| | | | |
|---|---|---|---|
| Physics Department | **ATLAS & CMS instrumentation irradiation test campaign No.3** | | |
| *Document identifier:* | *Institute Document No.*<br><br>*EDMS: 2978185* | *Created: 08/11/2023*<br><br>*Modified:* | *Page:*<br><br>*Rev. No* |

# Test Summary

# ATLAS & CMS instrumentation irradiation test campaign No.3

***Abstract***

This document outlines the irradiation testing of ATLAS & CMS components for their inner detectors' $CO_2$ cooling systems carried out at the CHARM facility.

| ***Prepared by:*** | ***Checked by:*** | ***Approved by:*** |
|---|---|---|
| **David SCHMID**<br>[EP-ADO-PO]<br><br>**Marcin CIUPINSKI**<br>[EP-DT-FS] | **Bart VERLAAT**<br>[EP-DT-FS]<br><br>**Martin DOUBEK**<br>[EP-ADO-PO]<br><br>**Tym PAKULSKI**<br>[EP-CMX-SCI] | **Lukasz ZWALINSKI**<br>[EP-DT-FS]<br><br>**Jérôme DAGUIN**<br>[EP-DT-FS] |

*Distribution List*

## *History of Changes*

| ***Rev. No.*** | ***Date*** | ***Pages*** | ***Description of Changes*** |
|---|---|---|---|
| 1 | 08/11/2023 | NA | Creation of document by David SCHMID |

## Table of contents

## TABLE OF FIGURES

# 1 Introduction

The purpose of this irradiation test campaign is to qualify instrumentation and components designated for the use in the $CO_2$ cooling systems of the ATLAS and CMS tracker detectors during the run of the HL-LHC. The third instrumentation irradiation test campaign has been carried out to test additional equipment and/or to follow up the previous tests of instrumentation – documented in EDMS-Docs. 2772760 [1] and 2839350 [2] – with additional features. The procedure of the third campaign is mainly based and oriented on the previous ones. The differences between campaign No. 3 and No. 1&2 are elaborated in this document.

# 2 Specifications and components tested

## 2.1 Specifications

The radiation conditions at the tracker's $CO_2$ cooling system within the ATLAS and CMS experiments during the HL-LHC are analyzed and summarized in [3] and [4] respectively. The reports anticipate the following radiation doses and suggest the following worst-case scenarios:

- ATLAS [3]: "For a design purpose, we shall assume the maximum value out of all simulations. FLUKA => 43.16 +/- 24 [Gy] => **worst case scenario 67 [Gy]**"

- CMS [4]: "Assuming the worst-case scenario we shall assume the maximum value out of all simulations. **Max dose= $1.10^{-2}$ x 3000 = 30 Gy**. All electronics equipment installed in the CMS UXC55 cavern should therefore withstand at least 30 Gy over the lifetime of the $CO_2$ system."

## 2.2 Components tested

The following components are included in this test campaign:

- 2x Pressure Switch from *HUBA Control (521.940S023301W)*
- 1x Absolute Pressure Transmitter: *Keller PAA-33X (233345.1373)*, covering a range from 0…150 bar abs.
- 1x Temperature Probe RTD (PT100) with Capton strap: xxx
- 1x Potentiometer Position Switch Board 2137 (PCB)
- 2x Level Gauges *Kobold NGR-1242G5L* & *Smeri Microcap* (tested on behalf of EN-CV)
- 8x Pressure Transmitter (tested on behalf of the EP-DT-FS gas group):
  - *Aplisens PRE-28 (05224090)*
  - *Aplisens PCE-28 (04224336)*
  - *Aplisens PRE-50G (05224091)*
  - *Aplisens PRE-28 1/4NPTF (04224522)*
  - *Aplisens PCE-28 G1/4 (04224332)*
  - *Aplisens PCE-28 (04224338)*
  - *SIKA DSI52835420W01*
  - *SIKA DSI525-677-420WO2-1/4G*
- Material samples:
  - 1x Insulation foam sample *Armaflex Ultima* (blue)
  - 1x Foam sample of "construction foam" xxx
  - 4x 3D-printed plastic samples from *Algona (Onyx 37% Infill, Onyx 100% Infill, Onyx FR 37% Infill, Onyx FR 100% Infill)* – tested on behalf of S. VOGT from MPI Munich.
  - 1x Sample of the 4-wire cable: *MEDIKabel Part-No. 629140431|01* – tested on behalf of S. VOGT from MPI Munich.

# 3 The Test Procedure

## 3.1 The test setup and preparations

A new test stand made of aluminium profiles was built for this campaign. The absolute pressure transmitter – *Keller PAA-33x series* – covers a pressure range from 0…150 bar abs. with a signal output 4…20 mA. The reference to their data sheet can be found in the appendix. The transmitter is connected to the compressed air circuit of the facility via a manifold. The air pressure is manually set with a pressure regulator to ~5.6 bar.

The two *HUBA* Pressure Switches, the T-Probe, the Position Switch Board, the two Level Gauges (from EN-CV) and the eight Pressure Transmitter (from the EP-DT-FS gas group) were mounted onto the test stand without being actuated. However, all of them were connected to the PLC rack for monitoring and recording the data. The material samples are mounted to the test frame. The arrangement of the components and the frame is illustrated in Figure 1.

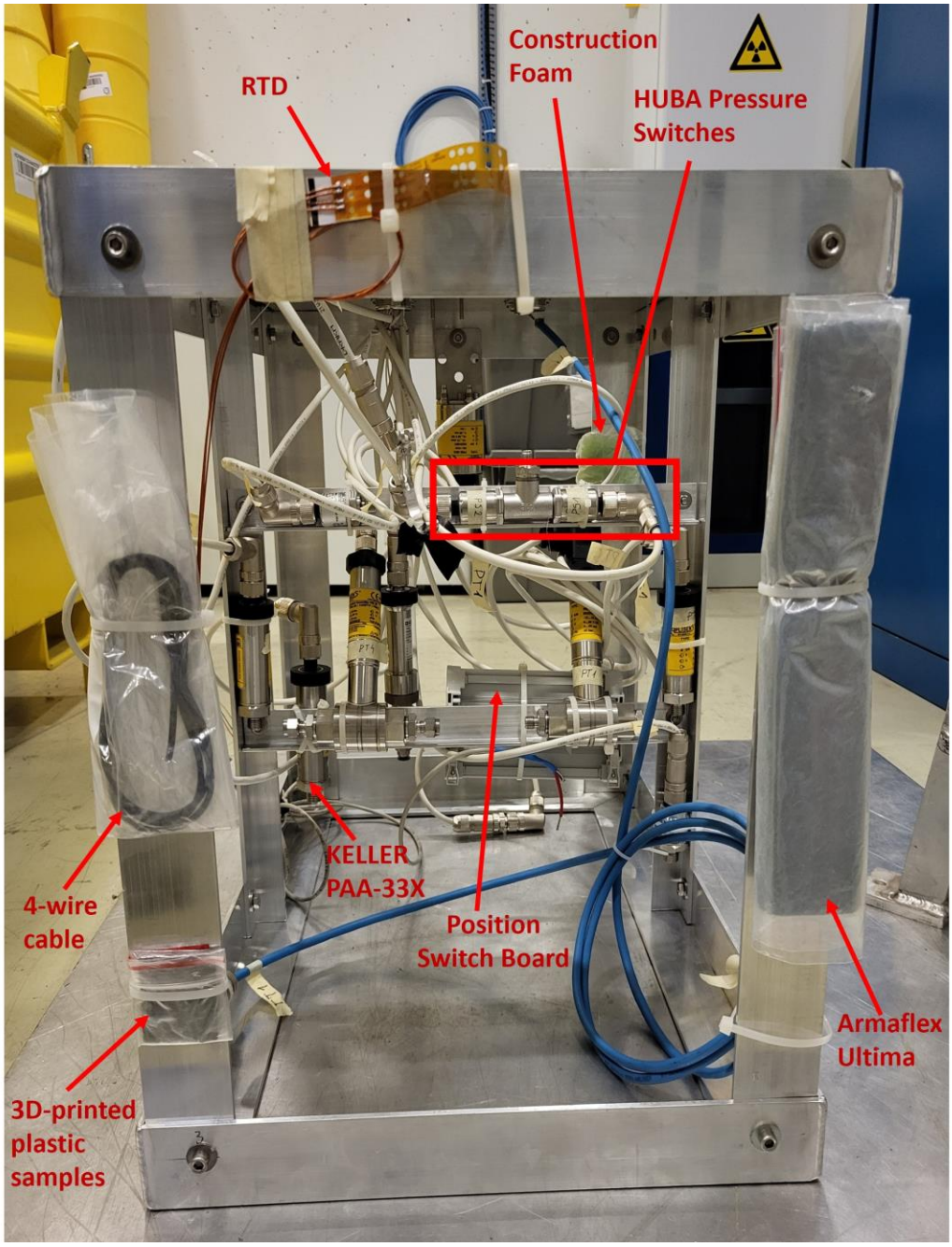


*Figure 1: Components to be tested mounted onto the test frame.*

Figure 2 depicts an isometric view of the test setup prior to installation and once mounted onto the chassis inside the test facility.

