



# Repair of welds with degradation due to stress corrosion in primary circuit piping: operational insights from 2023

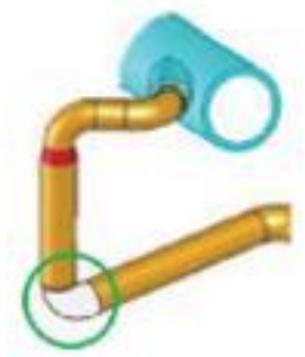
EDF DIPDE  
Marseille, France



# CONTEXT



- **Short historical background**
- **Understanding and delimiting the SCC phenomenon**
- **Technical scope**



- Dec 2021: Non-destructive testing carried out as part of the Periodic Basic Monitoring Program (PBMP) for monitoring Thermal Fatigue during the In-Service Inspection on an section of a **safety injection line** in Civaux 1 (1450 MW) highlighted **defects near the welds** of this section.
- ➔ EDF decided to **cut the sections of the affected pipelines** and launch laboratory expertise, which confirmed that the observed defects are related to Stress Corrosion Cracking (SCC).
  
- Jan 2022: Further inspections initiated on 4 other reactors show **similar defects**.
  
- ➔ EDF created a “Task Force Group” with 4 parts as shown
  
- Feb 2022: DIPDE takes over part 3, which suggests **extensive replacement work for complete lines** from connection to the primary circuit to the 2<sup>nd</sup> isolation organ.
  
- Nuclear Safety Authority **requests** :
  - **Review** of all “Indication Sheets” classified according to 3 levels: P1 (less serious) to P3 (more serious)
  - **Immediate shutdown** of all units concerned by P3 (6 reactors)
  
- Then, the analysis of the UT signals suggests that 2 more reactors could be affected by the SCC phenomenon...



**Part 1**  
Find origins of the defects and delimit the phenomenon

**Part 2**  
Conduct expertise to understand and provide NDT resources to detect and monitor defects in service

**Part 3**  
Provide necessary resources for on-site repairs

**Part 4**  
Perform understanding and justification calculations

**Stress Corrosion Cracking (SCC)** is a complex degradation mechanism of steel that involves three interacting domains: the **material**, the **conveyed fluid**, and the **stresses** (mechanical and thermal)

➔ **Early conclusions of the EDF expertise programme :**

- All observed defects appear in the **work-hardened zone** located in the vicinity of the **Heat Affected Zone (HAZ)** of the welds
- The predominant factor in the propagation of SCC seems to be related to the **geometry of the lines**
- The circuits show different **vortex penetration lengths** from primary piping to auxiliary piping and different **zones of thermal stratification** in horizontal sections

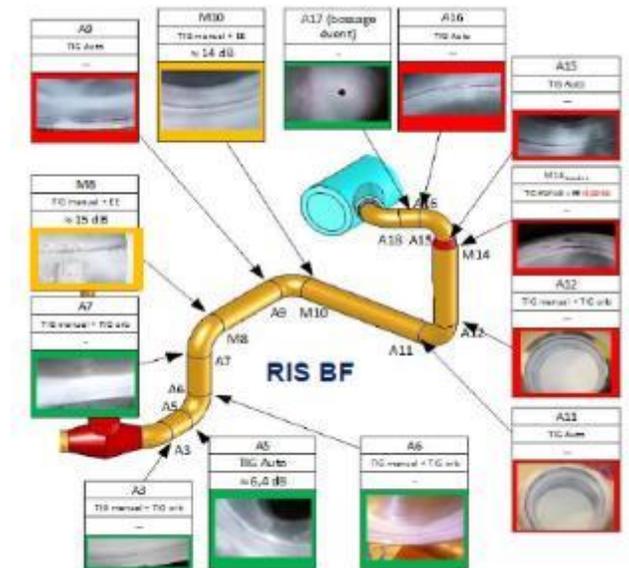
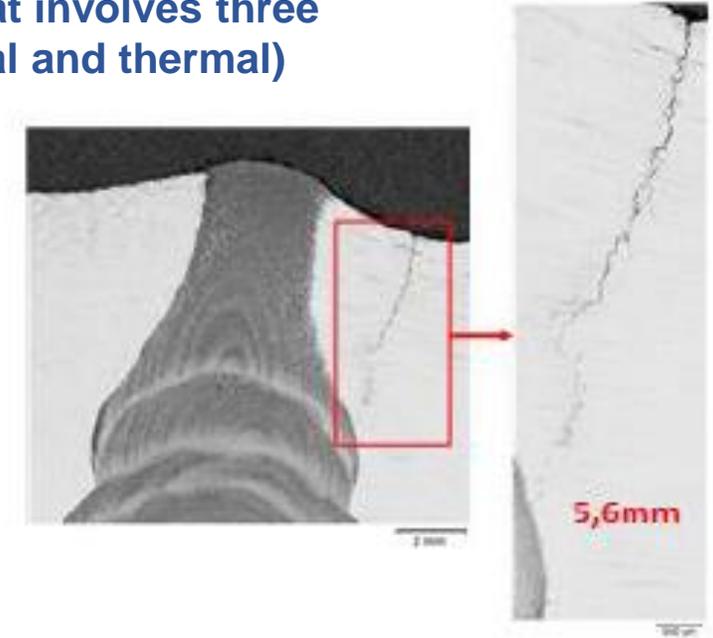
➔ **The coupling between vortex penetration and thermal stratification generates thermomechanical stress that constitutes a predominant cause in the occurrence of SCC.**

- A **temperature range** (approx. 100°C to 140°C) seems to be the limit **below** which the phenomenon of thermal stratification no longer occurs
- The **welding conditions** constitute a secondary factor but are considered as an **aggravating factor** for lines sensitive to SCC
- The results of numerical welding simulations and laboratory expertise show **existence of a compression zone that blocks the evolution of an SCC defect**

➔ **There is no risk of evolution towards through-thickness cracks leading to a loss of integrity of the circuits.**

- The phenomenon could appear very quickly given the oxidized nature of the cracks observed in the laboratory, but its evolution could be slow.

