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Report on the Radiation on Electronics measurements

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Summary

This document refers to the measurements carried out by Wireless IoT Monitoring System #17 that was installed to evaluate the TID and HeH fluence evolution in a specific position of the IRRAD facility for 2 weeks. In the following weeks, the BatMon remained in place to monitor cumulative radiation on a test device installed on 07/20/22.

1 Measurement request

The IRRAD proton facility is located on the T8 beam-line at the CERN PS East Hall (building 157) where the primary proton beam with a momentum of 24GeV/c is extracted from the PS ring. As shown in the figure below, the space allocated for irradiation tests in the East Hall is shared between two irradiation facilities: the IRRAD proton facility is located upstream while the e CERN High energy AcceleRator Mixed field (CHARM) facility [1] mixed-field facility is implemented downstream. Since most of the protons pass through the IRRAD facility without interacting, the mixed-field facility can profit from the same protons used by IRRAD. Inside CHARM, these protons impinge on a target surrounded by a well-calculated shielding configuration.
The scope of the request is to calibrate a specific IRRAD position that will be used in the future to irradiate a sample that will be positioned where the Wireless IoT monitoring system will be during this installation.

Table 1: Measurement request

Name	Section	Request Date
Federico Ravotti	EP-DT-DD	May 2022

2 Measurements

To characterize the radiation environment permeating the investigated location, different physical quantities have been measured: the High Energy Hadron fluence (Φ_{HEH}), the Thermal Neutron fluence (Φ_{ThN}) and the Total Ionizing Dose (TID). The fluences have been measured by using the Wireless IoT monitoring system, also called BatMon [2], which is a wireless version of the RadMon system [3], whereas the TID has been measured by using Floating Gate Dosimeters.

The Φ_{HEH} and Φ_{ThN} are measured by exploiting the technique shown in [4]. The Single Event Upsets (SEUs) induced by radiation in two different well-calibrated parallel SRAMs, whose sensitivity to both ThN and HeH is known, allow retrieving the different fluences:

$$\begin{cases} SEU_{SRAM1} = \sigma_{SRAM1}^{ThN} \times \Phi_{ThN} + \sigma_{SRAM1}^{HEH} \times \Phi_{HEH} \\ SEU_{SRAM2} = \sigma_{SRAM2}^{ThN} \times \Phi_{ThN} + \sigma_{SRAM2}^{HEH} \times \Phi_{HEH} \end{cases} \quad (1)$$

Where the subscript *SRAM1 and SRAM2* indicate the two different well-calibrated parallel SRAMs, SEU is the sum of the counts for each bank, σ^{ThN} is the cross-section of the memory to thermal neutrons, whereas σ^{HEH} is the cross-section of the memory to high energy hadrons.

The measurements of the Φ_{HEH} and Φ_{ThN} allow the calculation of an important parameter, which is helpful to understand the risk of the radiation environment associated with the possible impact of the typically unknown thermal neutron sensitivity. This parameter is called R-Factor and is defined as follow:

$$\mathrm{R} = \frac{\Phi_{ThN}}{\Phi_{HEH}} \quad (2)$$

Another measurement carried out is relative to the Total Ionizing Dose (TID). This quantity is measured by FGDOS dosimeters, the SI unit is the Gy.

The BatMon measurements are transmitted via LoRa and stored in a dedicated database. For this installation, the system is not powered by the batteries but connected to the 230 V supply. The data rate is maximized (300 s) always being compliant with the LoRaWAN specification.

The investigated location is in the IRRAD proton facility is located on the T8 beamline at the CERN PS East Hall (building 157).

A summary of the device installed in each position and of the installation time is reported in Table 2. During the different runs, the IRRAD configuration was not always the same and different tables with devices under test mounted were inserted modifying the spectrum of the facility every week. The different tables in the beam during each week are reported in Table 2. The layout of IRRAD is shown in Figure 1 and in Figure 2 with the different tables locations, where the position of the system is reported. In Figure 3, the BatMon installed in IRRAD can be seen.

Table 2: Summary of the different Irradiation Run

Position	Week	Monitoring system	From UTC	To UTC	Table Inside
A	1	Wireless IoT Monitoring #17	06/07/22 12:03:00	12/07/22 7:25:00	7, 13
	2		12/07/22 7:25:00	19/07/22 14:25:00	9, 13
	3		20/07/22 11:22:00	27/07/22 00:00:00	9, 13
	4		27/07/22 00:00:00	03/08/22 01:05:00	9, 13
	5		03/08/22 01:05:00	09/08/22 06:20:00	7, 9, 13
	6		09/08/22 06:20:00	17/08/22 03:00:00	3,13
	7		17/08/22 03:00:00	24/08/22 02:58:00	7, 9
	8		24/08/22 02:58:00	31/08/22 03:00:00	X

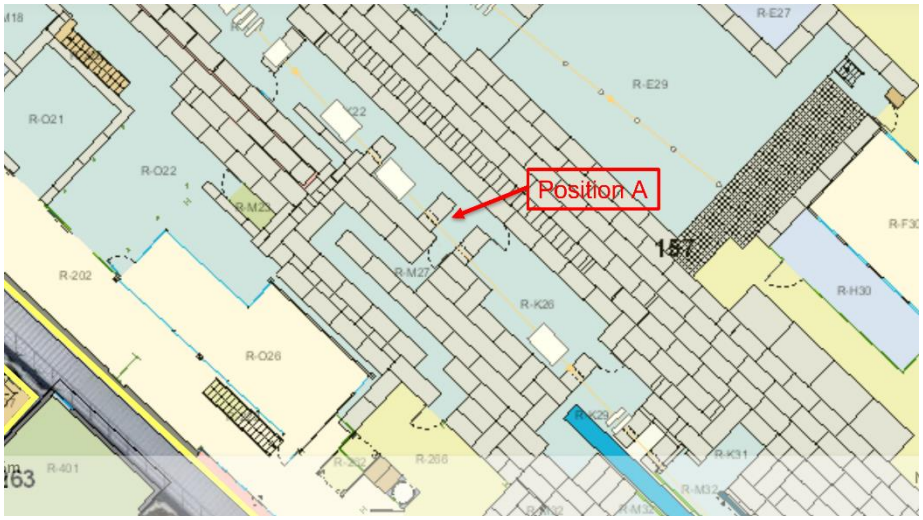

Figure 1: *Layout of the IRRAD Facility. (Source: [5]).*

***Figure 3**: BatMon installation in Irrad (Position A)*

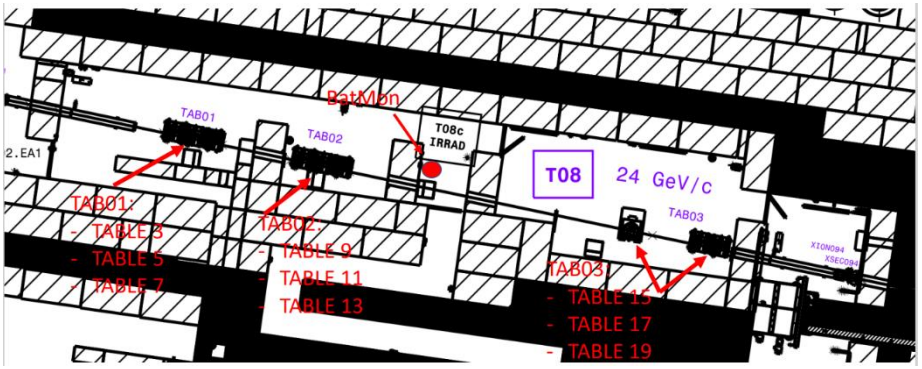

***Figure 2:** Layout of the IRRAD Facility. (Source: [5]).*

3 Radiation Monitoring Week 1

During the 1st week of operation, the configuration of the facility was not always the same. Table 7, inside at the beginning of the run, was removed at 10:00 a.m. on 11/07/22, while Table 13 was inserted at 5:14 p.m. on 11/07/22. This change of configuration is reflected created an increase in the dose and fluence delivered in the position of interest.

Radiation Data

In this section, the results of the radiation monitoring performed using the Wireless IoT Monitoring #17 system are reported in Table 3 (TID) and 4 (Fluences) and shown in Figures 4 (TID), 5 (Fluences), and 6 (R-Factor).

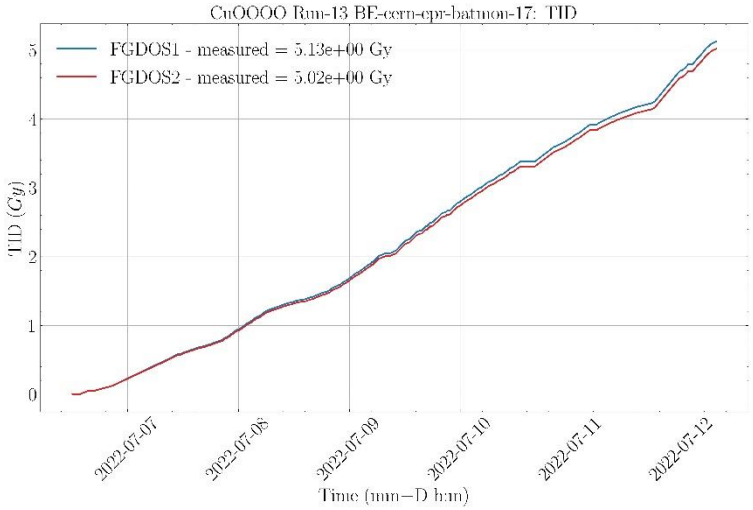

***Figure 4**: TID over time (week 1)*

Table 3: Radiation data (TID) (week 1)

Position	TID [Gy]	*TID per hour [Gy/h]*	*TID per day [Gy/D]*
A	5.13	0.037	0.883

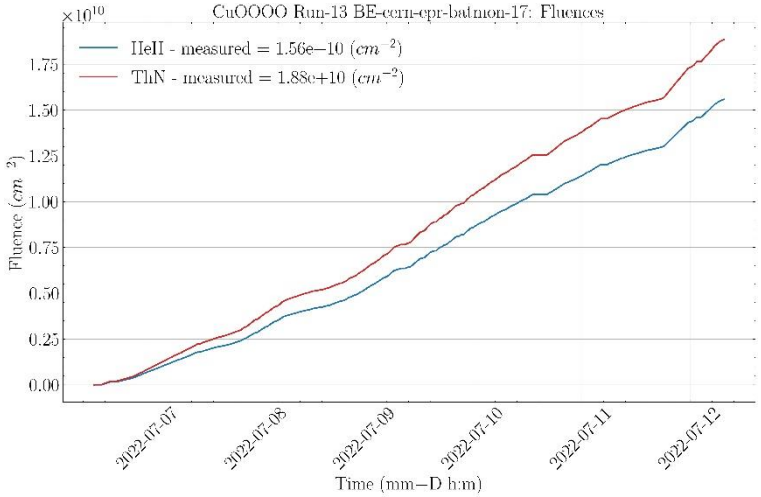

***Figure 5**: HeH and ThN fluences over time (week 1)*

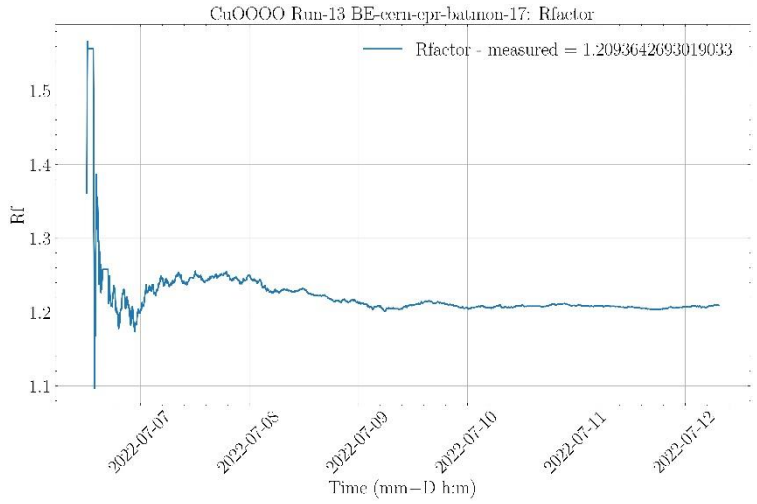

***Figure 6**: R-Factor over time (week 1)*

Table 4: Radiation data (Fluences) (week 1)

Position	R-Factor	φ_{HEH} [pp/cm^2]	φ_{ThN} [pp/cm^2]	Φ_{HEH} [$pp/(s \times cm^2)$]	Φ_{ThN} [$pp/(s \times cm^2)$]
A	1.209	$1.56x10^{10}$	$1.88x10^{10}$	$3.11x10^{4}$	$3.76x10^{4}$

Normalization Factors

Radiation data are normalized to the number of primary protons on target (POT). Typical POT figures at CHARM are approx. $5 \cdot 10^{11}$ protons/spill and $1.5 \cdot 10^{16}$ protons/week. Normalization factors are called K-Factors and can be reused to estimate, for example, the TID at the calibrated position knowing only the number of Proton on Target (POTs) delivered. The POT for this run is shown in Figure 7.

