Contribution aux exercices de prospective nationale 2020-2030

Détecteurs et instrumentation associée

COUPLING OF DETECTIONS OF NEUTRONIC FLUXES BY SILICON CARBIDE AND CALORIMETRIC SENSORS

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1. Informations générales

Titre : Coupling of Detections of Neutronic Fluxes by Silicon Carbide and Calorimetric Sensors

Acronyme : SiCCALO

Résumé *(max. 600 caractères espaces compris)*

The aim of SICCALO project is to develop a new type of radiation detection system, able to perform online measurements under intense neutron fluxes and in the presence of high absorbed dose rates (5.5 10^{14} n/(cm^2.s) for an energy > 1 MeV, 16 dpa/year and up to 20 kGy/s), and to propose a coupling of these detectors with calorimeters. SiC semiconductor material is chosen since it is particularly suitable for measurements in extreme environments. Electronic and thermal simulations will be carried out, as well as experimental studies. A multi-sensor device will be proposed.

Préciser le domaine technologique *(plusieurs choix possibles)*

- **Détecteurs semi-conducteurs (Si, Ge, HgCdTe, Diamant…)**
- Détecteurs gazeux (Micromegas, GEM, TPC…)
- Scintillateurs
- Photo-détecteurs (SiPM, PMT…)
- Détecteurs cryogéniques (KIDS, bolomètres…)
- **Micro-électronique, Electronique Front End**
- Acquisition de données, Temps réel
- Mécanique, integration

Préciser la motivation principale de recherche visée par la contribution :

- **R&D Calorimétrie**
- R&D Trajectographe
- R&D Identification de particules
- **R&D Détection de neutrons**
- R&D Détection d'ondes gravitationnelles
- R&D Détecteurs de neutrinos
- R&D Détection de gammas
- R&D Détecteurs imagerie médicale
- *Autre R&D spécifique : (préciser)*

2. Description des objectifs scientifiques et techniques *(1 page max incl. figures)*

SICCALO project falls within the framework of collaborative research and development programs with CEA within IM2NP UMR 7334 laboratory, as well as within the joint laboratory AMU-CEA-CNRS LIMMEX (Laboratory of Instrumentation and Measurements in Extreme Media). For several years, the teams of IM2NP have been carrying out experimental research coupled with simulations in order to design, characterize, qualify and optimize innovative detectors under laboratory conditions and in real conditions in several European research reactors. These detectors relate to the online measurement of different quantities, such as neutron (thermal and fast) and photon (prompt and delayed) fluxes and the absorbed dose rate. The main related projects were : 1) H2020 Project **EIT KIC Inno Energy « I_SMART »** "Innovative Sensor for Material Ageing and Radiation Testing" (2012 – 2014, coordinated by CEA Cadarache ; 2) **IN-CORE project** "Instrumentation for Nuclear radiations and Calorimetry Online in Reactor" between CEA and Aix-Marseille University (2009-2024) involving the Jules Horowitz Reactor program.

The main objective of SICCALO ("Coupling of Detections of Neutronic Fluxes by Silicon Carbide and Calorimetric Sensors") project is to develop a new type of radiation detection system for counting and spectrometry of neutrons and gamma-ray fluxes and induced adsorbed dose rate for use under harsh environment, leading to the ability of identifying radiological sources, including nuclear materials. Since these materials may be developed into nuclear weapons, and then directly threaten European security, this project would provide new security solutions for the protection of critical infrastructures against many kinds of physical threats.

This innovative detection system will be based on Silicon Carbide (SiC) radiation-resistant detectors coupled with calorimeters, allied with specific read-out electronics adapted to sensor characteristics. SICCALO project relies on a consortium able to study and develop the SiC-based detector and calorimeters and the related electronics, to integrate the complete sensor system and to test the module under irradiation (JSI, KIT, CEA).