➔ **Studies suggest an indicative and conservative value of 0.5 mm/year.**



## Removal phase

### Site preparation (ooc):

- Removal of interferences
- Removal of insulation
- Installation of biological protections
- Installation of containment airlock
- Installation of easements

Preparation of equipment and tools

### Dose rate mapping

Installation of lifting/handling accessories

Installation of line blocking devices

Line cutting marking

Installation of section handling clamps

Installation of cutting machine

### Cutting

Removal of cutting machine

### Installation of shielded plugs

Dimensional surveys

Lifting and removal of sections

Decontamination of the airlock and piping

Transition to reinstallation phase

## Reinstallation phase

Receipt of new piping sections

Preparation of equipment and tools

### Dose rate mapping

Dimensional surveys of piping tips

### Removal of shielded plugs

Installation of beveling tool

### Beveling of piping tips

Removal of beveling tool

### Installation of plugs

Topography

Installation of lifting/handling accessories

Transportation of new piping section to the work area for docking

Installation of inerting system

### Lifting section for blocking and docking

### Manual welding (root passes)

Orbital welding machine installation

### Orbital welding

Removal of orbital welding machine

Non-Destructive Tests (NDT)

### Internal piping cleanliness check

Site demobilization

### Final positional checks

Restoration of support elements configuration

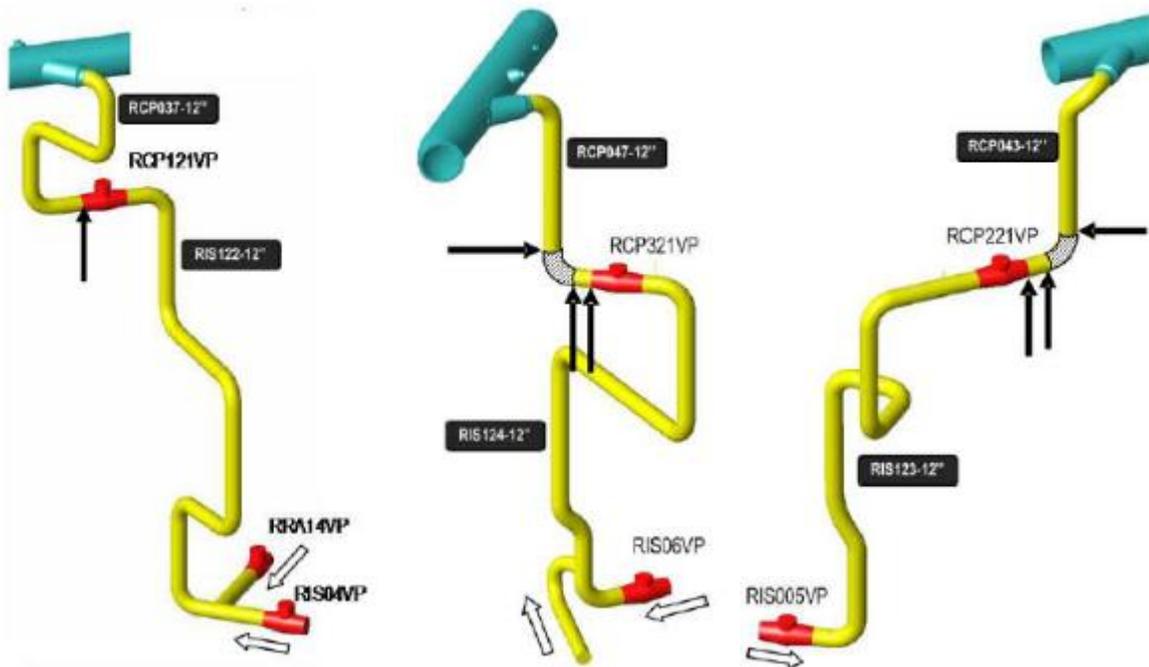
Reconciliation report

Logistics removal (airlocks, easements, etc.)

Removal of equipment and tools

Reinstallation of interferences (ooc)

Security Injection system (RIS)  
in 900 MW reactors:



