ECo60-JUICE

Final Project Report

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CONTRACT REPORT
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Contents

1 Executive Summary

1.1 Contractual

The following document has been prepared by LIP for ESA/ESTEC and refers to the WP3200 "Definition of Test Plans" of ESA contract RFQ/3-13975/13/NL/PA, "Verification of Co-60 testing representativeness for EEE components flown in Jupiter electron environment". The radiation test plans presented in this document are listed in the deliverable items as documents D2 to D5 of WP3200.

1.2 General

The objective of the present activity, corresponding to RFQ/3-13975/13/NL/PA, Verification of Co-60 testing representativeness for EEE components flown in Jupiter electron environment, is to verify that the standard EEE component Total Ionising Dose (TID) irradiation testing employing ^{60}Co gammas is valid for the high energy electron field observed in the Jovian environment. In this activity a number of typical EEE component technologies will be irradiated with Co-60 gammas and with high energy (≥ 10MeV) electron beams. The results of both irradiations will be subsequently compared and employed in the JUICE RHA process.

The activity is divided in 3 phases: Phase 1, corresponding to the selection of test candidates; Phase 2, corresponding to the preparation of the EEE parts irradiation tests and Phase 3, in which the components will be irradiated and the results of the irradiation tests will be analysed. WP3200 tasks are described in the corresponding PSSA20 form, in section 13.

1.3 Purpose

The purpose of work package WP3200 is to define the test plans in conformance to the requirements layout in the Statement of Work and the ESCC (European Space Components Coordination) "Total Dose Steady-State Irradiation Test Method" (ESCC Detail Specification No. 22900, Issue 2, August 2003).

2 Related Documents

2.1 Applicable and Reference Documents

[AD1] - "Total Dose Steady-State Irradiation Test Method", Ref. ESCC 22900

[AD2] – "ECo60-JUICE - Procurement of Test Candidates", Ref. Eco-60/P2/WP3100/PR

[AD3] – "Department Of Defense - Test Method Standard - Environmental Test Methods for Semiconductor Devices", Ref. MIL-STD-750

[AD4] –"U-EEE-RAD-1080650-RSE, Issue 1"

2.1.1 Definitions, acronyms and abbreviations

AA:	Agency Approval
AD:	Applicable Document
DD:	Directionality Detector
ESA:	European Space Agency
ELDRS:	Enhanced Low dose Rate Sensitivity

ESTEC:	European Space Research and Technology Centre
HDR:	High dose Rate
HK:	House Keeping
KO:	Kick-Off
LDR:	Low Dose Rate
LIP:	Laboratório de Instrumentação e Física Experimental de Partículas
MC:	Monte Carlo
RD:	Reference Document
SOW:	Statement Of Work
UUID:	Universal Unique Identification
TBD:	To Be Determined
TN:	Technical Note
WP:	Work Package

3 General Procedures and Equipment

3.1 Device Description and Serialization

The test plan involves five different types of devices (A, B, C, D, E) defined in [AD2]. The components are listed in Table 3-1 and can be seen in Figure 3-1.

Table 3-1 List of components to be tested

Component Type	A	B	C	D	E
	Transistor (discrete MOS/CMOS)	FLASH-NAND Memory (MOS/CMOS IC)	Transistor (Bipolar)	Analog ICs non ELDRS	Analog ICs displaying ELDRS
Reference	STRH100N10	MT29F32G08ABAAAWP-ITZ	2N2222	LM124	LM4050WG5.0-MPR
Manufacturer	STMicroelectronics	Micron	STMicroelectronics	Texas Instruments	Texas Instruments
Marking	520502101F BeO	29F32G08ABAAA	520100212	RM124AJRQMLV -JMO7C6273	LM4050WG5.0-MPR
Date Code	1305A	1412	1345A	H7B1033W	HOB1022A
# of units	27	32	26	30	30

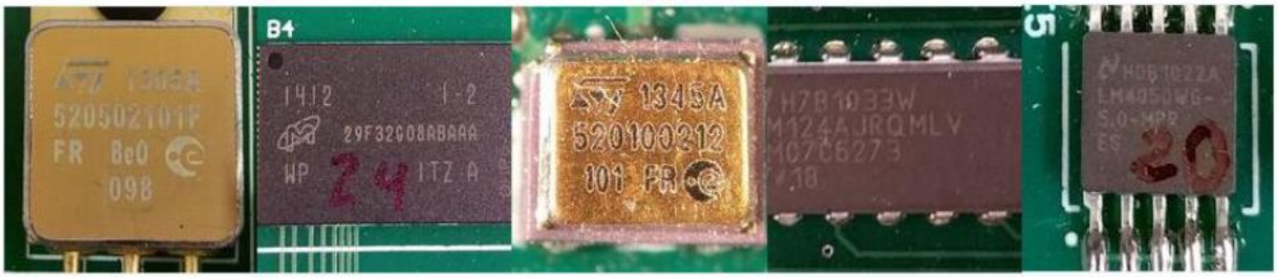


Figure 3-1 Component pictures from left to right, component A to E.

The components are serialized with an ID in the form of:

<component type>-<serial #>

Where:

- <component type> is a one letter code indicating the type of component in accordance with Table 3-1.
- <serial #> is a two digit number indicating the serial number for each component type. This code will be marked in the component. The components that are marked by the manufacturer with a serial number will not be marked with the “serial #”.

The components were serialized prior to the pre-irradiation measurements. After the pre-irradiation measurements the components were selected to form the different set of samples and a Universal Unique ID was assigned by adding the "irradiation type" code. The UUID takes the form:

<irradiation type>-<component type>-<serial #>

Where:

- <irradiation type> indicates the type of irradiation to be performed in the component:
  - Co1 – Irradiation with Co-60 source in LDR
  - Co2 – Irradiation with Co-60 source in HDR
  - Eb1 – Irradiation with electron beam with energy E1=12 MeV at Santa Maria Hospital
  - Eb2 – Irradiation with electron beam with energy E1=12 MeV at RADEF
  - Eb3 – Irradiation with electron beam with energy E2=20 MeV at RADEF
  - Ref – Reference component.
  - SPA – Spare parts

3.2 Component parameters

For each type of components the relevant parameters were measured with focus on the understanding differences between the different types of irradiation, namely between Co-60 irradiation and electron irradiation. In the following sections the relevant parameters to be measured for each component type are identified.

The components were irradiated and measured at room temperature T_{amb}=+22±3°C.

3.2.1 Component A

Component A is a 100V N channel MOS transistor manufactured by ST Microelectronics with the reference STRH100N10. This component was irradiated unbiased. The measured parameters are listed in Table 3-2.

Table 3-2 - Electrical parameters to be measured for Component A

Characteristics	Symbols	Test Conditions	Limits		
			Min	Max	Un.
Gate-to-Source Leakage Current 1	I_{GSS1}	V_{GS}=20V, V_{DS}=0V	-	100	nA
Gate-to-Source Leakage Current 2	I_{GSS2}	V_{GS}=-20V, V_{DS}=0V	-100	-	nA
Drain Current	I_{DSS}	V_{DS}=40V, V_{GS}=0V	-	10	µA
Gate-to-Source Threshold Voltage	$V_{GS(th)}$	$V_{DS} \geq V_{GS}$ I_D=1mA	2	4.5	V
Static Drain-to-Source On Resistance	$r_{DS(on)}$	V_{GS}=12V, I_D=24A	-	35	mΩ
Source-to-Drain Diode Forward Voltage	V_{SD}	V_{GS}=0V, I_{SD}=48A	-	1.5	V

3.2.2 Component B

Component B is a NAND-flash memory manufactured by Micron with reference MT29F32G08ABAAAWP-ITZ. This component was irradiated under static bias with V=3.3V.

The test consisted in the determination of error rates in holding values and in the operation of set/reset.

The memory size of the component is 32 GBits. To estimate the error rate with small statistical error it is possible to test only a part of the chip. As such, we made partitions of the chip and performed several tests in the same chip. The memories were partitioned in 64 blocks portions that were tested according to following table:

Table 3-3 Memory Tests Summary

Partition #	Pattern	Type of test
0	All ‘0’	Static
1	All ‘1’	Static
2	Checkerboard	Static
3	Inv. Checker	Static
4	All ‘0’	Dynamic
5	All ‘1’	Dynamic
6	Checkerboard	Dynamic
7	Inv. Checker	Dynamic

Note: Due to time constraints tests with partitions 3 and 7 were not performed except in Co2.

In the static test, the memory is loaded with the specific pattern prior to irradiation and is only read during the whole test. In the dynamic test the memory is rewritten in each intermediate measurement step. During the rewriting the partitions are tested for set/reset errors. The test sequences are as follows:

1) Prior to irradiation
    a. Erase
    b. Write patterns in ALL partitions
    c. Read to validate
2) Irradiate DUTs
3) Read all partitions to test data retention
4) Erase partitions 4 to 7 and test reset operation
5) Write patterns in partitions 4 to 7
6) Read partitions 4 to 7 to validate and to test set errors
7) Repeat points 2 to 6 for each irradiation step and points 3 to 6 for each annealing step.

Besides the functional test, the power supply current of the memory was also measured after each irradiation step.

DC characteristics, namely the currents from power supply were also measured. The parameters listed in Table 3-2 were measured prior to irradiation, in between radiation steps, after radiation finishes and during the annealing phase.

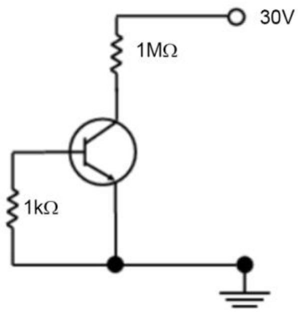
Table 3-4 – List of electrical parameters to be measured for component B

Characteristics	Symbols	Test Conditions	Limits		
			Min	Max	Un.
Standby current - VCC	I_{SB}	CE# = VCCQ - 0.2V; WP# = 0V/VCCQ	-	50	uA
Array read current (active)	I_{CC1_A}	-	-	50	mA

3.2.3 Component C

Component C is a bipolar transistor from ST Microelectronics with reference 2N2222. This component was biased during irradiation. The biasing circuit is shown in Figure 3-2.
The post-irradiation gain calculation of [hFE], was made using hFE measurements from each step, as specified in [AD3], test method 1019.

Figure 3-2 – Biasing circuit for 2N2222 irradiation



The parameters listed in Table 3-5 were measured prior to irradiation, in between radiation steps, after radiation finishes and during the annealing phase.

Table 3-5 – List of electrical parameters to be measured for component C

Characteristics	Symbols	Test Conditions	Limits		
			Min	Max	Un.
Collector-Base Cut-off Current	I_{CBO}	V_{CB} = 60V	-	10	nA
Emitter-Base Cutoff Current	I_{EBO}	V_{EB} = 3V	-	10	nA
Collector-Emitter Saturation Voltage	$V_{CE(sat)}$	I_C = 150mA, I_B = 15mA	-	300	mV
Base-Emitter Saturation Voltage	$V_{BE(sat)}$	I_C = 150mA, I_B = 15mA	-	1.2	V
Forward-Current Transfer Ratio	h_{FE1}	V_{CE} = 10V, I_C = 100μA	35	-	-
	h_{FE2}	V_{CE} = 10V, I_C = 10mA	75	-	-
	h_{FE3}	V_{CE} = 10V, I_C = 150mA	100	300	-
	h_{FE4}	V_{CE} = 10V, I_C = 500mA	40	-	-

3.2.4 Component D

Component D is an operational amplifier manufactured by Texas Instruments with reference LM124. This component was irradiated unbiased with all leads tied to ground.

The parameters listed in Table 3-6 were measured prior to irradiation, in between radiation steps, after radiation finishes and during the annealing phase.

Table 3-6 – List of electrical parameters to be measured for component D

Characteristics	Symbols	Test Conditions	Limits		
			Min	**Max**	**Un.**
Power Supply Current	Icc	Vcc+ = 30V, Vcc- = Gnd		3	mA
Input Bias Current	±Iib	Vcc+ = 30V, Vcc- = Gnd, Vcm = +15V	-75	+0.1	nA
Input Offset Current	Iio	Vcc+ = 30V, Vcc- = Gnd, Vcm = +15V	-15	15	nA
Input Offset Voltage	Vio	Vcc+ = 30V, Vcc- = Gnd, Vcm = 15V	-2	2	mV
Common Mode Rejection Ratio	CMRR		76		dB
Power Supply Rejection Ratio	PSRR	Vcc- = Gnd, Vcm = +1.4V, 5V ≤ Vcc ≤ 30V	-100	100	uV/V
Voltage Gain	Avs	Vcc+ = 30V, Vcc- = Gnd, 1V ≤ Vo ≤ 26V, Rl = 10K Ohms	40		V/mV
Slew Rate: Rise	$+S_R$	VCC+ = 30V, VCC- = Gnd	0.1		V/uS
Slew Rate: Fall	$-S_R$	VCC+ = 30V, VCC- = Gnd	0.1		V/uS
Maximum Output Voltage Swing	$+V_{OP}$	VCC+ = 30V, VCC- = Gnd, VO = +30V, RL = 10KΩ	27		V

3.2.5 Component E

Component E is a shunt voltage reference manufactured by Texas Instruments with reference LM4050. This component was irradiated unbiased with all leads tied to ground.

The parameters listed in Table 3-7 were measured prior to irradiation, in between radiation steps, after radiation finishes and during the annealing phase.

Table 3-7 – List of electrical parameters to be measured for component E

Characteristics	Symbols	Test Conditions	Limits – Maximum tolerance (from nominal 5.0V)			
			0 krad	30 krad	50 krad	100krad
Reference Voltage	V_R	I_R=74 µA	±5.0 mV			
		I_R=100 µA	±5.0 mV			
		I_R=1 mA	±8 mV	+0.42%	+0.67%	+1.75%
		I_R=10 mA	±18 mV			
		I_R=15 mA	±20 mV			

3.3 Radiation Test Facilities

The components were irradiated using a Cobalt-60 radioactive source with Low Dose Rate (LDR) and High Dose Rate (HDR) and electron beams at two different energies (12 and 20 MeV) with HDR up to a Level of Interest dose of 100 kRad (H_2O).

The dosimetry system of the facilities provided information about the absolute dose of the device under test with a resolution better than 10% and with dose rate of the Cobalt-60 sources known up to a 5% level or better.

The beam size allowed to irradiate all the 3 carrier boards at the same time in all irradiation campaigns.

3.3.1 Co1 – Co-60 irradiation at LDR

The Co-60 irradiation at LDR (Co1) comprised the irradiation of all the five type of components using a Co-60 source at LDR of ~280 rad/hour. The Cobalt-60 radioactive source available at the ESA-ESTEC facilities premises was used in Co1. Due to an overlap with another experiment the irradiation steps were not 20 kRad but 23.73 kRad, 20.42 kRad, 24.11 kRad, 26.07 kRad and 19.37 kRad in that order up to a total 113.7 kRad. All doses are given in water.

3.3.2 Co2 – Co-60 irradiation at HDR

The Co-60 irradiation at HDR (Co2) comprised the irradiation of all the five type of components using a Co-60 source at a High Dose Rate (24 kRad/hour) in 20 kRad steps up to 100kRad (all doses in water). The HDR testing was performed in CTN-IST (Campus Tecnológico e Nuclear – Instituto Superior Técnico), a facility that provides dose rates compatible with what was required and with a dosimetry system of the facility that provides information about the absolute dose of the device under test with a resolution better than 10%.

3.3.3 Eb1 – Irradiation with electrons of energy 12 MeV at HSM

The Eb1 irradiation comprises the irradiation of all the five type of components using an electron beam at an energy of E1=12 MeV at HDR (Eb1).

The testing was performed at Hospital Santa Maria radiotherapy unit in Lisbon, Portugal. Hospital Santa Maria is a teaching hospital of the Medical School of Lisbon University. The unit also performs research in physics having staff with PhDs in Physics.

The irradiation was performed during the weekend when patient treatments are suspended, with a dose rate of the order of 21.6 kRad/hour in 18 kRad steps up to 90kRad.

The dosimetry system of the facility provided information about the absolute dose of the device under test with a resolution better than 10%. Since the dose was measured in water at maximum peak which is about 2.6cm under the water surface (see Figure 3-3), a factor of 0.90 had to be applied to the measured value to achieve the dose (in water) at the surface of the components.

3.3.4 Eb2 – Irradiation with electrons of energy 12 MeV at RADEF

The Eb2 irradiation comprises the irradiation of a limited set of components using an electron beam at an energy of E1=12 MeV at HDR.

The testing was performed at RADEF with a dose rate of the order of 21.6 kRad/hour in 18 kRad steps up to 90 kRad.

The dosimetry system of the facility provided information about the absolute dose of the device under test with a resolution better than 10%. Since the dose was measured in water at maximum peak which is about 2.6cm under the water surface (see Figure 3-4), a factor of 0.90 had to be applied to the measured value in order to achieve the dose (in water) at the surface of the components.

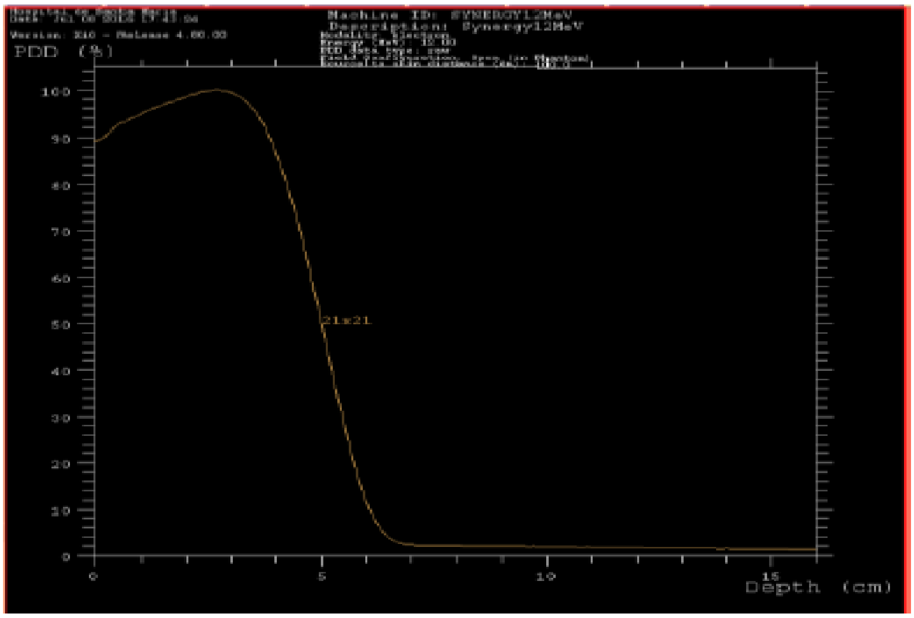


Figure 3-3 12 MeV Electron dose profile in water at a given depth in the HSM facilities.

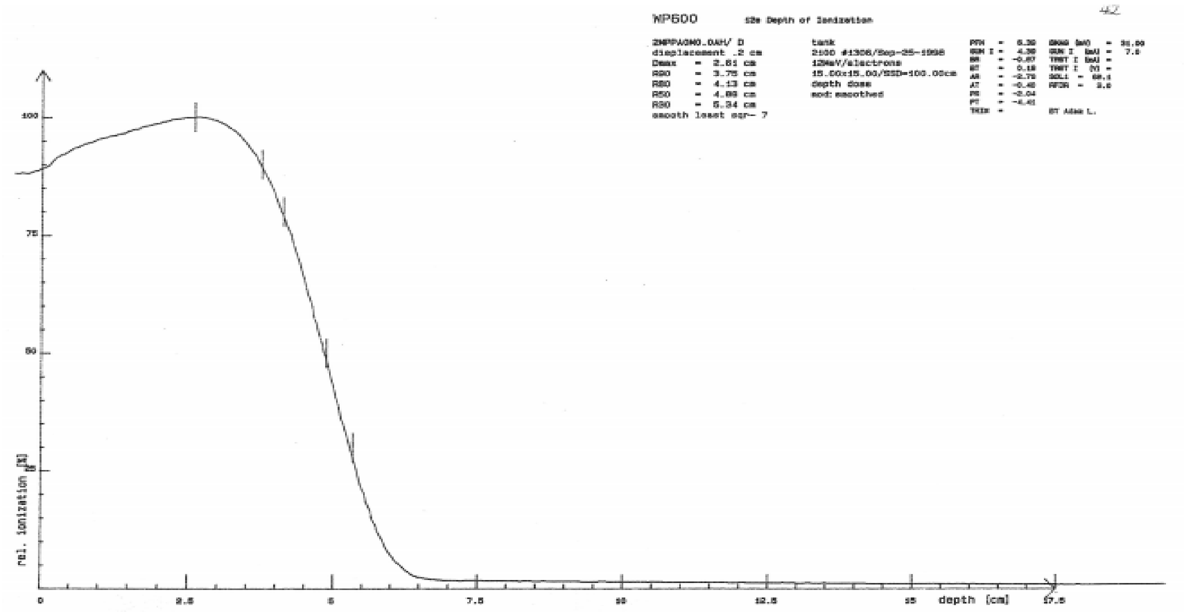


Figure 3-4 12 MeV Electron dose profile in water at a given depth in the RADEF facilities.

3.3.5 Eb3 – Irradiation with electrons of energy 20 MeV at RADEF

The Eb3 irradiation comprises the irradiation of a limited set of components using an electron beam at an energy of E2=20 MeV at HDR.

The testing was performed at RADEF with a dose rate of the order of 22.8 kRad/hour in 19 kRad steps up to 95kRad.

The dosimetry system of the facility provided information about the absolute dose of the device under test with a resolution better than 10%. Since the dose was measured in water at maximum peak which is about 1.6cm under the water surface (see Figure 3-5), a factor of 0.95 had to be applied to the measured value to achieve the dose (in water) at the surface of the components.

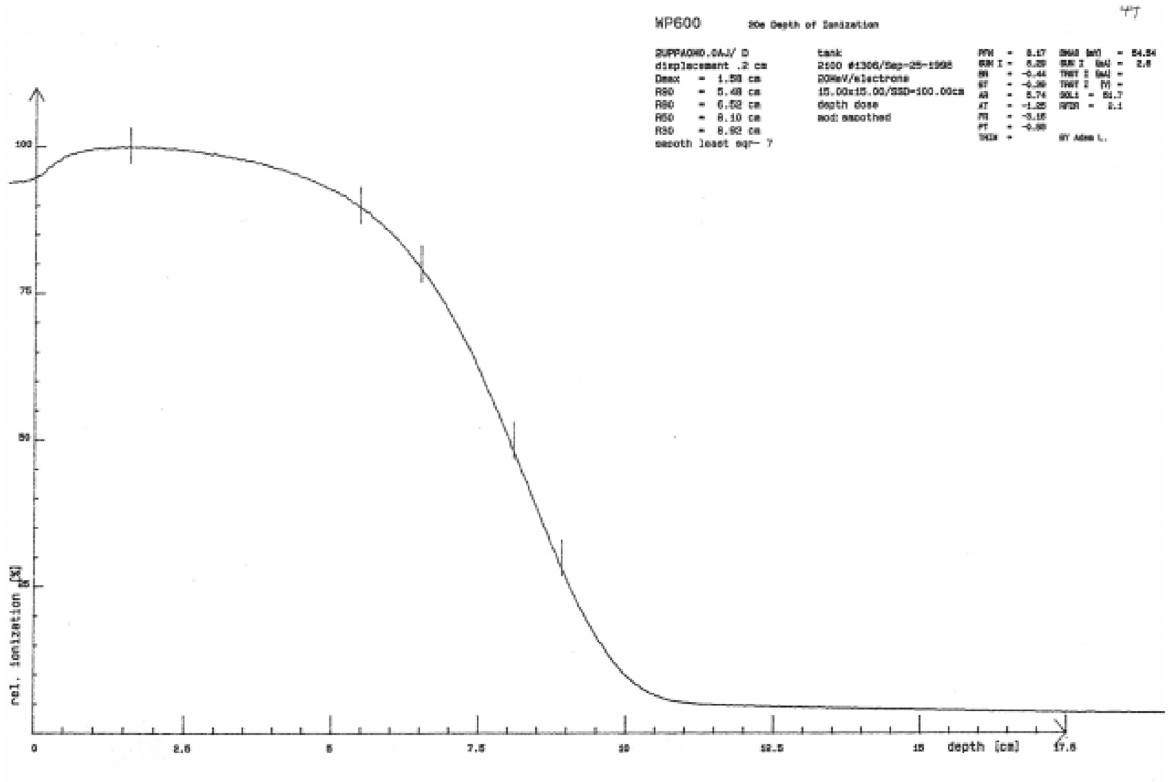


Figure 3-5 20 MeV Electron dose profile in water at a given depth in the RADEF facilities.

4 Test Plan

4.1 Pre-Irradiation Tests

The development of the readout system took place during the Pre-Irradiation phase which ended with the acquisition of the reference data for the components for comparison with the irradiation and annealing phase data.

4.2 Irradiation Plan

In the test plan it was foreseen the irradiation of the test components in several conditions. Due to component availability, the number of samples used in Eb2 and Eb3 was limited. Table 4-1 summarizes the number of samples used in all irradiation campaigns.

Table 4-1 Number of samples per component used in each irradiation campaign.

Component	Co1	Co2	Eb1	Eb2	Eb3
A	5	5	5	0	5
B	5	5	5	0	0
C	5	5	5	2	0
D	5	5	5	5	5
E	5	5	5	5	5

The samples were irradiated in carrier boards. Each carrier board could contain up to 5 samples of a component type to be irradiated in a specific condition. Three types of carrier boards were available:

i) carrier board with 5 samples of component A (Power Carrier)

ii) carrier board with 5 samples of component B (Memory Carrier)

iii) carrier board with 5 samples of component C, 5 samples of component D and 5 samples of component D (Generic Carrier)

The carrier boards allow two modes of operation: Measurement and irradiation. In the irradiation mode the samples were biased according to section 3.2. In the measurement mode the carrier boards couple to the measuring system so that the measurements can be done accordingly to section 3.2.

As reference, there was also an extra carrier board of each type that was not irradiated and was measured at several points for comparison with irradiated samples.

Since the duration of the tests on memories was larger than the others, the memories were irradiated simultaneously or interleaved with the other ones.

4.3 Annealing Plan

After the irradiation the parts entered an annealing phase to study the response in time after irradiation.

Samples irradiated using Co-60 at LDR (Co1) and HDR (Co2, Eb1, Eb2 and Eb3) have been submitted to an annealing phase of 8 months at room temperature. All components were unbiased during this phase.

5 Test Setup Description

The test setup used is based on SMU units from Keithley (2636B – generic SMU and 2651a– Power SMU). The units are combined and provide a total of three channels. The Master Unit digital interface is used to control a switch board developed specifically for the system.

The switch board, shown in Figure 5-1, was developed at LIP to automatize part of the measurements. A conceptual scheme of the switch board is presented in Figure 5-2. The generic carrier board can be connected in one of two connectors, giving access to five OpAmp chips or to five shunt plus five transistor chips. Ports are also available for the connection to the memory carrier (to measure current) and to the Power Carrier. Two SMU channels are connected to the board (SMUA, SMUB) and are connected to the different measurement points via a set of relays. The relays are bi-stable to allow to perform the measurements without power applied to the coil. To minimize the number of relays the commuting between chips is realized by means of a cable.

The channel from the Power SMU was connected directly to the Power Carrier. Due to the potential high currents involved, the cable used had an increased section and the remote sensing mode of the 2651a unit was used.

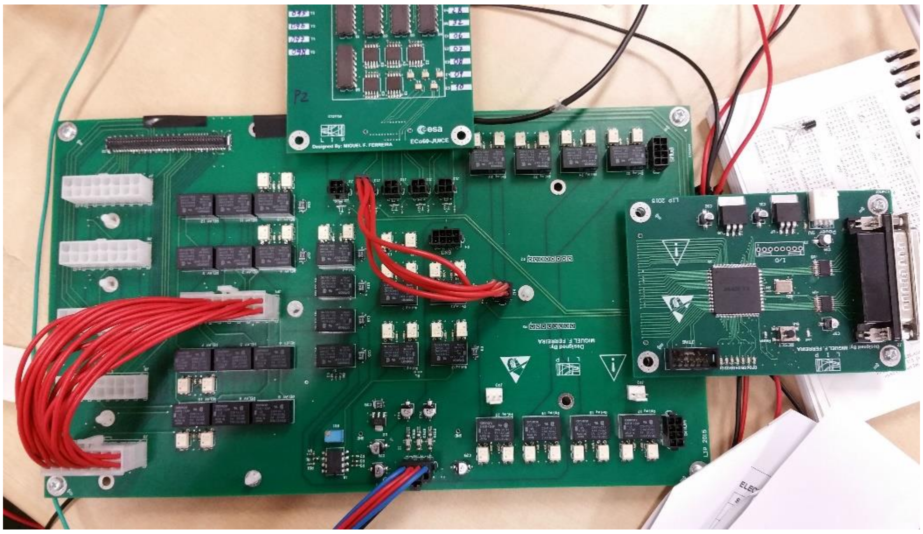


Figure 5-1: Switch Board

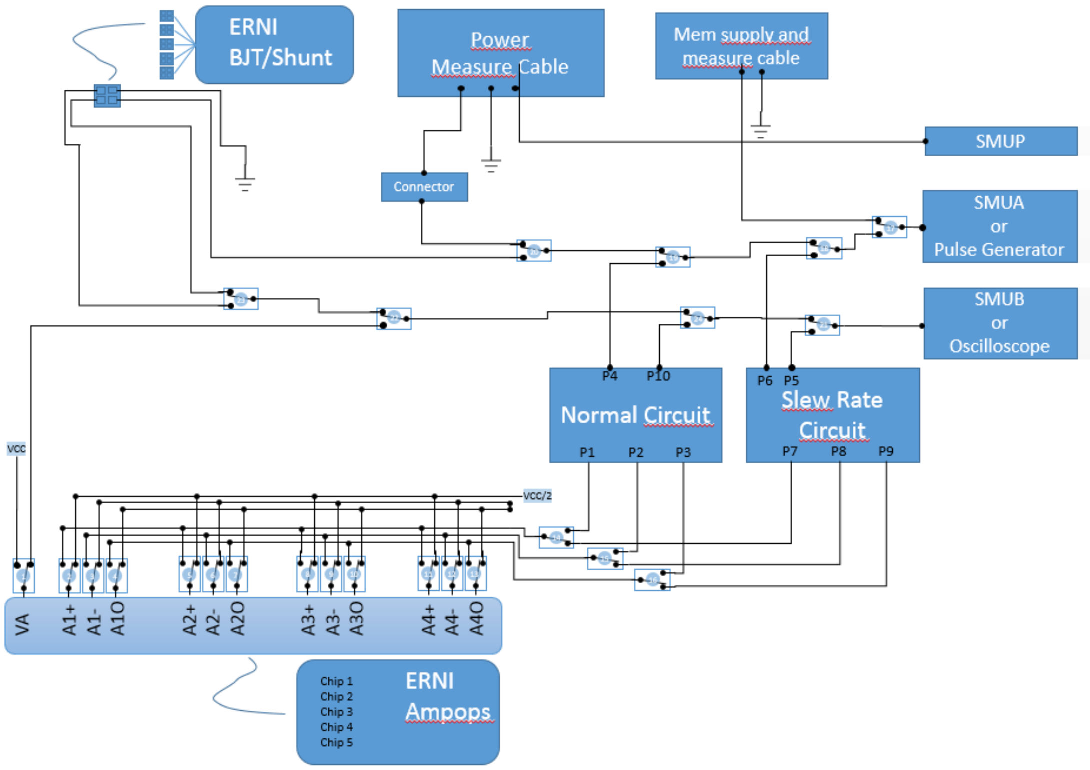


Figure 5-2 Conceptual scheme of the Switch Board

The switch board also carries the auxiliary circuitry for the measurement of the OpAmp parameters. Two auxiliary circuits (with some control relays) are present in the board and their schemes are shown in Figure 5-3 and Figure 5-4.

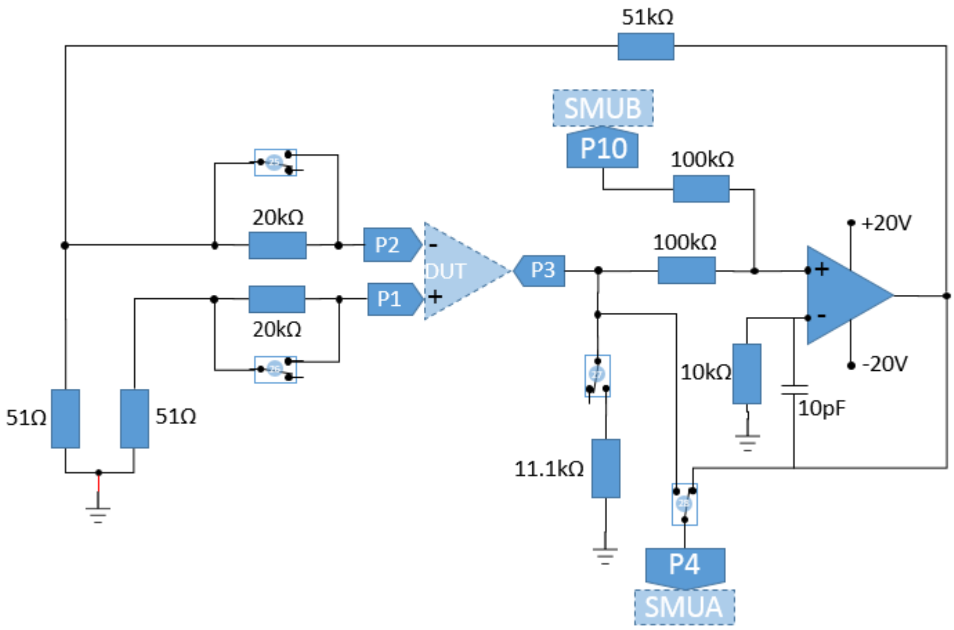


Figure 5-3 OpAmp measurement circuit

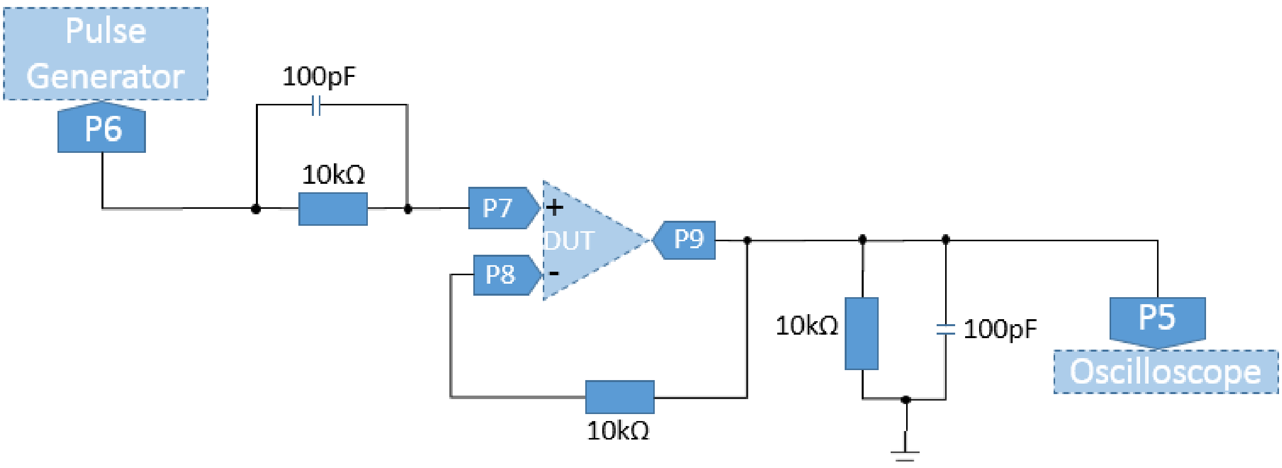


Figure 5-4 Opamp test circuit for Slew Rate measurement

The test setup of component B – the NAND-FLASH memories – includes a SOC development board from ARROW/ALTERA based on a Cyclone V to interface the memory and perform the functional tests. This setup is shown in Figure 5-5 with a memory carrier board connected. A LINUX system is implemented in the SOC that runs the software that control the firmware on the FPGA part which in turn is responsible for the communication with the NAND-FLASH memory. The interaction with the test system is realized by network.

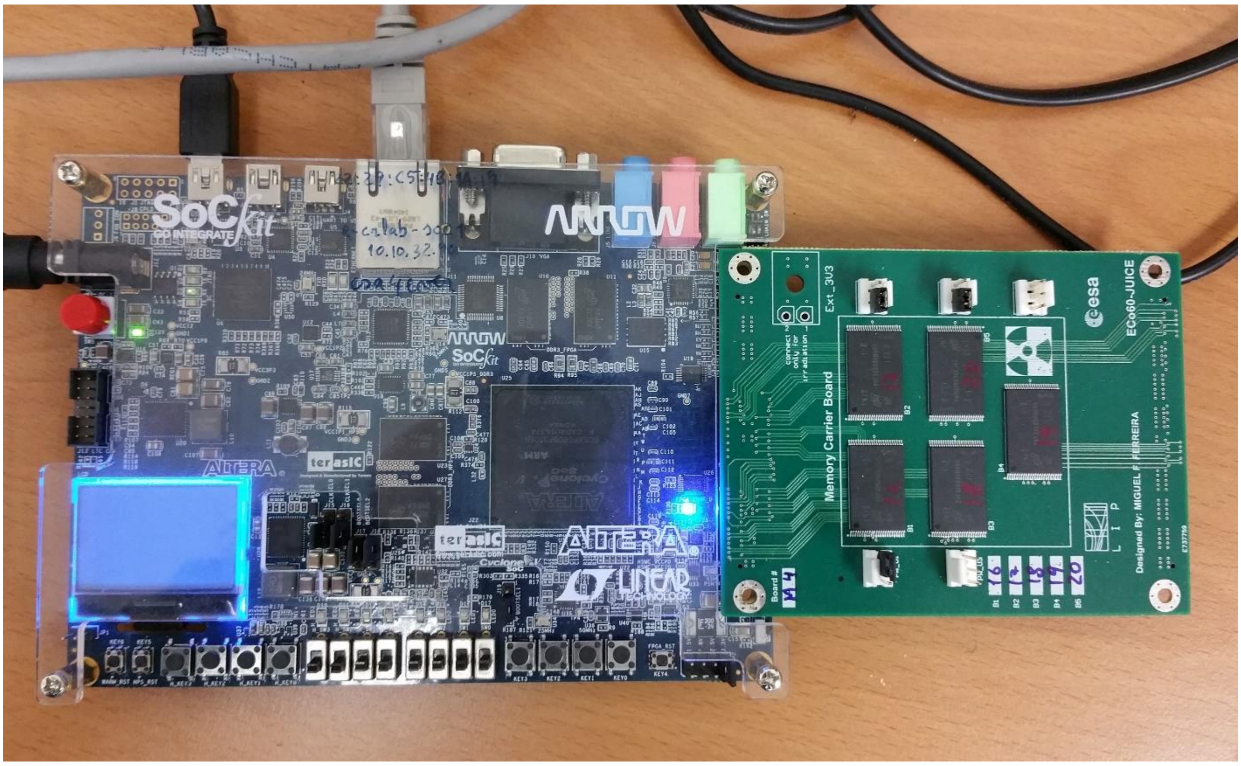


Figure 5-5: Memory test system (left) with a memory carrier connected (right)

6 Chip serialization

6.1 Component A – STRH100N10

ID	UUID	Board type	Chip Type	Board Number	Chip Number	Serial on chip
A-01	Eb1-A-01	PC	A	P1	T1	086
A-02	Eb1-A-02	PC	A	P1	T2	087
A-03	Eb1-A-03	PC	A	P1	T3	088
A-04	Eb1-A-04	PC	A	P1	T4	089
A-05	Eb1-A-05	PC	A	P1	T5	090
A-06	Ref-A-06	PC	A	P2	T1	092
A-07	Ref-A-07	PC	A	P2	T2	093
A-08	Ref-A-08	PC	A	P2	T3	095
A-09	Ref-A-09	PC	A	P2	T4	096
A-10	Ref-A-10	PC	A	P2	T5	097
A-11	Co2-A-11	PC	A	P3	T1	098
A-12	Co2-A-12	PC	A	P3	T2	099
A-13	Co2-A-13	PC	A	P3	T3	101
A-14	Co2-A-14	PC	A	P3	T4	102
A-15	Co2-A-15	PC	A	P3	T5	103
A-16	Co1-A-16	PC	A	P4	T1	104
A-17	Co1-A-17	PC	A	P4	T2	105
A-18	Co1-A-18	PC	A	P4	T3	106
A-19	Co1-A-19	PC	A	P4	T4	107
A-20	Co1-A-20	PC	A	P4	T5	108
A-21	Eb3-A-21	PC	A	P6	T1	109
A-22	Eb3-A-22	PC	A	P6	T2	110
A-23	Eb3-A-23	PC	A	P6	T3	111
A-24	Eb3-A-24	PC	A	P6	T4	112
A-25	Eb3-A-25	PC	A	P6	T5	113

