CNID Strategic Planning
WG12 - Low background experiments

Conveners: Susana Cebrián, Francesc Monrabal, Roberto Santorelli

1 Executive Summary (Recommended: one page maximum)

There is a strong connection between experiments investigating very different rare events (like the direct detection of dark matter particles, the neutrinoless double beta decay or the neutrino interactions) involving Spanish institutions, which motivated the creation of this WG. The R&D carried out in the context of underground experiments often focuses on common topics, making it relevant to all groups active in this field.

This specific, transversal WG has been joined by ten research groups from different institutions: IFCA (CSIC-UC); Universidad Politécnica de Cataluña; IFIC (CSIC-UV); CAPA-Universidad de Zaragoza; CIEMAT; ICTEA-Universidad de Oviedo; IGFAE-Universidad de Santiago de Compostela; Universidad Autónoma de Madrid; and Donostia International Physics Center. In their experiments different detection technologies (with liquid, solid, or gas detector targets) are applied, but there is a common interest in low background techniques and underground physics.

Several possible R&D topics have been identified:

- Radiopurity assessment, including new or improved screening techniques.
- Radiopure crystal growing.
- Improved shieldings, both active and passive.
- New target materials and gas mixtures.
- New veto materials and veto techniques.
- Background studies and mitigation techniques.
- Radon studies and material surface cleaning techniques.
- Reduction of energy threshold.
- Pulse shape discrimination techniques.
- New calibration techniques for underground experiments.
- Gas/Liquid purification/recirculation/mixing.
- New analysis and imaging techniques of low energy events.
- Optimized gas scintillation in the context of particle identification, fast trigger and sensitivity.
- Optimization of dual-phase chambers, specifically in regard to the gas-liquid interface.

2 Findings (Recommended: two pages maximum)

2.1 Scientific and Technical Focus Areas

The participating groups cover a broad spectrum of instrumentation activities for nuclear, particle and astroparticle physics, with particular emphasis on rare-event searches (dark matter, neutrinoless double beta decay, neutrino interactions) and gamma/neutron spectroscopy.

Main technological domains:

- Semiconductor radiation detectors (pixel sensors, vertexing and tracking, radiation tolerance, timing and 4D tracking, skipper-CCD, HPGe).
- Noble element detectors (liquid argon TPCs, dual-phase chambers).
- Gaseous detectors (Micromegas readouts, gas mixtures optimization).

- Scintillators (NaI crystals, light detection systems).
- Water Cherenkov detectors (mechanical structures, light transmission).
- Bolometers and quantum single-photon detectors.
- Neutron detectors and neutron dosimetry systems (including patented technologies).

Main R&D topics:

- Radiopurity assessment and ultra-low background screening (HPGe, ICP-MS, dedicated detectors such as DArT).
- Background modelling and mitigation using Monte Carlo tools (GEANT4, FLUKA, MCNP).
- Neutron detection and long-term neutron background measurements.
- Sensor characterization (including TCAD simulations and TPA-TCT techniques).
- Electronics and digital signal processing for low-rate experiments.
- Light detection in the VUV region and photon-counting systems.
- Optimization of dual-phase TPCs and noble liquid detectors.
- Machine-learning-based background rejection techniques.

Main experiments targeted: ANAIS+, DarkSide-20k, HyperKamiokande, IAXO, LiquidO, NEXT and RADES, many of them connected to the Canfranc Underground Laboratory.

2.2 SWOT Analysis

Strengths	**Weaknesses**
• Experience on design of diverse type of neutron detectors (including patents). • Consolidated experience and frequent access to relevant facilities like Canfranc or CERN. • Long experience in rare event physics within important international collaborations. • Successful design and construction of novel detectors for radioassay like DArT.	• Reduced number of engineers and technical personnel. • Absence of a facility to operate with high intensity radioactive sources.
Opportunities	**Threats**
• Involvement in many different international projects and collaborations in contact with world-wide experts. • Possible access to world-class laboratories, such as underground facilities in Europe and North America.	• Loss of researchers due to lack of consolidation options. • Reduced funding specifically for instrumentation R&D. • Failure in MoUs signatures and payments.

2.3 Human Resources

The eleven participating groups represent a consolidated national community in low-background instrumentation. The aggregated effort dedicated to CNID-related instrumentation corresponds approximately to:

- ∼138 FTE senior scientists (including permanent and tenure-track staff),
- ∼95 FTE engineers and research support staff,
- ∼51 FTE PhD students,

- ∼25 FTE postdoctoral researchers,
- ∼13 FTE technical personnel.

Institutional support typically includes mechanical and electronics workshops, clean rooms, sensor characterization laboratories, computing clusters for simulation and data analysis, and access to radioactive sources and screening facilities. However, several groups report limited availability of permanent engineers and technicians, which constitutes a structural weakness.