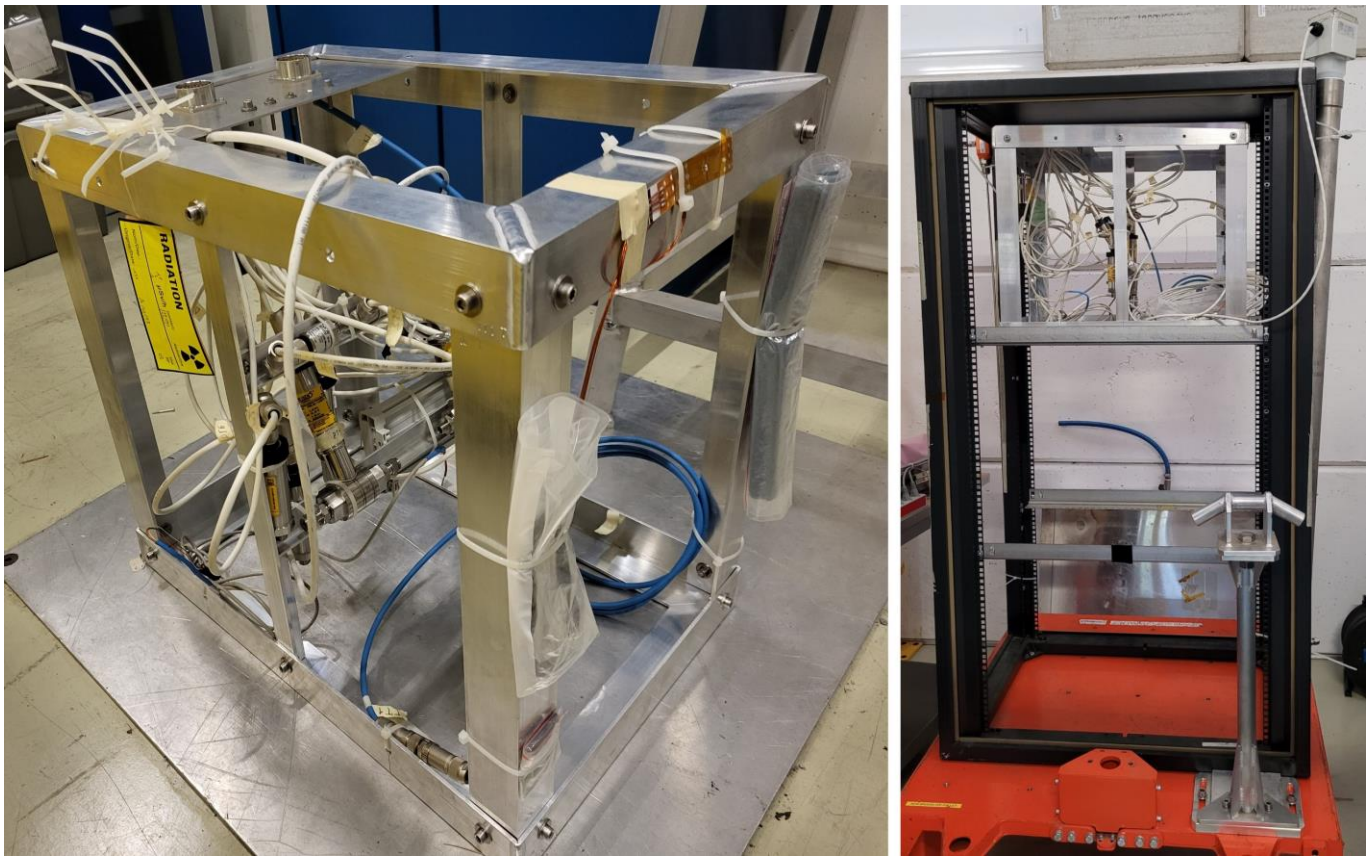


*Figure 2: Left: Isometric view of the test frame with all components installed. Right: Final configuration of the test bench with all the components placed inside the carrier at the CHARM irradiation facility.*

## 3.2 The test procedure at the CHARM irradiation facility

The 3rd radiation campaign has been carried out at CERN's CHARM facility already described in chapter 3.1 of the 1st- and chapter 3.2 of the 2nd test campaign. Further information can be found in the EDMS-doc 2721313 v.4.

The 3rd irradiation test campaign has been carried out between the following dates:

- Begin: Aug 16, 2023; ~ 10:35 AM
- End: Aug 22, 2023; ~ 09:19 AM

The entire radiation dose the test setup has been exposed to accumulates to ~ 400 Gy. Figure 3 illustrates the radiation dose as a function of time. In the end, this test campaign exceeds the radiation doses specified by ATLAS [3] and CMS [4] by factors ~ 6 and ~ 13 respectively.