In this section, the K-Factors measured for the position of interest are reported in Table 5 (TID and Fluences) and shown in Figures 8 and 9 (TID) and 10 and 11 (Fluences).

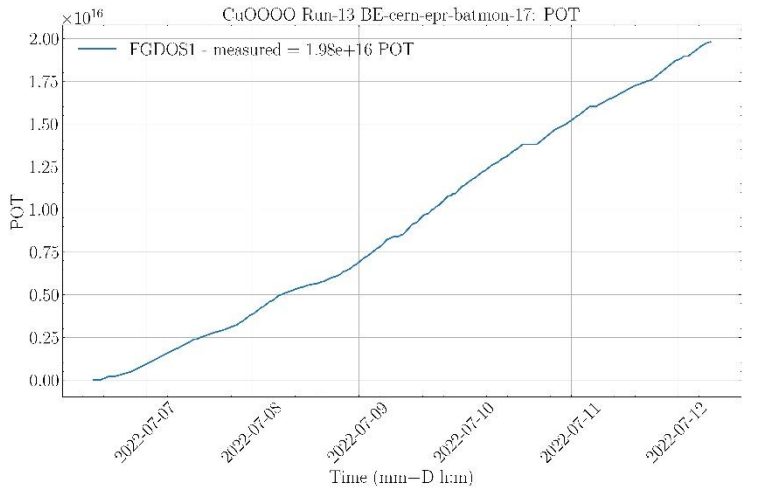

***Figure 7**: POT1 over time (week 1)*

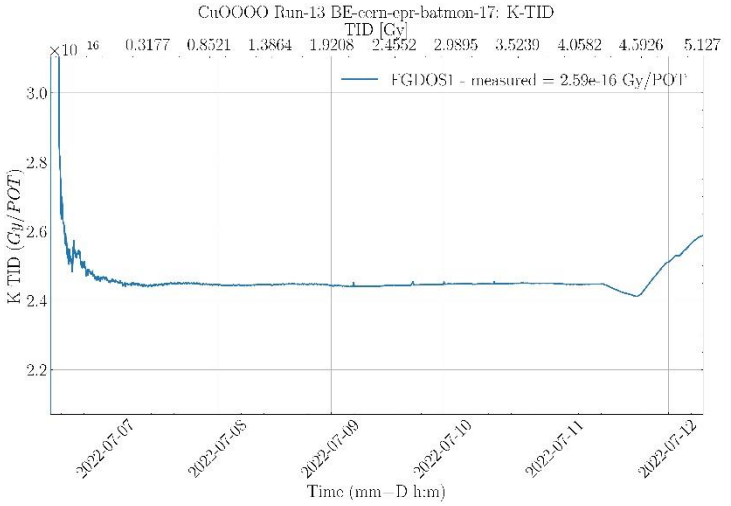

Figure 8: *K-Factor TID (FGDOS1) (week 1)*

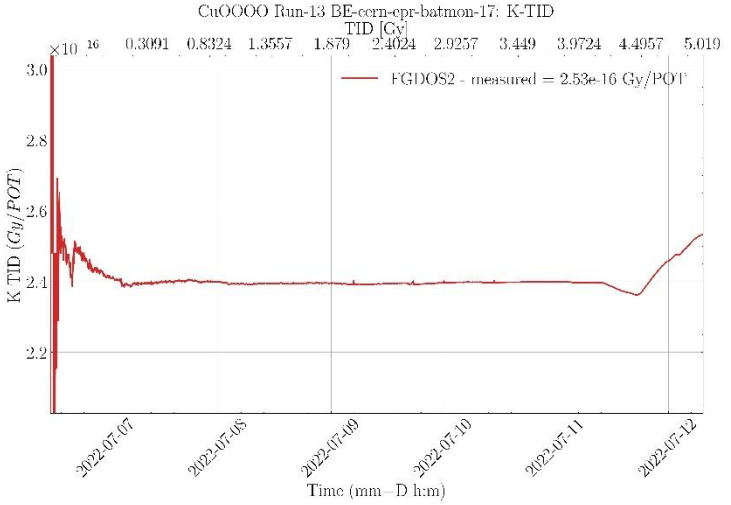

Figure 9: *K-Factor TID (FGDOS2) (week 1)*

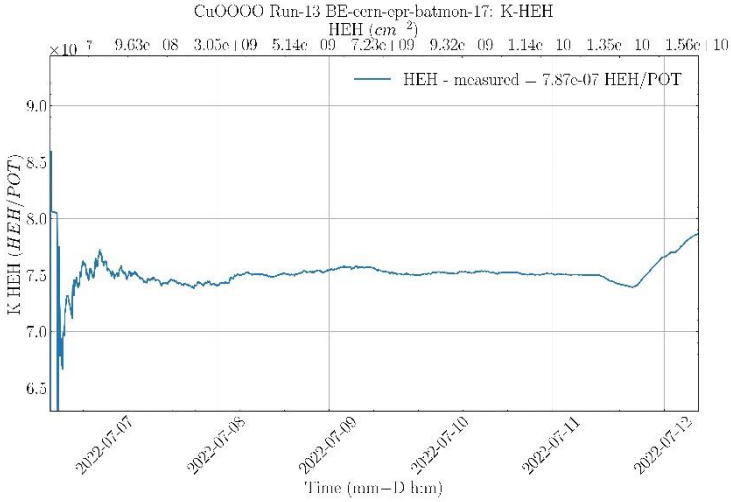

Figure 10*: K-Factor HeH fluence (week 1)*

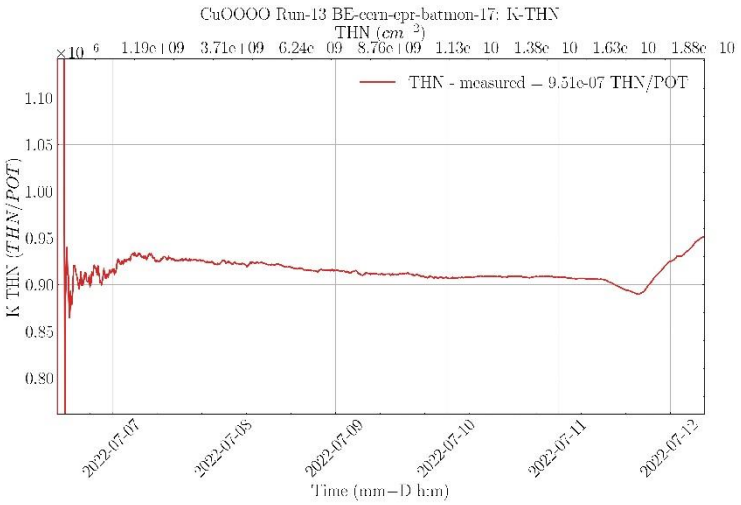

***Figure 11**: K-Factor ThN fluence (week 1)*

Table 5: K-Factor (week 1)

Position	K-TID [*Gy/POT*]	K-HEH [*HEH/POT*]	K-ThN [*HEH/POT*]
A	$2.59x10^{-16}$	$7.87x10^{-7}$	$9.51x10^{-7}$

4 Radiation Monitoring Week 2

During the 2nd week of operation, the configuration of the facility was not always the same. Table 13, inside at the beginning of the run, was removed at 4:28 p.m. on 12/07/22, while Table 9 was inserted at 2:13 p.m. on 13/07/22. This change of configuration is reflected created an increase in the dose and fluence delivered in the position of interest.
In addition, other problems affected the beamline which reduced the quality homogeneity of the beam during the whole irradiation.

Radiation Data

In this section, the results of the radiation monitoring performed using the Wireless IoT Monitoring #17 system are reported in Table 5 (TID) and 6 (Fluences) and shown in Figures 12 (TID), 13 (Fluences) and 14 (R-Factor).

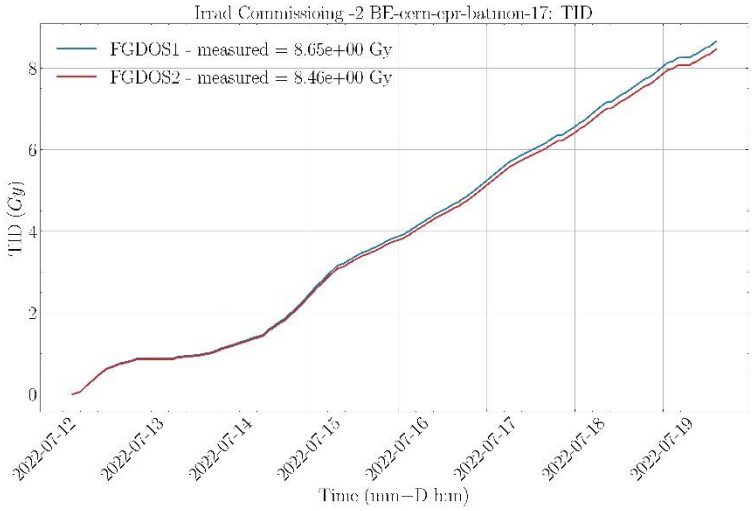

***Figure 12**: TID over time (week 2)*

Table 5: Radiation data (TID) (week 2)

Position	TID [*Gy*]	*TID per hour* [*Gy/h*]	*TID per day* [*Gy/D*]
A	8.65	0.049	1.187

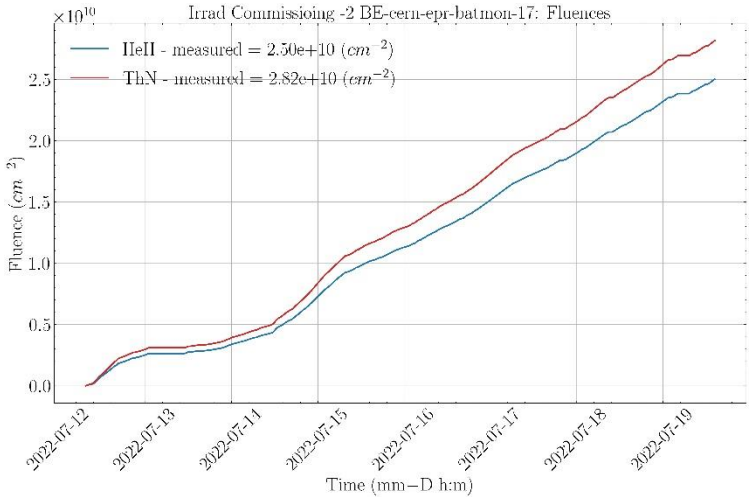

***Figure 13**: HeH and ThN fluences over time (week 2)*

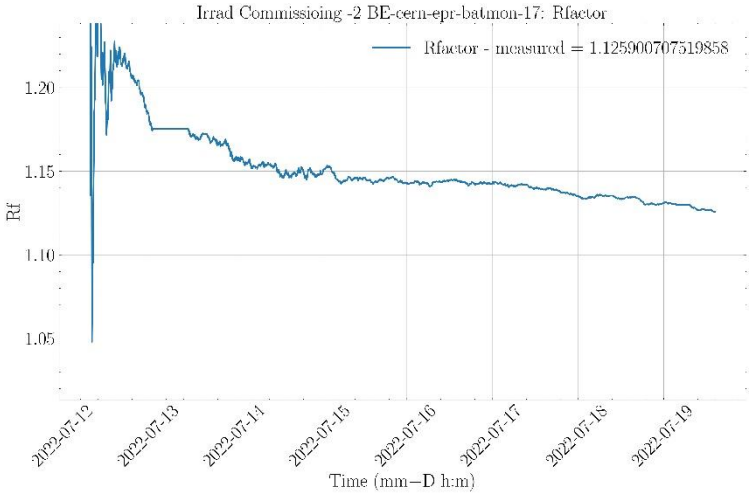

***Figure 14**: R-Factor over time (week 2)*

Table 6: Radiation data (Fluences) (week 2)

Position	R-Factor	φ_{HEH} [pp/cm^2]	φ_{ThN} [pp/cm^2]	Φ_{HEH} [$pp/(s \times cm^2)$]	Φ_{ThN} [$pp/(s \times cm^2)$]
A	1.126	$2.50x10^{10}$	$2.82x10^{10}$	$3.97x10^{4}$	$4.47x10^{4}$

Normalization Factors

The POTs for this run are shown in Figure 15. In this section, the K-Factors measured for the position of interest are reported in Table 7 (TID and Fluences) and shown in Figures 16 and 17 (TID) and 18 and 19(Fluences).

