Advancement and Innovation for Detectors at Accelerators

Task 4.3 - Common Tools for Irradiation Facilities QC: Data Management, Traceability, Dosimetry and Activation Measurements

P. Garosi, B. Gkotse, **F. Ravotti**, on behalf of Task 4.3

18 March 2024

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004761.

Outline

- Task Objectives & Management
- Activities Status
  - **Objective 1:** IDM Updates & Generalization
  - **Objective 2:** Integrated system for induced activation measurements and RFID tagging
  - **Objective 3:** Common NIEL dosimetry calibration set for cross-comparison of irradiation facilities
- Timeline
- Conclusion

Task 4.3 Objectives

1. **Generalize the <u>I</u>RRAD facility <u>D</u>ata <u>M</u>anager (IDM)** system to **include new facilities** and **improve its features** (usability, sharing of irradiation experiment results and operational data, etc.)

2. **Design and develop** a prototype for an **integrated system** to **manage induced activation** (APEX-gamma, etc.) and **traceability data for irradiated objects** (CAEN DigiWaste) based on IDM

3. **Produce a common dosimetry calibration set** for **cross-comparing irradiation facilities** by evaluating, with **dedicated dosimeter structures,** the **Non-Ionizing Energy Loss (NIEL)** of their particle beam

Task 4.3 Management

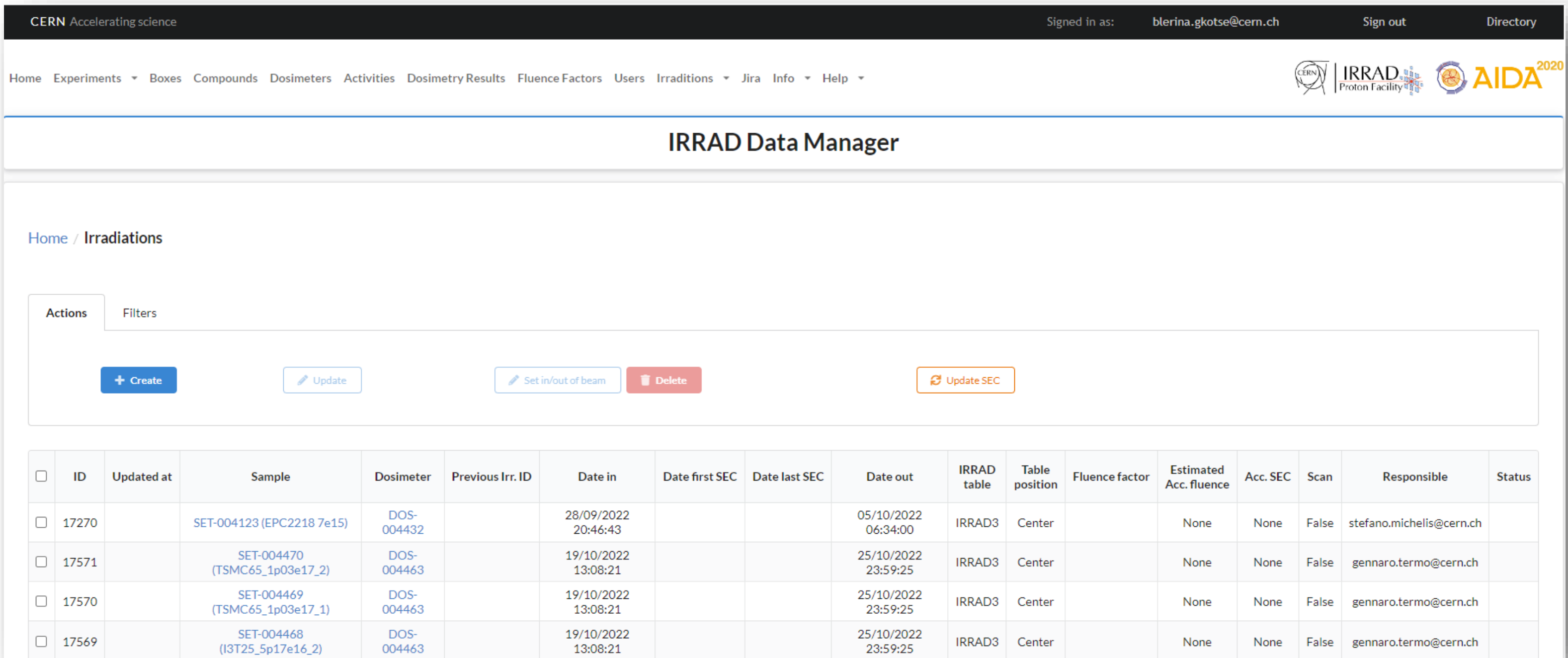
- Blerina Gkotse **moved from CERN to the University of Madison**, Wisconsin (USA) as of 2024:
  - CERN User (EP-DT) collaborating in common R&D activities

- **Paola Garosi (CAEN)** is the new Task 4.3 leader!