Example inside a 1450MW N4 reactor building

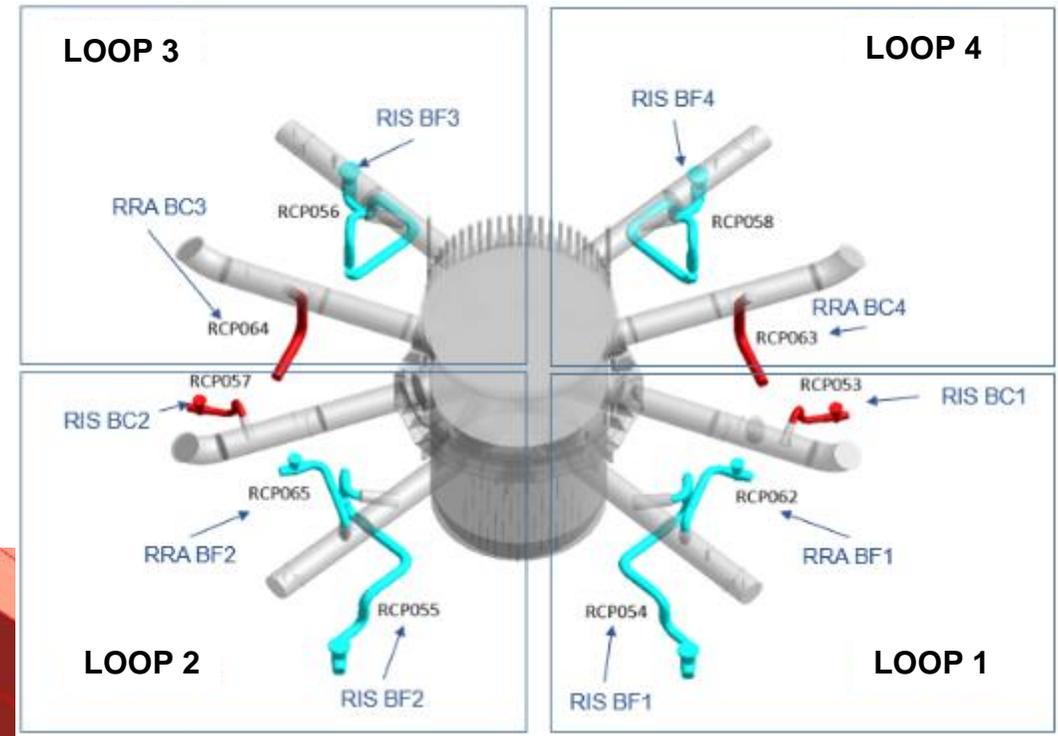
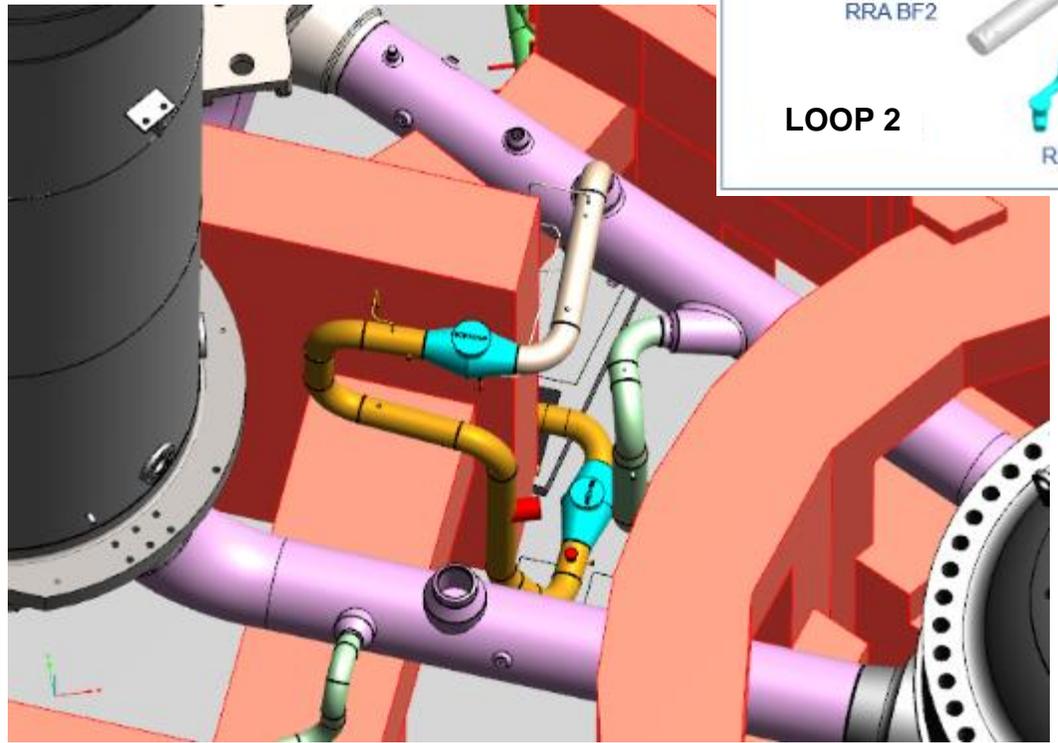
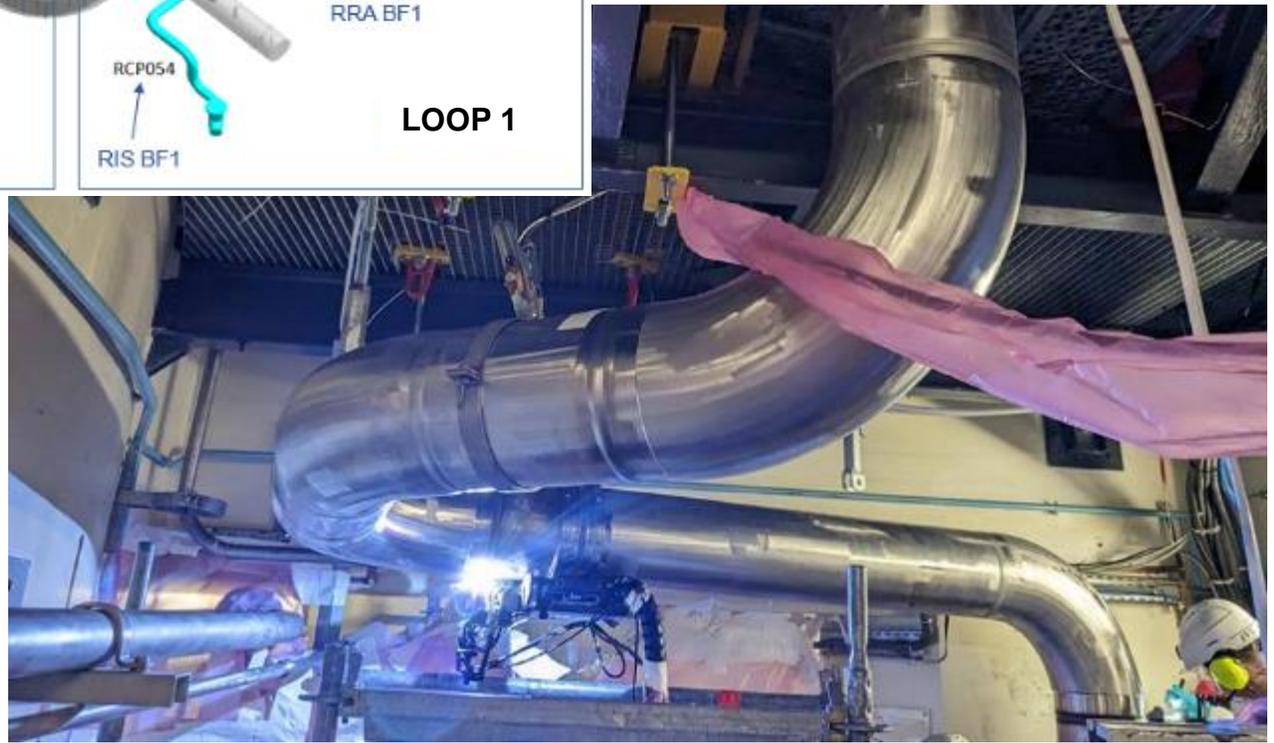


