ENHANCEMENT OF SCIENTIFIC EXCELLENCE AND INNOVATION POTENTIAL IN ELECTRONIC INSTRUMENTATION FOR IONIZING RADIATION ENVIRONMENTS

*WIDESPREAD-3-2018-TWINNING*


Centro Nacional de Aceleradores

# Centro Nacional de Aceleradores: an interdisciplinary research centre in Spain

Pedro Martín-Holgado[1], Yolanda Morilla[1], Amor Romero-Maestre[1]

[1]Centro Nacional de Aceleradores (Universidad de Sevilla, CSIC, JA). Spain.

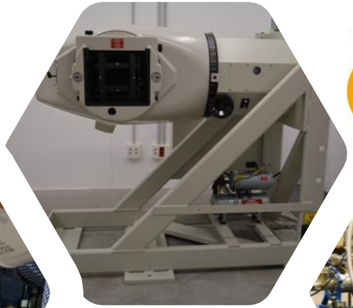

# Centro Nacional de Aceleradores

*Spanish National Accelerators Centre*

# Sevilla, Andalucía, España

## *Seville, Andalusia, Spain*

*Sevilla… ~250 km …Granada*



CNA
Centro Nacional de Aceleradores

**CNA** is a joint research center of the University of Seville, the Spanish National Research Council (CSIC), and the Andalusian regional government. It is one of the **Unique Science and Technology Infrastructures (ICTS)** in our country, dedicated to interdisciplinary research in the field of applications of particle accelerators and ionizing radiation.

Centro Nacional de Aceleradores

# CNA: Institutional Agreements

IAEA Collaborator

RD50 CERN

n-TOF CERN

Curium

ALTER

HUVR

ENRESA

Centro Nacional de Aceleradores

# CNA: International Research Projects

**"Accelerator and Research Reactor Infrastructures for Education and Learning" – ARIEL. H2020-847594.**

Carlos Guerrero

**"Supplyng Accurate Nuclear Data for Energy and non-energy Applications" – SANDA. H2020-847552.**

Carlos Guerrero

**"WPSA: Preparation and Explotation of JT-60SA" CFP-IPH-Awp19-SA-05-CIEMAT-01. Horizonte 2020.**

Manuel García Muñoz y Juan Manuel Ayllón

**"RADiation facility Network for the EXploration of effects for indusTry and research (RADNEXT) H2020-INFRAIA-2020-1. 4178/1117**

Yolanda Morilla

# CNA: National Research Projects

Centro Nacional de Aceleradores

**"Hermorrage Outcome Predictor". CI19-00068. Obra Social Fundación La Caixa.**

Marcin Balcerzyk

**"Graphene-enhanced radiation detector on silicon carbide for hash environment (GRACE)". RTC-2017-6369-3.**

María del Carmen Jiménez y Javier García López

**"Rompiendo el 12C: Una Sonda Hacia la Evolución de las Estrellas y el Origen de la Vida". PGC2018-096996-B-C21.**

Juan Pablo Fernandez  y Marcos A. Gonzalez

**"Neutrones, Instrumentacioón Nuclear e Investigación Relacionada con Terapia con Protones en el CNA e Instalaciones Internacionales". RTI2018-098117-B-C21.**

Joaquín Gómez Camacho y José Manuel Quesada Molina

**Buscando los L´ımites en Espectrometr´ıa de Masas con Aceleradores de Baja Energ´ıa (LEAMS) en el Centro Nacional de Aceleradores: M´etodos y Aplicaciones".**

**PGC2018-094546-B-100.**

Rafael García-Tenorio y José Mª López

# CNA: Other Research Projects

Centro Nacional de Aceleradores

**“Nuclear Physics Developments for Proton Therapy: delivering the right effective dose to the right place (NucPhysPT)”. P18-RT-1900. Proyecto Ayuda PAIDI2020. I+D+I.** Miguel Antonio Cortés y Carlos Guerrero

**“Protocolo de Caracterizacion in Situ de Obras Pictoricas mediante Tecnicas Nucleares no Destructivas y Otras Tecnicas no Invasivas: Aplicacion a las Colecciones del Arzobispado y Catedral de Sevilla,”. P18-RT-1877. Proyecto Ayuda PAIDI2020. I+D+I.** Miguel Angel Respaldiza y Francisco Jose Ager

**“AMS and radiometrically determined radionuclides as tracers of natural processess in the Artic and Southern Oceans”. US-1263369. Proyectos I+D+I FEDER Andalucía.** Marıa Villa y Jose María Lopez Gutierrez

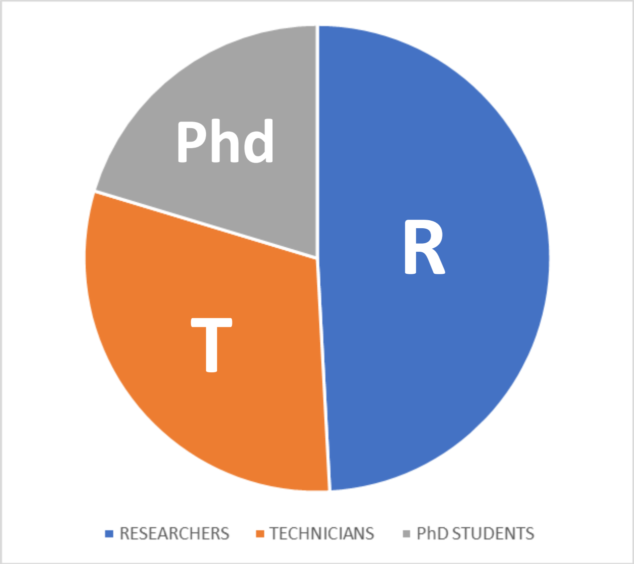
**“Puesta en marcha y explotacion de la lınea de tiempo de vuelo en el CNA”. US-1261006. Proyectos I+D+I FEDER Andalucía 2014-2020 1ª Convocatoria.** Begoña Fernandez Martınez.

**“Predicción del Comportamiento Eléctrico de Dispositivos Electrónicos bajo Radiación (PRECEDER)”, Subvención a la Investigación: Proyecto Singular de Transferencia de Conocimiento (Inteligencia Artificial-Andalucía Tech). Junta de Andalucía. Consejería de Economía, Conocimiento, Empresas y Universidad.** Yolanda Morilla.

**Desarrollo del Laboratorio de Estudios Avanzados de DEtectores de Radiación. (LEADER). Proyectos I+D+I FEDER Andalucía 2014-2020. 2ª Convocatoria.** Maria del Carmen Jimenez Ramos.

# CNA: Employees

| | |
|---|---|
| **TOTAL:** | **59** |
| **RESEARCHERS:** | **29** |
| **TECHNICIANS:** | **18** |
| **PhD STUDENTS:** | **12** |