- **#3 task meetings during** the last year:
  - https://indico.cern.ch/category/13502/

IRRAD Data Manager (IDM) Updates

Objective 1



	ID	Updated at	Sample	Dosimeter	Previous Irr. ID	Date in	Date first SEC	Date last SEC	Date out	IRRAD table	Table position	Fluence factor	Estimated Acc. fluence	Acc. SEC	Scan	Responsible	Status
☐	17270		SET-004123 (EPC2218 7e15)	DOS-004432		28/09/2022 20:46:43			05/10/2022 06:34:00	IRRAD3	Center		None	None	False	stefano.michelis@cern.ch	
☐	17571		SET-004470 (TSMC65_1p03e17_2)	DOS-004463		19/10/2022 13:08:21			25/10/2022 23:59:25	IRRAD3	Center		None	None	False	gennaro.termo@cern.ch	
☐	17570		SET-004469 (TSMC65_1p03e17_1)	DOS-004463		19/10/2022 13:08:21			25/10/2022 23:59:25	IRRAD3	Center		None	None	False	gennaro.termo@cern.ch	
☐	17569		SET-004468 (I3T25_5p17e16_2)	DOS-004463		19/10/2022 13:08:21			25/10/2022 23:59:25	IRRAD3	Center		None	None	False	gennaro.termo@cern.ch	

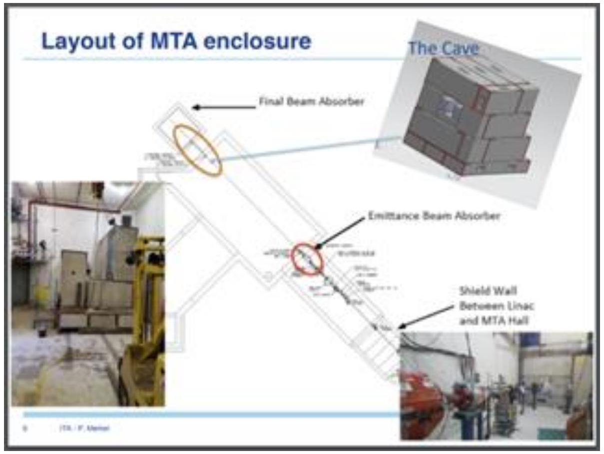
- For irradiation run 2024, **new version of IDM deployed** implementing the recommendations gathered during the **usability session:**
  - SMTP server **changes for e-mail notifications**
  - Making IDM **settings more configurable**
  - etc.

- ## Change of target facility for D4.3

<< While the ***extension of IDM to CERN-GIF++ is completed****,* ***the departure of the senior staff leading the AIDAinnova task at ENEA-FNG in Rome*** *(who moved to a new position at the beginning of 2023), as well as of his post-doc working on the technical development,* ***de facto stopped the software deployment work ongoing at ENEA-FNG required to fully achieve the future D4.3.***

Since the contribution of ENEA-FNG to D4.3 (…) aims to prove that IDM can be generalized and employed in facility infrastructures other than the CERN one, for the purposes of D4.3, ***we propose the change of the target facility for the software deployment from ENEA-FNG to the Fermilab-ITA proton irradiation facility in the USA where the deployment of an extended version of the original IDM tool is currently ongoing*** *with the support of the CERN team involved in Task 4.3. The proposed change of target facility infrastructure* ***does not change the scope of the work and still demonstrate the technical feasibility of the task*** *originally foreseen in D4.3. >>*

Proposal **submitted to the EU and accepted** in September 2023
D4.3 (M45)

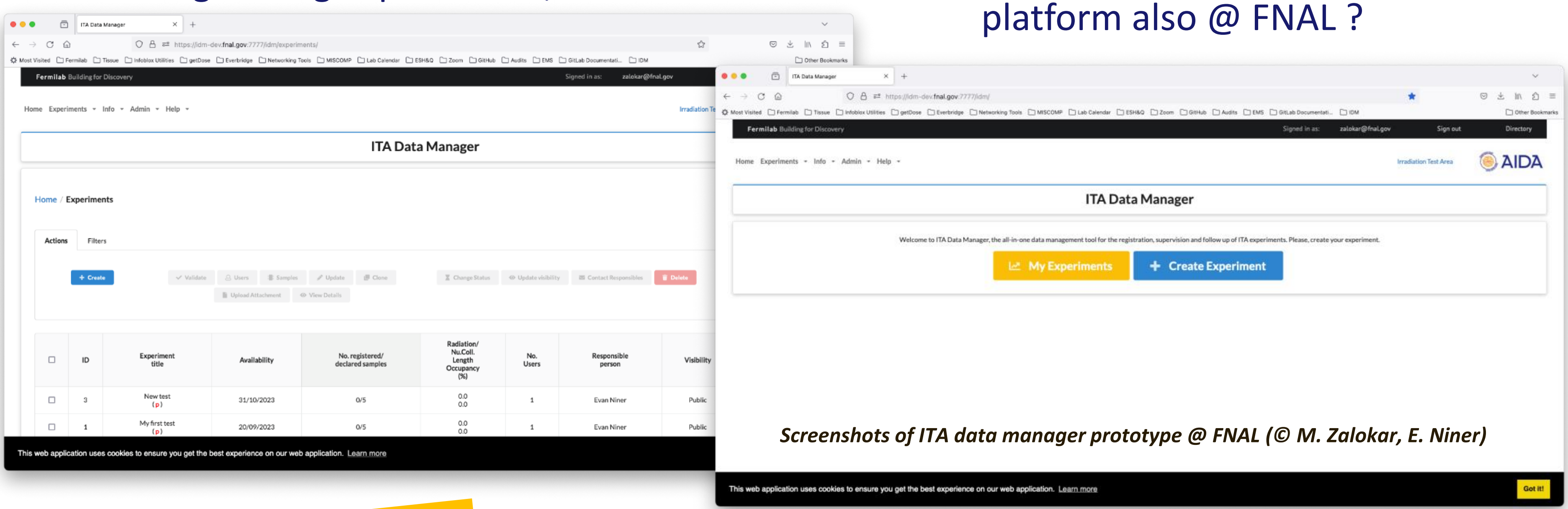


Objective 1

ITA Data Manager @ FNAL

- **Cloning and adapting IDM according to ITA requirements** (based on the work of MS13):
  - a prototype version already exist
- **Meeting @ FNAL on 08/03/24** to discuss technical issues, advancement, support:
  - IT system updates, warnings to users while registering experiments, etc.