6.2 Component B - Memory

ID	UUID	Board type	Chip Type	Board Number	Chip Number	Serial on chip	Internal UUID
B-01	Eb1-B-01	MC	B	M1	B1	01	8205697578f86010ff00ff00ff00ff007df a968a87079fef00ff00ff00ff00ff
B-02	Eb1-B-02	MC	B	M1	B2	02	8205e99370f96010ff00ff00ff00ff007df a166c8f069fef00ff00ff00ff00ff
B-03	Eb1-B-03	MC	B	M1	B3	03	8205e910b0f96030ff00ff00ff00ff007df a16ef4f069fcf00ff00ff00ff00ff
B-04	Eb1-B-04	MC	B	M1	B4	04	8205e915f1f86070ff00ff00ff00ff007dfa 16ea0e079f8f00ff00ff00ff00ff
B-05	Eb1-B-05	MC	B	M1	B5	05	8205e95530f86010ff00ff00ff00ff007df a16aacf079fef00ff00ff00ff00ff
B-06	Co1-B-06	MC	B	M2	B1	06	8205e9b458f96010ff00ff00ff00ff007df a164ba7069fef00ff00ff00ff00ff
B-07	Co1-B-07	MC	B	M2	B2	07	8205e93010f96010ff00ff00ff00ff007df a16cfef069fef00ff00ff00ff00ff
B-08	Co1-B-08	MC	B	M2	B3	08	8205e9d5a0f86030ff00ff00ff00ff007df a162a5f079fcf00ff00ff00ff00ff
B-09	Co1-B-09	MC	B	M2	B4	09	8205e930b0f96010ff00ff00ff00ff007df a16cf4f069fef00ff00ff00ff00ff
B-10	Co1-B-10	MC	B	M2	B5	10	8205e975a0f86030ff00ff00ff00ff007df a168a5f079fcf00ff00ff00ff00ff
B-11	B-11	MC	B	M3	B1	11	NA
B-12	B-12	MC	B	M3	B2	12	8205697410f96030ff00ff00ff00ff007df a968bef069fcf00ff00ff00ff00ff
B-13	B-13	MC	B	M3	B3	13	8205e99360f96050ff00ff00ff00ff007df a166c9f069faf00ff00ff00ff00ff
B-14	B-14	MC	B	M3	B4	14	820569b188f86030ff00ff00ff00ff007df a964e77079fcf00ff00ff00ff00ff
B-15	B-15	MC	B	M3	B5	15	8205e9d590f86030ff00ff00ff00ff007df a162a6f079fcf00ff00ff00ff00ff
B-16	Co1-B-16	MC	B	M4	B1	16	82056953d8f86030ff00ff00ff00ff007df a96ac27079fcf00ff00ff00ff00ff
B-17	Co1-B-17	MC	B	M4	B2	17	8205e93088f96050ff00ff00ff00ff007df a16cf77069faf00ff00ff00ff00ff
B-18	Co1-B-18	MC	B	M4	B3	18	820569b460f86030ff00ff00ff00ff007df a964b9f079fcf00ff00ff00ff00ff
B-19	Co1-B-19	MC	B	M4	B4	19	8205e97520f86070ff00ff00ff00ff007df a168adf079f8f00ff00ff00ff00ff
B-20	Co1-B-20	MC	B	M4	B5	20	8205e9b488f96050ff00ff00ff00ff007df a164b77069faf00ff00ff00ff00ff
B-21	Ref-B-21	MC	B	M5	B1	21	82056953e8f86030ff00ff00ff00ff007df a96ac17079fcf00ff00ff00ff00ff
B-22	Ref-B-22	MC	B	M5	B2	22	8205e970b8f86030ff00ff00ff00ff007df a168f47079fcf00ff00ff00ff00ff
B-23	Ref-B-23	MC	B	M5	B3	23	8205e93050f96050ff00ff00ff00ff007df a16cfaf069faf00ff00ff00ff00ff
B-24	Ref-B-24	MC	B	M5	B4	24	8205e97008f96030ff00ff00ff00ff007df a168ff7069fcf00ff00ff00ff00ff
B-25	Ref-B-25	MC	B	M5	B5	25	8205697518f96050ff00ff00ff00ff007df a968ae7069faf00ff00ff00ff00ff

6.3 Component C – 2N2222

ID	UUID	Board type	Chip Type	Board Number	Chip Number	Serial on chip
C-01	Eb1-C-01	GC	C	P1	T1	42
C-02	Eb1-C-02	GC	C	P1	T2	43
C-03	Eb1-C-03	GC	C	P1	T3	44
C-04	Eb1-C-04	GC	C	P1	T4	45
C-05	Eb1-C-05	GC	C	P1	T5	46
C-06	Eb2-C-06	GC	C	P2	T1	094
C-07	Eb2-C-07	GC	C	P2	T2	095
C-08	Eb2-C-08	GC	C	P2	T3	096
C-09	Eb2-C-09	GC	C	P2	T4	097
C-26	Eb2-C-26	GC	C	P2	T5	
C-11	Co1-C-11	GC	C	P3	T1	089
C-12	Co1-C-12	GC	C	P3	T2	090
C-13	Co1-C-13	GC	C	P3	T3	091
C-14	Co1-C-14	GC	C	P3	T4	092
C-15	Co1-C-15	GC	C	P3	T5	093
C-16	Ref-C-16	GC	C	P4	T1	47
C-17	Ref-C-17	GC	C	P4	T2	099
C-18	Ref-C-18	GC	C	P4	T3	100
C-19	Ref-C-19	GC	C	P4	T4	101
C-20	Ref-C-20	GC	C	P4	T5	102
C-21	Co2-C-21	GC	C	P5	T1	084
C-22	Co2-C-22	GC	C	P5	T2	085
C-23	Co2-C-23	GC	C	P5	T3	086
C-24	Co2-C-24	GC	C	P5	T4	087
C-25	Co2-C-25	GC	C	P5	T5	088

6.4 Component D – LM124

ID	UUID	Board type	Chip Type	Board Number	Chip Number	Serial on chip
D-01	Eb1-D-01	GC	D	P1	D1	26
D-02	Eb1-D-02	GC	D	P1	D2	25
D-03	Eb1-D-03	GC	D	P1	D3	24
D-04	Eb1-D-04	GC	D	P1	D4	23
D-05	Eb1-D-05	GC	D	P1	D5	27
D-06	Eb2-D-06	GC	D	P2	D1	31
D-07	Eb2-D-07	GC	D	P2	D2	30
D-08	Eb2-D-08	GC	D	P2	D3	29
D-09	Eb2-D-09	GC	D	P2	D4	28
D-10	Eb2-D-10	GC	D	P2	D5	32
D-11	Co1-D-11	GC	D	P3	D1	41
D-12	Co1-D-12	GC	D	P3	D2	40
D-13	Co1-D-13	GC	D	P3	D3	39
D-14	Co1-D-14	GC	D	P3	D4	38
D-15	Co1-D-15	GC	D	P3	D5	42
D-16	Ref-D-16	GC	D	P4	D1	36
D-17	Ref-D-17	GC	D	P4	D2	35
D-18	Ref-D-18	GC	D	P4	D3	34
D-19	Ref-D-19	GC	D	P4	D4	33
D-20	Ref-D-20	GC	D	P4	D5	37
D-21	Co2-D-21	GC	D	P5	D1	21
D-22	Co2-D-22	GC	D	P5	D2	20
D-23	Co2-D-23	GC	D	P5	D3	19
D-24	Co2-D-24	GC	D	P5	D4	18
D-25	Co2-D-25	GC	D	P5	D5	22
D-26	Eb3-D-26	GC	D	P6	D1	
D-27	Eb3-D-27	GC	D	P6	D2	
D-28	Eb3-D-28	GC	D	P6	D3	
D-29	Eb3-D-29	GC	D	P6	D4	
D-30	Eb3-D-30	GC	D	P6	D5	

6.5 Component E - LM4050

ID	UUID	Board type	Chip Type	Board Number	Chip Number	Serial on chip
E-01	Eb1-E-01	GC	E	P1	E1	01
E-02	Eb1-E-02	GC	E	P1	E2	02
E-03	Eb1-E-03	GC	E	P1	E3	03
E-04	Eb1-E-04	GC	E	P1	E4	04
E-05	Eb1-E-05	GC	E	P1	E5	05
E-06	Eb2-E-06	GC	E	P2	E1	06
E-07	Eb2-E-07	GC	E	P2	E2	07
E-08	Eb2-E-08	GC	E	P2	E3	08
E-09	Eb2-E-09	GC	E	P2	E4	09
E-10	Eb2-E-10	GC	E	P2	E5	10
E-11	Co1-E-11	GC	E	P3	E1	11
E-12	Co1-E-12	GC	E	P3	E2	12
E-13	Co1-E-13	GC	E	P3	E3	13
E-14	Co1-E-14	GC	E	P3	E4	14
E-15	Co1-E-15	GC	E	P3	E5	15
E-16	Ref-E-16	GC	E	P4	E1	16
E-17	Ref-E-17	GC	E	P4	E2	17
E-18	Ref-E-18	GC	E	P4	E3	18
E-19	Ref-E-19	GC	E	P4	E4	19
E-20	Ref-E-20	GC	E	P4	E5	20
E-21	Co2-E-21	GC	E	P5	E1	21
E-22	Co2-E-22	GC	E	P5	E2	22
E-23	Co2-E-23	GC	E	P5	E3	23
E-24	Co2-E-24	GC	E	P5	E4	24
E-25	Co2-E-25	GC	E	P5	E5	25
E-26	Eb3-E-26	GC	E	P6	E1	
E-27	Eb3-E-27	GC	E	P6	E2	
E-28	Eb3-E-28	GC	E	P6	E3	
E-29	Eb3-E-29	GC	E	P6	E4	
E-30	Eb3-E-30	GC	E	P6	E5	

Board Type:

PC – Power Carrier

MC – Memory Carrier

GC – Generic Carrier

6.6 Carrier Boards

The electronic parts are mounted in three different carrier boards: Power Carrier; Memory Carrier; Generic Carrier.

6.6.1 Power Carrier board

The Power Carrier board accommodates 5 samples of component A (STRH100N10 - Power MOSFET). The component bodies sit on a 5 cm x 5 cm area, the irradiation area where the irradiation level is to be made homogeneous. Each sample is connected to a 3-pin connector. In Figure 6-1, the five power carrier boards are shown assembled.

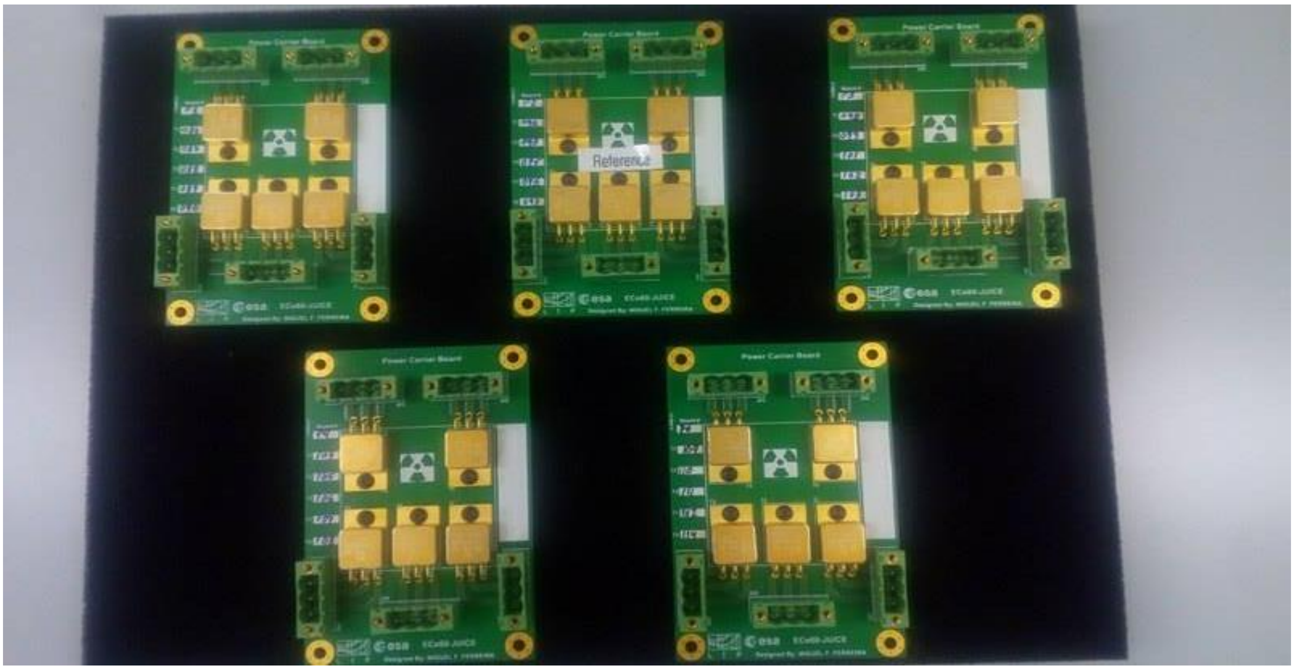


Figure 6-1: Power Carrier Board

6.6.2 Memory Carrier Board

The Memory Carrier board accommodates 5 samples of component B (MT29F32G08ABAAAWP-ITZ – NAND-FLASH memory). The component bodies sit on a 5 cm x 5 cm area, the irradiation area where the irradiation level is to be made homogeneous. The memory I/Os are connected to HSMC connectors. Power supply can be provided by the HSMC for regular testing; from individual connectors for current supply measurements; from a global connector for irradiation tests. The source for each component can be selected individually by means of a jumper. In Figure 6-2 five memory carrier boards are shown (connectors are on the bottom side).

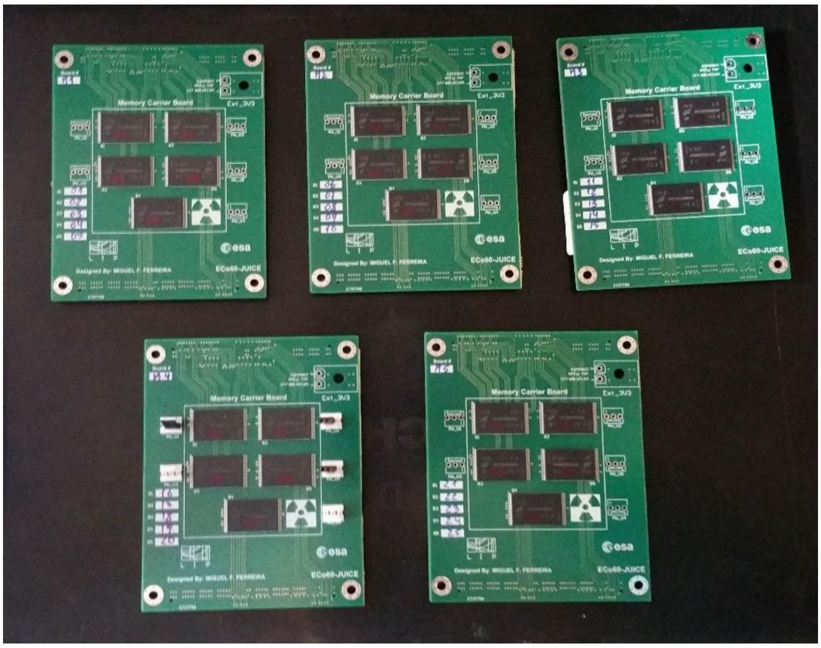


Figure 6-2: Memory Carrier Boards

6.6.3 Generic Carrier board

The Generic Carrier board accommodates 5 samples of component C (2N2222 - transistor), 5 samples of component D (LM124 - OpAmps) and 5 samples of component E (LM4050 – shunt regulators). The component bodies sit on a 5cm x 5 cm area, the irradiation area where the irradiation level is to be made homogeneous. The pins of all LM124 are routed to one connector. The pins of LM124 and LM4050 are routed to another connector (independently). In Figure 6-3 five generic carrier boards are shown (connectors are on the bottom side).

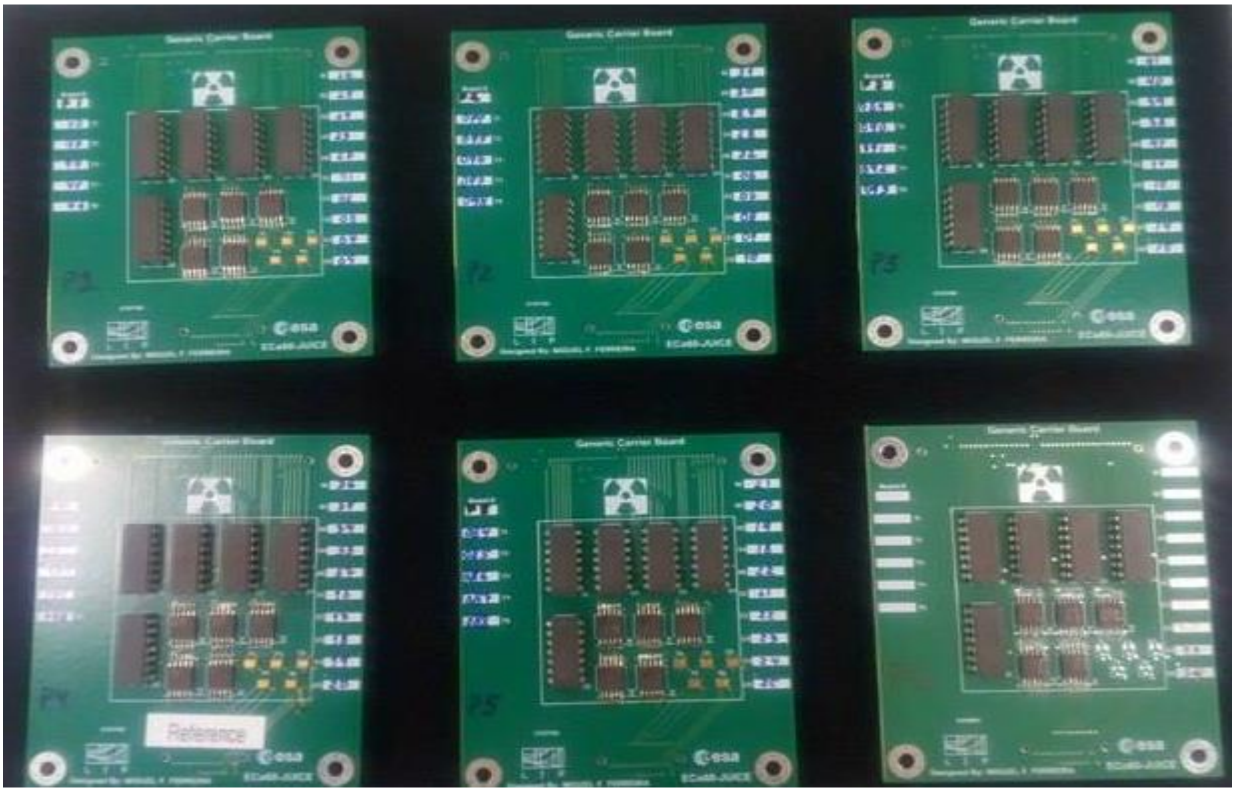


Figure 6-3: Generic Carrier boards.

7 Measuring Protocol

Irradiated boards were measured before the first irradiation and between irradiations as well as afterwards according to the annealing plan. Reference boards were measured at several points for comparison with the irradiated samples.

Each component is measured independently.

7.1 Component A – STRH100N10

Every serialized MOSFET was tested with the following procedure:

- Loop on all units:
    - Input cable introduced in the corresponding slot;
    - Run script MOSFET.tsp:
        - Sets path from SMUs to MOSFET;
        - Loop on all measurements:
            - Define measurement parameters;
            - Measure 10x (averaged);
            - Record parameters and measurement values;
            - Average the results over the 10 measurements;

7.2 Component B – Memory

Every serialized memory was tested and initialized. The test procedure was as follows:

- The 16 copies of the Unique ID of the memory is read, checked and saved on the output file;
- All partitions are erased;
- The test patterns are written in the partitions;
- The test patterns are read and checked;

In every operation the response of the memory is checked for success. If an error occurs the control state machine and the memory are reset and the operation is retried. Such retry is done three times after which an error in the operation is assumed. Also, the test pattern read in the final step is also checked to the assigned test pattern to the partition being read. If an error is detected it is written on the output file with its location. Bad blocks are still read.

A log file is written with greater level of information about the operations made, including information about retrials.

7.3 Component C – 2N2222

Every serialized BJT was tested with the following procedure:

- Input corresponding board to switch board
- Run script BJT_AND_SHUNT.tsp:
  - Loop on all components:
    - Sets path from SMUs to BJT
    - Input the BJT/Shunt connector into the corresponding position
    - Loop on all measurements (all but hFe):
      - Define measurement parameters
      - Measure 10x (averaged)
      - Record parameters and measurement values
- Connect cable with 0.511kΩ resistance to the BJT base;
- Run script hFe.tsp:
  - Loop on all components:
    - Sets path from SMUs to BJT;
    - Input the BJT/Shunt connector into the corresponding position;
    - Define measurement parameters;
    - Measure full range;
    - Record parameters and measurement values

The tests had to be divided into two steps since for the last one a resistance was required to stabilize the circuit. This adds up to the measuring time since the process is not automatized though the difference is negligible since the first set of tests is very fast.

After each BJT, a Shunt is also tested since each connector sets the path to a BJT/Shunt pair diminishing the number of iterations with the connector

7.4 Component D – LM124

Every serialized AMPOP was tested. The procedure was divided into two stages:

- Input corresponding board to switch board

1st stage

- Runscript AMPOPS.tsp;
- Input AMPOP connector into the corresponding position;
    - Loop on all measurements:
        - Sets correct path from SMU to AMPOP to each specific measurement;
        - Define measurement parameters;
        - Measure;
        - Record parameters and measurement values;

2nd stage

- Set supply voltage to +30/+0;
- Connect a Pulse Generator (square wave 5 to 15V, 1kHz) and Oscilloscope to the switch board;
- Loop on all AMPOP chips:
    - Input AMPOP connector into the corresponding position;
    - Run slewrate.py on the computer:
        - Loop on the all AMPOPs in the chip:
            - Set path to the Slew Rate circuit;
            - Set Oscilloscope Mode to Rise;
            - Measure Δt between 7.5 and 12.5 (SR+) with oscilloscope;
            - Record measurement values;
            - Set Oscilloscope Mode to Fall;
            - Measure Δt between 12.5 and 7.5 (SR-) with oscilloscope;
            - Record measurement values;

7.5 Component E – LM4050

Every serialized Shunt was tested after its correspondent BJT pair since the connector position serves two at each time. The procedure is similar to the one described for the BJT_AND_SHUNT.tsp script with circuit path going to the Shunt instead of the BJT.

8 Irradiation Test Results

Results for each component and variable of interest are analysed individually. Since we are only interested in the comparing data between different irradiation conditions, a chart with the variation along irradiation steps for each campaign is shown for each case (Figure 8-2 to Figure 8-37). For reference, the absolute values for each campaign are also presented alongside the first chart. Figure 8-1 offers comments on an example taken from the Shunt Voltage Reference results to be used as guideline to read the other charts. All error bars correspond to one standard deviation.

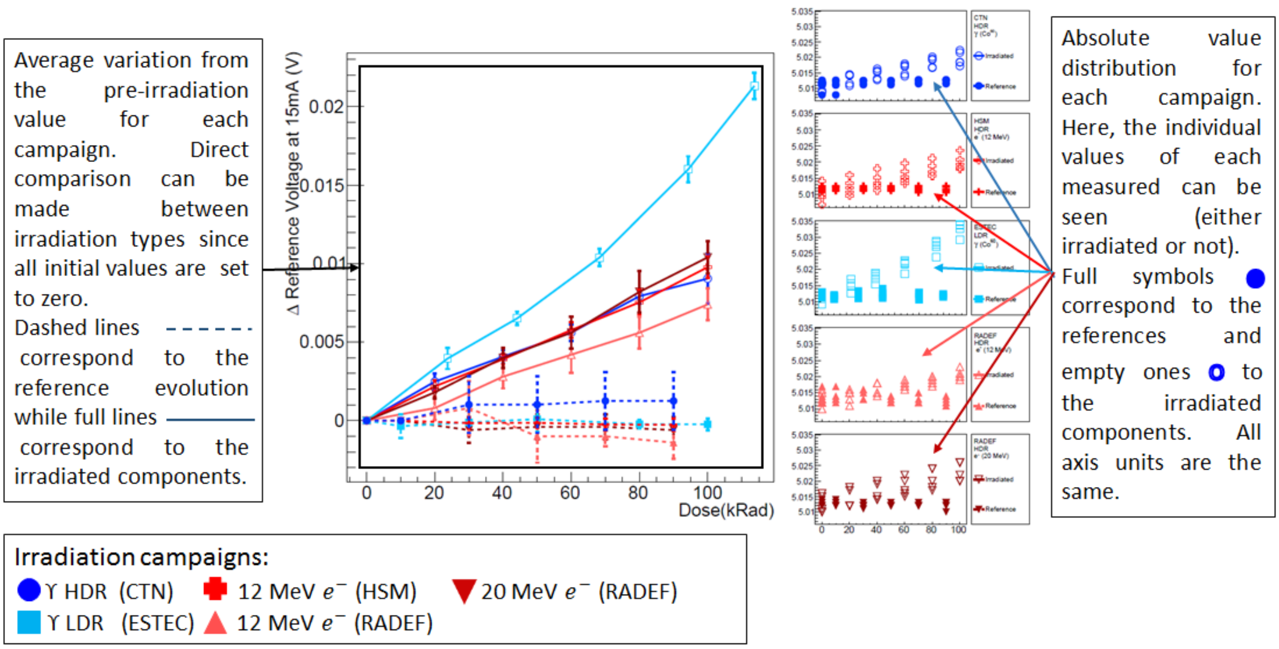


Figure 8-1 Example to be used as guideline to analyse the results.

8.1 Component A – STRH100N10

Results for each component and variable of interest are analysed individually. Since we are only interested in the comparing data between different irradiation conditions, a chart with the variation along irradiation steps for each campaign is shown for each case (Figure 8-2 to Figure 8-37). For reference, the absolute values for each campaign are also presented alongside the first chart. All error bars correspond to one standard deviation (1 RMS assuming a Normal/Gaussian distribution). Component A was included in campaign Eb2.

Table 8-1 Component A parameter irradiation status.

Characteristics	Test Conditions	Status
Gate-to-Source Leakage Current 1	VGS=20V, VDS=0V	No apparent degradation
Gate-to-Source Leakage Current 2	VGS=-20V, VDS=0V	No apparent degradation
Drain Current	VDS=40V, VGS=0V	Radiation degradation Similar for electrons and gammas
Gate-to-Source Threshold Voltage	VDS≥VGS, ID=1mA	Radiation degradation Similar for electrons and gammas
Static Drain-to-Source On Resistance	VGS=12V, ID=24A	No apparent degradation
Source-to-Drain Diode Forward Voltage	VGS=0V, ISD=48A	No apparent degradation

8.1.1 Gate-to-Source Leakage Current 1

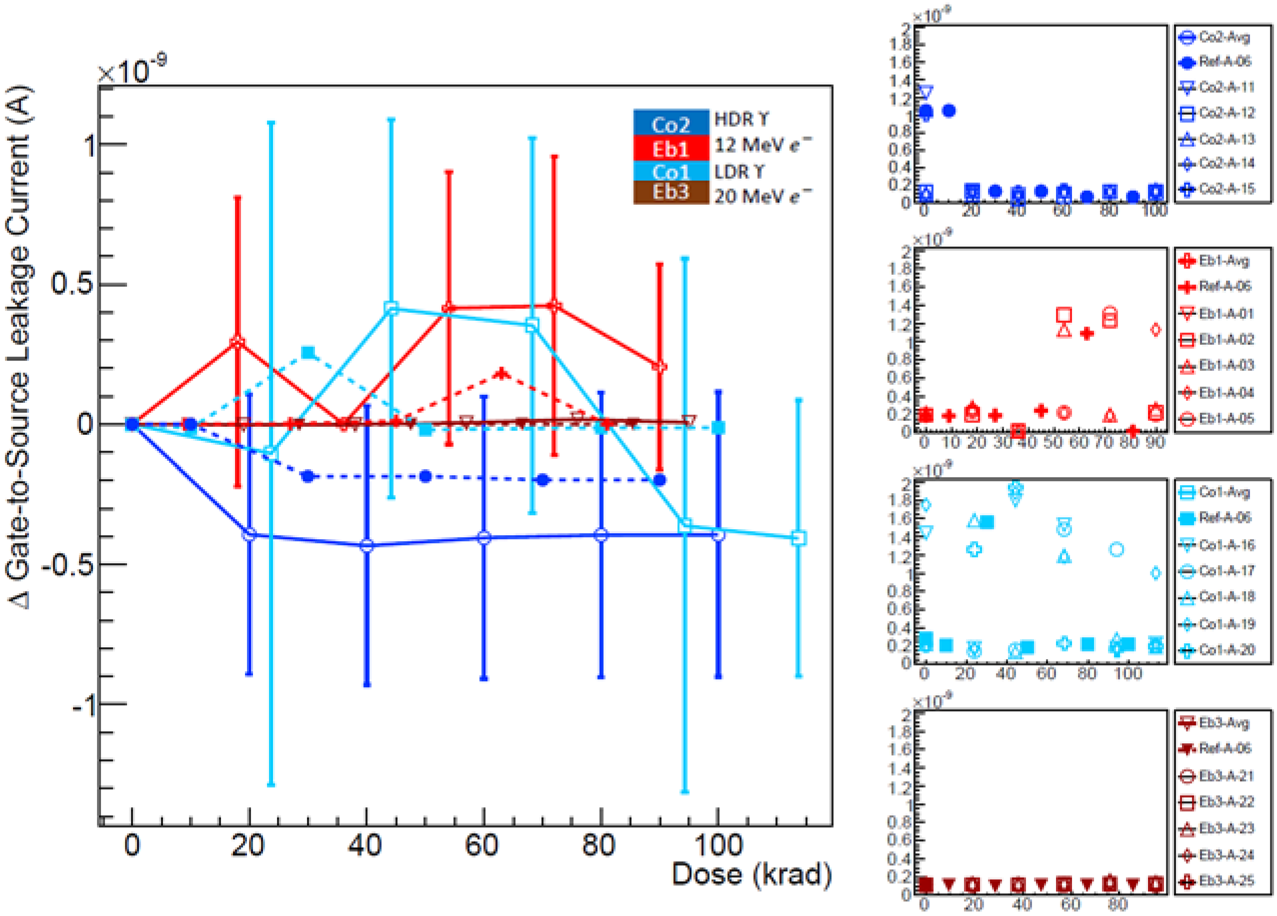


Figure 8-2 Gate-to-Source Leakage Current 1 variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

8.1.2 Gate-to-Source Leakage Current 2

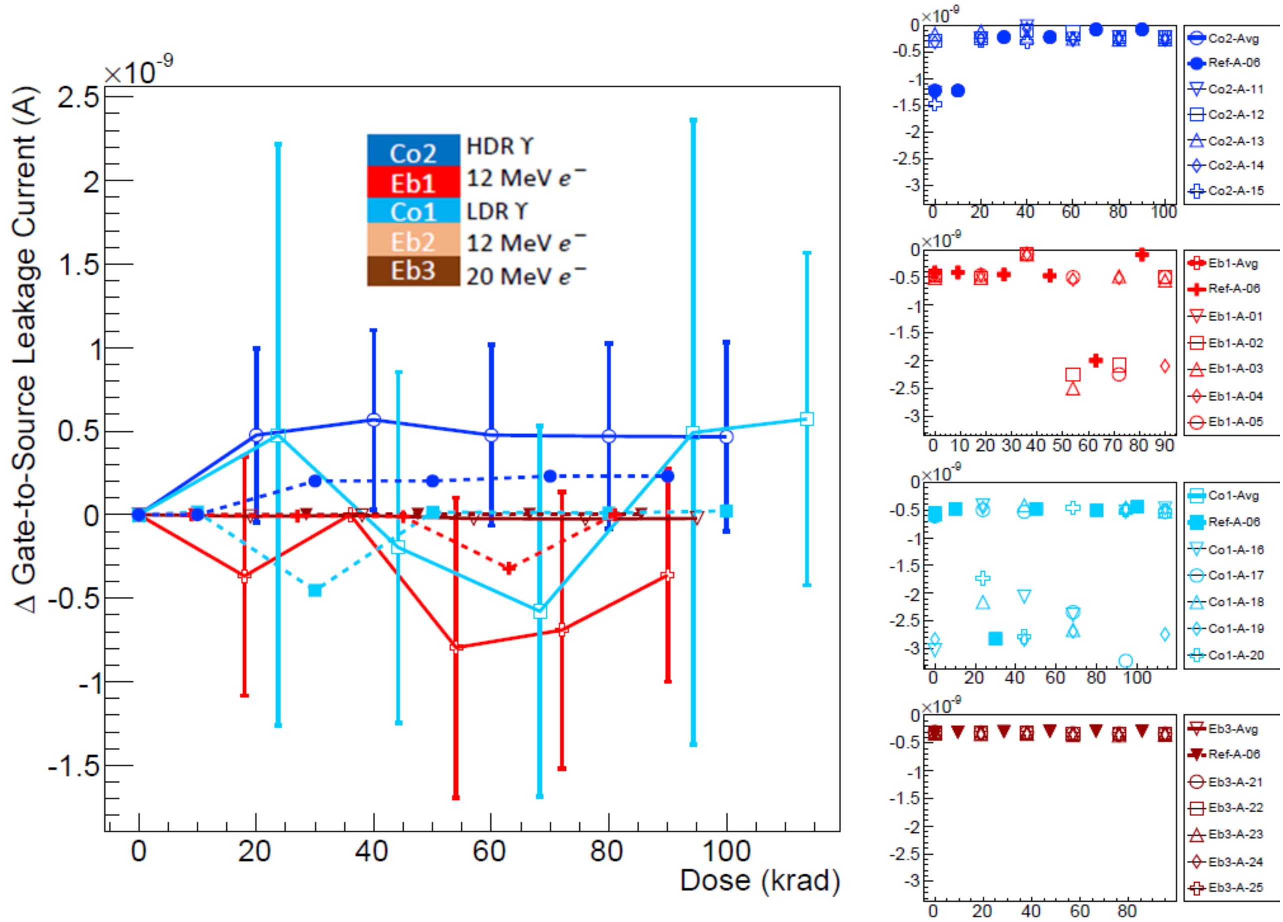


Figure 8-3 Gate-to-Source Leakage Current 2 variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

8.1.3 Drain Current

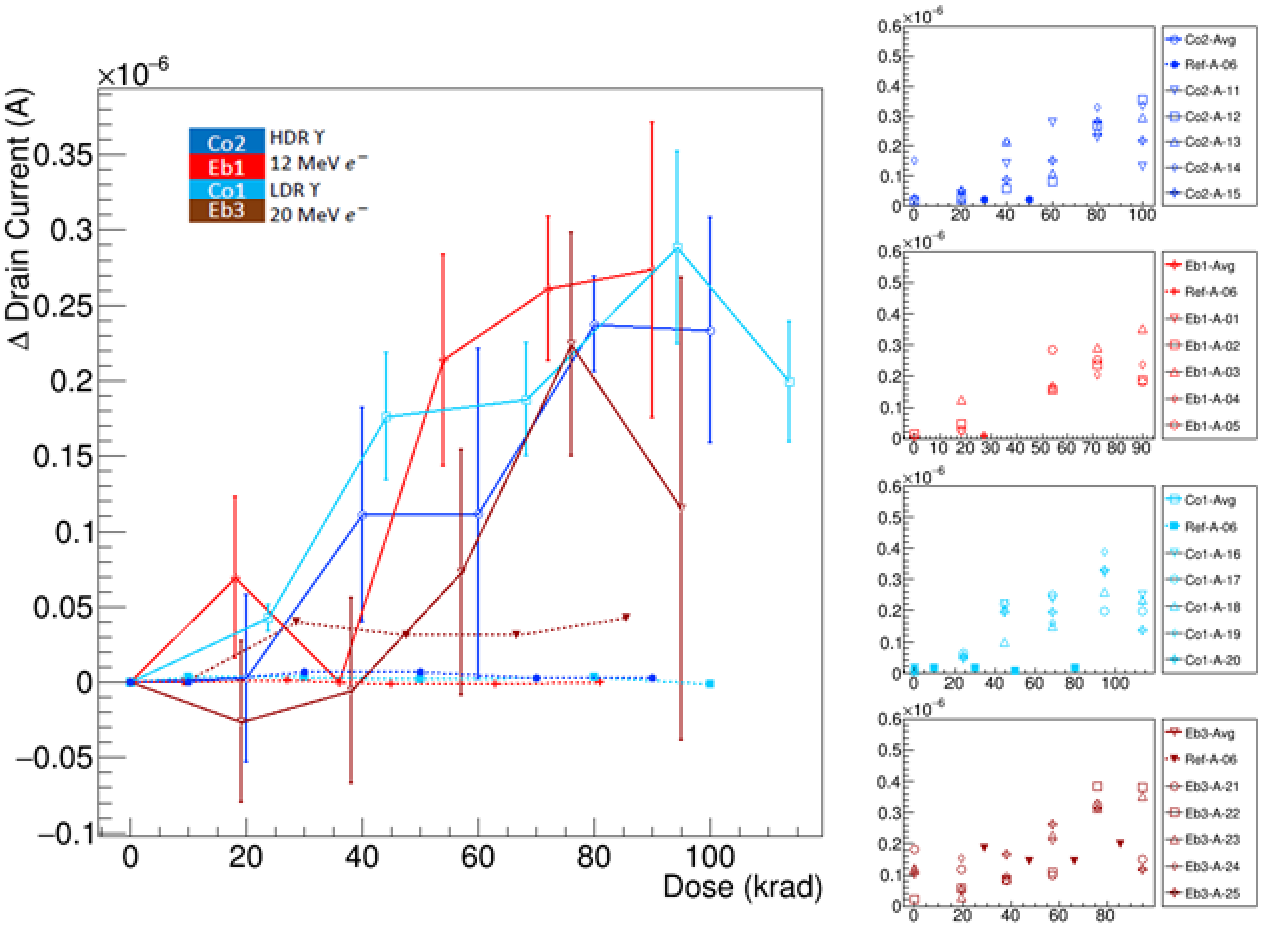


Figure 8-4 Drain Current variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

8.1.4 Gate-to-Source Threshold Voltage

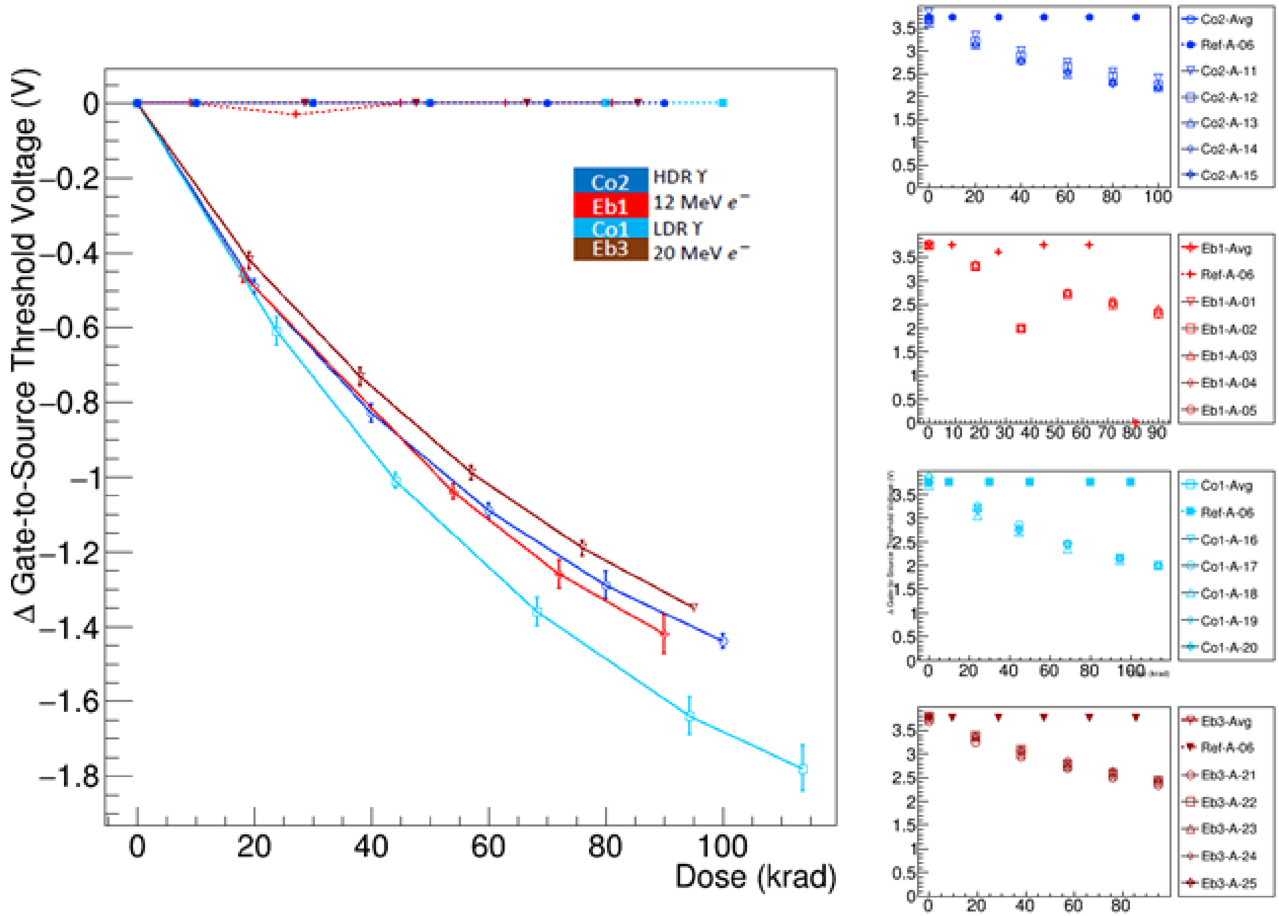


Figure 8-5 Gate-to-Source Threshold Voltage variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

8.1.5 Static Drain-to-Source On Resistance

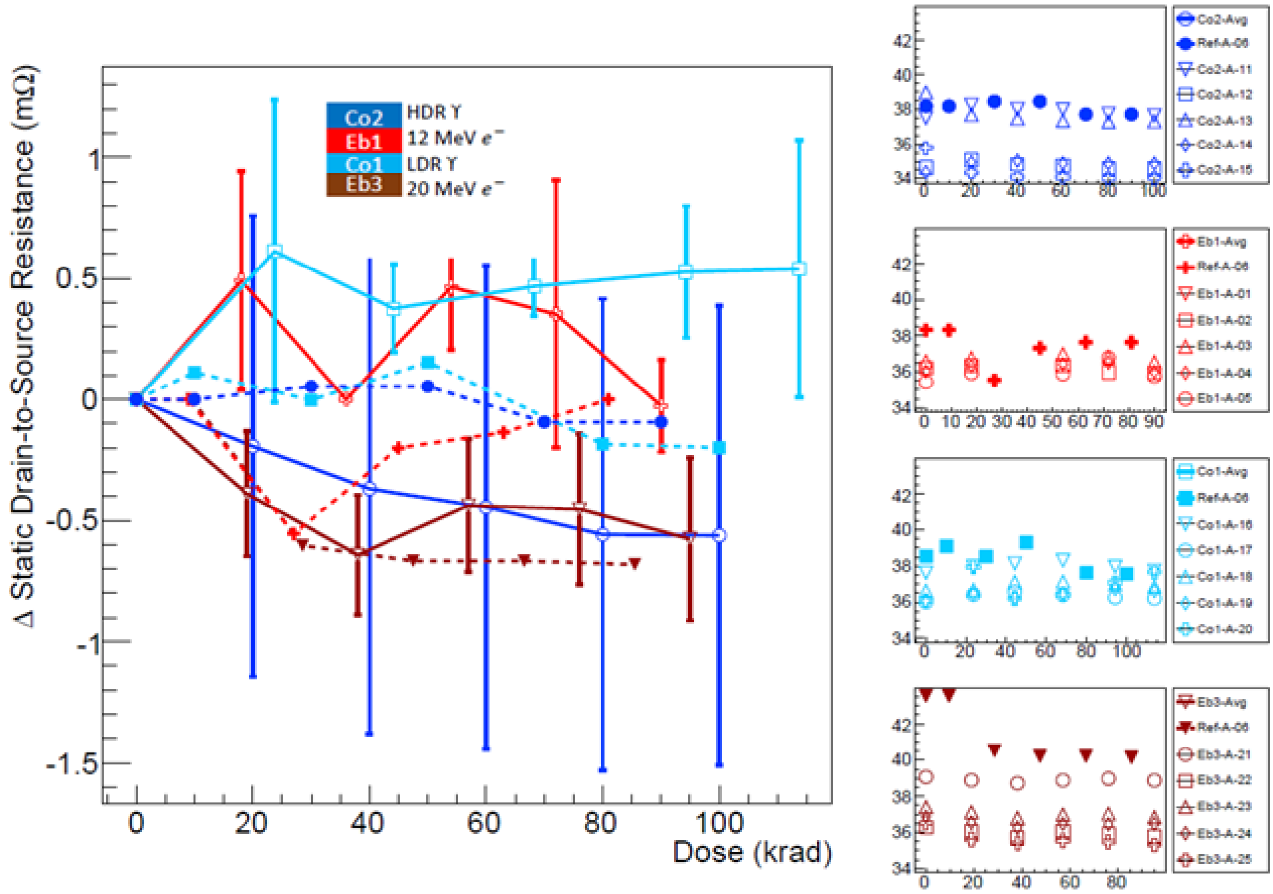


Figure 8-6 Static Drain-to-Source On Resistance variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

8.1.6 Source-to-Drain Diode Forward Voltage

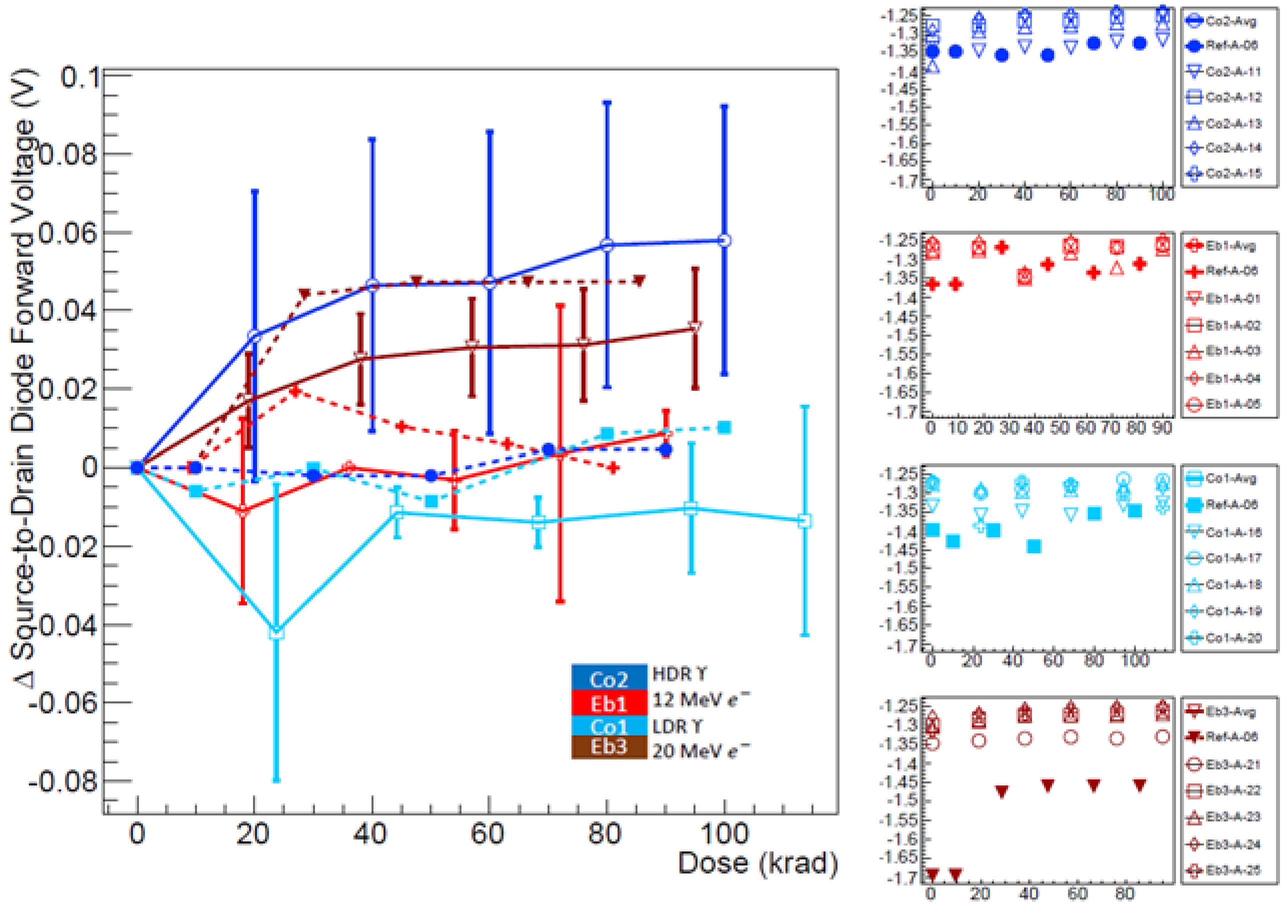


Figure 8-7 Source-to-Drain Diode Forward Voltage variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

8.2 Component B – Memory

Results of the functional and power supply tests measured (absolute values not drift) for component B are shown in Figure 8-8 to Figure 8-13. Partitions #1 and #5 are not shown since their results and null (no errors were found due to the nature of the tests (bits only flip from 0 to 1). All functional tests show enhanced degradation for gamma irradiations. All HDR gamma irradiated memories became unresponsive after two steps (at 40kRad), while memories from other irradiations could sustain their functions up to higher doses. LDR gamma irradiated memories had higher error count than electron irradiated memories and were unresponsive to dose levels below electron irradiated ones. A summary of the results for this component can be found in Table 8-2.

