post-doc
The commissioning of S^3-LEB is scheduled to start mid-2025, for a period of two years. A post-doc is strongly needed to strengthen the commissioning team for 2025-2026 and to help preparing the future of the scientific program at S^3-LEB.
The aim of the post-doc is to carry out the on-line commissioning of S^3-LEB and to prepare future studies of proton emitting nuclei (accessible for the first time at low energy) at S^3-LEB.
Skills: Nuclear physics, nuclear structure, laser spectroscopy, mass spectrometry, instrumentation, simulation

S^3-SIRIUS

The commissioning of S^3 with its original instrumental devices will open up entirely new perspectives in basic physics, pushing back the limits of our field of knowledge in nuclear physics. The whole installation is a major component of the research carried out by international collaborations (GANIL, LPC Caen, Irfu, IPHC, IJCLAB, in France; GSI, University of Mainz in Germany; ANL in the United States; KU Leuven in Belgium and JYFL University in Finland).

The project aims to study rare nuclei with low cross-section at the limit of nuclear stabilitý. In particular, it will enable the study of the heaviest elements, with the ultimate goal of synthesizing new elements and thus completing Mendeleïev's periodic table. This research will help to answer the fundamental question: "What is the limit, in terms of the number of protons and neutrons, to the existence of atomic nuclei?".

In order to study the fundamental properties of very rare heavy and super-heavy atoms, it is essential to have a new detection tool at the focal plane of the S^3 spectrometer separator, enabling the use of the radioactive decay labelling technique. This requires the development of versatile instrumentation capable of detecting heavy ions, electrons, photons, protons, alpha particles and fission products. This new measurement system, SIRIUS, is in the final stages of testing and is also scheduled to go into beam operation in 2025 and 2026, with the study of reference reactions to maximize its performance. This commissioning phase will end with a study of the ^{40}Ar + ^{209}Bi reaction to produce the mendelevium isotopes ($^{244\text{-}247}Md$), which have different decay modes (α, β, SF) and isomers, and for which additional measurements are needed to determine their nuclear structure.

PhD
The commissioning of SIRIUS is scheduled to start at the end of 2025 for a period of two years. A PhD student is required to strengthen the commissioning team for 2025-2026 and to perform the day-1 experiment in 2027. The aim of this PhD thesis is to carry out the first decay spectroscopy measurements at SIRIUS.
Skills: Nuclear physics, nuclear structure, spectroscopic studies of heavy and superheavy nuclei, instrumentation.

T-3.1, 3.2 Commissioning of the separator spectrometer & implementation of machine learning (GANIL)

- Lead Partner (GANIL): H. Savajols & B. Jacquot
- Recruitment: Post-doc - 18 months + 6 months GANIL funding (March 2025)
- Role of participants:

- H. Savajols: coordination, dissemination
- B. Jacquot: coordination optical commissioning (T-3.1)
- H. Savajols: coordination scientific commissioning (T-3.2)
- Post-doc fellow: optical commissioning and machine learning implementation

T-3-3 S3-LEB installation & commissioning

- Lead Partner (LPC Caen/ GANIL): A. de Roubin, N. Lecesne and V. Manea
- Recruitment: ERC Post-doc – 18 months (November 2026)
- Role of participants:
  - A. de Roubin, N. Lecesne and V. Manea: coordination, dissemination
  - Post-doc: commissioning and future perspectives of S^3-LEB
  - A. de Roubin: submission of ERC on innovative instrumentation development for S3-LEB

T-3-4, 3-5 S3-SIRIUS installation & commissioning and Day1 experiment

- Lead Partner (GANIL): J. Piot
- Recruitment: PhD- 3 years (October 2025)
- Role of participants:
  - J.Piot: coordination, dissemination
  - PhD: commissioning of S^3-SIRIUS, preparation and data analysis of day1 experiment

Deliverables (brief description and month of delivery)

- PhD defense
- Separator spectrometer optical commissioning report
- Separator spectrometer scientific commissioning report
- Papers submission to international journals
- Oral presentations at international conferences
- WP reports (15 days before WP1 report)

Work package number	4	**Person in charge**		JC Thomas (GANIL) & L. Hayen (LPCC)
Work package title	DESIR			
Start month	11	**End month**	72	

Objectives Commissioning of DESIR and Day1 experiments

Description of work (where appropriate, broken down into tasks), lead partner and role of participants

The DESIR low-energy beam facility is dedicated to nuclear physics, astrophysics, and fundamental interaction studies using exotic nuclei provided by the SPIRAL1 and S^3 production sites of GANIL-SPIRAL2. The main assets of the facility are:

- the large spectrum of available exotic nuclei, including neutron-deficient refractory and (super-) heavy species selectively laser-ionized with S3-LEB,
- the use of highly selective and efficient beam preparation and handling devices that will provide ultrapure samples of radioactive ions,
- the possibility to investigate the fundamental properties of exotic nuclei using complementary techniques based on ion trapping, collinear laser spectroscopy and up-to-date gamma-rays, charged-particle and neutron detection devices.

A high-resolution mass-separator (HRS-1P) and a double Penning trap (PIPERADE) coupled to a RadioFrequency Quadrupole cooler and buncher (GPIB) will allow performing experiments with high-purity and high optical-quality radioactive ion beams by the end of 2027. These beam-preparation and beam-handling devices have been developed and are currently commissioned at LP2i-Bordeaux with stable ions. They will be installed at GANIL in 2025, as soon as the DESIR building is operational. The HRS-1P will be associated to the RFQ-1P currently developed at LPCC.
This instrumentation will be unique for addressing a number of physics objectives. These can be categorized into three distinct topics focused on exotic nuclei: Precision measurements using ion or atom traps (the so-called DETRAP program); excited state spectroscopy via decay experiments (BESTIOL); laser-spectroscopy of fundamental nuclear properties and moments (LUMIERE). Both MORA (GANIL-LPCC collaboration) and MLLTrap (IJCLab, Orsay) are examples of the first devices to be installed in the DESIR hall. The use of Superconducting Tunnel Junctions (STJs) is an opportunity for novel probes of fundamental symmetries that should be explored at DESIR.