Photo inside a 1300MW PP4 reactor building



# RADIATION PROTECTION



- **RP Optimization**
- **2023 RP Report**
- **Operational insight & guidelines**

Water level
Biological protections
Decontamination of piping tips
Containment airlocks
Tools
Staff preparation
RP Supervision
Evacuation of deposited sections
Respiratory protection devices
Good practices

**Fully filled circuits** as long as possible for logistics and equipment installation, for removal of interferences and for the beginning of cutting.

→ ~15% dose rate reduction at the “vessel joint plan” water level.

**Standard lead wool blankets:** directly on pipelines (approximately 1,50m on each side of the cutting line) when possible.



**T-flex® ribbons:** additionally, for dosing interferences, with an effective decrease in passage dose rate.



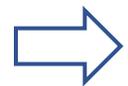
→ ~10% to 20% dose rate reduction.

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**Contamination spectrum:**

Deposited Activity (GBq/m<sup>2</sup>) in primary circuit:

AD moy (GBq/m <sup>2</sup> )	Before oxygenation & purification						After oxygenation & purification					
	<sup>58</sup> Co	<sup>60</sup> Co	<sup>54</sup> Mn	<sup>59</sup> Fe	<sup>124</sup> Sb	<sup>110m</sup> Ag	<sup>58</sup> Co	<sup>60</sup> Co	<sup>54</sup> Mn	<sup>59</sup> Fe	<sup>124</sup> Sb	<sup>110m</sup> Ag
<b>CIRCUITS</b>												
RCP	3,32	1,53	0,16	0,07	0,07	0,05	3,08	1,29	0,13	0,08	0,12	0,04
RCV	0,99	0,23	0,03	0,01	0,04	0,14	1,30	0,38	0,05	0,02	0,06	0,39
RRA	0,79	0,16	0,03	0,01	0,03	0,04	1,10	0,36	0,07	0,06	0,08	0,06
REN	2,84	0,19	0,14	0,09	0,57	1,98	1,71	0,52	0,13	0,03	0,12	0,60
RIS	1,61	0,48	0,06	0,03	0,07	0,08	1,63	0,66	0,12	0,04	0,09	0,03