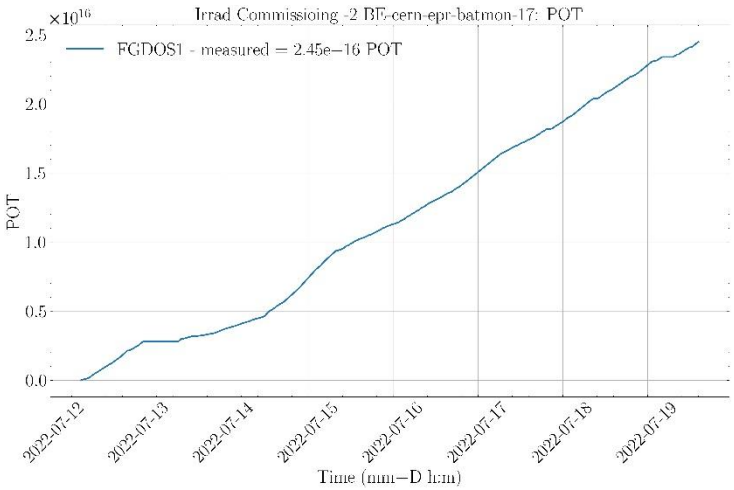

***Figure 15**: POT1 over time (week 2)*

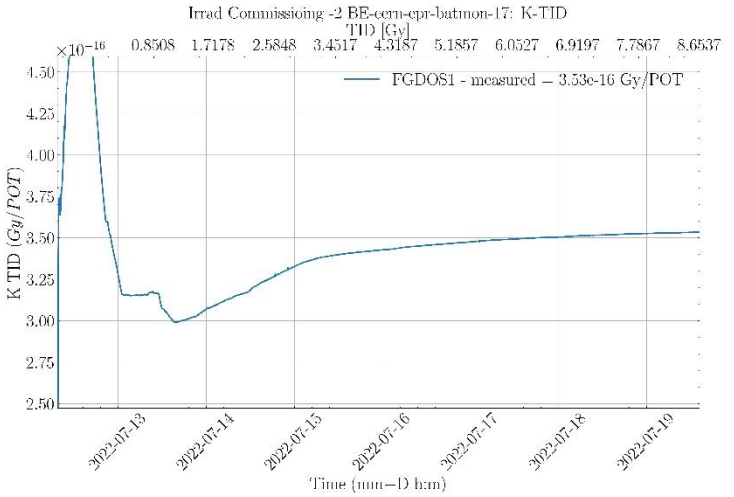

***Figure 16:** K-Factor TID (FGDOS1) (week 2)*

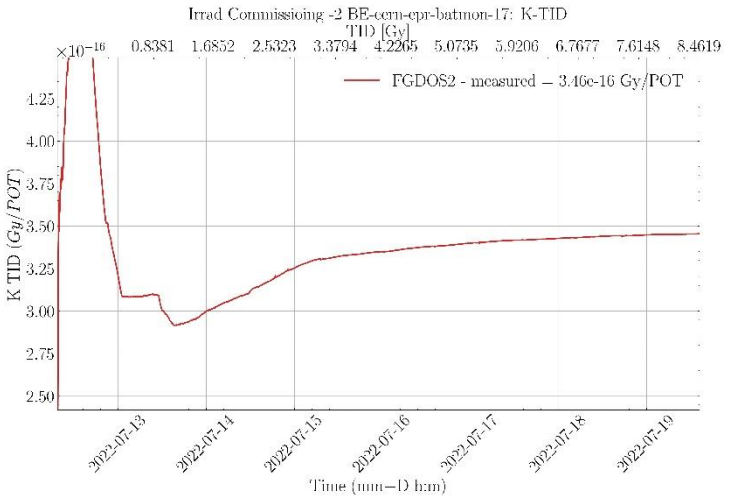

Figure 17: *K-Factor TID (FGDOS2) (week 2)*

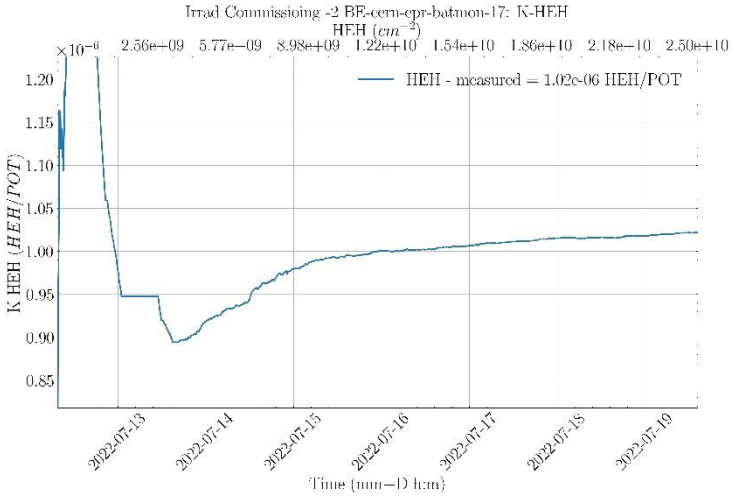

Figure 18*: K-Factor HeH fluence (week 2)*

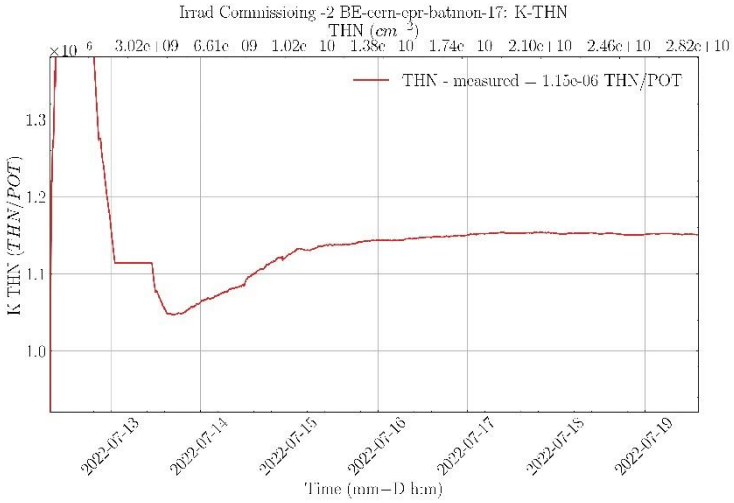

Figure 19*: K-Factor ThN fluence (week 2)*

Table 7: K-Factor (week 2)

Position	K TID [*Gy/POT*]	K HEH [*HEH/POT*]	K ThN [*HEH/POT*]
A	$3.53x10^{-16}$	$1.02x10^{-6}$	$1.15x10^{-6}$

5 Radiation Monitoring Week 3

During the 3rd week of operation, the configuration of the facility was not changed. Tables 9 and 13 were inside during the whole run. This stability in terms of configuration is also visible in the measurements.

Radiation Data

In this section, the results of the radiation monitoring performed using the Wireless IoT Monitoring #17 system are reported in Table 8 (TID) and 9 (Fluences) and shown in Figures 20 (TID), 21 (Fluences), and 22 (R Factor).

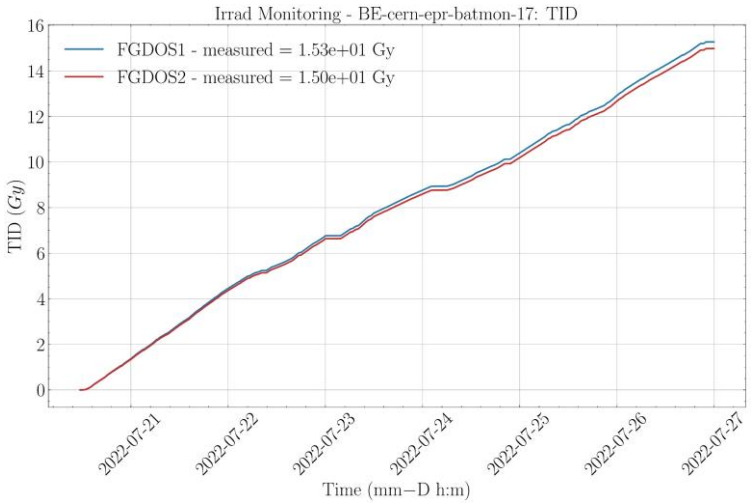

***Figure 20**: TID over time (week 3)*

Table 8: Radiation data (TID) (week 3)

Position	TID [Gy]	*TID per hour [Gy/h]*	*TID per day [Gy/D]*
A	15.27	0.097	2.340

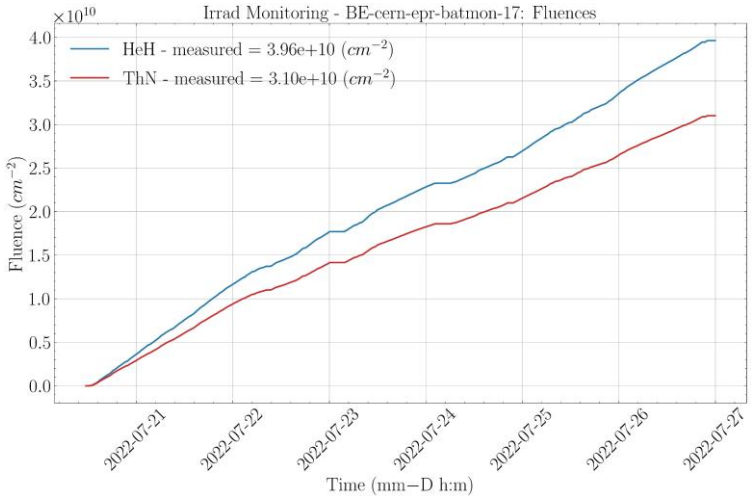

***Figure 21**: HeH and ThN fluences over time (week 3)*

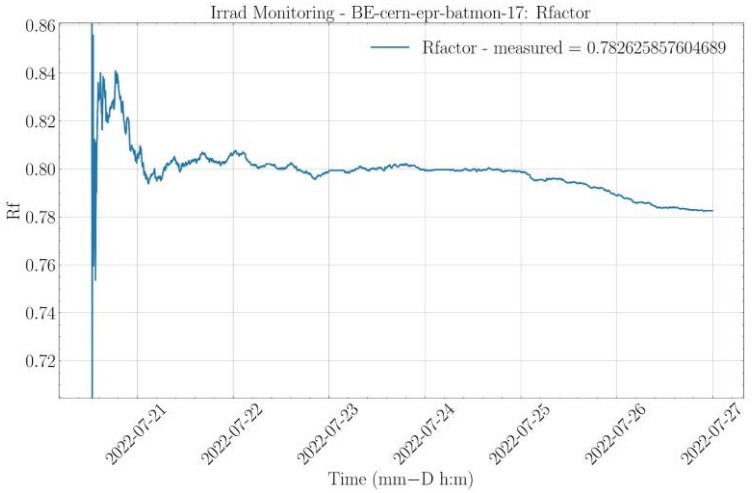

***Figure 22**: R-Factor over time (week 3)*

Table 9: Radiation data (Fluences) (week 3)

Position	R-Factor	φ_{HEH} [pp/cm^2]	φ_{ThN} [pp/cm^2]	Φ_{HEH} [$pp/(s \times cm^2)$]	Φ_{ThN} [$pp/(s \times cm^2)$]
A	0.783	$3.96x10^{10}$	$3.10x10^{10}$	$7.03x10^{4}$	$5.50x10^{4}$

Normalization Factors

The POTs for this run are shown in Figure 23. In this section, the K-Factors measured for the position of interest are reported in Table 10 (TID and Fluences) and shown in Figures 24 and 25 (TID) and 26 and 27 (Fluences).