# CNA: Interdisciplinar Research

Centro Nacional de Aceleradores

**Material Science**

Thin films, ceramics, metallic alloys

**Medicine and Biology**

Organic fluids, tissues, radiopharmacy

**Art and Archaeometry**

Metals, ceramics, paintings

**Environmental research**

Water, aerosols, sediments, soils

**Basic Nuclear Physics**

Astrophysics, detectors, nuclear electronic

**Mass Spectrometry with accelerators**

Carbon dating, environmental applications

**Accelerated irradiation testing**

Astrophysics, detectors, nuclear electronic

**Scholar and scientific outreach activities**

Academic training, high and secundary school visits

CNA
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# CNA: Laboratories

**Van de Graaff 3 MV Tandem Accelerator**

**Gamma Irradiator (RadLab)**

**Accelerator 1MV Mass Spectrometer (SARA)**

**Radiocarbon Dating System (MiCaDaS)**


**18/9 MeV Cyclotron Accelerator**

**PET / CT scanner**

**Radiopharmacy**

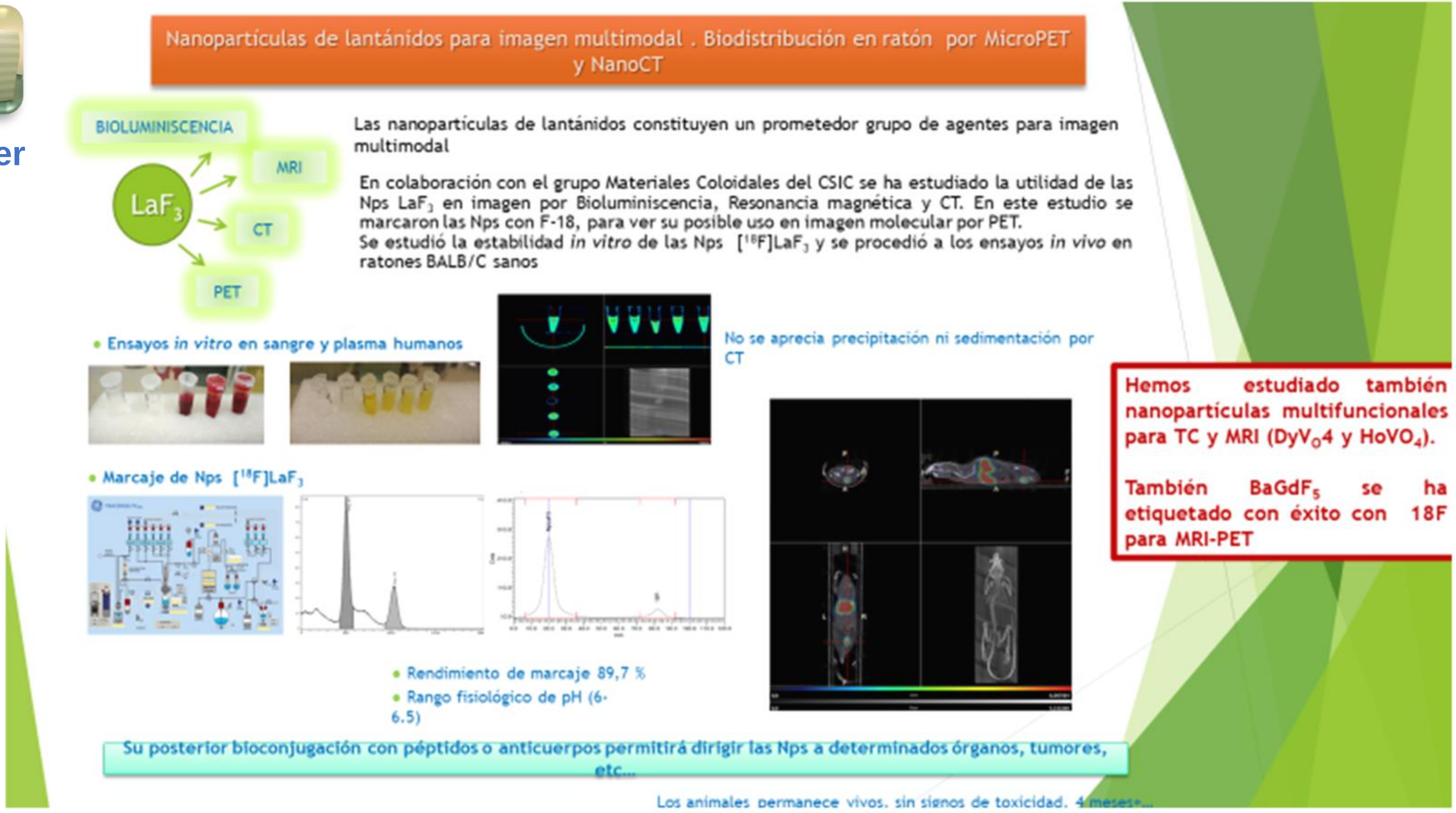
# CNA: Molecular Imaging

PET / CT scanner

# CNA: Nanoparticles.

Centro Nacional de Aceleradores

PET / CT scanner



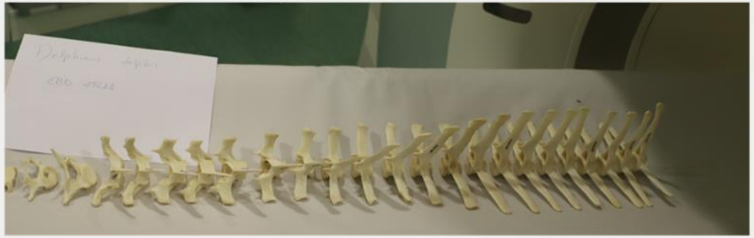
# CNA: Spinal Column Evolution

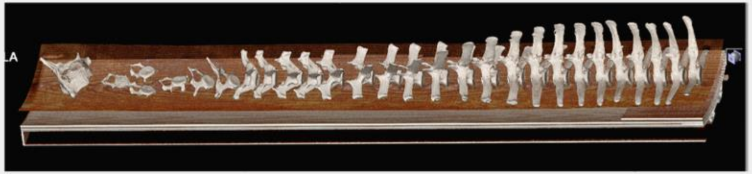
PET / CT scanner

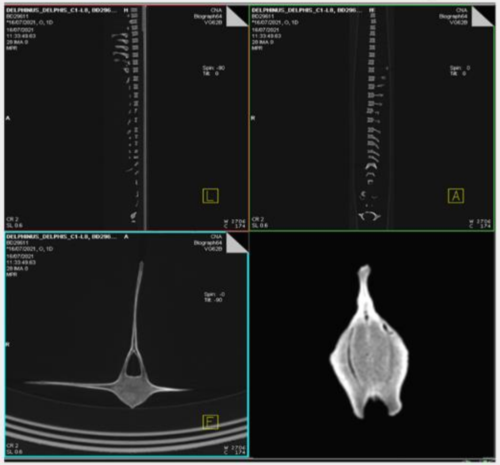
# CNA: Spinal Column Evolution

PET / CT scanner

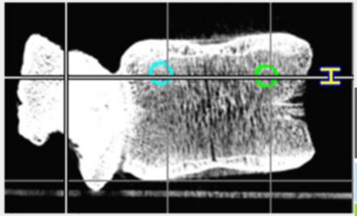
## Delphinus Delphis (EBD29611M)







Mar abierto y oceánico



| Min (HU) | Max (HU) | Hot Averaged (HU) | Averaged (HU) | Sd (HU) |
|---|---|---|---|---|
| -857.407 | 3262.409 | 3182.582 | **546.089938** | 329.134196 |
| -1000 | 3942.877 | 3613.26 | **389.676953** | 381.667774 |

# CNA: SARA (Spanish Accelerator for Radionuclides Analysis)

Centro Nacional de Aceleradores

**Accelerator 1MV Mass Spectrometer (SARA)**

# Isotopic relation $^{233}U/^{236}U$

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**Accelerator 1MV Mass Spectrometer (SARA)**

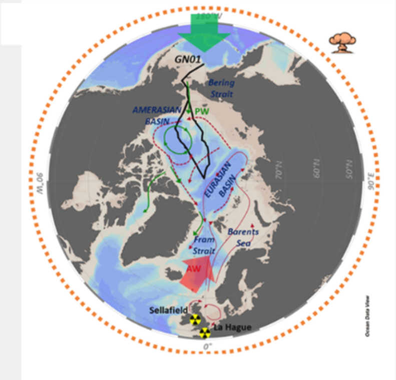
## ¿Puede usarse la relación isotópica $^{233}U/^{236}U$ para trazar masas de agua en el Océano Ártico?


E. Chamizo, M. Christl, M. López-Lora, N. Casacuberta, A.M. Wefing, T. Kenna

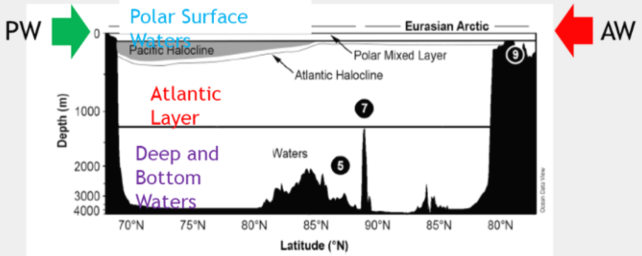
Lamont-Doherty Earth Observatory
COLUMBIA UNIVERSITY | EARTH INSTITUTE

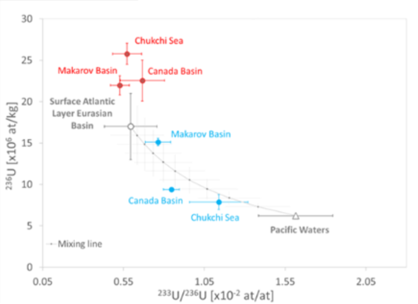
Centro Nacional de Aceleradores

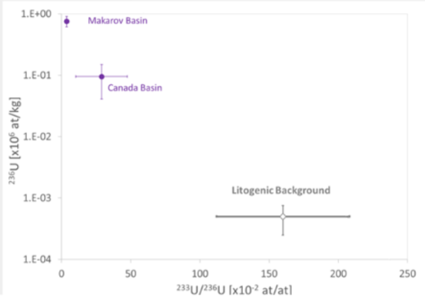
ETH Zürich


| | GF | SF+LH |
|---|---|---|
| $^{236}U$ | 1000 kg | 250 kg |
| $^{233}U$ | 1.2 kg | <1 g |
| $^{233}U/^{236}U$ | $(1.14 \pm 0.02)\times10^{-2}$ [Hain et al., 2020] | $<10^{-6}$ |

