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RADIOLOGICAL INVESTIGATIONS IN HARD-TO-ACCESS ZONES DURING D&D OPERATIONS BY REMOTE OSL/FO DOSIMETRY : INSPECT PROJECT

ISOE International Symposium
Session 9 • RP and Decommissioning
Sylvain MAGNE | Tours, France, 23rd June 2022

SUMMARY

CHALLENGE : REMOTE DOSIMETRY IN HARD-TO-ACCESS ZONES

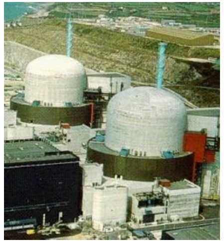
OSL/FO - Basics

OSL/FO 1D PROBES, READOUT UNIT and WEB APP

FIELD TESTS

CONCLUSIONS

REMOTE DOSIMETRY = ESSENTIAL TOOL FOR D&D



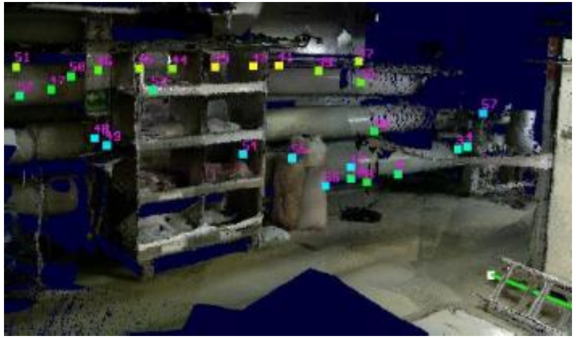
(Photos CEA, EDF)

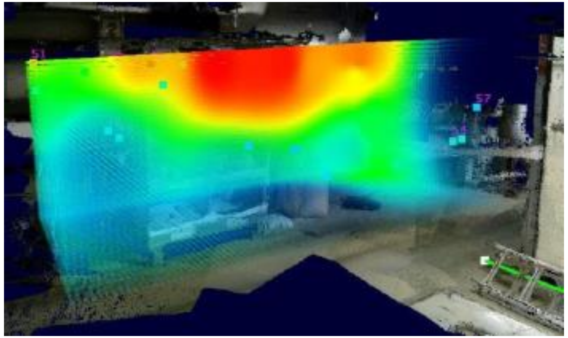
Provides radiological and topographical data

- ⇨ Investigations during pre-dismantling stage & cleanup ,
- ⇨ Setup cost-effective D&D scenario and risk analysis (worker exposition).

3D dose rate reconstruction

➤ **In open spaces** (outdoor or indoor) : GM, CZT, γ-camera + SLAM





Simultaneous Localization & Mapping (SLAM)
MANUELA
(Photos ORANO DS)

➤ **In hard-to-access zones ? ... Still challenging !**

Radiological investigations from the outside is tricky and conveys large uncertainties

Remote inspection through existing access is complex, time-consuming & costly

REMOTE DOSIMETRY IN HARD-TO-ACCESS ZONES

3D dose rate reconstruction in hard-to-access zones

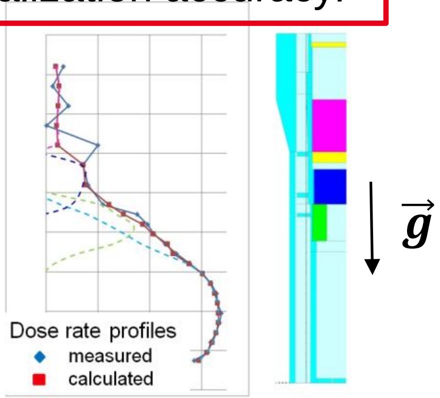
Miniature dosimeters : dosimetric assessment in hidden/out-of-reach parts,
Inverse calculation : performed with the help of Monte-Carlo codes.

***INSPECT innovation* : Miniature 1D OSL/FO dosimeter probes**

⇨ Spares heavy duty at pre-dismantling stage,
⇨ Dosimetry from the inside provides better results,
⇨ Possible continuous monitoring for cleanup assessment,
⇨ 1D monitoring (profiles) speeds up investigations and improves localization accuracy.

Radiological investigations within pipe circuitry using OSL/FO dosimetry during cleanup process
(APM Marcoule, France, photos CEA DES)

3D dose rate reconstruction inside the RNG reactor using OSL/FO dosimetry
(CEA DAM & CEA DES/DTN-SMTA-LMN)



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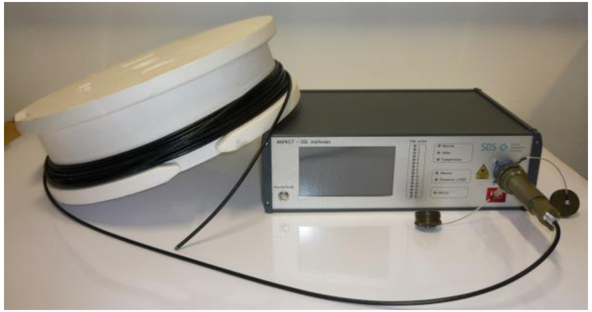
OSL/FO : CHRONOLOGY

OSL/FO = Fiber-coupled OSL → **Online** dosimetry

OSL #1
(single channel, 1998-2002)

OSL #2 (Eu-MAESTRO)
(multichannel, 2005-2015)



INSPECT (PIA-Andra)
(multichannel, 2015-…)

For more information …

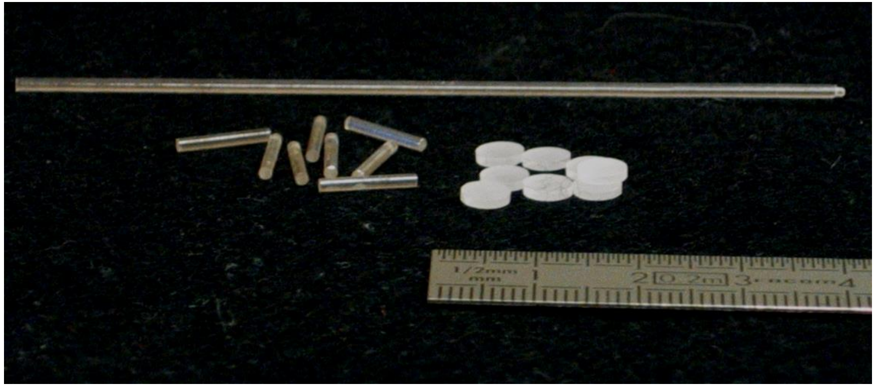
O. Roy, S. Magne, J.C. Gaucher, L. Albert, L. Dusseau, J.C. Bessière and P. Ferdinand*,*
12th Int. Conf. on Optical Fiber Sensors, OFS'97, 28-31 Oct. 1997, Williamsburg, Virginia, USA