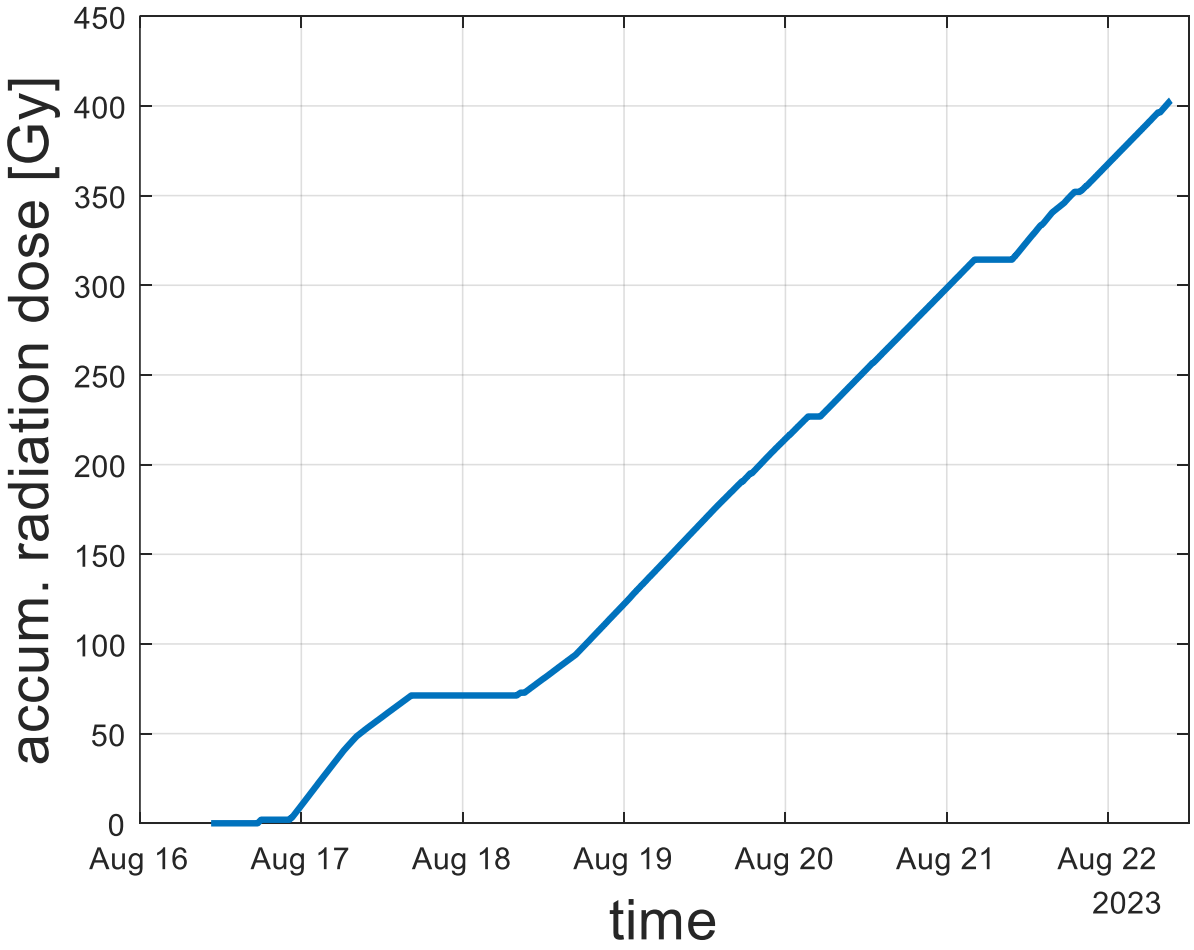


*Figure 3: Received radiation dose over time during the irradiation campaign.*

## 3.3 Data Acquisition

The DAQ of the instrumentation is realized with a PLC based control unit and is embedded in CERN's UNICOS environment. The instrumentation is monitored with CERN's Supervisory Control and Data Acquisition (SCADA) system.

# 4 Results

## 4.1 Absolute pressure transmitter Keller PAA-33X

Figure 4 illustrates the measurements of the absolute pressure transmitter *KELLER PAA-33X* as a function of the radiation dose during the test campaign. The pressure of the compressed air circuit has been set manually to ~5.6 bar and the detailed view in Figure 5 highlights that the measurements are reliable up to a value of about 90 Gy. The several spikes between doses of about 50 – 90 Gy can be explained either by Single Event Upsets (SEU) or by an other related behaviour of electronics in a constant field of radiation.

At ~92 Gy, a SEU was observed, which has been reset by the automatic power-cycling of the controls logic to its nominal measuring value of ~5.6 bar. At values >100 Gy, the transmitter shows a significant increase of the signal towards the max. value of the transmitter's range. This clearly indicates the failure of the transmitter since the steep increasing curve to high pressures up to the order of 160 bar generally violates the principles of $CO_2$ refrigeration systems. Moreover, the steep increasing graph with a remarkable $\Delta p$ towards the upper boundary of the transmitter's range make potential failures due to radiation easy to detect. Power-cycles at >100 Gy had no significant influence on the measurements and a consistently noisy, hence unreliable signal has been observed.

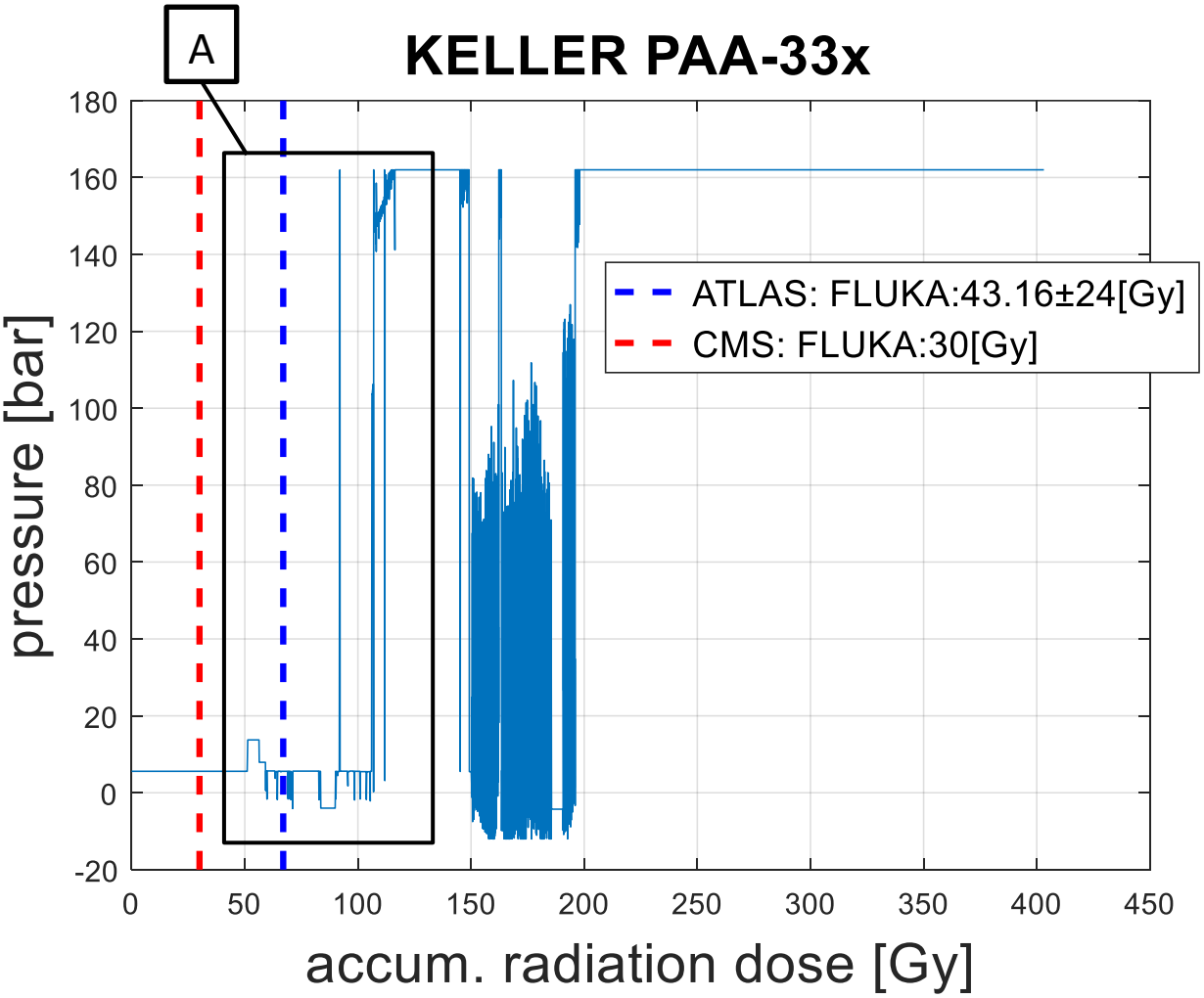


*Figure 4: Measurements of abs. pressure transmitter (KELLER PAA-33X) as a function of the radiation dose. Reference pressure during tests set to ~5.6 bar.*