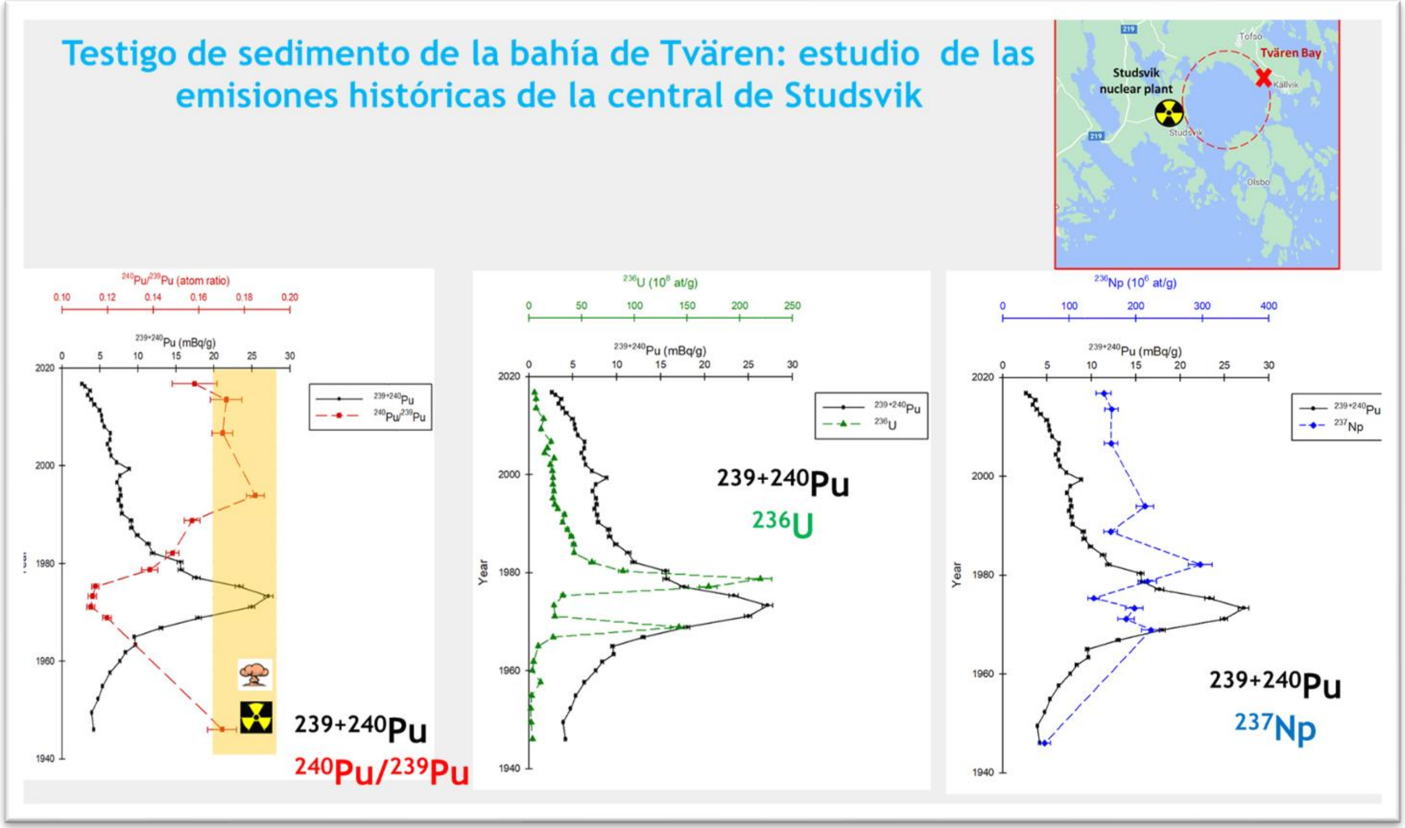


# Historic Emissions from Studsvik

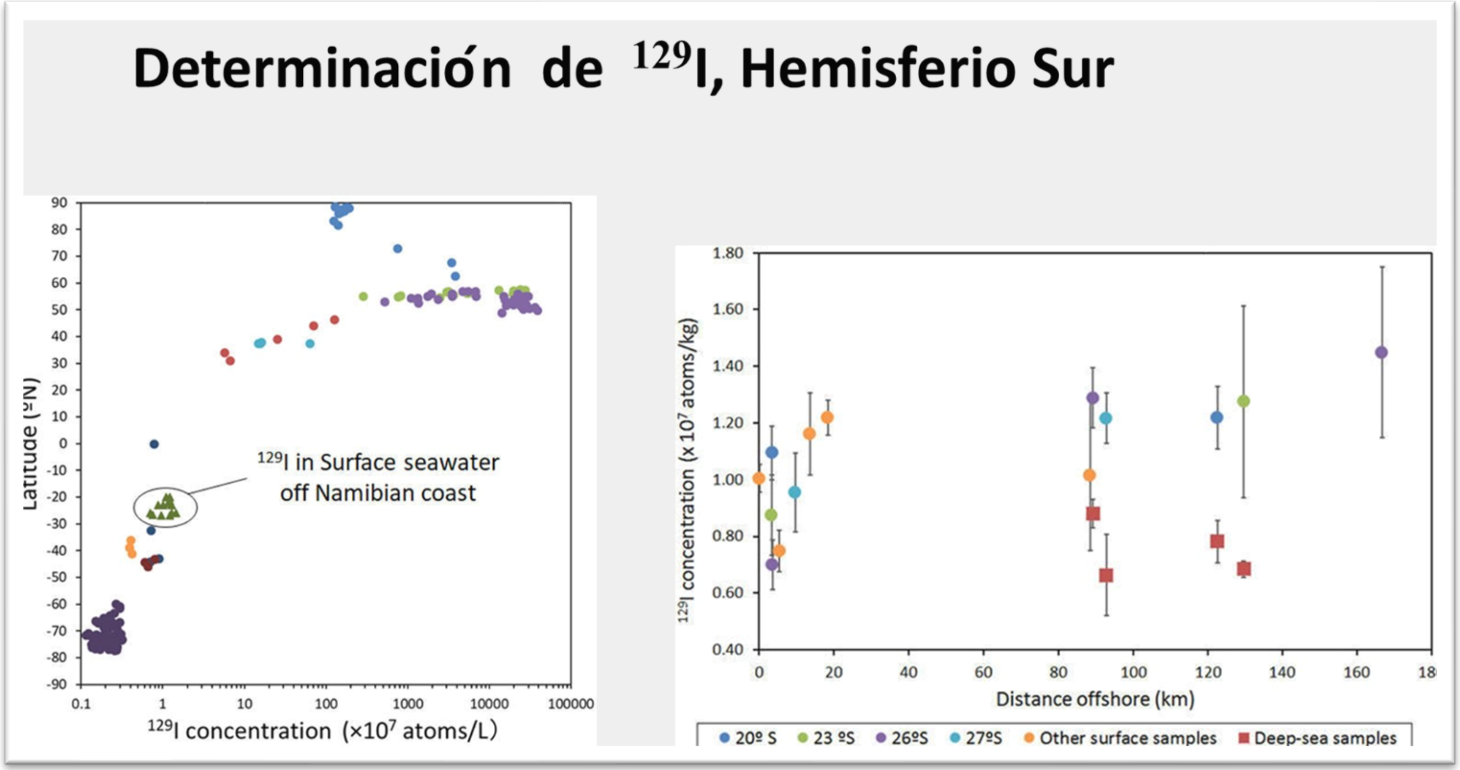
**Accelerator 1MV Mass Spectrometer (SARA)**



Centro Nacional de Aceleradores

# $^{129}$I from Southern Hemisphere

**Accelerator 1MV Mass Spectrometer (SARA)**



# MiCaDaS (Mini Carbon Dating System)

**Radiocarbon Dating System (MiCaDaS)**

# Radiocarbon against illegal ivory trafficking

Centro Nacional de Aceleradores

Radiocarbon Dating System (MiCaDaS)

## Radiocarbono contra el tráfico ilegal de marfil

- El CNA participa en el plan TIFIES realizando dataciones de piezas de marfil para verificar su antigüedad.
- La datación se basa en la señal de radiocarbono generada por las pruebas nucleares.


- Greg Hodgins, de la Universidad de Arizona, fue demandado por un "cliente descontento". Una talla de madera de 200 años y $15.000 resultó ser de 1975.
- Nuevo protocolo para la aceptación de muestras de particulares. "Radiocarbon dating and the protection of cultural heritage", Hajdas, Jull y Synal, 2020.
- CNA está en el grupo de laboratorios que acuerdan compromisos de comportamiento.