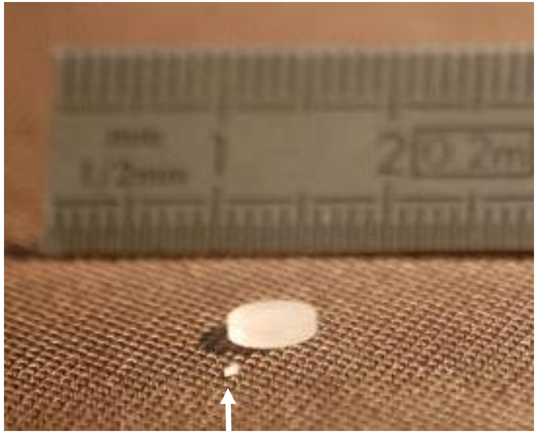
S. Magne, L. Auger, J. M. Bordy, L. de Carlan, A. Isambert, A. Bridier, P. Ferdinand, J. Barthe*,*
Radiat. Prot. Dosim., ***131*** *(1), 2008, pp. 93-99.*

S. Magne, L. de Carlan, J.M. Bordy, A. Isambert, A. Bridier, P. Ferdinand,
IEEE Trans. Nucl. Sci. 58 (2), 2011, pp. 386-394

DOSIMETRIC-GRADE AL_2O_3:C CRYSTALS

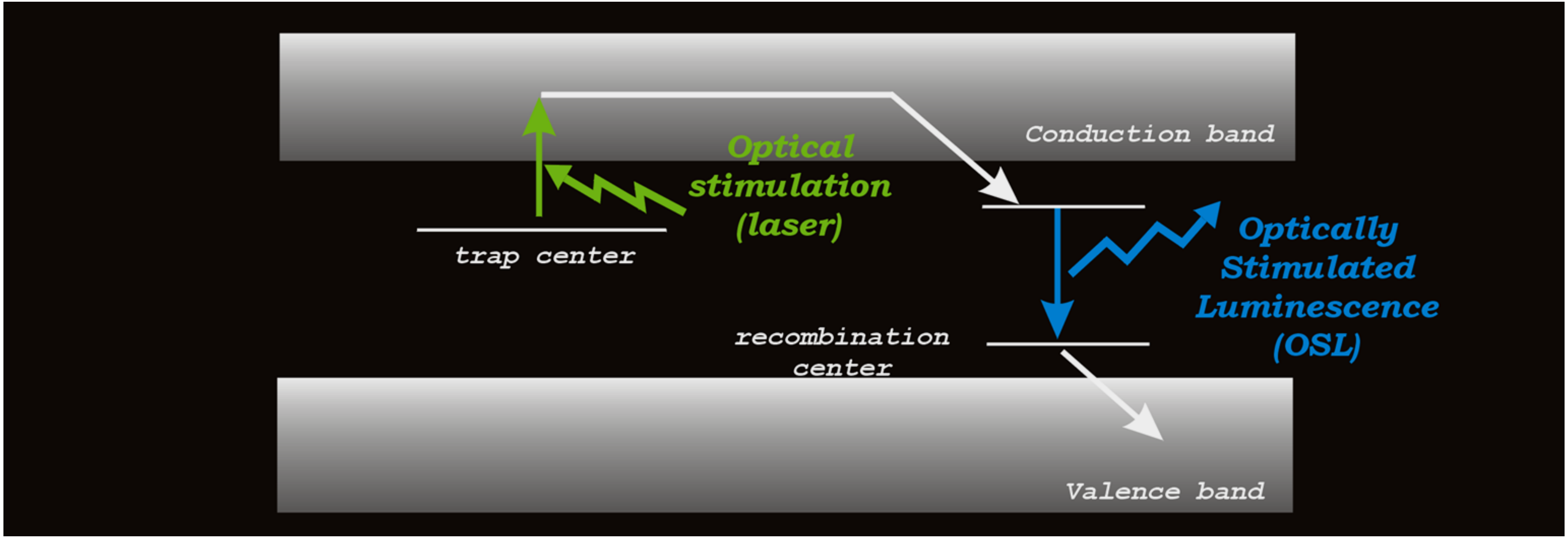
- **TLD_{500}**
  - Leading dosimetric material (high sensitivity)
  - Low fading at usual temperature
  - Small temperature dependence (0.3 %/K)
  - Radiation-resistant
  - Optically transparent & inert material
  - Low Z, low cost.





Sapphire crystal (sub-mm)
(0.3 x 0.3 x 1 mm^3 = 0.09 mm^3)