Table 8-2 Component B parameter irradiation status

Functional Tests			
Partition #	Pattern	Type of test	Status
0	All ‘0’	Static	Radiation degradation Higher degradation for gammas
1	All ‘1’	Static	No degradation
2	Checkerboard	Static	Radiation degradation Higher degradation for gammas
4	All ‘0’	Dynamic	Radiation degradation Higher degradation for gammas
5	All ‘1’	Dynamic	No degradation
6	Checkerboard	Dynamic	Radiation degradation Higher degradation for gammas
Power Supply tests			
Current		Status	
Idle		Radiation degradation Similar for electrons and gammas	
Active		Radiation degradation Similar for electrons and gammas	

8.2.1 Functional Tests

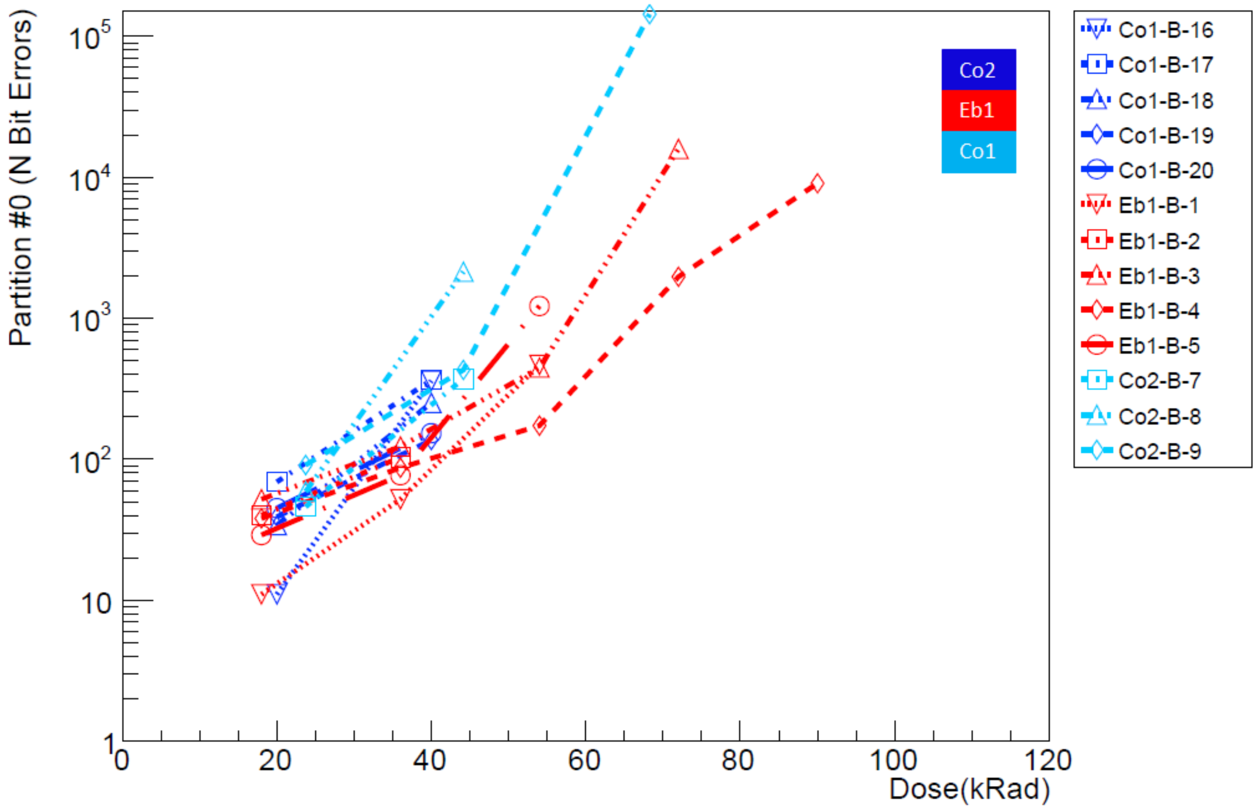


Figure 8-8 Number of bit errors in partition #0. Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign and Teal points to the LDR γ ESTEC campaign.

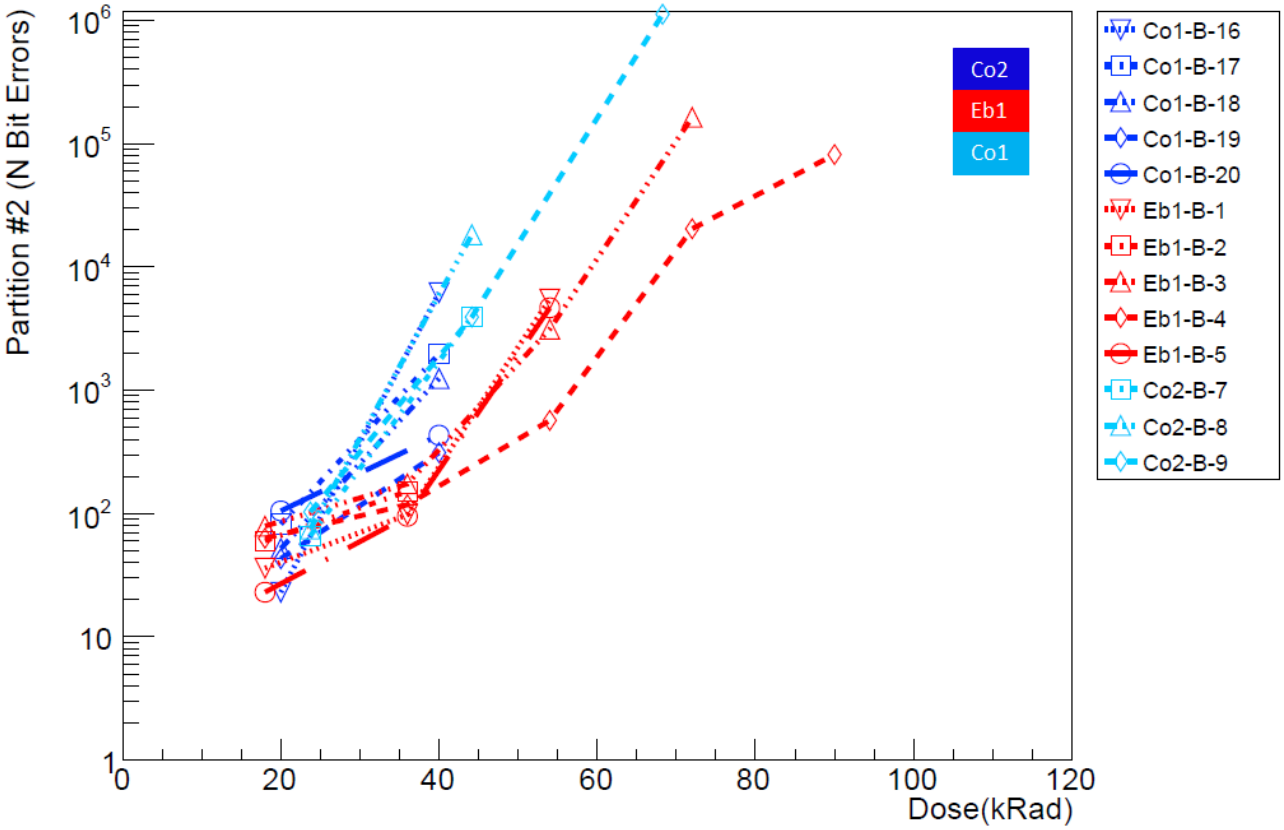


Figure 8-9 Number of bit errors in partition #2. Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^{-} HDR Hospital campaign and Teal points to the LDR γ ESTEC campaign.

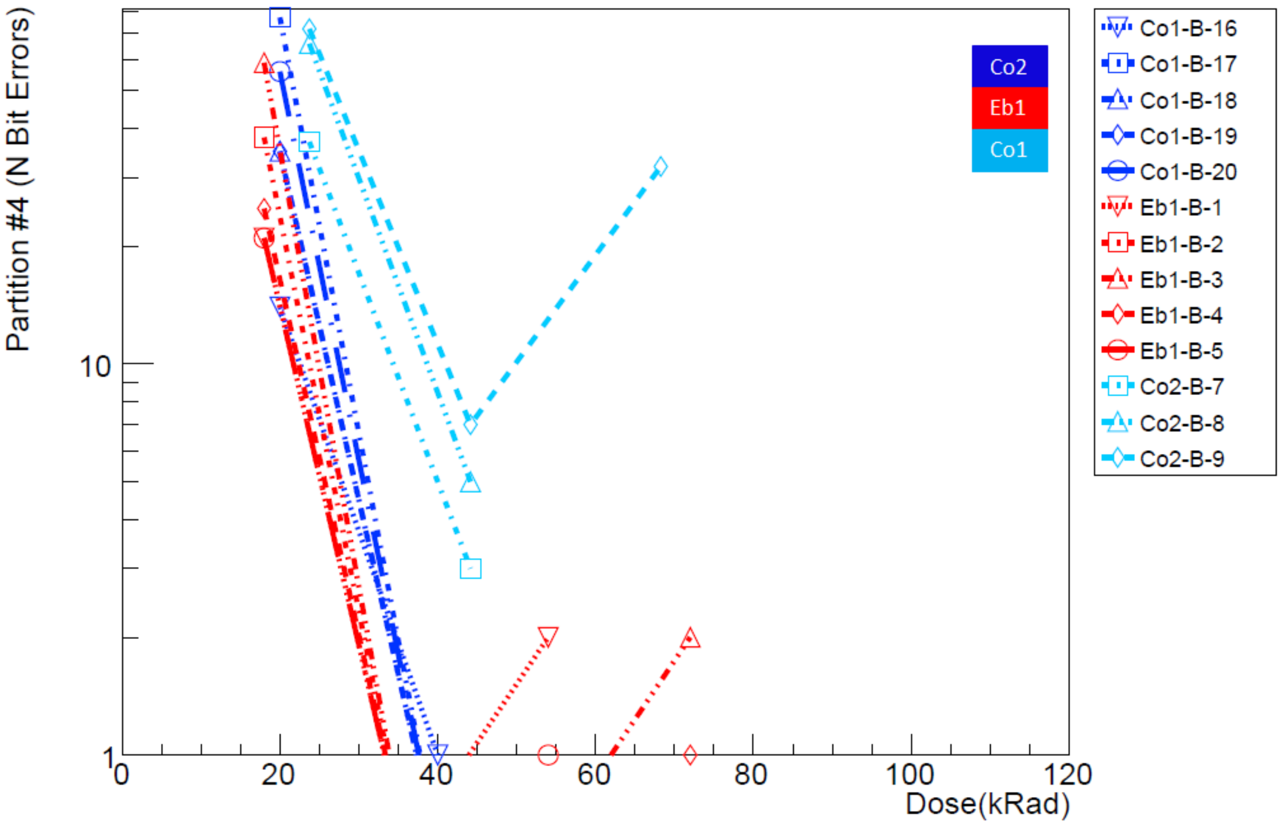


Figure 8-10 Number of bit errors in partition #4. Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign and Teal points to the LDR γ ESTEC campaign.

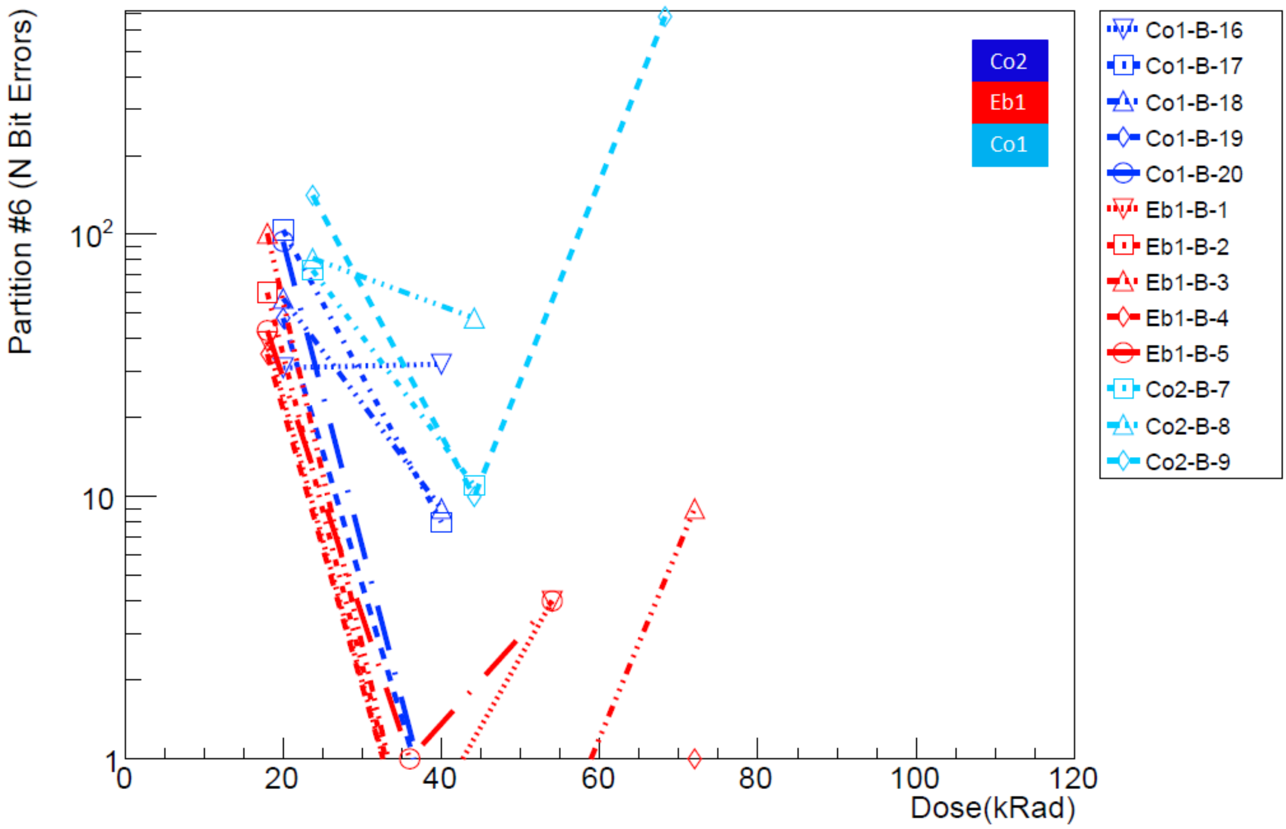


Figure 8-11 Number of bit errors in partition #6. Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign and Teal points to the LDR γ ESTEC campaign.

8.2.2 Power Supply Tests

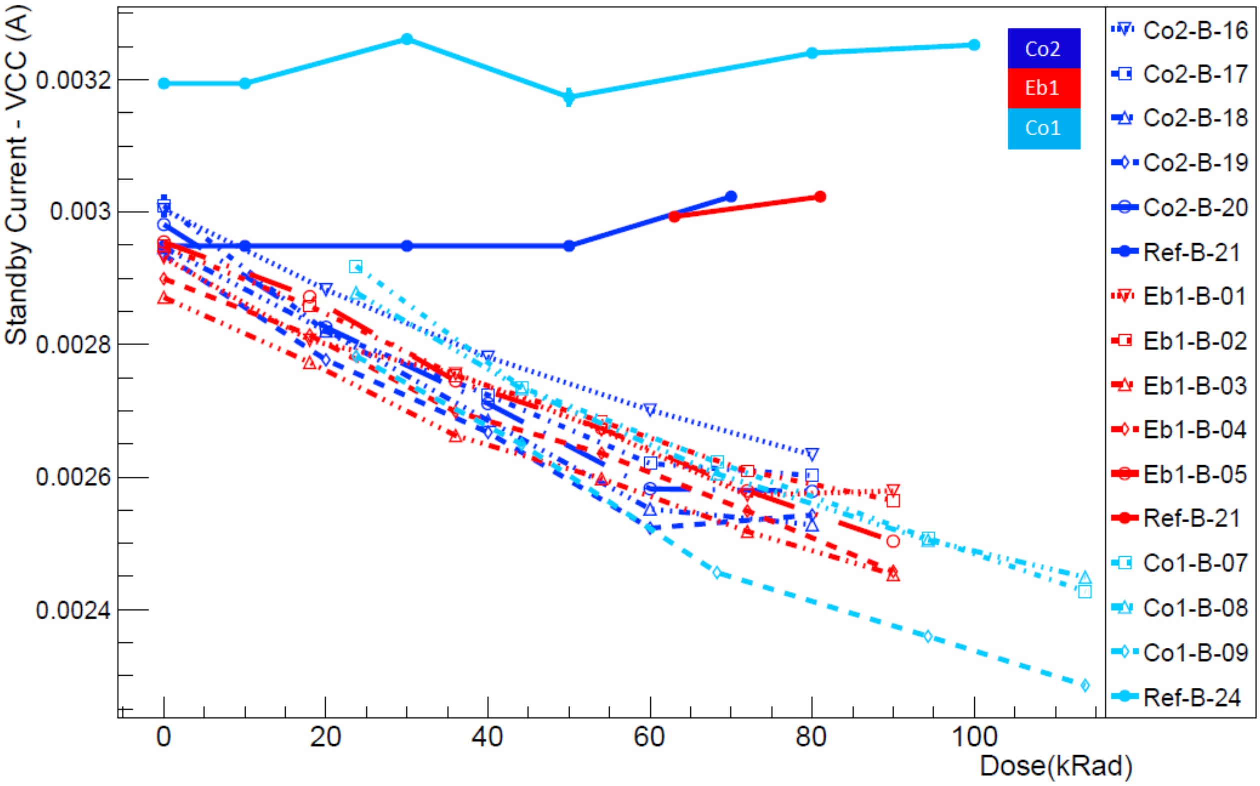


Figure 8-12 Standby current (biased). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign and Teal points to the LDR γ ESTEC campaign.

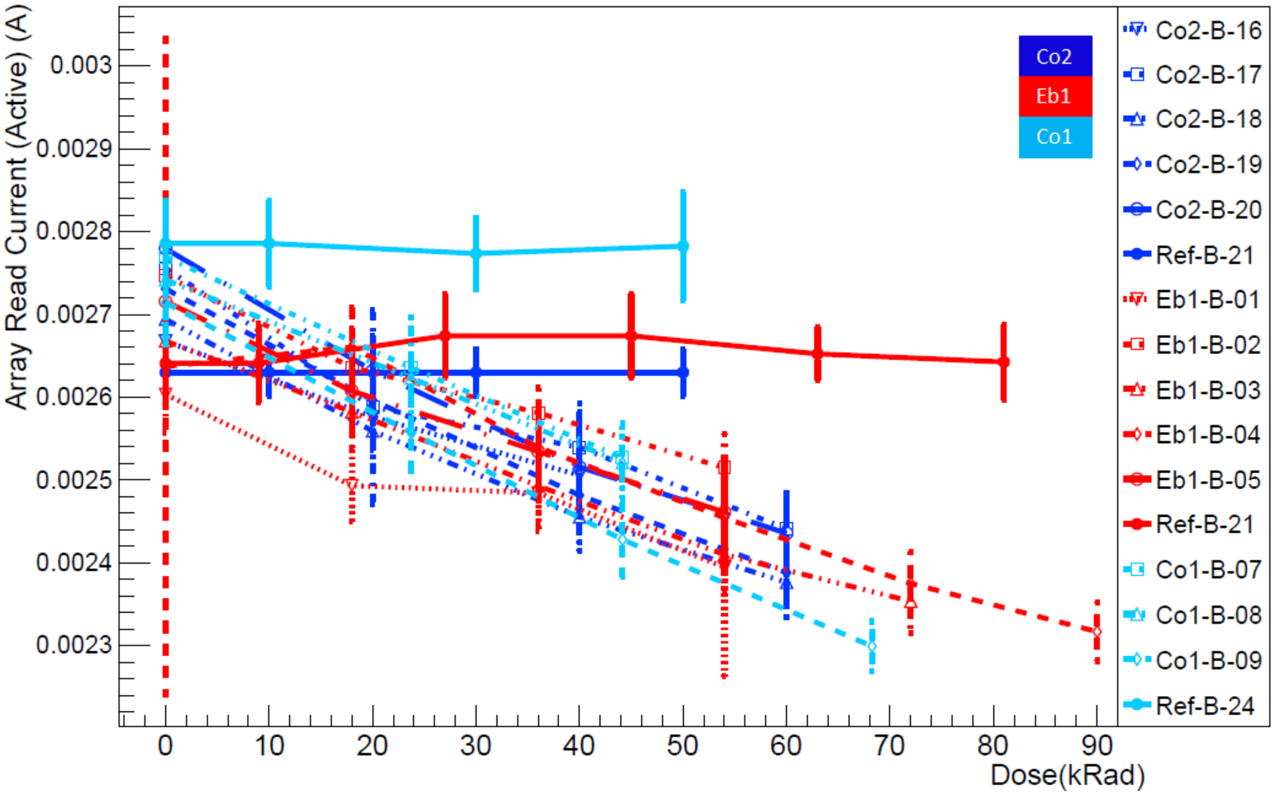


Figure 8-13 Standby current (biased). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign and Teal points to the LDR γ ESTEC campaign.

8.3 Component C – 2N2222

The results for the 8 parameters measured for component C are presented in sections 8.3.1-8.3.8. The Forward-Current Transfer Ratio in all measured regimes shows sensitivity to radiation but a similar behavior between HDR Co60 and electrons, besides ELDRS, which was expected. All other parameters showed no sensitivity to radiation. A summary of the results for this component can be found in Table 8-3.

Collector-Emitter Saturation Voltage in Eb2 (section 8.3.3) large drift after 20 krad is due to a bad first value in one of the two parts measured.

Table 8-3 Component C parameter irradiation status

Characteristics	Test Conditions	Status
Collector-Base Cut-off Current	V_{CB} = 60V	No apparent degradation
Emitter-Base Cutoff Current	V_{EB} = 3V	No apparent degradation
Collector-Emitter Saturation Voltage	I_C = 150mA, I_B = 15mA	No apparent degradation
Base-Emitter Saturation Voltage	I_C = 150mA, I_B = 15mA	No apparent degradation
Forward-Current Transfer Ratio	V_{CE} = 10V, I_C = 100µA	Radiation degradation Similar for electrons and Co60 ELDRS
	V_{CE} = 10V, I_C = 10mA	Radiation degradation Similar for electrons and Co60 ELDRS
	V_{CE} = 10V, I_C = 150mA	Radiation degradation Similar for electrons and Co60 ELDRS
	V_{CE} = 10V, I_C = 500mA	Radiation degradation Similar for electrons and Co60 ELDRS

8.3.1 Collector-Base Cut-Off Current

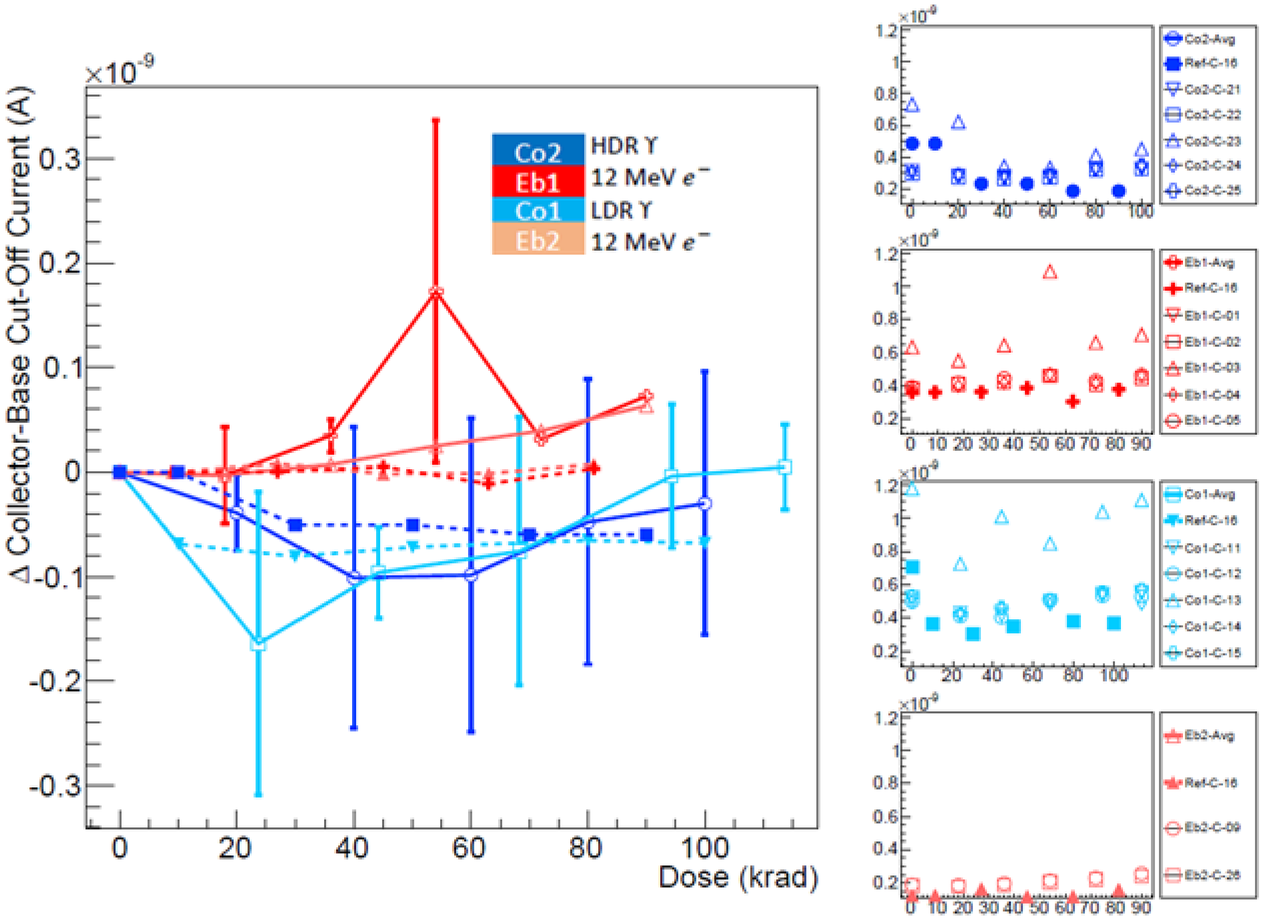


Figure 8-14 Collector-Base Cut-Off Current variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign.

8.3.2 Emitter-Base Cut-Off Current

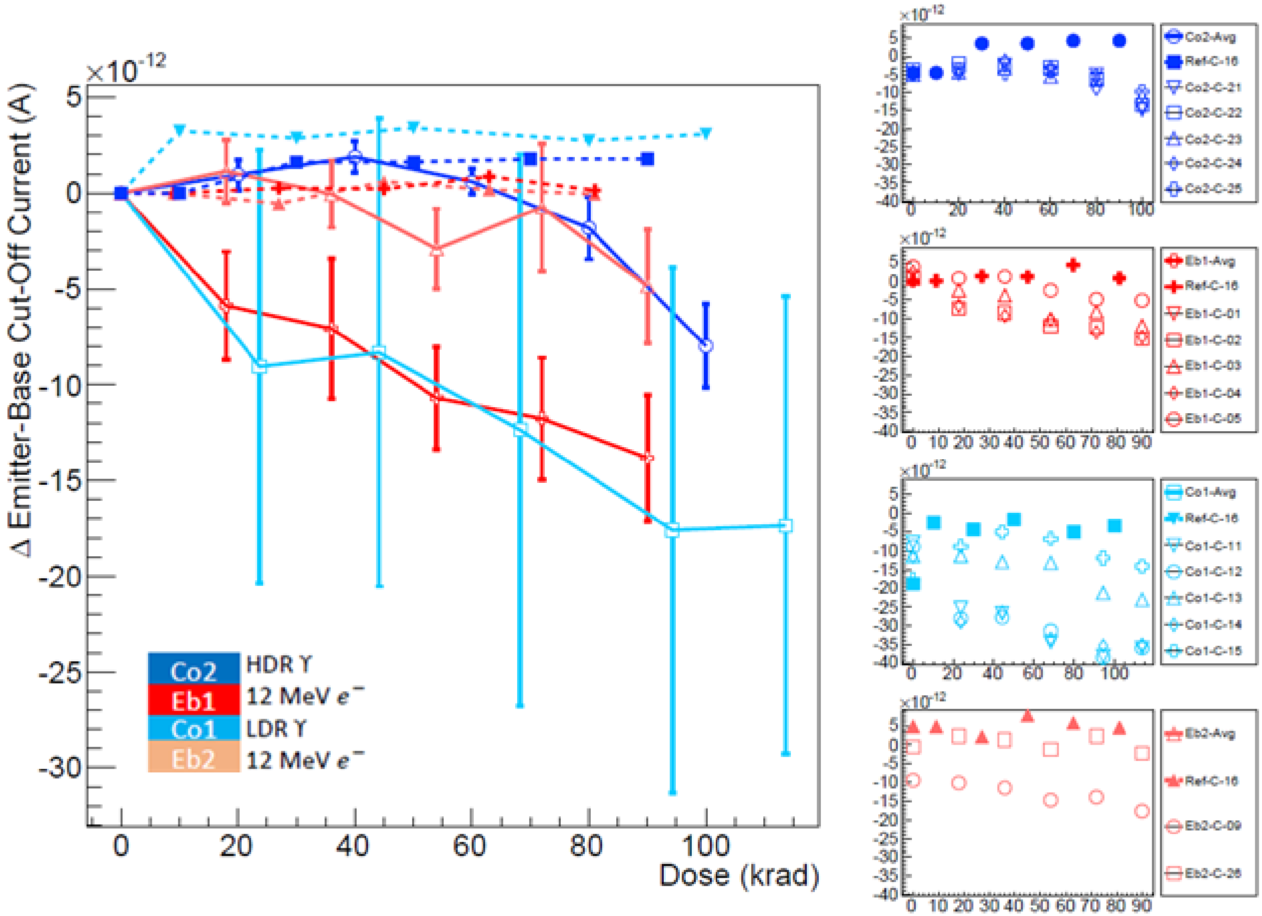


Figure 8-15 Emitter-Base Cut-Off Current variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign.

8.3.3 Collector-Emitter Saturation Voltage

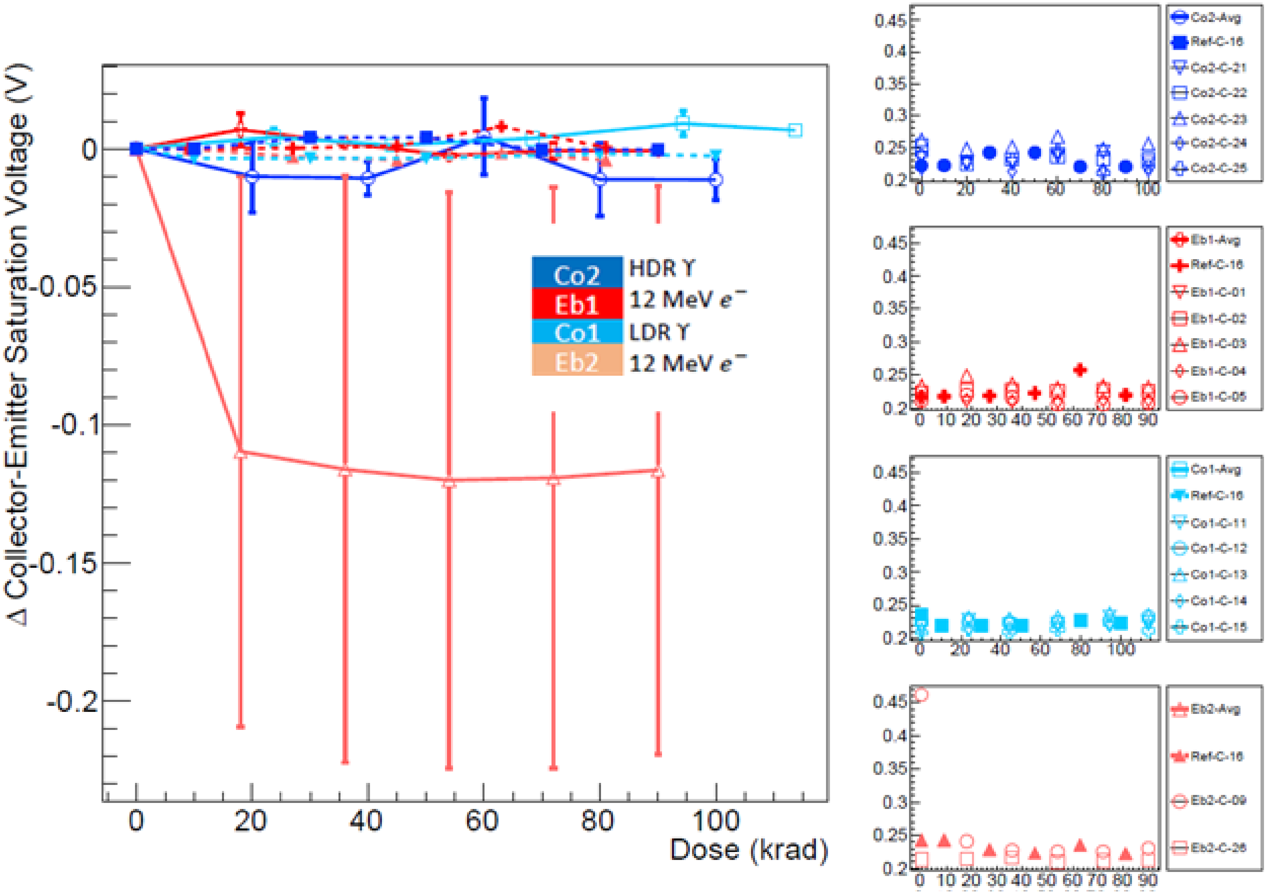


Figure 8-16 Collector-Emitter Saturation Voltage variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign.

8.3.4 Base-Emitter Saturation Voltage

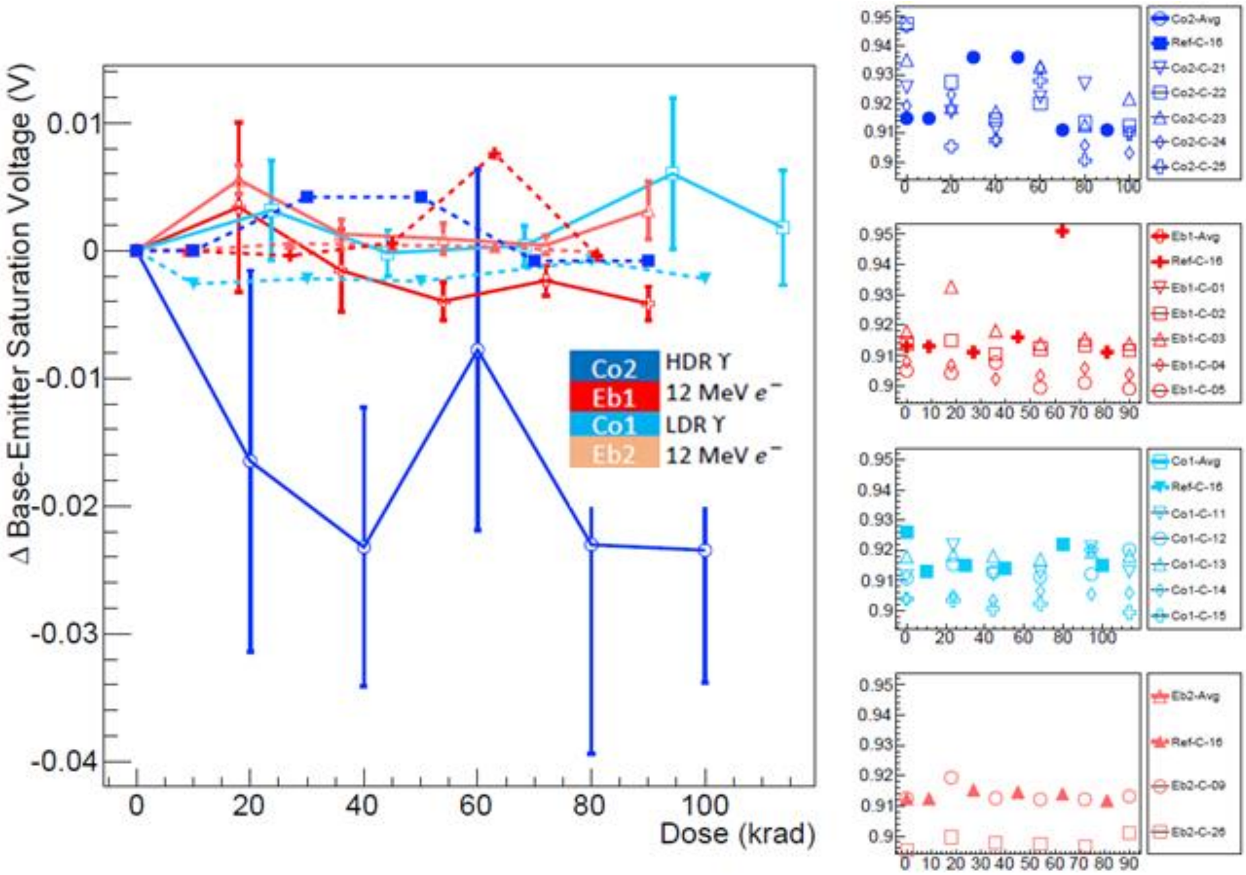


Figure 8-17 Base-Emitter Saturation Voltage variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign.