2.4 Infrastructure and Capability Mapping

- The participating institutions host a broad range of infrastructures supporting detector R&D and low-background experiments. These include clean rooms and sensor characterization laboratories, mechanical and electronics workshops, cryogenic and vacuum laboratories, and computing facilities for simulation and data analysis.
- Several groups operate advanced detector characterization infrastructures, including laser-based setups (SPA-TCT and TPA-TCT), optical benches, cryogenic test facilities, radioactive and X-ray sources, and detector calibration systems. Some groups also have dedicated semiconductor characterization laboratories and optical metrology equipment.
- Radiopurity and low-background measurements are supported through access to ultra-low background detectors (mainly HPGe), radon monitoring systems, and material screening techniques such as ICP-MS and XRF. Access to underground infrastructures, particularly the Canfranc Underground Laboratory (LSC), is essential for several of the participating groups.
- Other relevant infrastructures include cryogenic laboratories for noble liquid detectors, vacuum systems, laser systems for detector calibration, high-performance computing servers for simulations and machine learning, and laboratories dedicated to nuclear detector development and assembly.
- The technological capabilities of the groups span the full detector development chain, including:
  - detector design and simulation (GEANT4, MCNP, TCAD),
  - sensor characterization and packaging,
  - electronics and DAQ development,
  - signal processing and FPGA-based systems,
  - detector calibration and optical system design,
  - machine learning techniques for detector data analysis.

2.5 Internationalization

- The research groups participating in this WG are strongly integrated in international detector R&D networks and large experimental collaborations in particle, nuclear and astroparticle physics.
- Several groups are actively involved in the ECFA Detector R&D roadmap through participation in different DRD collaborations, including DRD1, DRD2, DRD3, DRD5 and DRD7. These collaborations cover areas such as gaseous detectors, liquid detectors, quantum sensing technologies, detector characterization and detector electronics.
- The groups also participate in a wide range of international experiments and infrastructures, including ANAIS+, DarkSide, HyperKamiokande, IAXO, LiquidO, NEXT and other underground physics programs.
- Access to major international research facilities plays a key role in the activities of the WG, including:
  - CERN (ISOLDE, n_TOF),
  - underground laboratories such as the Canfranc Underground Laboratory and LNGS in Italy,
  - nuclear physics facilities such as GANIL, GSI/FAIR, ILL and JYFL,
  - international neutrino and rare-event collaborations.

- Participation in international collaborations provides access to unique infrastructures, strengthens technology transfer opportunities and facilitates the training of young researchers within global detector development programs.

2.6 Current and Potential National Collaborations

- Strong collaboration exists among groups within ANAIS+, DarkSide-20k, HyperKamiokande and NEXT, as well as coordinated national projects in low-background techniques.
- Active or potential KTT lines include:
  - Neutron dosimeters (including patented technologies).
  - Semiconductor detector characterization for medical and industrial applications.
  - Applications in hadron therapy, brachytherapy (UHDR dosimetry), and proton therapy.
  - Potential applications in medical imaging and radiation monitoring.
- Identified synergies requiring coordination:
  - Neutron detection and dosimetry.
  - Radiation damage studies at CERN n_TOF.
  - Fast-response detectors for high count-rate environments.
  - Photon detection and light sensor characterization.
  - Development of noble-gas TPCs and LAr detectors.
  - Long-term underground neutron and gamma background monitoring.

2.7 Funding

The primary source of funding for the different groups on the spanish community of underground physics is the national research program (Plan Nacional) where, typically, the instrumentation takes a small part of the main project. In that sense, there are very few funds directly assigned to instrumentation development. It has to be remarked that several projects have obtained excellence european projects, like European Research Council grants, demonstrating the very high level of the projects being carried by the spanish community.

3 Recommendations

3.1 Strategic Priorities for the WG (5-Year Horizon)

- Consolidation of national expertise in ultra-low background techniques and radiopurity screening.
- Development of next-generation neutron detection systems.
- Strengthening electronics and digital signal processing capabilities for rare-event searches.
- Optimization of noble liquid and dual-phase TPC technologies.
- Expansion of machine-learning tools for low-energy event identification.
- Creation of a cross-WG task force on radiation damage and sensor qualification (in collaboration with WG3, WG6 and WG10).
- Creation of a mission-oriented task force addressing the shortage of electronics engineers, including training initiatives and shared recruitment strategies.

3.2 Infrastructure and Resource Optimization

- Promote coordinated access to Canfranc Underground Laboratory and shared radiopurity screening facilities.
- Establish a shared national platform for neutron detector calibration and characterization.
- Invest in:
  - Advanced digital electronics laboratories,
  - Dedicated low-background material screening infrastructure,
  - Long-term underground neutron monitoring setups.

3.3 Training and Talent Development

- Priority areas: digital electronics, FPGA programming, low-noise front-end design, cryogenics, and radiopurity techniques.
- Organization of annual national schools on low-background techniques and underground instrumentation.
- Mobility programs for engineers, technicians and PhD students between laboratories and underground facilities.
- Promotion of joint supervision of PhD theses across institutions.

3.4 Strategic Risks and Mitigation Measures

- Risk: loss of young researchers due to limited consolidation opportunities. Mitigation: coordinated national recruitment strategy and stabilization pathways.
- Risk: reduced funding dedicated specifically to instrumentation R&D. Mitigation: increased participation in European DRD programs and Horizon Europe calls.
- Risk: overcommitment of technical staff. Mitigation: shared technical pools and inter-institutional service agreements.

3.5 Knowledge and Technology Transfer (KTT)

- Neutron dosimetry and radiation monitoring systems.
- Semiconductor detector characterization for medical and industrial applications.
- Radiation-hard sensor technologies.
- Medical imaging and hadron-therapy related detector developments.

3.6 Internationalization

- Strengthen coordinated participation in DRD initiatives (DRD1, DRD2, DRD3, DRD5, DRD7).
- Increase representation in ECFA and related detector R&D strategic bodies.
- Promote joint Spanish proposals within Horizon Europe and EURATOM.
- Facilitate Spanish leadership roles in international collaborations linked to underground physics.