OSL/FO : BASICS



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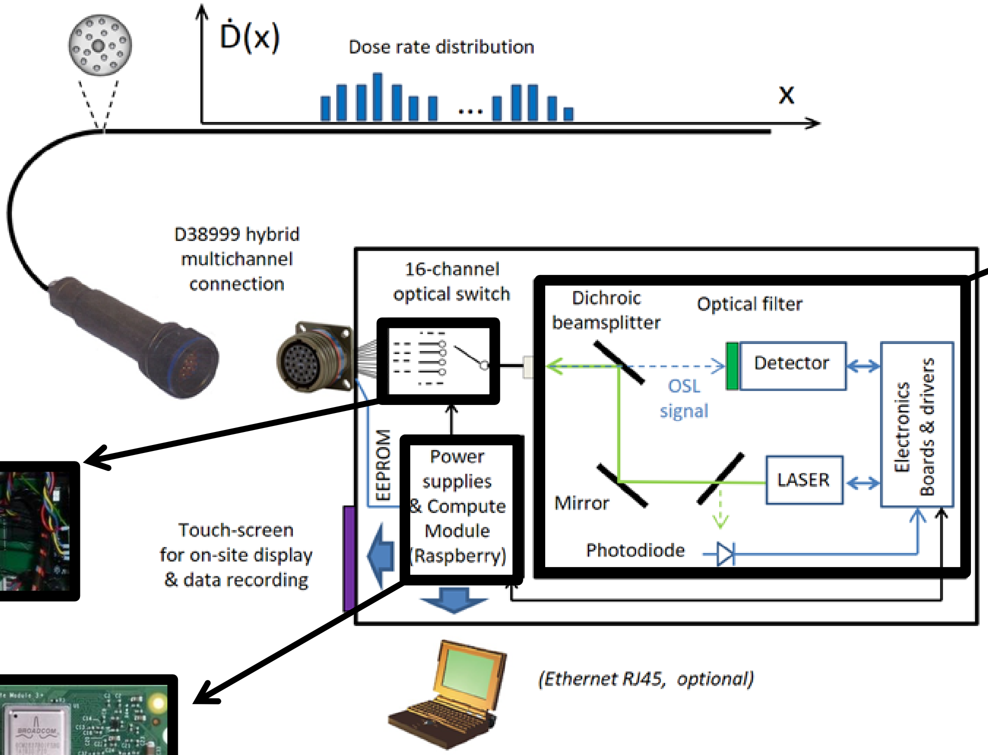
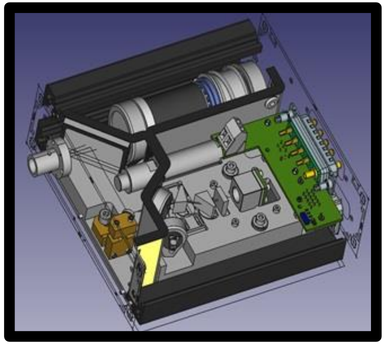
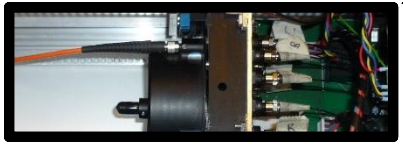
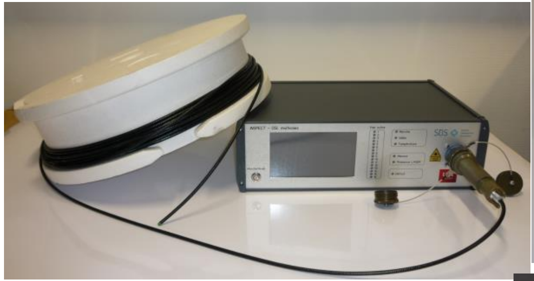
INSPECT : READOUT UNIT

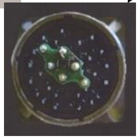




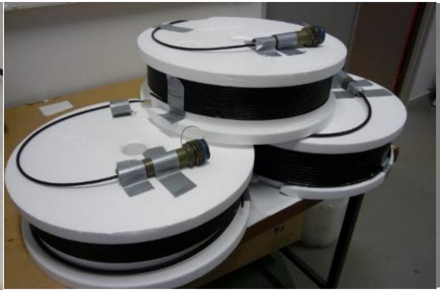


INSPECT : 1D OSL/FO PROBES AND UNIT FOR D&D

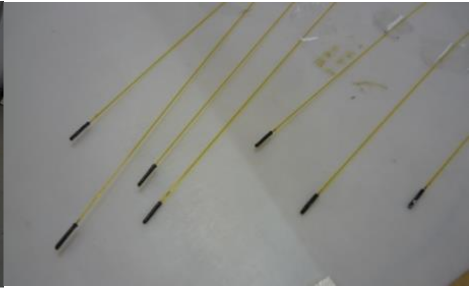




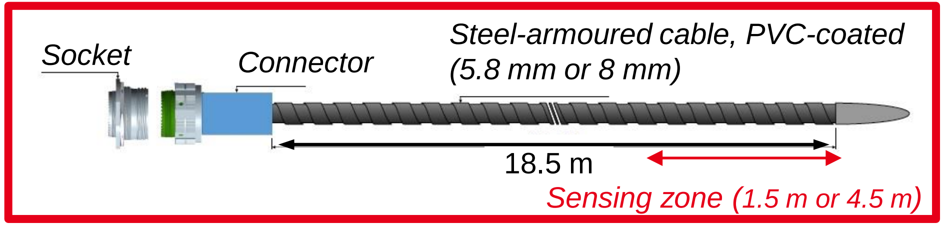
EEPROM inside !



1D probes



Miniature crystals affixed onto fiber extremity (∅480 µm)



- **Remote** & **online** dose rate measurement
- **Multichannel** operation (profile), up to 16 points
- Localization uncertainty : < ± 2 cm
- INSPECT reader placed away (typ. **18.5 m**) in safe, uncontaminated zone
- **Flexible and rugged design** (push-pull operation, crush-resistant), **radiation-resistant**,
- **No dependence of OSL readout *vs* dose rate** (very low fading),
- **Large dose rate range** (30 µGy/h - 20 Gy/h)
- **Large energy range** (> 50 keV, stainless steel housing)
- **Immunity *vs* Cerenkov and electromagnetic perturbations**
- **Waterproof, easy to decontaminate.**

OSL/FO : PERFORMANCE OF MINIATURIZED PROBES

- **Performance evaluation**

- Miniaturisation → active volume ↘ → Limit in Dose Detection (LOD) ↘

  e.g. active volume ~ 0.1 mm^3 ↔ LOD ~ 5 mGy (INSPECT, miniaturized)

  ~ 100 mm^3 ↔ LOD ~ 5 µGy (Radiation protection, not miniaturized)

  [G. Ranchoux, S. Magne, J.P. Bouvet, P. Ferdinand, Radiat. Prot. Dosim. 100 (1-4), 2002, pp. 255-260]

  Typical dose range ~ 5 mGy → 3 Gy (INSPECT)