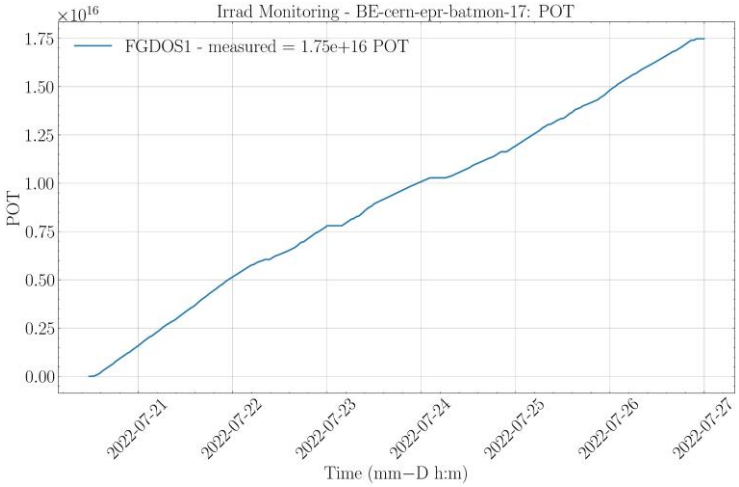

***Figure 23**: POT1 over time (week 3)*

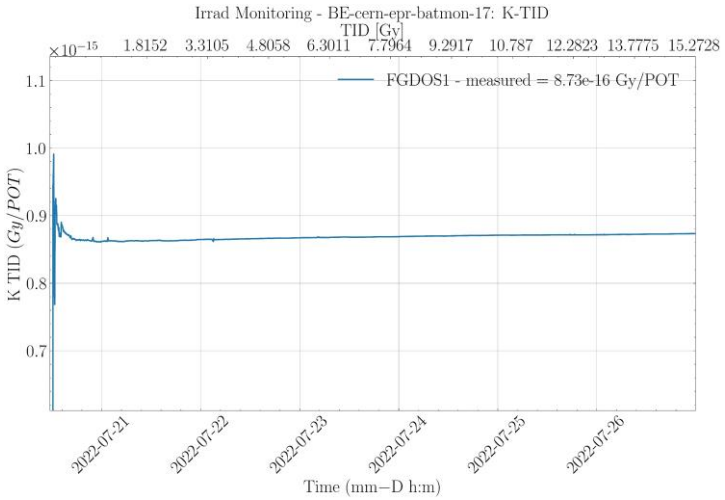

***Figure 24:** K-Factor TID (FGDOS1) (week 3)*

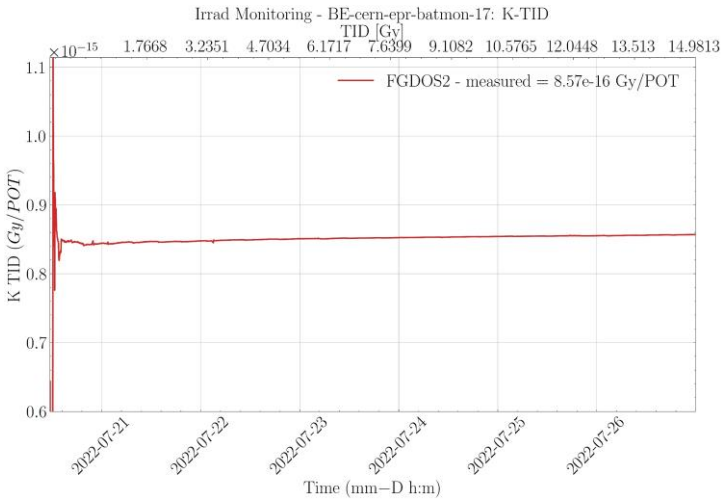

Figure 25: *K-Factor TID (FGDOS2) (week 3)*

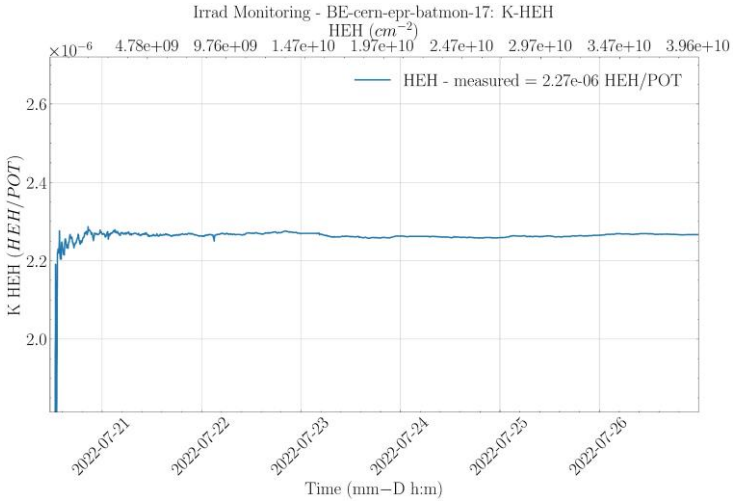

Figure 26*: K-Factor HeH fluence (week 3)*

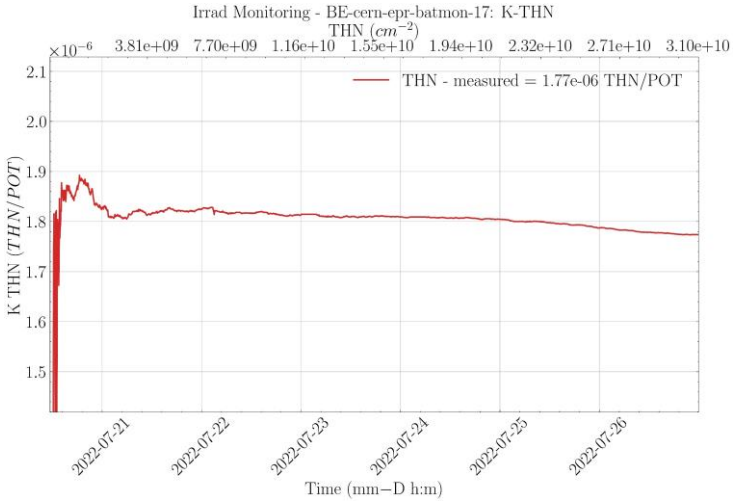

Figure 27*: K-Factor ThN fluence (week 3)*

Table 10: K-Factors (week 3)

Position	K TID [*Gy/POT*]	K HEH [*HEH/POT*]	K ThN [*HEH/POT*]
A	$8.73x10^{-16}$	$2.27x10^{-6}$	$1.77x10^{-6}$

6 Radiation Monitoring Week 4

During the 4th week of operation, the configuration of the facility was not always the same. Table 13 was inside during the whole run, while Table 9 was removed at 2:05 p.m. on 01/08/22. This change of configuration is reflected created a decrease in the dose and fluence delivered in the position of interest.

Radiation Data

In this section, the results of the radiation monitoring performed using the Wireless IoT Monitoring #17 system are reported in Table 11 (TID) and 12 (Fluences) and shown in Figures 28 (TID), 29 (Fluences) and 30 (R Factor).

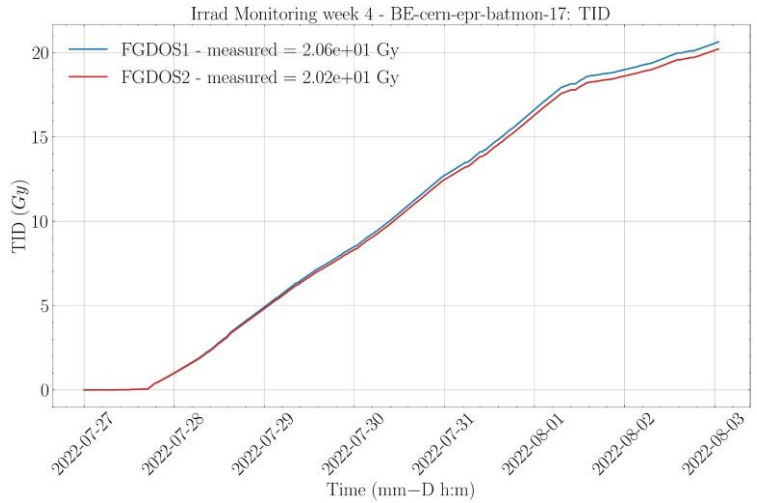

***Figure 28**: TID over time (week 4)*

Table 11: Radiation data (TID) (week 4)

Position	TID [*Gy*]	*TID per hour* [*Gy/h*]	*TID per day* [*Gy/D*]
A	20.63	0.122	2.929

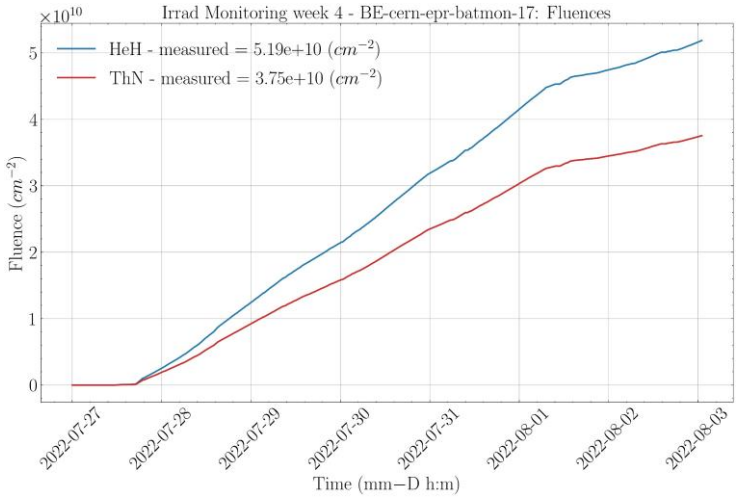

***Figure 29**: HeH and ThN fluences over time (week 4)*

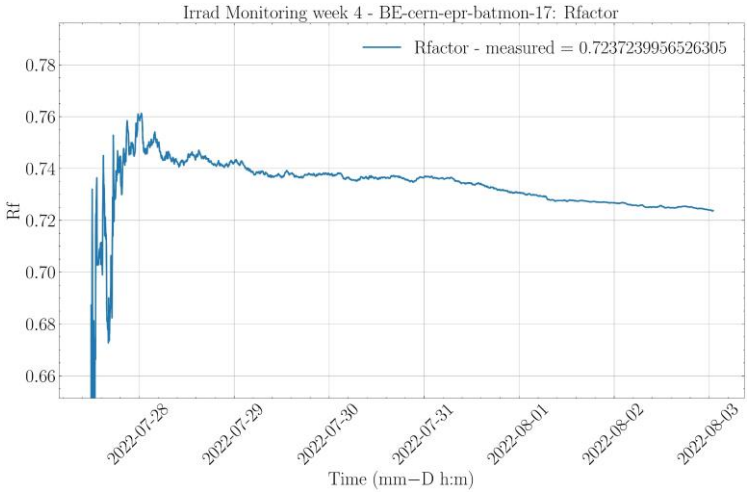

***Figure 30**: R-Factor over time (week 4)*

Table 12: Radiation data (Fluences) (week 4)

Position	R-Factor	φ_{HEH} [pp/cm^2]	φ_{ThN} [pp/cm^2]	Φ_{HEH} [$pp/(s \times cm^2)$]	Φ_{ThN} [$pp/(s \times cm^2)$]
A	0.724	$5.19x10^{10}$	$3.75x10^{10}$	$8.52x10^{4}$	$6.17x10^{4}$

Normalization Factors

The POTs for this run are shown in Figure 23. In this section, the K-Factors measured for the position of interest are reported in Table 13 (TID and Fluences) and shown in Figures 31 and 32 (TID) and 33 and 34 (Fluences).