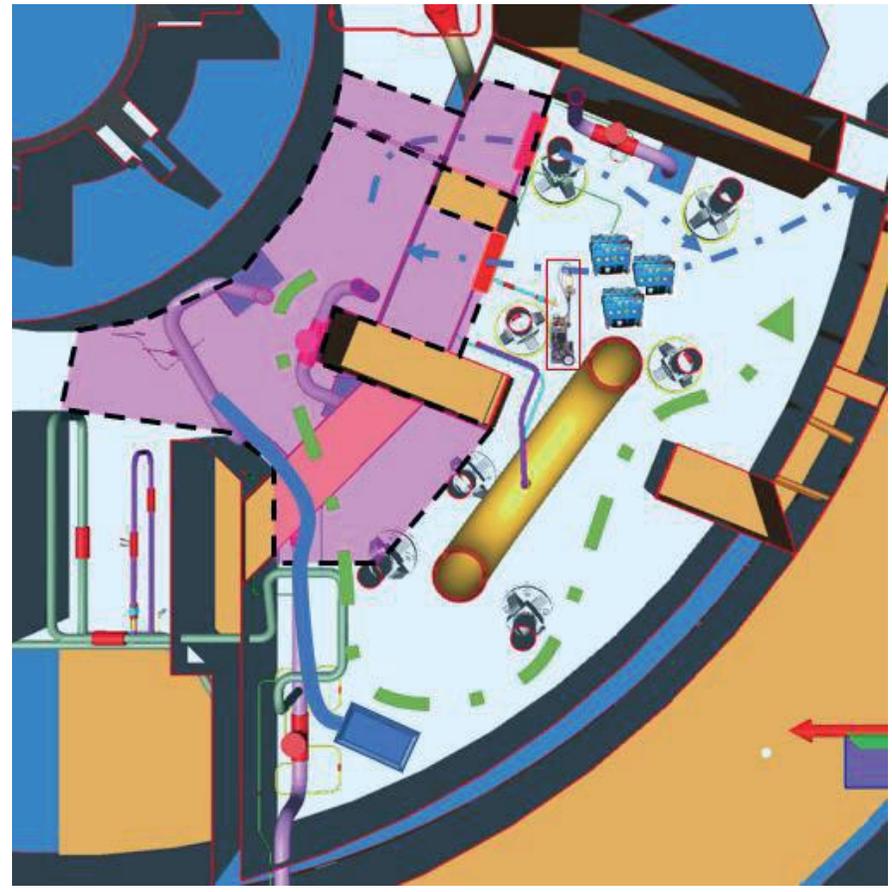
**Internal RIS pipe contamination estimated at ~200 000 Bq/cm<sup>2</sup>**

**Manual decontamination of piping tips:** using a cloth soaked in decontaminating product.

- ➔ Objective for removal phase : reduce to < 40 Bq/cm<sup>2</sup> & work with respiratory protection while circuits are open
- ➔ Objective before welding : reduce to < 4 Bq/cm<sup>2</sup> outside piping & < 40 Bq/cm<sup>2</sup> inside piping

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## Precise description of containment airlocks:



Distinction between flows:



## Double (or more) vinyl layer on the floor

Regular decontaminations **especially** before reinstallation phase and **very especially** before welding

Maintaining a **good depression** in the airlock is not easy due to the ergonomics of the premises (creation of access at the upper level)

➔ **Source capture (aspiration)**



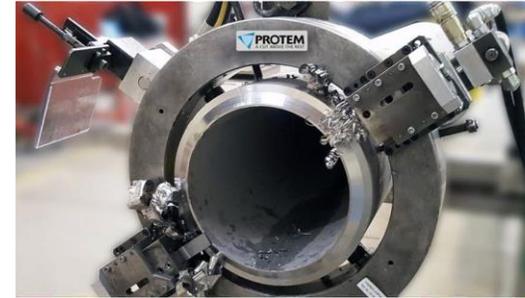
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### Orbital cutting machines:

Best: automated lubrication with oil recovery system.

Generation of long curling chips.

➔ Use of long gripping tongs (distance ~60 cm)



### Beveling machines:

Best: numerically controlled automatic beveling machine.

100% remotely operated equipment.

No human intervention required in the airlock.

Generation of small incandescent chips.



### Welding:

Except for the first root pass, prioritize 100% remote operation.

Modifications on qualified equipment have a high financial cost.

**May 24:** the first 100% remotely operated weld performed!

➔ ~3 times less dose.



Some contractors offer trainings on 1:1 scale mock-ups.

Others partner with specialized companies: tracing/piping, handling, surveying, etc.

The training focuses on the most dosed specialties.



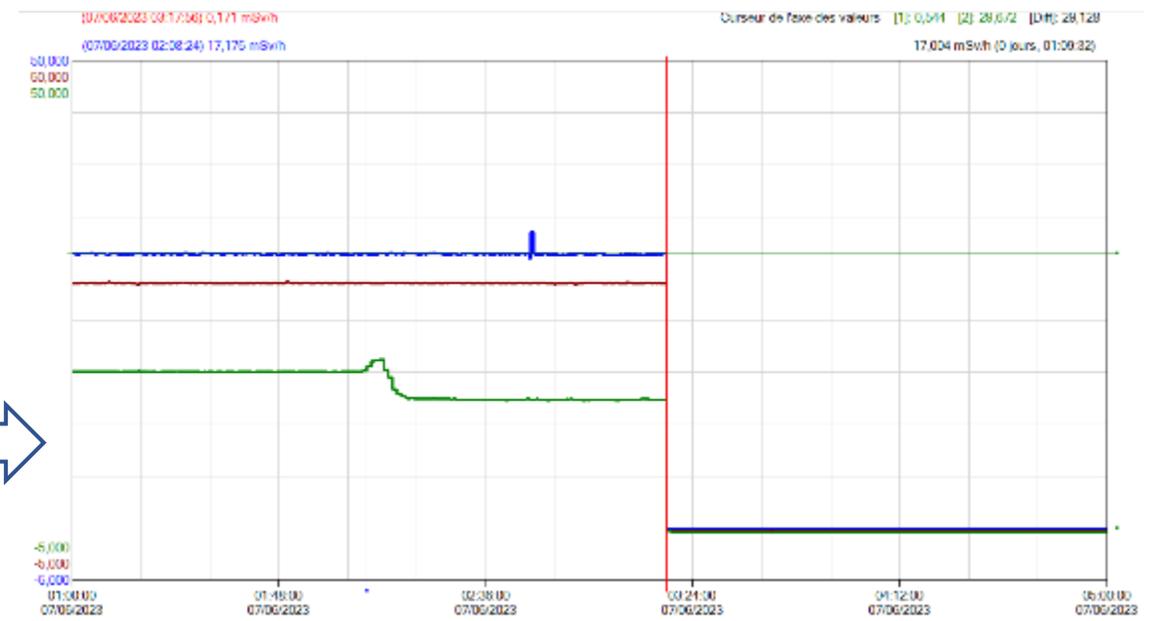
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## « PSPR » instrumentation used to monitor primary circuit flushing:



Flushing = essential RP optimization.  
Effectiveness is observed using PSPR instrumentation.  
As well as in the RIS counter-slopes

Flushing only lasts ~30 minutes.