- Discussion started about possibility to test CAEN DigiWaste platform also @ FNAL ?



Screenshots of ITA data manager prototype @ FNAL (© M. Zalokar, E. Niner)

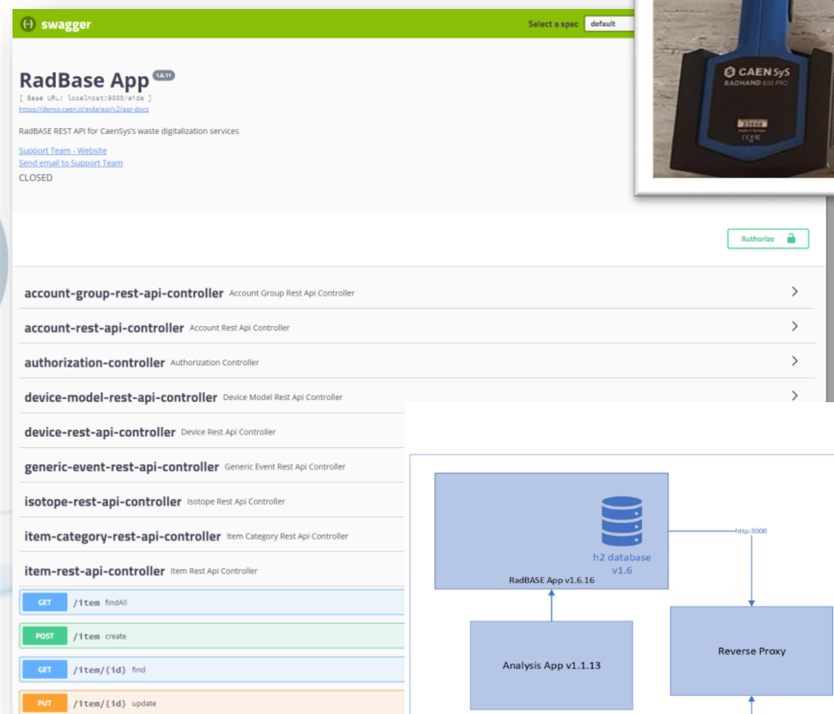
D4.3 (M45)

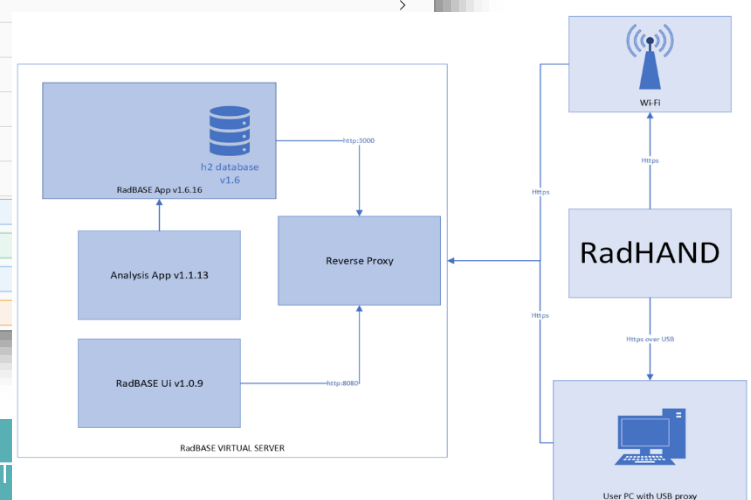
Objective 2

Spectrometry & Traceability Data Aggregation

- CAEN **RadHAND** device delivered at CERN
- **RadBASE interface** configured, and workflow tested for IRRAD