8.3.5 Forward-Current Transfer Ratio (I_C = 100µA)

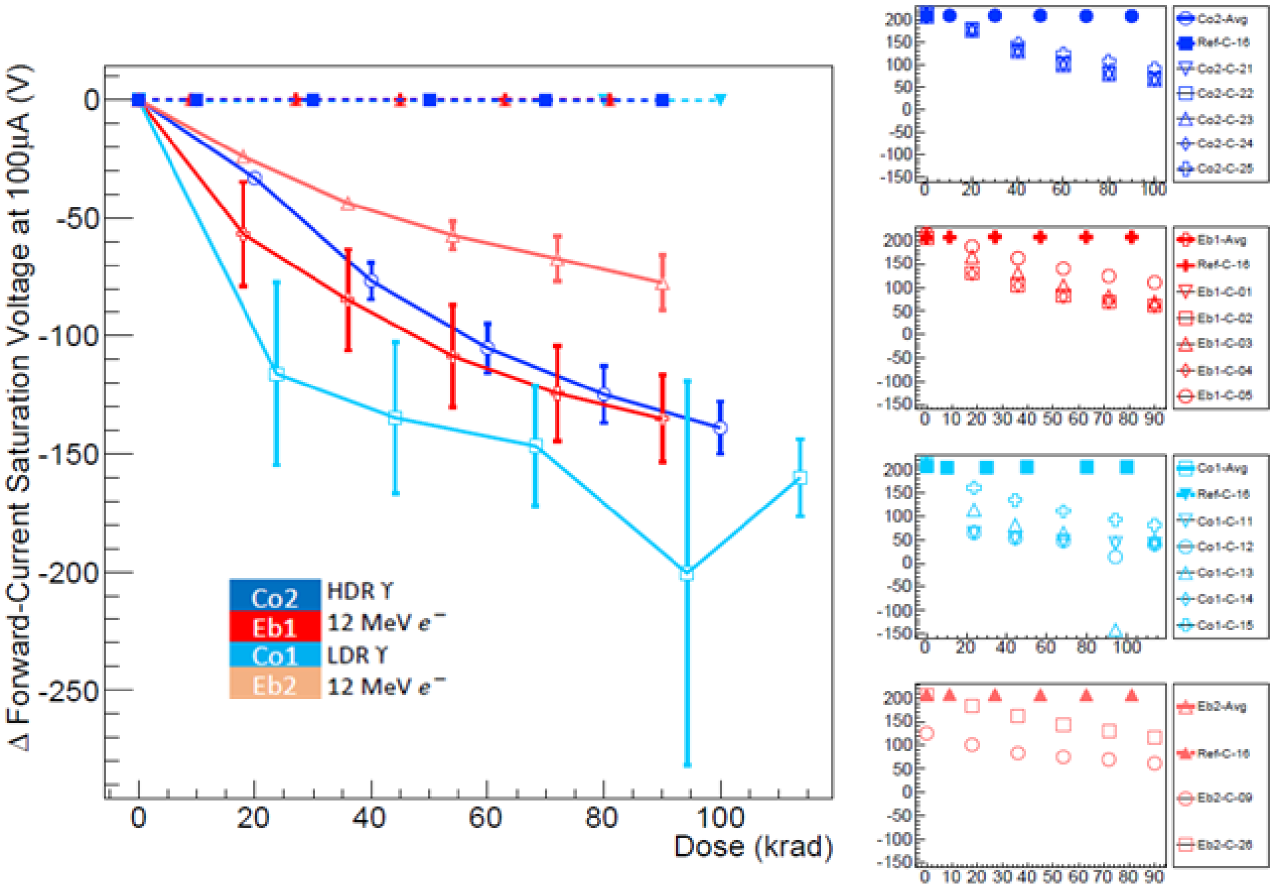


Figure 8-18 Forward-Current Saturation Voltage (Ic=100µA) variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign.

8.3.6 Forward-Current Transfer Ratio (I_C = 10mA)

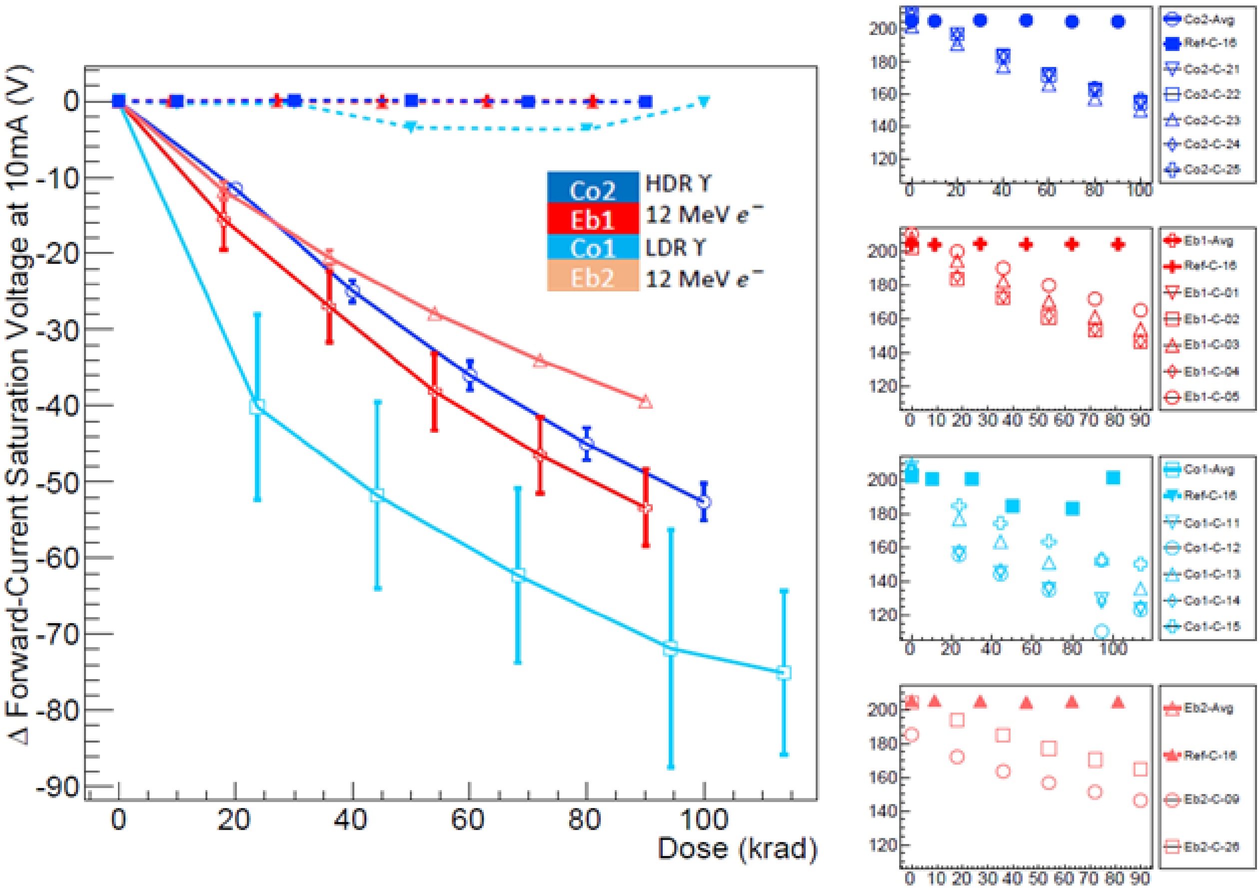


Figure 8-19 Forward-Current Saturation Voltage (Ic=10mA) variation (left side) and absolute values (right side). Blue points correspond to the HDR y CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR y ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign.

8.3.7 Forward-Current Transfer Ratio (I_C = 150mA)

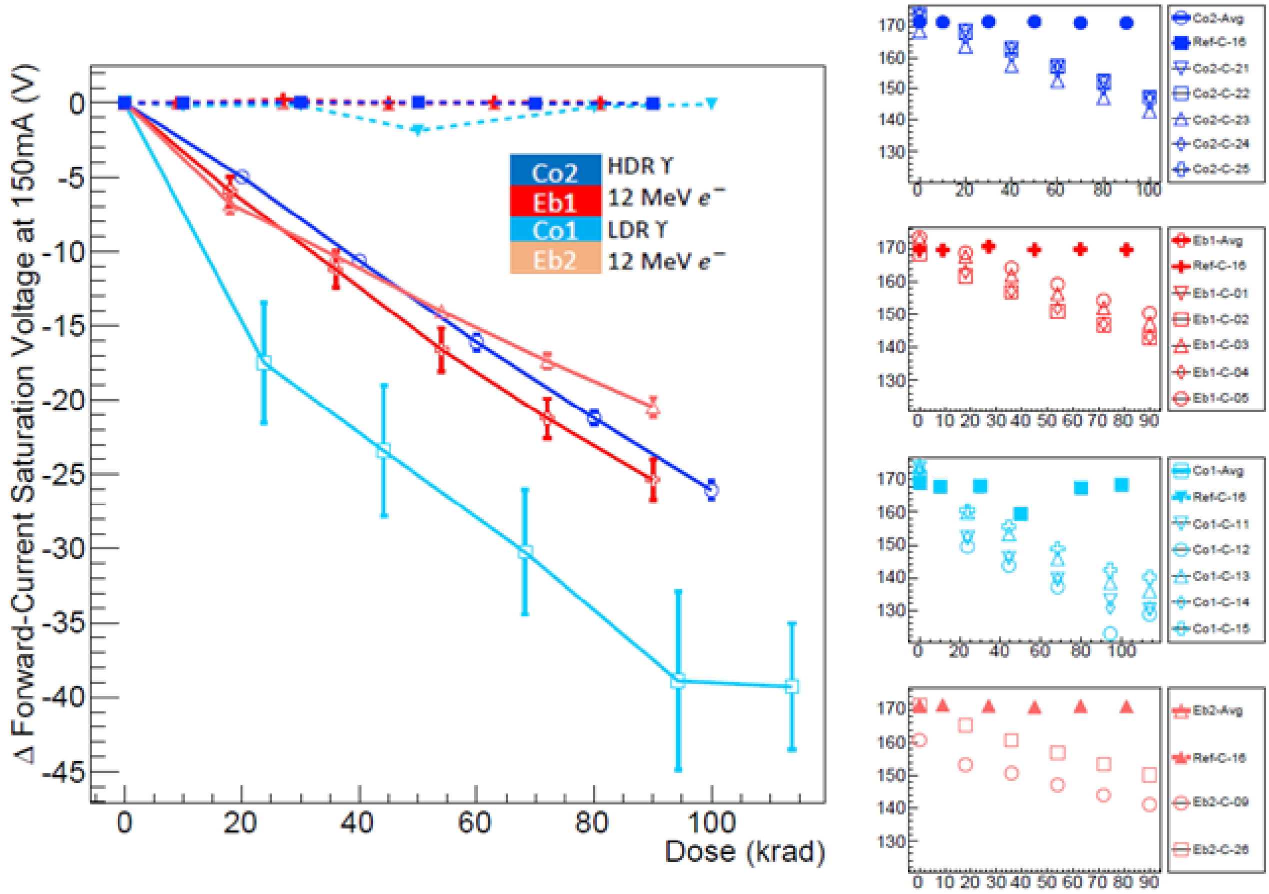


Figure 8-20 Forward-Current Saturation Voltage (Ic=150mA) variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign.

8.3.8 Forward-Current Transfer Ratio (I_C = 500mA)

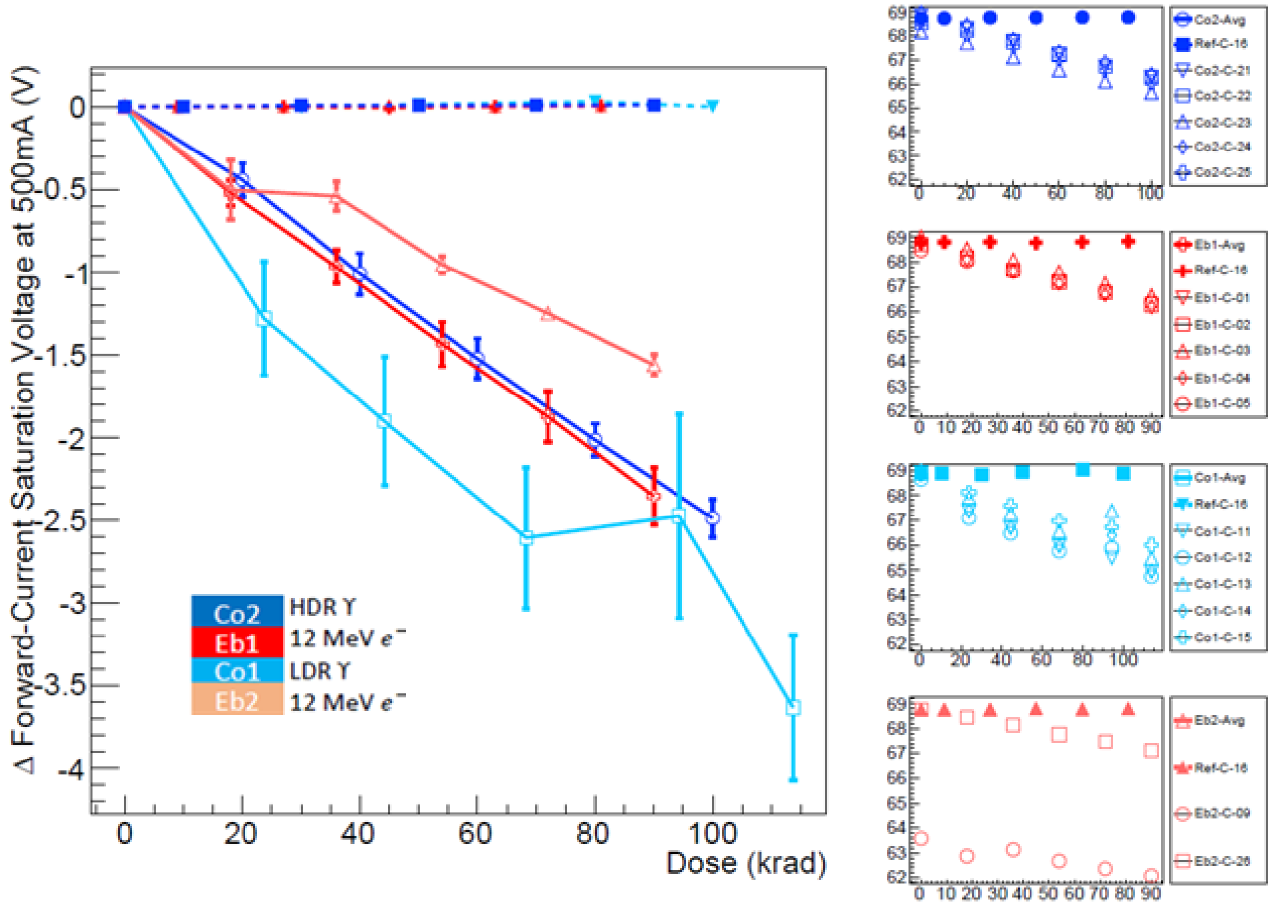


Figure 8-21 Forward-Current Saturation Voltage (Ic=500mA) variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign.

8.4 Component D – LM124

The results of the 11 parameters measured for component D are presented in sections 8.4.1-8.4.11. 6 parameters (Input Bias Current +, Input Bias Current –, Input Offset Voltage, Common Mode Rejection Ratio (CMRR), Power Supply Rejection Ratio (PSRR) and Slew Rate +) show sensitivity to radiation. While the Input Bias Current +, the Input Bias Current – and Common Mode Rejection Ratio (CMRR) show enhanced sensitivity to electron sources, all other parameters have similar or no sensitivity to radiation. According to [AD4] this behavior can be explained due to displacement damage by electrons, since the parameters with highest degradation observed during irradiations with electrons are the ones expected to be sensitive to TNID, unlike those for which no difference was observed in the tests (see section 10 for a more detailed discussion). A summary of the results for this component type can be found in Table 8-4.

Table 8-4 Component D parameter irradiation status

Characteristics	Test Conditions	Status
Power Supply Current	Vcc+ = 30V, Vcc- = Gnd	No apparent degradation
Input Bias Current	Vcc+ = 30V, Vcc- = Gnd, Vcm = +15V	Radiation degradation Higher degradation for electrons
Input Offset Current	Vcc+ = 30V, Vcc- = Gnd, Vcm = +15V	No apparent degradation
Input Offset Voltage	Vcc+ = 30V, Vcc- = Gnd, Vcm = 15V	Radiation degradation Similar for electrons and Co60
Common Mode Rejection Ratio	Vcc+=30V, Vcc- = Gnd, Vcm=-15V Vcc+=2V, Vcc- =-28, Vcm=-13V	Radiation degradation Higher degradation for electrons
Power Supply Rejection Ratio	Vcc- = Gnd, Vcm = +1.4V, 5V ≤ Vcc ≤ 30V	Radiation degradation Similar for electrons and Co60
Voltage Gain	Vcc+ = 30V, Vcc- = Gnd, 1V ≤ Vo ≤ 26V, Rl = 10K Ohms	No apparent degradation
Slew Rate: Rise	VCC+ = 30V, VCC- = Gnd	No apparent degradation
Slew Rate: Fall	VCC+ = 30V, VCC- = Gnd	No apparent degradation

Maximum Output Voltage Swing	VCC+ = 30V, VCC- = Gnd, VO = +30V, RL = 10KΩ	Radiation degradation Similar for electrons and Co60

8.4.1 Power Supply Current

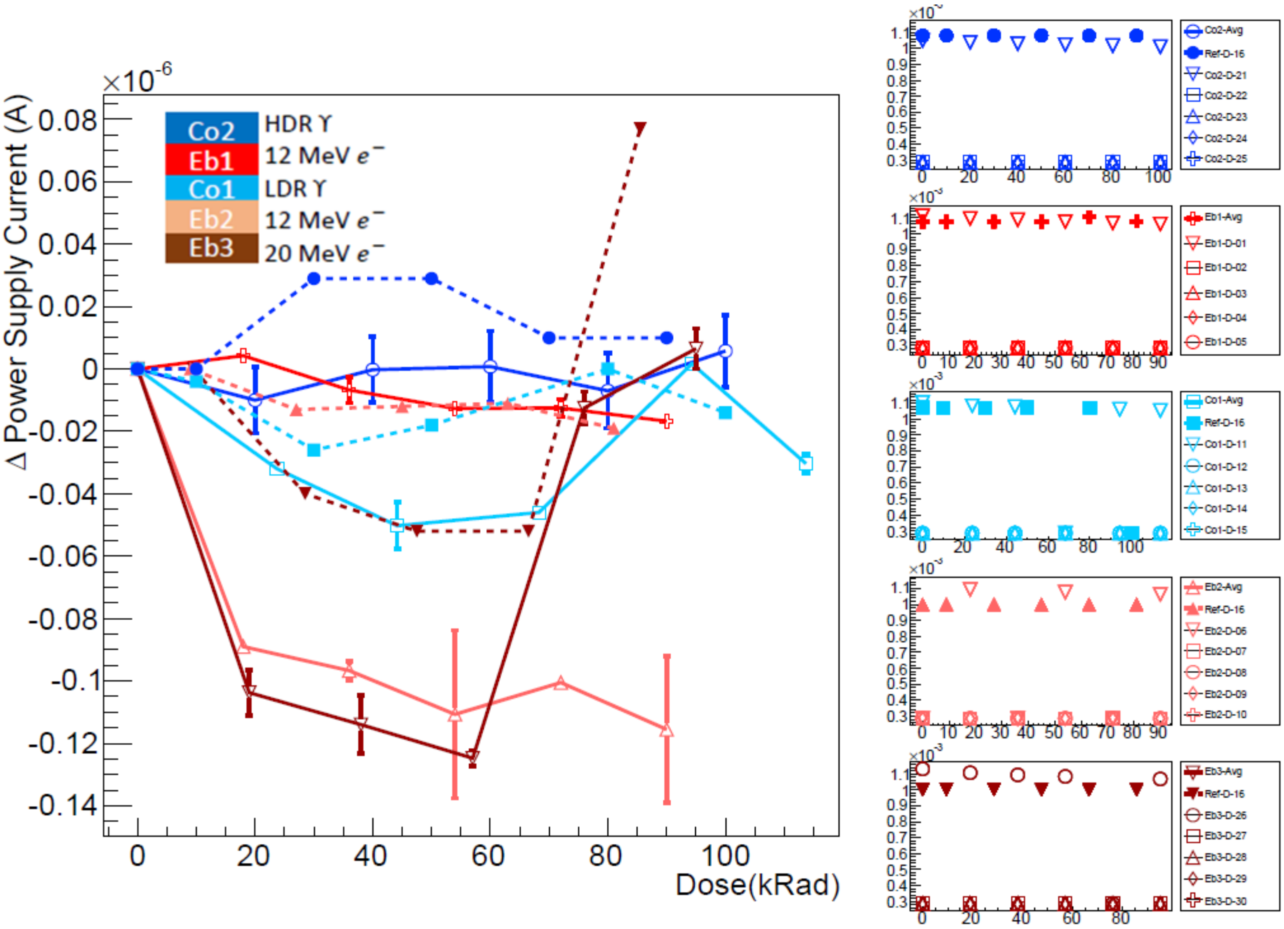


Figure 8-22 Power Supply Current variation (left side) and absolute values (right side). Blue points correspond to the HDR y CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR y ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

8.4.2 Input Bias Current +

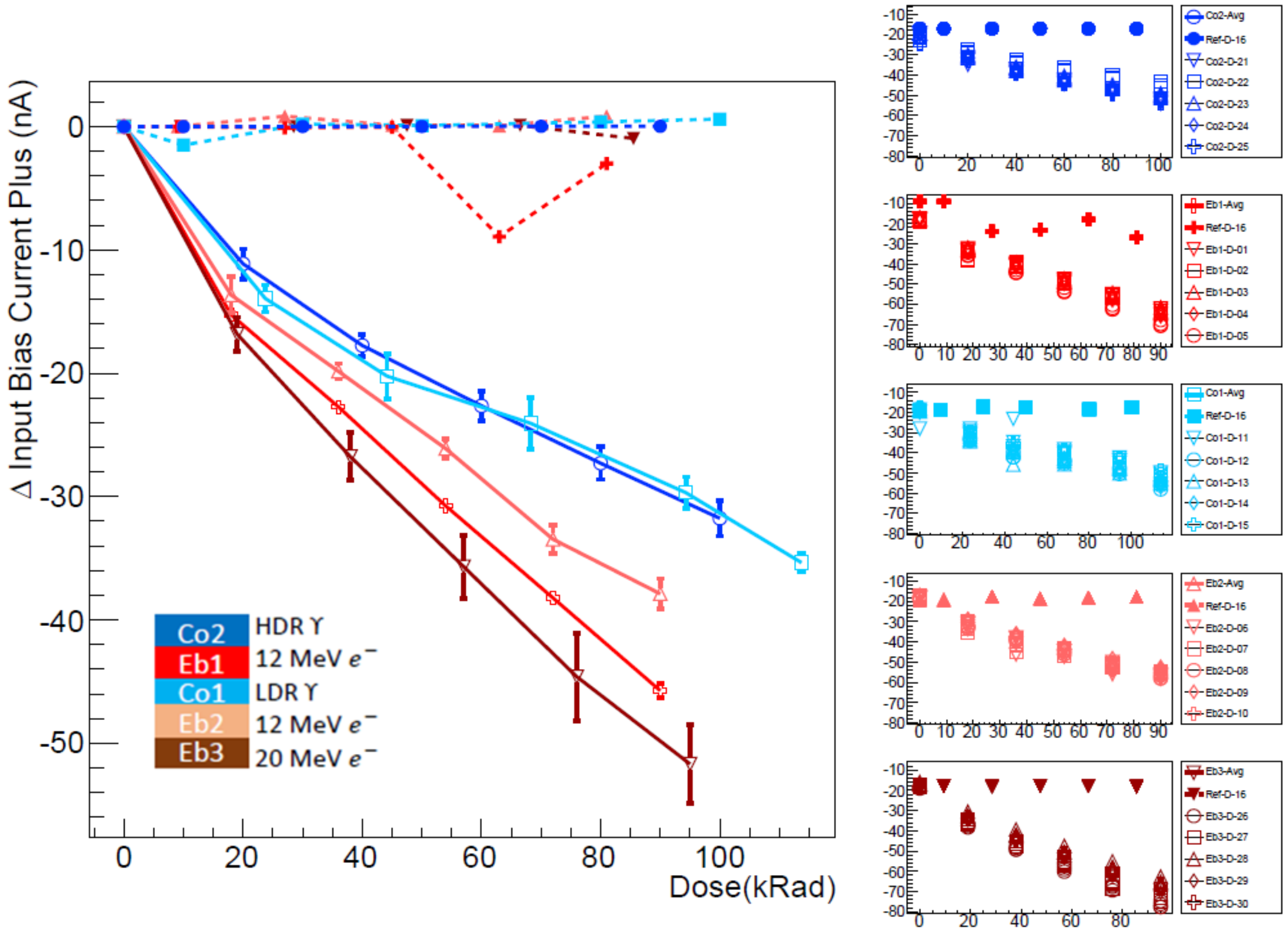


Figure 8-23 Input Bias Current Plus variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

8.4.3 Input Bias Current –

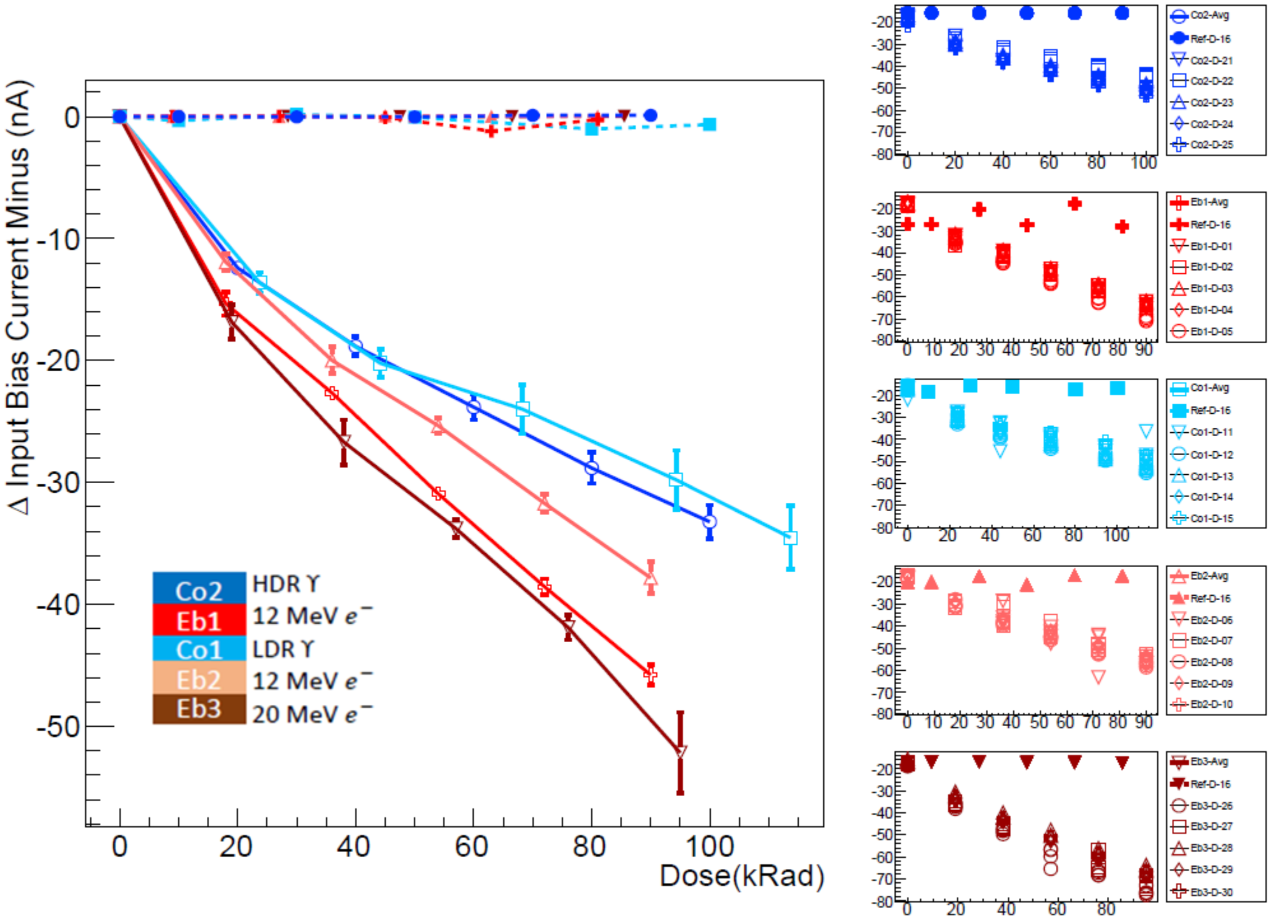


Figure 8-24 Input Bias Current Minus variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

8.4.4 Input Current Offset

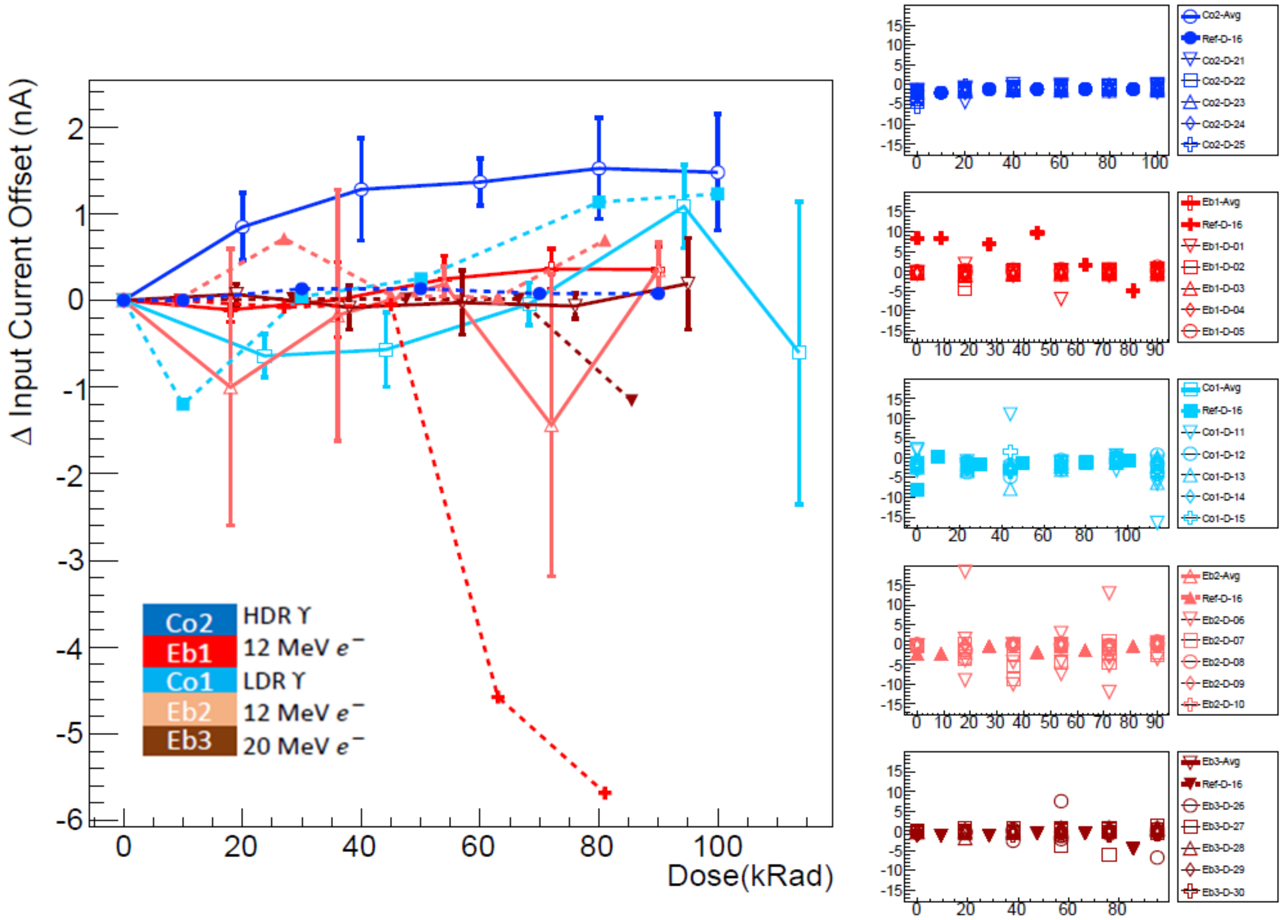


Figure 8-25 Input Current Offset variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

8.4.5 Input Offset Voltage

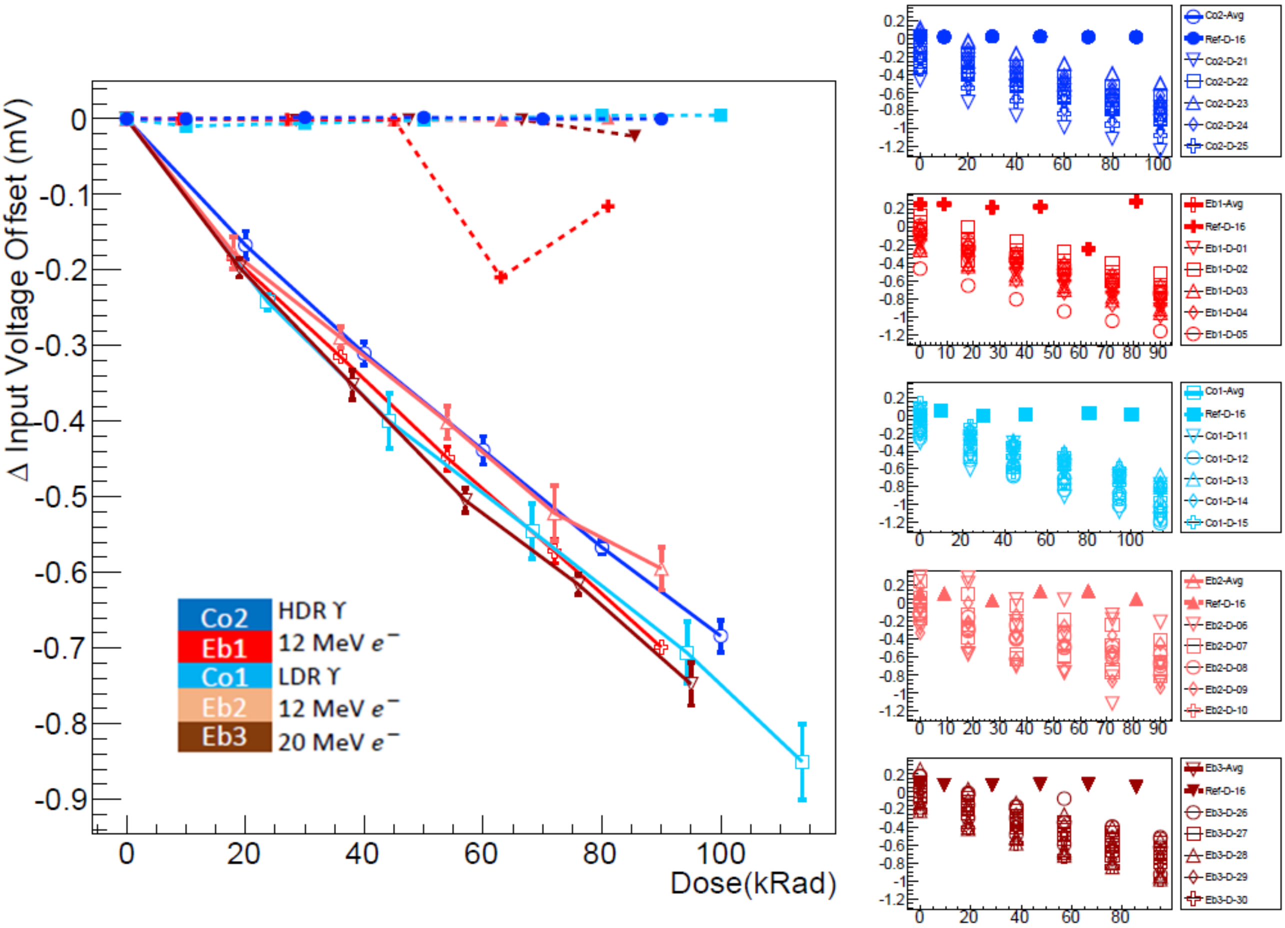


Figure 8-26 Input Voltage Offset variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

8.4.6 Common Mode Rejection Ratio (CMRR)

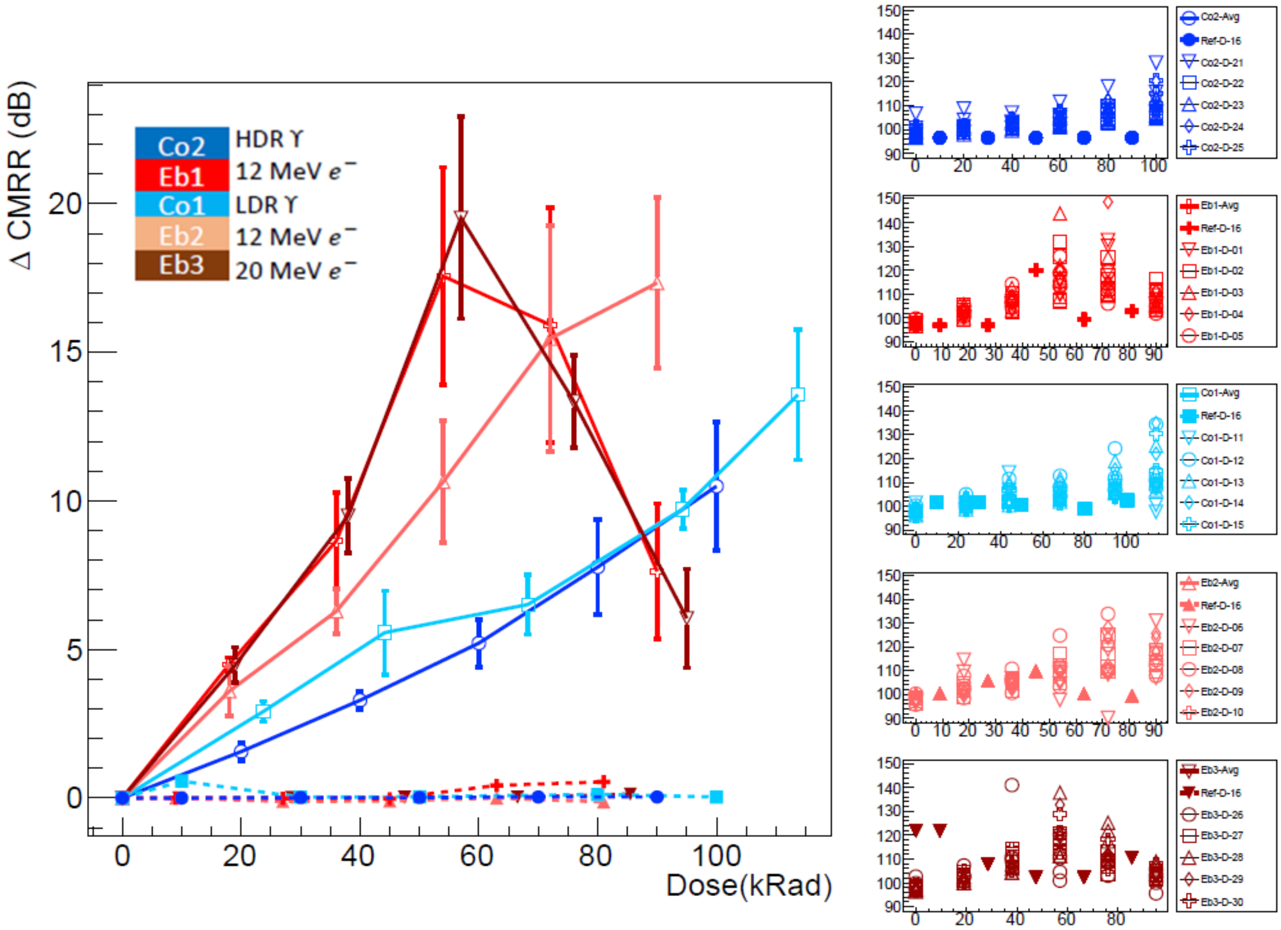


Figure 8-27 Common Mode Rejection Ratio variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

8.4.7 Power Supply Rejection Ratio (PSRR)

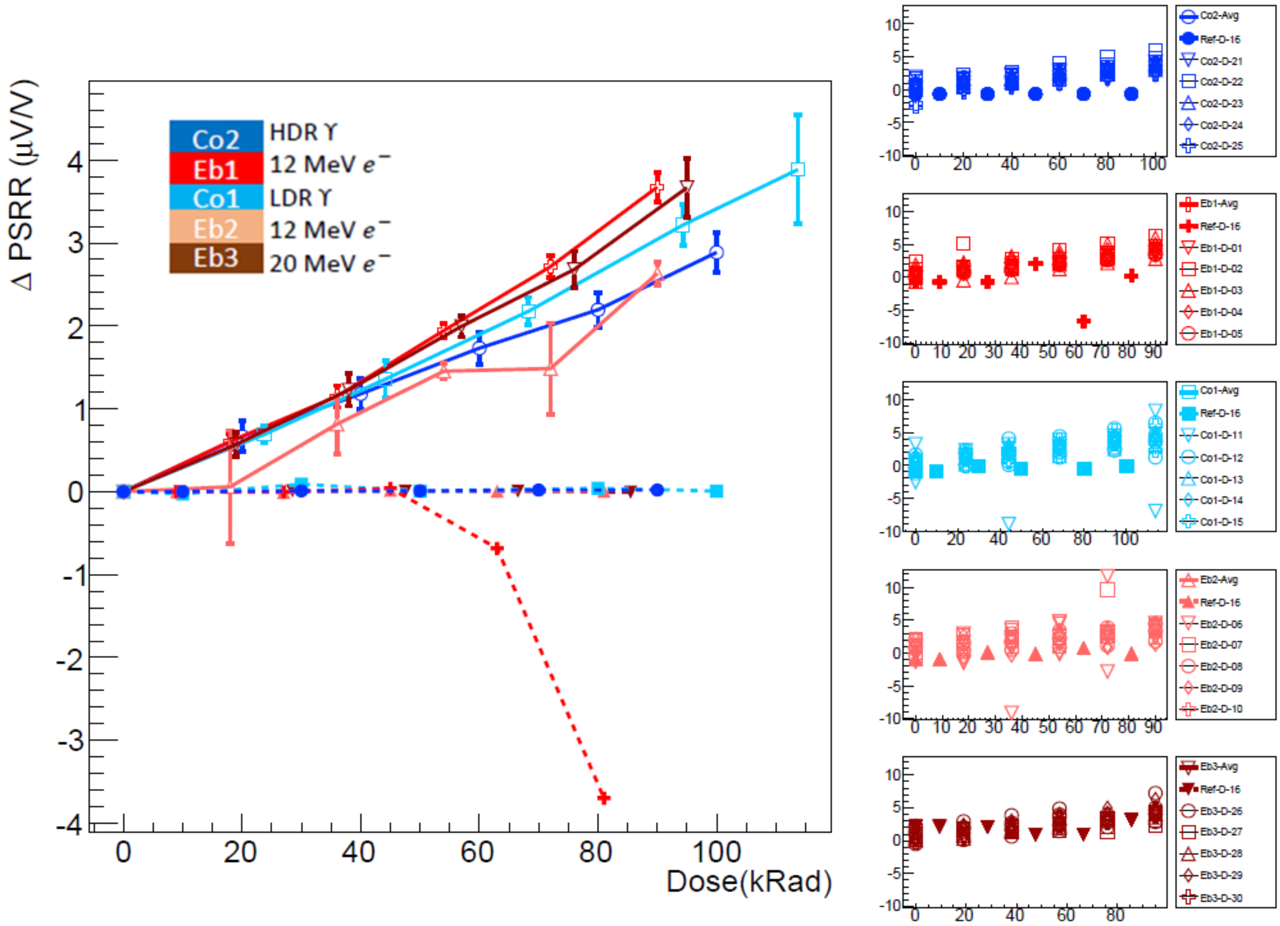


Figure 8-28 Power Supply Rejection Ratio variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