Contact dose rate decreases from 18 mSv/h to 0,630 mSv/h

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## Evacuation of piping sections:

Custom-made carts: supporting the piping sections + standard biological protections strapped over if necessary. Route determined with RP Department, vinyl wrapping, regular dose rate monitoring. Scheduled evacuations to avoid peak periods.



## Respiratory protection devices vary throughout the intervention:

Automatic orbital pipe cutting	Manual pipe cutting	Pipe handling before plugs installation	Manual root welding on contaminated parts
Ventilated Helmet + Paper clothing 	Reinforced ventilated sealed suit 	Ventilated Helmet OR Self-contained hood with assisted ventilation + Paper clothing 	Speedglass + Welder's suit 

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**Quick-installation shielded plugs** to limit the increase in dose rate after opening the piping  
 → Dose Reduction Factor of 0.5 (reduces dose rate generated by the contamination inside of the piping).



**Gamma camera** to guide the placement of **lead wool blankets**.



→ Useful in degraded radiological context.

**Vibrating wristband** to relay hardly audible dosimeter alarm to the wrist



Adhesive labels on piping to **improve high dose rates signalization**



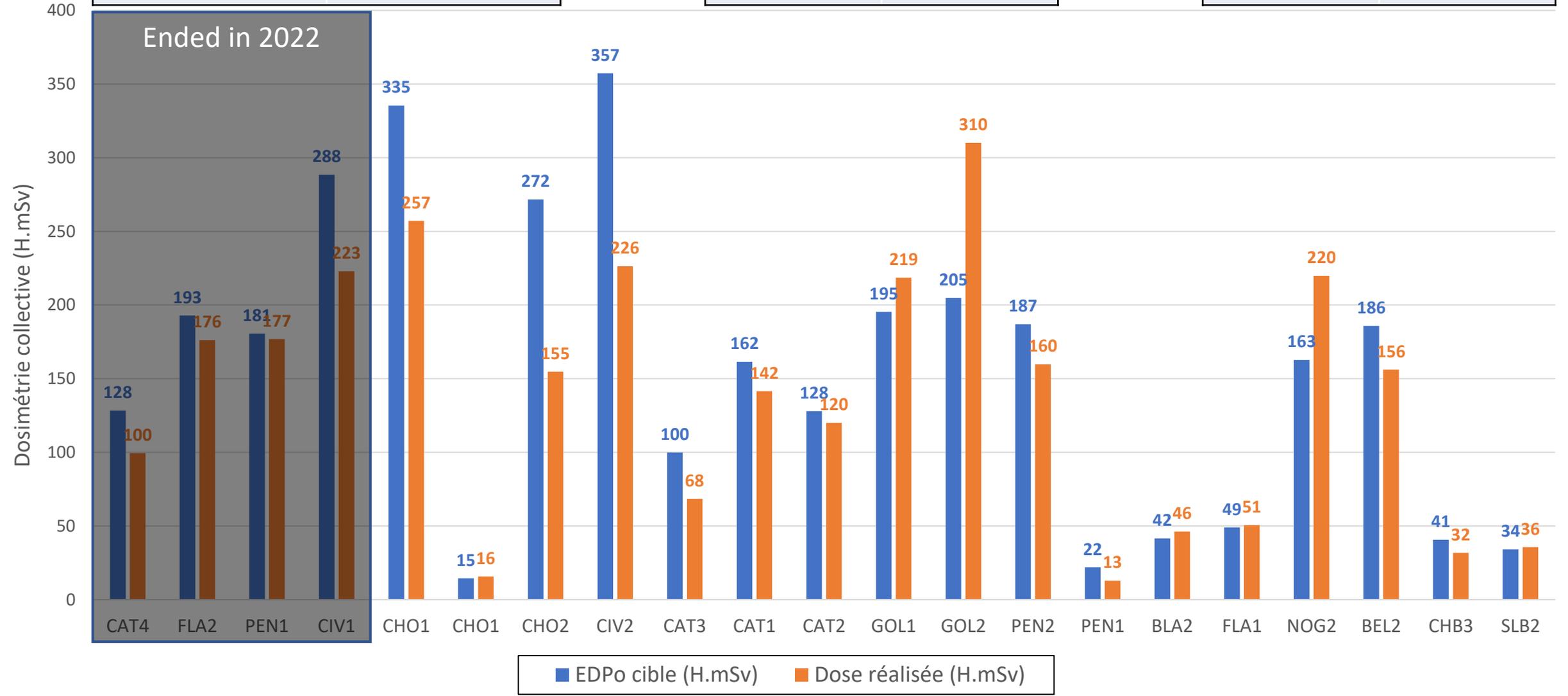
→ Useful when working in high dose rate environment