DigiWaste platform

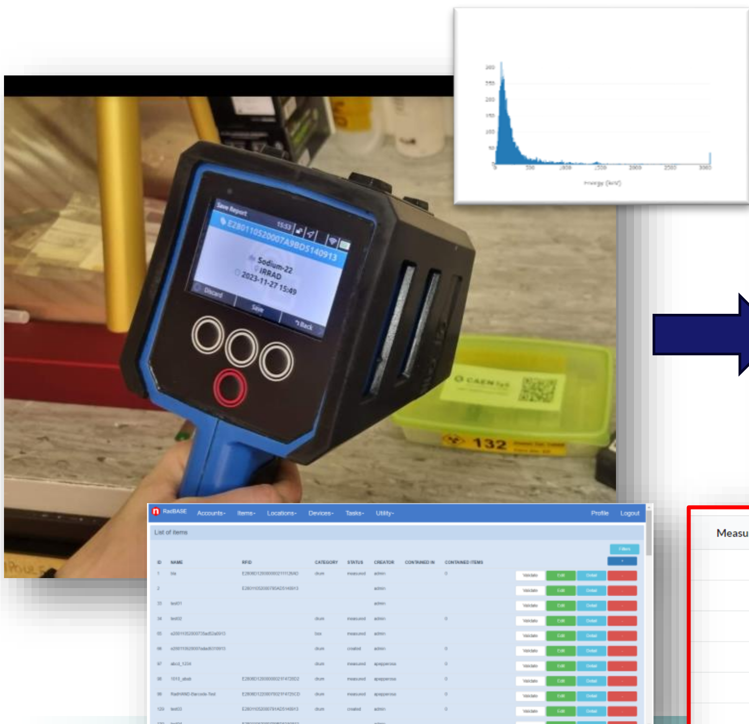


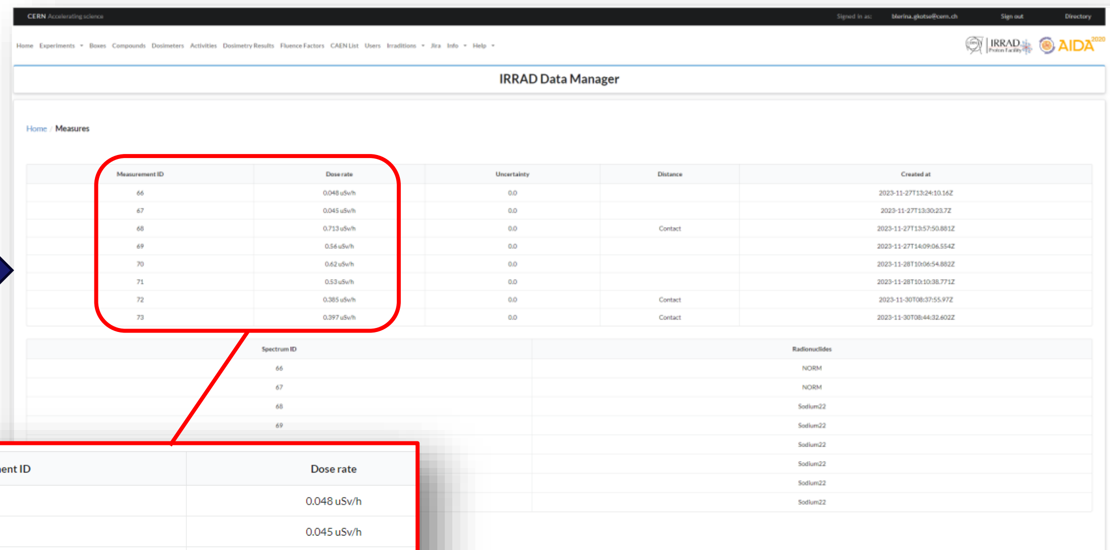


Spectrometry & Traceability Data Aggregation

Objective 2

- New integrated system RFID-based is being tested at IRRAD
  - RadHAND device used with RFID tags tested within AIDAinnova (slide 11)
- Complete workflow tested using the RadHAND device:
  - **Data acquired with RadHAND integrated in IDM** using CAEN API
- Operation also **shown in WP2 promotional video** recorded in Nov. 2023





Measurement ID	Dose rate
66	0.048 uSv/h
67	0.045 uSv/h
68	0.713 uSv/h
69	0.56 uSv/h
70	0.62 uSv/h
71	0.53 uSv/h
72	0.385 uSv/h
73	0.397 uSv/h