8.4.8 Voltage Gain

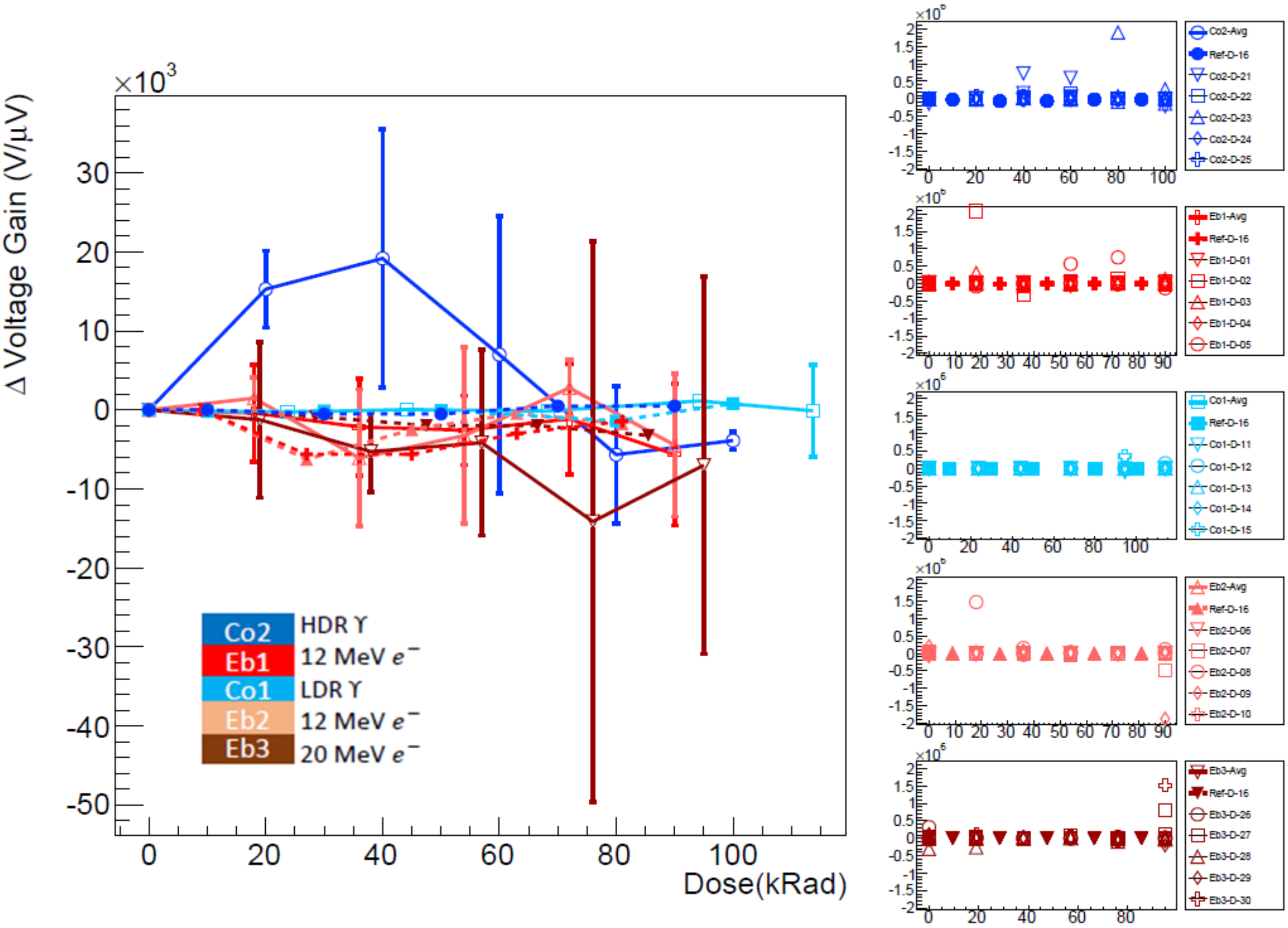


Figure 8-29 Voltage Gain variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

8.4.9 Maximum Output Voltage Swing

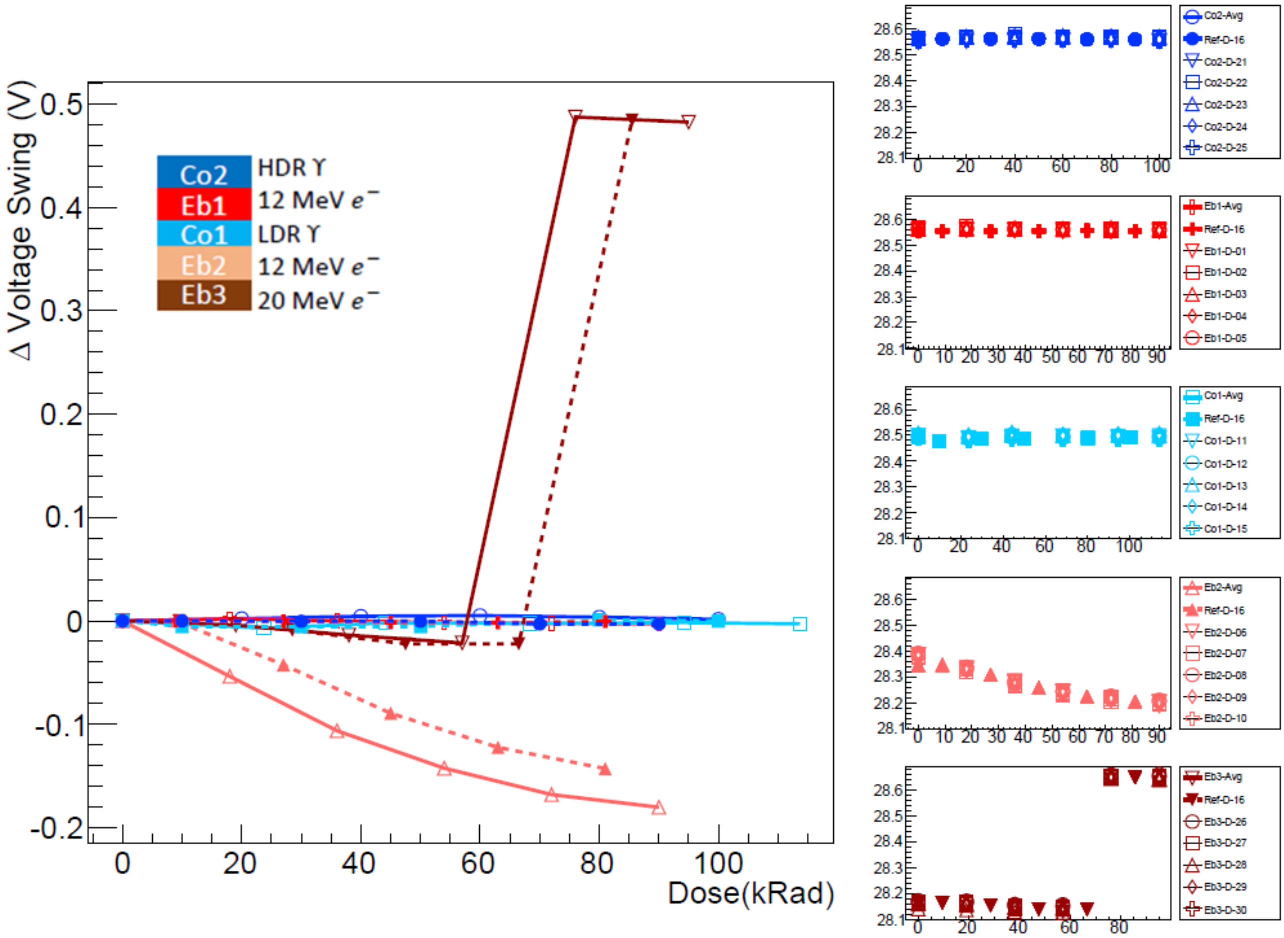


Figure 8-30 Maximum Output Voltage Swing variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

8.4.10 Slew Rate +

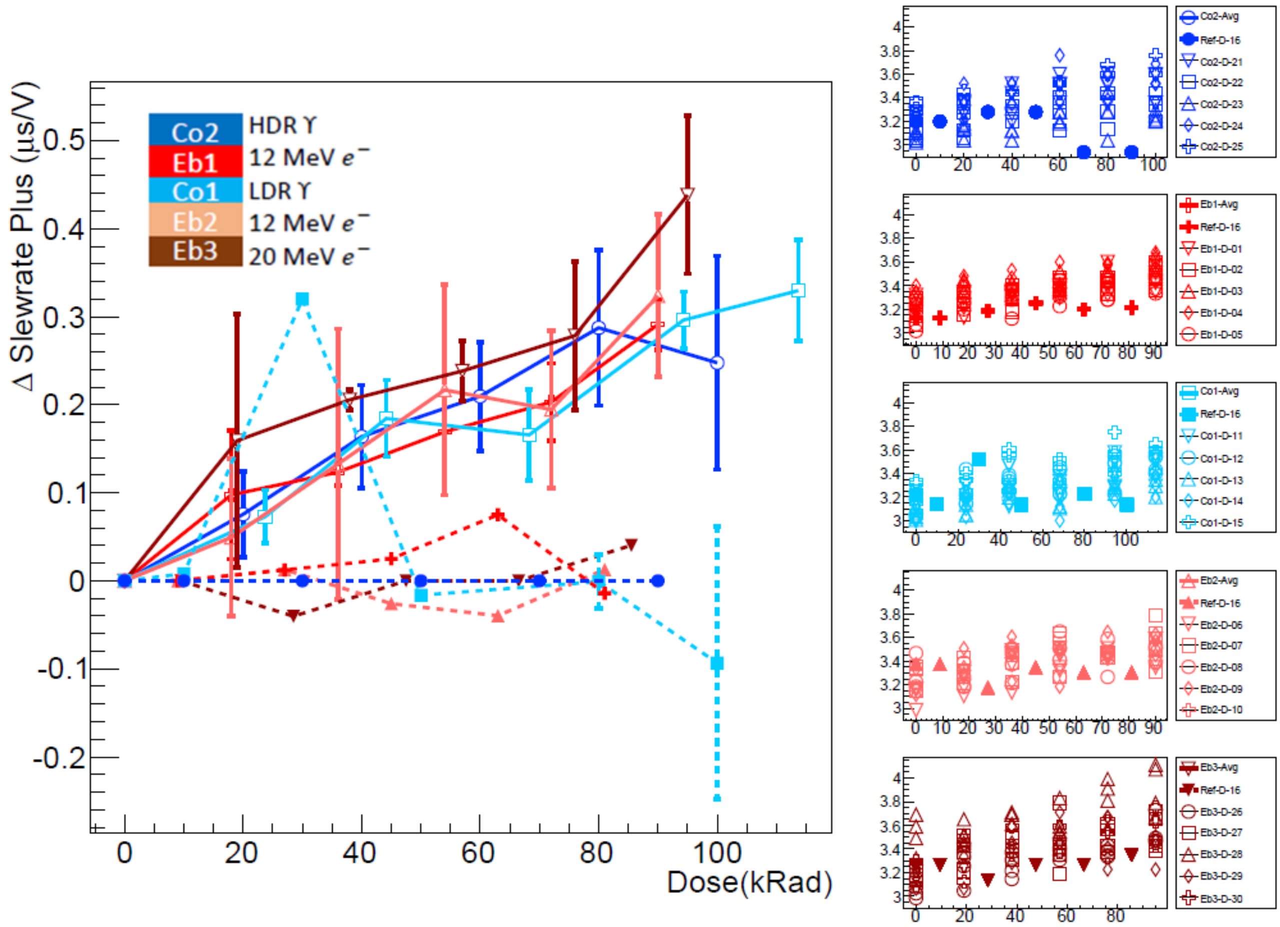


Figure 8-31 Slew Rate Plus variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

8.4.11 Slew Rate –

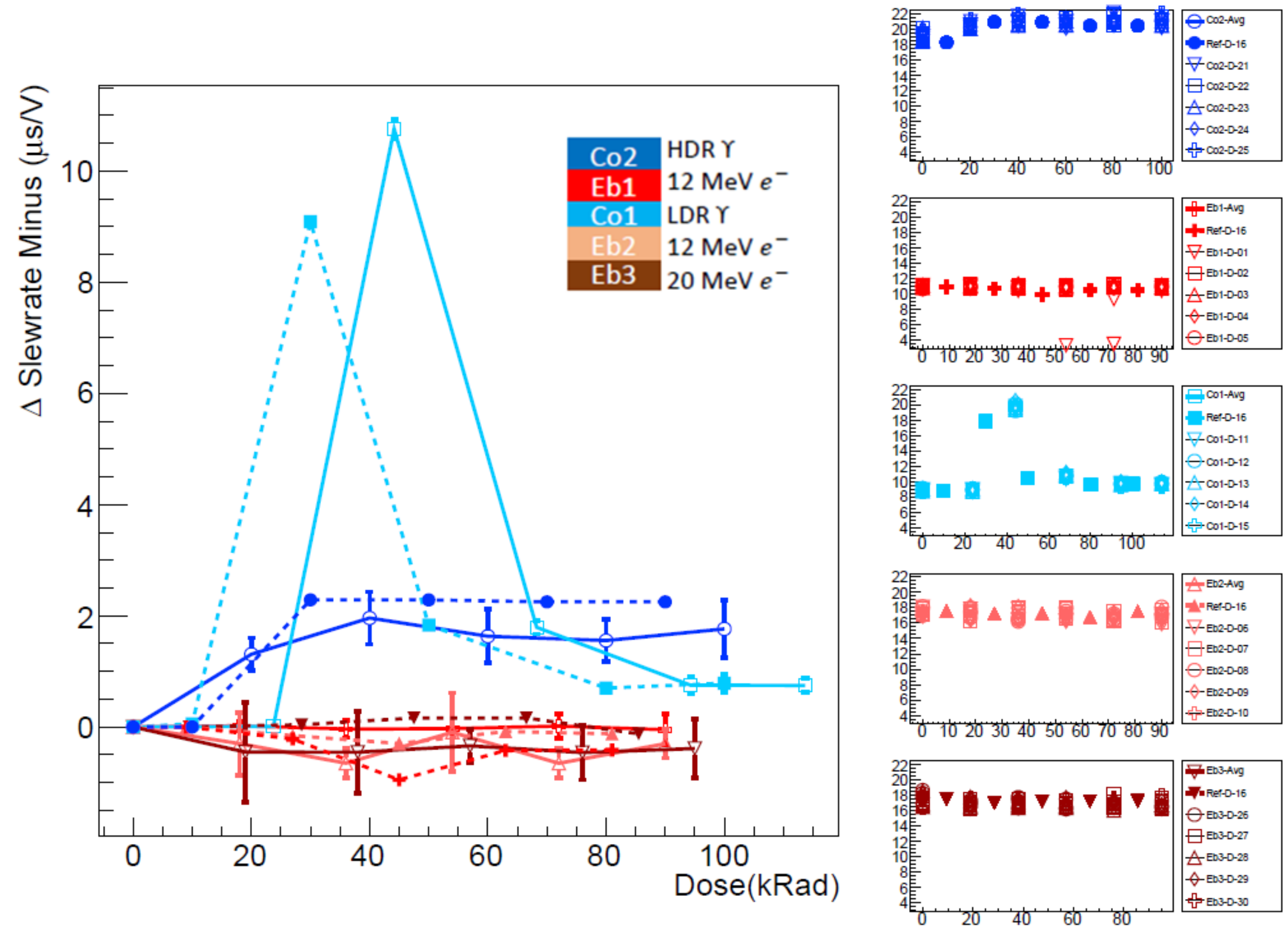


Figure 8-32 Slew Rate Minus variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

8.5 Component E – LM4050

The results for the 5 parameters measured for component E are presented in sections 8.5.1-8.5.5. All parameters show sensitivity to radiation although it the sensitivity is more pronounced for regimes with higher bias current. Parameter variation with TID is comparable for all radiation types - for Co-60 and electrons at similar dose rates -, displaying ELDRS, which was expected. A summary of the results for this component can be found in Table 8-5.

Table 8-5 Component E parameter irradiation status

Characteristics	Test Conditions	Status
Reference Voltage	I_R=74 µA	Radiation degradation Similar for electrons and Co60 ELDRS
	I_R=100 µA	Radiation degradation Similar for electrons and Co60 ELDRS
	I_R=1 mA	Radiation degradation Similar for electrons and Co60 ELDRS
	I_R=10 mA	Radiation degradation Similar for electrons and Co60 ELDRS
	I_R=15 mA	Radiation degradation Similar for electrons and Co60 ELDRS

8.5.1 Reference Voltage (I_R=74μA)

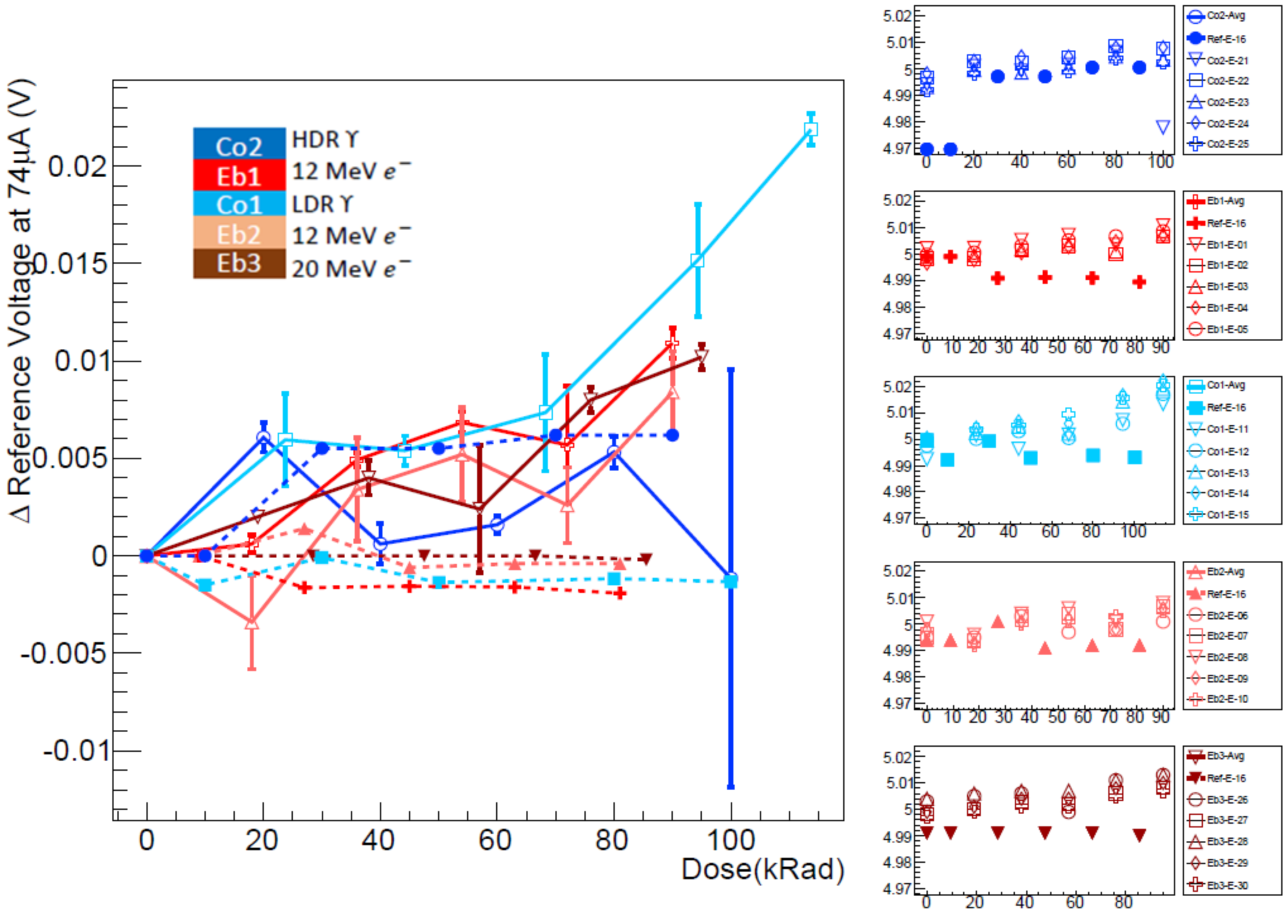


Figure 8-33 Reference Voltage (Ir=74μA) variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^{-} HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

8.5.2 Reference Voltage (I_R=100µA)

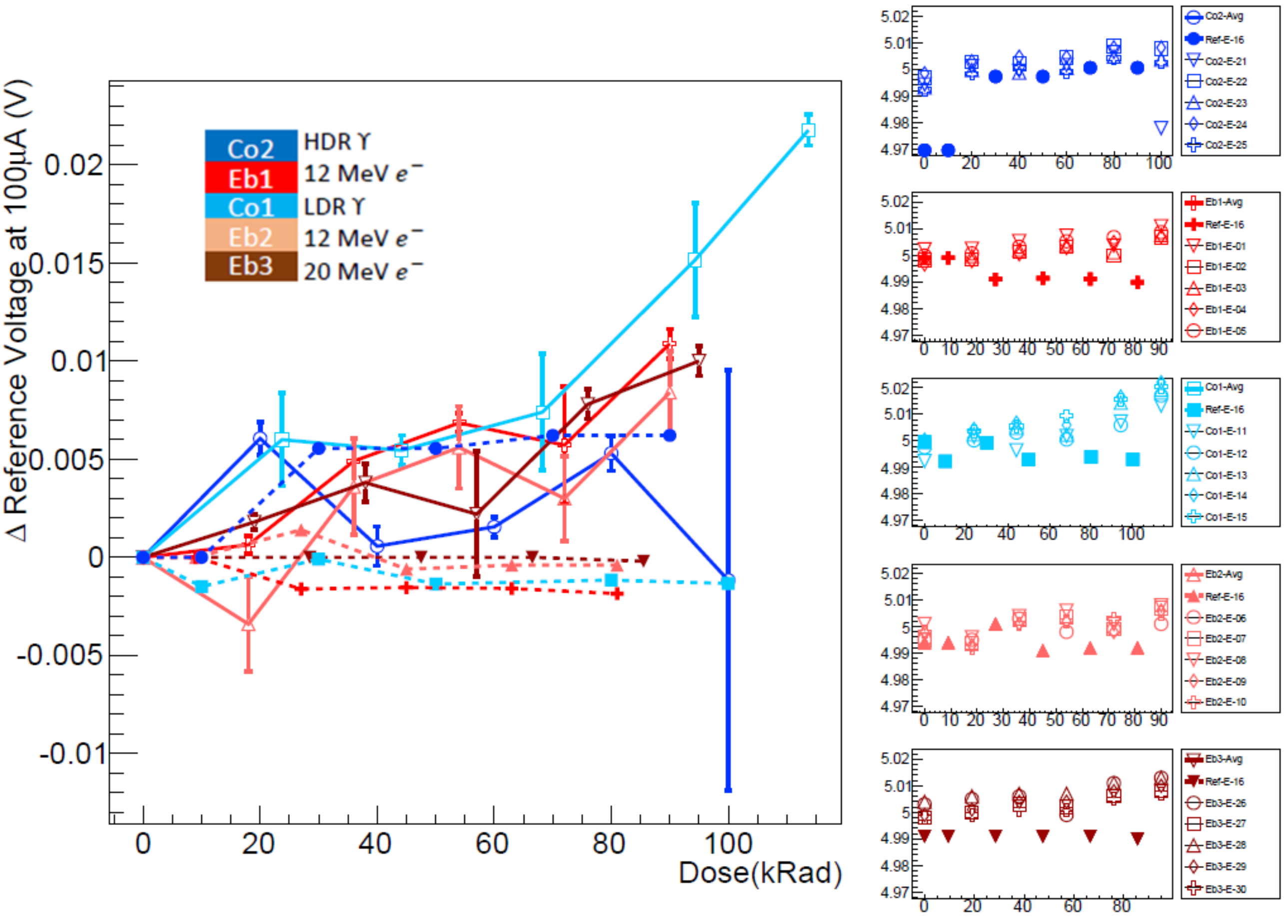


Figure 8-34 Reference Voltage (Ir=100µA) variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

8.5.3 Reference Voltage (I_R=1mA)

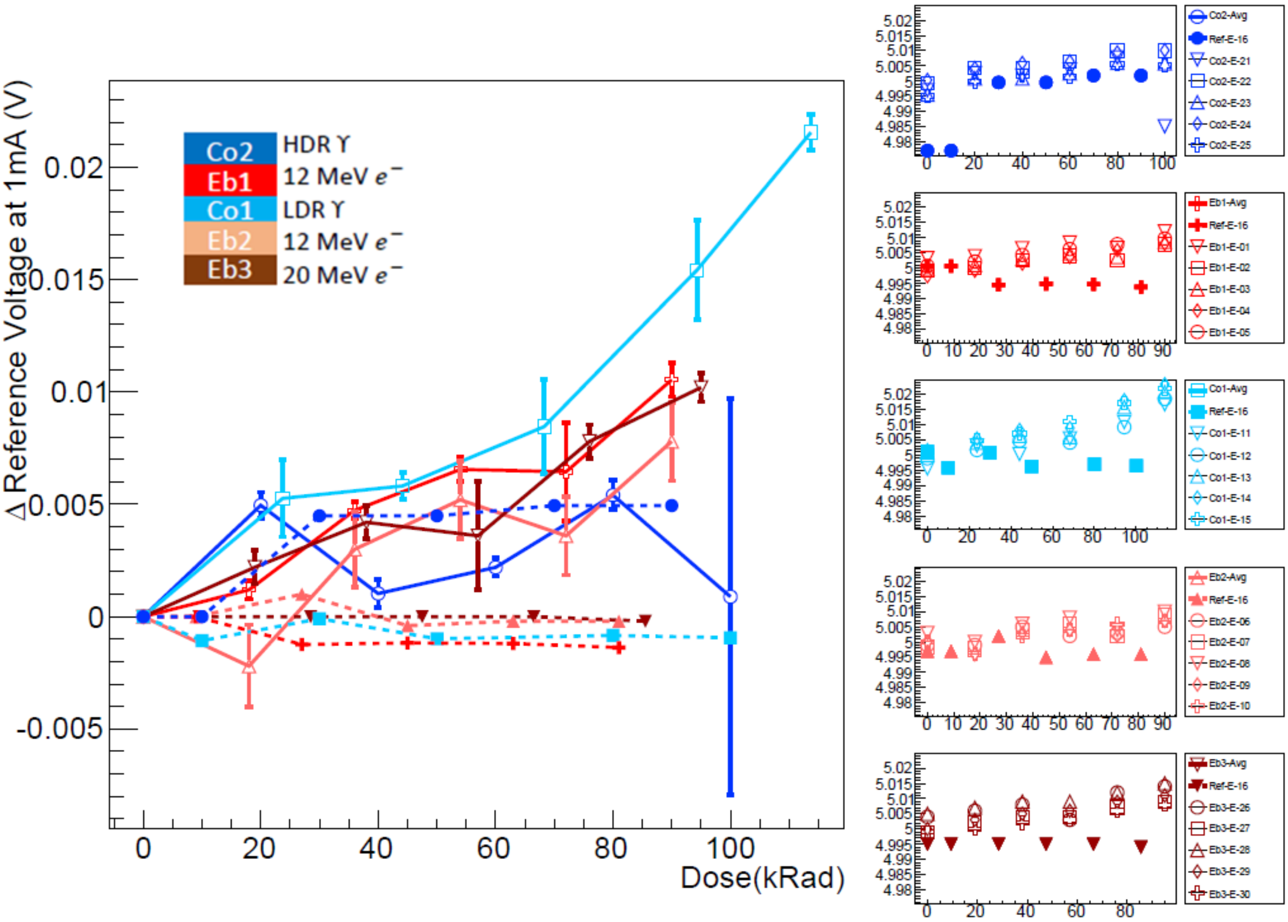


Figure 8-35 Reference Voltage (Ir=1mA) variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

8.5.4 Reference Voltage (I_R=10mA)

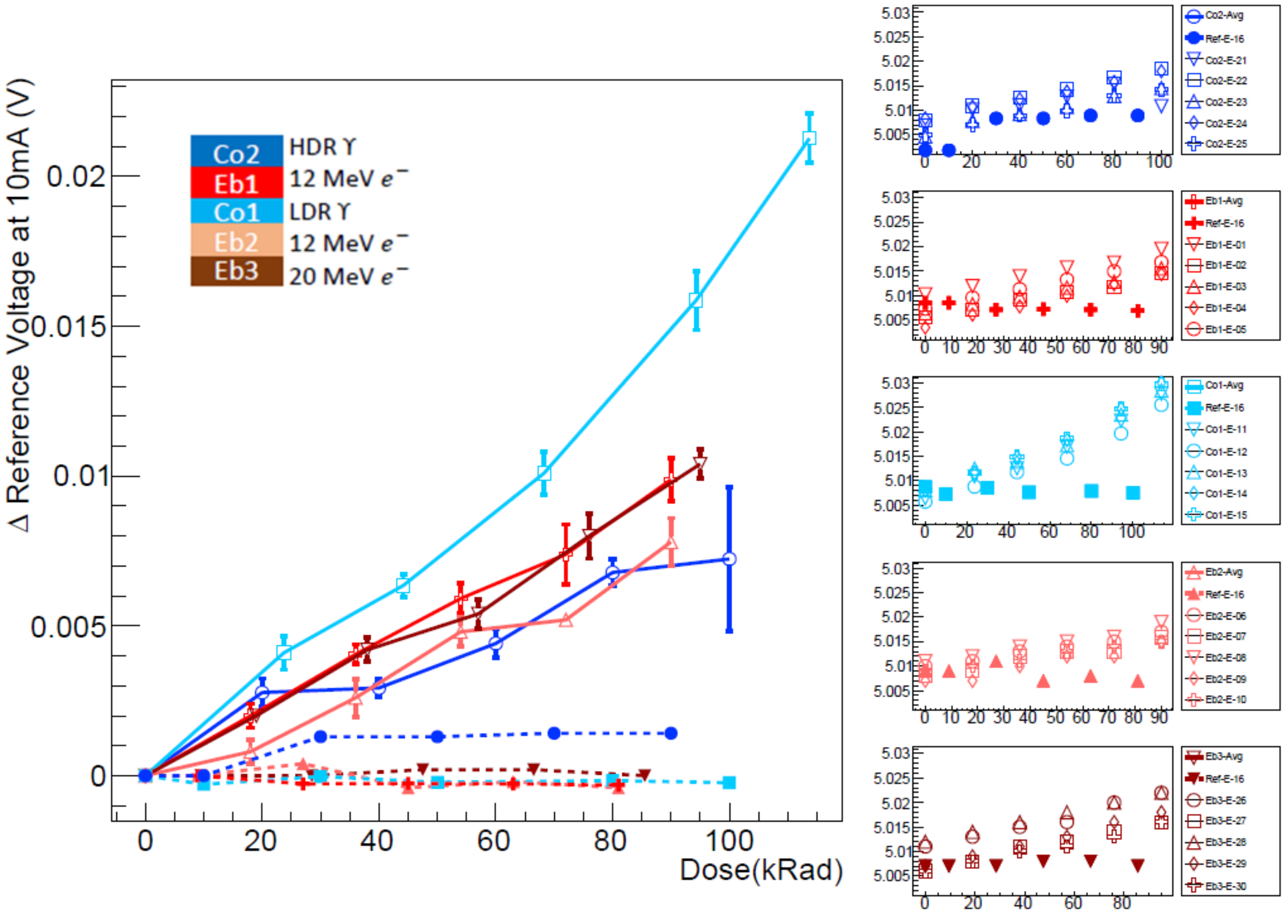


Figure 8-36 Reference Voltage (Ir=10mA) variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

8.5.5 Reference Voltage (I_R=15mA)

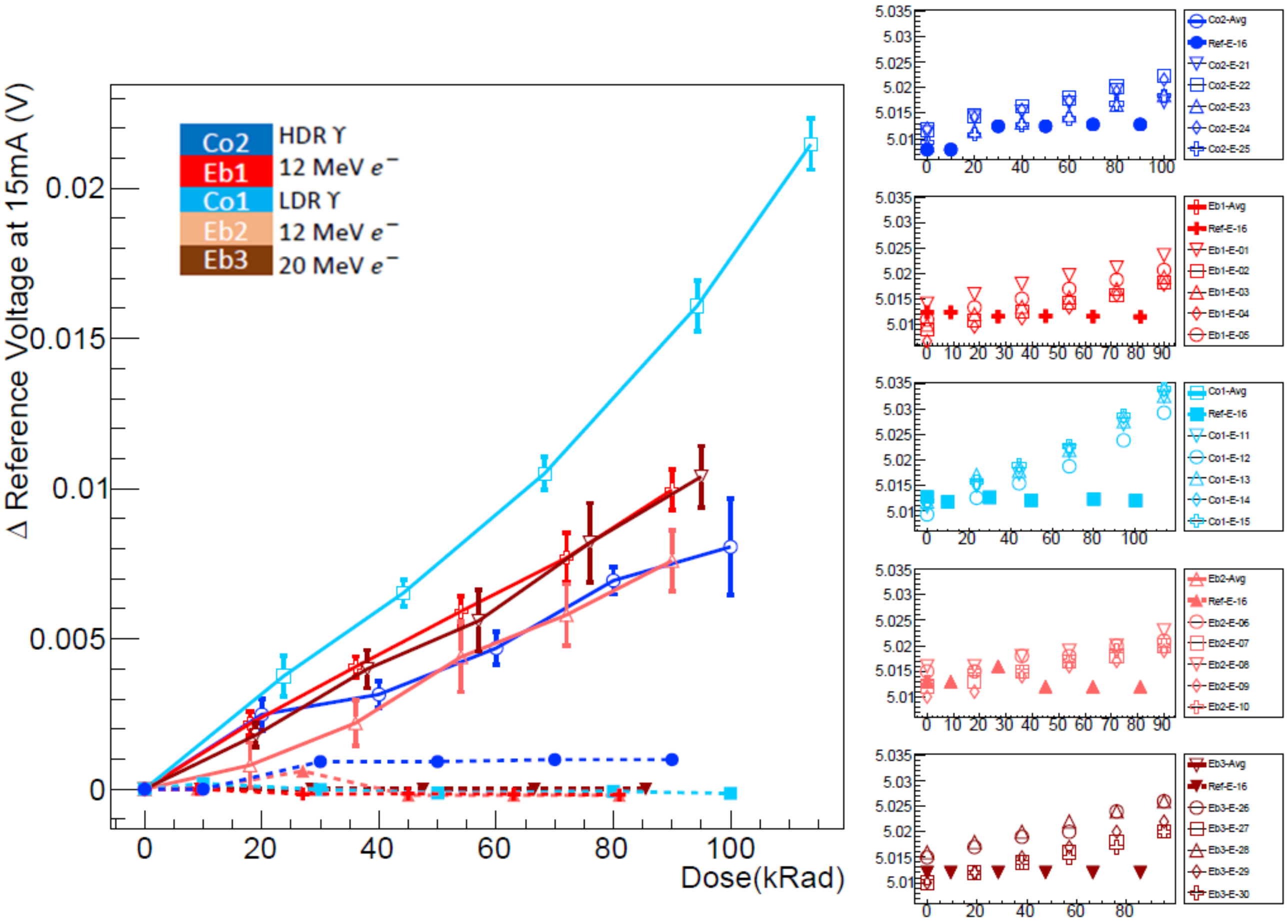


Figure 8-37 Reference Voltage (Ir=15mA) variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9 Annealing Results

After irradiation, components were measured on a weekly basis for the first month and on monthly basis for seven months. Results are shown in sections 9.1-9.5 , one for each component. Components were unbiased for the whole annealing process.

9.1 Component A – STH100N10

Results for the 6 parameters measured for component a are presented in sections 9.1.1-9.1.6. No annealing effect was observed.