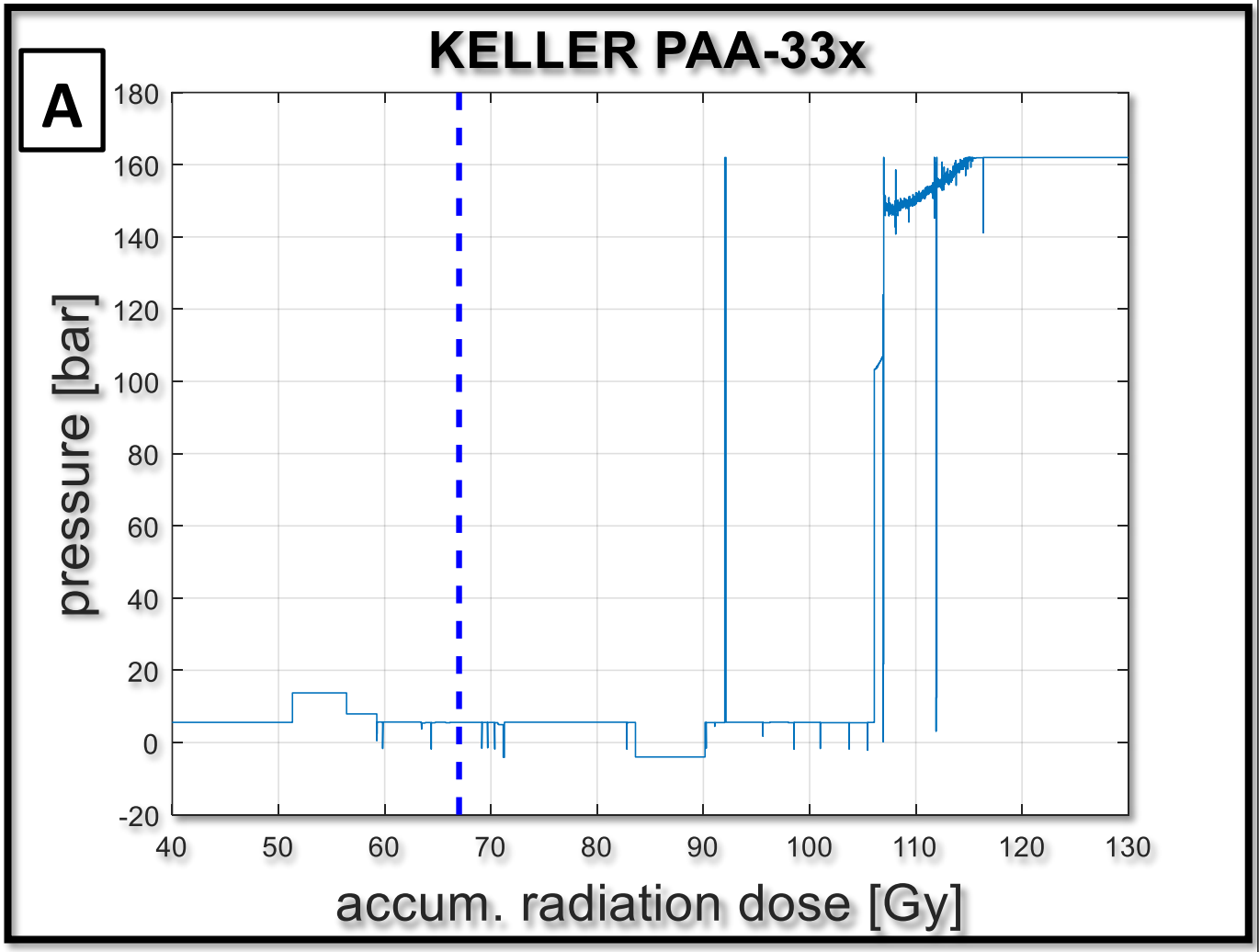


*Figure 5: Detailed view of the pressure measurements from Figure 4.*

## 4.2 Pressure Switch HUBA Control (521.940S023301W)

The two pressure switches from *HUBA Control (521.940S023301W)* were manually power cycled in irregular intervals. According to Figure 6, the following observations have been made:

- The responses of both devices were concurrent, at least up to a dose of 96.8 Gy.
- From a dose of >183.9 Gy on an inconsistent response between the two switches can be observed.
- However, there are no detailed information available between the doses of 96.8 – 183.9 Gy, since the devices have not been actuated during that period.
- No Single Event Upsets (SEU) have been observed during this test campaign.


*Figure 6: Actuation and responses of pressure switches from HUBA controls.*

### 4.3 Temperature Probe with Capton strap (RTD – PT100)

The RTD with Capton strap has been constantly exposed to the ambient conditions inside the irradiation facility and Figure 7 illustrates the measurements. The first spike that can be observed in the data corresponds to the disconnection/connection of the DAQ. For the second one there is not really an explanation. However, since it's way beyond the anticipated radiation doses, one might not investigate deeply in its nature.

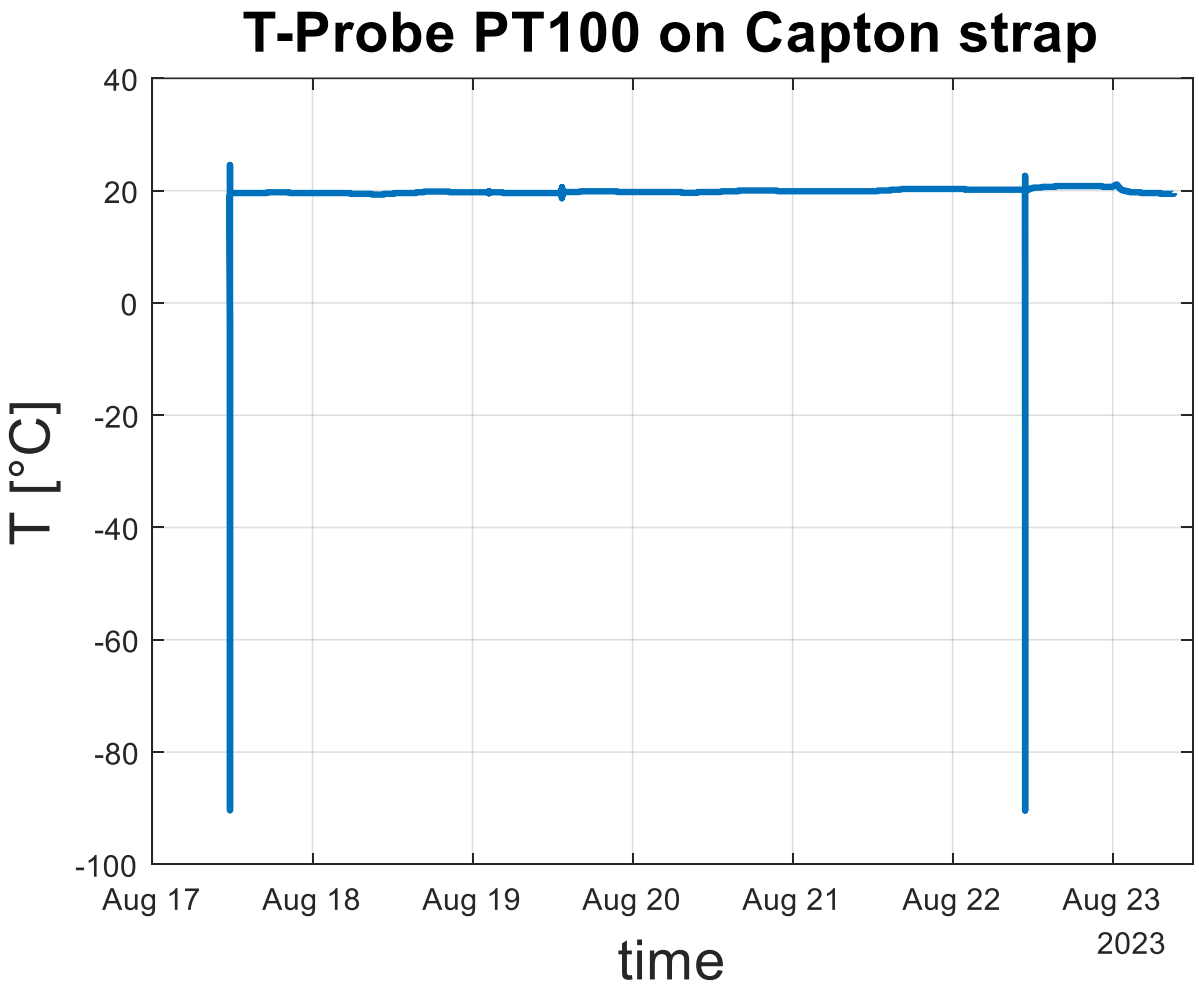


*Figure 7: Measurements of PT100 temperature probe.*

## 4.4 Potentiometer Position Switch Board

*The Potentiometer Position Switch Board 2137 (a printed circuit board – PCB) has been manually triggered with a few power cycles in irregular intervals as shown in*

Figure 8. Both times, at 57 Gy and 103 Gy, the switch board responded.