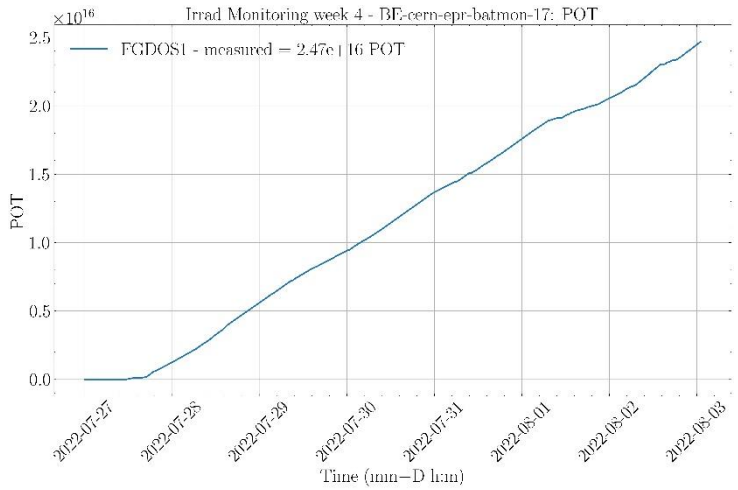

***Figure 31**: POT1 over time (week 4)*

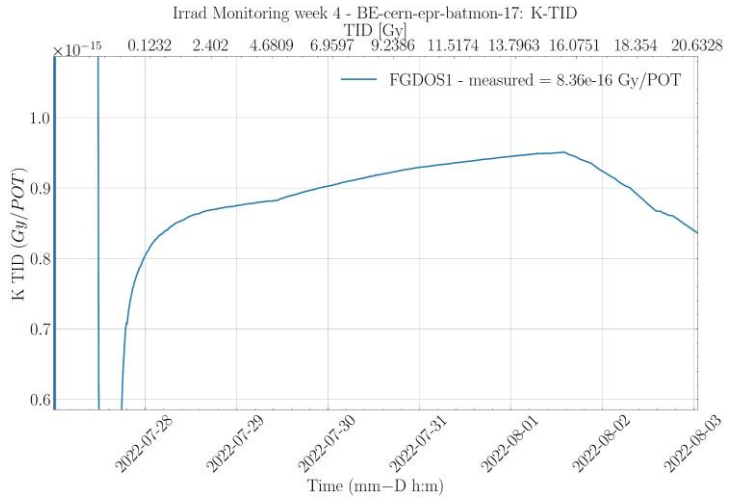

***Figure 32:** K-Factor TID (FGDOS1) (week 4)*

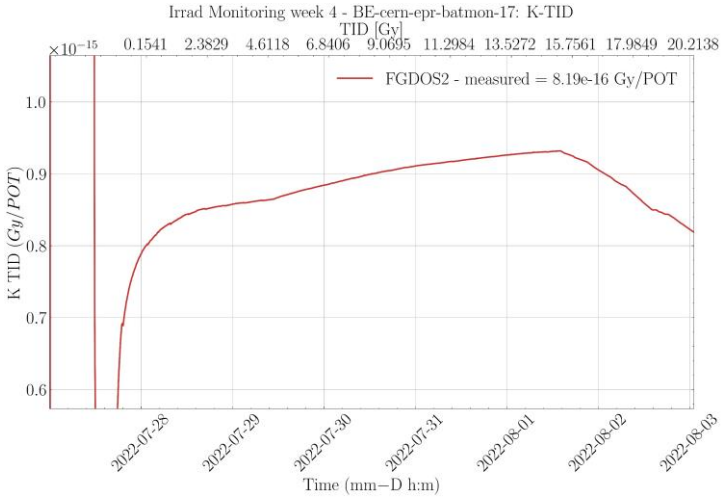

Figure 33: *K-Factor TID (FGDOS2) (week 4)*

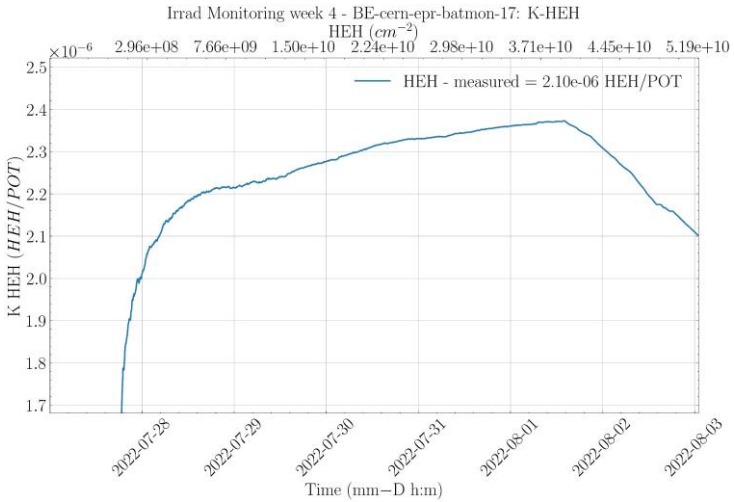

Figure 34*: K-Factor HeH fluence (week 4)*

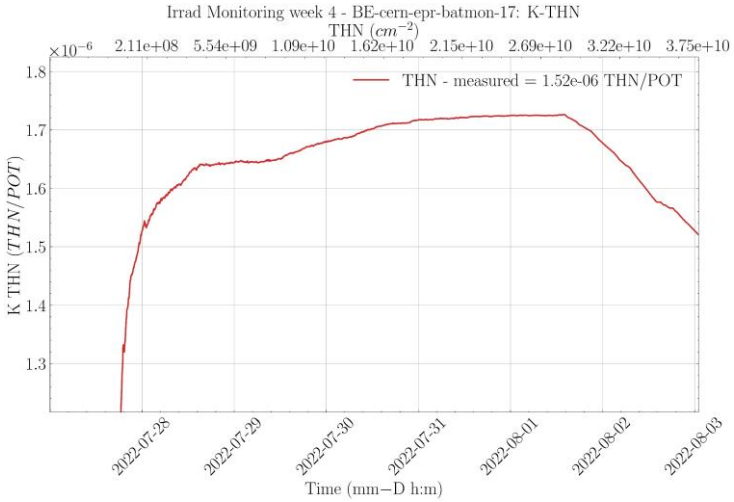

Figure 35*: K-Factor ThN fluence (week 4)*

Table 13: K-Factors (week 4)

Position	K TID [*Gy/POT*]	K HEH [*HEH/POT*]	K ThN [*HEH/POT*]
A	$8.30x10^{-16}$	$2.10x10^{-6}$	$1.52x10^{-6}$

7 Radiation Monitoring Week 5

During the 5th week of operation, the configuration was not changed. Tables 7, 9, and 13 were inside during the whole run. This stability in terms of configuration is also visible in the measurements.
At the end of the run, a decrease of the k-factor is observable: started at 3:28 p.m. on 08/08/22 is probably due to a change in the facility or a problem on the beamline.

Radiation Data

In this section, the results of the radiation monitoring performed using the Wireless IoT Monitoring #17 system are reported in Table 14 (TID) and 15 (Fluences) and shown in Figures 36 (TID), 37 (Fluences) and 38 (R Factor).

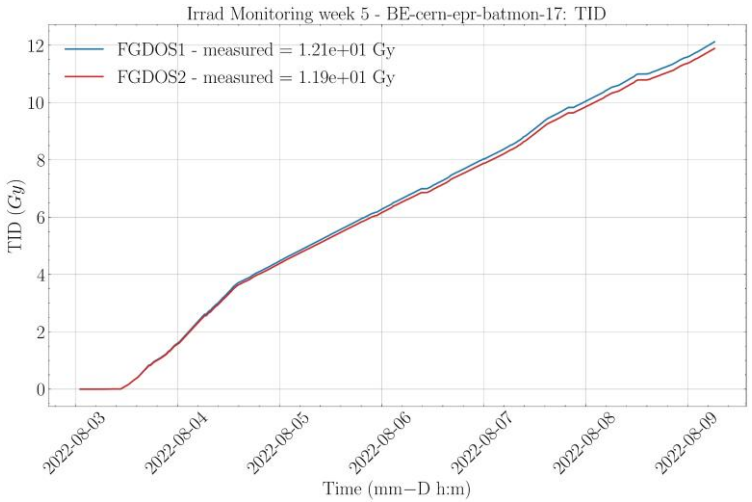

***Figure 36**: TID over time (week 5)*

Table 14: Radiation data (TID) (week 5)

Position	TID [*Gy*]	*TID per hour* [*Gy/h*]	*TID per day* [*Gy/D*]
A	12.12	0.081	1.949

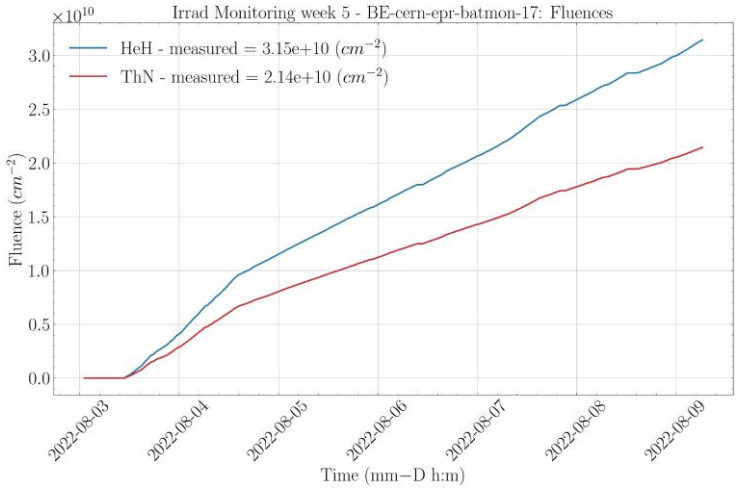

***Figure 37**: HeH and ThN fluences over time (week 5)*

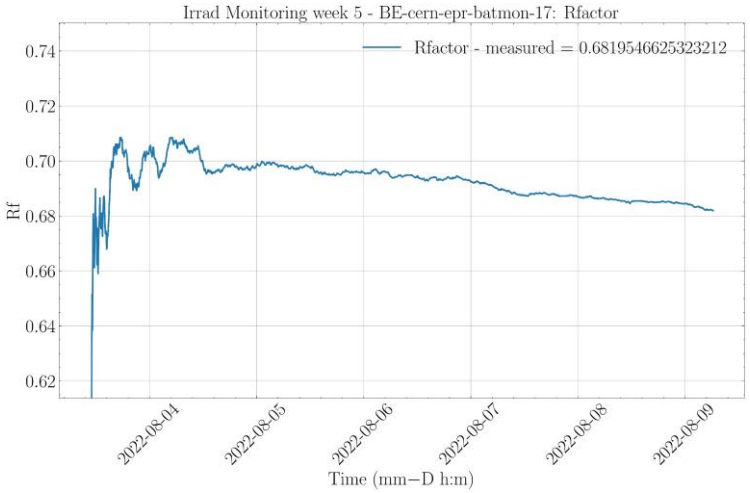

***Figure 38**: R-Factor over time (week 5)*

Table 15: Radiation data (Fluences) (week 5)

Position	R-Factor	φ_{HEH} [pp/cm^2]	φ_{ThN} [pp/cm^2]	Φ_{HEH} [$pp/(s \times cm^2)$]	Φ_{ThN} [$pp/(s \times cm^2)$]
A	0.682	$3.15x10^{10}$	$2.14x10^{10}$	$5.85x10^{4}$	$3.99x10^{4}$

Normalization Factors

The POTs for this run are shown in Figure 39 In this section, the K-Factors measured for the position of interest are reported in Table 16 (TID and Fluences) and shown in Figures 40 and 41 (TID) and 42 and 43 (Fluences).

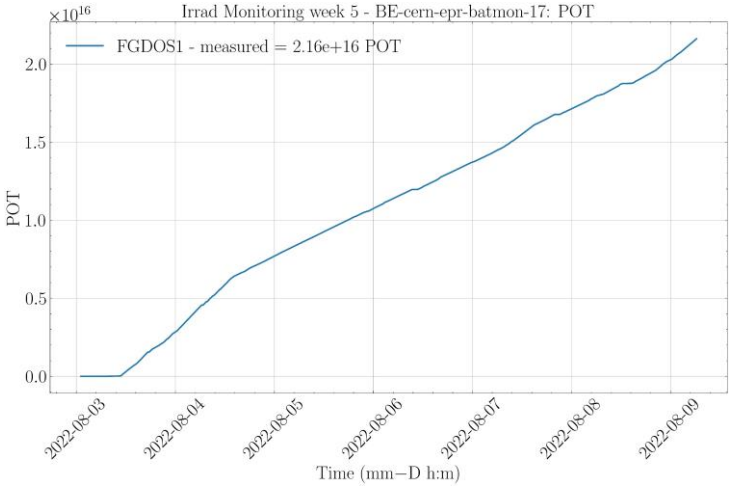

***Figure 39**: POT1 over time (week 5)*

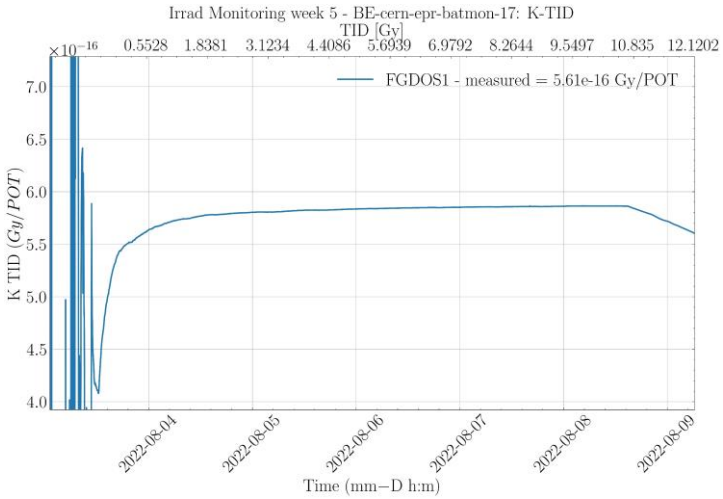

***Figure 40:** K-Factor TID (FGDOS1) (week 5)*

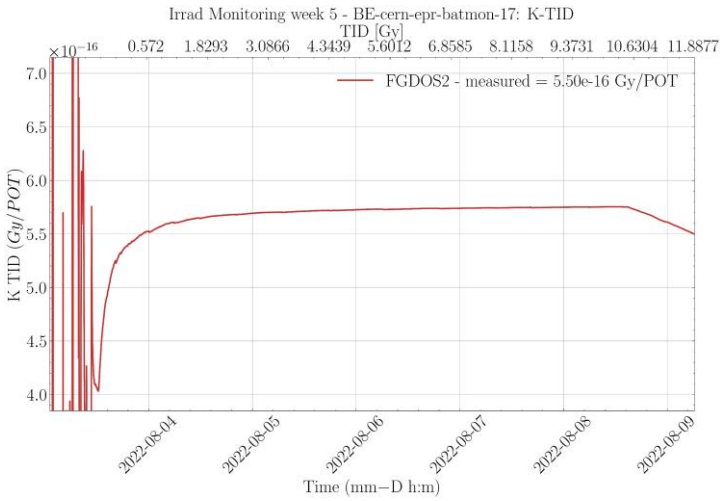

Figure 41: *K-Factor TID (FGDOS2) (week 5)*

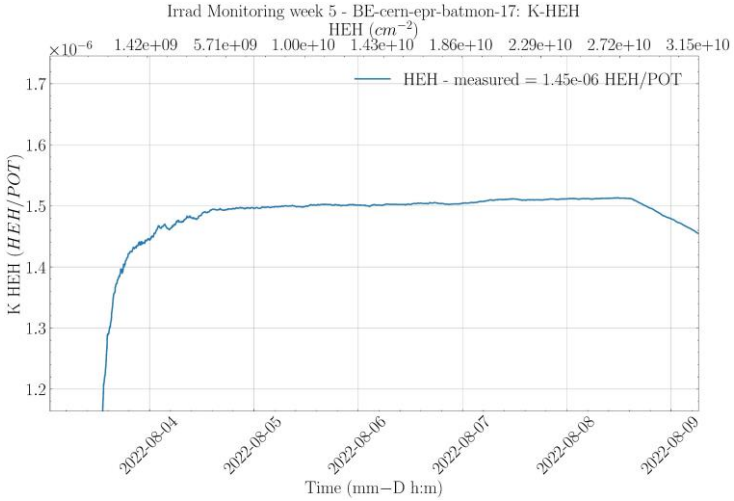

Figure 42*: K-Factor HeH fluence (week 5)*

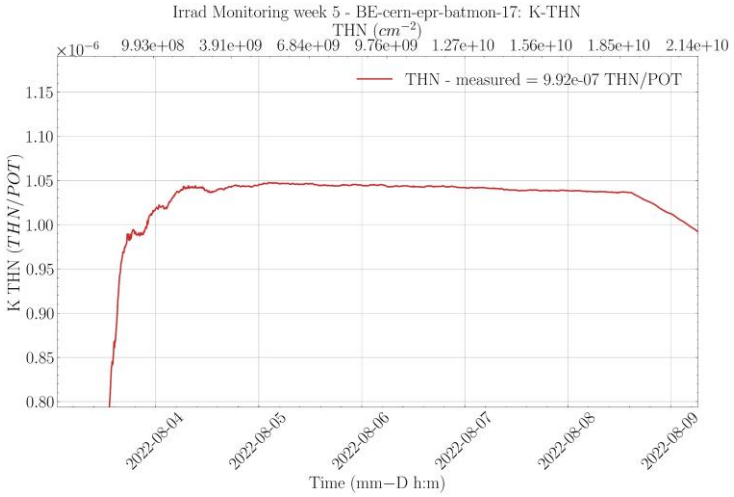

Figure 43*: K-Factor ThN fluence (week 5)*

Table 16: K-Factors (week 5)

Position	K TID [*Gy/POT*]	K HEH [*HEH/POT*]	K ThN [*HEH/POT*]
A	$5.61x10^{-16}$	$1.45x10^{-6}$	$9.92x10^{-7}$

8 Radiation Monitoring Week 6

During the 6th week of operation, the configuration was not changed. Tables 3 and 13 were inside during the whole run. This stability in terms of configuration is also visible in the measurements.