# 2023 RP report - Collective dosimetry

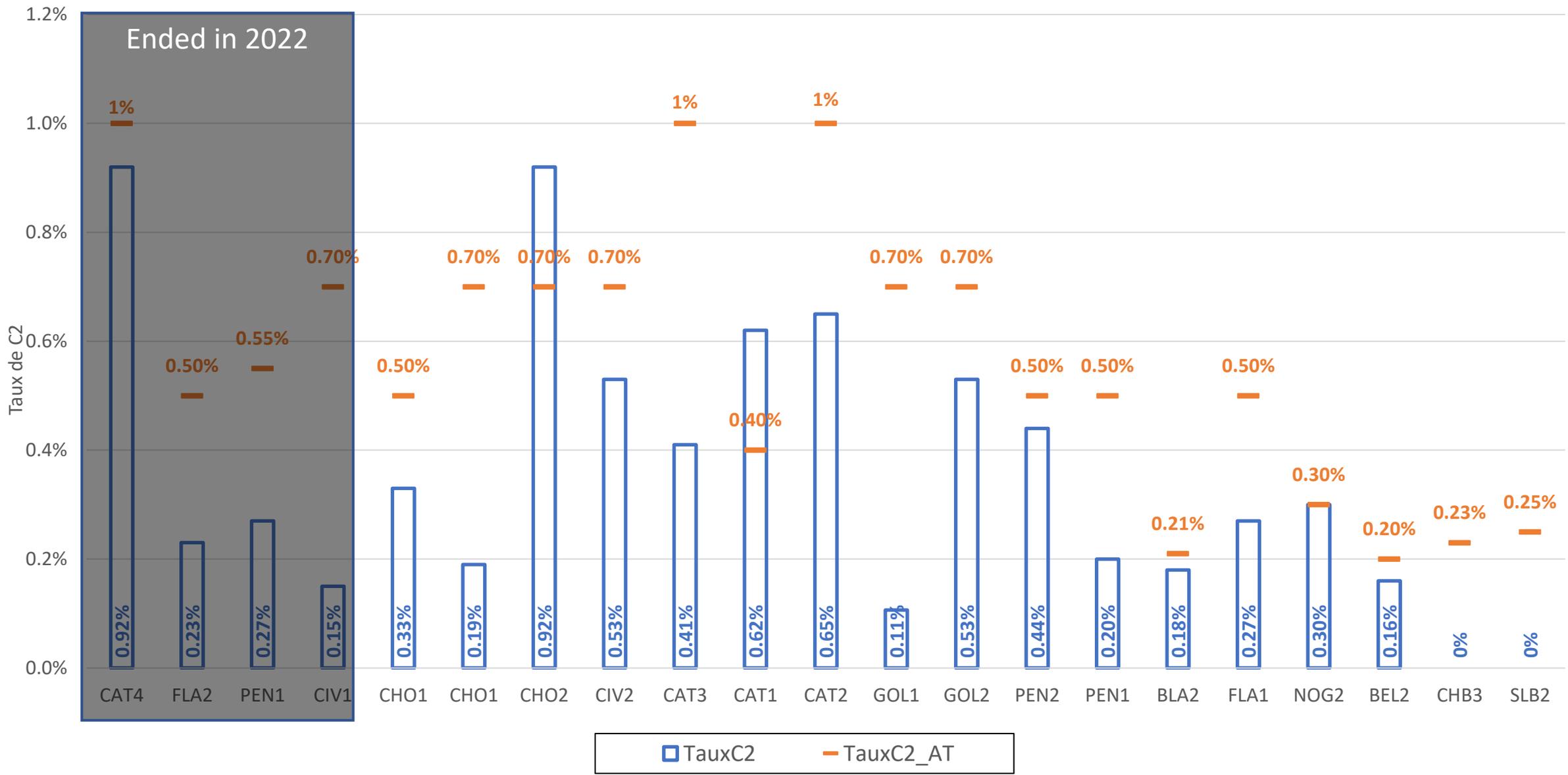
Nb of welds repaired in controlled area	
2022	2023
74	228