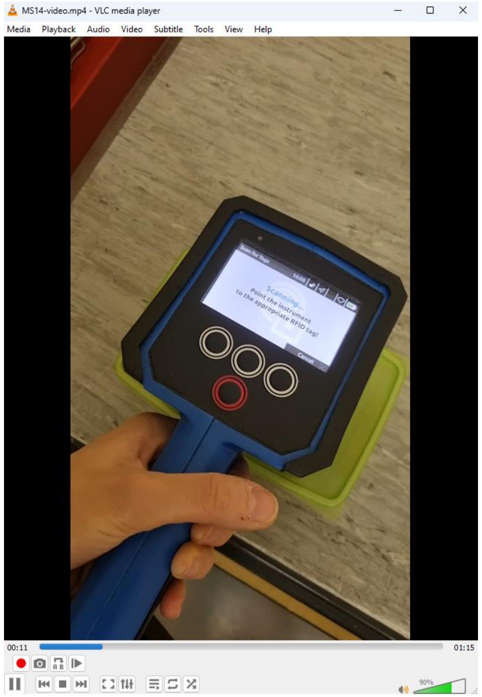
RadHAND measurements integrated in IDM

IDM Generalisation

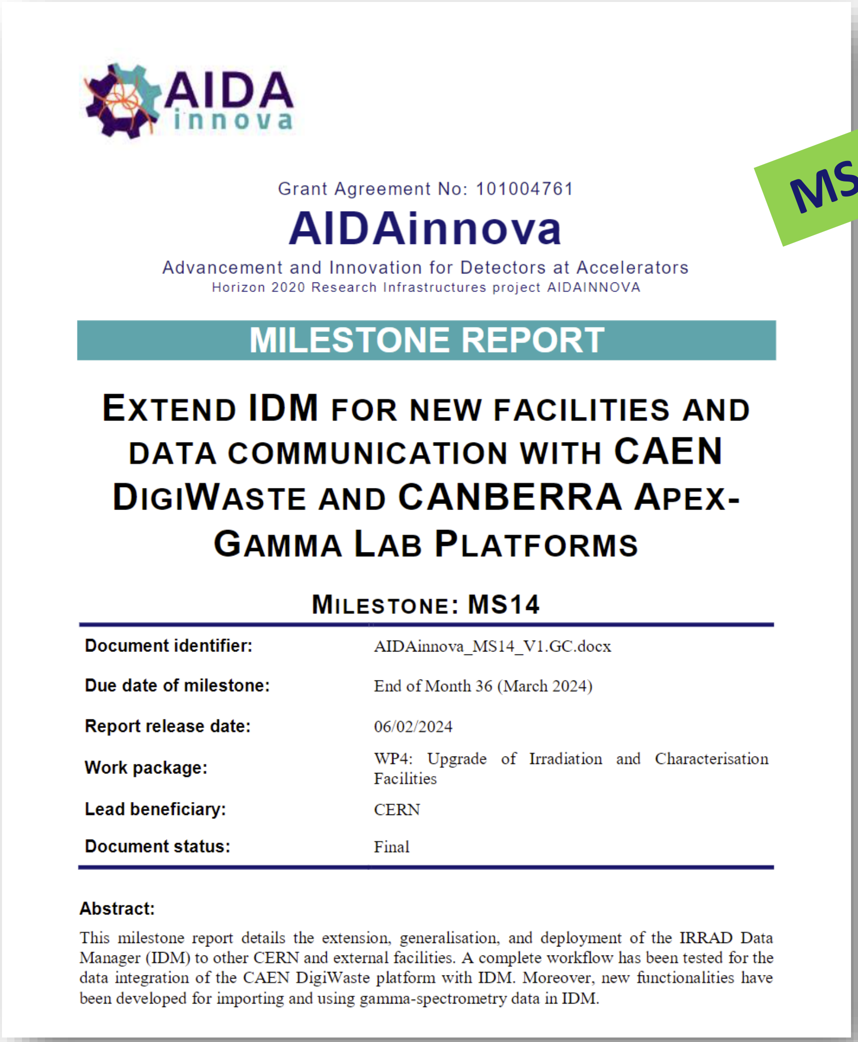
Milestone MS14 **completed** and **released**

Available in Zenodo:
https://zenodo.org/records/10809780

(including demo video!)



MS14



Grant Agreement No: 101004761

AIDAinnova

Advancement and Innovation for Detectors at Accelerators
Horizon 2020 Research Infrastructures project AIDAINNOVA

MILESTONE REPORT

EXTEND IDM FOR NEW FACILITIES AND DATA COMMUNICATION WITH CAEN DIGIWASTE AND CANBERRA APEX-GAMMA LAB PLATFORMS

MILESTONE: MS14

Document identifier:	AIDAinnova_MS14_V1.GC.docx
Due date of milestone:	End of Month 36 (March 2024)
Report release date:	06/02/2024
Work package:	WP4: Upgrade of Irradiation and Characterisation Facilities
Lead beneficiary:	CERN
Document status:	Final

Abstract:

This milestone report details the extension, generalisation, and deployment of the IRRAD Data Manager (IDM) to other CERN and external facilities. A complete workflow has been tested for the data integration of the CAEN DigiWaste platform with IDM. Moreover, new functionalities have been developed for importing and using gamma-spectrometry data in IDM.

Test of RFIDs for Samples Tagging

Objective 2

- Investigating the suitability of RFIDs to be used in radiation environment:
  - one model chosen at the beginning of the project (size, packaging, etc.)
  - **photons:** bibliography data exist
  - **protons at IRRAD** (AIDAinnova):
    - Report (also in Zenodo): https://edms.cern.ch/document/2680300/
  - **neutrons at ENEA-FNG** (AIDAinnova) funded by RADNEXT TA:
    - Report (also in Zenodo): https://edms.cern.ch/document/2884302/
  - **mixed-field at CERN**: planned in 2024

- Summary of these investigations to be compiled in form of MS report by M42

MS15 (M42)

NIEL (Non-Ionizing Energy Loss)

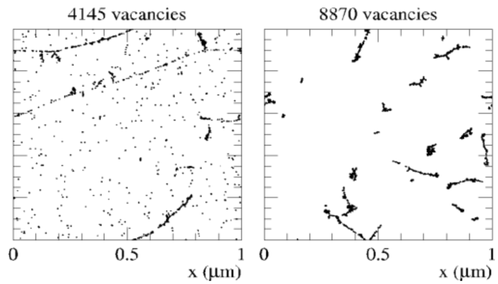
Objective 3

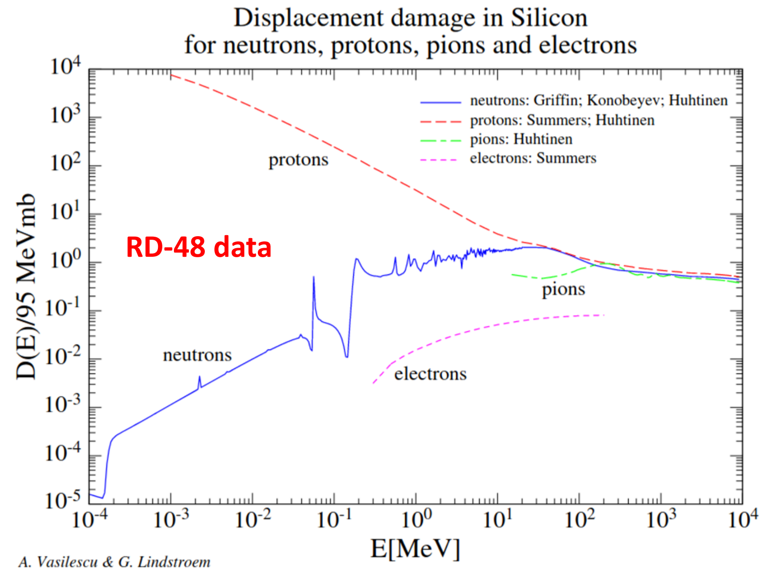
- **NIEL** is a physical quantity describing the non-ionizing energy loss as the particle travels through the medium
- **NIEL** can be used to predict the radiation damage and therefore to predict the lifetime of the detectors and components necessary for measurements
- **NIEL** is usually expressed as an equivalent to **NIEL** of 1 MeV neutrons
- **NIEL is used by most of the LHC experiments**

V. Subert (PhD, synergy with EP-R&D)

NIEL for Silicon was determined from various sources 20 years ago by A. Vasilescu and G. Linstrom[1-5] (RD-48 data).