9.1.1 Gate-to-Source Leakage Current 1

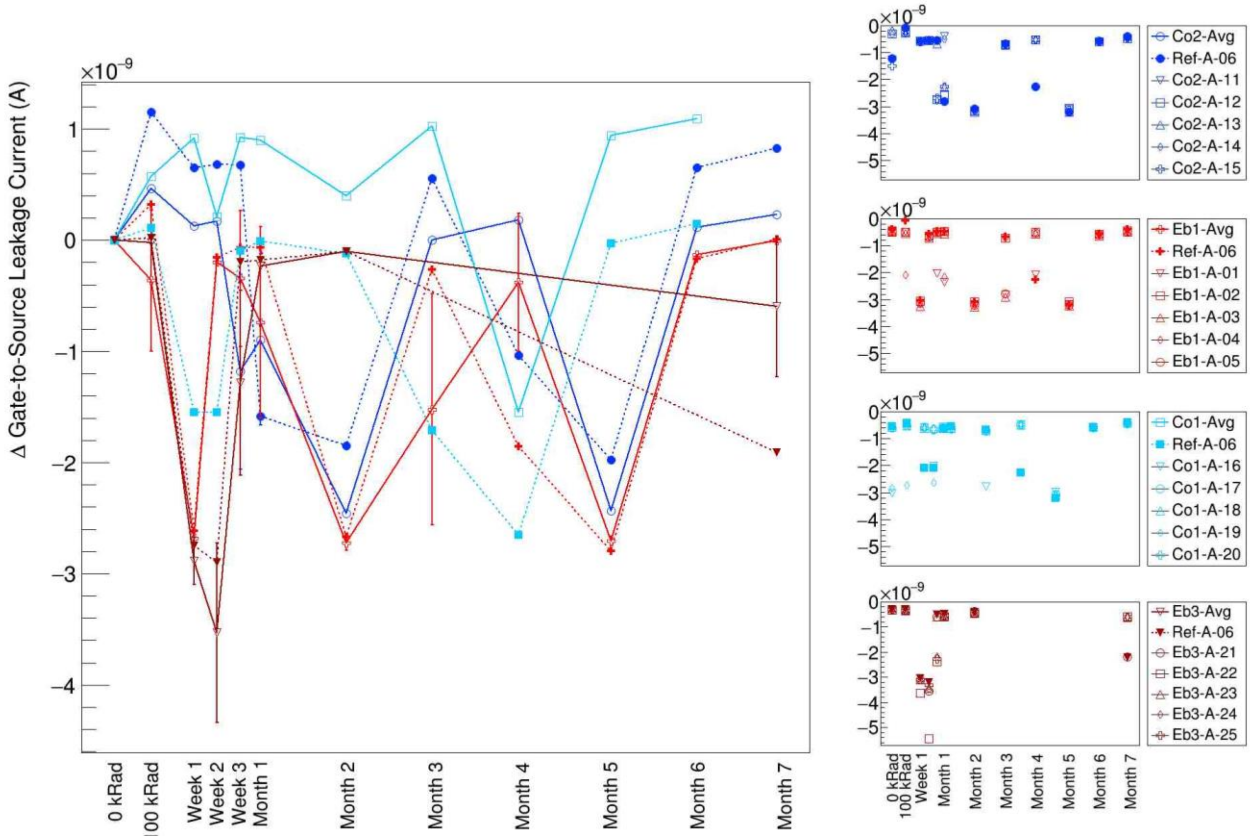


Figure 9-1 Gate-to-Source Leakage Current 1 variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^{-} HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9.1.2 Gate-to-Source Leakage Current 2

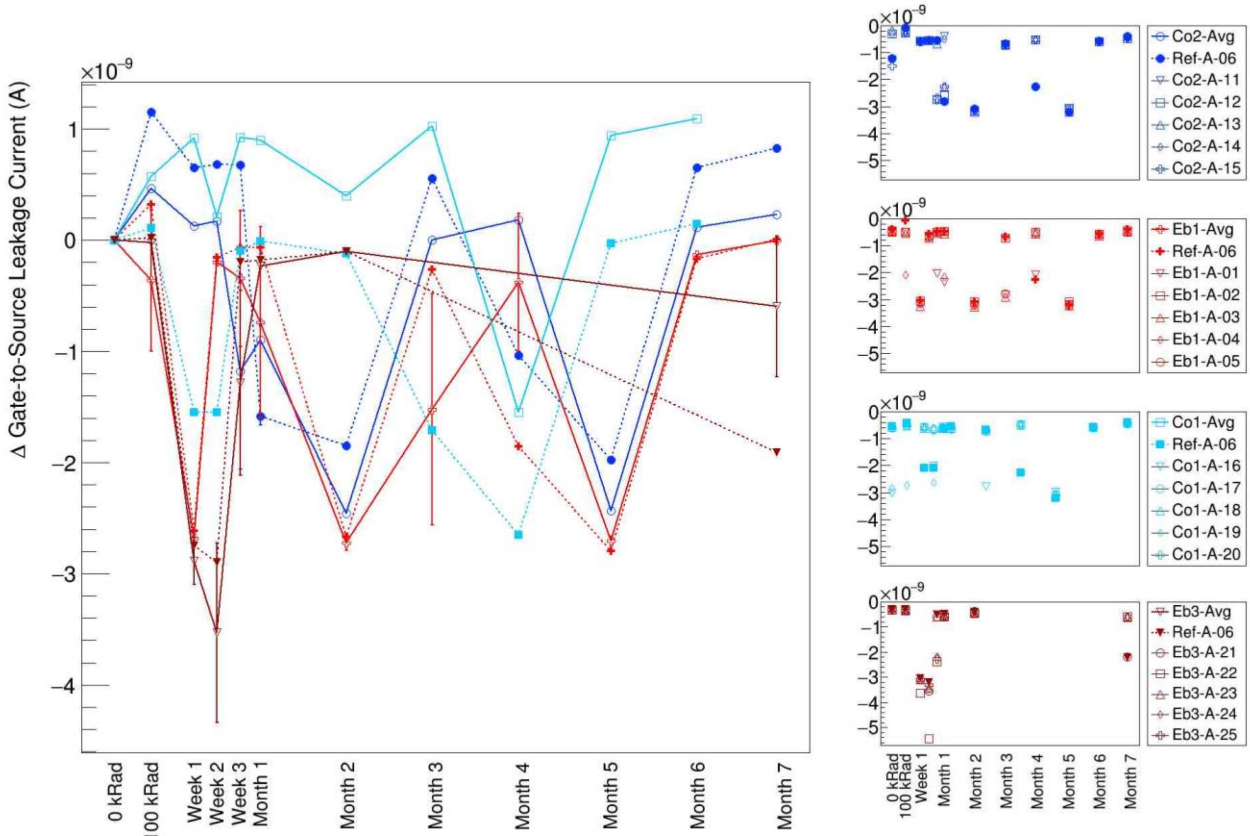


Figure 9-2 Gate-to-Source Leakage Current 2 variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9.1.3 Drain Current

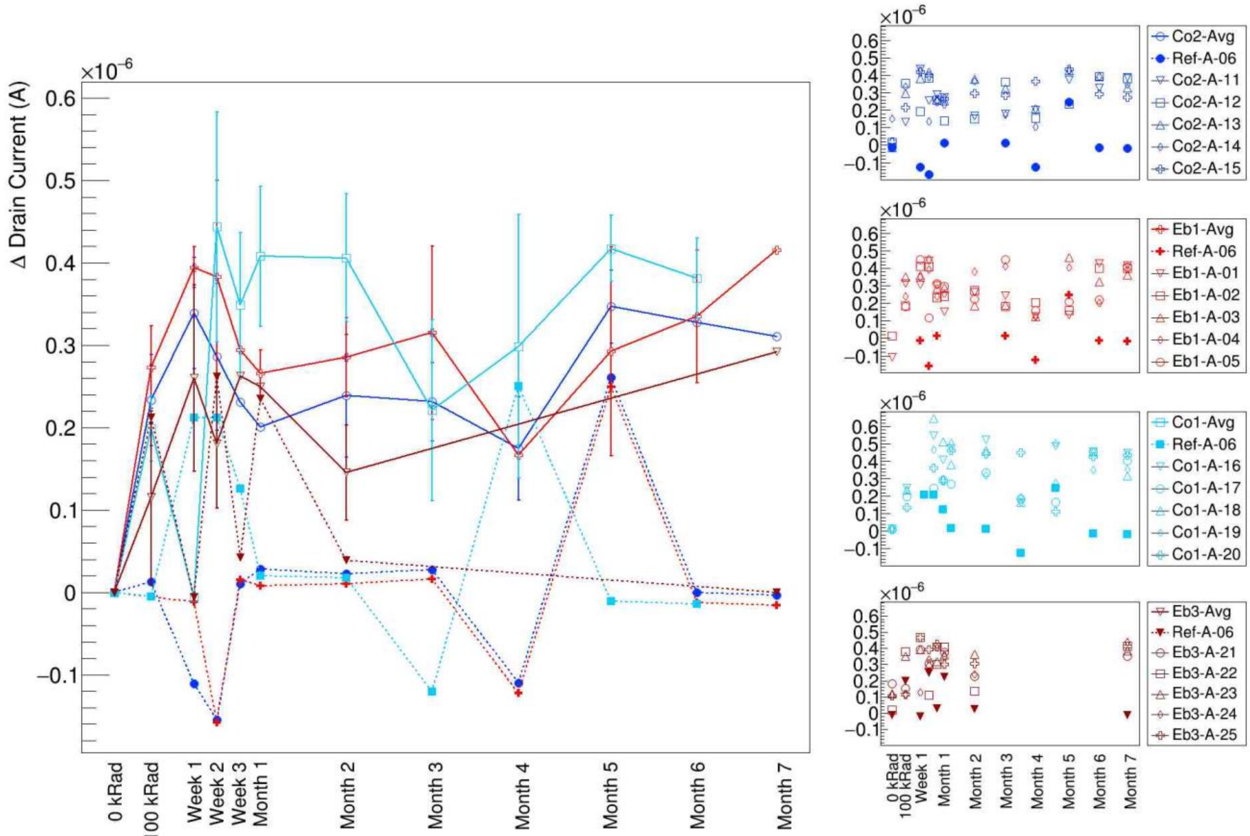


Figure 9-3 Drain Current variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^{-} HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9.1.4 Gate-to-Source Threshold

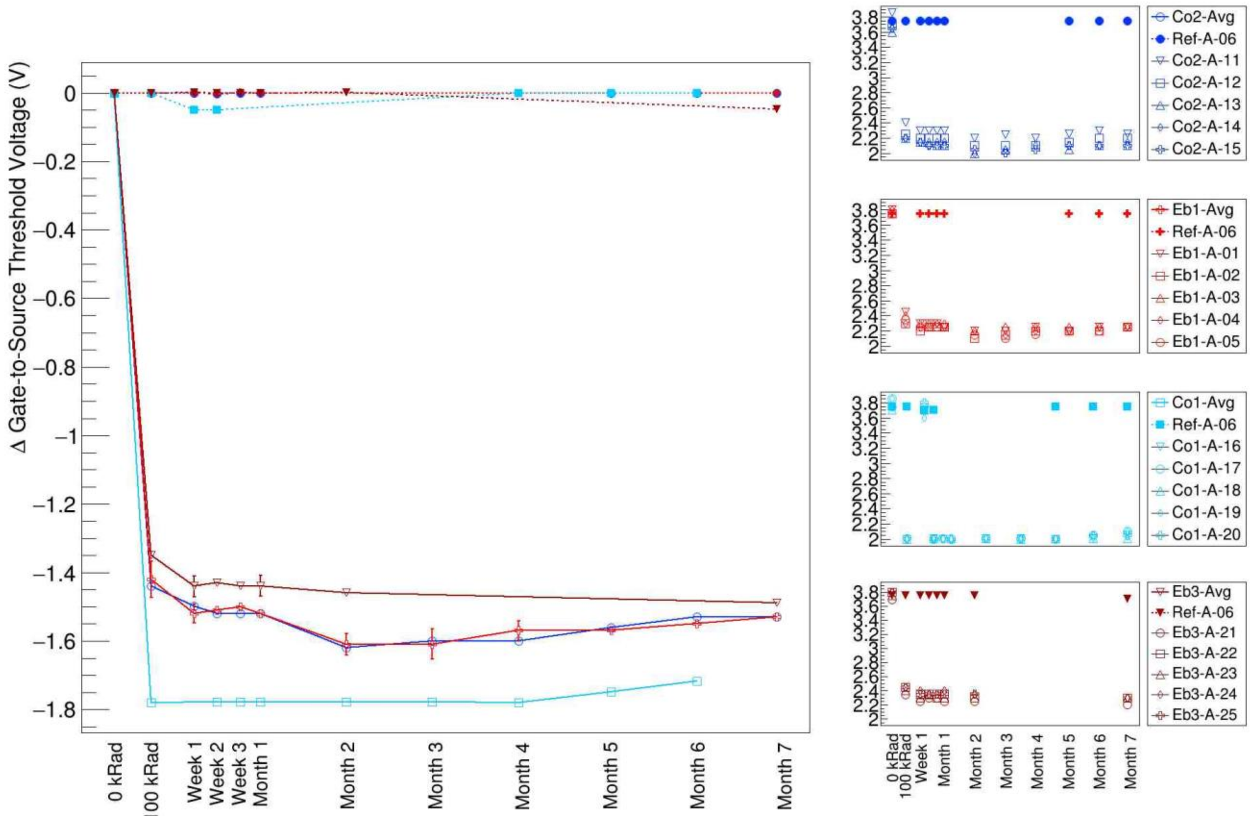


Figure 9-4 Gate-to-Source Threshold Voltage variation (left side) and absolute values (right side). Blue points correspond to the HDR y CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR y ESTEC campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9.1.5 Static Drain-to-Source On Resistance

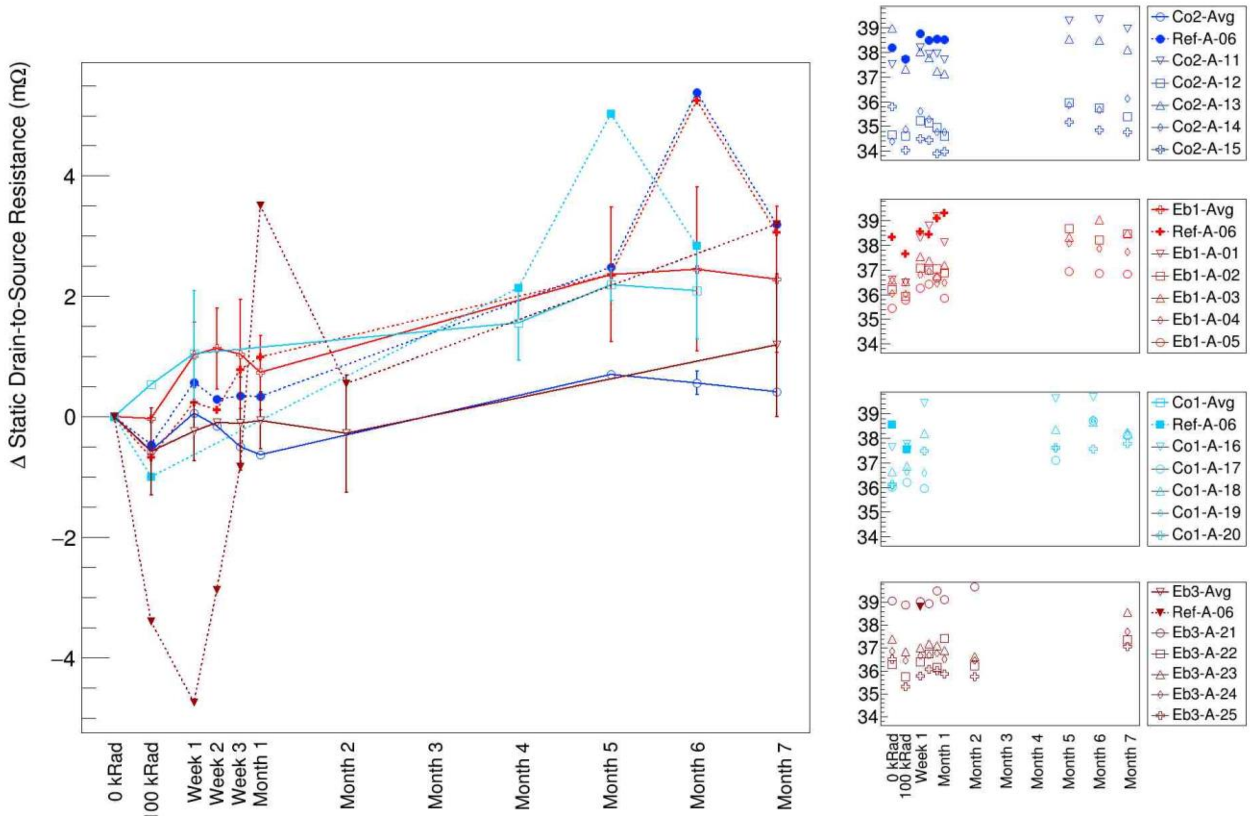


Figure 9-5 Drain-to-Source On-Resistance variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9.1.6 Source-to-Drain Diode Forward Voltage

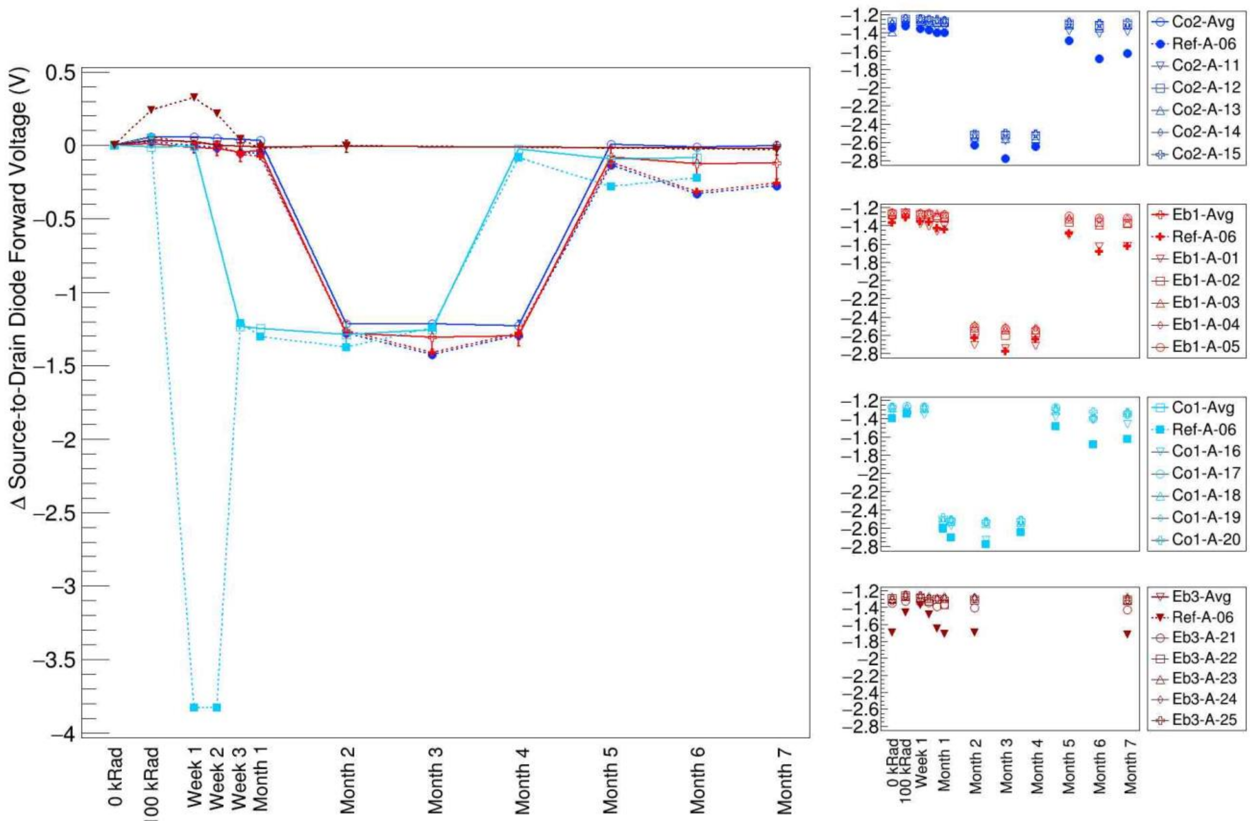


Figure 9-6 Source-to-Drain Diode Forward Voltage variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^{-} HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9.2 Component B – Memories

Since memories were unresponsive no annealing was performed on them. After the last annealing measurements from all other components they were checked for responsiveness, but no recovery had taken place.

9.3 Component C – 2N2222

Component C results are shown in sections 9.3.1-9.3.8. No significant annealing effect was observed.

9.3.1 Collector-Base Cut-Off Current

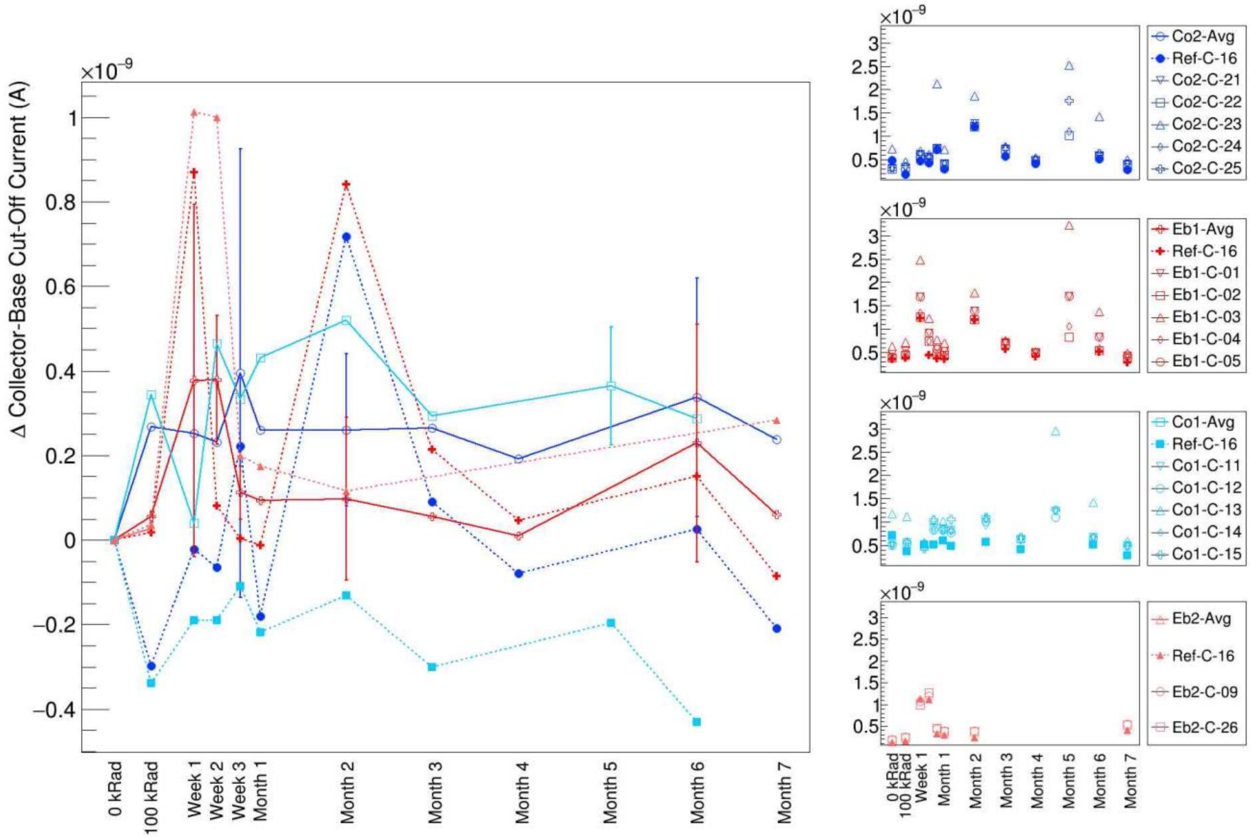


Figure 9-7 Collector-Base Cut-Off Current variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign.

9.3.2 Emitter-Base Cut-Off Current

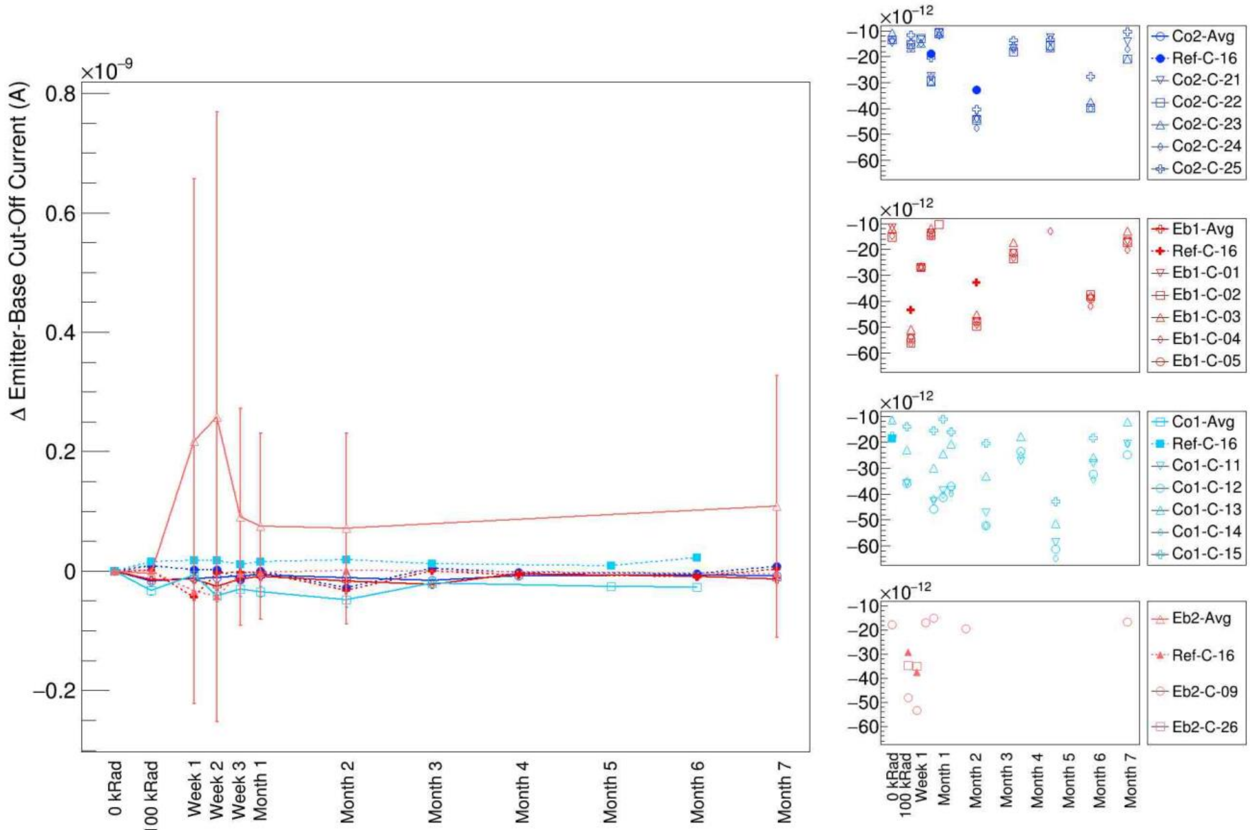


Figure 9-8 Emitter-Base Cut-Off Current variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign.

9.3.3 Collector-Emitter Saturation Voltage

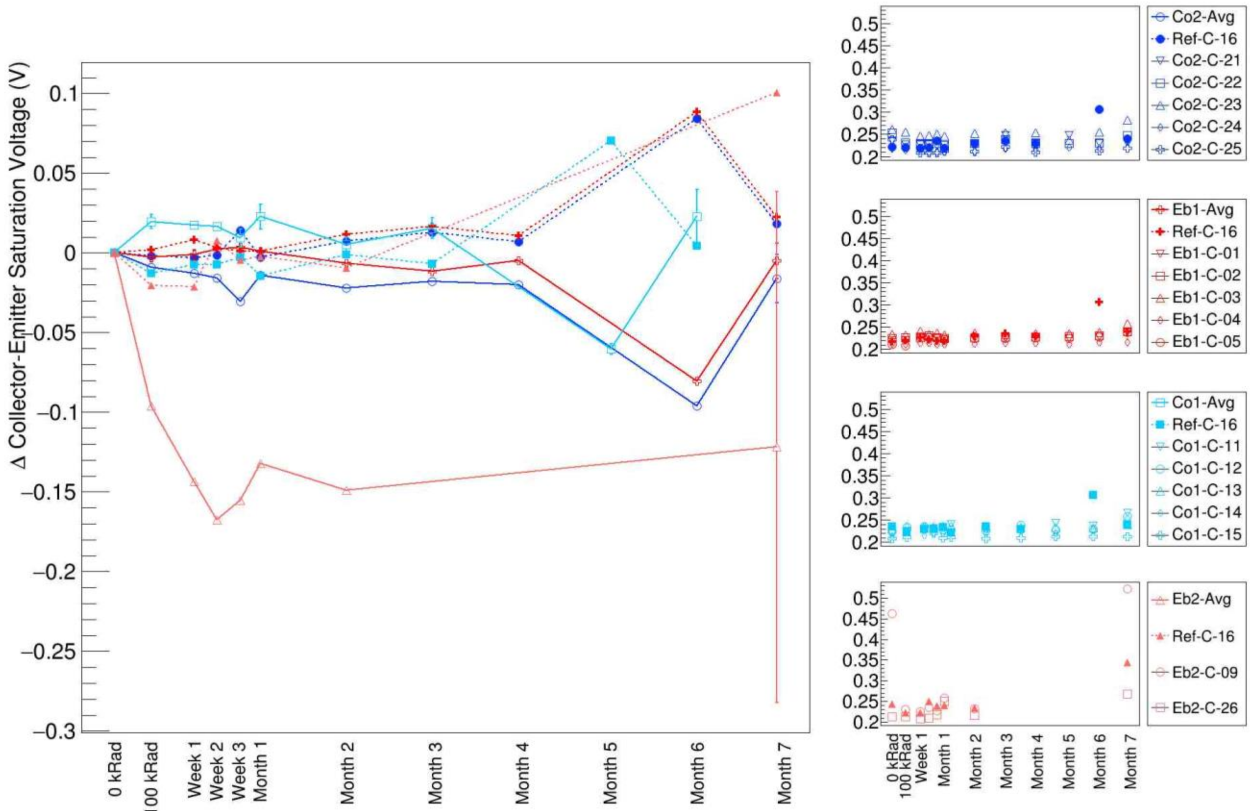


Figure 9-9 Collector-Emitter Saturation Voltage variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign.

9.3.4 Base-Emitter Saturation Voltage

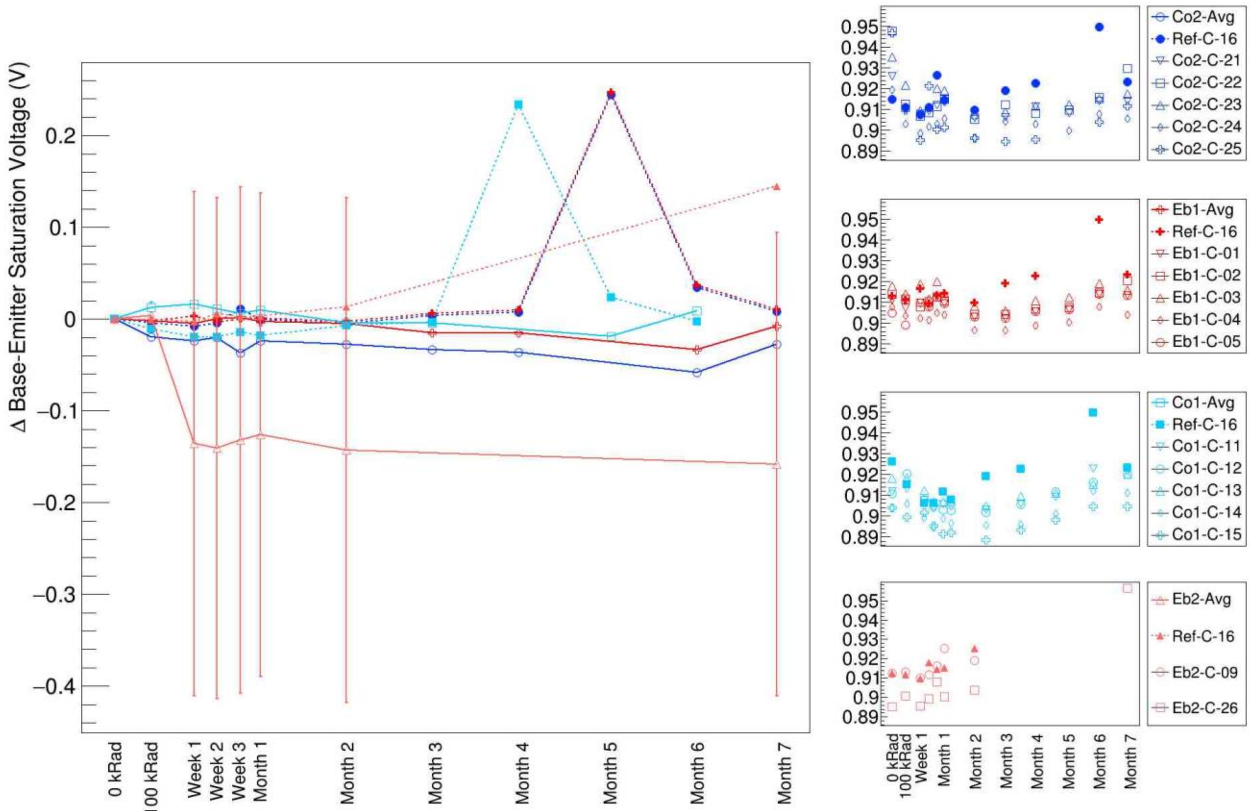


Figure 9-10 Base-Emitter Saturation Voltage (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^{-} HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign.

9.3.5 Forward-Current Transfer Ratio (Ic=100µA)

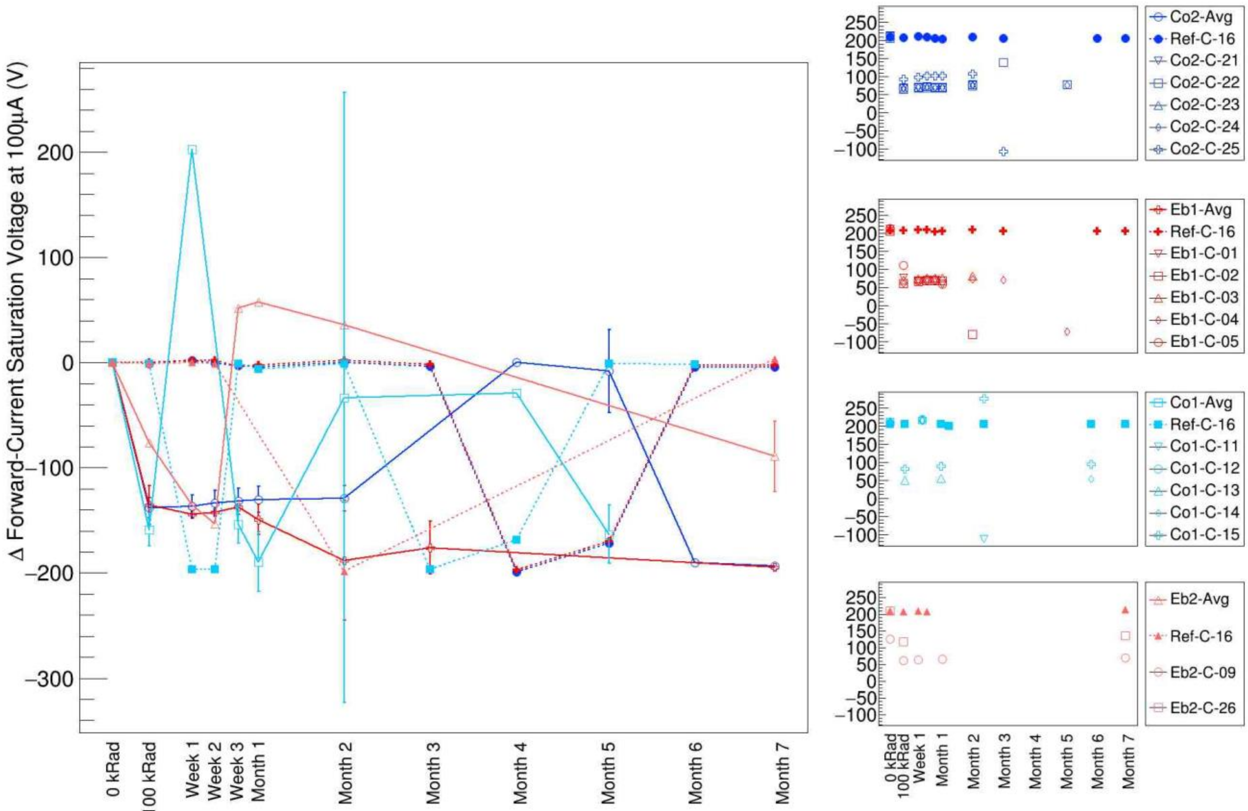


Figure 9-11 Forward-Current Saturation Voltage (Ic=100µA) variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign.

9.3.6 Forward-Current Transfer Ratio (Ic=10mA)

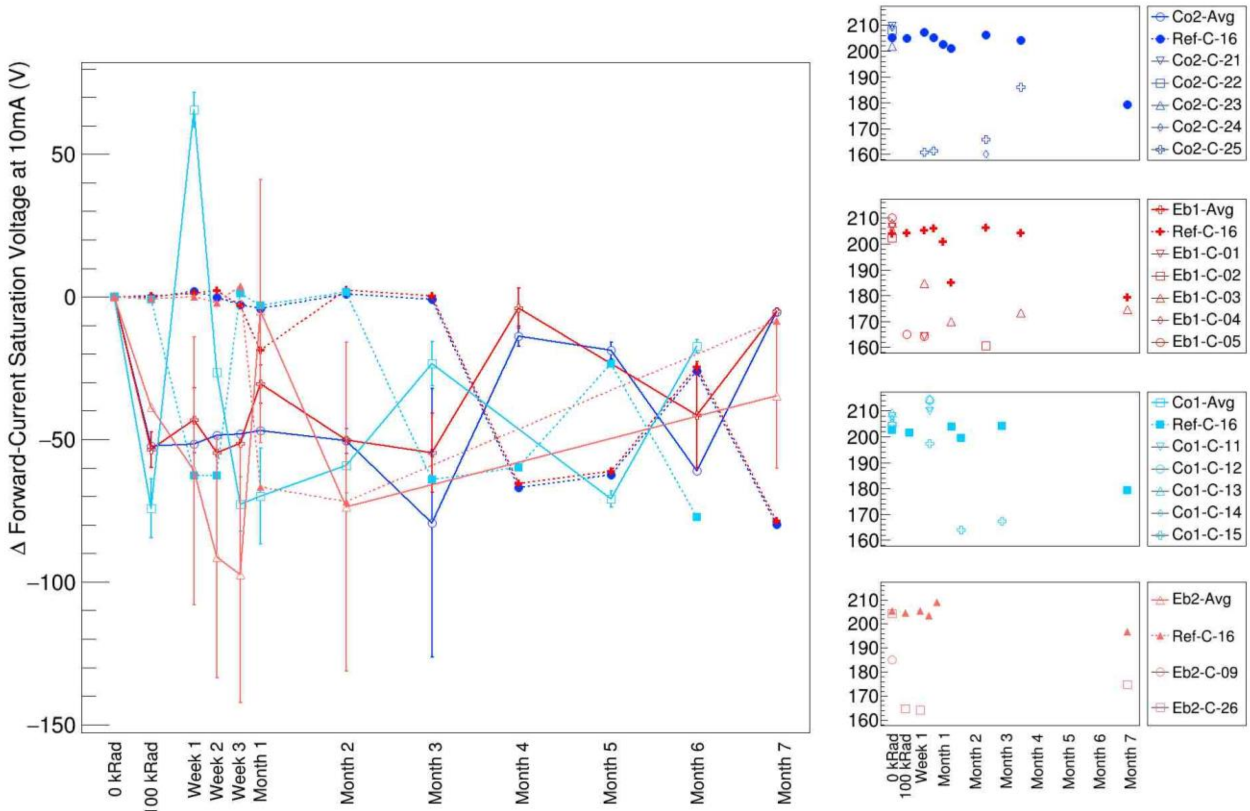


Figure 9-12 Forward-Current Saturation Voltage (Ic=10mA) variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^{-} HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign.

9.3.7 Forward-Current Transfer Ratio (Ic=100mA)

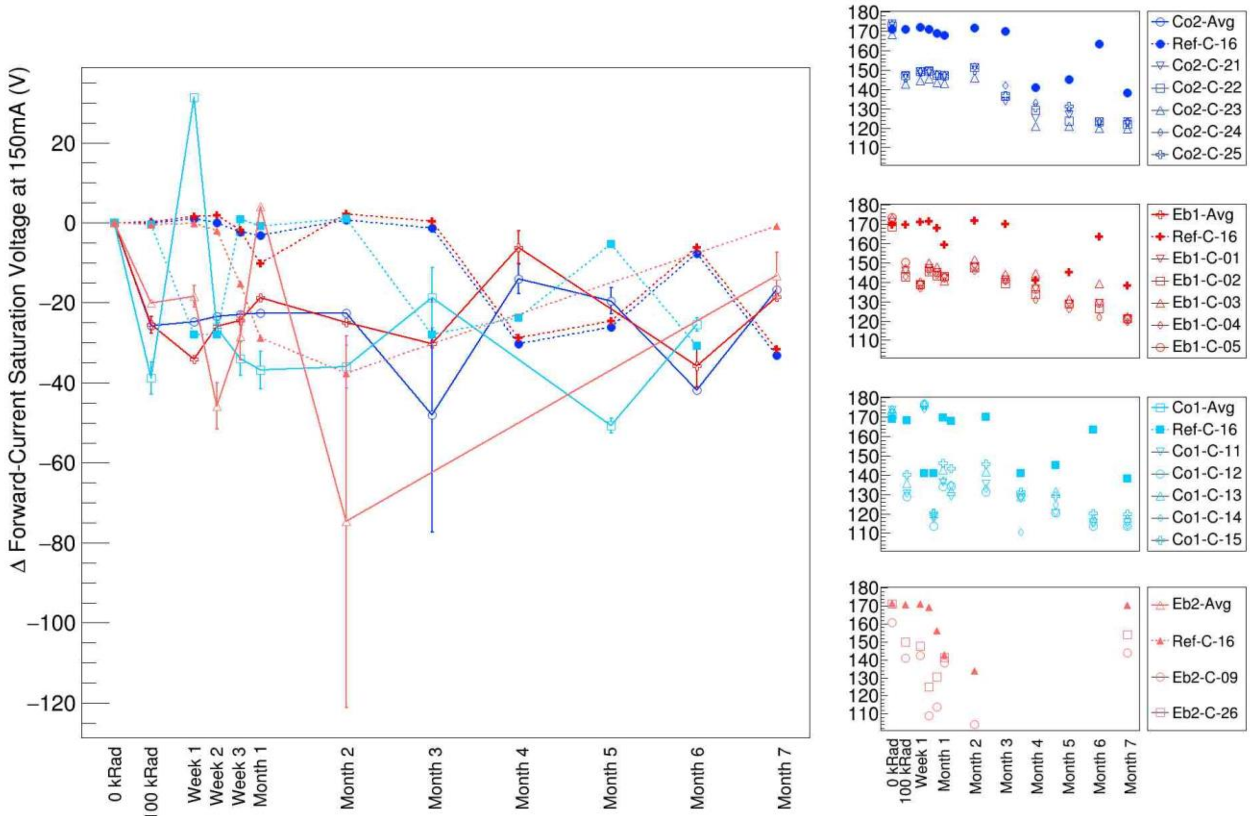


Figure 9-13 Forward-Current Saturation Voltage (Ic=150mA) variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign.

9.3.8 Forward-Current Transfer Ratio (Ic=500mA)

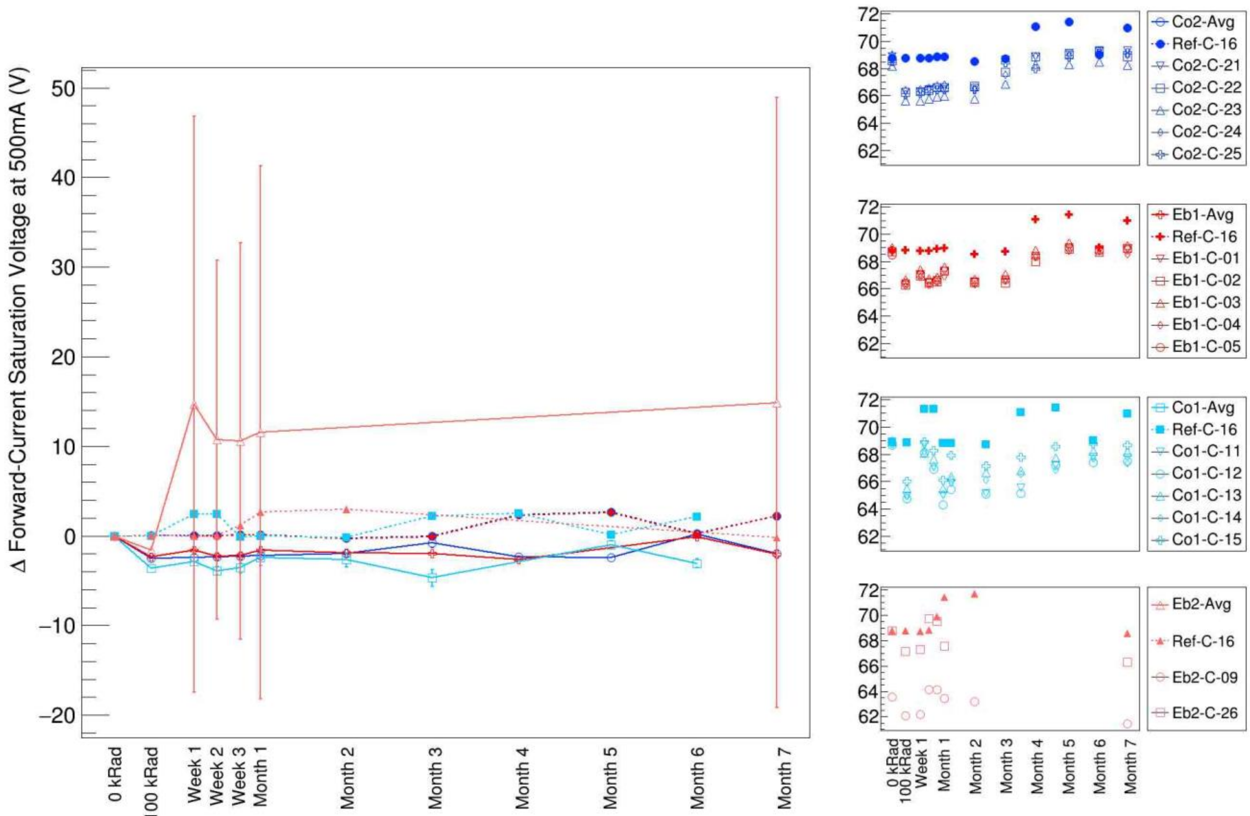


Figure 9-14 Forward-Current Saturation Voltage (Ic=500mA) variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign.

9.4 Component D – LM124

Annealing results for component D are presented in sections 9.4.1-9.4.11. No annealing effects were observed.