- **Large range in dose rate (up to 6 decades)**

- Exposure time T is chosen according to expected dose rate
  The higher the exposure time, the better the uncertainty in dose
- Time range ~ 10 min → weeks or more (INSPECT)
- **DR Range :** ~ 30 µGy/h (T = 1 week) → 20 Gy/h (T = 10 min)

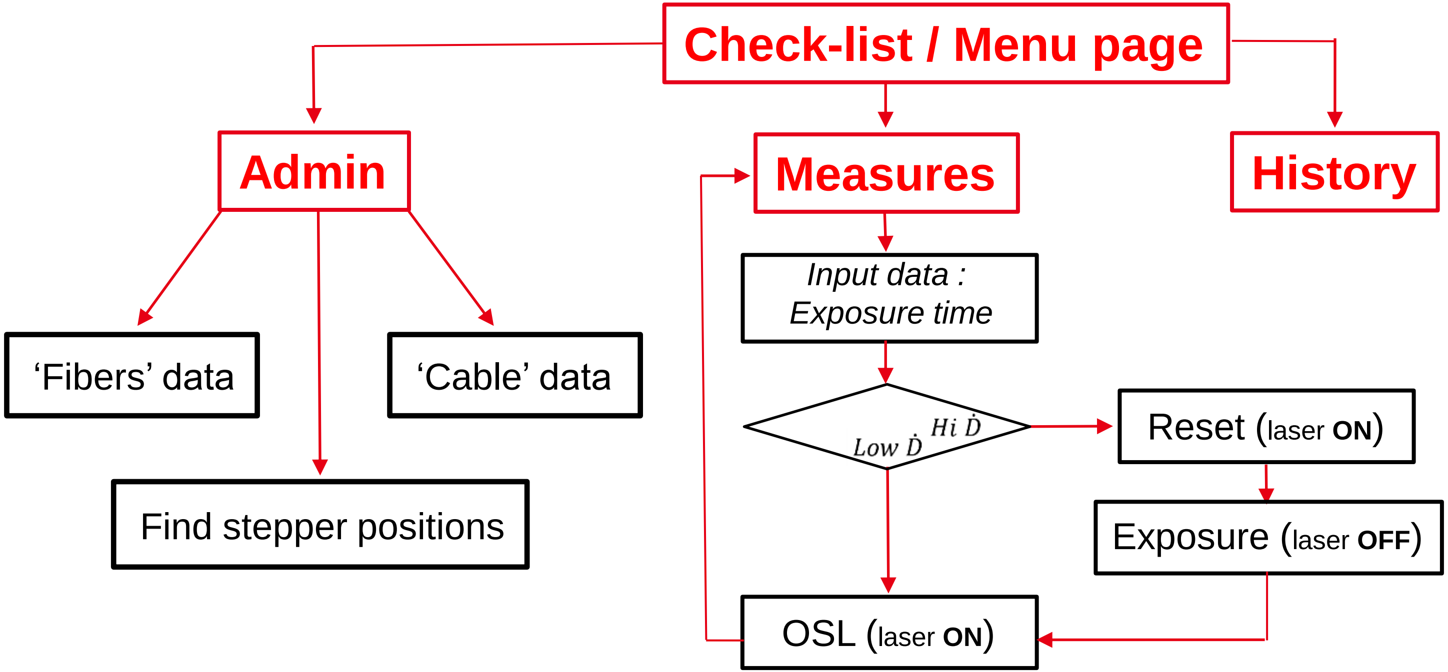
3 decades

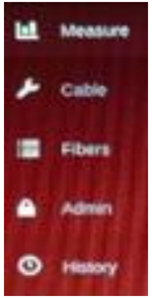
$$\dot{D}\ (Gy/h) = \frac{Dose\ OSL\ (Gy)}{Exposure\ Time\ T\ (h)}$$

5 to 6 decades

2 to 3 decades

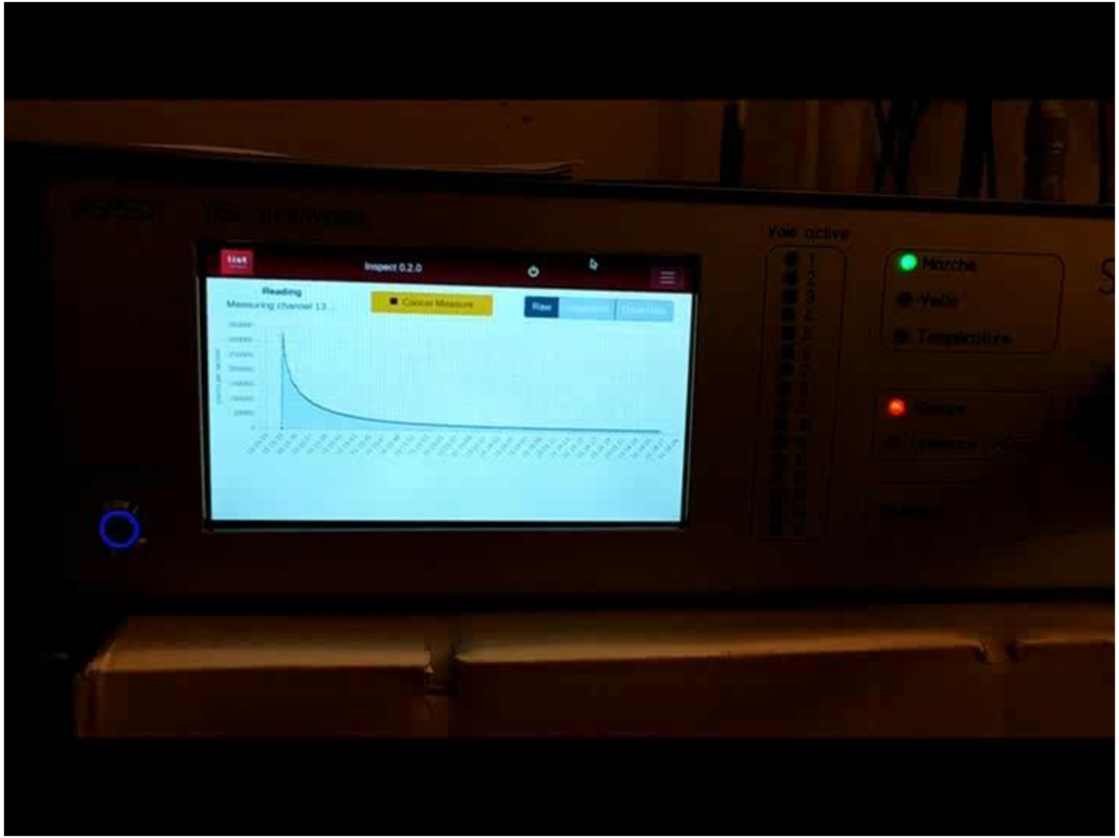
INSPECT 0.3.0 : WEB APP (1/2)