NIEL does not distinguish in point defects/ cluster defects, NIEL violation has been reported. [6-7]->need to **revisit NIEL**





1) Data from A. Vasilescu (INPE Bucharest) and G. Lindström (Univ. of Hamburg)
2) P.J. Griffin et al., SAND92-0094 (Sandia Natl. Lab.93), priv. comm. 1996: E = 1.025E-10 - 1.995E+01 MeV
3) Konobeyev, Alexander Yu., et al. "Nuclear Data to Study Damage in Materials under Irradiation by Nucleons with Energies up to 25 GeV." Journal of Nuclear Science and Technology, vol. 39, no. sup2, Aug. 2002, pp. 1236–39. Taylor and Francis+NEJM, https://doi.org/10.1080/00223131.2002.10875327.
4) Huhtinen, M., and P. A. Aarnio. "Pion Induced Displacement Damage in Silicon Devices." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 335, no. 3, Nov. 1993, pp. 580–82. ScienceDirect, https://doi.org/10.1016/0168-9002(93)91246-J.
5) Summers, G. P., E. A. Burke, P. Shapiro, et al. "Damage Correlations in Semiconductors Exposed to Gamma, Electron and Proton Radiations." IEEE Transactions on Nuclear Science, vol. 40, no. 6, Dec. 1993, pp. 1372–79. IEEE Xplore, https://doi.org/10.1109/23.273529.
6) Huhtinen, M. "Simulation of Non-Ionising Energy Loss and Defect Formation in Silicon." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 491, no. 1, Sept. 2002, pp. 194–215. ScienceDirect, https://doi.org/10.1016/S0168-9002(02)01227-5.
7) Gurimskaya, Yana, et al. "Radiation Damage in P-Type EPI Silicon Pad Diodes Irradiated with Protons and Neutrons." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 958, Apr. 2020, p. 162221. ScienceDirect,

NIEL (Non-Ionizing Energy Loss)

Objective 3

$$NIEL(T_0) = \frac{N_A}{A} \sum_i \int_{T_{min}}^{T_{max}} Q(T)T\left(\frac{d\sigma}{dT}\right)_i dT$$

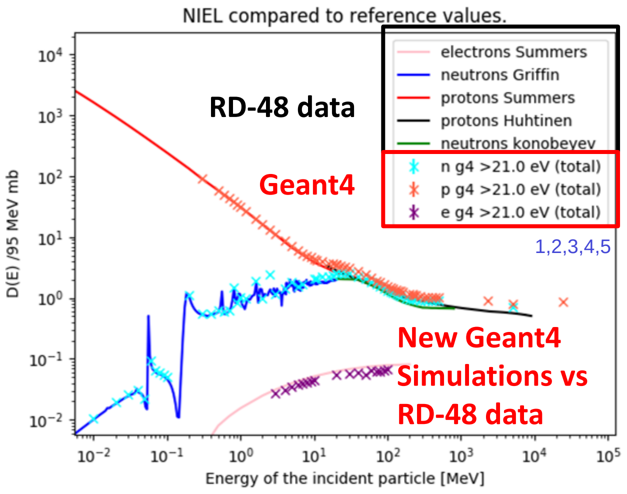
- T_0: energy of incident particle
- **T**: energy transferred to the recoil atom
- **(dσ/dT)**: differential partial cross section for a particle with energy T_0 to create a recoil atom with energy **T** in the i-th reaction
- **Q(T)**: partition factor giving the fraction of **T** that is going into further displacements
- N_A : Avogadro number
- **A :** atomic mass of target atom

Displacement damage function

$$NIEL(T_0) = \frac{N_A}{A} D(T)$$

MeV cm²/g

MeV mb



- NIEL curves in literature with Geant4 and FLUKA simulations successfully reproduced
- Algorithm for identifying clustered versus point defect damage implemented
- Agreement with qualitative analysis reached
- **The tuning of the parameters** (number of neighbours to be considered cluster, threshold energy for recoil production in Silicon) **ongoing: benchmarking with the measurements data**

Parameter tuning and meas. benchmarking

X: axis measurement points
Y axis: nearest neighbor parameter in A
Z: recoil threshold production cutoff
Yellow shows the settings for which the simulation and measurements does not agree by > 5 %
We look for a row that is dark along the X-axis: good candidate for parameter tuning.
Cubes: Simulation predict higher fraction of clusters/isolated then measurements
Spheres: Simulation predict lower fraction of clusters/isolated then measurements