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# CNA: Particle accelerators (irradiation)

Van de Graaff 3 MV Tandem Accelerator

Gamma Irradiator

18/9 MeV Cyclotron Accelerator

# CNA: TANDEM

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Van de Graaff 3 MV
Tandem Accelerator

Protons: from 550keV to 6MeV

Ions: from H to Au

Neutrons: ~1.5 – 9 MeV

Air or Vacuum

$p^+$ HI n

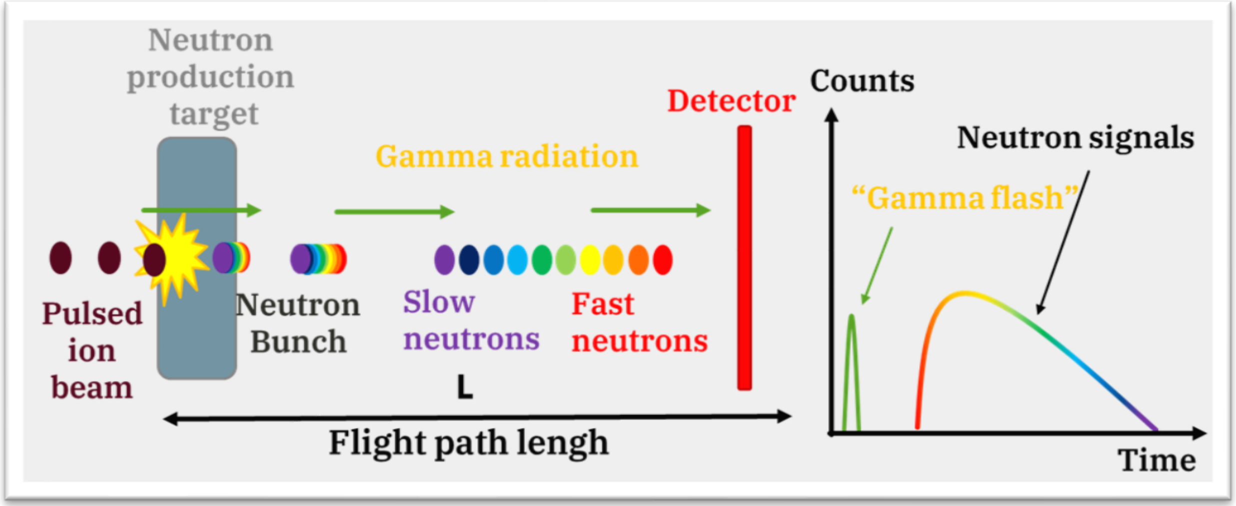
Centro Nacional de Aceleradores

# Tandem: 8 different lines

# CNA: TANDEM. Time-of-Flight

Van de Graaff 3 MV
Tandem Accelerator

**Neutron Production: time-of-flight**




$$E_n = \frac{1}{2} m_n \left( \frac{L}{ToF} \right)^2$$

**It allows to know the energy of the neutron which initiated the reaction**

# CNA: TANDEM. Detectors tests.

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Van de Graaff 3 MV
Tandem Accelerator

## Detectors characterization

Detectores CLYC para diagnóstico en fusión
(Colab. con INFN-MIB & Fusión@CNA)

Sensibilidad neutrónica de detectores
i-TED para captura de neutrones en CERN
n_TOF (Colab. con CSIC-IFIC & CIEMAT)

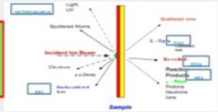

Desarrollo de detector *muiltifoi-BSS*
(Colab. con n_TOF-CERN & CIEMAT)

# CNA: TANDEM. Materials characterization

Centro Nacional de Aceleradores

Van de Graaff 3 MV
Tandem Accelerator

**CARACTERIZACIÓN MATERIALES TÉCNICAS IBA (Ion Beam Analysis)**



nano on surf

WILEY-VCH

FULL PAPER

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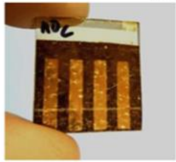
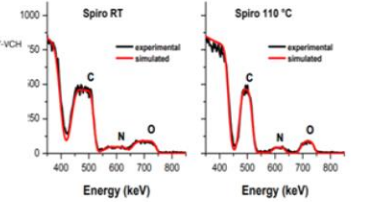
## Enhanced Stability of Perovskite Solar Cells Incorporating Dopant-Free Crystalline Spiro-OMeTAD Layers by Vacuum Sublimation

*Angel Barranco,* Maria C. Lopez-Santos, Jesus Idigoras, Francisco J. Aparicio, Jose Obrero-Perez, Victor Lopez-Flores, Lidia Contreras-Bernal, Victor Rico, Javier Ferrer, Juan P. Espinos, Ana Borras, Juan A. Anta, and Juan R. Sanchez-Valencia**






3. Rutherford Backscattering Spectra. Experimental and simulated spectra RBS with 2.0 MeV alpha particles and PIPS detector set at 165° of Spiro-OMeTAD deposited at

Nuclear Inst. and Methods in Physics Research, A 890 (2018) 142–147

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

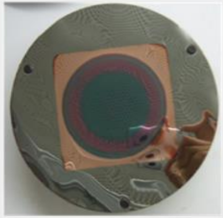
journal homepage: www.elsevier.com/locate/nima

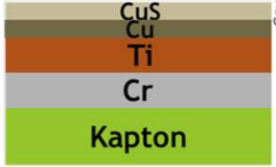
ELSEVIER

Technical Notes

## Preparation and characterization of $^{33}$S samples for $^{33}S(n,\alpha)^{30}Si$ cross-section measurements at the n_TOF facility at CERN

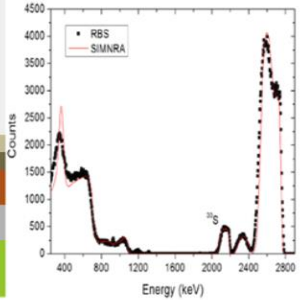
J. Praena [1,*], F.J. Ferrer [2], W. Vollenberg [3], M. Sabaté-Gilarte [4,3], B. Fernández [2,4], J. García-López [2,4], I. Porras [1], J.M. Quesada [4], S. Altstadt [5], J. Andrzejewski [6], L. Audouin [7], V. Bécares [8], M. Barbagallo [9], F. Bečvář [10], F. Belloni [11], E. Berthoumieux [11], J. Billowes [12], V. Boccone [3], D. Bosnar [13], M. Brugger [3], F. Calviño [14], M. Calviani [3], D. Cano-Ott [8], C. Carrapiço [15], F. Cerutti [3], E. Chiaveri [3,11], M. Chin [3], N. Colonna [9], G. Cortés [14], M.A. Cortés-Giraldo [4], M. Diakaki [16], M. Dietz [17], C. Domingo-Pardo [18], R. Dressler [19], I. Durán [20], C. Eleftheriadis [21], A. Ferrari [3], K. Fraval [11], V. Furman [22], K. Göbel [5], M.B. Gómez-Hornillos [14], S. Ganesan [23], A.R. García [8], G. Giubrone [18], I.F. Gonçalves [15], E. González-Romero [8], A. Goverdovski [24], E. Griesmayer [25], C. Guerrero [3], F. Gunsing [11], T. Heftrich [5], A. Hernández-Prieto [3,14], J. Heyse [26], D.G. Jenkins [27], E. Jericha [25], F. Käppeler [28], Y. Kadi [3], D. Karadimos [16], T. Katabuchi [29], V. Ketlerov [24], V. Khryachkov [24], N. Kivel [19], P. Koehler [30], M. Kokkoris [16], J. Kroll [10], M. Krtička [10], C. Lampoudis [11], C. Langer [5], E. Leal-Cidoncha [20], C. Lederer [31], H. Leeb [25], L.S. Leong [7], J. Lerendegui-Marco [4], R. Losito [3], A. Mallick [23], A. Manousos [21], J. Marganiec [6], T. Martínez [8], C. Massimi [32,33], P. Mastinu [34], M. Mastromarco [9], E. Mendoza [8], A. Mengoni [35], P.M. Milazzo [36], F. Mingrone [32], M. Mirea [37], W. Mondelaers [26], C. Paradela [20], A. Pavlik [31], J. Perkowski [6], A.J.M. Plompen [26], T. Rauscher [38], R. Reifarth [5], A. Riego-Perez [14], M. Robles [20], C. Rubbia [3], J.A. Ryan [12], R. Sarmento [15], A. Saxena [23], P. Schillebeeckx [26], S. Schmidt [5], D. Schumann [19], P. Sedyshev [22], G. Tagliente [9], J.L. Tain [18], A. Tarifeño-Saldivia [18], D. Tarrío [20], L. Tassan-Got [7], A. Tsinganis [3], S. Valenta [10], G. Vannini [32,33], V. Variale [9], P. Vaz [15], A. Ventura [32], M.J. Vermeulen [27], V. Vlachoudis [3], R. Vlastou [16], A. Wallner [39], T. Ware [12], M. Weigand [5], C. Weiss [25], T. Wright [12], P. Žugec [13],






n_TOF

CERN



Centro Nacional de Aceleradores

# TANDEM. Neutron imaging

Van de Graaff 3 MV
Tandem Accelerator

# CNA: TANDEM. Nuclear physics

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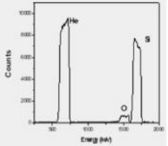
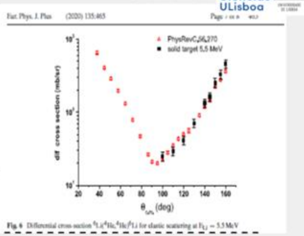
**Van de Graaff 3 MV Tandem Accelerator**