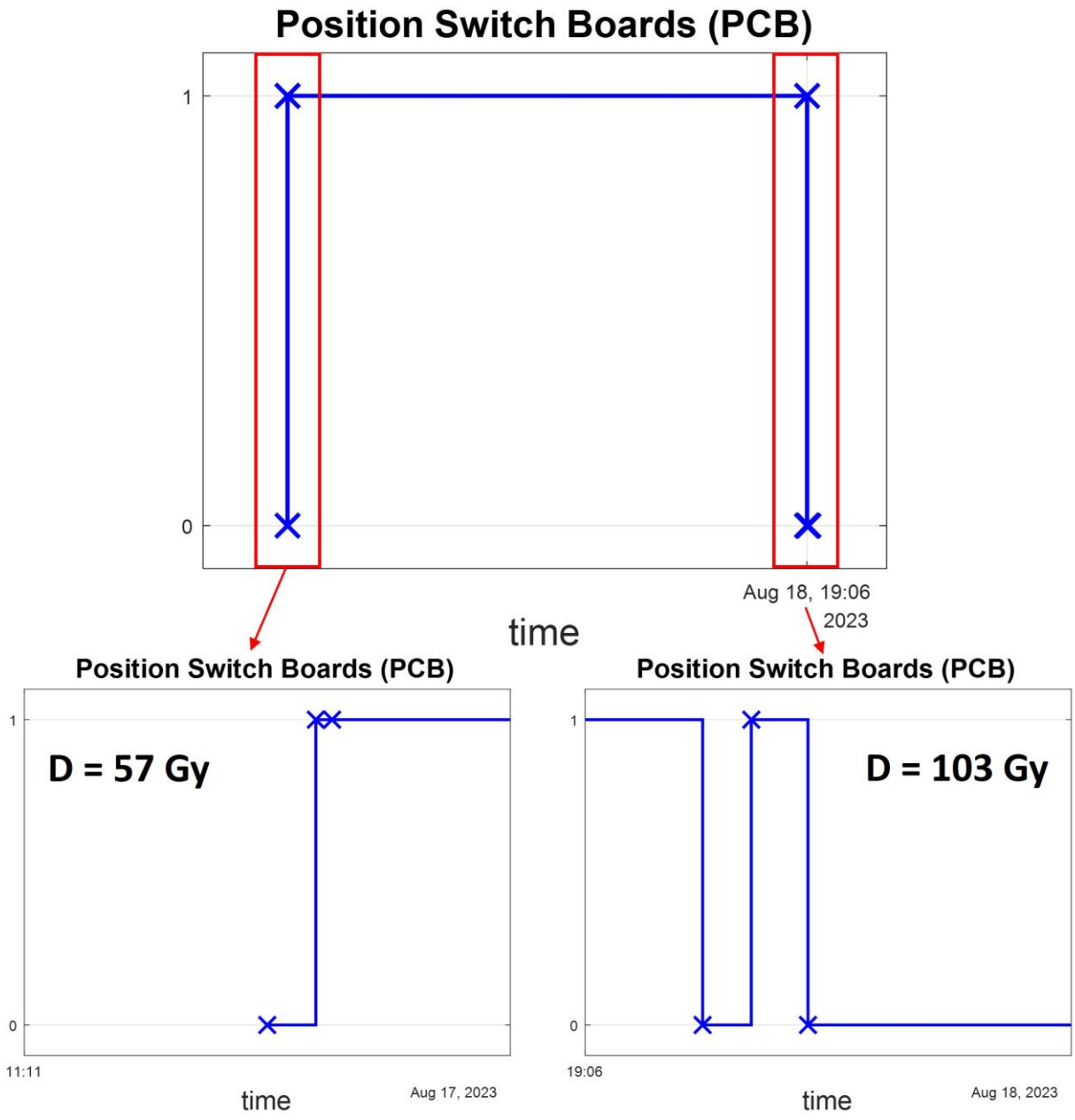


*Figure 8: Actuation and response of Potentiometer Position Switch Board.*

## 4.5 Level Gauges

The two level gauges *Kobold NGR-1242G5L* and *Smeri Microcap* were included into this test campaign on behalf of the Engineering – Cooling and Ventilation (EN-CV) department at CERN. The results are presented in Figure 9. The interpretation of the results will be left up to the EN-CV department.

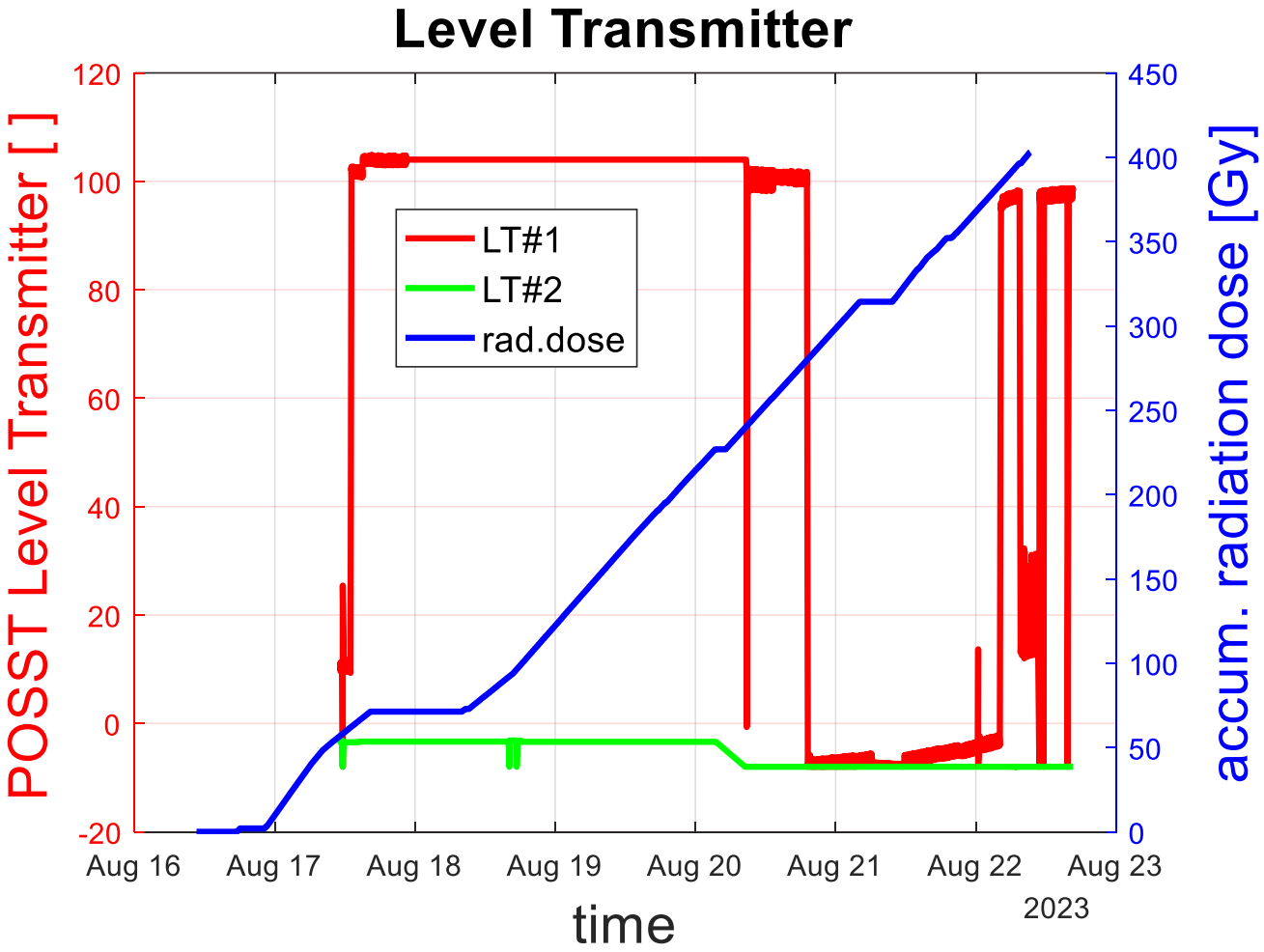


*Figure 9: Test results of the level gauges Kobold NGR-1242G5L and Smeri Microcap (on behalf of EN-CV).*

## 4.6 Pressure Transmitter Aplisens and SIKA (EP-DT-FS gas group)

The eight pressure transmitter from *Aplisens* and *SIKA* were included into this test campaign on behalf of the EP-DT-FS gas group and the results are illustrated in Figure 10. The interpretation of the results will be left to the EP-DT-FS gas group.