The fundamental impact of SICCALO is then to contribute in enhancing quality and accuracy of measurements in severe media i.e. under up to very high radiation neutrons and photons fluxes (up to 5.5 10^{14} $n.cm^{-2}.s^{-1}$) and under high temperature up to 500°C. These sensor systems with extremely radiation hardness based on SiC material could be applied in innovative solutions to prevent and detect physical threats to nuclear research/power reactors as well as in severe accident monitoring. It will provide a crucial contribution towards the development of advanced and scalable radiation detectors for security applications, in the context of specific European critical infrastructures.

A thesis started on October 2019, co-directed by IM2NP and CEA. The consortium will apply to H2020 SU-INFRA01-2020 call "Prevention, detection, response and mitigation of combined physical and cyber threats to critical infrastructure in Europe".

3. Livrables associés, calendrier et budget indicatifs (1 page max. incl. figures)

SICCALO proposes design and manufacturing of a detector system made of SiC and calorimeters, exhibiting the best up-to-date temperature/radiation tolerance versus manufacturability trade-offs for delivering new security solutions. Crucial for a successful fulfilment of SICCALO is the selection of groups involved, each with a specific competence, including SiC device design and processing, system integration and end-user perspectives. This hierarchy is manifested in the eight different work packages (WP's). SMEs are required.

WP1 Project management: *AMU* *Start month : 1* *End month : 36*
Deliverables: kick-off meeting; progress reports; public final project report; commercial road map. Budget: 40 K€.

WP2 SiC spectroscopic detector: *AMU/RBI* *Start month : 1* *End month : 24*
Deliverables: development of thermal neutron converter layer; thermal and radiation stability of neutron converter layer; filter efficiency for gamma-ray; realization of pixelated prototype; electrical characterization of defects induced by irradiation; modeling of defect interaction kinetic; optimization of detector characteristics. Budget: 50 K€ (20 K€ equipment).

WP3 Calorimeter: AMU *Start month : 1* *End month : 24*
Deliverables: a highly-sensitive compact calorimeter optimized for TRIGA irradiations, preliminary calibration curves under laboratory conditions
Budget: 50K€ (30K€ equipment).

WP4 High temperature electronics: *AMU* *Start month : 1* *End month : 24*
Deliverables: circuit qualification; temperature and radiation tolerance of passive and active components. Budget: 50 K€ (20 K€ equipment).

WP5 Tools for signal treatment and analysis: *CEA/AMU Start month : 1 End month : 24*
Deliverables: Quantitative assessments of numerical simulation. Budget: 30 K€.

WP6 Integration of the SIDECURE system: *SME* *Start month :12 End month : 36*
Deliverables: Design of the functional units; conception and realization of a proper ASIC, validated by the system integration. Budget: 60 K€ (40 K€ equipment).

WP7 Radiation testing and calibration: *JSI/CEA* *Start month :24 End month : 36*
Deliverables: Reports on TRIGA irradiations; calibration procedures for the final radiation detection systems; demonstration of the system's functionality. Budget: 100 K€.

WP8 Qualification of SIDECURE system for safety applications: *SME* *Start month: 12 End month : 36*
Deliverables: final demonstration of an advanced and innovative prototype. Budget: 50 K€.

4. Impact *(1/2 page max.) (optionnel)*

The fundamental impact of the SICCALO project is in developing and launching on the market an innovative detection system for selective neutron and gamma measurements in harsh environments for delivering new security solutions. The uptake of the innovation results of the project is considered for both existing and new business processes.

The SICCALO project will encompass highly innovative research which may potentially result in revolutionizing the infrastructure protection as such having direct potential impacts towards nearly all impact-issues listed in the H2020 work program.

Firstly, within the SICCALO consortium we establish closer business relationships between integrators, manufacturing plants and institutes as evident from the consortium structure and initial negotiation with additional industry partners to up-scale the prototypes/demonstrators generated in the course of the project.