## Solid He targets for Nuclear Physics Experiments

**Small Scale Facility** (CNA)

$^4He(^6Li,^4He)^6Li$
$E_Li = 0,9$ MeV/uma

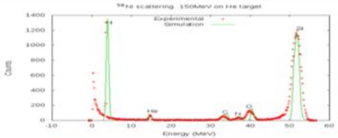



↓

**Large Scale Facility** (INFN – Laboratori Nazionali del Sud)

$^4He(^{58}Ni,^4He)^{58}Ni$
$E_{Ni} = 2,6$ MeV/uma



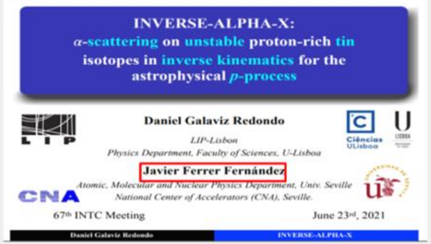

| Thick(um) | %He/%Si |
|---|---|
| 1.09 | 0.068 |

| Element | Si | He | C | O | N |
|---|---|---|---|---|---|
| Quantity (x10¹⁵atoms/cm²) | 3886 | 264 | 264 | 377 | 151 |

↓

**Radiactive Ion Beam** (CERN – ISOLDE)

$^4He(^{108}Sn,^4He)^{108}Sn$
$E_{Ni} = 4,9$ MeV/uma


INVERSE-ALPHA-X:
α-scattering on unstable proton-rich tin isotopes in inverse kinematics for the astrophysical p-process

Daniel Galaviz Redondo
LIP-Lisbon
Physics Department, Faculty of Sciences, U-Lisboa
Javier Ferrer Fernández
Atomic, Molecular and Nuclear Physics Department, Univ. Seville
National Center of Accelerators (CNA), Seville.
67th INTC Meeting
June 23rd, 2021

# CNA: TANDEM. Materials characterization

**Van de Graaff 3 MV Tandem Accelerator**

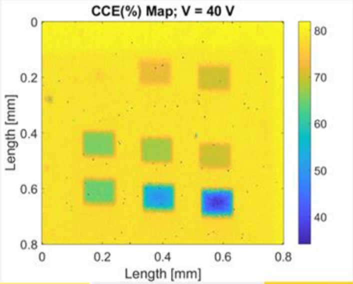
Proyecto RETOS-Empresa (RTC-2017-6369-3):
**Graphene-enhanced RAdiation detector on Silicon Carbide for harsh Environments**

**Consorcio:** Universidad de Sevilla, CNM (Centre Nacional de Microelectrònica, IMB), ALTER TECHNOLOGY

Equipo: **M. C. Jiménez-Ramos** (Representante de la USE en el CP), J. García López y A. García

**Detector de SiC (ancho gap)**
Nuevo diagnóstico para partículas alfa en reactores de fusión ( He 3.5 MeV)


**¿Cómo se degrada el detector con la dosis de He?**
Daño micrométrico controlado usando una microsonda iónica
(8 regiones 100x100 micras con distintas dosis)

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MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

# CNA: Cyclotron Accelerator


18/9 MeV Cyclotron Accelerator

**Protons: 18MeV**

**Deuterium: 9MeV**

**Lower energies availables using degraders.**

**Air or Vacuum**

$p^+$

# CNA: Real-Time Dosimeter



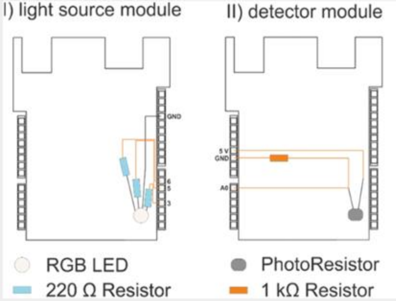
**18/9 MeV Cyclotron Accelerator**

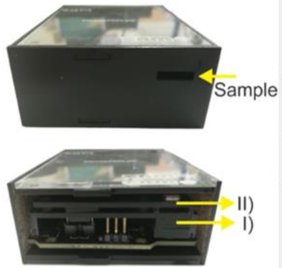
## PATENTE: CNA & CNRS & CNM)

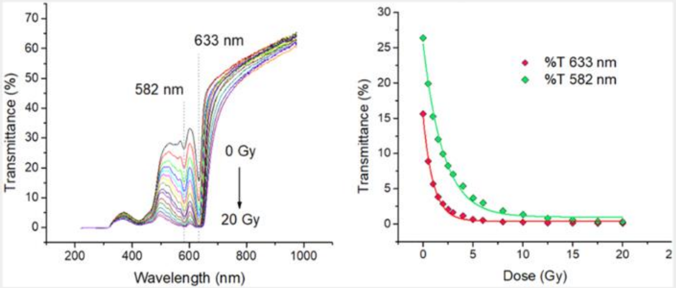
Patent Appllication: Europe N° 21305315.0
March 12, 2021

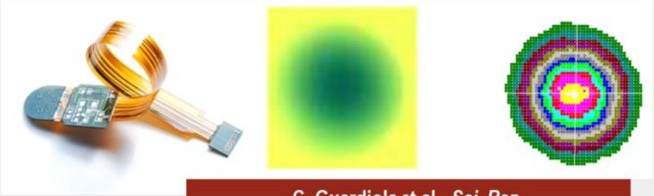
### DOSIMOEMS:
### DEVELOPMENT OF REAL-TIME DOSIMETER BASED ON MICRO-OPTO-ELECTROMECHANICAL SYSTEMS

**New MOEMS-based dosimeter which overcomes the limitations of processing radiochromic films by transforming a passive detector into an active sensor.**



C. Guardiola et al., *Sci. Rep.* 11, 2021, 10414

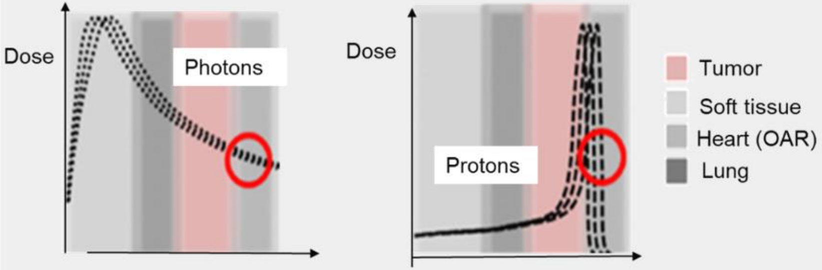
1) Developing MOEMs for obtaining 2D-dose maps
2) Developing thin flexible printed circuit to integrated MOEMs
3)Performing micro-antennas integrated into the DOSIMOEM multi-array and wireless communication systems for sending the output-signal from the device attached in the patient-body to the external radiotherapy control room.

# CNA: Beta+ emitters

Centro Nacional de Aceleradores

**18/9 MeV Cyclotron Accelerator**

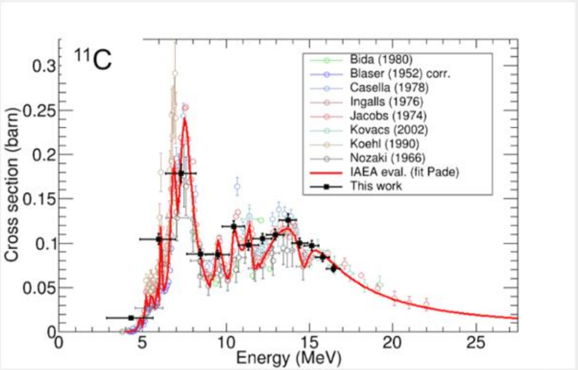
## Range verification measures through the determination of the cross section of production of β+ emitters




**Need of more accurate measurement of cross-section values in the full energy range (0-250 MeV):** PET range verification method could give mm accuracy.

Our marked objective!