Within the CaeSAR project, the recruitment between 2025 and 2029 of young scientists and a research technician is planned for ensuring a strong start to the physics program of DESIR. This will focus on supporting DESIR's first experiments. The break down structure of the WP4 work package is as follow:

T-4.1, 4.2: Experimental setup installation, commissioning and day1 experiments at DESIR

- Lead partner: GANIL (J.-C. Thomas, V. Morel)
- Recruitments: PI Chair - External - 36 months (January 2025), Post-doc - 18 months (January 2026), PhD student - 36 months (October 2026), PI Research technician - 36 months (January 2025)
- Role of participants:
  - J.-C. Thomas: coordination, dissemination
  - V. Morel: technical coordination, technician mentoring
  - PI Chair - External: Management of the installation and commissioning of the DESIR beam preparation and experimental setups, GANIL contact for day1 experiments at DESIR, Spokesperson of a day1 experiment

- PI Chair - Post-doc: Commissioning of the DESIR beam preparation and experimental setups
- PI Chair - PhD student: Preparation, running and data analysis of a day1 experiment
- PI Research technician: installation and commissioning of the transport beam lines and experimental setups

T-4.3, 4.4: First precision measurements at DESIR

- Lead partner: LPC Caen (L. Hayen)
- Recruitments: PI Post-doc - 18 months (September 2025), PI PhD student - 36 months (October 2026)
- Role of participants:
  - L. Hayen: coordination
  - PI Post-doc: Installation, commissioning and first physics measurements with one of the first setups for precision measurements (MORA, STJs,…).
  - PI PhD student: Preparation, running and data analysis of a day1 precision experiment

Deliverables (brief description and month of delivery)

- PhDs defense
- Papers submission to international journals
- Oral presentations at international conferences
- WP reports (15 days before WP1 report)

Work package number	5	**Person in charge**		P. Rousseau ou JY Chesnel(CIMAP)
Work package title	Interdisciplinary research			
Start month	3	**End month**	71	

Objectives

Description of work (where appropriate, broken down into tasks), lead partner and role of participants

- Collaboration CIMAP, GANIL & LPCC
- Preparation and submission of ERC on COLIMACON for the determination of damage threshold (Sylvain Maclot)
- Increase of the research potential of AMA, MADIR and/or SIMUL teams for giving the opportunity to submit competitive project.
- Determination of the radio-oxidation of polymers in nuclear waste context: on-line study of radicals creation and reactions using Electron Paramagnetic Resonance in association with Kinetic Monte-Carlo calculations (KMC)
- Improving experimental equipment for interdisciplinary research

Deliverables (brief description and month of delivery)

- PhDs defense
- Papers submission to international journals
- Oral presentations at international conferences
- WP reports (15 days before WP1 report)

Work package number	6	**Person in charge**		Francesca Gulminelli (LPCC)
Work package title	Graduate School			
Start month	1	**End month**	70	

Objectives Promotion of the International Nuclear Physics master of UCN

Description of work (where appropriate, broken down into tasks), lead partner and role of participants

- Close collaboration between LPCC, GANIL & CIMAP
- Attribution of 18 "excellence" internship grants (6 months, for a total of 6k€) for second-year Master's students with a track record of excellence and committed to their Master's thesis on a project in a Caen laboratory on the themes of the "Normandy Nuclear Physics" Graduate School https://graduateschool-n2p.unicaen.fr/. The GS selection committee is responsible for selecting candidates. The internship allowances will be awarded from 2024 to 2028. As the award criterion is first and foremost scientific excellence, we reserve the right to have unfilled grants. For this reason, the schedule of scholarships ends in 2028, and the year 2029 is reserved for the possible allocation of unfilled scholarships.
- Organisation of 4 summer schools in Normandy between 2025 and 2029 on the theme: "Nuclear physics: from fundamental research at GANIL to the energies of the future". Each school will be organised over one week at the beginning of September, to make it possible to invite both M1 and M2 students. It will also be open to doctoral students and young researchers. Each school will consist of a series of four lectures given by international experts. We will be setting up a Scientific Advisory Committee to identify the specific topics and speakers for each edition. The last school, scheduled for the first week of September 2029, will be combined with a feedback session on the project.

Deliverables (brief description and month of delivery)

- Reports on summer schools (15 days before WP1 report)

Table 3: List of Deliverables

Only include deliverables that you consider essential for effective project monitoring.

Deliverable (number)*	**Deliverable name** (+ short description)	**WP number**	**Delivery (month)****

***Deliverable numbers** in order of delivery dates. Please use the numbering convention <WP number>.<number of deliverable within that WP>. For example, deliverable 4.2 would be the second deliverable from work package 4.*

***Delivery date**
Measured in months from the project start date (month 1)

Table 3.2d: List of milestones

Milestone number	**Milestone name**	**Related WP**	**Due date ***	**Means of verification****

Due date
Measured in months from the project start date (month 1)

Means of verification *
Show how you will confirm that the milestone has been attained. Refer to indicators if appropriate. For example: a laboratory prototype that is 'up and running'; software released and validated by a user group; field survey complete and data quality validated.