58583X01008862,
ps.org/prb/pdf/10.1103/PhysRevB.79.075206
3.65.245201
cle/abs/pii/0168583X95007024
direct.com/science/article/pii/S0168583X01011612
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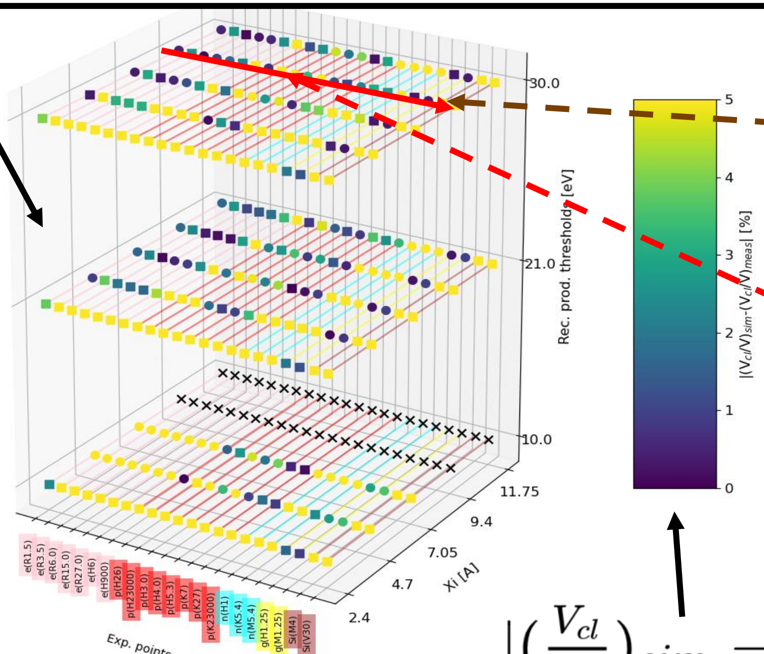
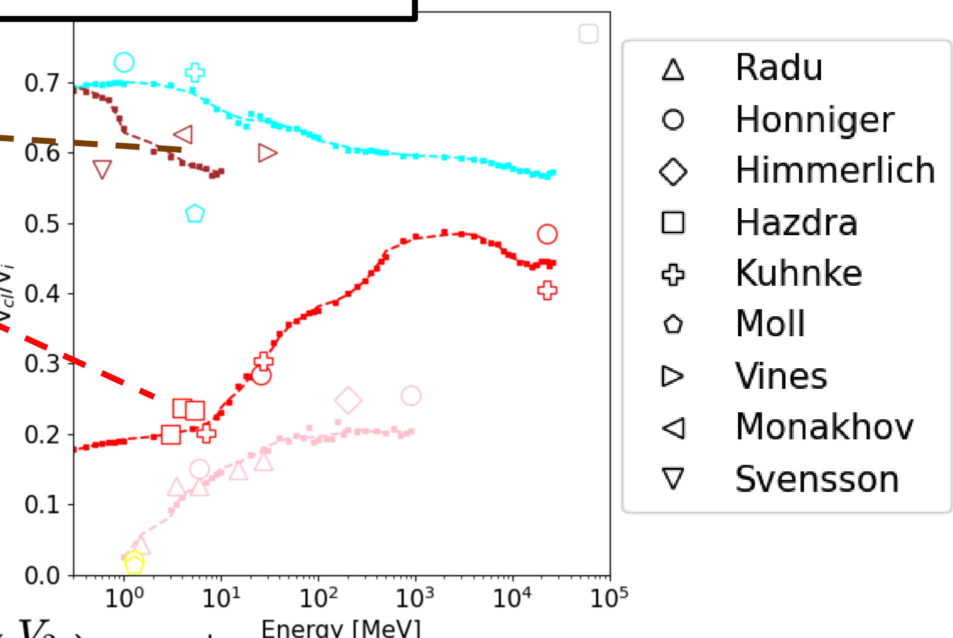


$$\left|\left(\frac{V_{cl}}{V}\right)_{sim} - \left(\frac{V_2}{V}\right)_{meas}\right|$$

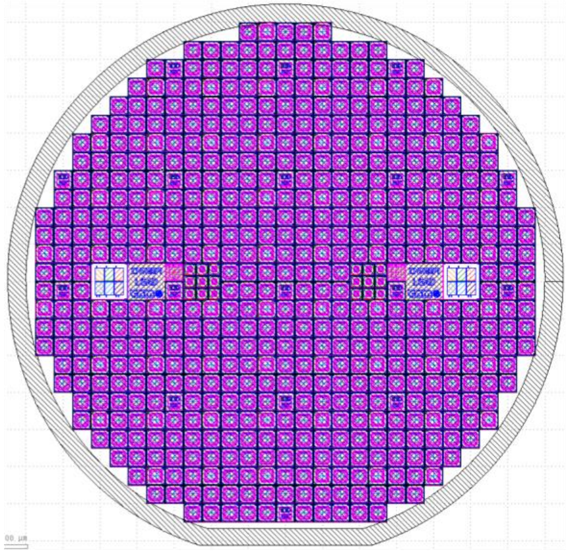


Sensors for NIEL measurements

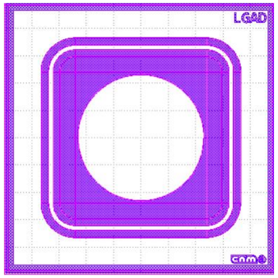
Objective 3

- **NIEL sensors**
  - **Produce a set of identical sensors that will be used to**
    - **(a) study more profoundly the NIEL Hypothesis in dependence of particle type and energy**
      - **Measurement of damage parameters: Diode (leakage, depletion, E-Field) and material (defect spectroscopy)**
    - **(b) inter-compare radiation facilities in terms of their ‘hardness factors’**
      - **Measurement of leakage current after exposure and specified annealing [alpha-value]**