Radiation Data

In this section, the results of the radiation monitoring performed using the Wireless IoT Monitoring #17 system are reported in Table 17 (TID) and 18 (Fluences) and shown in Figures 44 (TID), 45 (Fluences), and 46 (R Factor).

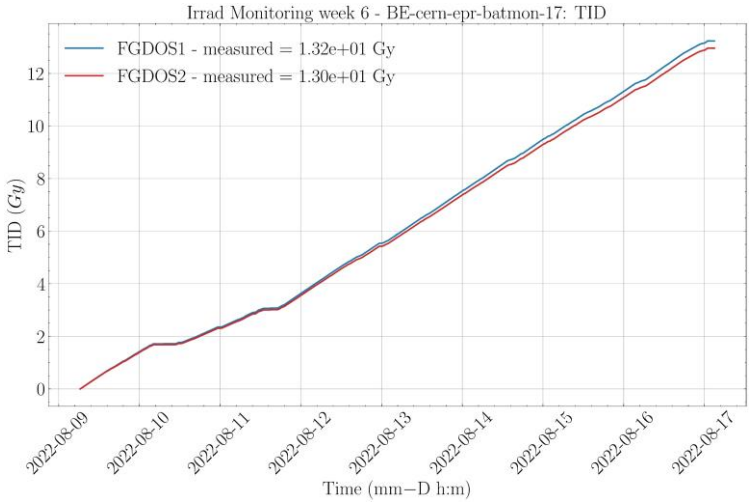

***Figure 44**: TID over time (week 6)*

Table 17: Radiation data (TID) (week 6)

Position	TID [*Gy*]	*TID per hour* [*Gy/h*]	*TID per day* [*Gy/D*]
A	13.23	0.070	1.683

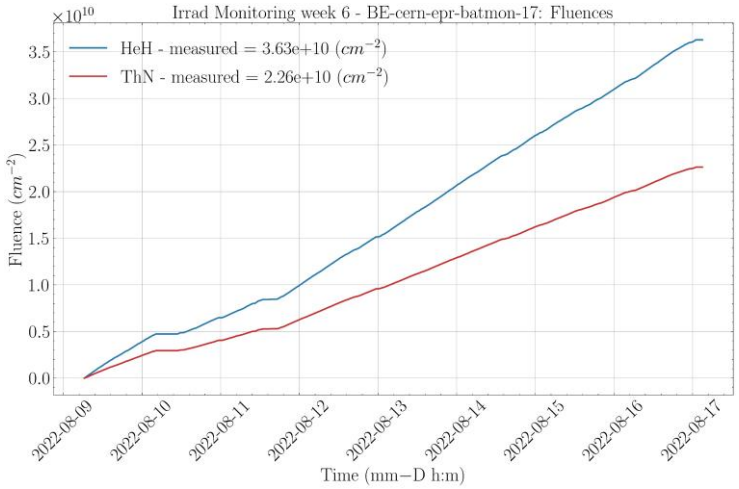

***Figure 45**: HeH and ThN fluences over time (week 6)*

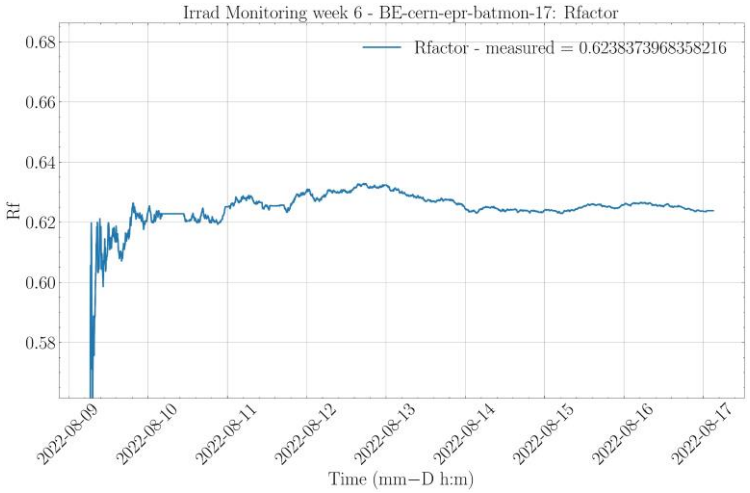

***Figure 46**: R-Factor over time (week 6)*

Table 18: Radiation data (Fluences) (week 6)

Position	R-Factor	φ_{HEH} [pp/cm^2]	φ_{ThN} [pp/cm^2]	Φ_{HEH} [$pp/(s \times cm^2)$]	Φ_{ThN} [$pp/(s \times cm^2)$]
A	0.624	$3.63x10^{10}$	$2.26x10^{10}$	$5.34x10^{4}$	$3.33x10^{4}$

Normalization Factors

The POTs for this run are shown in Figure 47 In this section, the K-Factors measured for the position of interest are reported in Table 19 (TID and Fluences) and shown in Figures 48 and 49 (TID) and 50 and 51 (Fluences).

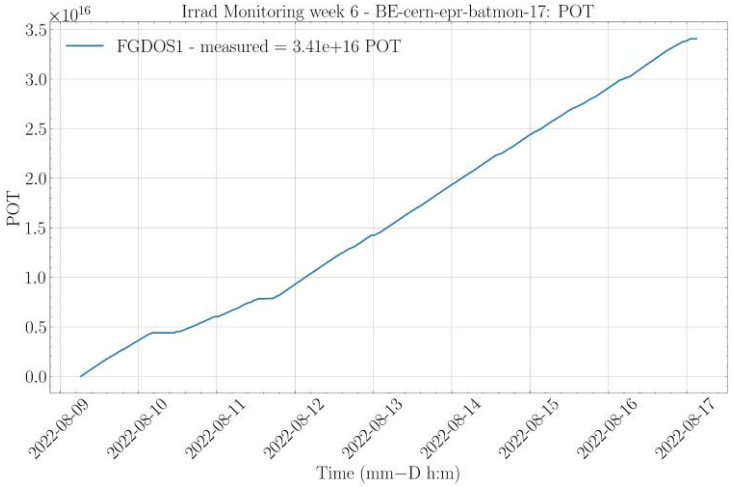

***Figure 47**: POT1 over time (week 6)*

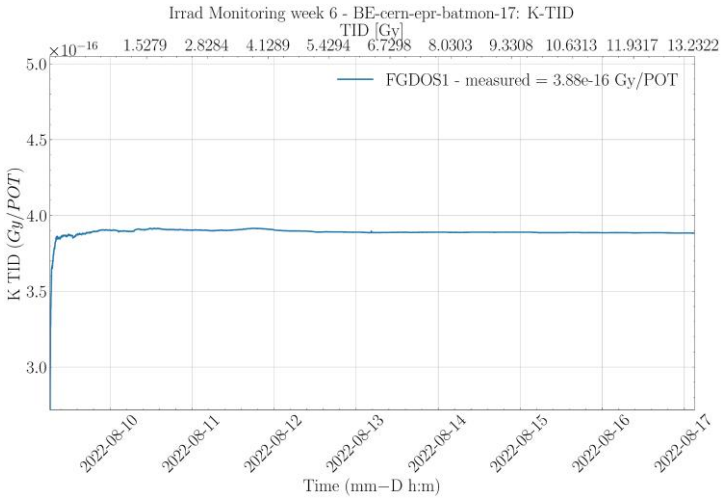

***Figure 48:** K-Factor TID (FGDOS1) (week 6)*

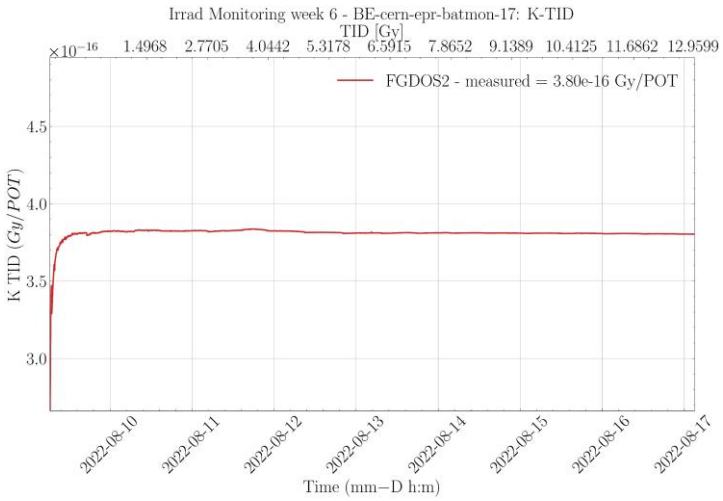

Figure 49: *K-Factor TID (FGDOS2) (week 6)*

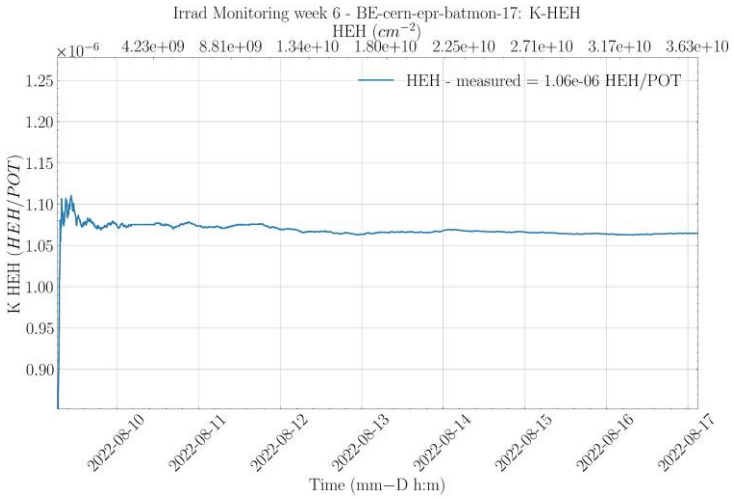

Figure 50*: K-Factor HeH fluence (week 6)*

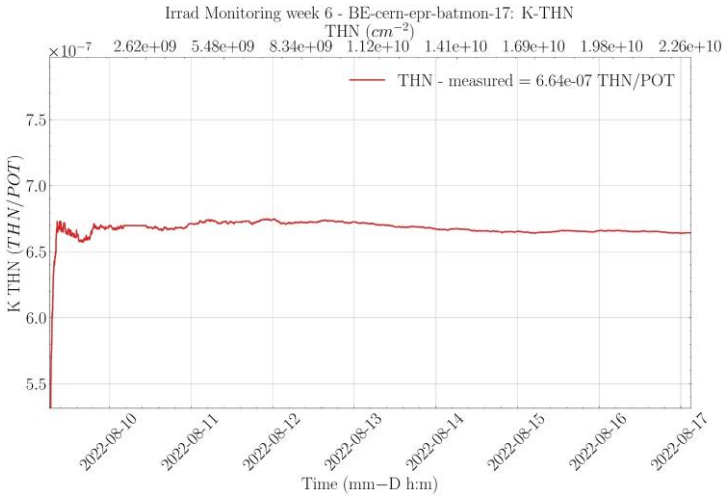

Figure 51*: K-Factor ThN fluence (week 6)*

Table 19: K-Factors (week 6)

Position	K TID [*Gy/POT*]	K HEH [*HEH/POT*]	K ThN [*HEH/POT*]
A	$3.88x10^{-16}$	$1.06x10^{-6}$	$6.64x10^{-7}$

9 Radiation Monitoring Week 7

During the 7th week of operation, the configuration of the facility was not always the same. Tables 7 and 9 present at the start of the run were removed at 8:03 a.m. and 2:36 p.m. on 22/08/22, respectively.
This change of configuration is reflected created a decrease in the dose and fluence delivered in the position of interest.

Radiation Data

In this section, the results of the radiation monitoring performed using the Wireless IoT Monitoring #17 system are reported in Table 20 (TID) and 21 (Fluences) and shown in Figures 52 (TID), 53 (Fluences) and 54 (R Factor).