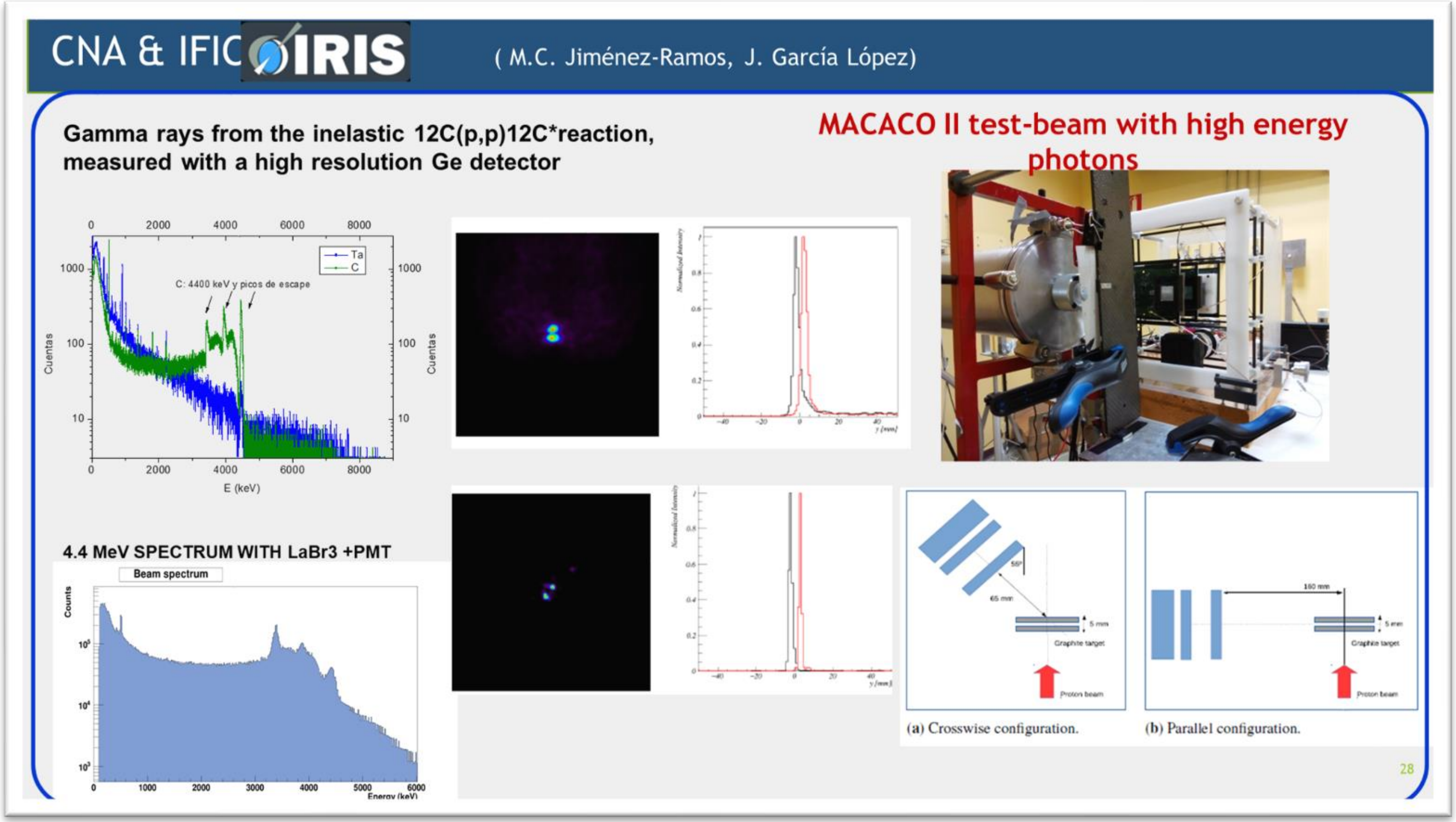
- β+ emitters $^{11}C$ (20 min) and $^{13}N$ (9.9 min) produced in the body of the patient during the irradiation.
- The simultaneous 511 keV photons allows the monitoring of the range after the irradiation.
- Relation between the induced activity distribution and the dose distribution is not straightforward: **Need of comparison of the measured activity distribution with a simulated (MC codes) activity distribution.**
- Accuracy of the MC codes dominated by the **underlying cross section data**.



# CNA: Gamma rays from inelastic reaction 12C(p,p)12C*

Centro Nacional de Aceleradores

**18/9 MeV Cyclotron Accelerator**



# CNA: Irradiation Capabilities


Gamma Irradiator

# CNA: Irradiation Capabilities

Centro Nacional de Aceleradores

γ

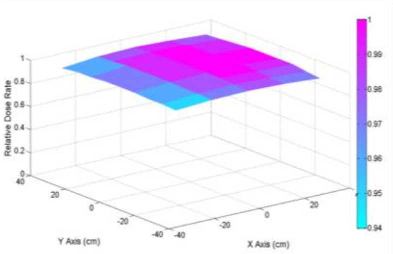

Gamma Irradiator

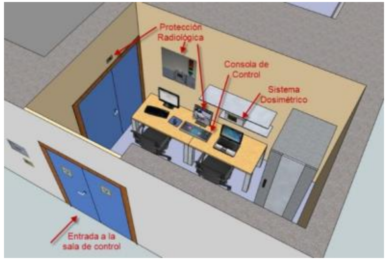
**Co-60 Gammabeam™ X200 Irradiator**

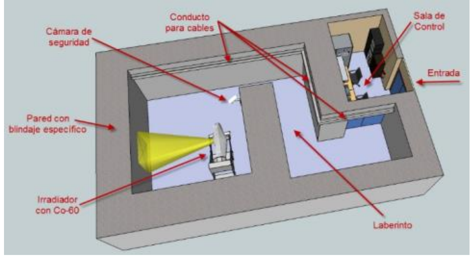
**Photons: 1.17MeV and 1.33MeV**

**Activity: 121TBq** (to date)

**Kerma rate up to 150 Gy/h** (to date)



# CNA: RADNEXT

Centro Nacional de Aceleradores

**Gamma Irradiator**

## RADNEXT

- RADiation facility Network for the EXploration of effects for indusTry and research
- H2020 INFRAIA-02-2020: Integrating Activities for Starting Communities
- EU Project 101008126 (CNA Key person: Yolanda Morilla)
- Objective of creating a network of facilities and related irradiation methodology for responding to the emerging needs of electronics component and system irradiation; as well as combining different irradiation and simulation techniques for optimizing the radiation hardness assurance for systems, focusing on the related risk assessment.

**Partners & Associates**


https://radnext-network.web.cern.ch/radnext-network/main/

WP01/MGT Project Management

**Networking Activities**
- WP02/NA1 Communication, dissemination, exploitation and training
- WP03/NA2 Transnational access management and harmonization
- WP04/NA3 Roadmap and pre-design of future irradiation facilities

**Joint Research Activities**
- WP05/JRA1 Radiation monitors, dosimeters and beam instrumentation
- WP06/JRA2 Standardization of system level radiation qualification methodology
- WP07/JRA3 Cumulative radiation effects on electronics
- WP08/JRA4 Complementary modelling tools

**Transnational Access**
- WP09/TA1 Neutron, muon and mixed-field spallation facilities and irradiation
- WP10/TA2 Proton and heavy ion beams and irradiation

**Coordinator:** CERN

**Facilities:**
- GSI (Germany)
- KVI-CART (Netherlands)
- GANIL (France)
- RADEF (Finland)
- UCLouvain (Belgium)
- PSI (Switzerland)
- CNA (Spain)
- NPI CAS (Czech Republic)
- TRIUMF (Canada)
- STFC-ISIS (UK)
- FNG (Italy)
- CNRS/LPSC (France)
- Uppsala University/NESSA (Sweden)
- ILL (France)
- Centre Spatial Liege (Belgium)
- HZDR (Germany)
- ESRF (France)
- ELI Beams (Czech Republic)
- CLPU (Spain)
- PTB/PIAF (Germany)
- Seibersdorf Laboratories (Austria)

**Academia:**
- University of Montpellier (France)
- KU Leuven (Belgium)
- Padova University (Italy)
- Saint-Etienne University (France)
- Oldenburg University (Germany)
- Carlos III Madrid University (Spain)
- ISAE-SUPAERO (France)