Similarly to the KELLER pressure transmitter, these sensors reveal a similar behaviour in response to irradiation. The measured signal starts to float at some point which can be an indication of electronics malfunctioning or damage.

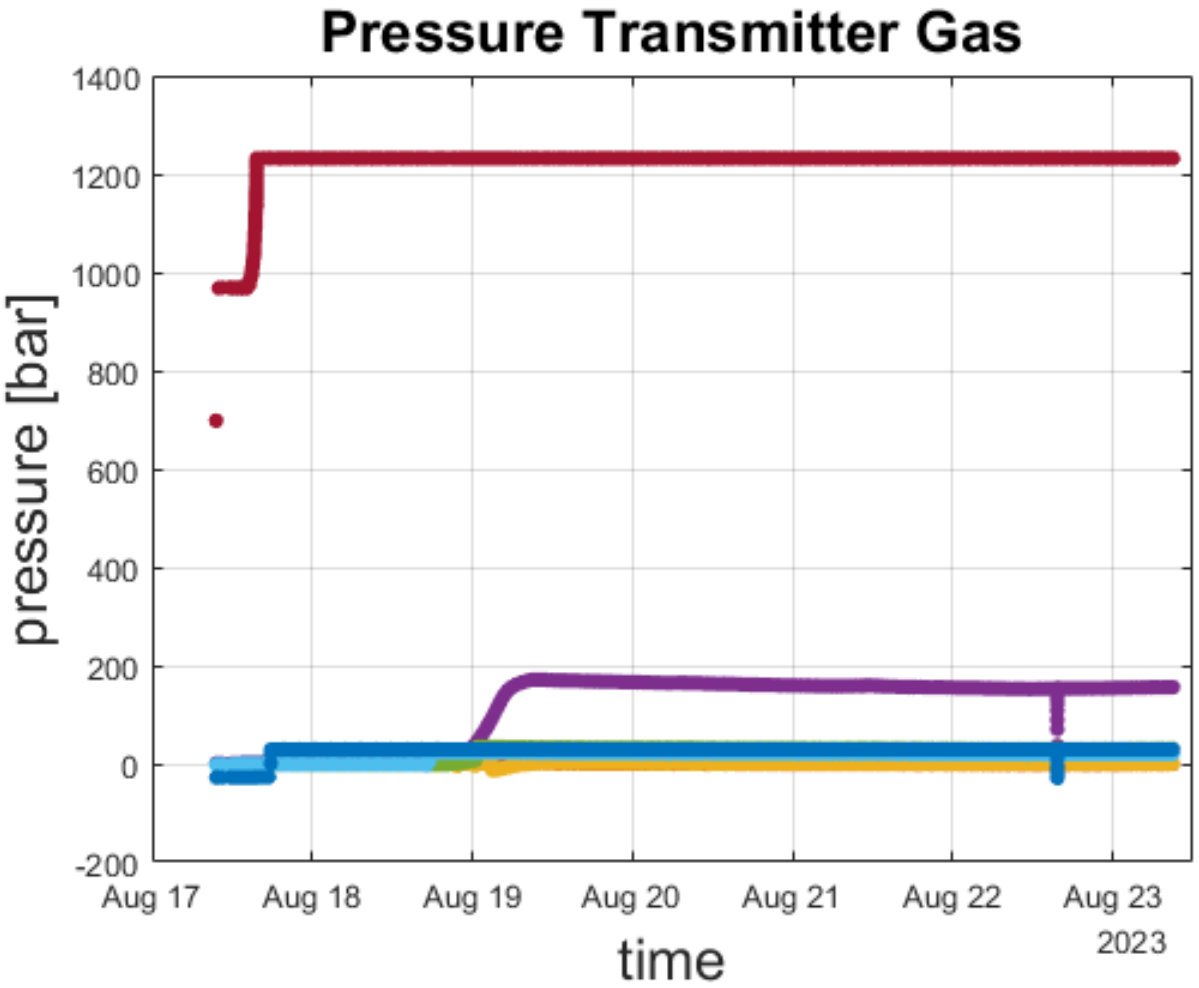


*Figure 10: Test results of the pressure transmitter Aplisens and SIKA (on behalf of EP-DT-FS).*

## 4.7 Material Samples

### 4.7.1 Insulation Foam *Armaflex Ultima*

*The material sample of the Armaflex Ultima insulation foam does not show any traces of deterioration, change of physical properties or any other kind of damage induced by radiation (see*

Figure 11).

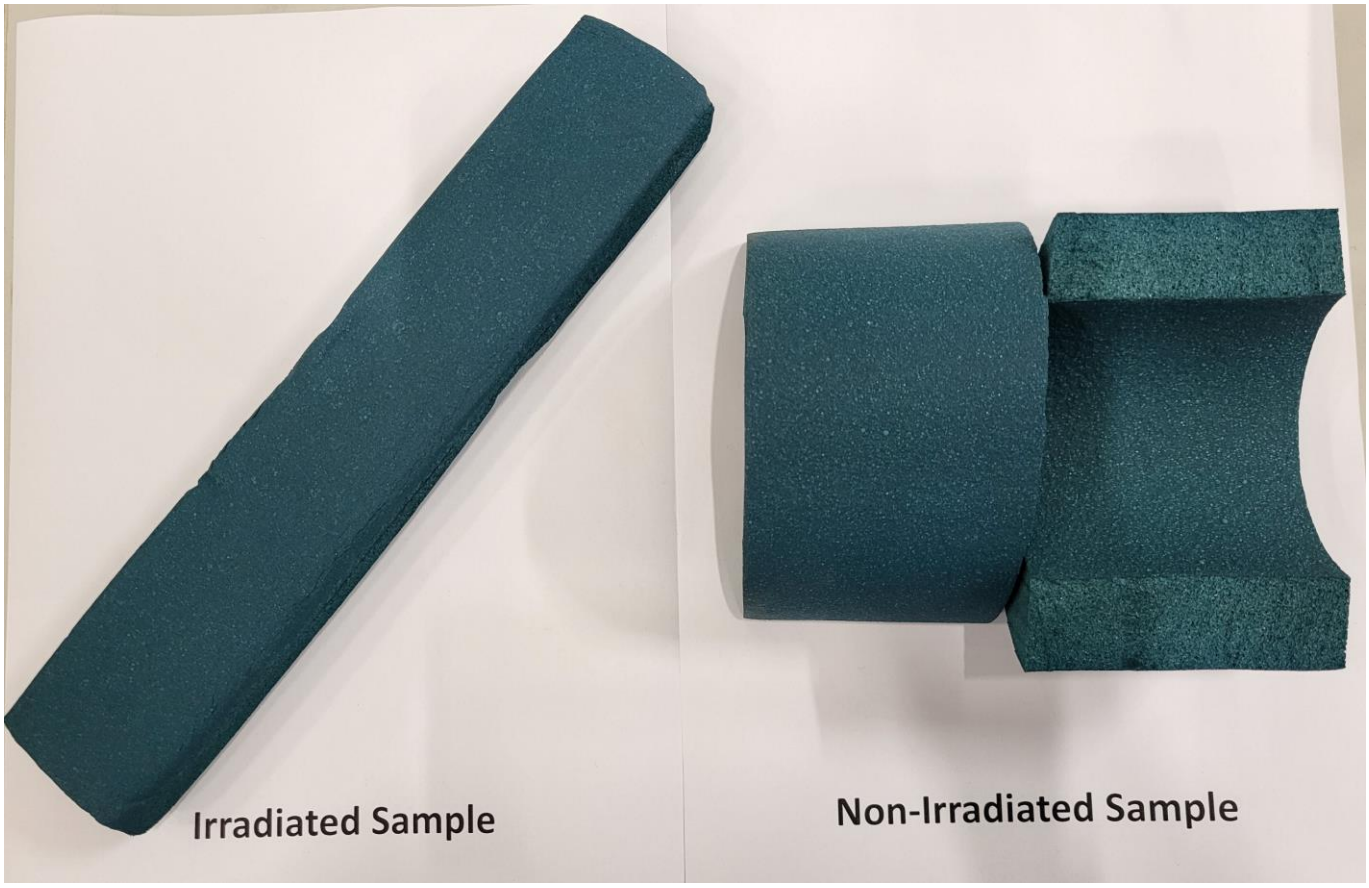


*Figure 11: Irradiated and non-irradiated sample of Armaflex Ultima insulation foam.*