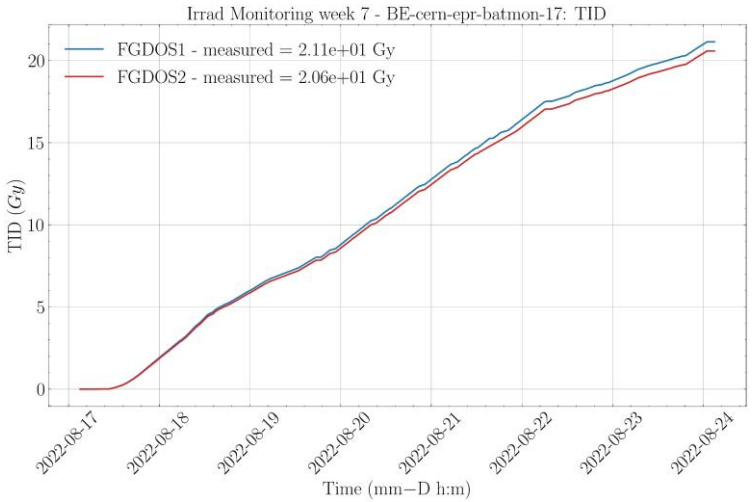

***Figure 52**: TID over time (week 7)*

Table 20: Radiation data (TID) (week 7)

Position	TID [Gy]	*TID per hour [Gy/h]*	*TID per day [Gy/D]*
A	21.14	0.126	3.020

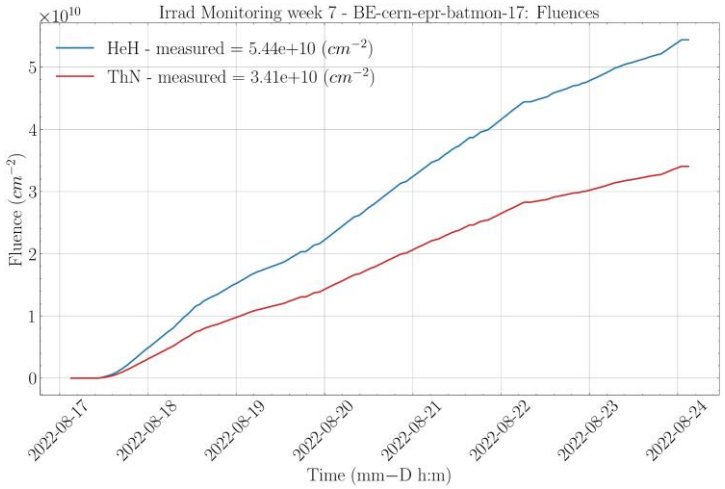

***Figure 53**: HeH and ThN fluences over time (week 7)*

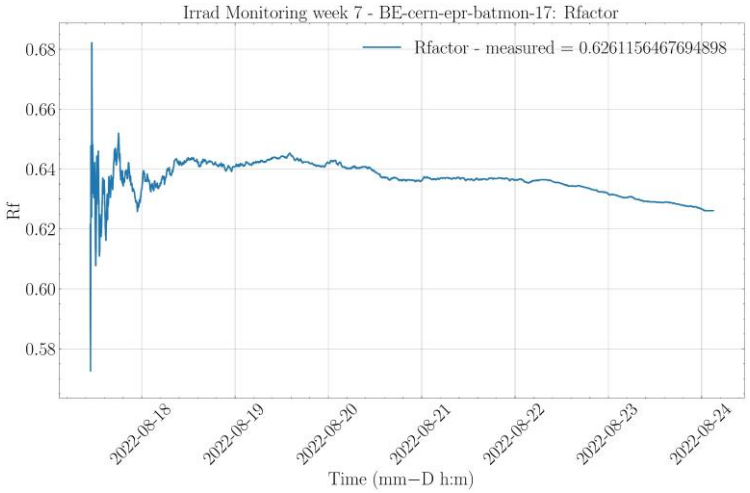

***Figure 54**: R-Factor over time (week 7)*

Table 21: Radiation data (Fluences) (week 7)

Position	R-Factor	φ_{HEH} [pp/cm^2]	φ_{ThN} [pp/cm^2]	Φ_{HEH} [$pp/(s \times cm^2)$]	Φ_{ThN} [$pp/(s \times cm^2)$]
A	0.626	$5.44x10^{10}$	$3.41x10^{10}$	$9.00x10^{4}$	$5.63x10^{4}$

Normalization Factors

The POTs for this run are shown in Figure 55 In this section, the K-Factors measured for the position of interest are reported in Table 22 (TID and Fluences) and shown in Figures 56 and 57 (TID) and 58 and 59 (Fluences).

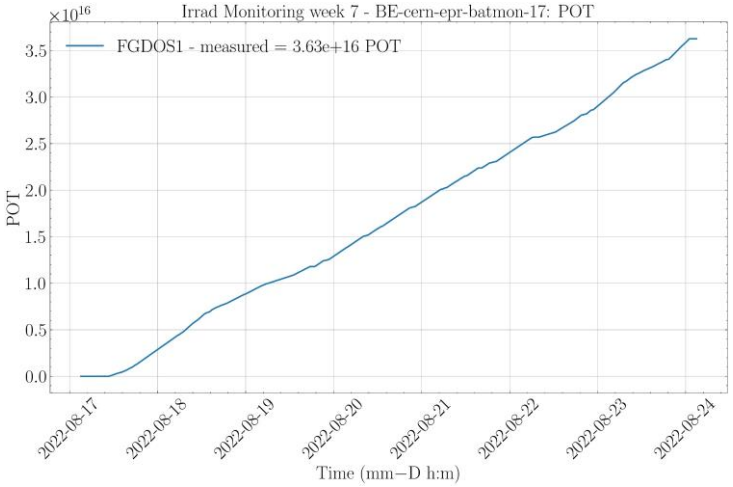

***Figure 55**: POT1 over time (week 5)*

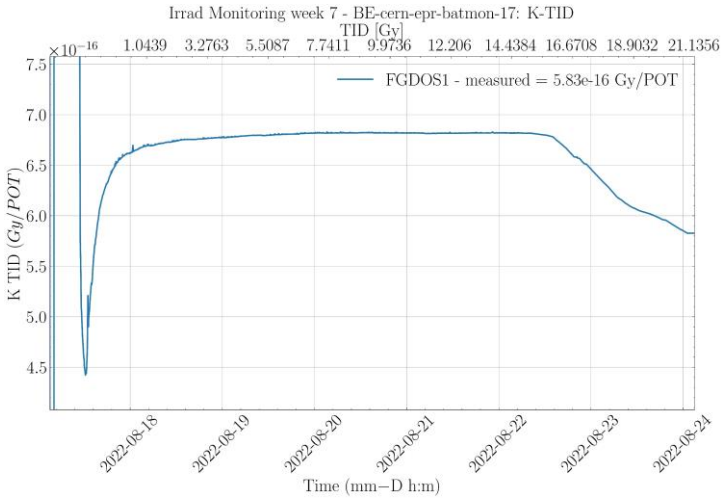

***Figure 56:** K-Factor TID (FGDOS1) (week 5)*

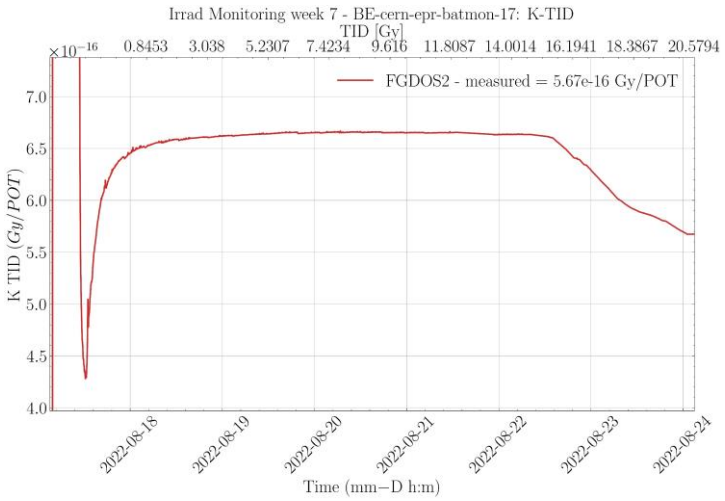

Figure 57: *K-Factor TID (FGDOS2) (week 5)*

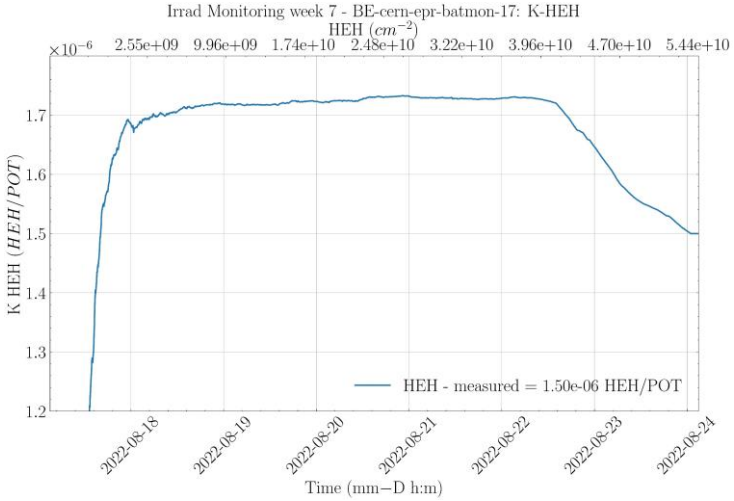

Figure 58*: K-Factor HeH fluence (week 7)*

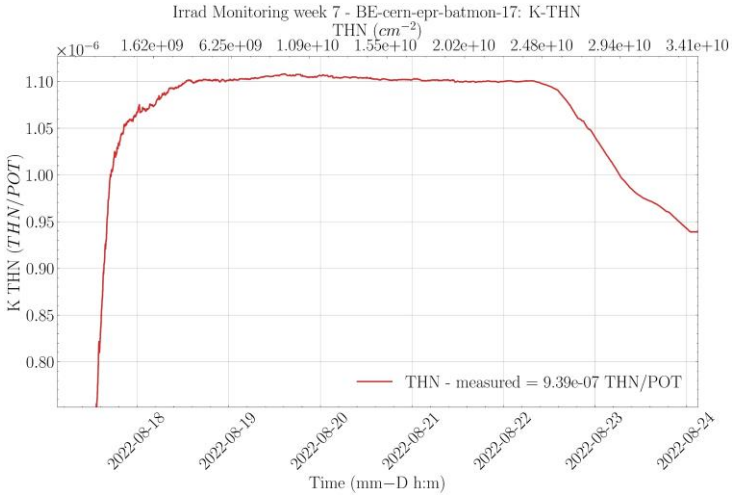

Figure 59*: K-Factor ThN fluence (week 7)*

Table 22: K-Factors (week 7)

Position	K TID [*Gy/POT*]	K HEH [*HEH/POT*]	K ThN [*HEH/POT*]
A	$5.83x10^{-16}$	$1.50x10^{-6}$	$9.39x10^{-7}$

10 Radiation Monitoring Week 8

During the 8th week of operation, no table was inside and thus, the dose and fluence delivered to the target were the lowest of the 8 weeks.

Radiation Data

In this section, the results of the radiation monitoring performed using the Wireless IoT Monitoring #17 system are reported in Table 23 (TID) and 24 (Fluences) and shown in Figures 60 (TID), 61 (Fluences) and 62 (R Factor).