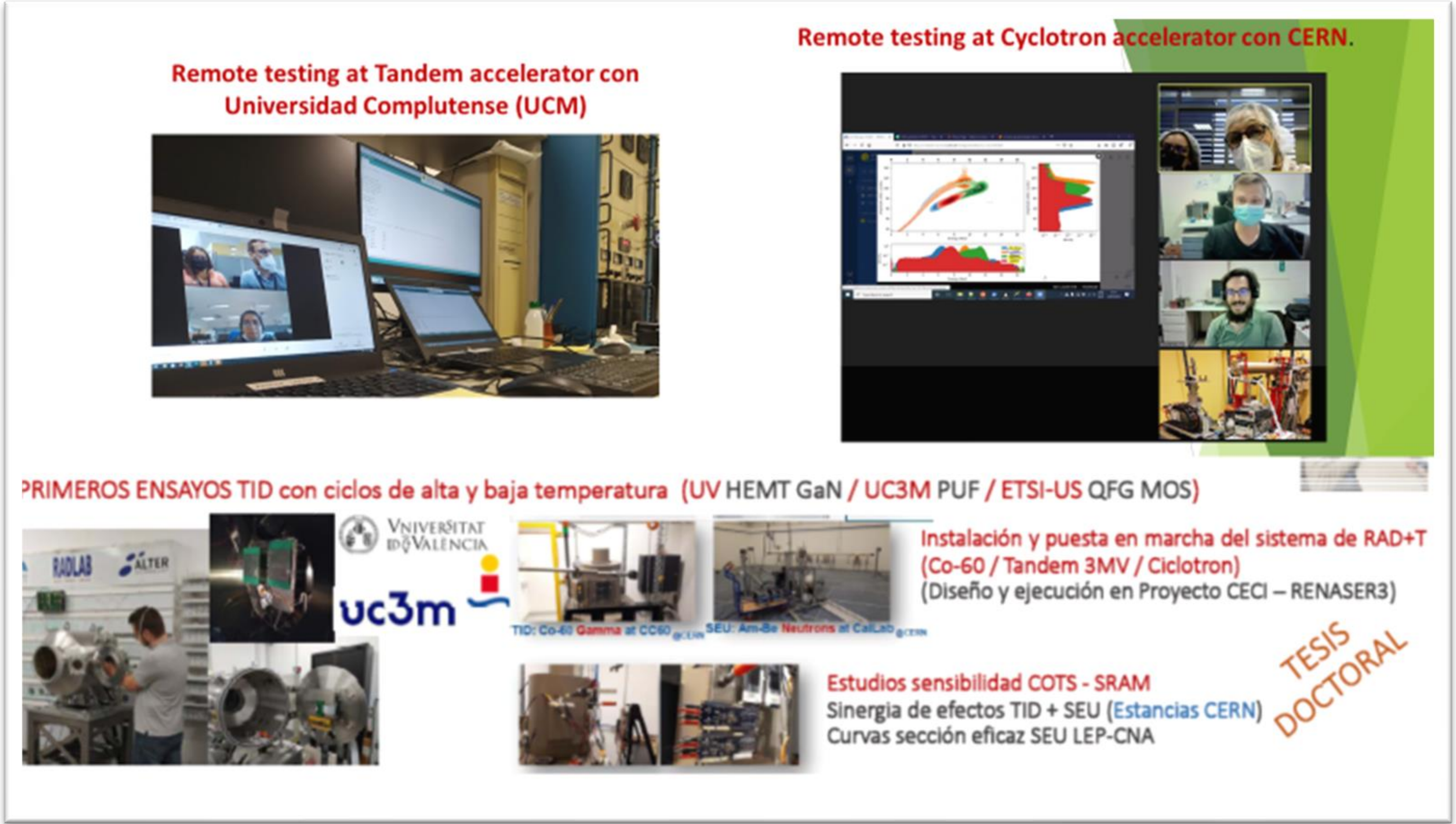
**Agencies & Institutes:**
- CNES (France)
- DLR (Germany)
- INTA (Spain)
- Fraunhofer INT (Germany)

**Industry:**
- Airbus (International)
- 3D-Plus (France)
- IROC Technologies (France)
- ALTER (Spain)

Centro Nacional de Aceleradores

# CNA: Remote Testing

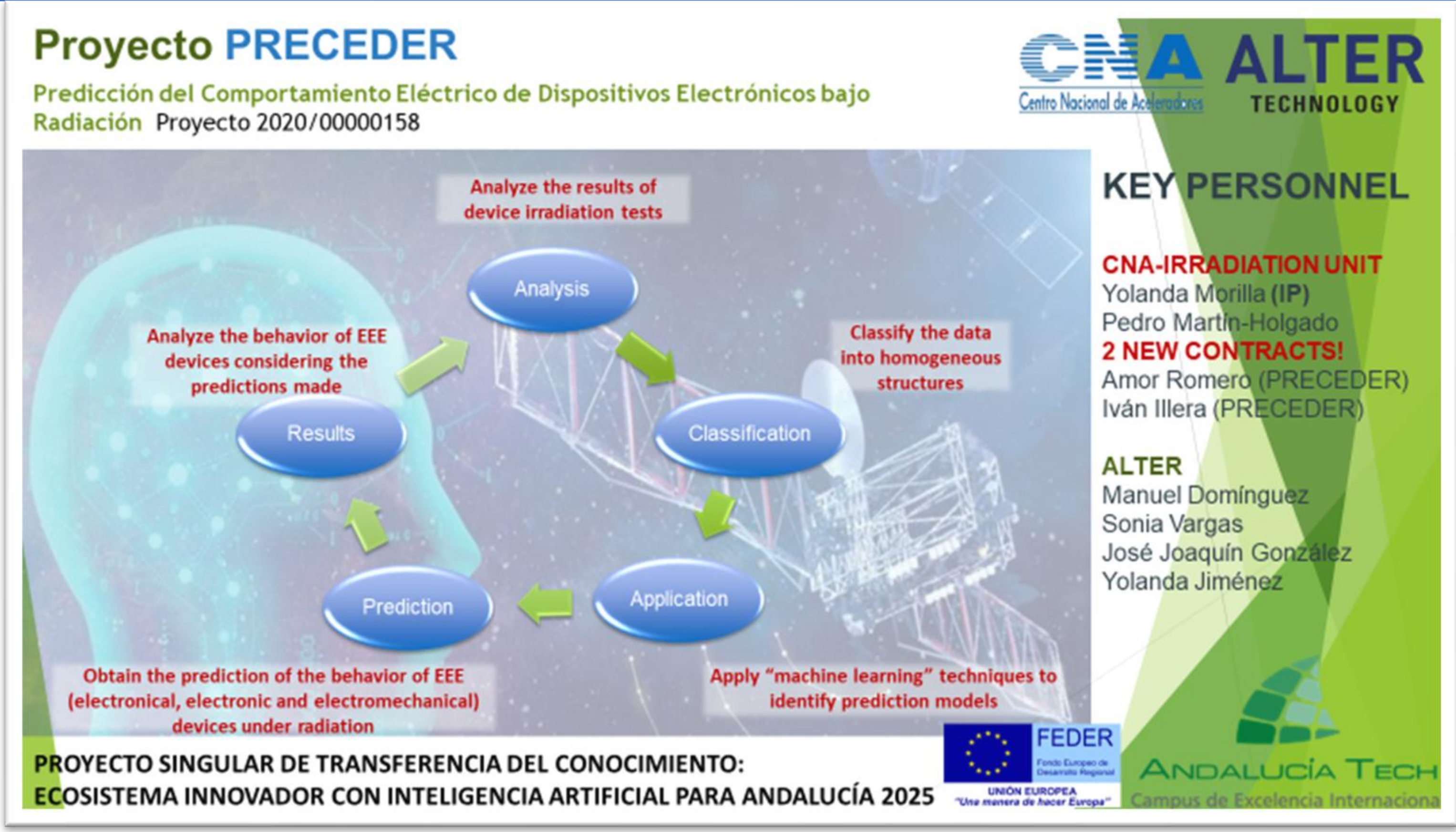

Gamma Irradiator



# CNA: Prediction of Radiation Degradation of EEE devices

Centro Nacional de Aceleradores

**Gamma Irradiator**



Centro Nacional de Aceleradores

# CNA: Prediction of Radiation Degradation of EEE devices

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 69, NO. 7, JULY 2022 1691

## How the Analysis of Archival Data Could Provide Helpful Information About TID Degradation. Case Study: Bipolar Transistors

Pedro Martín-Holgado, *Student Member, IEEE*, Amor Romero-Maestre, José de-Martín-Hernández, José J. González-Luján, Iván Illera-Gómez, Yolanda Jiménez-de-Luna, Fernando Morilla, Mario Sacristan Barbero, Rubén García Alia, *Member, IEEE*, Manuel Domínguez, and Yolanda Morilla