### 4.7.2 Construction Foam

The material sample of the construction foam seems to be slightly discoloured and appears slightly darker than the non-irradiated sample. However, the change of colour can hardly be noticed. Besides that, the sample does not show any traces of deterioration, change of physical properties or any other kind of damage induced by radiation (have a look at Figure 12 and Figure 13).

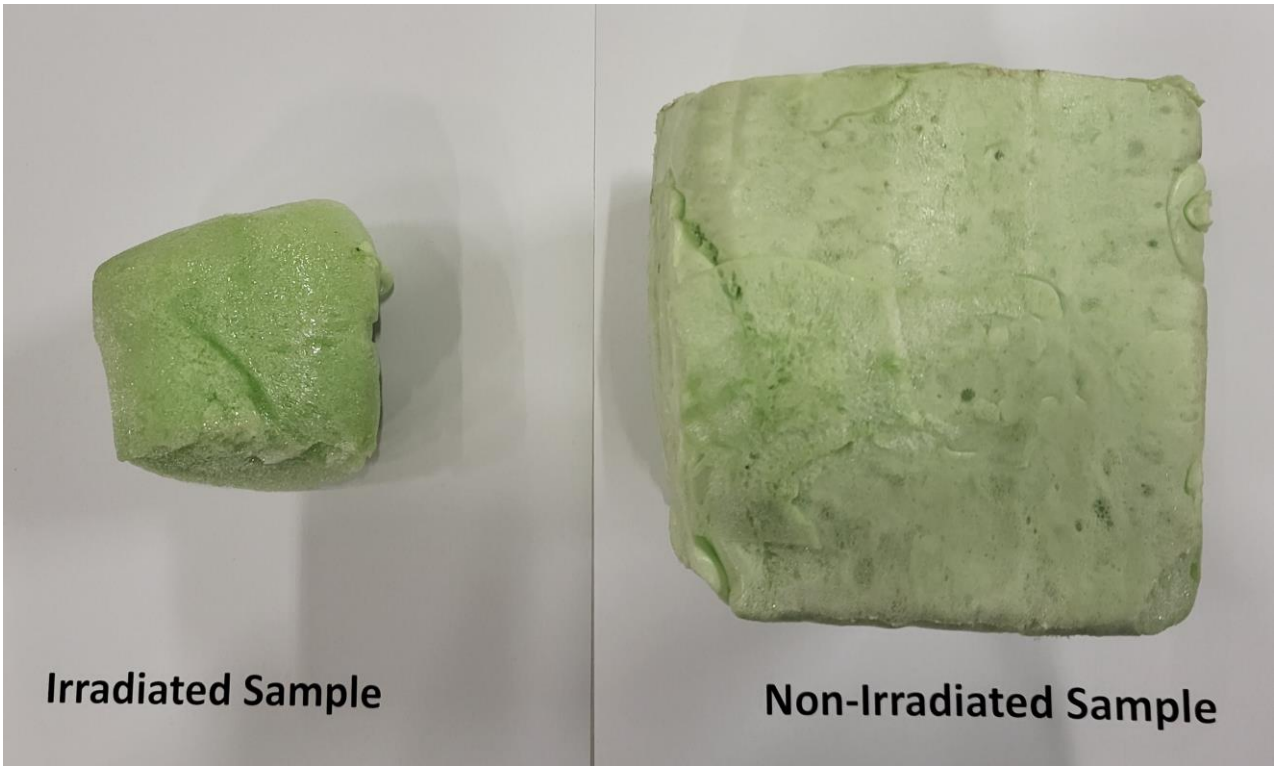


*Figure 12: Irradiated and non-irradiated sample of construction foam – view 1.*

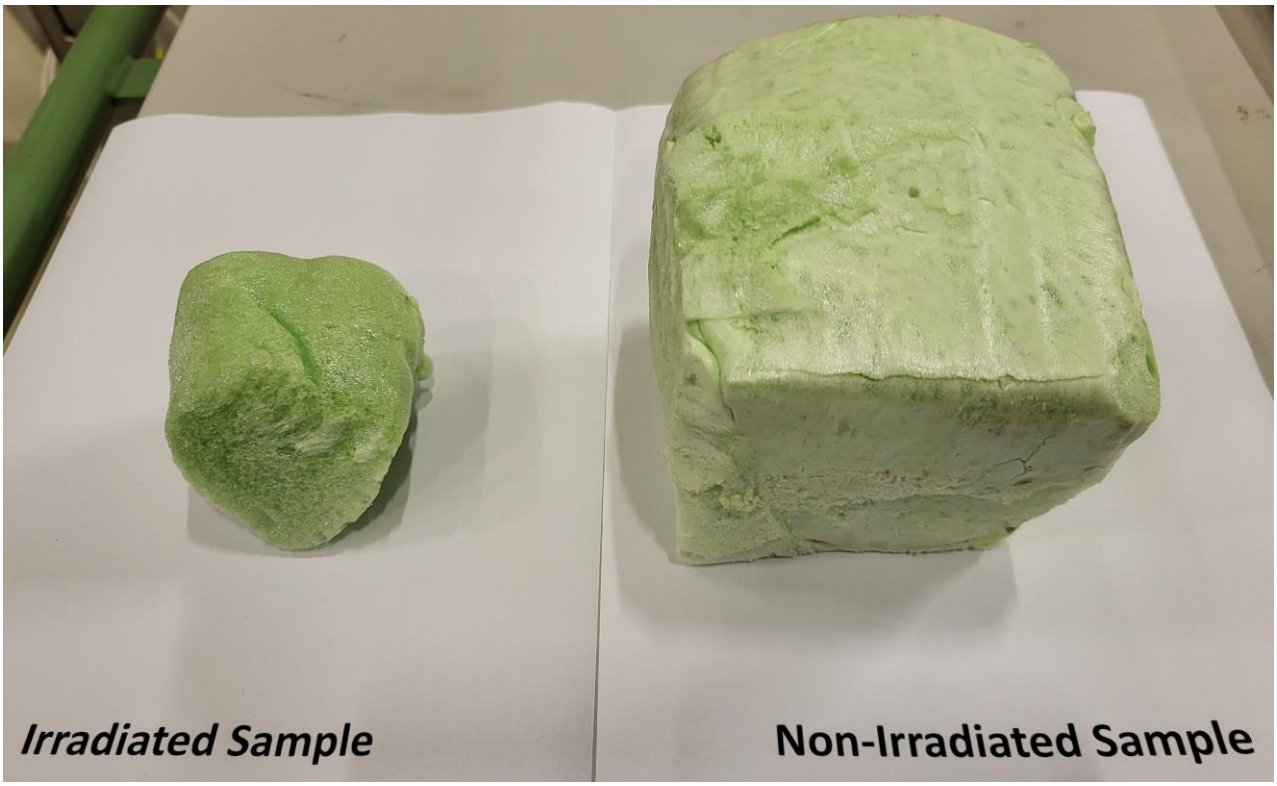


*Figure 13: Irradiated and non-irradiated sample of construction foam – view 2.*

### 4.7.3 3D-printed plastic samples (*Algona*)

Four 3D-printed samples *Onyx 37% Infill, Onyx 100% Infill, Onyx FR 37% Infill, Onyx FR 100% Infill from Alonga*, illustrated prior to testing in Figure 14, have been tested on behalf of Mr. S. VOGT from MPI Munich. Figure 15 and Figure 16 illustrate the pre- and post-irradiated samples. The samples do not show any traces of deterioration, change of physical properties or any other kind of damage induced by radiation.