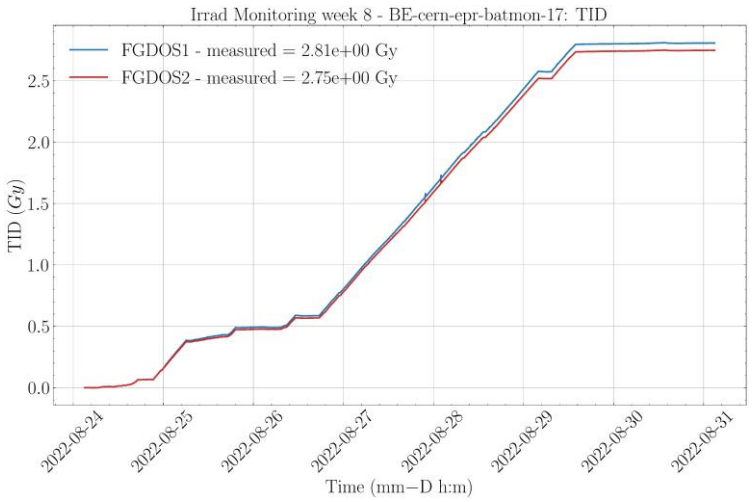

***Figure 60**: TID over time (week 8)*

Table 23: Radiation data (TID) (week 8)

Position	TID [Gy]	*TID per hour [Gy/h]*	*TID per day [Gy/D]*
A	2.81	0.017	0.401

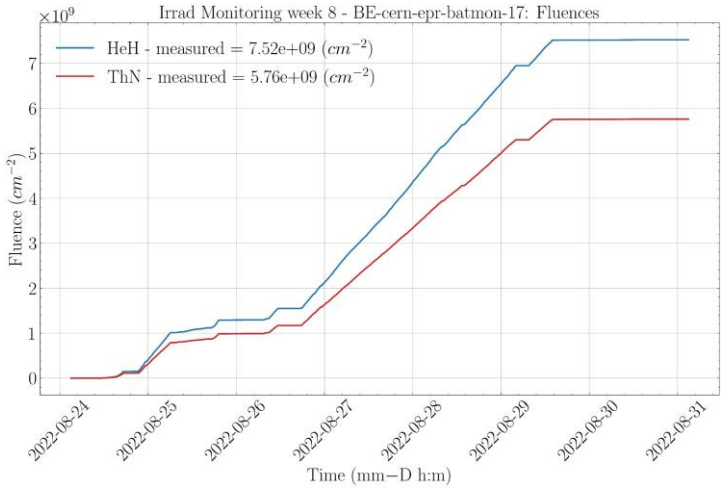

***Figure 61**: HeH and ThN fluences over time (week 8)*

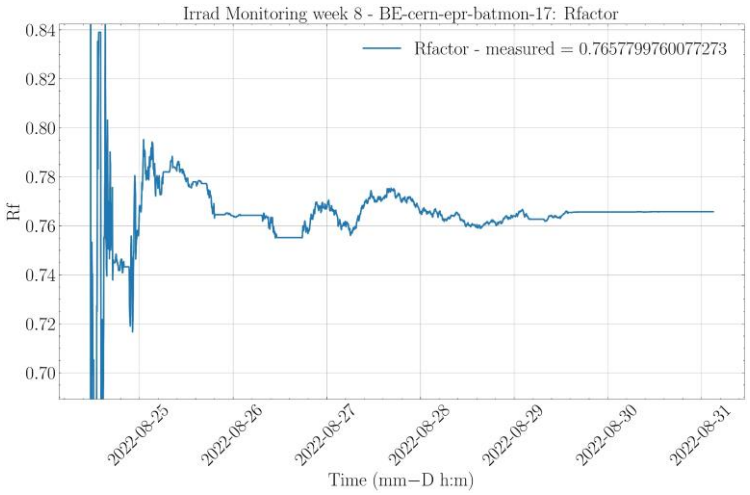

***Figure 62**: R-Factor over time (week 8)*

Table 24: Radiation data (Fluences) (week 8)

Position	R-Factor	φ_{HEH} [pp/cm^2]	φ_{Thn} [pp/cm^2]	Φ_{HEH} [$pp/(s \times cm^2)$]	Φ_{Thn} [$pp/(s \times cm^2)$]
A	0.766	$7.52x10^9$	$5.76x10^9$	$1.24x10^4$	$9.52x10^5$

Normalization Factors

The POTs for this run are shown in Figure 63 In this section, the K-Factors measured for the position of interest are reported in Table 25 (TID and Fluences) and shown in Figures 64 and 65 (TID) and 66 and 67 (Fluences).

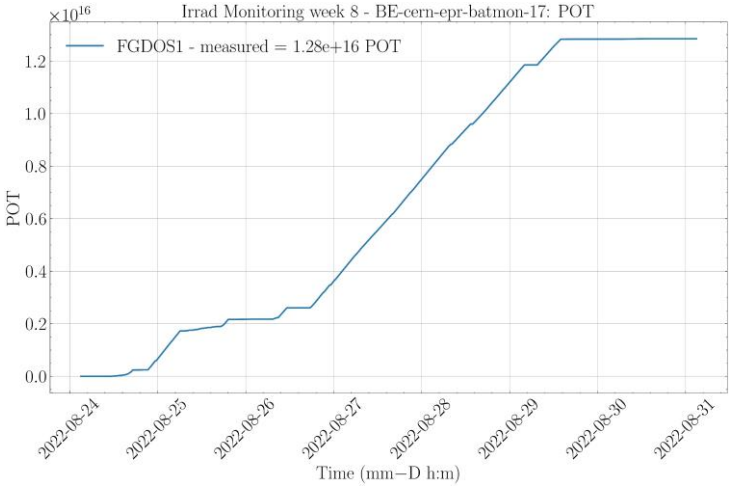

***Figure 63**: POT1 over time (week 8)*

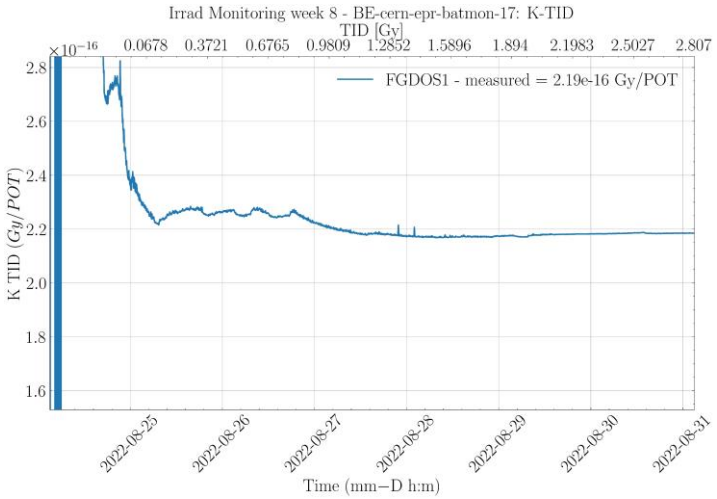

***Figure 64:** K-Factor TID (FGDOS1) (week 8)*

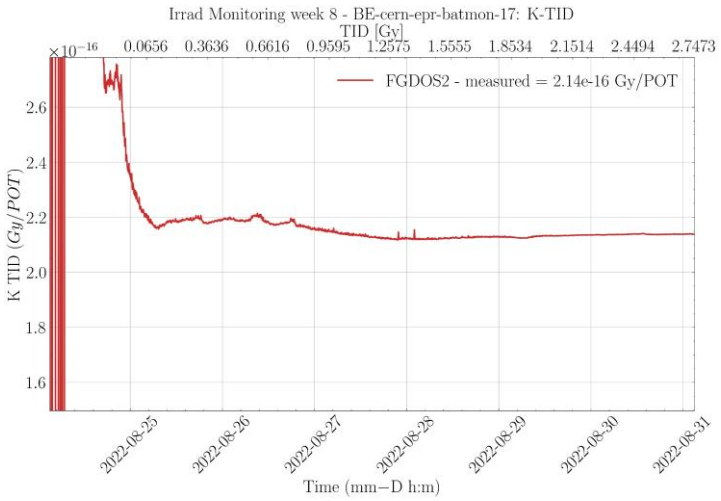

Figure 65: *K-Factor TID (FGDOS2) (week 8)*

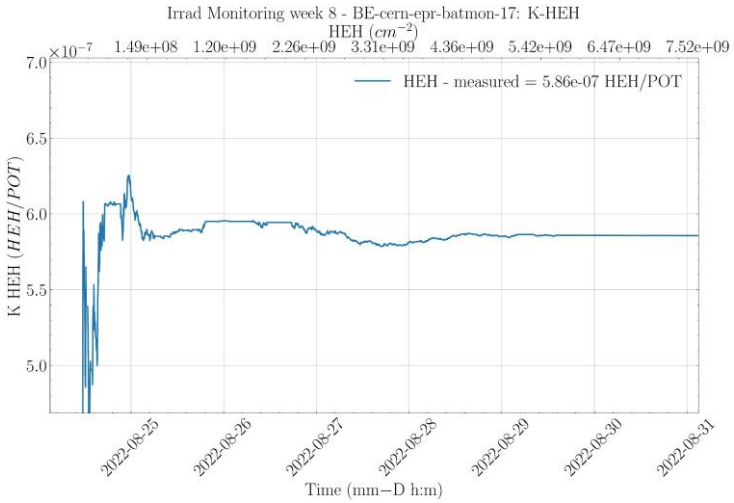

Figure 66*: K-Factor HeH fluence (week 8)*

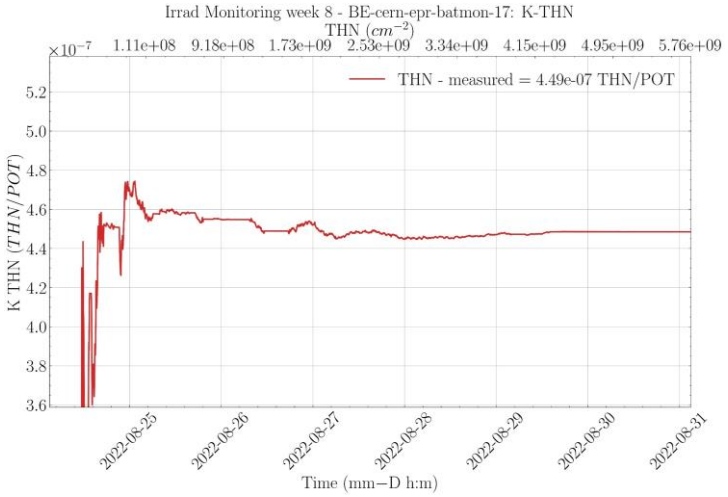

Figure 67*: K-Factor ThN fluence (week 8)*

Table 25: K-Factors (week 8)

Position	K TID [*Gy/POT*]	K HEH [*HEH/POT*]	K ThN [*HEH/POT*]
A	$2.19x10^{-16}$	$5.86x10^{-7}$	$4.49x10^{-7}$

11 Conclusion

The BatMon was installed at IRRAD for a dual purpose. For the first two weeks it was used to calibrate a location of interest, and for the following weeks to monitor cumulative radiation on a sample under investigation.
It was removed at 10:30 a.m on 08/31/22. and showed no failures during the 8 weeks of operation. During this period, a large difference in weekly measurements was observed depending on the facility configuration.
The cumulative TID and Fluences on the test device are shown in Figures 68 and 69.

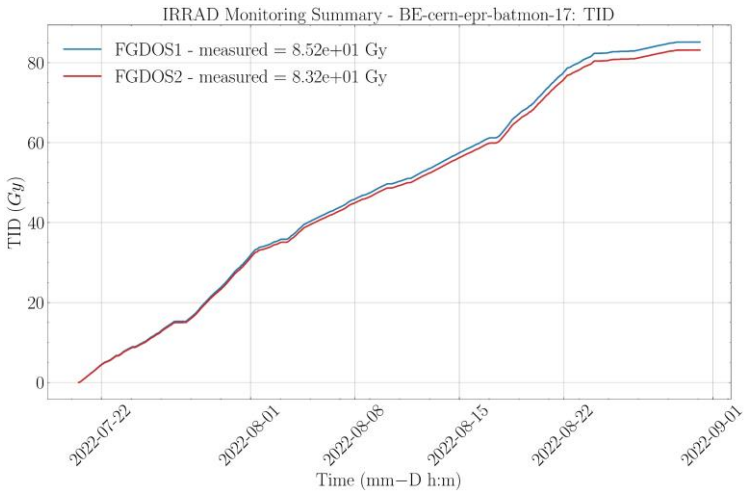

***Figure 68**: TID from week 3 to 8*

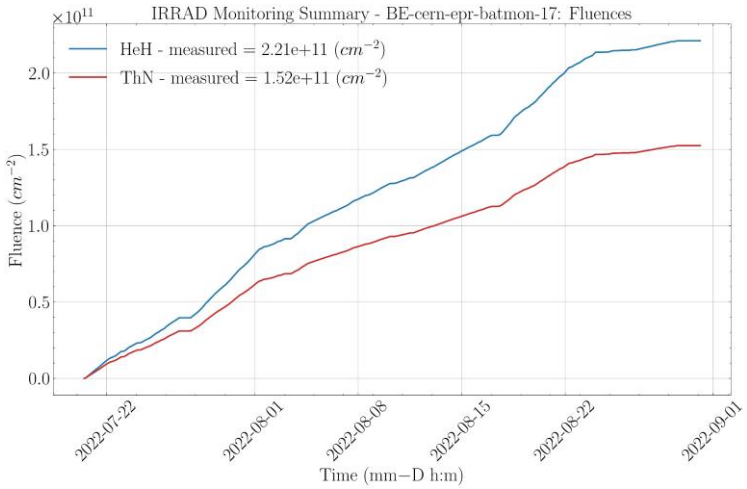

***Figure 69**: Fluences from week 3 to 8*

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[1] J. Mekki, M. Brugger, R. G. Alia, A. Thornton, N. C. D. S. Mota and S. Danzeca, "CHARM: A Mixed Field Facility at CERN for Radiation Tests in Ground, Atmospheric, Space and Accelerator Representative Environments," in IEEE Transactions on Nuclear Science, vol. 63, no. 4, pp. 2106-2114, Aug. 2016, doi: 10.1109/TNS.2016.2528289.

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[3] G Spiezia, P Peronnard, A Masi, M Brugger, M Brucoli, S Danzeca, R Garcia Alia, R Losito, J Mekki, P Oser, R Gaillard, and L Dusseau. A New RadMon Version for theLHC and its Injection Lines. IEEE Trans. Nucl. Sci., 61:3424–3431. 8 p, 2014.

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[5] GIS portal: https://gis.cern.ch/gisportal/Machine.htm