Secondly, our work will certainly enhance European competitive ecosystems for the design, R&D, prototyping and testing, manufacturing and industrialization of smaller, smarter (predictive, reactive and cognitive) and energy autonomous smart systems. Indeed, assuming SICCALO reaches its objective and demonstrates an autonomous intelligent radiation monitoring system to be used in future generations of nuclear research/power plants, for example, it will certainly mean improved safety of nuclear energy generation. Moreover, the detector systems which may be directly developed based on the results of the consortium discoveries may, without any doubt, enhance the competitiveness of the companies involved and, even more strategically important, the many billion euro EU reactor development project in Cadarache.

5. Références

1. Brevet AMU/CEA « Procédé de réalisation d'un détecteur de neutrons et détecteur de neutrons » (B2944-HD15654). 19/12/2014
2. F. Issa, V. Vervisch, L. Ottaviani, D. Szalkai, L. Vermeeren, A. Lyoussi, A. Kuznetsov, M. Lazar, A. Klix, 2. O. Palais, and A. Hallén, "Radiation Silicon Carbide Detectors based on Ion Implantation of Boron" IEEE Transactions on Nuclear Science, Vol. 61, issue 4, pp. 2105-2111, Aug. 2014
3. O. Obraztsova, L. Ottaviani, A. Klix, T. Döring, O. Palais, A. Lyoussi, « Comparing the response of a SiC and a sCVD Diamond detectors to 14 MeV neutron radiation". IEEE Transactions on Nuclear Science Vol. 65, issue 9, pp. 2380-2384 (Sept. 2018). DOI : 10.1109/TNS.2018.2848469
4. F. Issa, L. Ottaviani, D. Szalkai, L. Vermeeren, V. Vervisch, A. Lyoussi, R. Ferone, A. Kuznetsov, M. Lazar, A. Klix, O.Palais, "4H-SiC Neutron Sensors Based on Ion Implanted ^{10}B Neutron Converter Layer". IEEE Transactions on Nuclear Science Vol. 63 (3) : 1976-1980 June 2016.

5. M. Carette – A. Lyoussi – J. Brun – C. Reynard-Carette – J-F. Villard – P. Guimbal, Patent CEA/AMU, Test specimen for measuring nuclear heating in a nuclear reactor, and calorimetric cell including at least one such test specimen, Eprouvette pour mesure d'échauffements nucléaire dans un réacteur nucléaire, et cellule calorimétrique comprenant au moins une telle éprouvette, Inventeurs, Date de dépôt :10 Avril 2015, N° de dépôt: FR1553136A, (FR3034867A1, US20180090236A1, JP2018518658A, KR20170135894A, EP3280985A1, WO2016162470A1).
6. A. Volte, C. Reynard-Carette, J. Brun, C. De Vita, M. Carette, T. Fiorido, A. Lyoussi, D. Fourmentel, J-F. Villard and P. Guimbal, Study of the Flow Temperature and Ring Design Influence on the Response of a new Reduced-Size Calorimetric cell for Nuclear Heating Quantification. IEEE TNS, Volume: 65 , Issue: 9 , Sept. 2018, Page(s): 2461 - 2470, DOI: 10.1109/TNS.2018.2827084
7. J. Brun, M. Tarchalski, C. Reynard-Carette, K. Pytel, A. Lyoussi, J. Jagielski, D. Fourmentel, J-F. Villard, M. Carette, Responses of Single-Cell and Differential Calorimeters: from Out-of-Pile Calibration to Irradiation Campaigns, IEEE Transactions on Nuclear Science, Vol. 63, NO. 3, June 2016, 1630-1639, DOI 10.1109/TNS.2016.2564923
8. C. Reynard-Carette, G. Kohse, J. Brun, C. Carette, A. Volte, A. Lyoussi, Review Of Nuclear Heating Measurement By Calorimetry In France And USA, ANIMMA « Advancements for Nuclear Instrumentation and Measurement Methods and their Applications » 20 - 23 June 2017 à Liège, Belgium, https://doi.org/10.1051/epjconf/201817004019