Integrated dose (H.mSv)	
2022	2023
675	2225

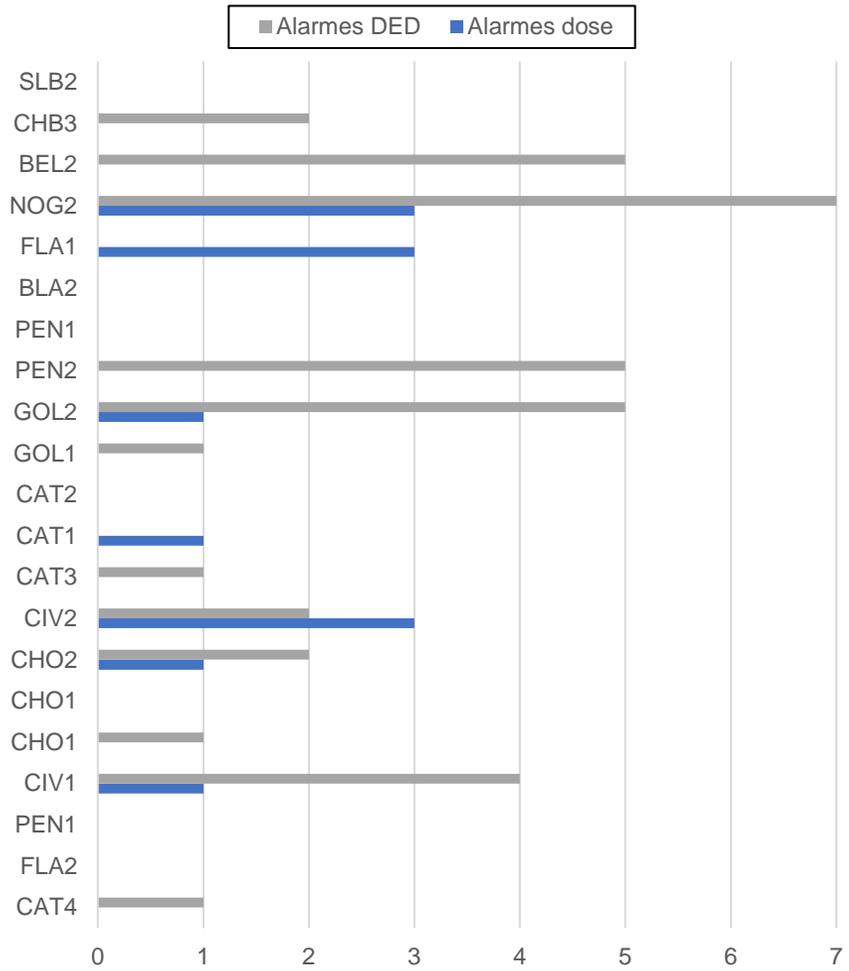
Dose per weld repair	
2022	2023
9,12	9,76 (+7%)



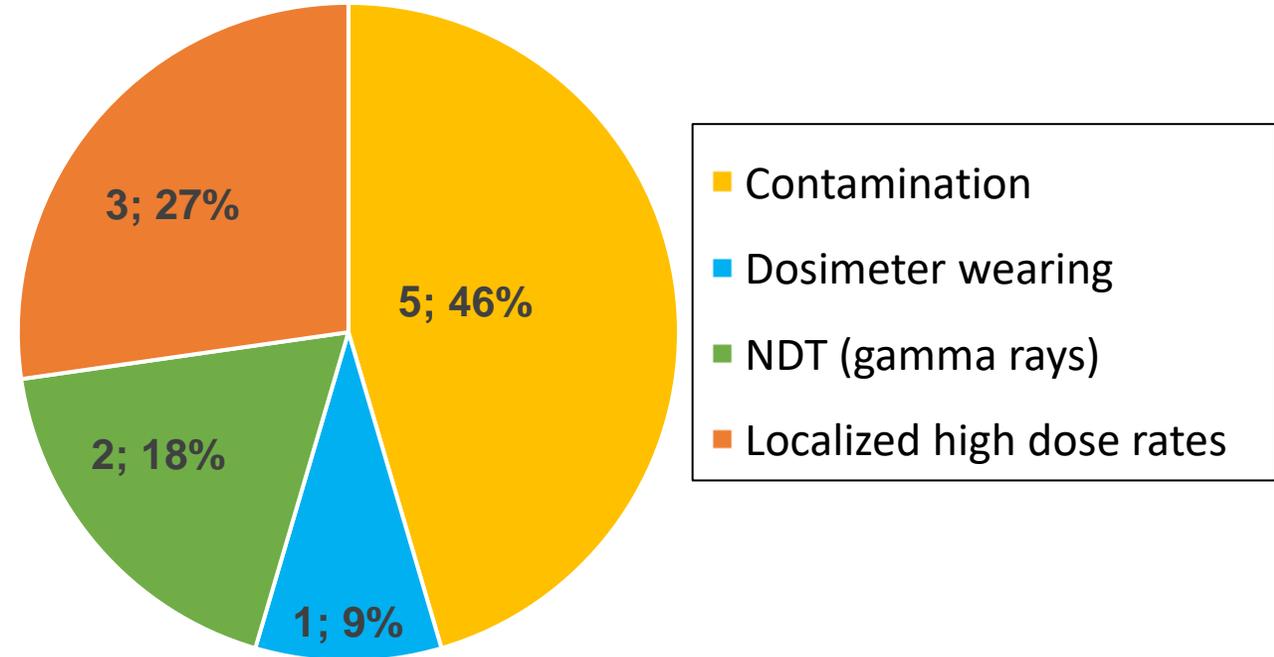
## Maintaining cleanliness in the airlocks leads to a downward trend in the C2 rate



### Dosimeter alarms



### RP Events topics



Nb of dosimeter alarms	
2022	2023
6	43

A rising trend to be stemmed...

Nb événements (ESR + EIR)	
2022	2023
1 ESR + 3 EIR	2 ESR + 5 EIR

Increase linked to the numerous SCC interventions in 2023

### **Reduce the dose** by limiting exposure to **high dose rates** in the work environment:

- Mandate primary circuit flushing with RP monitoring
- Enhance tools and procedures
- Prioritize RP technicians on high-risk phases: sensitive dose rate measurements, checks on equipment exiting contaminated area, verify access conditions...

### **Limit the contamination dispersion** by improving management of **sensitive activities**:

- Cleanliness in the containment airlocks
- Precise description of activities in the Risk Analysis: pipe cleanliness check, removal of irradiated materials from circuits, etc.
- Clearly define equipments (clamp, vacuum cleaner, etc.) and specific measures to take into account
- Implement countermeasures on the field



Thank you



Division de l'Ingénierie du Parc  
et De l'Environnement