- Written MS **C#**, compiled (CIL) under **.NET Core 3.1** (open-source cross-platform framework)
- Loaded onto CM3+, run under Raspbian OS,
- Libraries: **Dotnet.iot** (GPIO, i2C, SPI bus control), **Blazor** (graphics)
- Client-server application (distant or local use (Chromium))

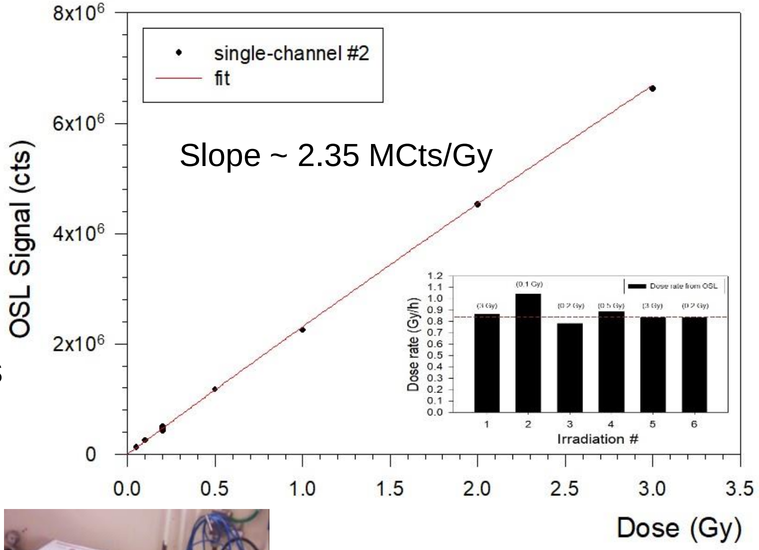
INSPECT 0.3.0 : WEB APP (2/2)



DOSE CALIBRATION

Panoramic irradiation

- ^{137}Cs source (~ 16 TBq), dose rate ~ 0.84 Gy/h ± 0.01 Gy/h
- INSPECT readout unit placed in control room
- OSL probes disposed along a circular isodose,
- OSL readouts performed one after another.
- **Calibration stability** : second calibration performed 6 months later (sept. 2021) → same coefficients (within 10 %)



Buchler OB20
(ORANO, La Hague, feb. 2021)

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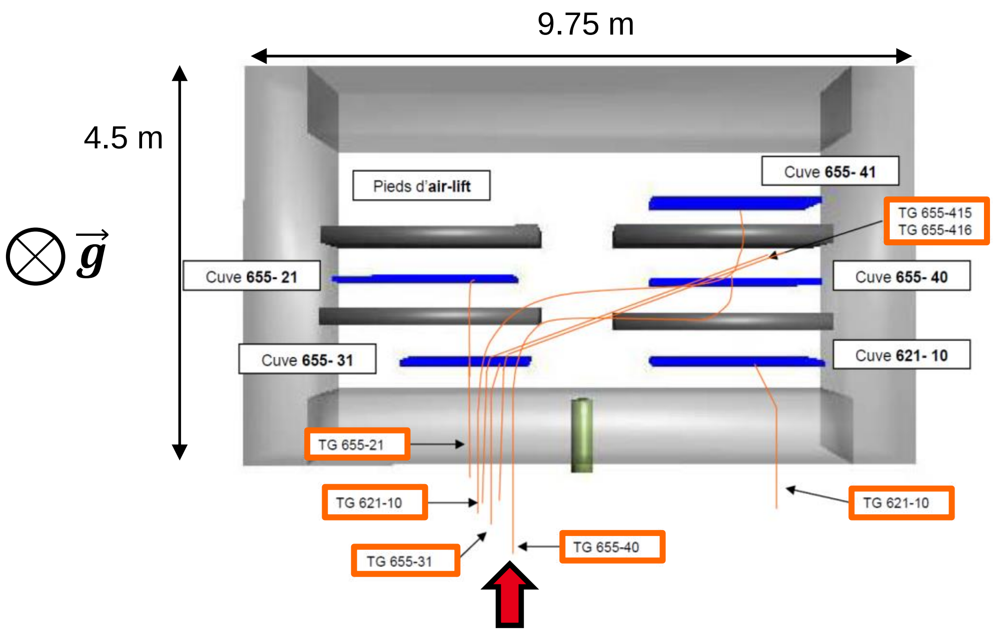
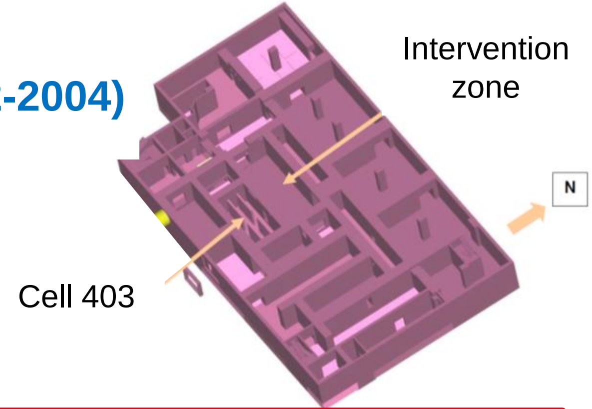
FIELD TESTS