***Abstract*—A critical step of radiation hardness assurance (RHA) for space systems is given by the parts selection in accordance with the observed (or estimated) radiation effects. Although radiation testing is the most decisive way of studying the radiation degradation of electronic components, the increasing use of commercial off-the-shelf (COTS) devices and the challenges posed by *NewSpace* are pushing the need of finding new approaches to assess the risk associated with radiation environments. This work tries to evaluate if valuable information might be extracted from archival data to carry out this assessment despite the well-known and dramatic lot-to-lot, or even part-to-part, variability for some technologies and the impact of the different test conditions, such as the bias conditions and the dose rate in enhanced low dose rate sensitivity (ELDRS). These factors are briefly explained for some examples. A new radiation database is briefly introduced, and some statistical approaches are cited, apart from the analysis herein followed. To finish, a first analysis on three families of bipolar transistors is presented together with the independent results from three external reports, with a good agreement between the experimental results and the expected ones.**

Manuscript received 3 May 2022; accepted 26 May 2022. Date of publication 23 June 2022; date of current version 18 July 2022. This work

***Index Terms*—Bipolar transistors, commercial off-the-shelf (COTS), data analysis, electrical, electronic, and electromechanical (EEE) parts database, gain degradation, lot-to-lot variability, machine learning (ML), *NewSpace*, part-to-part variability, PRECEDER, predictive analysis, radiation hardness assurance (RHA), radiation test, total ionizing dose (TID), virtual laboratory.**

### I. Introduction and Background

SURVIVAL and the successful operation of space systems in the space radiation environment cannot be ensured without careful consideration of the effects of radiation. Radiation hardness assurance (RHA) consists of all those activities undertaken to ensure that the electronics of a space system perform to their specification after exposure to the space radiation environment. A key element of RHA is the selection of components having sufficient tolerance to radiation effects for their application [1].

According to [1] and [2], radiation effects that are important to be considered for instrument and spacecraft design fall roughly into three categories: degradation from total ionizing dose (TID), degradation from displacement damage (DD), and single event effects (SEEs). In this work, we focus on TID



## Predictive study of the performance characteristics degradation of optocouplers combining TID-DD effects with gamma and proton radiation

Pedro Martín-Holgado, Amor Romero-Maestre, José de-Martín-Hernández, José Manuel Ramírez-García, José J. González-Luján, Álvaro Ricca-Soaje, Mario Sacristan Barbero, Rudy Ferraro, Rubén García Alia, Manuel Domínguez, and Yolanda Morilla

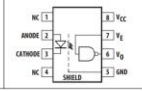
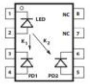
***Abstract*—Optocouplers are crucial components in harsh environments, and therefore prediction of their degradation as a result of irradiation is highly demanded. This work shows a successful predictive tool for the CTR parameter based on archival data.**

***Index Terms*—Archival data, COTS, CTR, Data analysis, Displacement Damage, Input Threshold Current, Optocoupler, PRECEDER, Predictive analysis, Radiation test, Total Ionizing Dose**

### I. Introduction

SIMILARLY to the work performed on bipolar transistors [1], the authors' purpose now is to find a mathematical model of the performance characteristics degradation of two optocouplers based on the analysis of archival data, and validate it with radiation test results from new pristine samples. These models may help to predict the behavior of these devices in radiation environments.

TABLE I: Basic Properties of Devices Under Test

| | HCPL-060-500E | HCNR-200-300E |
|---|---|---|
| Technology | GaAsP | AlGaAs |
| Package | SOIC-8 | DIL-8 |
| Date code | 2118 | 2140 |
| Operating Temperature | -40 °C to +85 °C | -55 °C to +100 °C |
| Aver. Input Current ($I_F$) | 20 mA | 25 mA |
| Diagram |  |  |

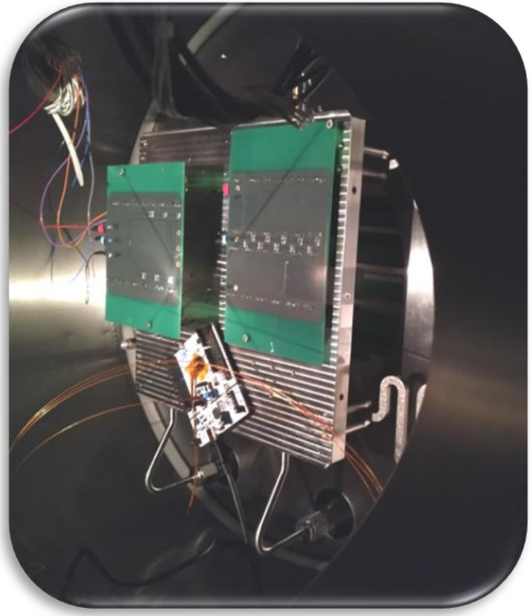
### II. Device Under Test

# CNA: Low and High Temperatures

**Van de Graaff 3 MV Tandem Accelerator**

**Gamma Irradiator**

**18/9 MeV Cyclotron Accelerator**

# CNA: Low and High Temperatures

Centro Nacional de Aceleradores

## First Chamber in Spain to Irradiate at Low and High Temperature with Gamma, Neutrons and Low-Energy Protons

Pedro Martín-Holgado, Ángel J. Romero, Juan A. Labrador, Álvaro Vizcaíno, Juan Herranz, and Yolanda Morilla

***Abstract*—In this work we present the commissioning of the first system, implemented in Spain, to perform irradiation testing at Low and High Temperature with Gamma, Neutrons and Low-Energy Protons. A new chamber has been designed and manufactured in order to be shared in three different laboratories at the CNA. The current control system covers the standard operating temperature ranges of electronic components for space applications.**

***Index Terms*— Chamber, Co-60, Displacement Damage, Enhanced Low Dose Rate Sensitivity (ELDRS), Low Temperature, Gamma, Heat Transmission, High Temperature, JULABO, Low-Energy Protons (LEP), Neutron, Radiation, Single Event Effects (SEE), Total Ionizing Dose (TID), Vacuum.**

### I. Introduction

THE Spanish National Accelerator Centre, Centro Nacional de Aceleradores (CNA) [1], is a public research centre with an Irradiation Unit consisting of three different laboratories which provide gamma radiation (from a Co-60 source) [2], neutrons [3] and low-energy protons [4] for various radiation test purposes: Total Ionizing Dose (TID), Displacement exposure. For instance, to compare the low dose rate (room temperature) to the high dose rate elevated temperature irradiations on linear bipolar microcircuits [10], [11]. Also at low temperatures, showing that the dose rate sensitivity is reduced at low temperature irradiations [12], or how it is possible to improve the radiation performance at reduced temperature [13]. And more recently, a method has been presented to test the Enhanced Low Dose Rate Sensitivity (ELDRS) in linear bipolar devices and ICs [14], by using that the interface-trap density is relatively low at high temperature and low dose.

Concerning SEE, the temperature has also an important role: the worst-case condition for Latch-up (SEL) is maximum operating temperature, whereas for Burnout (SEB) and Gate Rupture (SEGR) is low operating temperature [8]. Other studies show significant increase of upset multiplicity over at elevated temperatures (300-400 K) in 65 nm CMOS SRAM [15].

Some instruments have been presented in previous works to irradiate at different temperature ranges, like the cryostat developed by CNES for heavy ion and high-energy proton testing from 80 K to 300 K [16], and the small chamber used by

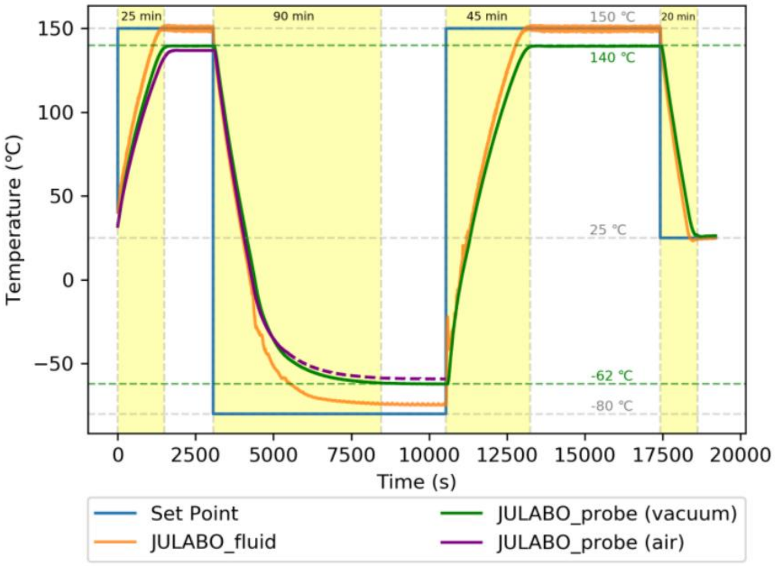



Fig. 5. Rise and fall ramps from maximum and minimum temperatures using the maximum temperature gradient per minute for cooling and heating respectively.


# Thank you very much for your attention!