9.4.1 Power Supply Current

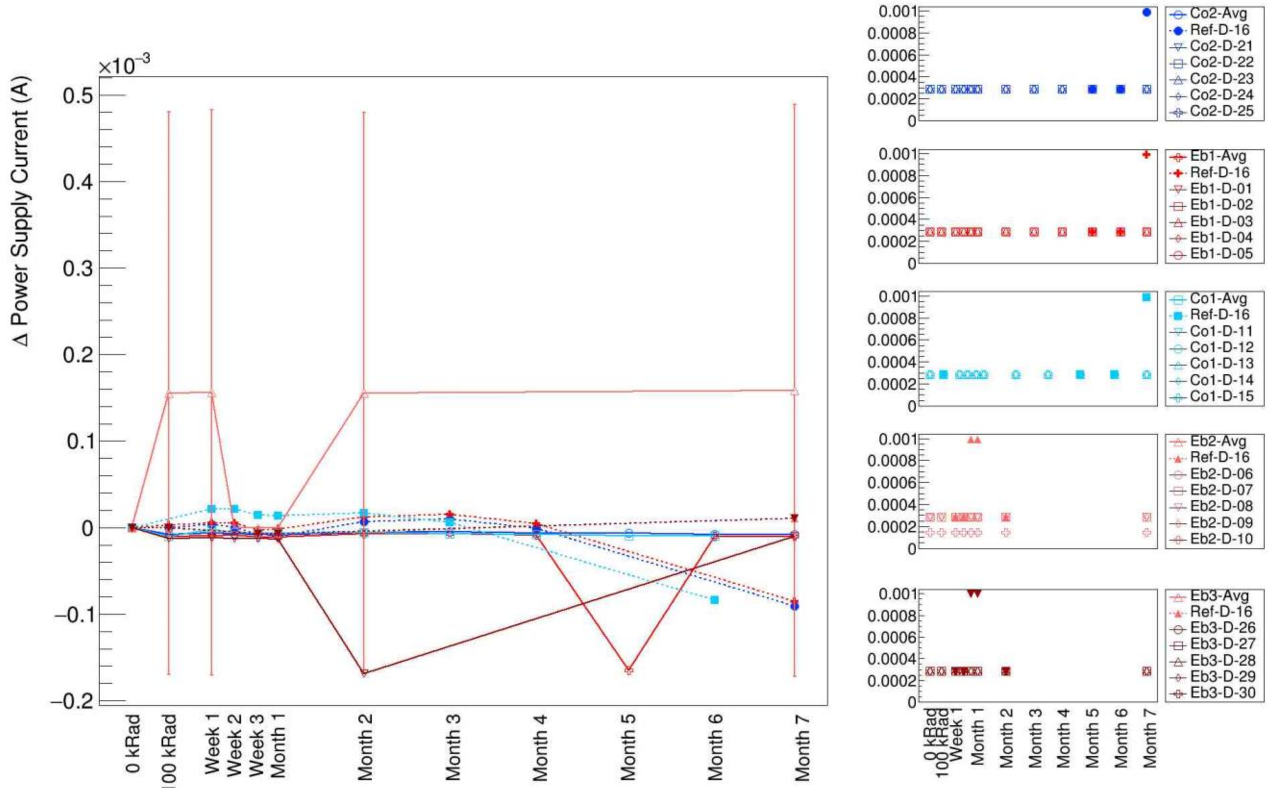


Figure 9-15 Power Supply Current variation (left side) and absolute values (right side). Blue points correspond to the HDR y CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR y ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9.4.2 Input Bias Current –

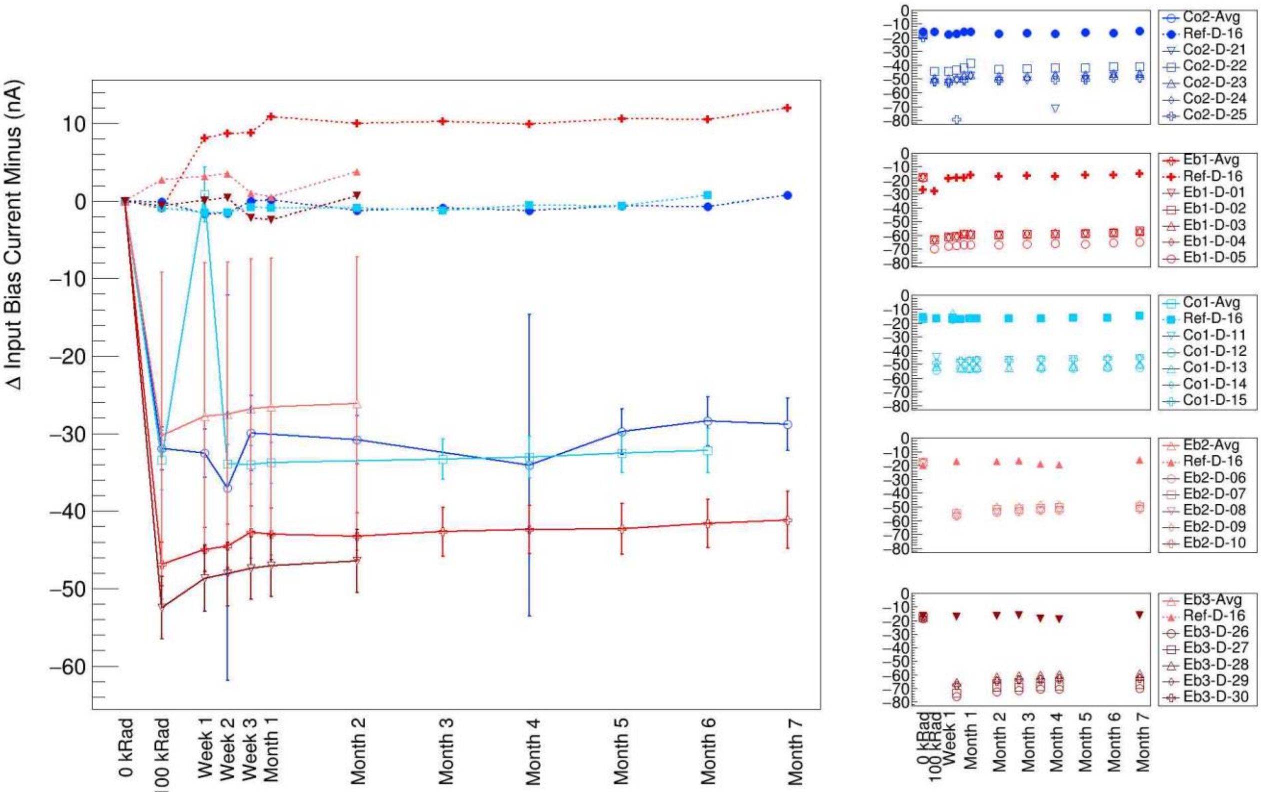


Figure 9-16 Input Bias Current Minus (left side) and absolute values (right side). Blue points correspond to the HDR y CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR y ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9.4.3 Input Bias Current +

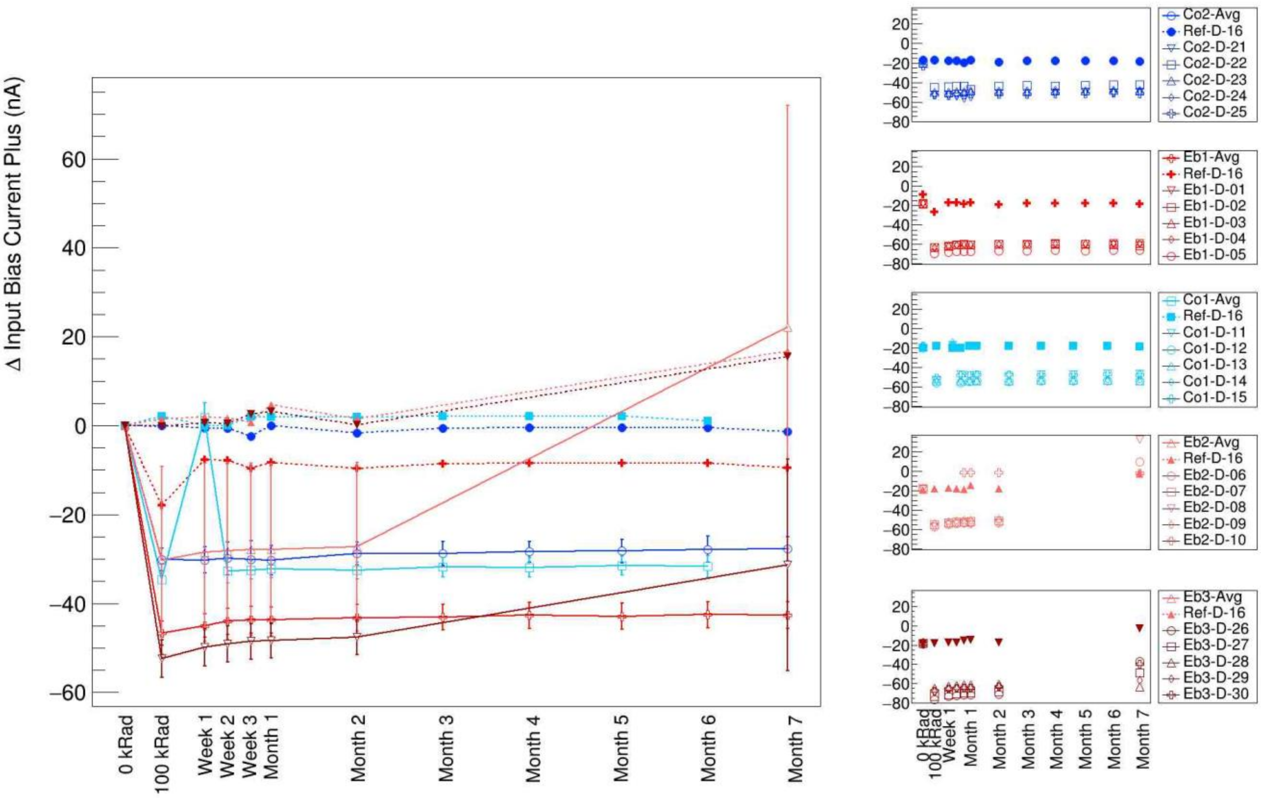


Figure 9-17 Input Bias Current Plus (left side) and absolute values (right side). Blue points correspond to the HDR y CTN campaign, Red points to the 12 MeV e^{-} HDR Hospital campaign, Teal points to the LDR y ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9.4.4 Input Current Offset

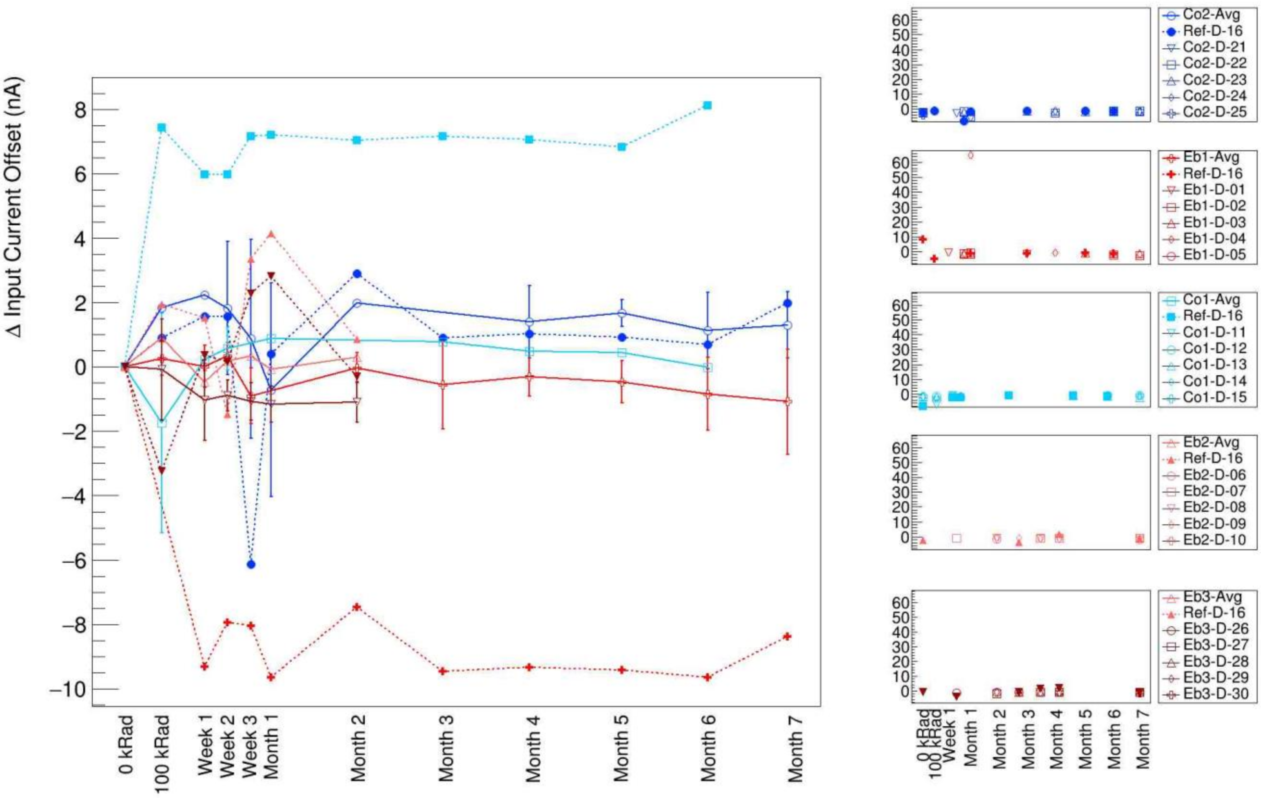


Figure 9-18 Input Current Offset variation (left side) and absolute values (right side). Blue points correspond to the HDR y CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR y ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9.4.5 Input Voltage Offset

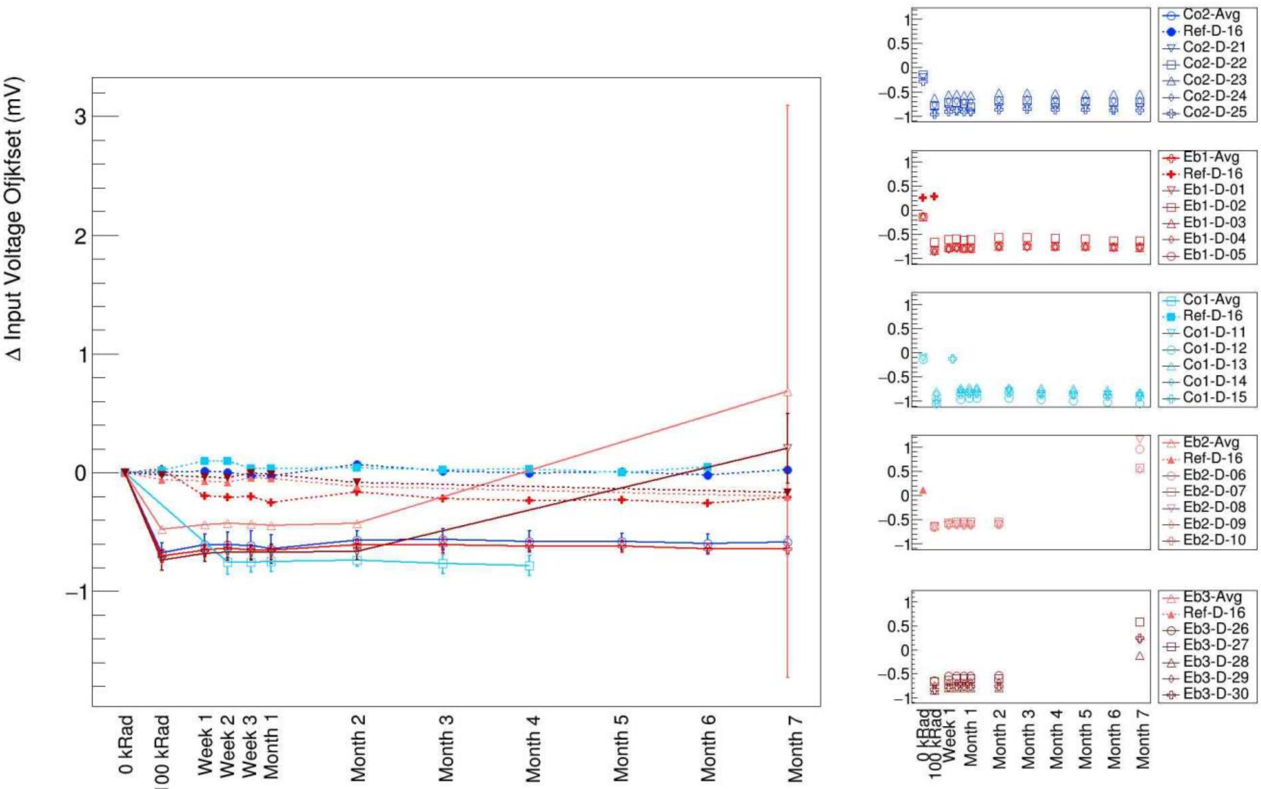


Figure 9-19 Input Voltage Offset variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^{-} HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9.4.6 Common Mode Rejection Ratio

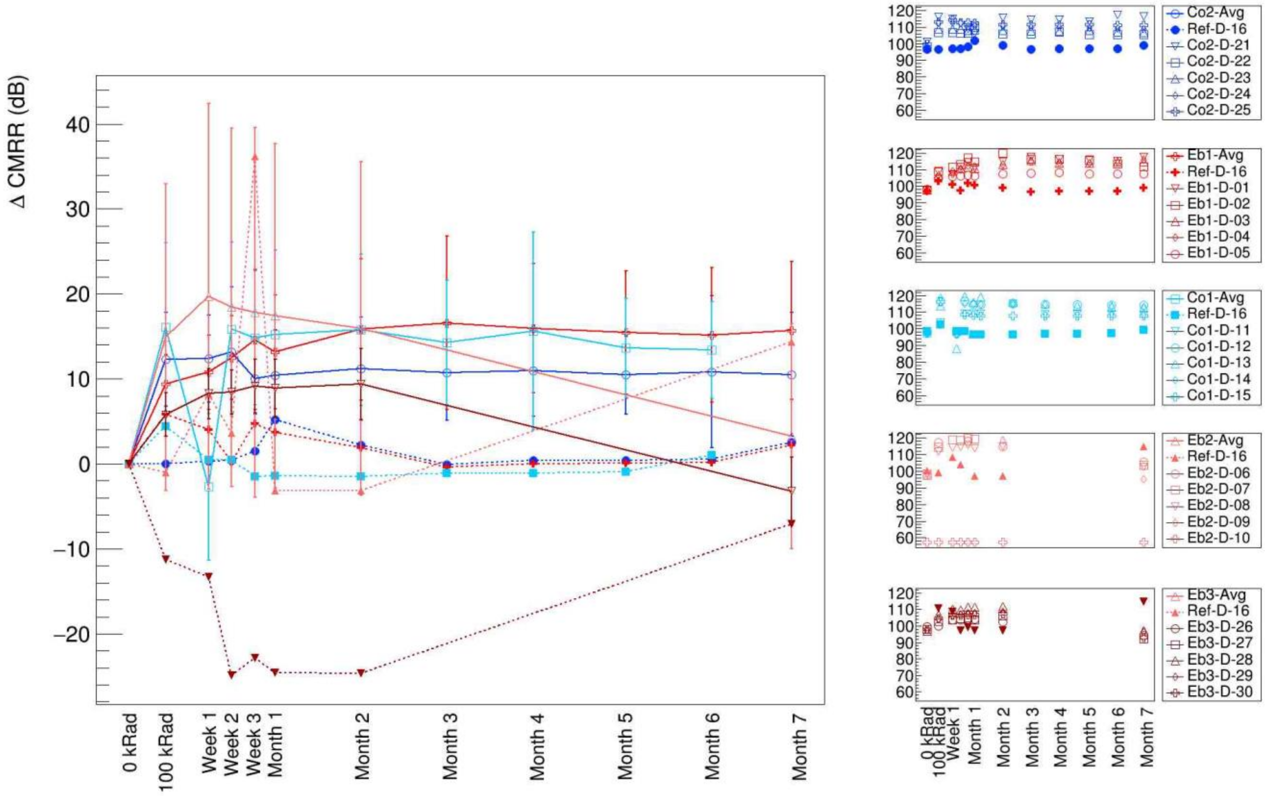


Figure 9-20 Common Mode Rejection Ratio variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9.4.7 Power Supply Rejection Ratio

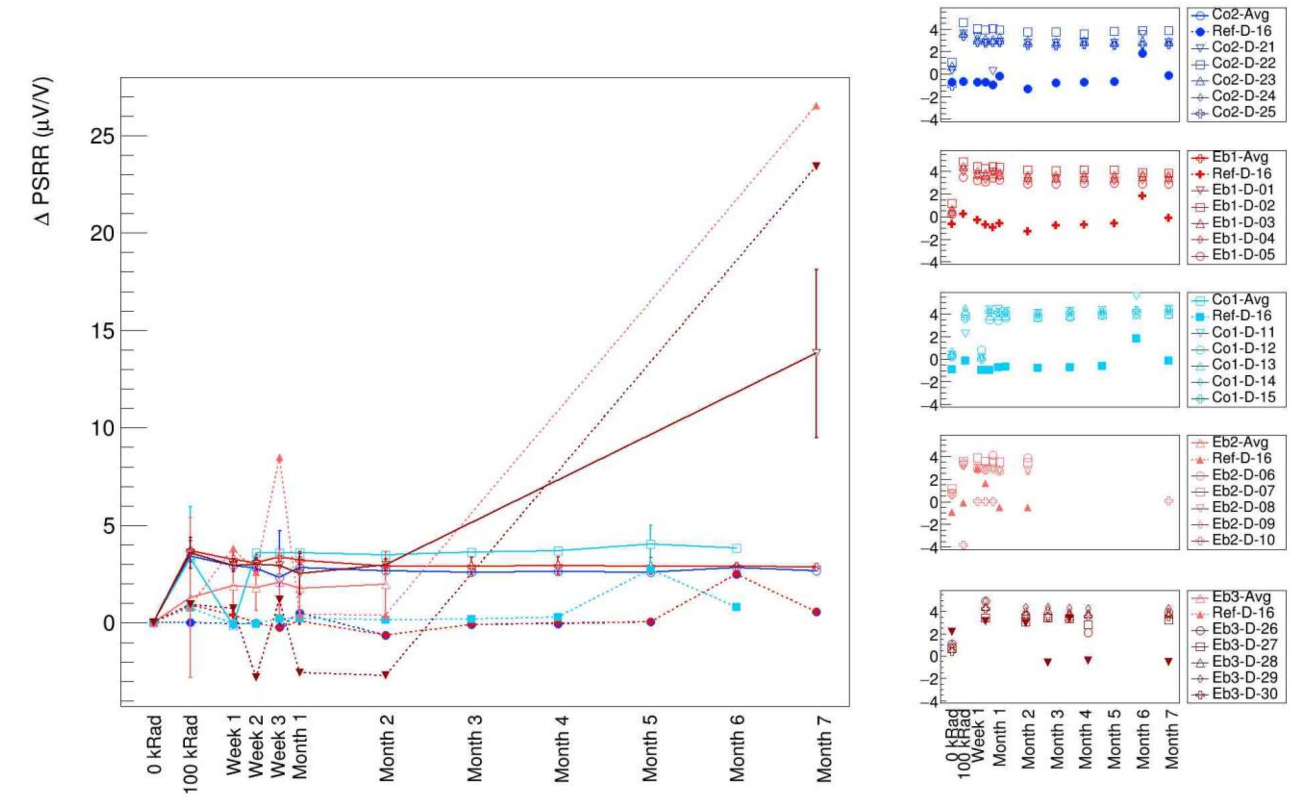


Figure 9-21 Power Supply Rejection Ratio variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^{-} HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9.4.8 Voltage Gain

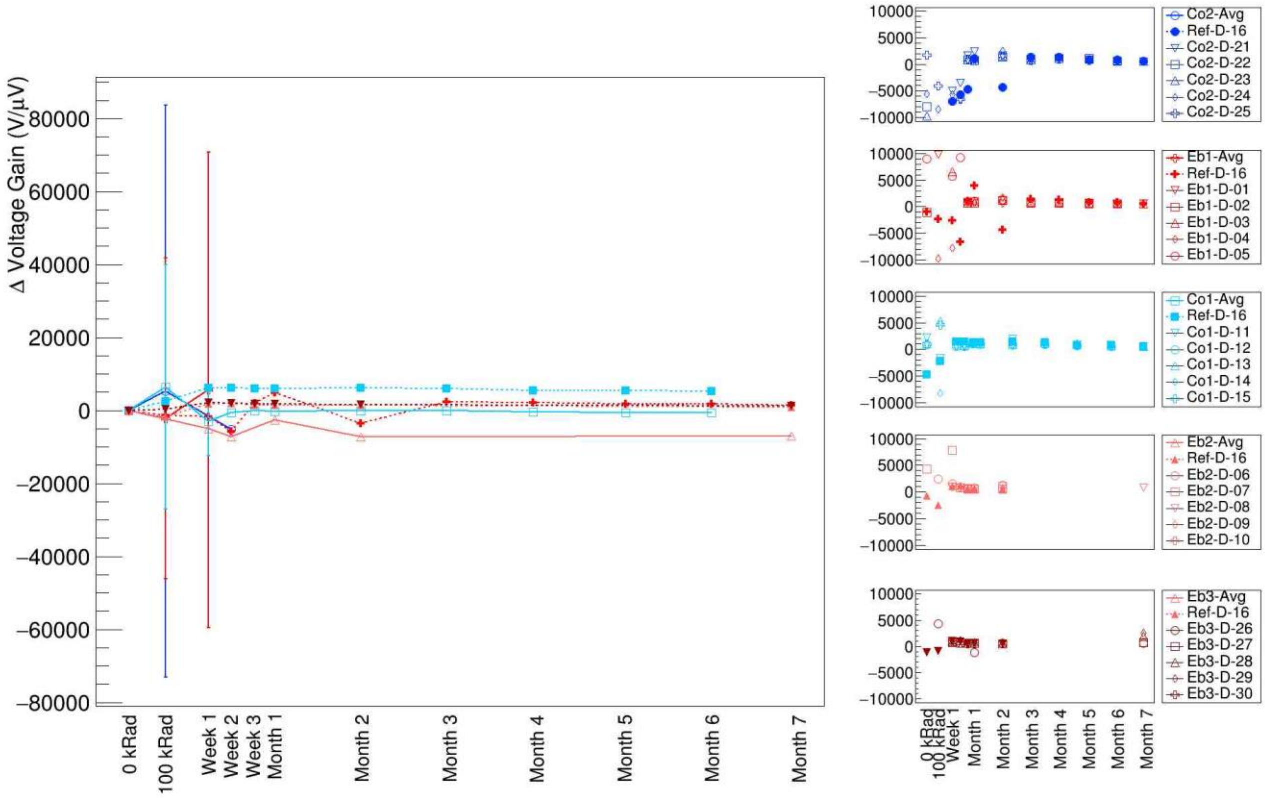


Figure 9-22 Voltage Gain variation (left side) and absolute values (right side). Blue points correspond to the HDR y CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR y ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9.4.9 Maximum Output Voltage Swing

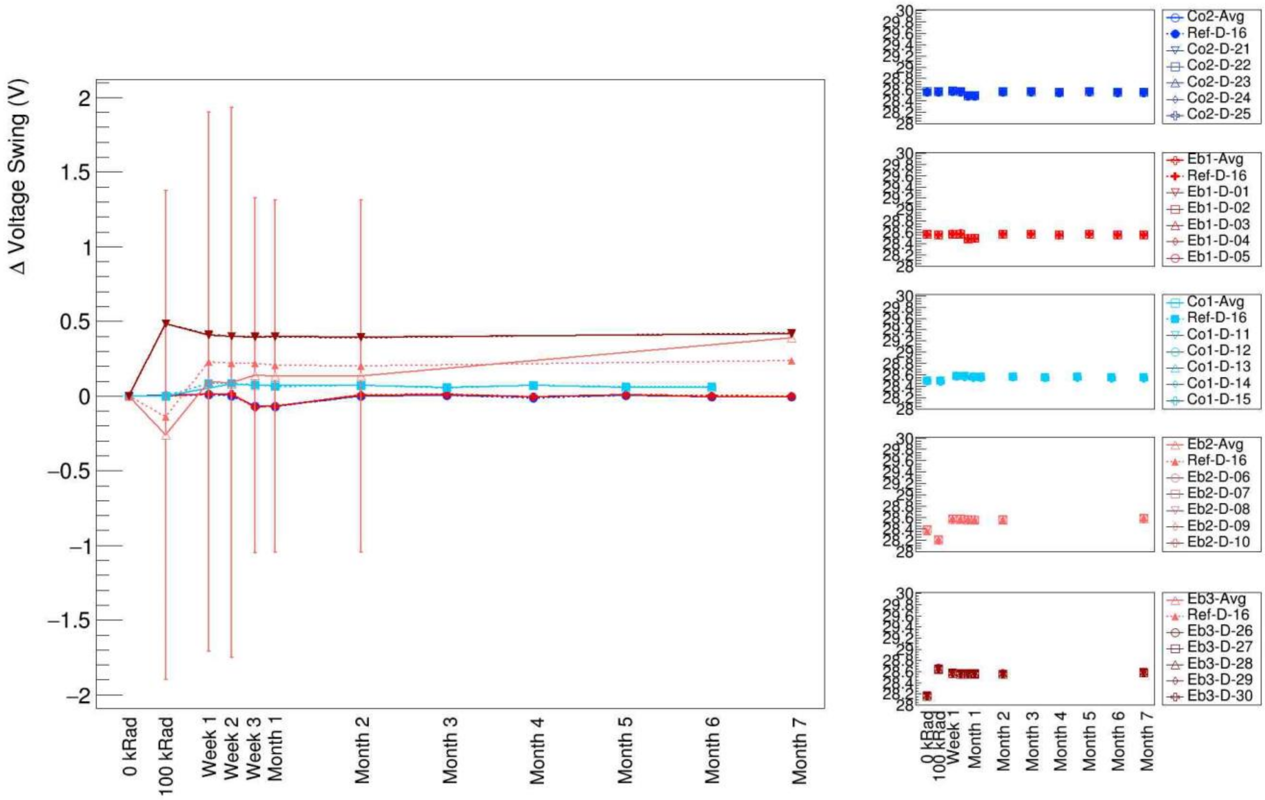


Figure 9-23 Maximum Output Voltage Swing variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9.4.10 Slew Rate +

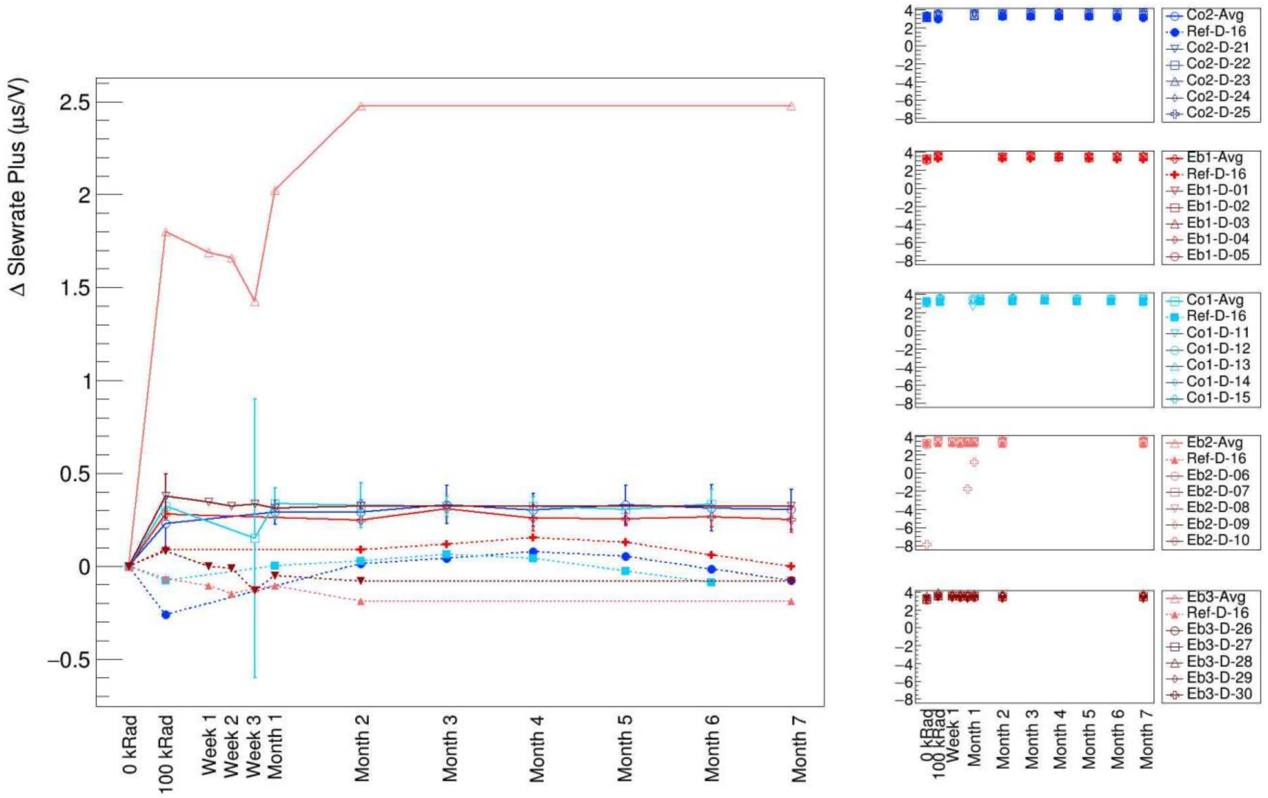


Figure 9-24 Slew Rate Plus variation (left side) and absolute values (right side). Blue points correspond to the HDR y CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR y ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9.4.11 Slew Rate -

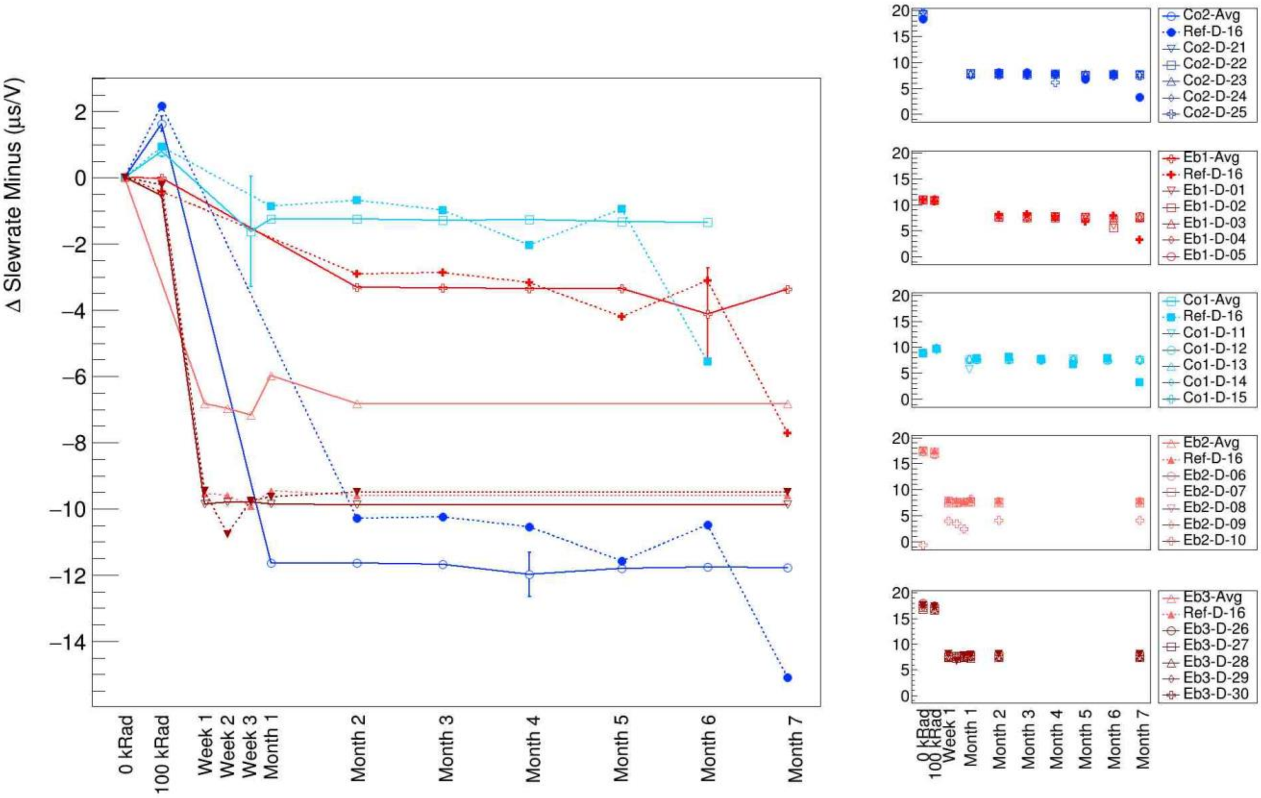


Figure 9-25 Slew Rate Minus variation (left side) and absolute values (right side). Blue points correspond to the HDR y CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR y ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9.5 Component E – LM4050

Component E annealing results can b seen in sections 9.5.1-9.5.5. No annealing effects were observed.

9.5.1 Reference Voltage (I_R=74µA)

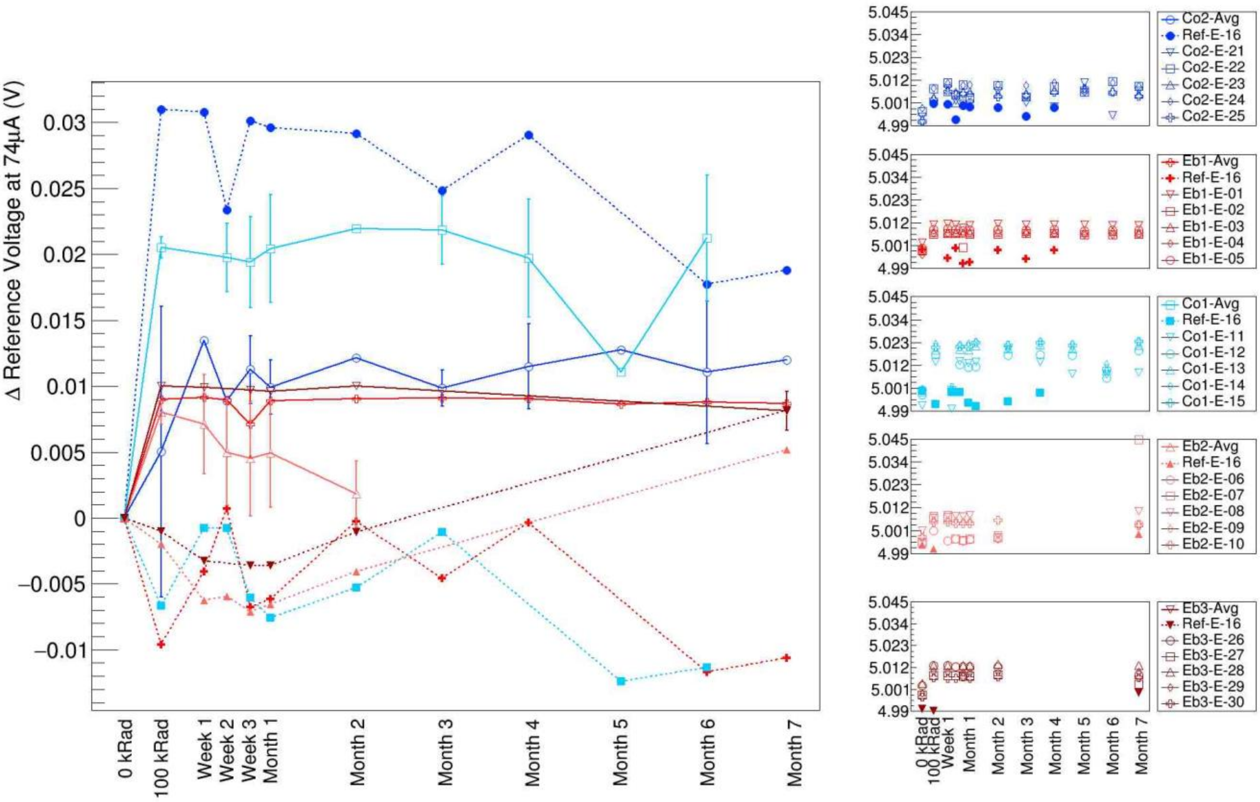


Figure 9-26 Reference Voltage (Ir=74µA) variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^{-} HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9.5.2 Reference Voltage (I_R=100μA)

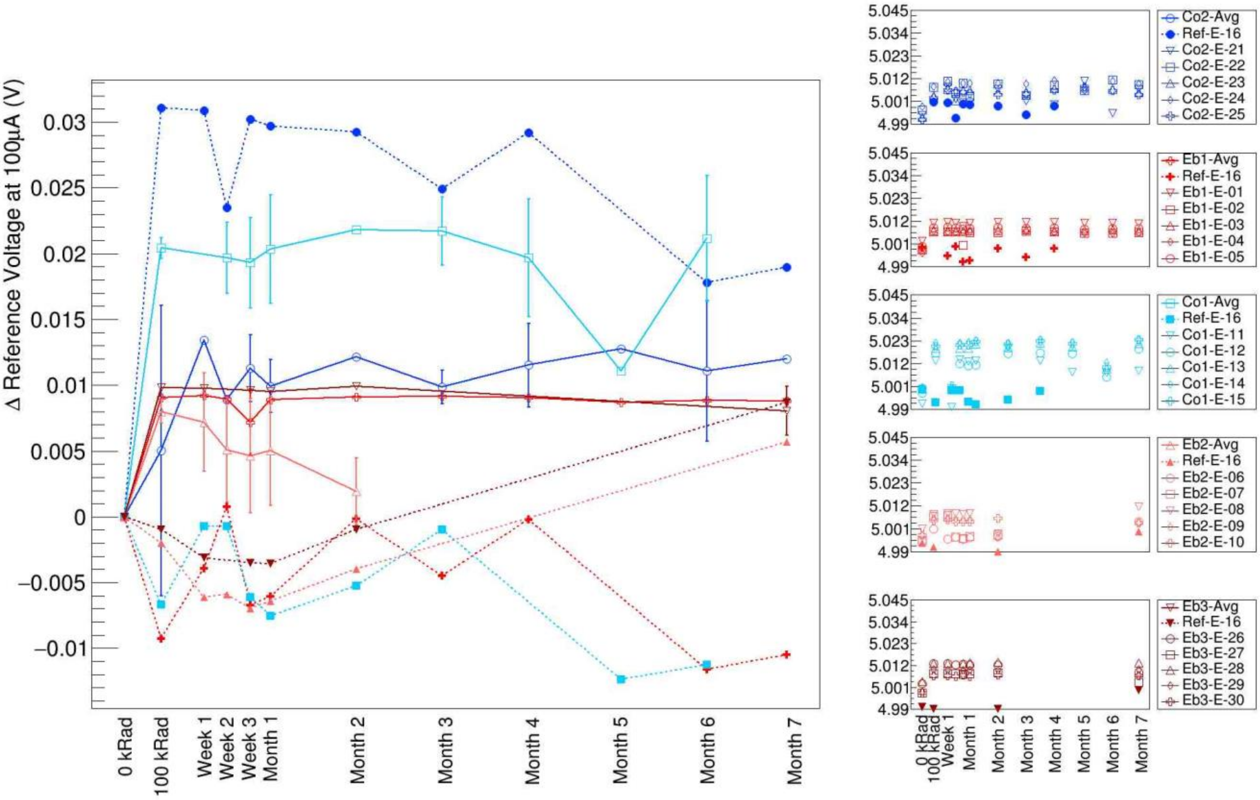


Figure 9-27 Reference Voltage (Ir=100μA) variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^{-} HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9.5.3 Reference Voltage (I_R=1mA)