CONCLUSIONS

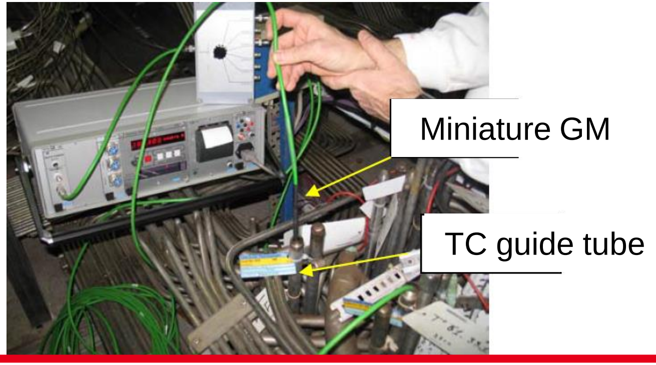
FIELD TEST #1 : APM (CEA/MAR), CELL 403 (1/3)

- **Objective : Consolidation of previous measurements (2002-2004)**
- **Path of thermocouple (TC) guide tubes in the ceiling**





Reference miniaturized dosimeters:
Geiger-Muller (GM), CZT probes



FIELD TEST #1 : APM (CEA/MAR), CELL 403 (2/3)

- **Investigation procedure with OSL/FO probes**

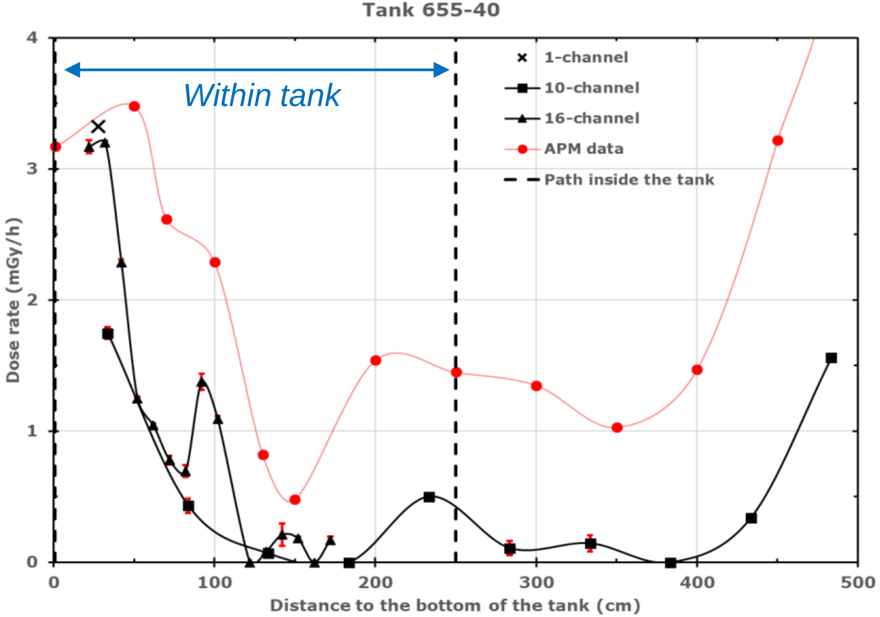
✓ 3 OSL/probes were used :
single-channel, 10-channel (50 cm, 4.5 m), 16-channel (10 cm, 1.5 m)
✓ Assembled with a fiber optic endoscope (VIZAAR),
✓ Insertion through TC guide tubes (Ø = 12 mm),
✓ Probes taken out from zone after inspection (no contamination).

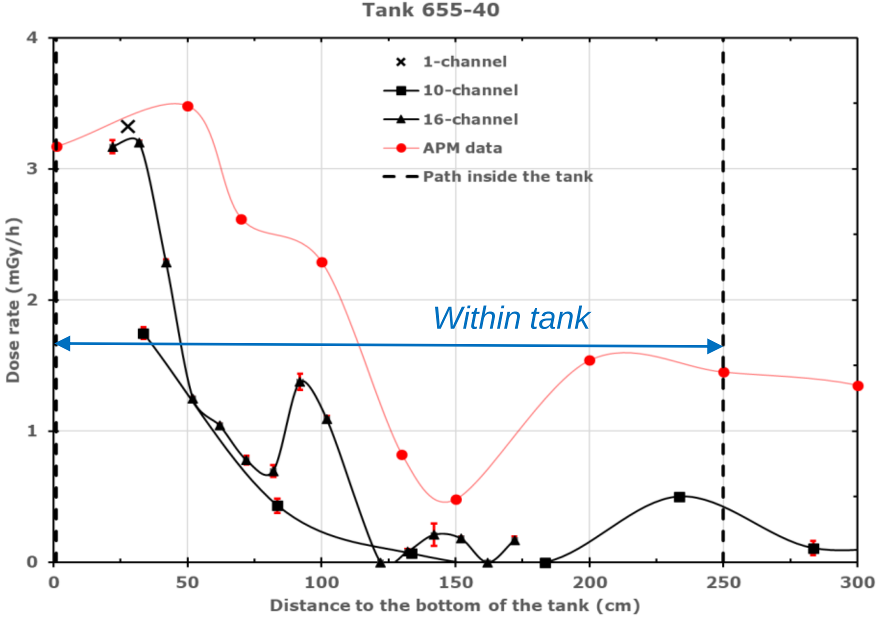
Photos CEA/DTN/SMTA/LMN

Insertion of OSL probes inside guide tubes

FIELD TEST #1 : APM (CEA/MAR), CELL 403 (3/3)