*Figure 14: Test samples of 3D-printed thermoplast prior to irradiation testing.*


*Figure 15: Irradiated and non-irradiated sample of 3D-printed plastics - view 1.*


*Figure 16: Irradiated and non-irradiated sample of 3D-printed plastics - view 2.*

### 4.7.4 Sample of the 4-wire cable

*The sample of the 4-wire cable MEDIKabel (629140431|01) does not show any traces of deterioration, change of physical properties or any other kind of damage induced by radiation (see*

Figure 17). The sample has been included into the test campaign on behalf of the Max-Planck-Institute Munich (Mr. Sven VOGT).

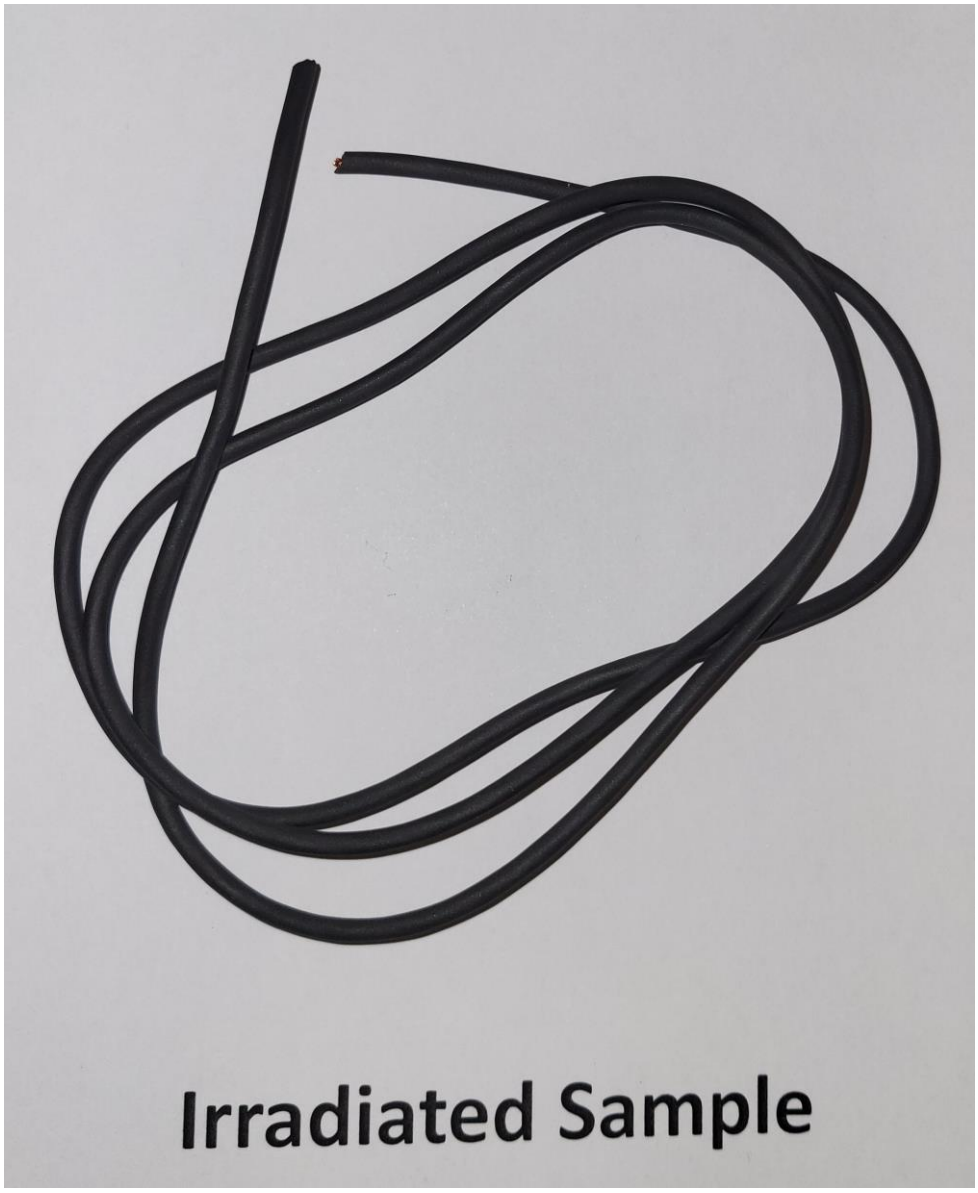


*Figure 17: Irradiated sample of the 4-wire cable (MEDIKabel (629140431|01)).*

# 5 Sanity Check

After the "cool down" of the equipment, additional tests have been performed to check the sensors behavior at initial conditions prior to the irradiation campaign.

- All the pressure transmitters and level transmitters showed no signal or IO error, which means they got irreversibly damaged.
- The Pt100 sensor, as well as the pressure switches, worked fine and have no visible marks of any degradation.
- The position switch board showed some irregularity such as no LED indication. The potentiometer, which has been used to trigger the switch, showed values in wrong ranges (Figure 18) according to its initial ones (0-10 kΩ).


*Figure 18: Resistance measurement of irradiated potentiometer.*

# 6 Conclusions

**Pressure transmitters KELLER PAA-33X**

- Reliable measurements up to a value of about 80 Gy.
  → The requirements of both ATLAS and CMS are therefore met.
- Transmitter dying at accumulated radiation doses of ~110 Gy what corresponds to a factor of ~1.6 to ~3.7 respectively with regards to the specifications.
- Failure clearly indicated and noticeable by a significant increase of the signal (Δp).
- Several single-event upsets (SEU) have been observed.
- SEU were reset by power-cycles.
- No signs of physical material damages due to radiation.

**Pressure Switch HUBA Control (521.940S023301W)**

- Concurrent and most probably reliable response at least up to a dose of 96.8 Gy.
- No detailed information available between doses of 96.8 – 183.9 Gy.
- Inconsistent response between the two switches at >183.9 Gy.
- No single-event upsets (SEU) have been observed.
- No signs of physical material damages due to radiation.

**T-Probe PT100**

- Despite the two spikes due to disconnection/connection of the PLC, the temperature probe shows reliable data.

**Position Switch Board**

- The position switch board responded at 57 Gy and 103 Gy.

**Material samples**

- The construction foam seems to be slightly discoloured and turned into a slightly darker green. Besides that, the irradiated sample does not show any changes in its physical properties.
- None of the other material samples tested (*Armaflex Ultima* foam panel, the 3D-printed plastic samples (*algona*), the sample of the 4-wire cable (*MEDIKABEL 629140431|01*)) show any hints of physical material degradation, delamination or any other kind of damage induced by radiation.

# 7 Bibliography

[1] A. Bogan and M. Ciupinski, "EP-DT-FS CHARM Component Testing Summary," CERN, Geneva, Switzerland, 2022.

[2] D. Schmid and M. Ciupinski, "ATLAS & CMS instrumentation irradiation test campaign No.2," CERN, Geneva, Switzerland, 2023.

[3] L. Zwalinski, "ATLAS radiation hardness requirement for instrumentation - Phase II CO2," CERN, Geneva, 2018.

[4] J. Daguin, "Radiation resistance requirements for instrumentation of CMS Ph2 CO2 cooling system in UXC55," CERN, Geneva, 2018.

## Appendix

Equipment is stored at xxx.

Article Code: CR-xxx
Dose rate Contact: xx µSv
Dose rate 10cm: xx µSv
TREC link : https://cmmsx.cern.ch/SSO/trec/rpmperform?wo=xxx

### Data Sheets

Keller PAA-33X series