- **A set of Silicon Sensors (n-in-p) are in production at CNM, Barcelona**



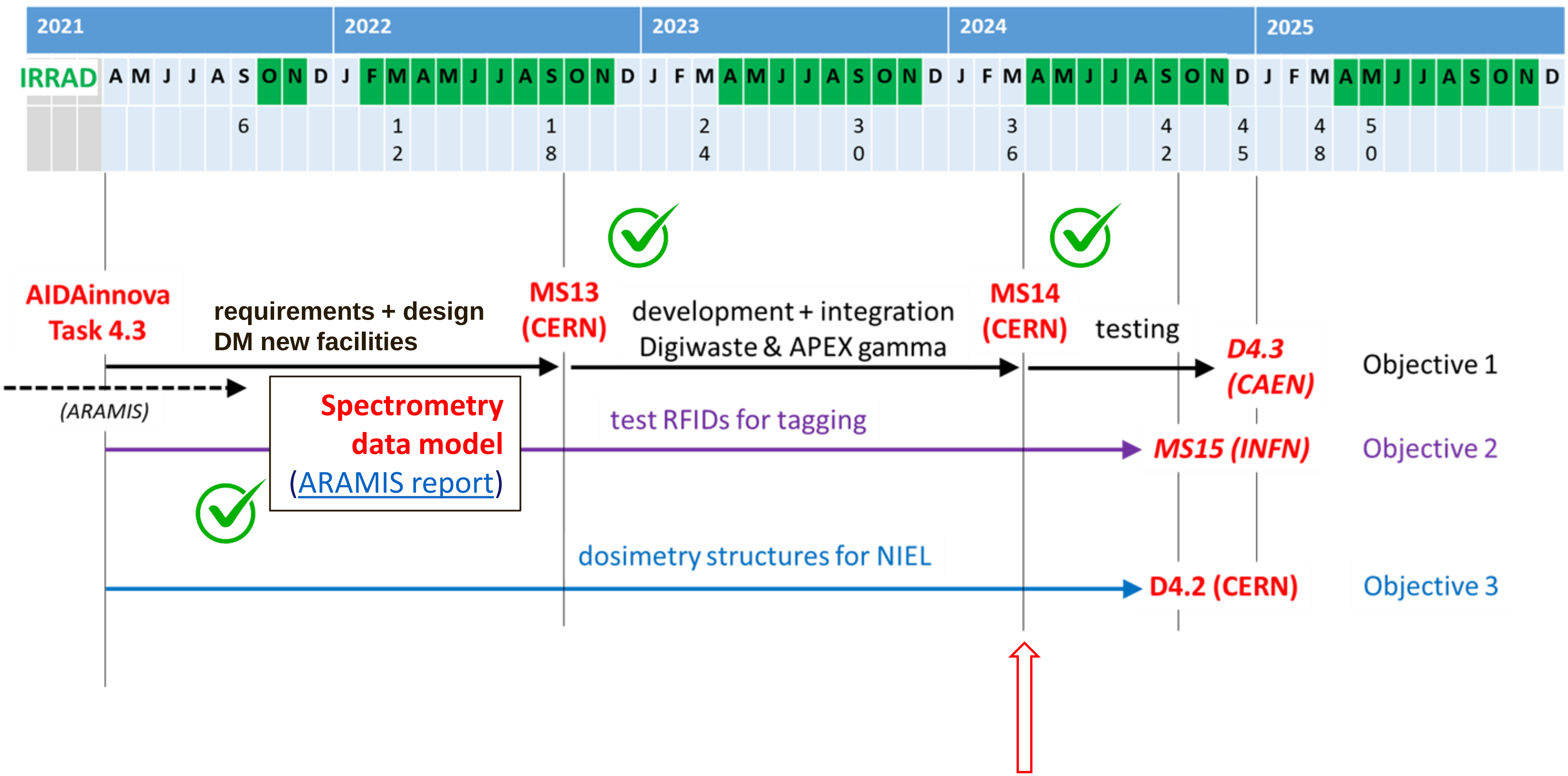
- simple mask: 8 mask levels
- 600 devices of 5x5 mm^2 per wafer (150 mm)
- 10 wafers in production
  - 2 wafers will go to Ljubljana reactor
  - 2 wafers will go to CERN IRRAD
  - 6 wafers for in-depth NIEL studies



- Status: In production since beginning of 2024
  - 33% of processing steps done

D4.2 (M42)

Timeline


2021
2022
2023
2024
2025
IRRAD
A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
6
12
18
24
30
36
42
45
48
50
AIDAinnova Task 4.3
requirements + design
DM new facilities
(ARAMIS)
Spectrometry data model
(ARAMIS report)
MS13 (CERN)
development + integration
Digiwaste & APEX gamma
MS14 (CERN)
testing
D4.3 (CAEN)
Objective 1
test RFIDs for tagging
MS15 (INFN)
Objective 2
dosimetry structures for NIEL
D4.2 (CERN)
Objective 3

Conclusion

- Objective 1 – Generalisation of IDM
  - IDM specifications for deployment to new facilities finalised (MS13)
  - Deployment @ GIF^{++} finalized
  - Deployment @ FNAL ongoing (D4.3)
- Objective 2 – Integrated system for induced activation data management and traceability
  - APEX-gamma DB communication with IDM and proton fluence computation (MS14)
  - CAEN RadHAND / RadBASE API → IDM integration tested (MS14)
  - Irradiation campaigns for CAEN RFID tags performed in IRRAD (protons) and ENEA-FNG (neutrons) while other tests are being planned (MS15)
- Objective 3 – **Common dosimetry calibration set** for **cross-comparison of irradiation facilities** by NIEL evaluation
  - Geant4 and FLUKA simulations for NIEL curves successfully reproduced and algorithm for identifying clustered vs point defect damage implemented
  - Benchmarking simulations with measurements data is ongoing
  - Production of silicon sensors is ongoing (D4.2)