- **Tank 655-40 [10-channel : 18 h, 16-channel : 24h, single channel : 90 h]**

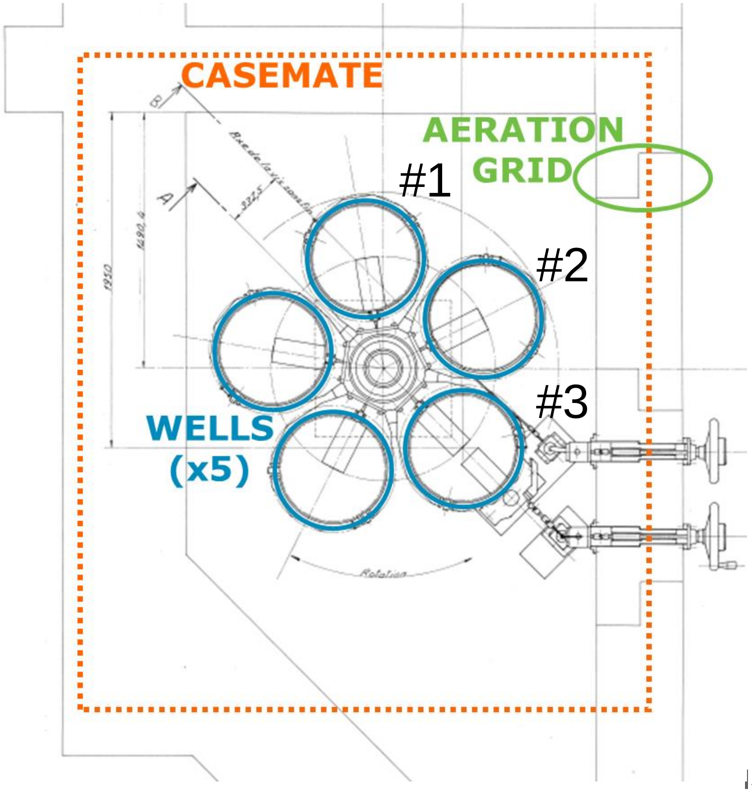


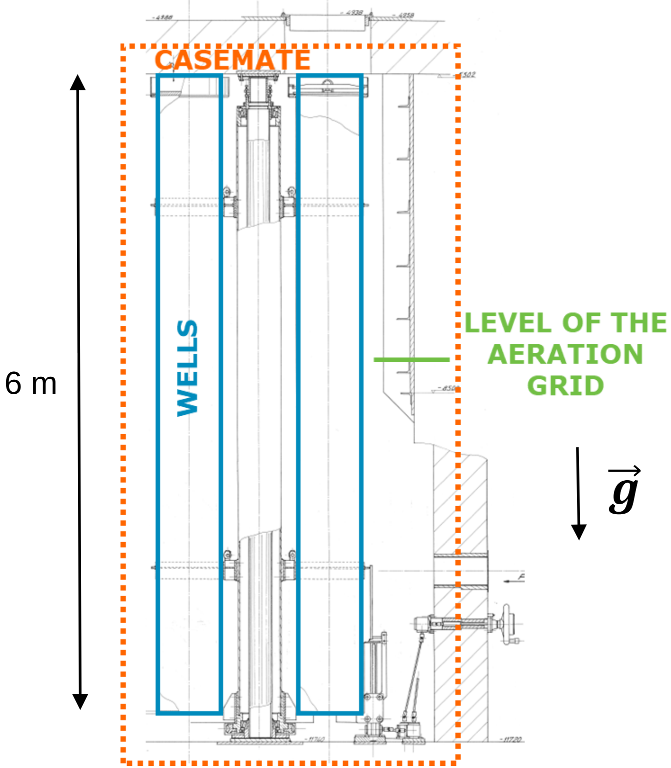


- ✓ Consistency of results obtained with the 3 INSPECT probes
- ✓ Underestimation of the DR values in comparison with GM data
- ✓ DR min ~ 67 µGy/h (32 %) et ~ 81 µGy/h (28 %)

FIELD TEST #2 : PHEBUS (CEA/CAD), CAROUSEL CASEMATE (1/3)

- **Objective : Assessment of the radiological state along vertical well walls (#1, #2 and #3)**





FIELD TEST #2 : PHEBUS (CEA/CAD), CAROUSEL CASEMATE (2/3)

- **Investigation procedure with OSL/FO probes**

✓ OSL/FO probes are guided by a tube up to the well wall and lowered by gravity (suspended mass),

✓ No contamination (casemate internal),

✓ Probe geolocalization, near contact to well wall

→ radially (position of the tube extremity),

↓ vertically (curvilinear coordinate along the cable)

$\downarrow \vec{g}$

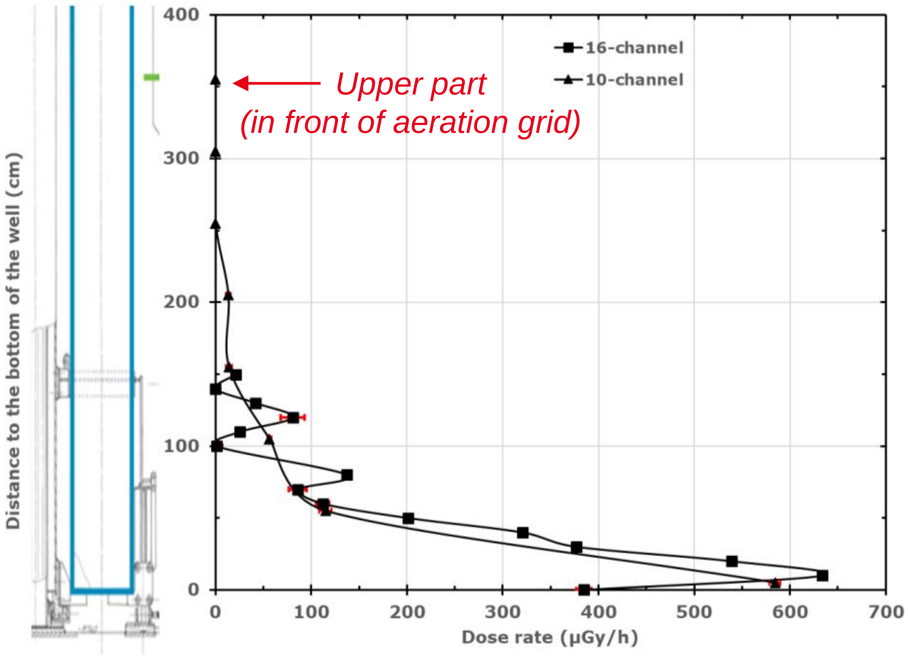
Suspended mass (lead)

Insertion of OSL probes through the aeration grid

FIELD TEST #2 : PHEBUS (CEA/CAD), CAROUSEL CASEMATE (3/3)