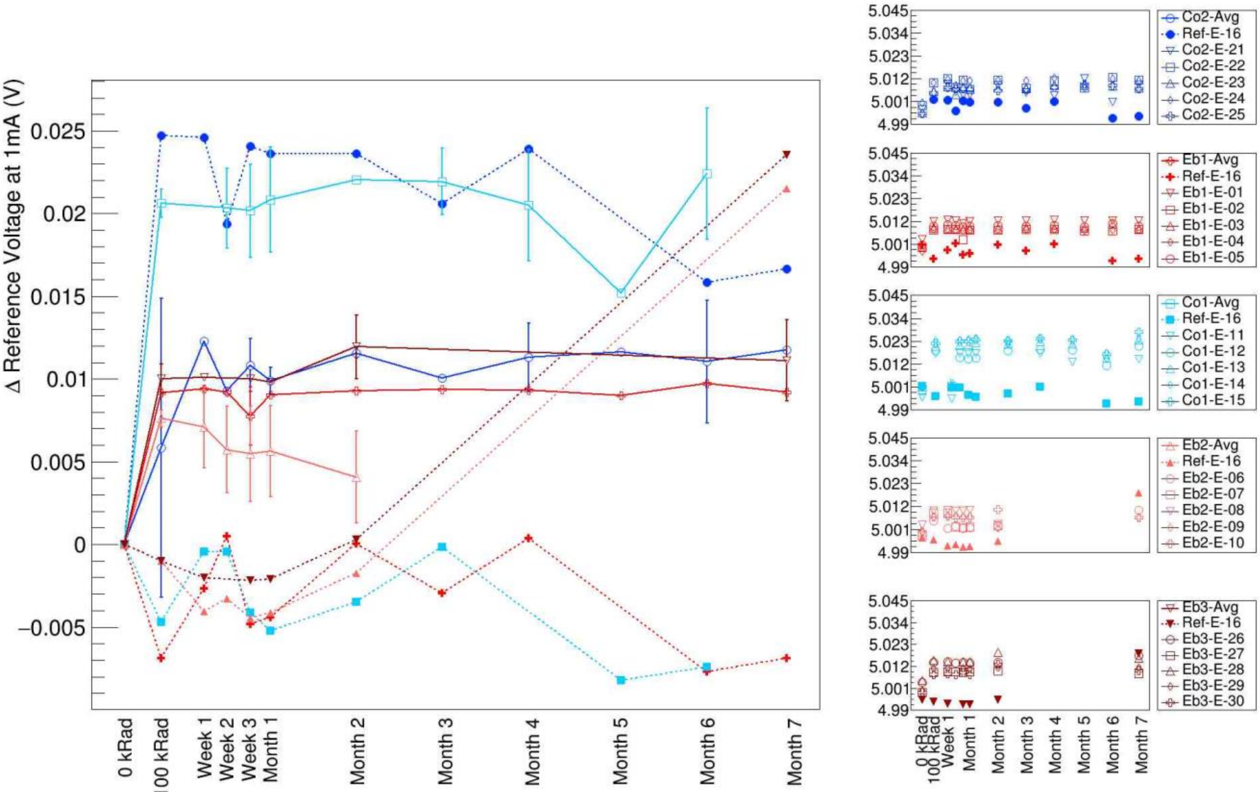


Figure 9-28 Reference Voltage (Ir=1mA) variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^{-} HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9.5.4 Reference Voltage (I_R=10mA)

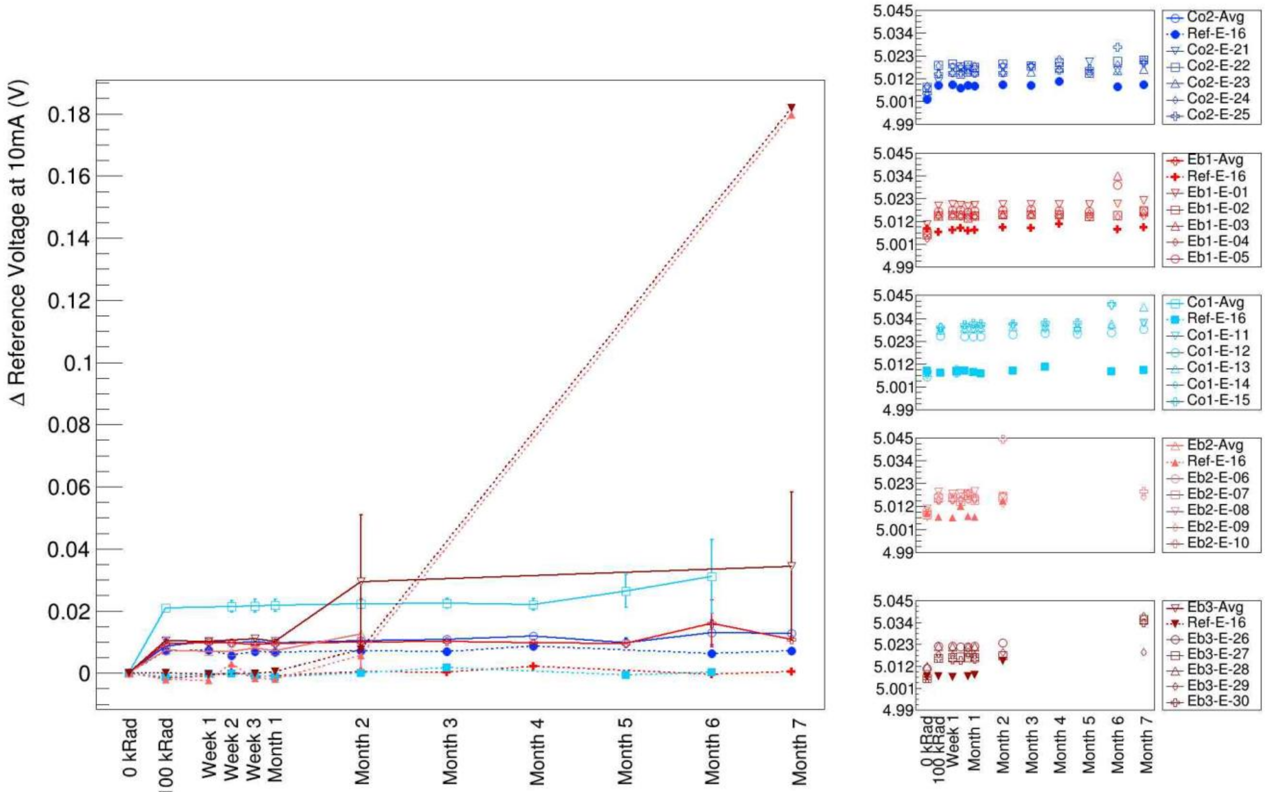


Figure 9-29 Reference Voltage (Ir=10mA) variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

9.5.5 Reference Voltage (I_R=15mA)

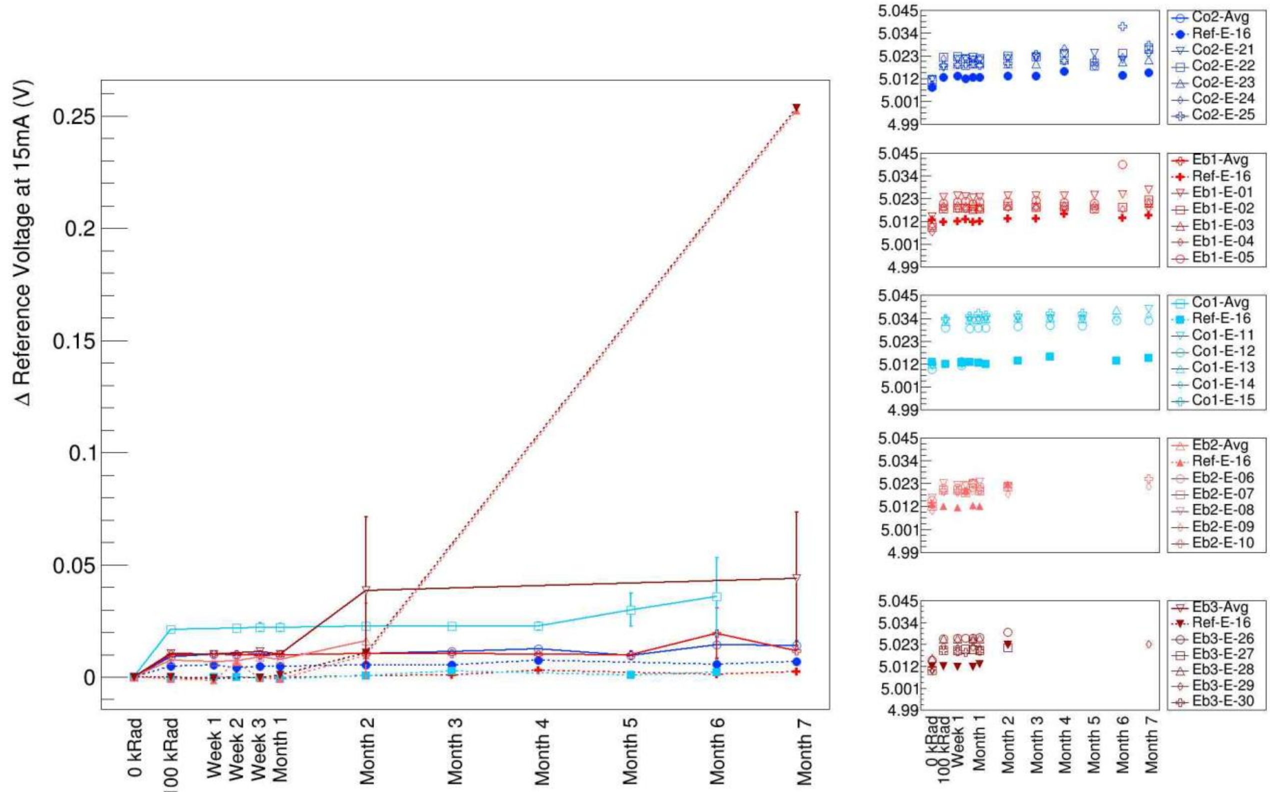


Figure 9-30 Reference Voltage (Ir=15mA) variation (left side) and absolute values (right side). Blue points correspond to the HDR γ CTN campaign, Red points to the 12 MeV e^- HDR Hospital campaign, Teal points to the LDR γ ESTEC campaign and Light Red points to the 12 MeV HDR RADEF campaign and Dark Red points to the 20 MeV HDR RADEF campaign.

10 Displacement Damage to LM124 from Electrons

In section 8.4 it was pointed out that, for the same TID, some parameters of LM124 drifted at a higher rate when subjected to 12 and 20 MeV electron beams than when subjected to Co60 gammas. To understand if this behavior is due to ionizing processes or to Displacement Damage (DD) the results from this study are compared with the ones presented in [AD4]. The later tests Displacement Damage of Linear Devices such as LM124 with different 50 MeV proton fluences, 1E11, 2E11, 3.5E11 and 5E11 p/cm^2 (referred in this work as DD_1, DD_2, DD3 and DD_4 respectively), complemented with Co60 irradiation to reach TID of 100 krad. A TID only campaign with the components unbiased (referred as DD_0) was also performed which allowed to directly compare with our results.

Since in [AD4] the displacement damage is given as a 50MeV proton fluence, the same quantity must be calculated for the two cases of interest (12 MeV and 20 MeV electrons). For any particle of interest, TID is related to the particle fluence ($P_{fluence}$) by:

$$TID = \frac{P_{fluence} * dE/dx * \frac{\rho}{th}}{m}$$

Where dE/dx is the stopping power of the particle in the material, ρ is the density of the material and th and m are the thickness and mass of the target respectively. For a given TID we can then calculate the fluence by inverting the previous formula:

$$P_{fluence} = \frac{TID}{dE/dx} * \frac{m * th}{\rho}$$

The last term was isolated because neither m nor th are known. ρ is introduced for convenience as it will be clear later. This term can be obtained since we know from[AD4], that a 50 MeV proton fluence of 1E+11 p/cm^2 corresponds to a TID of 16 krad.

Finally, to convert the particle fluence to a 50 MeV proton equivalent fluence we need to ponder the Non-Ionizing Energy Loss (NIEL) magnitudes of the particle of interest (12 and 20 MeV electrons) and of 50 MeV electrons. The equivalent fluence can then be calculated as:

$$Eq.Fluence\ (p\ 50\ MeV) = \frac{TID}{dE/dx} * \frac{m * th}{\rho} * \frac{NIEL\ (particle\ of\ interest)}{NIEL\ (p\ 50\ MeV)}$$

For the 12 MeV (TID = 90krad) and 20 MeV (TID = 95 krad) electron irradiations, the eq. fluence is 2.61E+10 and 2.93E+10 p/cm^2 respectively. Though these values are small when compared to the ones in [AD4], below 30% of the smallest value reported, some interpolation is still possible.
In sections 10.1-10.9, each parameter is treated individually due to their different radiation responses. Some units were converted to match those in [AD4]. Voltage Gain was not considered due to the high variability observed. One standard deviation is considered for all errors given.

10.1 Power Supply Current

Results from this work show no degradation to the Power Supply Current (Icc) from Electron and Co60 radiation. In [AD4] however, DD_0 leads to a 400% increase in this parameter while the same irradiation for biased LM124 OpAmps, shows no degradation. Displacement damage also contributes to an increase in Icc but only by 28% for an eq. fluence of 1E11 p/cm^2 and always much lower than for the case of DD_0. See Table 10-1 for all test values.
This means that some other factor was likely affecting the result of DD_0 irradiation outcome, and that no displacement damage from electrons needs to be accounted for in the case of the Power Supply Current.

Table 10-1 Power Supply Current for all test conditions in this study (ECo 60) and in [AD4]

Test Report	Test Campaign	Eq. Fluence (50 MeV p)	Power Supply Current (A)		
			Pre-irradiaton	Post-Irradiation	Drift
Eco60	Co2	0	4.39E-04 ± 3.05E-04	4.31E-04 ± 2.90E-04	-7.83E-06 ± 4.21E-04
	Eb1	2.61E+10	4.51E-04 ± 3.31E-04	4.41E-04 ± 3.10E-04	-1.04E-05 ± 4.53E-04
	Eb2	2.61E+10	2.86E-04 ± 1.12E-08	4.80E-04 ± 3.37E-04	1.94E-04 ± 3.37E-04
	Eb3	2.93E+10	4.55E-04 ± 3.38E-04	4.42E-04 ± 3.13E-04	-1.26E-05 ± 4.60E-04
[AD4]	DD_0	0	1.08E-03 ± 1.23E-02	4.83E-03 ± 1.74E-01	3.74E-03 ± 1.75E-01
	DD_1	1E+11	1.09E-03 ± 1.10E-02	8.49E-04 ± 1.36E-02	-2.38E-04 ± 1.75E-02
	DD_2	2E+11	1.09E-03 ± 4.23E-03	7.35E-04 ± 7.60E-03	-3.59E-04 ± 8.70E-03
	DD_3	3.5E+11	1.08E-03 ± 4.52E-03	6.30E-04 ± 2.46E-02	-4.49E-04 ± 2.50E-02
	DD_4	5.00E+11	1.08E-03 ± 4.37E-03	5.42E-04 ± 9.46E-03	-5.39E-04 ± 1.04E-02

10.2 Input Offset Voltage

Regarding Voltage Offset degradation, both unbiased test campaigns, Co2 and DD_0, match in magnitude as it can be observed in Table 10-2. In Figure 10-1 one can see that DD degradation follows an exponential trend doubling the TID drift at 1E+11 50 MeV Proton Eq. Fluence. This explains why there is no enhanced degradation in Eb1, Eb2 and Eb3 since the displacement damage effect is small and within uncertainty values (~0.200 mV).

Table 10-2 Input Voltage Offset for all test conditions in this study (ECo 60) and in [AD4]

Test Report	Test Campaign	Eq. Fluence (50 MeV p)	Input Voltage Offset (mV)		
			Pre-D	Post-Irradiation	Drift
Eco60	Co2	0	0,141 ± 0,162	0,815 ± 0,182	0,673 ± 0,243
	Eb1	2.61E+10	0,103 ± 0,130	0,806 ± 0,140	0,702 ± 0,191
	Eb2	2.61E+10	0,049 ± 0,170	0,652 ± 0,183	0,603 ± 0,250
	Eb3	2.93E+10	0,011 ± 0,129	0,750 ± 0,152	0,739 ± 0,200
[AD4]	DD_0	0	0,096 ± 0,064	0,791 ± 0,120	0,695 ± 0,260
	DD_1	1,00E+11	0,101 ± 0,070	1,513 ± 0,316	1,412 ± 0,183
	DD_2	2,00E+11	0,144 ± 0,104	3,360 ± 0,343	3,216 ± 0,182
	DD_3	3.5E+11	0,089 ± 0,072	6,783 ± 1,771	6,694 ± 0,210
	DD_4	5.00E+11	0,159 ± 0,086	15,316 ± 1,980	15,157 ± 0,253

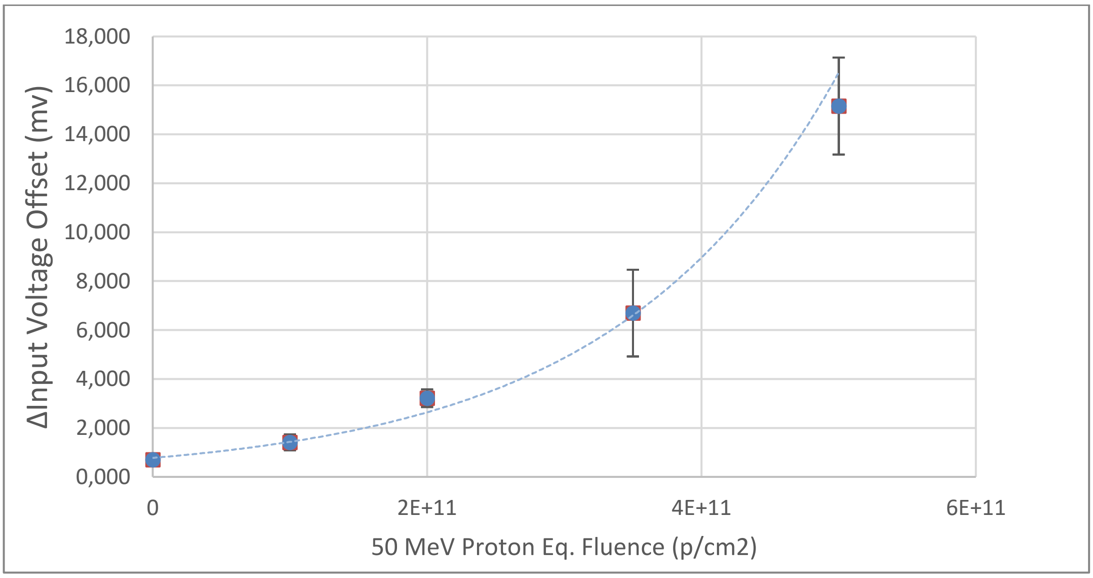


Figure 10-1 Input Voltage Offset drift in [AD1] showing an exponential fit.

10.3 Input Bias Current +

Input Bias Current+ drift after Co60 irradiation is slightly higher in this work than in [AD4]. The difference is acceptable however (within 2σ), considering that the components are not from the same manufacturer and within limits. For this parameter, DD is of importance, increasing its drift by ~4x for a 50 MeV Proton Eq. Fluence of 1E+11. The parameter logarithmic trend (see Figure 10-2) shows that even for low TNID, as in electron testing, this effect should be observed. In fact, we see that drifts in electron testing are consistently above those registered after Co60 irradiation. No predictions could be made on the parameter drift, due to the different heritage of components used in the two studies.

Table 10-3 Input Bias Current + for all test conditions in this study (ECo 60) and in [AD4]

Test Report	Test Campaign	Eq. Fluence (50 MeV p)	Input Bias Current + (nA)		
			Pre-irradiaton	Post-Irradiation	Drift
Eco60	Co2	0	20,4 ± 1,7	50,5 ± 3,0	30,1 ± 3,5
	Eb1	2.61E+10	18,0 ± 0,5	64,7 ± 2,7	46,7 ± 2,8
	Eb2	2.61E+10	17,8 ± 0,6	55,7 ± 1,7	37,9 ± 1,8
	Eb3	2.93E+10	17,8 ± 0,7	70,2 ± 4,3	52,4 ± 4,3
[AD4]	unbiased	0	11,4 ± 0,3	33,4 ± 0,7	22,0 ± 0,8
	DD_0	1,00E+11	11,7 ± 0,2	91,7 ± 8,8	80,0 ± 8,8
	DD_2	2,00E+11	11,4 ± 0,2	176,9 ± 10,3	165,5 ± 10,3
	DD_3	3.5E+11	11,5 ± 0,2	245,2 ± 19,6	233,6 ± 19,6
	DD_4	5.00E+11	11,5 ± 0,3	297,3 ± 13,2	285,8 ± 13,2

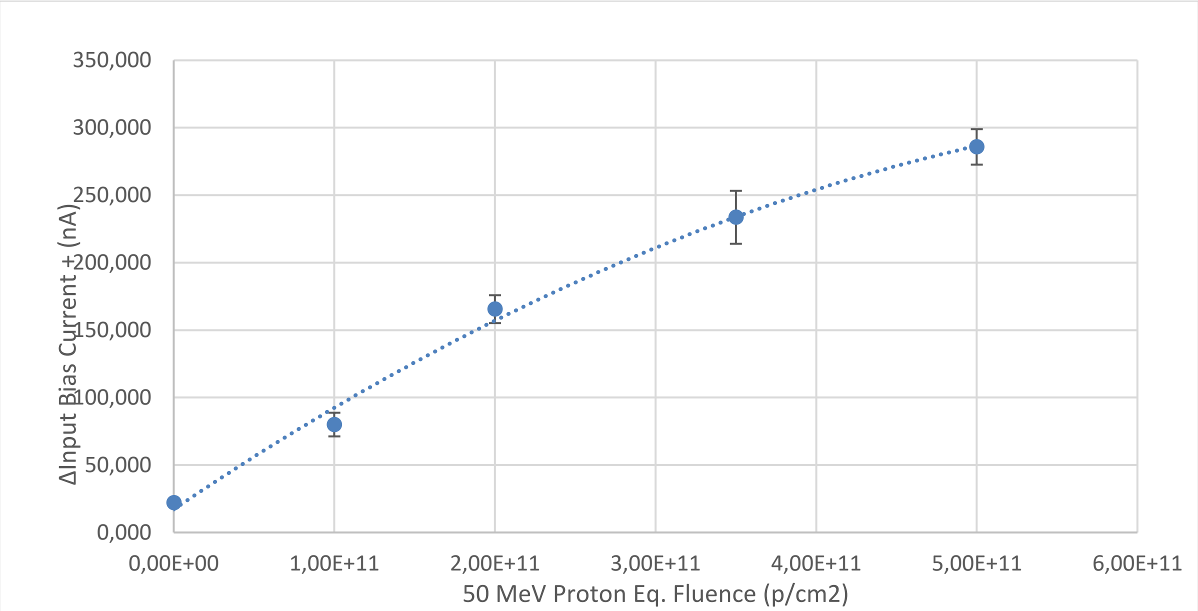


Figure 10-2 Input Bias Current + drift in [AD1] showing a logarithmic fit.

10.4 Input Bias Current –

Similar results to the previous section (10.3).

10.5 Input Current Offset

Current Offset measurements show high variability in this study with uncertainties greater than 50% for most measurements as can be seen in Table 10-4. Therefore, comparisons between test campaigns are inconclusive.

Table 10-4 Current Offset + for all test conditions in this study (ECo 60) and in [AD4]

Test Report	Test Campaign	Eq. Fluence (50 MeV p)	Current Offset (nA)		
			Pre-irradiaton	Post-Irradiation	Drift
ECo60	Co2	0	2,51 ± 1,04	0,67 ± 0,47	-1,84 ± 1,15
	Eb1	2.61E+10	0,31 ± 0,15	0,05 ± 0,55	-0,26 ± 0,57
	Eb2	2.61E+10	0,21 ± 0,12	0,40 ± 1,22	0,20 ± 1,23
	Eb3	2.93E+10	0,16 ± 0,10	0,25 ± 1,58	0,09 ± 1,58
[AD4]	DD_0	0	0,03 ± 0,04	0,35 ± 0,23	0,31 ± 0,24
	DD_1	1,00E+11	0,08 ± 0,06	3,15 ± 2,20	3,08 ± 2,20
	DD_2	2,00E+11	0,10 ± 0,06	5,33 ± 5,72	5,23 ± 5,72
	DD_3	3.5E+11	0,08 ± 0,05	7,76 ± 5,03	7,68 ± 5,03
	DD_4	5.00E+11	0,08 ± 0,05	21,97 ± 7,94	21,89 ± 7,94

10.6 Voltage Swing

No degradation was observed on this parameter from TID or TNID testing.

10.7 Power Supply Rejection Ratio

This parameter follows a similar trend as that of Input Offset Voltage. Though displacement damage is relevant at 1E+11 Eq. Fluence (see Table 10-5) for this parameter, it was not observed in this study due to the electron irradiation fluences being 30% below that value.

Table 10-5 Power Supply Rejection Ratio for all test conditions in this study (ECo 60) and in [AD4]

Test Report	Test Campaign	Eq. Fluence (50 MeV p)	Power Supply Rejection Ratio (dB)		
			Pre-Irradiation	Post-Irradiation	Drift
Eco60	Co2	0	124,0 ± 6,2	109,1 ± 5,5	-14,9 ± 8,3
	Eb1	2.61E+10	125,6 ± 6,3	107,6 ± 5,4	-18,0 ± 8,3
	Eb2	2.61E+10	124,3 ± 6,2	109,8 ± 5,5	-14,5 ± 8,3
	Eb3	2.93E+10	123,4 ± 6,2	107,2 ± 5,4	-16,2 ± 8,2
[AD4]	unbiased	0	124,1 ± 7,4	115,4 ± 3,8	-8,7 ± 8,3
	DD_1	1,00E+11	119,0 ± 4,1	101,6 ± 2,2	-17,4 ± 4,7
	DD_2	2,00E+11	121,3 ± 7,6	90,7 ± 1,4	-30,6 ± 7,7
	DD_3	3.5E+11	127,1 ± 8,0	82,6 ± 2,9	-44,4 ± 8,5
	DD_4	5.00E+11	119,8 ± 5,8	72,8 ± 1,5	-47,0 ± 6,0

10.8 Common-Mode Rejection Ratio

CMRR results in Table 10-6 show higher degradation in TID than TID+TNID cumulative testing. In fact, TNID and TID have opposite effects on the drift of CMRR. This explains why in Eb1 and Eb3 CMMR values start drifting with opposite trends after the third irradiation step.

Table 10-6 Common-Mode Rejection Ratio for all test conditions in this study (ECo 60) and in [AD4]

Test Report	Test Campaign	Eq. Fluence (50 MeV p)	Common Mode Rejection Ratio (dB)		
			Pre-Irradiation	Post-Irradiation	Drift
Eco60	Co2	0	98,5 ± 1,3	108,9 ± 2,3	10,5 ± 2,6
	Eb1	2.61E+10	98,0 ± 0,6	105,6 ± 1,0	7,6 ± 1,1
	Eb2	2.61E+10	97,7 ± 1,3	116,3 ± 2,8	18,6 ± 3,1
	Eb3	2.93E+10	97,6 ± 0,4	103,6 ± 0,9	6,0 ± 1,0
[AD4]	unbiased	0	90,1 ± 0,3	111,1 ± 0,7	21,0 ± 0,8
	DD_1	1,00E+11	89,7 ± 0,2	99,7 ± 8,8	10,0 ± 8,8
	DD_2	2,00E+11	89,4 ± 0,2	99,2 ± 10,3	9,8 ± 10,3
	DD_3	3.5E+11	90,4 ± 0,2	83,8 ± 19,6	-6,7 ± 19,6
	DD_4	5.00E+11	89,7 ± 0,3	72,9 ± 13,2	-16,8 ± 13,2

10.9 Slew Rate Rise and Fall

Both Rise and Fall of Slew Rates follow the same trend as in 10.1. Degradation is not observed in Co60 testing and it is negligible for low TNID in after DD_1, hence it can be stated that it not present in electron testing. Co60 irradiation results obtained are compatible with [AD4], though Slew Rate Fall measured values are of the same order of magnitude as the Rise in [AD4] and almost one order of magnitude highe in this work.

11 Conclusions

In this activity, the response of five different EEE technologies under irradiation with Co60 electrons and with electrons with E>= 10 MeV was compared.

For this purpose 5 irradiation campaigns were performed: with a Co60 source at High Dose Rate ( ) at *Campus Tecnológico Nuclear* of *Instituto Superior Técnico* in Lisbon, with a Co60 source at Low Dose Rate ( ) at ESTEC, with two different 12 MeV (HDR) electron sources at *Hospital Santa Maria* (in Lisbon) and at the RADEF facility in University of Jyvaskyla in Finland and with 20 MeV (HDR) electrons also at RADEF.

Components A, C, D and E – the CMOS transistor, the bi-polar transistor, the Operational-Amplifier and the shunt voltage reference, respectively - showed similar degradation with TID for all tested radiation sources at HDR. Some parameters of component D display larger drifts for electron irradiations, within the values expected from electron contribution to TNID effects. A complete analysis showed that for this type of components electron testing should always consider Displacement Damage effects. Component B – the FLASH-NAND Memory - displayed enhanced sensitivity for gamma irradiation, especially at HDR.

Results obtained in these tests show that Co60 testing is representative for components A, C, D and E to be flown in the Jupiter electron environment and conservative in the case conservative of component B.

Annealing measurements were also performed for components A, C, D and E. No significant recovery was observed in any of the components.

12 Annex I - Test Plan Forms

Summary Test Plans

Test Plan n.	SetId	Component
001	Co1	A
002	Co1	B
003	Co1	C
004	Co1	D
005	Co1	E
006	Co2	A
007	Co2	B
008	Co2	C
009	Co2	D
010	Co2	E
011	Eb1	A
012	Eb1	B
013	Eb1	C
014	Eb1	D
015	Eb1	E
016	Eb2	A,B,C,D or E (TBD)
017	Eb2	A,B,C,D or E (TBD)
018	Eb2	A,B,C,D or E (TBD)

Co1 – Co-60 LDR

Co2 – Co-60 HDR

Eb1 – Electrons with E1

Eb2 – Electrons with E2

Specifics for Co1

14	Test facility name and address.	ESA ESTEC
16	Name of facility and type of radiation source.	ESA ESTEC Co60
17	Type of exposure (single or multiple).	Multiple
19	Level of Interest.	100 kRad
21	Multiple exposure: specification of number of exposures, doses and dose rates (or flux and duration of each exposure).	(See table below)
25	Irradiation test sequence	(See table below)

21: Multiple exposure: specification of number of exposures, doses and dose rates (or flux and duration of each exposure).

Multiple Irradiation Steps	1	2	3	4	5	6	7	8
Dose(krad(Si))	20.7	41.5	62.2	82.9	103.7			
Dose Rate (rad(Si)s^{-1})	0.01	0.01	0.01	0.01	0.01			
Exposure Time	24d	24d	24d	24d	24d			

25: Irradiation test sequence 1

Test Step	Description	Requirements
1	Irradiation T0 -> T0+24d	
2	Measurement @ T0+24d	
3	Irradiation T0+24d -> T0+48d	
4	Measurement @ T0+48d	
5	Irradiation T0+48d -> T0+72d	
6	Measurement @ T0+72d	
7	Irradiation T0+72d -> T0+96d	
8	Measurement @ T0+96d	
9	Irradiation T0+96d -> T0+120d	
10	Measurement @ T0+120d	

Specifics for Co2

14	Test facility name and address.	IST – CTN, Loures, Portugal
16	Name of facility and type of radiation source.	IST – CTN Co-60
17	Type of exposure (single or multiple).	Multiple
19	Level of Interest.	100 kRad
21	Multiple exposure: specification of number of exposures, doses and dose rates (or flux and duration of each exposure).	(see table below)
25	Irradiation test sequence	(see table below)

21: Multiple exposure: specification of number of exposures, doses and dose rates (or flux and duration of each exposure).

Multiple Irradiation Steps	1	2	3	4	5	6	7	8
Dose(krad(Si))	20	40	60	80	100			
Dose Rate (rad(Si)s^{-1})	6.67	6.67	6.67	6.67	6.67			
Exposure Time	50min	50min	50min	50min	50min			

25: Irradiation test sequence 1

Test Step	Description	Requirements
1	Irradiation T0 -> T0+50min	
2	Measurement @ T0+50min	
3	Irradiation T0+50min -> T0+100min	
4	Measurement @ T0+100min	
5	Irradiation T0+100min -> T0+150min	
6	Measurement @ T0+150min	
7	Irradiation T0+150min -> T0+200min	
8	Measurement @ T0+200min	
9	Irradiation T0+200min -> T0+250min	
10	Measurement @ T0+250min	

Specifics for Eb1

14	Test facility name and address.	Radiotherapy unit of Hospital Santa Maria
16	Name of facility and type of radiation source.	HSM - Electron beam from CLINAC @ E=12MeV
17	Type of exposure (single or multiple).	Multiple
19	Level of Interest.	100 kRad
21	Multiple exposure: specification of number of exposures, doses and dose rates (or flux and duration of each exposure).	(see table below)
25	Irradiation test sequence	(see table below)

21: Multiple exposure: specification of number of exposures, doses and dose rates (or flux and duration of each exposure).

Multiple Irradiation Steps	1	2	3	4	5	6	7	8
Dose(krad(Si))	20	40	60	80	100			
Dose Rate (rad(Si)s^{-1})	6.67	6.67	6.67	6.67	6.67			
Exposure Time	50min	50min	50min	50min	50min			

25: Irradiation test sequence 1

Test Step	Description	Requirements
1	Irradiation T0 -> T0+50min	
2	Measurement @ T0+50min	
3	Irradiation T0+50min -> T0+100min	
4	Measurement @ T0+100min	
5	Irradiation T0+100min -> T0+150min	
6	Measurement @ T0+150min	
7	Irradiation T0+150min -> T0+200min	
8	Measurement @ T0+200min	
9	Irradiation T0+200min -> T0+250min	
10	Measurement @ T0+250min	

Specifics for Eb2

14	Test facility name and address.	RADEF at University of Jyvaskyla
16	Name of facility and type of radiation source.	RADEF - Electron beam from CLINAC @ E=12MeV
17	Type of exposure (single or multiple).	Multiple
19	Level of Interest.	100 kRad
21	Multiple exposure: specification of number of exposures, doses and dose rates (or flux and duration of each exposure).	(see table below)
25	Irradiation test sequence	(see table below)

21: Multiple exposure: specification of number of exposures, doses and dose rates (or flux and duration of each exposure).

Multiple Irradiation Steps	1	2	3	4	5	6	7	8
Dose(krad(Si))	20	40	60	80	100			
Dose Rate (rad(Si)s^{-1})	6.67	6.67	6.67	6.67	6.67			
Exposure Time	50min	50min	50min	50min	50min			

25: Irradiation test sequence 1

Test Step	Description	Requirements
1	Irradiation T0 -> T0+50min	
2	Measurement @ T0+50min	
3	Irradiation T0+50min -> T0+100min	
4	Measurement @ T0+100min	
5	Irradiation T0+100min -> T0+150min	
6	Measurement @ T0+150min	
7	Irradiation T0+150min -> T0+200min	
8	Measurement @ T0+200min	
9	Irradiation T0+200min -> T0+250min	
10	Measurement @ T0+250min	

Specifics for Eb3

14	Test facility name and address.	RADEF at University of Jyvaskyla
16	Name of facility and type of radiation source.	RADEF - Electron beam from CLINAC @ E=20MeV
17	Type of exposure (single or multiple).	Multiple
19	Level of Interest.	100 kRad
21	Multiple exposure: specification of number of exposures, doses and dose rates (or flux and duration of each exposure).	(see table below)
25	Irradiation test sequence	(see table below)

21: Multiple exposure: specification of number of exposures, doses and dose rates (or flux and duration of each exposure).

Multiple Irradiation Steps	1	2	3	4	5	6	7	8
Dose(krad(Si))	20	40	60	80	100			
Dose Rate (rad(Si)s^{-1})	6.67	6.67	6.67	6.67	6.67			
Exposure Time	50min	50min	50min	50min	50min			

25: Irradiation test sequence 1

Test Step	Description	Requirements
1	Irradiation T0 -> T0+50min	
2	Measurement @ T0+50min	
3	Irradiation T0+50min -> T0+100min	
4	Measurement @ T0+100min	
5	Irradiation T0+100min -> T0+150min	
6	Measurement @ T0+150min	
7	Irradiation T0+150min -> T0+200min	
8	Measurement @ T0+200min	
9	Irradiation T0+200min -> T0+250min	
10	Measurement @ T0+250min	

Specifics for Component A

3	ESCC Component Number.		
4	Component designation.	STRH100N10	
5	Manufacturer/user Irradiation Test Specification (number, issue, revision).		
6	Device Family: ESCC Generic and Detail Specifications (number issues and revisions).		
10	Component family.		
11	Component group.		
12	Device package.	TO-254AA	
13	Manufacturer's name and address.	STMicroelectronics	
18	See Items 22 and 23.	Biased; Supply Voltage: VGS bias = +15V; VDS = 0V Temp: ºC Duration: Tamb; (119 day if LDR; <1 day if HDR)	
22	Irradiation conditions: remote or in situ, biased or unbiased.	Biased (Remote Test) Supply Voltages: VGS bias = +15V; VDS = 0V	
24	Electrical parameters to be tested	3.2.1	

Specifics for Component B

3	ESCC Component Number.		
4	Component designation.	MT29F32G08ABAAAWP-ITZ	
5	Manufacturer/user Irradiation Test Specification (number, issue, revision).		
6	Device Family: ESCC Generic and Detail Specifications (number issues and revisions).		
10	Component family.		
11	Component group.		
12	Device package.	48-pin TSOP (CPL)	
13	Manufacturer's name and address.	Micron	
18	See Items 22 and 23.	UNBiased; Temp: ºC Duration: Tamb; (119 day if LDR; <1 day if HDR)	
22	Irradiation conditions: remote or in situ, biased or unbiased.	Unbiased (Remote)	
24	Electrical parameters to be tested	3.2.2	

Specifics for Component C

3	ESCC Component Number.		
4	Component designation.	2N2222	
5	Manufacturer/user Irradiation Test Specification (number, issue, revision).		
6	Device Family: ESCC Generic and Detail Specifications (number issues and revisions).		
10	Component family.		
11	Component group.		
12	Device package.	UB	
13	Manufacturer's name and address.	ST Microelectronics	
18	See Items 22 and 23.	UNBiased; Temp: ºC Duration: Tamb; (119 day if LDR; <1 day if HDR)	
22	Irradiation conditions: remote or in situ, biased or unbiased.	UNBiased (remote)	
24	Electrical parameters to be tested	3.2.3	

Specifics for Component D

3	ESCC Component Number.		
4	Component designation.	LM124	
5	Manufacturer/user Irradiation Test Specification (number, issue, revision).		
6	Device Family: ESCC Generic and Detail Specifications (number issues and revisions).		
10	Component family.		
11	Component group.		
12	Device package.		
13	Manufacturer's name and address.	Texas Instruments	
18	See Items 22 and 23.	UNBiased; Temp: ºC Duration: Tamb; (119 day if LDR; <1 day if HDR)	
22	Irradiation conditions: remote or in situ, biased or unbiased.	UNBiased (remote)	
24	Electrical parameters to be tested	3.2.4	

Specifics for Component E

3	ESCC Component Number.		
4	Component designation.	LM4050	
5	Manufacturer/user Irradiation Test Specification (number, issue, revision).		
6	Device Family: ESCC Generic and Detail Specifications (number issues and revisions).		
10	Component family.		
11	Component group.		
12	Device package.		
13	Manufacturer's name and address.	Texas Instruments	
18	See Items 22 and 23.	UNBiased; Temp: ºC Duration: Tamb; (119 day if LDR; <1 day if HDR)	
22	Irradiation conditions: remote or in situ, biased or unbiased.	UNBiased (remote)	
24	Electrical parameters to be tested	3.2.5	

Irradiation form fields

1- Reference number of Test Plan (3 digits, starting from 001).
2- Reference (issue and revision with dates) of the irradiation Test Plan.
3- ESCC Component Number.
4- Component designation.
5- Manufacturer/user Irradiation Test Specification (number, issue, revision).
6- Device Family: ESCC Generic and Detail Specifications (number issues and revisions).
7- Acceptance Class: Applicable Type of Acceptance (i.e. acceptance of diffusion lot of wafers or procurement lot acceptance).
8- Sample size and number of control devices.
9- Project or Test Programme requiring this test.
10- Component family.
11- Component group.
12- Device package.
13- Manufacturer's name and address.
14- Test facility name and address.
15- Originator of Test Plan (name and telephone number).
16- Name of facility and type of radiation source.
17- Type of exposure (single or multiple).
18- See Items 22 and 23.
19- Level of Interest.
20- Single exposure: specification of values at the chip of dose and dose rate (or fluence, flux and duration in the case of particles).
21- Multiple exposure: specification of number of exposures, doses and dose rates (or flux and duration of each exposure).
22- Irradiation conditions: remote or in situ, biased or unbiased.
23- RT Anneal conditions (Note 2): Room temp (°C) Anneal time (hr) Ageing temp. (°C) Ageing time (hr)

13 Annex III – WP3200 PSSA20 form

<table>
<tr><td>PROJECT: PHASE: 2
Verification of Co-60 testing representativeness for EEE components flown in the Jupiter electron environment</td><td>WP: 3200</td></tr>
<tr><td>WP Title: Definition of test plans

Company: LIP
WP Manager: Patrícia Gonçalves

Start Event: KO + 1 m Planned Date: T0 + 1 month
End Event: KO + 3 m Planned Date: T0 + 3 months</td><td>Sheet 1 of 1

Issue Ref 1

Issue Date</td></tr>
<tr><td>Inputs:
• RFQ “SoW”
• Proposal
• Applicable Documents and Reference Documents listed in the Proposal
• Proposal
• D1- List of procured parts

Tasks:
1. Identification and selection of electron irradiation test facilities and definition of two electron beam energy values for the tests: E1 and E2 ≥ 10 MeV.
2. Identification and selection of Co-60 High dose rate test facility.
3. Elaboration of test plans for each part type for Co-60 at two different dose rates and for irradiation with electron beams of two different energies, up to a total accumulated dose of 100 krad (Si), including:
• Definition of measured electrical parameter, electrical and bias test conditions for each part type
• Definition of data analysis observables and analysis procedures
• For each of the 5 part types, the test samples will be organized as follows (x 2 biasing configurations for the 3 bipolar technology parts):
– Set Co1: 5 parts to be irradiated with Co-60 at Low Dose Rate
– Set Co2: 5 parts to be irradiated with Co-60 at High Dose Rate
– Set Eb1: 5 parts to be irradiated with electron beams at Energy=E1
– Set Eb2: 5 parts to be irradiated with electron beam at Energy= E2
• There will be 10 spare parts for each of the 5 selected technology parts, organized in Sets Sp-Co and Sp-Eb: 2 sets of 5 parts each to be kept as spares and for reference measurements.
• For each part type, Set Co1 will be submitted to a 3 months annealing at room temperature.
• For each part type, Sets Co2, Eb1 and Eb2 4 will undergo a 6 month annealing period at room temperature.
• If the irradiation data collected for any part type is inconsistent or incomplete, 5 spare parts (from Sets Sp) will be irradiated, under similar conditions.

Outputs:
• D2-D5: Radiation Test plans for each part type to be approved by the agency (AA2)</td><td></td></tr>
</table>