- **Well #2: [10-channel & 16-channel probes] / 6 days, 21 h and 20 minutes**

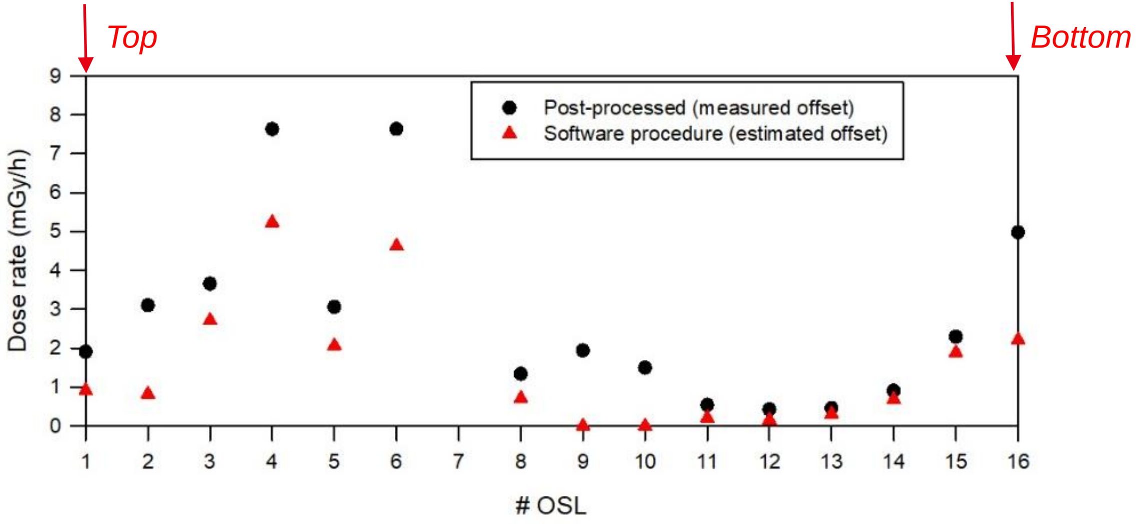
- ✓ One measure for each well (1-week long),
- ✓ Consistency of results obtained with both probes,
- ✓ Significant (unexpected) DR measured at well bottom,
- ✓ The combination of the two spatial periods (10 cm & 50 cm) allows for accurate localization of potential hot spots (~ 100 cm here for example).



FIELD TEST #3 : UP2-400 (LA HAGUE, FRANCE)

- **ELAN 2B : ^{137}Cs source manufacturing unit / filter #6**

✓ 16-channel OSL/FO probe, vinyl-protected,
✓ Night-time exposition (16h45 min),
✓ Offset measurement immediately after the OSL readout → bias in offset estimation (now corrected)



OSL/FO insertion

Photo ORANO/DS (with permission)

CONCLUSIONS

- Long-range remote OSL/FO dosimetry = **essential tool for D&D strategy**
- **INSPECT challenge :** ***remote radiological investigations in hard-to-access zones***

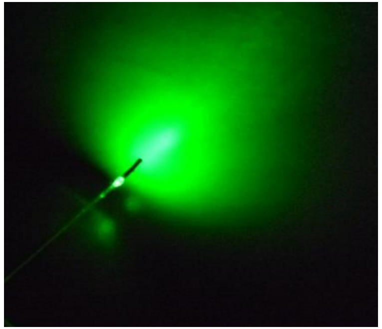
  → 3D dose rate reconstruction in hidden/out-of-reach places
- **Design of miniature 1D OSL/FO dosimeter probes & readout device (CEA List, TRL 8)**
- 1D (profile) monitoring speeds up investigations and improves localization accuracy
- **Assessment of performance of INSPECT device and probes for D&D on field**.

PERSPECTIVES

- Design improvements (visual inspection, shape sensing) within Eu-CLEANDEM Project
- Industrialization planned after project completion.

ACKNOWLEDGEMENTS

Special thanks to K. Boudergui, F. Carrel, J.M. Bourbotte (CEA List),
Lionel Boucher (CEA DTN) and P.G. Allinei (CEA DTN/SMTA/LMN) for their help.



The INSPECT Project is granted by the French government through the PIA initiative ("*Investing for the Future*" Program), operated by Andra, in collaboration with ANR (French National Research Agency)

FINANCÉ PAR LE GRAND PLAN D'INVESTISSEMENT

Thank you

Any questions ?

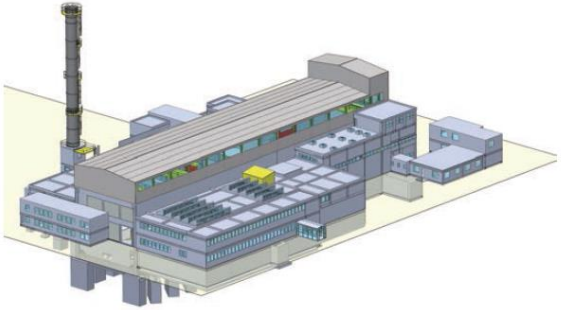
Commissariat à l’énergie atomique et aux énergies alternatives
Institut List | CEA SACLAY NANO-INNOV | BAT. 861 – PC142
91191 Gif-sur-Yvette Cedex - FRANCE
www-list.cea.fr

OSL/FO DOSIMETRY FOR D&D : PAST USE CASES

- **APM, Marcoule, France (1998-2000)**
  - User : CEA,
  - Commissioned : 1962, decommissioned : 1997
  - Treatment of spent fuels from several reactor technologies (NGGCR, FNR, PWR-UO_2 & MOX...)

(Photo CEA DES)

- **UP1, Marcoule, France (2000)**
  - User : ORANO,
  - Commissioned : 1958, decommissioned : 1996
  - Reprocessing of spent fuel (Pu extraction)



(Photo ONET Technologies)

- **RNG, Cadarache, France (2015)**
  - User : CEA DAM, operated by AREVA-TA
  - Commissioned : 1962, decommissioned : 2005
  - Qualification of technologies for on-board reactors dedicated to french marine propulsion

INSPECT PROJECT (PIA-ANDRA, 2016-2021)

- **Partner structure**

- **Innovative features : Remote online dosimetry in hard-to-access zones**
  - 2 OSL/FO multichannel units,
  - 1-D probes (sensing cables),
  - Experimental feedback from test sites,
  - Industrial transfer.

- **4 test sites**
  - **ORANO La Hague : UP2-400**
  - **CEA Marcoule : APM, G1**
  - **CEA Cadarache : Phebus**